DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 607

THE WILLOW CREEK DISTRICT ALASKA

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

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PREFACE.

By Alfred H. Brooks.

The exploration of the Susitna Valley, a part of the United States Geological Survey's first year's plan of Alaska surveys, was made by George H. Eldridge [1] and Robert Muldrow in 1898.[1] Eldridge's report contained the first official confirmation of the occurrence of alluvial gold in the Susitna basin. Meanwhile the prospectors had been at work and in 1897 discovered the Willow Creek placers. It was not until 1906 that the Geological Survey was able to extend its work in this field. Reconnaissance mapping was then carried over the entire Willow Creek basin and the salient features of its geology were determined. Gold-bearing quartz was found in this district during the same year and lode developments followed. This led to a second examination of the district by the Survey in 1910. The results of this second examination gave proof of the occurrence of valuable lodes, and plans were consequently made for a detailed survey. Because of urgent demands for work in other parts of the Territory, this detailed survey had to be deferred until 1913. It was then completed in one season, and the results are set forth in this volume.

The Willow Creek gold district lies along the contact zone of a great series of granodiorite intrusives that form much of the Talkeetna Mountains. As has been repeatedly pointed out, a large part of the gold deposits of Alaska occur in such contact zones. This is the condition in southeastern Alaska and in the Fairbanks, Chandalar, Iditarod, and other inland districts. The geology of the Willow Creek district is therefore favorable to the occurrence of gold deposits. Were it not for the intense glaciation of this field it would probably yield rich placers. As it is, the preglacial gravels that are most likely to contain bonanza placers have been swept away by glacial ice. The placers now found are chiefly postglacial concentrations, which are not likely to be so rich as the older gravels. In the absence of such rich placers and under the primitive conditions of transportation that existed until very recently, there has been little to attract the prospector, and hence the region has not been so carefully examined for mineral deposits as its geologic features would justify.

[1] Eldridge, G. H., A reconnaissance in the Susitna basin and adjacent territory, Alaska: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 1-29, 1900.

Though the Willow Creek district is the only part of the Talkeetna region in which commercial gold deposits have been found, other positive evidence of mineralization has not been lacking. Thus many of the northern tributaries of Matanuska River that cross the granodiorite contact carry some gold in their gravels, and the same is true of some of the eastern tributaries of the Susitna. All this evidence, together with what is known of the bedrock geology, makes it probable that other gold-bearing districts will be found in this province. In any event, the region in which the granodiorite intrusives occur is well worth thorough prospecting.

The veins of the Willow Creek district occur in well-defined fissures, and there is no known reason why they should not extend to considerable depth. Surface alteration is limited to a few feet, so that even the present shallow workings can be regarded as evidence of the character of ore that deeper mining may reveal. The outlook for a permanent lode district is therefore hopeful.

Mining costs are now high owing to the isolation of the district and the high price of fuel. The district, however, lies close to the line of the Government railroad from Seward to Fairbanks, on which construction has now begun. Moreover, this railroad is also projected into the Matanuska coal field. When this project is completed the district will be assured of an adequate transportation service and fuel at reasonable cost. Under these conditions larger mining operations will undoubtedly be undertaken.

THE WILLOW CREEK DISTRICT, ALASKA.

By Stephen R. Capps.

LOCATION AND AREA.

The Willow Creek district lies in south-central Alaska, 10 miles north of the head of Knik Arm, the farthest inland projection of Cook Inlet and the northernmost extension of Pacific Ocean waters in Alaska. This district, drained in part by Willow Creek, is an area of rather indefinite boundaries lying in the southwestern part of the Talkeetna Mountains and has gradually come to include not only the basin of Willow Creek but all the mountainous portion of the Little Susitna River basin. It is this larger region that is discussed in this report. The position of the district and its relation to the Susitna basin and to the adjoining coastal region are shown on the accompanying index map (Pl. I). The district lies between latitude 61° 41′ and 61° 52′ and longitude 149° 4′ and 149° 31′, and has an area of about 150 square miles, of which 90 square miles was mapped in 1913, the remainder having been mapped previously. A topographic map on a scale of 1:62,500 (Pl. II, in pocket) and a geologic map on the same scale (Pl. III, in pocket) are included with this report.

EXPLORATION AND SETTLEMENT.

The shores of Cook Inlet and Prince William Sound were among the first portions of Alaska to become known to the civilized world. Vitus Bering, the first white man to reach this part of Alaska, probably sighted land near the mouth of Cook Inlet in 1741. He did not land, however, and the English navigator James Cook was the first to sail a vessel up the inlet which now bears his name, on May 20, 1778. Although Cook spent only a few days in surveying the inlet, his chart was carefully made. He failed, however, to recognize the fact that the body of water which he had explored was an arm of the sea, but considered it the mouth of a great river system, and Turnagain Arm was called Turnagain River on his chart. In the meantime the Russian traders had pushed eastward along the Alaskan Peninsula, had established a trading post on Kodiak Island, and before the next English expedition arrived had made a settlement on the east shore of Cook Inlet near the present town of Kenai. By

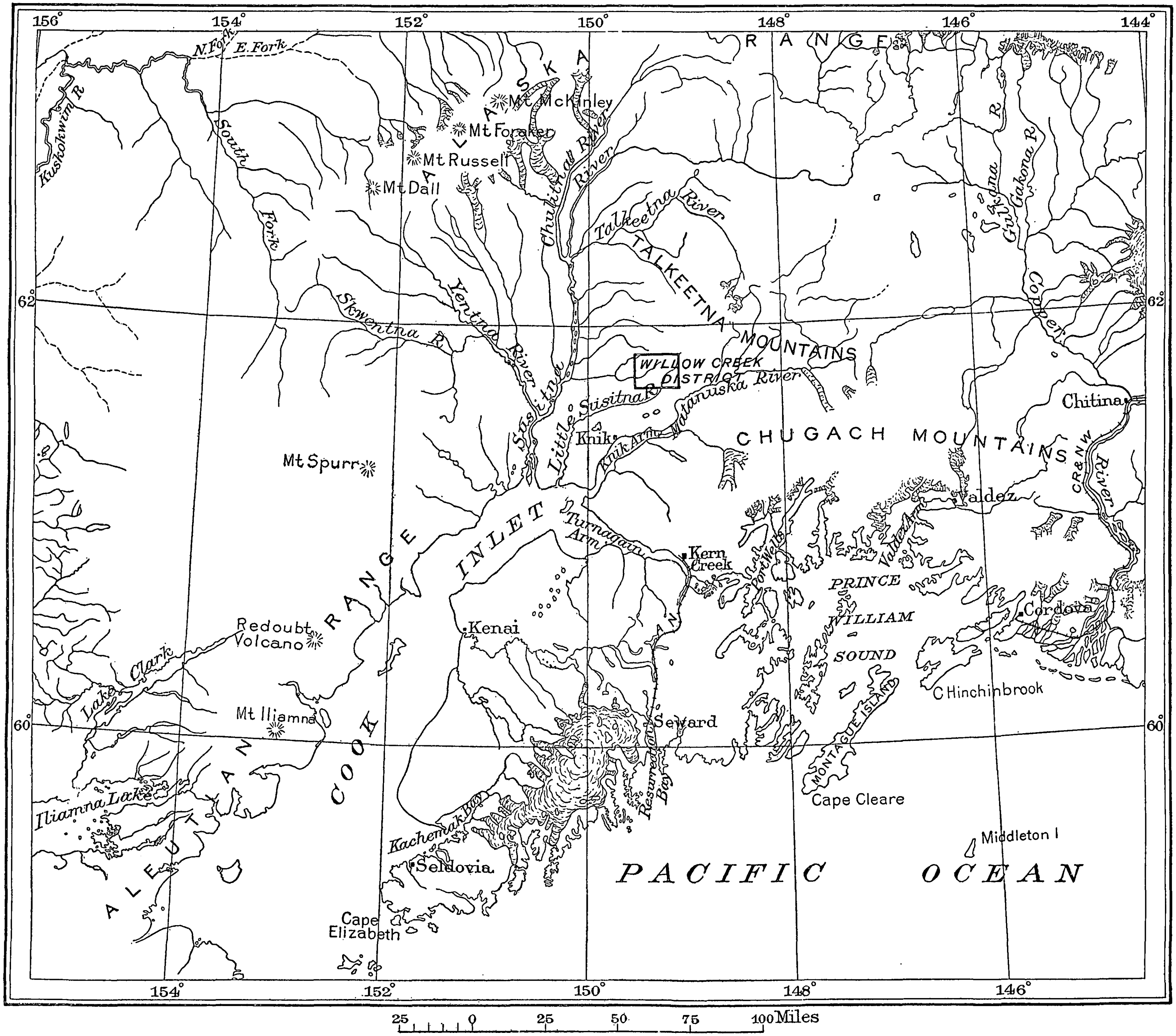
1794 Salvador Fidalgo, a Spanish navigator, had entered the inlet, and three of Cook's officers, George Dixon and Nathaniel Portlock in 1786 and George Vancouver in 1794, had returned to the scene of their earlier explorations. All these men made additions to Cook's earlier chart of the shore line, but no attempt was made to carry the surveys inland. Vancouver, however, completed the exploration of the upper ends of Turnagain and Knik arms and recognized their true character but failed to discover the mouth of Susitna River. The Susitna basin remained unknown until 1834, when the Russian Vassili Malakoff ascended the river, but little geographic knowledge of permanent value was obtained by his expedition. Mining in Alaska dates back to the expedition of a Russian mining engineer, P. P. Doroshin, in 1848.[1] Sent by the Russian American Co. to search for mineral deposits in Cook Inlet, he chose a locality on Kenai River, and during the summers of 1848 and 1850 he succeeded in extracting a few ounces of placer gold, but his operations were not commercially successful and the project was abandoned. In 1852 the Russian American Co. commenced to mine coal on Port Graham, at a locality which had been mentioned by Portlock in 1786, and mining was continued until the territory was transferred to the United States. In 1860 Russian maps which showed the general courses of Susitna and Matanuska rivers were published, though whether the Russians had actually explored all the area represented on these maps or whether their information had been procured from natives is not known. With the purchase of Alaska from Russia by the United States in 1867 the Russian fur trade was taken over by Americans, but the inland country tributary to Cook Inlet still remained unknown. The discovery of gold on Turnagain Arm was the impetus which sent many men to prospecting and exploring this great unknown portion of Alaska, and although these pioneers made their way to all parts of the Susitna and Matanuska basins, no accurate maps or descriptions of the country were published. The first discovery of gold is said to have been made in 1888, near Hope, but it was not until 1894 and 1895 that vigorous prospecting in that vicinity was carried on. In 1895 G. F. Becker[2] visited several localities on Cook Inlet and studied the geology and mineral resources.

Systematic surveys of this portion of Alaska were begun in 1898, when the discovery of the richness of the Klondike gold fields had focused the attention of the civilized world upon this great region. In that year G. H. Eldridge[3] and Robert Muldrow, of the United States Geological Survey, ascended Susitna River and crossed the

[1] Petrof, Ivan, Population, resources, etc., of Alaska: Tenth Census U. S., vol. 8, p. 78, 1884.

[2] Becker, G. F., Reconnaissance of the gold fields of southern Alaska, with some notes on the general geology: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 7-100, 1898.

[3] Eldridge, G. H., A reconnaissance in the Susitna basin and adjacent territory, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 1-29, 1900.



INDEX MAP SHOWING POSITION OF WILLOW CREEK DISTRICT AND ITS RELATION TO SUSITNA BASIN AND THE COASTAL REGION.

divide to the head of Nenana River, while J. E. Spurr[1] and W. S. Post, also of the Geological Survey, made their way up the Skwentna, across the Alaska Range, and down the Kuskokwim. During the same year W. C. Mendenhall,[2] while attached to a War Department expedition in charge of Capt. F. W. Glenn, had ascended Matanuska River to its head and crossed the broad basin to the northwest as far as Delta River. All these expeditions resulted in the publication of exploratory geologic and topographic maps of the routes traversed and were the beginnings of precise knowledge of this previously unknown country.

PREVIOUS GEOLOGIC WORK.

Although the expeditions of 1898 yielded valuable contributions to knowledge of the general geology of the area tributary to Cook Inlet, Mendenhall's report was the only one which in any close way touched the Willow Creek district. His route lay from Knik up the broad lowland bordered on the north by the Talkeetna Mountains and on the south by Knik Arm and Matanuska River, and although his map indicates a part of the Little Susitna Valley, he gained no information concerning the bedrock geology until he had passed to the east of this district. In 1902 A. H. Brooks[3] made a trip from Tyonek, on the west shore of Cook Inlet, up Skwentna River and along the northwest slope of the Alaska Range and mapped the geology along his route, but on this expedition he gained no knowledge of the east side of the Susitna basin. The next expedition to this vicinity was made in 1905, when G. C. Martin[4] spent about three weeks in a study of the coal of the lower Matanuska Valley. His geologic map included a portion of the Little Susitna basin. In 1906 T. G. Gerdine and R. H. Sargent carried a reconnaissance survey around the Talkeetna Mountains, and Sidney Paige and Adolph Knopf[5] mapped the geology of the area surveyed. Their geologic map covered the Willow Creek district, but the small scale of the map and the hasty manner in which the field work was necessarily done imposed sharp limitations upon the amount of detail that could be presented. Although Paige spent only a few days in the Willow Creek district, in that short time he succeeded in dividing the rocks into the three main groups which are still recognized.

In 1909 R. H. Sargent completed a topographic map of the lower Matanuska Valley on a scale of 1: 62,500, and in 1910 this map was used as a base for a detailed geologic investigation of the coal fields by

[1] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 31-264, 1900.

[2] Mendenhall, W. C., A reconnaissance from Resurrection Bay to Tanana River, Alaska: Idem, pp. 265-340.

[3] The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 16, 1911.

[4] A reconnaissance of the Matanuska coal field, Alaska, in 1905: U. S. Geol. Survey Bull. 289, 1906.

[5] Geologic reconnaissance in the Matanuska and Talkeetna basins: U. S. Geol. Survey Bull. 327, 1907.

G. C. Martin and F. J. Katz.[1] Their geologic map overlaps the map which accompanies this report (Pl. III, in pocket) on the southeast corner. In the fall of 1910 F. J. Katz and Theodore Chapin, after having left the Matanuska coal field, made a four days' trip into the Willow Creek district. In his report on the geology and mineral resources of the area Katz [2] described the economic development which had taken place up to that time and made some corrections to the geologic map of Paige and Knopf. In that same year a sketch map of the Willow Creek mining district, showing the general location of the mining claims and something of the drainage and topography of the district, was published by D. H. Sleem.

PRESENT INVESTIGATION.

Placer gold was first discovered in the Willow Creek district in 1897, and placer mining and prospecting have been carried on there to some extent ever since. The first gold quartz lode was located in 1906, and the later discovery of other gold lodes and active mining on three groups of claims have caused gold-lode mining to completely overshadow the feeble placer-mining industry. The geologic work done in the Willow Creek district by Paige, Katz, and Chapin, though it contributed greatly to the knowledge of the area, was done hurriedly and did not permit either close tracing of geologic boundaries or careful study of the ore deposits. Since their visits there has been a considerable advance in mining, and prospecting has been carried on continuously. The steadily increasing production of gold has attracted growing attention to this camp, and a more detailed examination of the geology and mineral resources than had hitherto been made seemed desirable. Plans were made to carry on this investigation in 1912, but the delay in appropriation of funds by Congress until late in August made the expedition impracticable that year. In 1913 it was determined to carry the delayed plans into effect. Accordingly C. E. Giffin was detailed to make a topographic map of the district, to be published on a scale of 1 : 62,500, and the writer was assigned to the study of the geology and ore deposits. The two parties, one consisting of the topographer, an assistant, and two camp hands, provided with four pack animals, and the other comprising the geologist, a packer, and a cook, with four pack horses, landed at Knik on July 13, 1913. Field work was commenced immediately and was continued by the topographic party until August 28 and by the geologic party until September 9. In that time both the topography and the geology of an area of about 90 square miles were mapped and all the mines and important prospects were visited. In this report free use has been made of the work of earlier investigators,

[1] Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500, 1912.
[2] A reconnaissance of the Willow Creek gold region: U. S. Geol. Survey Bull. 480, pp. 139-152, 1911.

especially that of Martin and Katz,[1] who studied the adjoining portion of the Matanuska Valley, and of Katz,[2] who described a number of prospects about which little additional information could be obtained. Thin sections of the unmineralized rocks collected were examined by J. E. Pogue, and the determinations of minerals and the classification of the rocks are the result of his study. A preliminary report on the mineral resources of the Willow Creek district has already been published.[3]

The writer wishes to express his indebtedness to the many miners and prospectors of the district for the expenditures of time and effort which they so willingly made in giving information about the properties, in supplying statistics, and in conducting him to the many points of interest.

GEOGRAPHY.

TOPOGRAPHY.

The Willow Creek district comprises the southwest corner of the Talkeetna Mountains. It is bordered on the south by the rolling lake-dotted lowland which lies between Knik Arm and the mountains and on the west by the broad Susitna Valley. The accompanying map (Pl. II, in pocket) does not cover the western part of the area commonly included in this district, but it shows that portion in which valuable discoveries of minerals have been made. The district is limited on the east and north by the basins of Little Susitna River and Willow Creek and their headward tributaries.

The north edge of the lowlands which lie between Knik Arm and the mountains extends along the southern border of the area shown on Plate II. In this lowland there are few bedrock exposures, the surface being an uneven rolling plain sloping gradually upward toward the mountains on the north. The form of the surface is much the same as it was when it was left by the retreating glacier. The innumerable lakes that dot the lowland are in general longest in an east-west direction, parallel to the direction of flow of the glacier that came down Matanuska Valley. The Knik lowland is directly continuous on the west and northwest with the Susitna lowland, which it resembles in topography and in mode of origin. In that part of the lowland over which the southward-flowing Susitna glacier moved the lakes are longest from north to south. Little Susitna River flows along the south base of the mountains and parallel to them in a shallow valley. Most of the lowland, however, is poorly drained, and

[1] Martin, G. C., and Katz, F. J., Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500, 1912.

[2] Katz, F. J., A reconnaissance of the Willow Creek gold region: U. S. Geol. Survey Bull. 480, pp. 139–152, 1911.

[3] Capps, S. R., Gold lodes and placers of the Willow Creek district: U. S. Geol. Survey Bull. 592, pp. 245–272, 1914.

there are few well-defined stream courses. It is well covered by a dense growth of spruce and birch, and the ridges afford firm ground for travel in the summer. The meadows and flats around the lakes and the marshy depressions between the hills are very soft when thawed and are difficult to cross with horses. No valuable minerals have been found in the lowlands, and their chief value will lie in their agricultural possibilities and timber resources.

The Knik lowland ends abruptly along its northern border and gives place to the Talkeetna Mountains, which rise steeply from the rolling plain. The mountain front is sharp, the long buttressing spurs common at the outer margins of mountain ranges being lacking. The straight line of the mountain face is due, in part at least, to the erosive action of the Matanuska Glacier, which once covered the lowland to a depth that in places exceeded 2,000 feet. The west slope of the mountains, in the Susitna Valley, is much more gentle. A large area in the heart of the Talkeetna Mountains, though unsurveyed, is known to be of the same general character as the surrounding regions that have been mapped. Near the west and north edges of the mountain mass the elevations are moderate and the summits of the ridges are rounded and smooth. Farther within the range the mountains are higher and more rugged and the crests consist of sharp peaks and pinnacled ridges. The highest peaks rise above 8,000 feet, and nearly all the larger streams head in glaciers. Most of the range is drained by Susitna and Matanuska rivers and their tributaries, although a considerable portion of its eastern slope falls within the Copper River basin.

DRAINAGE.

All the drainage from the Willow Creek district eventually finds its way to Cook Inlet, a part by way of Willow Creek and Susitna River and the remainder through Little Susitna River. Willow Creek heads opposite Fishhook Creek, in the heart of this mining district, and after following a southwestward course for 3 miles turns nearly due west and continues in that direction to its junction with Susitna River, 28 miles above the mouth of that stream. In the portion of its basin shown on Plate II Willow Creek flows in a broad U-shaped glaciated valley. West of the area mapped the mountains become smoother and lower, and as the great Susitna Valley is approached the stream flows across a broad high glacial bench and then descends somewhat abruptly through a canyon from which it emerges upon the Susitna flats. The area of the Willow Creek basin in the region here discussed is about 37 square miles. Within this district Willow Creek receives a number of tributary streams from the south, all of which drain the north slope of Bald Mountain Ridge. The largest of these tributaries from west to east are Wet, Grubstake, and Homestake creeks, and two unnamed streams. From the north Willow Creek is fed by Shorty and Craigie creeks. No glaciers exist in the basin of the main fork of Willow Creek shown on the map (Pl. II), and all the streams are clear. Near its head Willow Creek flows in a broad gently sloping valley, and the small stream has not reduced its bed noticeably below the valley floor. Two miles below its source, however, it begins to intrench itself and flows in a narrow though not very deep canyon over large bowlders as far west as the mouth of Craigie Creek. Below that point there is a gradually widening stream flat composed of moderate-sized stream gravels, which extends westward to the limits of the area here discussed. The tributaries from the south all head in glacial cirques and occupy hanging valleys. This is particularly true of Wet, Grubstake, and Homestake creeks, all of which have waterfalls or cascades at their lower ends, at the points where they join the Willow Creek valley, and also of Shorty and Craigie creeks, which enter from the north. Craigie Creek falls 400 feet within half a mile of its mouth, although its average gradient for the next 5 miles above is only 120 feet to the mile.

Little Susitna River is much the largest stream in the district, that portion of its basin shown on Plate II having an area of about 86 square miles. Its headward branches rise on the slopes of rugged mountains, the loftiest peaks of which reach elevations well over 6,000 feet. Several small glaciers occupy favorable positions, and the largest one, at the head of the river, discharges enough sediment to cloud the waters of the stream during periods of rapid melting. The other glaciers are all small and inactive, and the streams which drain them are comparatively clear. The mountainous portion of the river valley is shown on the accompanying map (Pl. II), and its course is in general a little west of south. For the upper 5 miles of its length the stream flows in the bottom of a broad valley, into which it has intrenched its channel but little. Below the first big bend terraces appear along the sides of the stream, showing that the river has lowered its bed below the bottom of the trough as left by the glacier. Below the mouth of Reed Creek the trench through the glacial deposits becomes gradually deeper toward the canyon. At the point where the river emerges from the mountains it flows through a narrow rock canyon, below which it bends to the west, flows along the base of the mountains, and after crossing the lowlands enters the north end of Cook Inlet. Between the mouth of Archangel Creek and the canyon the river bed is filled with large bowlders, the current is swift, and during most of the summer the stream can be forded at few places and only with difficulty. One wagon bridge and three footbridges span the stream in this stretch. The largest tributaries of Little Susitna River are Fishhook Creek and Archangel Creek.

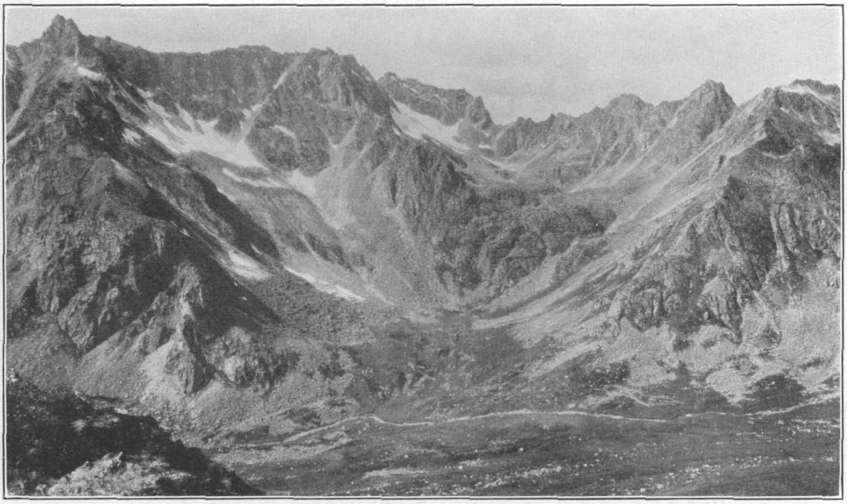
Fishhook Creek heads opposite Willow Creek (Pl. V, *B*), flows in a southerly direction for 3 miles through a high valley, turns sharply to the east, and descends abruptly from its hanging valley to join the Little Susitna, falling 1,100 feet in a distance of 1½ miles. The whole valley is a broadly U-shaped glacial valley and is itself bordered by a number of hanging cirques. The steep gradient of the stream has enabled it to intrench itself into its valley floor well toward its head, the stream channel being cut for the most part through glacial deposits. This stream trench begins a short distance above the upper mill and attains its greatest depth at the junction of the Fishhook and Little Susitna valleys, where the stream flows in a steep-sided gorge cut 200 feet below the bordering benches of glacial till.

Archangel Creek and its large northern branch, Reed Creek, both occupy broad U-shaped valleys surrounded by high mountains and in their lower courses flow through channels cut into the glacial morainic material. In the cirques in which all their tributaries head the streams flow for the most part close to bedrock.

INFLUENCE OF ROCK TYPES UPON TOPOGRAPHY.

In the Willow Creek district, as in other mountainous areas which have been subjected at no very remote time to intense glaciation, the tendency of the glaciers was to reduce all the divides to sharp ridges and to carve the valleys into broad U-shaped troughs with sweeping curves, leaving the valleys free from interlocking spurs and any other irregularities, and this work has been done without respect to the character of the rocks over which the ice moved. The type of rock has, however, had a notable effect on the topographic form, especially on the minor details, and each of the major geologic divisions shown on Plate III (in pocket) has a characteristic topography which distinguishes it from the other rock groups. The northern part of this district is composed of rocks of granitic character, which have in many places (Pl. IV, *A*) been eroded into sharp peaks and ragged, serrate ridges. The shape of the individual pinnacles is determined by the direction and abundance of joint cracks, and a sharp crag may be a single massive block of rock, its faces formed by joint planes. The talus from these ridges consists of angular blocks, some of which are of great size (Pl. V, *A*). The schist also weathers to form rugged peaks (Pl. IV, *B*), which are, however, quite different in appearance from those in the granitic areas. Sawtoothed ridges are lacking, and on close examination, the projecting points are seen to be intricately broken by a multitude of cracks. The rock waste from the schist mountains is composed for the most part of small fragments and is in sharp contrast to that from the granitic mountains.

Mountains carved from the Tertiary arkoses and sandstones bear some resemblance to the granitic mountains. The ridges are in



A. PART OF THE SOUTHWEST VALLEY WALL OF ARCHANGEL CREEK.

Showing typical rugged topography of the quartz diorite mountains.

B. EASTERN PART OF BALD MOUNTAIN RIDGE.

A characteristic mountain crest carved from mica schist.

places rough and ragged, and the talus consists of very coarse blocks. The bedding of the sediments has, however, exerted an influence upon the topography, which can readily be distinguished from that of the granitic areas (Pl. VI, *A*).

West of a line running north through the mouth of Craigie Creek the mountain summits are smooth and rounded and contrast strongly with the sharp peaks and ridges of the higher mountains to the north and east. This lack of ruggedness is not due to the character of the rock, for it appears on mountains composed of granitic, schistose, and sedimentary rocks. The cause of this difference in topographic character is to be attributed to the lower altitude of the mountains on the west border of the Talkeetna Range and their consequent freedom from severe glacial erosion. In the higher mountains each small valley head once contained a glacier and each glacier excavated its bed to form a glacial cirque. The cutting of these cirques into the mountains from all sides has reduced the crests to sharp ridges and peaks. In the lower mountains the altitude was insufficient for local glaciers to maintain themselves, and although the main valleys were eroded by ice streams whose sources were in the higher parts of the range, the local glaciers were fewer and more feeble, and the cirques were more widely spaced, leaving considerable areas of the old upland surface unsculptured by glacial ice (Pl. IX, *B*). In the lowlands, both south and west of the mountains, the larger topographic features are probably due to the form of the underlying bedrock as left by the ice, although exposures of rock in place are rare, but the minor details of surface configuration are due to the action of the glacial ice on the surficial deposits, the region having in general the mild hummock and kettle topography of glacial moraines, somewhat modified locally by the cutting of postglacial stream valleys.

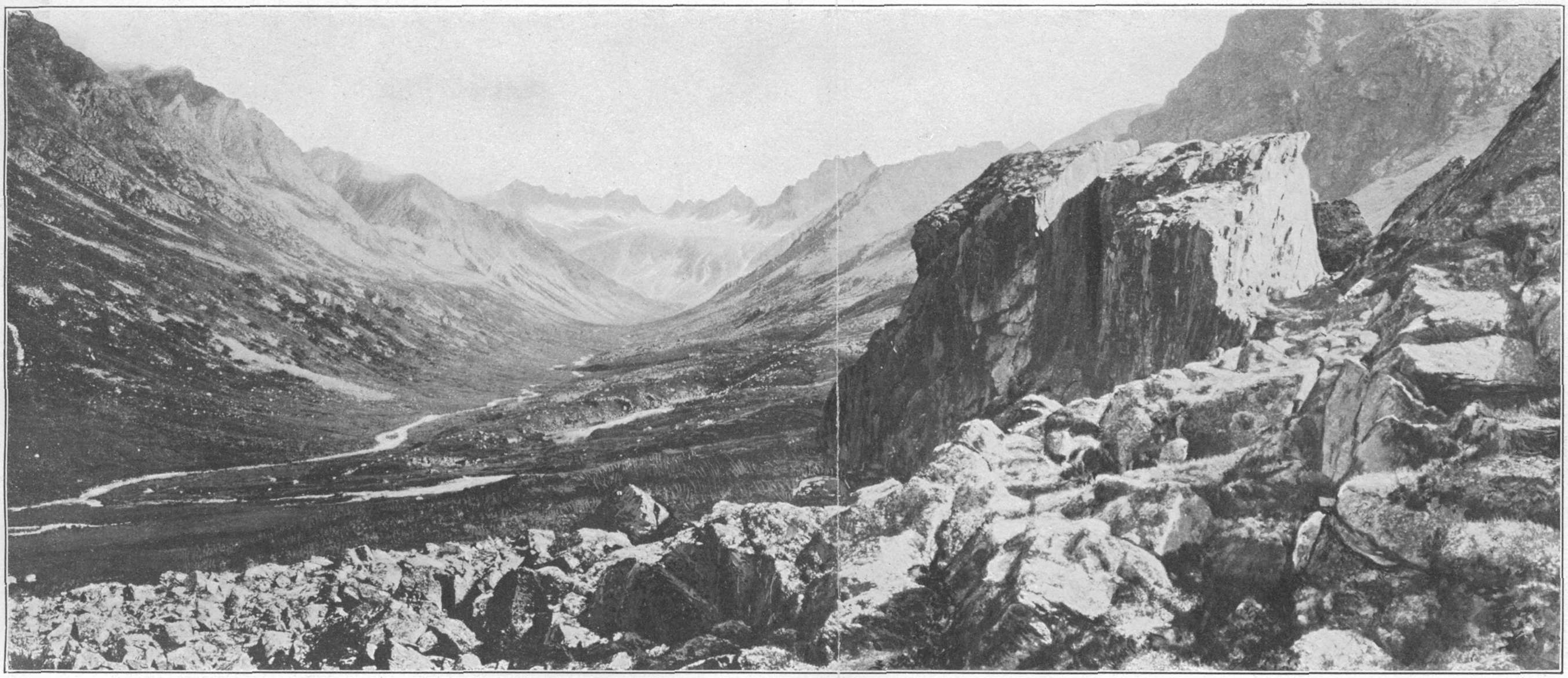
CLIMATE.

The Willow Creek district is, at its nearest point, only 10 miles from tidewater on Knik Arm, but the distance to the main line of the Pacific coast on the south is 120 miles, and high mountains lie between, so that the climate of the district more closely resembles that of interior Alaska than that of the coastal region. So far as is known, no systematic records of precipitation or temperature have been kept in the Susitna basin. It is well known, however, that the winters are longer and colder and the summers warmer than on the coastal belt, where the ocean waters have an equalizing effect on the temperature. The precipitation, though generally less than on the coast, is much heavier, both in summer and in winter, than it is north of the Alaska Range, the high mountains of the Talkeetna Range and of the Chugach Range south of Matanuska River having a noticeable influence on the distribution of the precipitation. The amount of rain and snow varies greatly in different years. In 1912, it is said, rain fell almost continuously during the summer. The summer of 1913 is said to have been unusually dry; between July 13 and September 17 it rained or snowed all day for only eight days and during parts of five other days. In general, the Willow Creek district lies within the area of moderate rainfall that includes much of the lower Susitna basin.

Activities in any Alaskan mining camp are to a large extent determined by the season. In the winter, when the ground is covered with snow and the streams are frozen, surface prospecting is abandoned, mining is confined to underground work, and mills which depend on water power are closed. The transportation of supplies, however, is facilitated by the snow, and the streams and marshes, which are impassable in summer, offer good routes for sledding in the winter. In the summer surface mining, milling, construction work, and prospecting are carried on. The length of the open season is therefore an important factor in determining the mining costs in any camp. From the last of November to late in April or early in May the ice in upper Cook Inlet prevents navigation to Knik Anchorage, and the streams in the Willow Creek district are usually frozen and the ground snow covered. From late in May until late in October surface mining may be done, thus giving a maximum working season of nearly 150 days, a somewhat longer period than is available in interior Alaska.

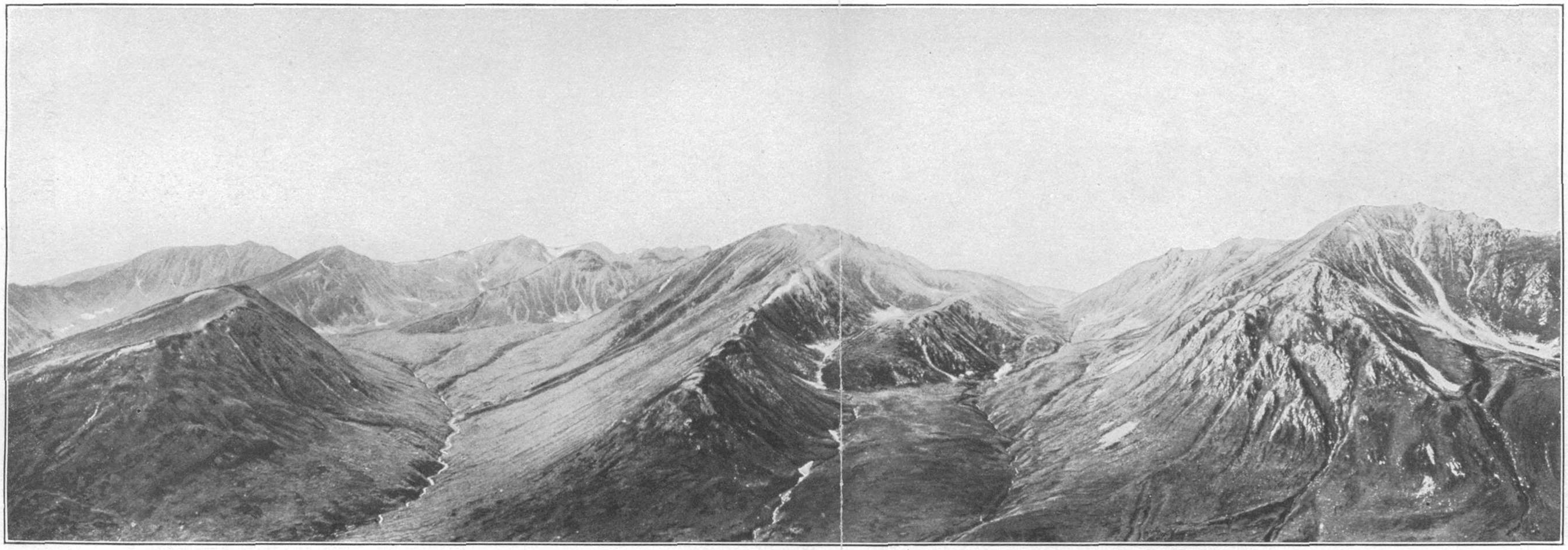
VEGETATION.

After the break-up in the spring, when the streams become free from ice and the snow first disappears from exposed slopes, the approach of summer is astonishingly rapid. Vegetation springs up as soon as the ground is bare of snow, and the long hours of sunlight and the warm days cause the snow to disappear quickly and the plants to grow with great rapidity and luxuriance. To those who use horses the appearance of grass for forage is an important event. Sufficient grass to support stock appears in the lowlands by the middle of May, and from that time until the heavy frosts late in September have withered it forage for horses is nearly everywhere abundant. The most common grass is of a variety known as red top, which is widely distributed in the timbered lowlands, among the alders and willows above timber line, and up the mountain slopes to an elevation of about 2,500 feet. It grows with remarkable luxuriance, in some places to a height of 6 or 7 feet (Pl. VI, *B*), and over thousands of acres its growth is so dense as to seriously retard progress through it. This grass makes good hay when properly cut and cured, but when withered by frost in the fall it affords little nourishment for stock, and horses worked after that time must be fed on hay and grain. Bracken



A. HEAD OF LITTLE SUSITNA VALLEY.

The great talus block in the foreground (about 40 feet long) and the mountains that border the valley are composed of quartz diorite.



B. VIEW FROM THE SOUTHEAST OF TWO TRIBUTARIES OF FISHHOOK CREEK.

Hatcher Creek (on the right) lies along the contact between the quartz diorite (on the right) and the mica schist (on the left).

ferns and the brilliant fire weed also grow among the red top, and in the fall the downy seeds of the fire weed may be seen drifting across the summits of the highest mountains.

The distribution of timber in the district is shown in figure 1. It will be seen that most of the mountainous region is destitute of timber, trees appearing only in the lowlands, on the lower slopes of the mountains, and in the larger valleys. In the lowlands there is

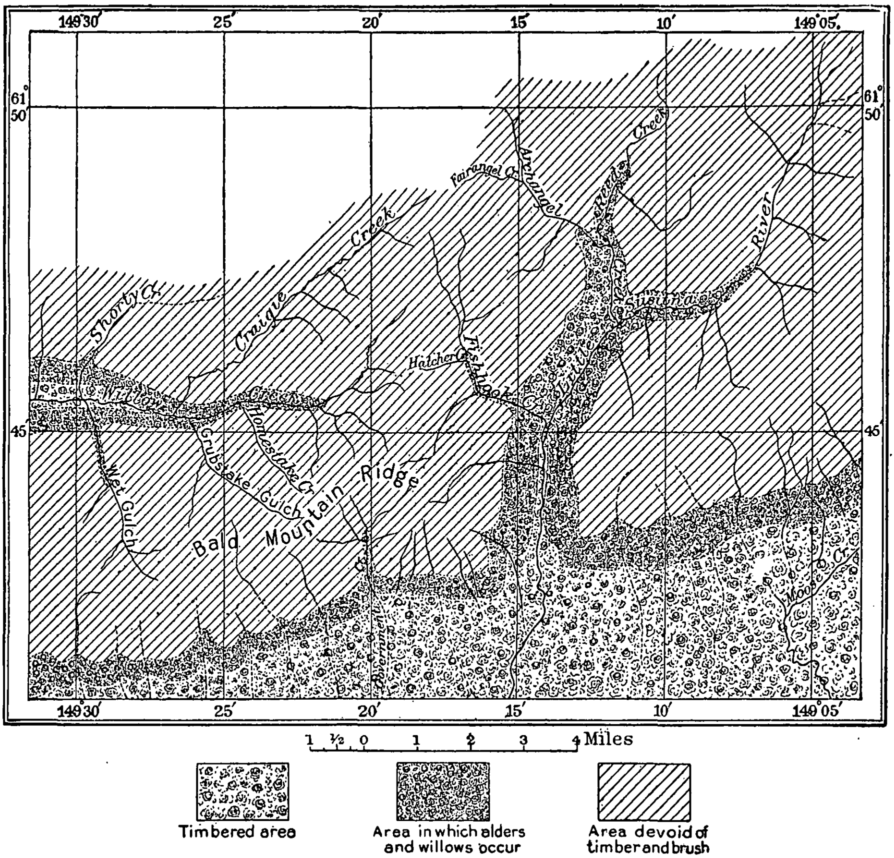


FIGURE 1.—Sketch map showing distribution of timber and brush in the Willow Creek district.

an abundant growth of spruce and birch, with cottonwood along the stream courses. Most of the birch trees do not exceed a foot in diameter, and this wood is used principally for fuel. Spruce trees with a diameter of 2 feet at the base are not uncommon and yield lumber of a very fair grade for buildings, sluice boxes, and mining purposes. Spruce is also preferred to birch for firewood in camps where the logs must be hauled some distance, as the wood makes good fuel and is much lighter than birch. Little use is made of the cottonwood, although the trees grow to greater size than either the spruce or the birch.

As timber line is approached, at an elevation of 1,500 to 2,000 feet, the trees become scattered and give way to a dense growth of alder bushes, in which travel is difficult and through which it is necessary to chop trails for horses. Alders grow in scattered clumps up to altitudes of 2,500 to 3,000 feet, and willow bushes extend to somewhat greater heights. For the prospector's camp fire alders are used almost exclusively, for they may be found at much greater altitudes than the more desirable spruce, but even alders must in many places be brought several miles. Alder wood can be burned green in a stove, and it soon dries out if cut and split and makes an excellent firewood.

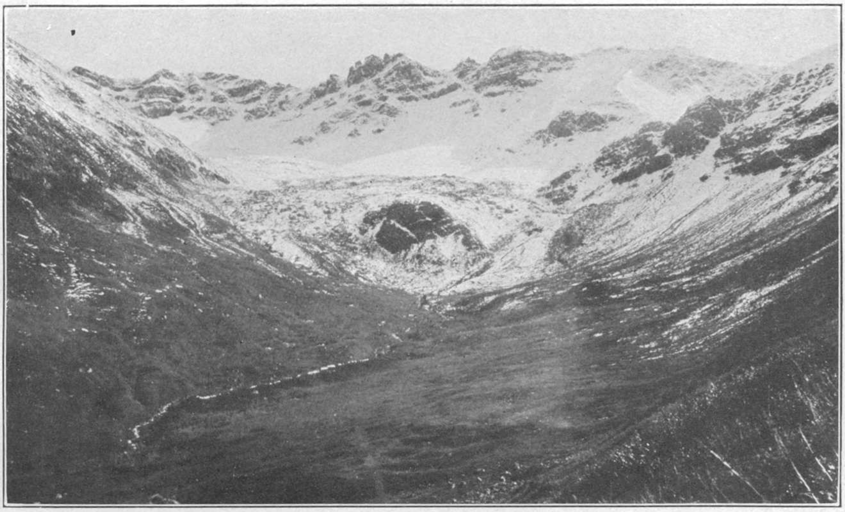
In Little Susitna Valley some good spruce formerly grew as far north as the mouth of Fishhook Creek, but the demand for this wood has already caused the cutting of practically all the good trees above the canyon, and it is now necessary to haul logs about 7 miles to the mines on Fishhook Creek. Timber for the mine on Craigie Creek is obtained about 4 miles away, the upper limit of spruce on Willow Creek being at about the mouth of Craigie Creek.

Sphagnum mosses are widely distributed, especially among the timber in the lowlands. Above the altitude to which grass and ferns grow the slopes are covered by a thin growth of moss and heather, which in places shows a curious arrangement of hummocks or of ridges and furrows. (See Pl. VII, *A* and *B*.) The cause of this irregular surface is not definitely known, but it probably has to do with the action of alternate freezing and thawing.

POPULATION.

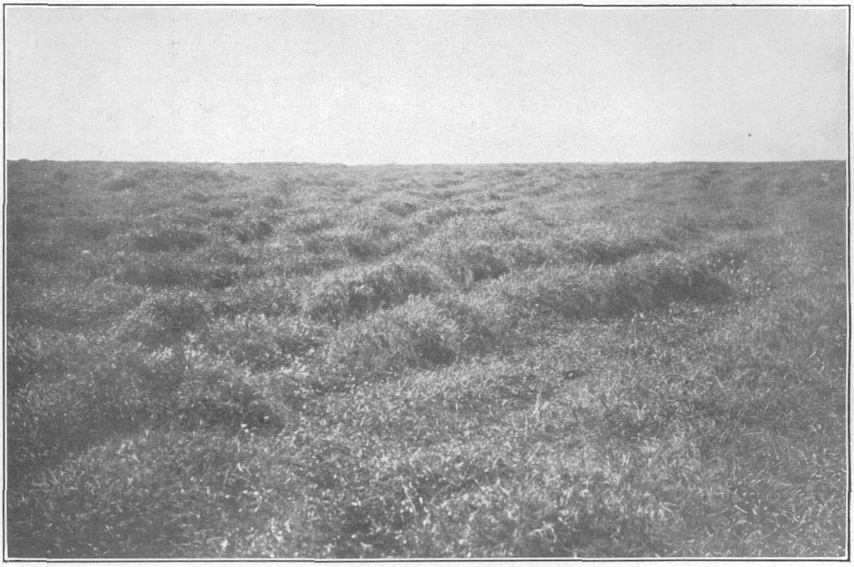
Knik village, on the northwest shore of Knik Arm, has long been a native settlement. For at least 15 years there has been a trading station at that place, and in 1910 the population was 118, including natives and whites. By 1913 the village had increased in white population and contained stores, road houses, a church, and a schoolhouse. It is the center of supplies for the Willow Creek district and the Matanuska Valley. The first white men to settle in the Willow Creek region were those who discovered placer gold on that stream in 1897, and this small placer camp contained the total population for several years. Since the first discovery of gold lodes in 1906 the mining population has steadily increased, and it is estimated that in 1913 there were about 100 people in the district. Of these, about 70 were engaged in mining and the rest in prospecting.

There are no permanent settlements of natives nearer than Knik. The Indians spend most of their time fishing and hunting near the shores of Knik Arm and in upper Cook Inlet, but in the fall and winter hunting and trapping trips are undertaken throughout the adjoining country.

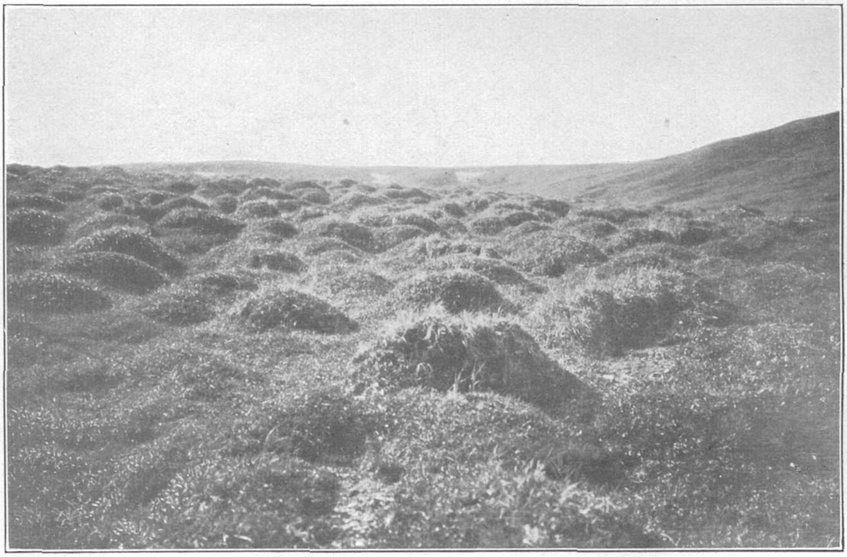


A. INTERBEDDED ARKOSE AND SHALE BEDS AT THE HEAD OF DELIA CREEK.

B. LUXURIANT GROWTH OF RED-TOP GRASS NEAR THE CANYON OF LITTLE SUSITNA RIVER.



A. MOSS AND HEATHER RIDGES ON TOP OF BALD MOUNTAIN RIDGE.



B. MOSS AND HEATHER HUMMOCKS ON TOP OF BALD MOUNTAIN RIDGE.

SUPPLIES AND TRANSPORTATION.

The Willow Creek district is always approached by way of the village of Knik, which is the center of supplies for this region. Although Knik is situated on Knik Arm, an embayment of Cook Inlet, it is on the shallow upper portion of the inlet and can be reached by boat only at high tide. When the tide is out no water is visible from the village, which then looks out upon miles of barren mud flats cut by an irregular network of tidal channels. At high tide boats drawing several feet of water may reach the town by following one of the deeper channels. During about half the year the upper part of Cook Inlet is closed to navigation on account of the ice which forms in it. The head of the inlet is made brackish by the large quantity of fresh water which it receives from Susitna, Matanuska, and other rivers, and on this brackish water ice forms more readily than on the normal salt water. The mean tidal range is about 30 feet, and in the rapid currents formed by the tides the ice is carried back and forth and renders navigation impossible during the winter. During this time the village maintains communication with the coast by way of a trail which crosses the divide at the head of Crow Creek, passes around the head of Turnagain Arm, and thence follows the general course of the railroad to Seward. The mail is brought over this route by dog trains, but the other traffic is so small as to be negligible.

During the open season practically all travelers to Knik go by ocean steamer to Knik Anchorage, near the mouth of Ship Creek, about 18 miles below the town. From the anchorage freight is lightered by scows to Knik and passengers are transferred by launch. In 1913, between May and November, one steamship, plying from Seattle through southeastern Alaska to ports on the Gulf of Alaska and Cook Inlet, made trips every three weeks to Knik Anchorage. The passenger rate in 1913 between Seattle and Knik Anchorage was $55 each way. The freight rate varied with the class of material shipped but was $30 each for horses and from $15 to $26 a ton for groceries and provisions. Wharfage at Seattle was not included in these charges, and the additional cost of transportation from Knik Anchorage to Knik was $2 each for passengers, $8 a head for horses, and 30 to 40 per cent of the freight rate from Seattle to Knik Anchorage for supplies.

Two routes were formerly in general use between Knik and the mines in the Willow Creek district, both of which followed the shore of Knik Arm in a northeasterly direction as far as the mouth of Cottonwood Creek, 6 miles from Knik. From Cottonwood the Bald Mountain trail extends northward across the lowlands, crosses Bald Mountain Ridge into the head of Wet Gulch, follows Wet Gulch to its mouth, and thence goes up Willow Creek. One branch extends up Craigie Creek valley, and another crosses the divide to the Little

Susitna basin, follows down Hatcher Creek, and ends at the mines on upper Fishhook Creek. The portion of this trail which lies in the mountains affords good footing, but the stretch between Cottonwood and Bald Mountain Ridge is said to be soft in summer. The lowland portion is now little used. The other route was the old Carle wagon road, which extended from Cottonwood northeastward to Little Susitna River, several miles below the canyon, and after crossing that stream kept on its west side to Fishhook Creek, which it followed up to the mines. The Carle road has now been displaced by a new wagon road completed by the Alaska Road Commission in 1913. This road follows the general course of the Carle road from Knik for 23 miles, but keeps to the right of Little Susitna River as far as the canyon, crosses it in the canyon, and extends up the west bank of the stream and up Fishhook Creek to the mines. This road is well graded, is furnished with good bridges, and is now used for practically all summer travel to the Willow Creek district as well as for winter travel to points in the Fishhook and Little Susitna valleys. The winter road for sledding to the Willow Creek basin leads northward from Knik, skirts the west end of Bald Mountain Ridge, and proceeds up Willow Creek.

The summer freight rate by wagon to upper Fishhook Creek from Knik is from 4 to 5 cents a pound. Supplies for the Willow Creek basin must be transported by pack train from Fishhook Creek, at a considerable additional expense. In winter freight may be sledded to the camps by either the new wagon road or the Willow Creek winter road, at about half the cost of summer transportation. The district will be made readily accessible by the Government railroad from Seward to Fairbanks, construction of which has been begun. This railroad will pass close to the southern margin of the district, and the distance to Seward, its coastal terminal, will be about 165 miles.[1] The plan includes a branch line into the Matanuska coal field, with another tidewater terminal at the mouth of Ship Creek near the entrance to Knik Arm, which will be available during the season of open navigation on Cook Inlet.

GEOLOGY.

PRINCIPAL FEATURES.

The areal distribution of the geologic formations of the Willow Creek district is shown on the accompanying map (Pl. III, in pocket) and the relations of the various rock formations to one another are represented in a generalized form in figure 2. The details of distribution of the different formations as shown on the geologic map differ somewhat from those shown on earlier published maps of this district, more accurate representation having been made possible by

[1] Railway routes in Alaska: Alaska Railroad Comm. Rept., House Doc. No. 1346, pts. 1 and 2, 62d Cong., 3d sess., 1913.

the longer time available for the actual tracing of geologic boundaries and by the completion of a base map on a larger scale than those previously published. The Willow Creek district was only a small part of a large area that was under investigation during the earlier surveys, and only a short time could then be spent in it. Nevertheless, the main subdivisions made by Paige and Knopf [1] and later by

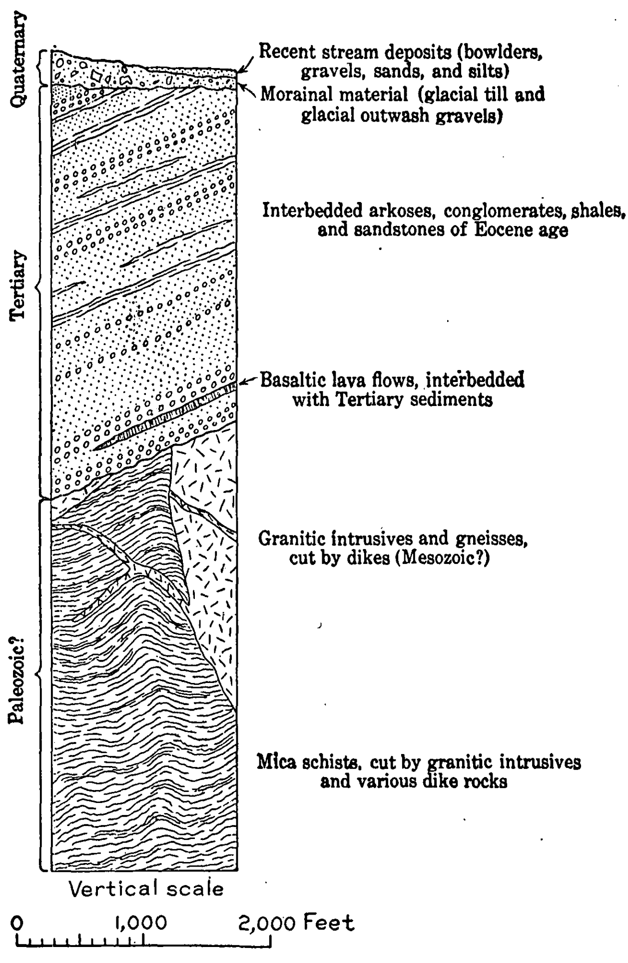


FIGURE 2.—Generalized columnar section of the rocks of the Willow Creek district.

Katz [2] are adopted here. The schists, most of which lie between Bald Mountain Ridge and Willow Creek, are the oldest rocks in the Willow Creek district and probably also in the entire Talkeetna Mountain region. They consist of highly fissile thoroughly foliated garnetiferous mica schists and chlorite-albite schists and are every-

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, Pl. II, 1907.

[2] Katz, F. J., A reconnaissance of the Willow Creek gold region: U. S. Geol. Survey Bull. 480, p. 143, 1911.

where very uniform in appearance. On the north they are cut off by intrusive quartz diorite and on the south they are overlain in part by gneisses and in part by Tertiary sediments. The schists have been cut by dikes of various kinds, some of which have themselves been metamorphosed along with the rocks which they intrude. The numerous quartz veins in the schists are probably the source of a part of the placer gold of the district (see p. 27), but, although some of these veins are rather large, no encouraging lode prospects have been found in the schist area. The great alteration of the schists indicates that the rocks from which they were derived were subjected to intense metamorphism for a long time. Neither the original character of these rocks nor their age is known, but their antiquity may be shown by comparing them with the much less altered Mesozoic rocks of the lower Matanuska Valley. At any rate, a long time elapsed between the deposition of the rocks that formed the schists and the intrusion of the next younger rocks of this district, the quartz diorites. Granitic rocks of the same general type as the quartz diorite form a large part of the Talkeetna Mountain mass and extend southward toward its southern margin. Whether or not these rocks were all intruded at the same time is not known. Several separate intrusions may be represented in this area; but it is certain that the schists had been greatly metamorphosed before they were cut by the granitic rocks, which are therefore much younger than the schists. In many places in this district the granitic rocks are decidedly gneissic along their southern border, as if the edges of the intrusion had been somewhat metamorphosed, whereas the main granitic mass to the north has remained massive and unaltered. A gradation from massive quartz diorite to a banded, somewhat gneissic rock, was seen, so it was not practicable to draw a line separating the gneiss from the unaltered diorite. In its characteristic development, however, the gneiss is very different in appearance from the diorite, and it is possible that some of the gneisses are older than the unaltered quartz diorites that form the heart of the Talkeetna Range. If a part of the gneiss is older than the main quartz diorite intrusion, that fact would indicate another period of metamorphism later than that which altered the schists but earlier than the intrusion of the diorite, for the gneisses are less profoundly metamorphosed than the schists. On the other hand, if the gneisses include parts of the main quartz diorite intrusion, then there was local metamorphism along the southern border of that intrusion which affected the rocks at some places but did not extend far into the intruded mass.

During the intrusion of the granitic rocks many dikes, of similar composition to the main intrusive mass, were injected into the surrounding rocks or into those parts of the intrusion itself, which cooled sufficiently to form cracks into which the dikes could penetrate. These dikes are, in general, light-colored fine-grained rocks, consisting, principally, of quartz and feldspar, and have been classified as aplite or alaskite dikes. After the intruded igneous rocks had cooled another long interval elapsed, during which erosion reduced the country to a surface of rather low relief and removed much material from the schist and quartz diorite areas. Upon this surface fresh-water deposits of Eocene age, consisting of muds, sands, coarse grits, and gravels, with abundant plant fragments and some coal, were laid down, sedimentation being interrupted in places by thin flows of basaltic lava. In adjacent areas the Eocene beds were succeeded conformably by conglomerates, which, after an erosion interval, were capped by lava flows and accumulations of volcanic breccias and tuffs; but if these materials were deposited in the Willow Creek district they were later removed by erosion, for no trace of them now remains. Next followed a period of uplift, during which the Eocene sediments, now hard rock, and any later deposits which may then have existed were tilted and gently folded. Upon this land mass streams carved their valleys and developed a rather mature though rugged topography. The next notable geologic event in this district was the accumulation of the great glaciers, which occupied all of the large valleys. The glaciers, by their erosion, profoundly altered the shapes of the basins and in their upper courses gathered an enormous load of soil and rock, which they transported for some distance and then dropped upon the surface of the older rock formations. The glacial deposits consist of morainal material dropped by the ice and of gravels supplied by the glaciers, but transported, rounded, and assorted, and then deposited by the glacial streams. The morainal deposits commonly consist of a clayey matrix through which pebbles, bowlders, and angular fragments of rock are scattered indiscriminately without assortment. Glacial striæ may be found on some of these fragments of rock, but the quartz diorite, of which most of them are composed, is hard and does not take striæ readily. Deposits of glacial outwash gravels are of minor amount in this district, the morainal deposits predominating. The glacial deposits shown on Plate III vary greatly in thickness from place to place, but over the area represented are of sufficient thickness to conceal the underlying hard-rock formations. The most recent deposits here considered are the gravels of the present streams, which form narrow strips along the bottoms of most of the stream valleys, but in general cover areas too small to be shown on a map of this scale.

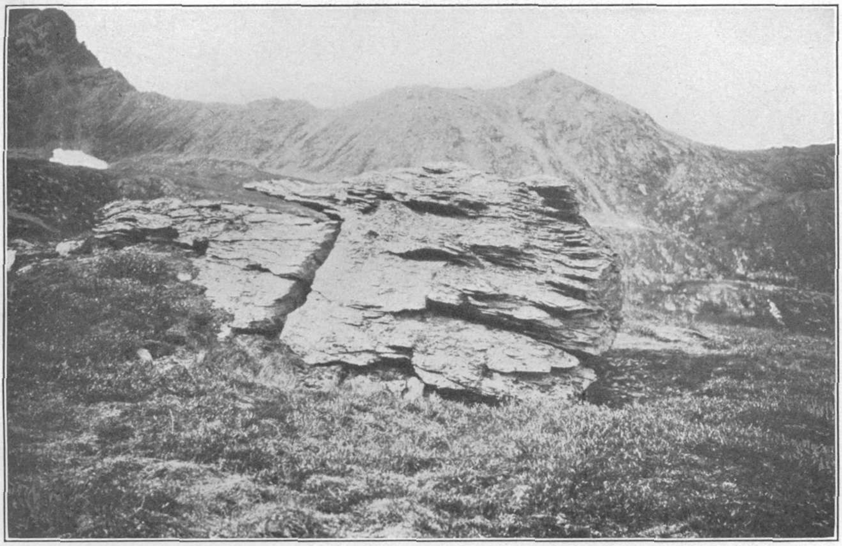
SEDIMENTARY ROCKS.

MICA SCHIST.

DISTRIBUTION AND CHARACTER.

As has already been stated, the mica schists occupy an area which in large part lies north of the crest of Bald Mountain Ridge, west of Little Susitna Valley, and south of Willow Creek. (See Pl. III, in pocket.) These limits are only approximate, for in places the outcrops of the schist extend a short distance south of Bald Mountain Ridge, especially in the valley of Government Creek, and the schist itself underlies much of the Bald Mountain Ridge beneath a comparatively thin cover of gneiss and Tertiary beds. On the north the schist is found over half a mile north of Willow Creek in the Craigie Creek canyon, being cut off on its north edge by the quartz diorite intrusive mass. On the west it extends beyond the area of the present investigation but is known to disappear beneath the glacial deposits on the edge of Susitna Valley. On the whole, however, the schist area here outlined is an isolated occurrence, no other rocks of this type having been seen in the Talkeetna Mountains or the lower Susitna basin. The resemblance of these schists to schists in the interior of Alaska will be discussed in another part of this report.

The schists may be seen in excellent exposures in a great number of places, especially at the heads of the cirques which cut Bald Mountain Ridge on the north. (See Pl. IV, *B*.) The predominant rocks are highly contorted mica schists and phyllites, which readily cleave into thin flakes along the lines of schistosity. The weathered surface phases are so friable that firm hand specimens could be procured with difficulty. The cleavage planes are not smooth but have an irregular, knotty appearance as they curve around included particles of more resistant minerals. In color the schists range from whitish, silvery rocks through reddish and green phases, the unweathered rocks having in general a greenish, silvery cast, a reddish tinge appearing on weathered surfaces, probably due to the oxidation of iron-bearing minerals. In the fresh exposures of recent stream canyons the schist appears to be rather massive and breaks along joint planes into large, angular blocks. When weathered the rock separates along the lines of schistosity into thin flakes and slabs. (See Pl. VIII, *A*.) The degree of schistosity varies from place to place; in some outcrops the rock appears rather massive and free from well-developed cleavage; in others it shows a large percentage of mica and is very fissile. Included within the schists are certain massive lenses of basic rock which have locally been considerably sheared and metamorphosed. In Grubstake Gulch rocks which presumably came from the schist series had been altered to satiny,



A. CHARACTERISTIC WEATHERED SURFACE OF A BLOCK OF MICA SCHIST.

B. GLACIAL LATERAL MORAINES ACROSS THE MOUTH OF SIDNEY CREEK VALLEY.

light-green amphibole asbestos. The asbestos fibers are brittle and somewhat bent, and the material is probably of too low grade to be commercially valuable. Quartz veins are abundant in the schists and show a tendency to follow the schistose structure, although many cut across the schistosity. Veins 1 to 4 feet thick were seen, and some of these could be traced for several hundred feet along the surface. The quartz is characteristically massive, milk-white in color, and is remarkably free from mineralization. Even a small quantity of pyrite in this quartz would reveal itself by rusty stains on the weathered outcrops, yet such stains are infrequent. Many samples of the quartz that have been crushed and panned by prospectors yielded no free gold, and assays yield from a trace to about $1 per ton. Besides being cut by the large, conspicuous quartz veins, the schist is at many places intricately cut by tiny quartz veinlets, some no thicker than a sheet of paper. No assays have been made of the quartz of these veinlets, and its metallic content is not known. It seems certain, however, that much of the placer gold of Grubstake Gulch has been derived from the schist, and it is probably contained in the quartz veins and veinlets and concentrated from them into the valley bottom by erosion.

At different times the schists have been intruded by rocks of a rather wide range of composition and texture. These rocks consisted originally of materials ranging from basic to acidic types and have undergone varying degrees of metamorphism along with the schists. Some basic intrusive rocks are now altered to serpentines and contain asbestos, and appear to be almost as old as the surrounding mica schists. Other acidic rocks have been metamorphosed little or not at all, and were injected after the schist had undergone most of its metamorphism. It is therefore evident that intrusive rocks of various kinds have been injected into the schists at different times and have been altered to a degree corresponding to the alteration of the schists since their intrusion. Most of the intrusive masses are small, and no attempt has been made to show the smaller masses on the accompanying map (Pl. III, in pocket). The following petrographic description of the schists is taken from Paige and Knopf:[1]

The schists are thoroughly foliated rocks of medium grain, and show in general no variations in appearance. Under the microscope they are found to comprise garnetiferous mica schists and chlorite-albite schists. The garnetiferous mica schist is composed largely of quartz, which shows powerful strain shadows, muscovite in long laths, chloritized biotite, orthoclase, and garnet altered almost completely to chlorite. In the albite schist soda feldspar is the dominant constituent. The albite poikilitically incloses various other constituents, chief among which is clinozoisite in long, stout prisms, usually oriented parallel to

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, pp. 10-11, 1907.

the schistosity. In addition to the albite abundant quartz, crushed and showing strain shadows, is present in considerable amount, with some chlorite and clouds of magnetite dust. Muscovite is but an accidental constituent, and is only found included in the albite plates. Some of the albite schists, however, contain muscovite as an important constituent. Such a schist, examined microscopically, shows large albites in the form of augen, quartz badly crushed and strained, muscovite of a sericitic nature, and chlorite, and is evidently a schist affected by a second period of dynamic activity.

Some serpentine and pyroxenite are included in the mica schist series. The pyroxenite presents a pseudoporphyritic aspect under the microscope, due to crushed plates of monoclinic pyroxene lying embedded in a ground-mass of serpentine. The pyroxene is noteworthy on account of the fine multiple twinning parallel to the orthopinacoid and of the slicing which has taken place along that plane. The shearing of the pyroxenite is probably to be correlated with the movement which crushed the schists.

A specimen collected during the present investigation, when studied in thin section, also proved to be a typical mica schist. The rock contains abundant shreds of white mica, closely associated with magnetite and arranged in lines of foliation. The components bend around and envelop attenuated eyes of granulated quartz showing undulatory extinction and what are probably altered orthoclase crystals. The rock contains some apatite and perhaps some garnet and was probably derived from a granite.

The structure of the schists is complex and can be deciphered only by extremely detailed study. Metamorphism has progressed so far that original characters have been destroyed, and the development of schistosity and cleavage planes has so obscured the old bedding planes that they can no longer be recognized. Observations of strike and dip can be made only on the schistosity, and this has at many places no relation to the original bedding. A study of certain of the igneous dikes in the schists shows that the schists have been closely and irregularly folded and faulted, and the problem is thus still further complicated. It may be said, however, that the schistosity in general strikes northeastward and dips about 45° on either side of the vertical, but the direction of dip and strike are by no means uniform.

THICKNESS.

No idea could be gained of the thickness of the schist series, but the elevation at which it outcrops within the area studied ranges from 2,000 to 4,800 feet. The base of the schist is nowhere exposed, and its downward extension is therefore undetermined; its top has been subjected to erosion at two known periods, and possibly at other times of which there is now no record. It may be safely assumed that the schists reach a maximum thickness of several thousand feet.

ORIGIN AND STRUCTURE.

It is not yet possible to state definitely the mode of origin of the mica schists. Whatever may have been the character of the original rocks of which the schists were formed, they have now been so greatly changed by metamorphism, with accompanying recrystallization of the rock-forming minerals and the production of schistosity, that they have lost all traces of their original character. They bear, however, some resemblance to other schists which consist, in part at least, of altered sediments, and they may therefore consist in part of sedimentary material. In places, however, the schists include igneous rocks, which show varying degrees of metamorphism and which are of later age than the typical mica schist that incloses them. It may therefore be tentatively affirmed that the schists originally consisted of sediments which were intruded by igneous rocks at various times and metamorphosed during two or more periods of deformation. The structural relations of the mica schists to the diorites and gneisses, to the Tertiary sediments, and the unconsolidated Quaternary deposits are shown diagrammatically in the geologic cross sections A–B and C–D, on Plate III (in pocket).

AGE AND CORRELATION.

No fossils have been found in the schists, and none are likely to be found in them, for the processes which altered the rocks to their present condition would almost certainly have destroyed any fossils they may have contained. The age and character of the rocks that underlie the schist are not known. The next succeeding sedimentary beds are of Eocene age, but they were not deposited until the schists had been metamorphosed, intruded, and then subjected to a long period of erosion. The schists are cut by granitic intrusives, which, as will be shown later, are probably of late Lower Jurassic or Middle Jurassic age. Before the granitic rocks were intruded the schists had been metamorphosed to their present condition, so that they must have been formed long before the intrusion. The only definite statement that can be made, however, is that they are of pre-Jurassic age.

Similar schists occur in south-central Alaska near Lake Klutina,[1] on Dadina River near Mount Drum,[2] in the Gulkana River district,[3] in the Iliamna region,[4] and about lower Cook Inlet,[5] but at none of these localities was their age determined.

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[1] Schrader, F. C., A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 410, 1898.

[2] Mendenhall, W. C., Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, pp. 27–30, 1905.

[3] Moffit, F. H., Headwater regions of the Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, pp. 26–27, 1912.

[4] Martin, G. C., and Katz, F. J., A geologic reconnaissance of the Iliamna region, Alaska: U. S. Geol. Survey Bull. 485, pp. 30–32, 1912.

[5] Martin, G. C., Contributions to the geology of Kenai Peninsula: U. S. Geol. Survey Bull., in press.

In the Yukon-Tanana region the Birch Creek schist, which closely resembles the schists of the Willow Creek district in its appearance, lithologic character, and relation to granitic intrusive masses, has a widespread occurrence and is, in part at least, of pre-Ordovician age and perhaps in part pre-Middle Cambrian.[1] Its correlation with the schists here considered is offered only as a suggestion and is at present unsupported by definite evidence. In the lack of conclusive proof the schists of the Willow Creek district are provisionally assigned to the Paleozoic, though they may be even older.

TERTIARY SYSTEM.

ARKOSE, SHALE, AND CONGLOMERATE.

DISTRIBUTION.

A group of rocks consisting of arkose, shale, sandstone, and conglomerate borders the Willow Creek district on its southern edge and forms the youngest group of hard rocks in the area here described. West of Little Susitna River these rocks are confined to the southward-facing flank of Bald Mountain Ridge and to the lowland south of it, where they are in part covered by later glacial deposits. The shape of the surface in the areas in which these rocks occur is due to their structure, for they dip to the south at an angle only a little steeper than the average slope of the mountain front and form a veneer of variable thickness on the underlying gneiss and schist. On the southeast flank of Government Mountain the dip of the beds is less steep than the slope of the mountain face, and the gneiss outcrops in an area from which the sediments have been removed by erosion. In the canyon of Little Susitna River conglomerate, shale, sandstone, and arkose of this group outcrop, forming the canyon walls, but this area is separated from the other areas mapped by a covering of glacial morainal material. East of Little Susitna River this group occupies a broader area and includes the rocks from which the front ridge of the mountains has been carved. There also the beds dip southward on the south flank of the mountains and are in part covered by glacial deposits and in part by still younger rock formations. East of the area here mapped (Pl. III, in pocket) this group of rocks extends for many miles along the mountain front.[2] Its westward extension beyond the Willow Creek district has not been traced.

CHARACTER.

All the Tertiary sediments are well indurated and consist of hard arkose, firm sandstone, shale which in places approaches argillite in character, and conglomerate which varies from a very dense massive

[1] Cairnes, D. D., Geological section along the Yukon-Alaska boundary line between Yukon and Porcupine rivers: Bull. Geol. Soc. America, vol. 25, pp. 179–204, 1913.

[2] Martin, G. C., and Katz, F. J., Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500, pl. 5, 1912.

bed in which the matrix is as hard as the included pebbles, to a more loosely cemented deposit which on weathering breaks down into sandy gravel.

The basal member of the group is commonly conglomerate with an arkosic matrix, locally very coarse in texture and containing bowlders, the largest a foot or more in diameter, intermingled with cobbles and pebbles. The interstices between the pebbles are filled with arkose, and the whole rock is very hard and shows evidence of metamorphism. Most of the pebbles and bowlders, as well as the arkosic matrix, consist of fragments of igneous rocks derived from the great intrusive mass to the north. Where this conglomerate is most strongly metamorphosed the borders of the bowlders seem to merge indefinitely into the matrix, and the whole rock closely resembles certain phases of the gneiss which it overlies, and from which it is in places hard to distinguish. At other places the basal conglomerate is composed of even-sized cobbles averaging about 6 inches in diameter, is little metamorphosed, and on weathering breaks down by the disintegration of the matrix. At still other places the basal conglomerate is absent, the lowest member being composed of arkose, perhaps containing a few scattered pebbles.

The arkose beds, which form by far the largest part of the group, are composed of the disintegration products of the granitic mass that lies north of and beneath them. They contain practically all the minerals of which the granitic rocks are composed and only a small proportion of material derived from any other sources. Since the igneous mass that supplied this material was weathered largely by mechanical disintegration rather than by chemical decay, and since the detritus was deposited not far from the source of the material, the resulting sedimentary formation closely resembles the original granitic rock in chemical composition. This resemblance has been emphasized by the induration of the sediments, which on hardening have taken on also much of the physical character of the granitic rocks. The arkose therefore bears a very deceptive resemblance to granular igneous rock and could be distinguished from it only with great difficulty if it were not for the presence in the arkose of scattered rounded pebbles and of carbonaceous prints of plant remains.

In the hand specimen the arkose is commonly gray, though locally it may have a greenish cast. It shows all gradations in coarseness from a sandy shale to a fine conglomerate. Some beds might well be termed graywackes; others are impure micaceous sandstones. The gradation from arkose to conglomerate may be gradual, a few small rounded pebbles appearing in the arkose at one place but becoming more abundant farther along until the bed is unquestionably a conglomerate with an arkose matrix. Quartz and feldspar are its most abundant constituents, but it contains numerous particles of ferromagnesian minerals and both primary and secondary mica.

A typical arkose and a finer-grained graywacke of this group were examined microscopically in thin section. The arkose consists of an interlocking granular aggregate of quartz and feldspar. The quartz crystals are clear, have very irregular borders, and show undulatory extinction due to pressure. The feldspars, which, as shown by their albite twinning, are mostly acid plagioclase, are dusted with kaolin and carry scattered shreds of sericite. They are notably angular in outline, showing no rounding whatever. Some of the quartz crystals have perfect hexagonal outlines, probably due to recrystallization.

The graywacke is an aggregate of rather irregular angular grains of quartz and feldspar knit together by shreds of partly chloritized biotite and containing grains and aggregates of epidote. The rock is a graywacke that has suffered metamorphism, the ferromagnesian minerals having been converted into biotite and epidote.

In places where the arkose has been somewhat metamorphosed and overlies gneiss, the line of contact is obscure and as mapped may be somewhat in error, especially in the vicinity of Government Mountain, on account of the similarity of certain phases of the two rocks.

Toward the top of the Tertiary sediments on the divide between Little Susitna River and Moose Creek the arkose is interbedded with irregular lenses of shale and impure micaceous sandstone. These lenses may locally reach a thickness of a hundred feet or more, but they thin out laterally, and no single bed could be traced for any great distance (Pl. VI, *A*). In the canyon of Little Susitna River a similar series of interbedded conglomerates, shales, arkoses, and micaceous sandstones occurs. There the shales have been much broken and slickensided and are intricately cut by fine calcite veinlets. The conglomerates contain very few bowlders that reach a foot in diameter and few larger than 6 inches, and the average diameter of the pebbles is about 1 inch. The pebbles are composed of quartz, various kinds of igneous rock, chert, and shale.

A characteristic feature of the Tertiary rocks is the presence in them of carbonaceous films, the remains of plants that were buried in the sediments. Such plant remains, although not everywhere abundant, are generally distributed throughout the group and are of great aid in enabling a recognition of the sedimentary character of some of the arkoses. Vegetable matter was locally sufficiently abundant in these rocks to form thin coaly layers, though no workable coal has yet been found in them. Thin coaly beds were seen in the east wall of Little Susitna Valley, 1½ miles below the mouth of Archangel Creek, and on the south slope of Bald Mountain Ridge.

STRUCTURE AND STRATIGRAPHIC RELATIONS.

Between the intrusion of the granitic rocks, which are the youngest rocks that lie beneath the Tertiary arkose beds in the Willow Creek district, and the deposition of sediments a very long time elapsed. During this time the schists, gneisses, and diorites were subjected to some metamorphism and reduced by erosion to a surface of mild relief. It is possible that other sedimentary beds were deposited upon these rocks or at least upon the schists, for Jurassic and Cretaceous sediments are found in the lower Matanuska Valley. If these were ever deposited in the Willow Creek district, however, they were removed by erosion before the Tertiary arkoses were laid down.

The arkosic sediments were deposited in fresh water, presumably first in the lowlands, but spreading laterally into regions of greater altitude as their thickness increased. The basal beds of the group are therefore not everywhere of the same age, for the overlapping edge of the deposits at one place may have been laid down after a great thickness of similar materials had already accumulated in other lower-lying basins. The structural relations of the sediments to the underlying rocks and to the succeeding unconsolidated Quaternary deposits are shown diagrammatically in the geologic cross sections on Plate III (in pocket).

The contact of the Tertiary arkose beds with the underlying formations, whether schists or gneisses, was, wherever observed, depositional, being parallel with the bedding of the sediments, and the straight course followed by the contact line at any given elevation indicates that the surface upon which the Tertiary beds were deposited was fairly level.

At several localities the deposition of the Tertiary sediments was interrupted by flows of basaltic lava. These flows are thin and are individually of small areal extent but were seen at points 11 miles apart. Near the west edge of this area, on the south slope of Bald Mountain Ridge, a lava flow about 50 feet thick occurs very near the base of the Tertiary arkose beds. East of Little Susitna River similar lava flows occur several hundred feet above the base of the Tertiary. If the lava flows at all localities are contemporaneous, then the lowest part of the section exposed east of Little Susitna River is lacking in the western part of the area. On the other hand, if the basal Tertiary beds at both places are contemporaneous and sedimentation at each place was equally rapid, then outpourings of lava occurred at intervals during the accumulation of several hundred feet of sediments.

The Tertiary sediments have been indurated and tilted and slightly folded. The deformation doubtless accompanied the uplift of the Talkeetna Mountains, for the general strike of the Tertiary arkoses is parallel with the mountain front and the dip is toward the south, away from the mountains. West of Little Susitna River, along the south flank of Bald Mountain Ridge, the sediments strike a few degrees north of east and dip southward at an average angle of about 50°. This is steeper than the average slope of the mountain front, and the sediments form a cover above the older rocks, becoming gradually thinner toward the south. The slope of the south side of Government Mountain, however, is steeper than the dip of the Tertiary beds, and the underlying gneisses have been exposed by erosion in areas south of the sediments. East of Little Susitna River the exposed portion of the arkosic rocks is thicker, though the beds strike in about the same direction as west of that stream and have here also a general dip to the south (Pl. IX, *A*). The monoclinal southward dips are broken by a shallow syncline whose axis runs northeastward from the head of Little Susitna Canyon. In this part of the area the contact of the beds, wherever it could be examined, was a depositional contact, with gneissic rocks beneath. Still farther east, in the lower Matanuska Valley, the arkosic beds are in contact with other Tertiary rocks and with Cretaceous and Jurassic sedimentary beds, but so far as known these relations have been brought about by faulting.[1]

THICKNESS.

The total maximum thickness of the Tertiary sediments is not known, for the beds at their southern edge dip beneath a covering of glacial deposits and their upper limit has not been defined, and the base of this rock group, as exposed in the Willow Creek district, is probably higher in the stratigraphic section than the lowest beds in the basins where the earliest sediments of this group were deposited. From his study of these rocks in the lower Matanuska Valley Martin[2] concludes that the beds exceed 2,000 feet in thickness. On the top of Bald Mountain Ridge, south of the head of Grubstake Gulch, more than 2,000 feet of the series is exposed, and it is elsewhere probably much thicker. There the beds have undergone only simple monoclinal tilting, and the chance that they may have been reduplicated by faulting is small. South of Idaho Peak, on the south side of Little Susitna River, the arkose beds are well exposed up to the divide between that stream and Moose Creek. The sediments dip uniformly to the south except at the divide, where they form a shallow syncline. A measurement of this section indicates that the Tertiary arkosic rocks are over 6,000 feet thick, but such a measurement must not be accepted as final, for the beds are faulted in some degree, and the

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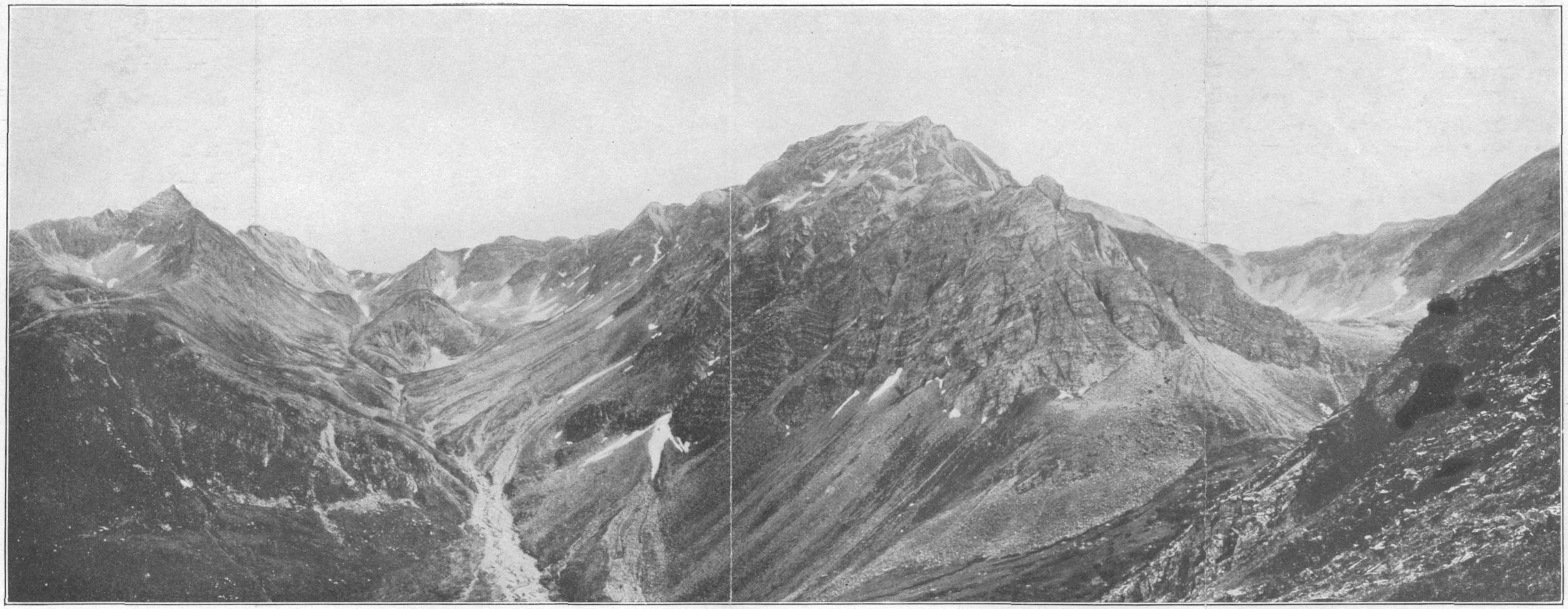
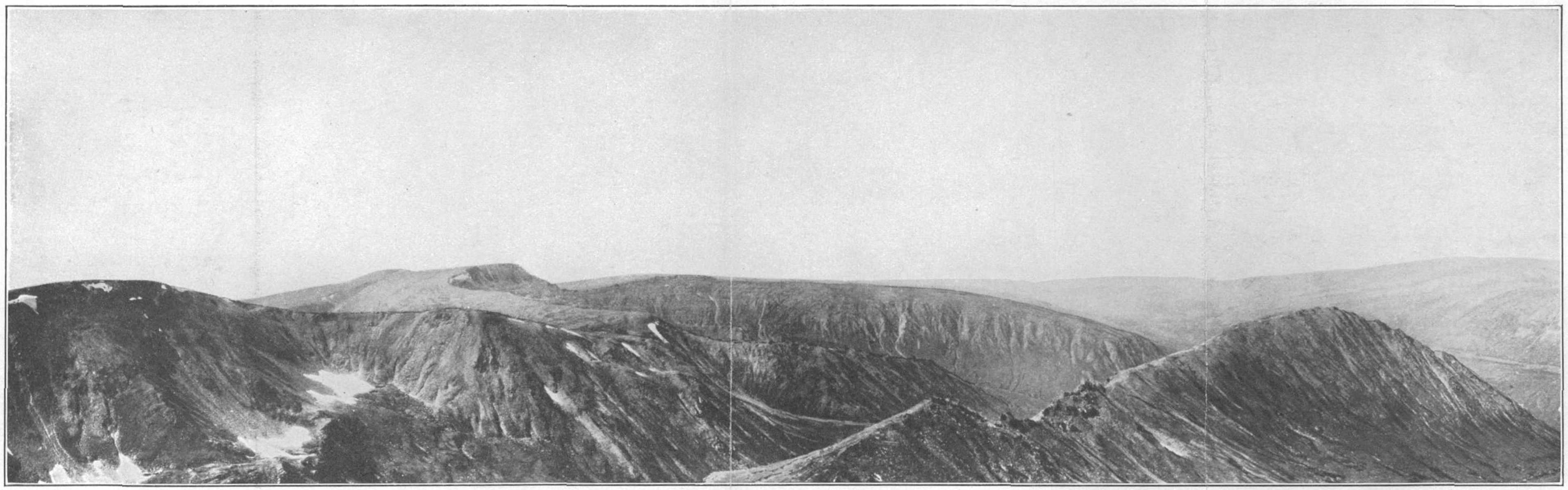
[1] Martin, G. C., and Katz, F. J., Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500, p. 41, 1912.
[2] Idem, p. 42.



A. VALLEY HEADS CUT IN SOUTHWARD-DIPPING TERTIARY SEDIMENTS.



B. WESTERN PART OF BALD MOUNTAIN RIDGE.

The rounded crest of the ridge (left center) is a part of the preglacial surface developed by stream erosion. The steep gulch heads are glacial cirques cut into the old upland surface.

thickness may therefore appear greater than it actually is. It is certain, however, that the maximum thickness in this district is several thousand feet.

AGE AND CORRELATION.

The age of the Tertiary arkosic sediments has been pretty definitely determined on the evidence of fossil plants collected from them. As the beds are of fresh-water origin, no marine fauna has been found in them, but carbonaceous imprints of the leaves and stems of plants are abundantly distributed throughout them. In most places the fossil plants are too fragmentary or have been too poorly preserved to be identifiable, and no satisfactory collections were made in the Willow Creek district. The eastward extension of the arkosic rocks has, however, yielded more perfect fossils. A collection made by Paige and Knopf [1] in 1906 and identified by F. H. Knowlton contained the following species:

Fossils from Arkose Ridge north of Moose Creek.

Taxodium distichum miocenum Heer.	Ficus? grönlandica? Heer.
Taxodium tinajorum Heer.	Paliurus colombi Heer.
Populus sp.?	Fruits, cf. Leguminosites sp.

Age apparently Kenai.

Another collection from the same formation in Sheep Valley, 6½ miles N. 70° E. of the mouth of Kings River (locality 5900, elevation 4,400 feet), made in 1910 by Martin and Katz,[2] was identified by Arthur Hollick, who reports that it contains *Populus arctica* Heer and *Quercus platania* Heer, of "Arctic Miocene" age (Eocene).

The above determinations seem to definitely correlate the arkosic rocks of the Willow Creek district with the Kenai formation of Cook Inlet, of Eocene age. Beds of like age are widely distributed along the shores of Cook Inlet, in the Matanuska Valley, at many localities around the borders of Susitna basin, and at other places in Alaska, and usually contain some lignitic coal.

The correlation of a part of the Eocene arkosic sediments of the Willow Creek district with those of the lower Matanuska Valley [3] is definitely made, for the rocks are directly continuous between the two areas. It is not certain, however, that the arkosic rocks here described are the equivalent of the whole arkosic group as described by Martin. Some beds may be lacking, or horizons represented in the Willow Creek district may not appear farther east. In both districts, however, the beds are dominantly arkosic.

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[1] Paige, Sidney, and Knopf, Adolph, op. cit., p. 26.

[2] Martin, G. C., and Katz, F. J., Geology and coal fields of the lower Matanuska Valley, Alaska: Bull. U. S. Geol. Survey No. 500, p. 42, 1912.

[3] Idem, pp. 39-42.

QUATERNARY SYSTEM.

PREGLACIAL CONDITIONS.

The period of deposition of the Eocene arkosic sediments, the youngest hard rocks of the Willow Creek district, was followed by a long period during which the beds were indurated, deformed, and eroded. In that period the arkosic rocks east of this area, in the Matanuska Valley, were buried beneath a thick covering of later materials, including the coal-bearing Chickaloon formation (of Eocene age), the Eska conglomerate (of Tertiary, possibly Miocene age), and several hundred feet of volcanic rocks. These later formations may have been deposited to some extent in the Willow Creek district also, but if so, they have since been removed by erosion. At any rate, in preglacial times the rocks of this district were hardened and deformed to about their present condition. The Talkeetna Mountain range had then about the same general elevation as it has to-day, but its appearance must have been greatly different. The surface forms were developed by the ordinary processes of erosion, chief among which was stream cutting and transportation. The mountains contained well-developed river systems, and were reduced by the streams to maturity, the stream valleys being predominantly of V shape. Most of the valleys were not so deep as they now are, the slopes of the valley sides were more gentle, and the ridges were rounded and smoothed. Some idea of the appearance of the old upland surface may be had from the parts of it that still remain. (See Pl. IX, *B*, p. 34.) The streams, flowing in valleys which had been developed by stream erosion, probably followed somewhat crooked courses, winding back and forth around spurs which projected from the bordering ridges into the valleys from both sides. There must have been present also large accumulations of soil and the products of rock weathering on the gentler slopes, of talus below the cliffs, and of stream deposits along the valley floors.

GLACIAL EPOCH.

ADVANCE OF THE ICE.

The beginning of glaciation in Alaska has not yet been correlated with any particular glacial stage in other parts of the world. In the northern part of the United States at several different periods during Quaternary time glaciers grew to great size and covered large areas. In Alaska no convincing evidence has so far been found that Quaternary glacial advances antedated the last great glaciation, the effects of which are so widespread. In mountainous regions such evidence would be difficult to obtain, for the ice at the time of the last glacial advance was so deep and its erosive action was so great that it would have removed or buried any earlier glacial deposits, and would have so modified the topography developed by the earlier ice as to make its recognition difficult. If, however, in earlier glacial stages the ice had been more extensive than it was during the last great advance it should have left definite traces either on the topography of the region or as deposits beyond the limits to which the last glaciers reached. Up to the present time no such evidence has been found, and it seems probable that at no time have the glaciers greatly exceeded in size those which developed during the last great ice advance.

The beginning of glaciation in Alaska was brought about by some decided change in climate, probably involving both a decrease in the temperature and an increase in precipitation. As this change progressed, snowbanks accumulated on the protected slopes of the higher mountains and grew until they formed glaciers. Each elevated valley head finally contained a glacier, and these small ice fields gradually lengthened and extended downward, joining in the main valleys to form larger ice tongues. The glaciers probably did not grow continuously, doubtless they oscillated back and forth, each advance being followed by a pause or even by a recession, but the total result of all the movements was growth of the ice fields, both in length and thickness. The advancing ice, moving over surfaces which had long been exposed to weathering, found much loose surface material, such as soil, talus, and the valley bottom deposits of streams, and it readily picked up and removed this unconsolidated material. The bedrock surfaces thus exposed were then attacked, for the thick ice streams, which contained abundant fragments of rock, pressed down with tremendous weight upon their beds, and in their slow forward movement dragged the embedded rocks as cutting tools along the slopes which inclosed them. Each glacier, by freezing to its bed and then moving forward, tore loose great blocks of rock from its channel, and additional detrital material, falling upon the ice surface, was carried slowly down the valley. The tendency of a valley glacier is to attack most vigorously all projecting hills and spurs which obstruct its course, and by the removal of these interruptions to produce a great trough, U-shaped in cross section, and following straight lines or sweeping curves. The multitude of small tributary glaciers at the valley heads cut back their basins toward the divides, developed cirques, and by their combined action reduced the original smoothed and rounded ridges to ragged and broken crests.

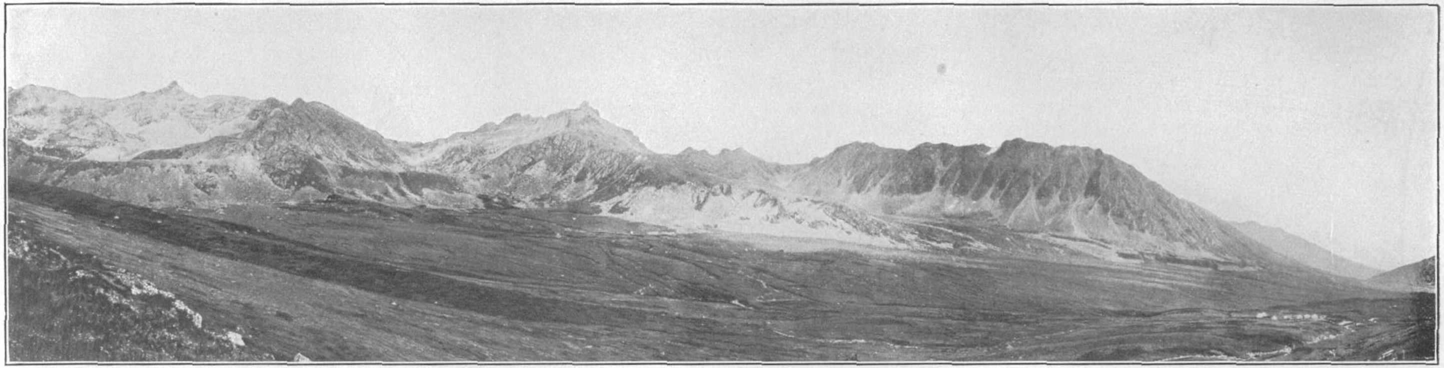
No exact measure is available of the amount of material that was removed by glacial erosion, but there can be no doubt that the valleys were widened and greatly deepened; and the widespread blanket of glacial deposits which mantles the lowlands bears testimony to the effectiveness of this method of erosion in the mountains from which this material was brought. In the Willow Creek district practically all the streams that join the main drainage lines lie in valleys that show a noticeable topographic discordance with the main valleys.

These are known as hanging valleys. The main trough of Little Susitna River (disregarding the postglacial cut of the stream at the canyon) joins the lowland to the south with a discordance of over 200 feet. Willow Creek, at the west border of the Talkeetna Mountains, falls 800 feet in about 4 miles, although the stream gradient above is much more gentle. Many of the tributaries of Little Susitna River emerge from hanging valleys to descend steeply before joining the river. The glacial trough of Fishhook Creek hangs more than a thousand feet above the bottom of the main river valley, and is itself bordered by a number of hanging cirques. (See Pl. X.) All the principal tributaries of Willow Creek, namely, Shorty, Craigie, Wet, Grubstake, and Homestake creeks, flow in hanging valleys and have falls or cascades at their lower ends. If the discordance between the mouth of a hanging valley and the stream which it joins can be used as a measure of the amount of glacial deepening, then Willow Creek below the mouth of Craigie must have been lowered 400 feet by glacial erosion and Little Susitna Valley at the mouth of Fishhook almost twice that amount.

EXTENT OF GLACIATION.

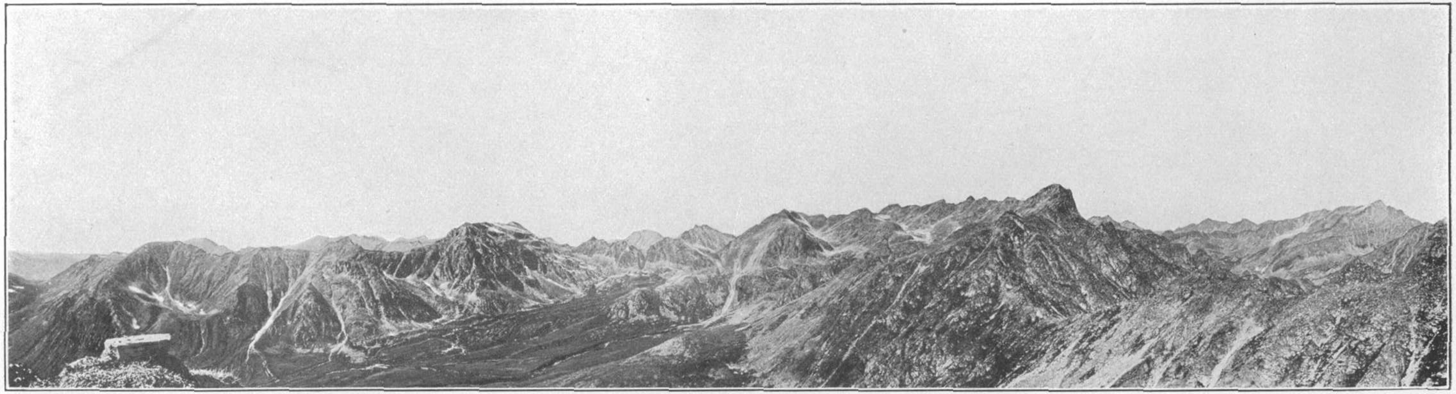
The Willow Creek district was but a small portion of the supply field for the great glaciers which once buried most of that part of Alaska which lies within the arc of the Alaska Range. All the mountains which surround Susitna basin contributed to a huge ice field which filled that basin and extended southward to tidewater in Cook Inlet. The Talkeetna Mountains furnished many tributary glaciers, and an important feeder came down the Matanuska Valley. Only the higher mountain peaks and ridges broke the great expanse of moving ice. At the same time the Copper River basin was similarly glaciated, and the two basins were connected by continuous ice fields through the Matanuska Valley and the upper Susitna Valley. The larger valleys merely afforded passageways for the downward-moving ice flood, but most of the snow accumulated in the small valleys among the peaks of the mountain ranges. There the snowfall was greatest, the slopes were steep, and the ice, confined within narrow valleys, moved rapidly and was able to accomplish the greatest erosion. In the broad basin of Susitna River, where many glaciers came together, the ice spread out and, becoming more sluggish, lost much of its erosive power, and the accumulated burden of rock waste, gathered by the tributary glaciers, was gradually deposited over the basin floor.

The vigor of any particular mountain glacier depends to a large extent upon the size of its basin, the height of the surrounding mountains, and its exposure to the sun. In an area of equal snowfall a valley surrounded by high mountains and having a northern slope



A. NORTHEAST VALLEY WALL OF UPPER FISHHOOK CREEK.

The view shows three tributary hanging valleys. The top of one stamp mill may be seen in the lower right corner and another camp and mill appear just above it.



B. HEAD OF FISHHOOK VALLEY FROM THE SOUTHEAST.

will support a larger glacier than another valley of equal size surrounded by lower mountains and having a slope more directly exposed to the sun's rays. Little Susitna Valley is surrounded near its head by high mountains, and in spite of its southern exposure it once sent down a strong glacier to join the ice from Matanuska Valley. For so long as it joined the Matanuska Glacier the level of the ice surface in Little Susitna Valley was determined by the height to which the Matanuska Glacier dammed that valley. At the period of its greatest thickness the Matanuska Glacier stood up to an elevation of about 3,600 feet on the south flank of Government Mountain and dammed back the Little Susitna Glacier to that height. The ice surface increased in elevation to the north, and at the mouth of Reed Creek reached an elevation of about 4,000 feet.

The basin of Willow Creek is not so large as that of the Little Susitna, nor are the surrounding mountains so high, and the glacier that occupied it was smaller and less vigorous. All its headward tributaries lie in glacial cirques, and the main valley shows strongly the effects of glacial erosion, but at the mouth of Wet Gulch the maximum thickness reached by the glacier was about 1,000 feet, as compared with a thickness of 2,000 feet at the forks of the Little Susitna. The north slope of Bald Mountain ridge supported a number of glaciers, each of which eroded its basin into a glacial cirque. The south side of the same ridge had no local glaciers, except perhaps one at the head of Government Creek. Toward its west end this ridge was not high enough for glaciers to form upon it, and its crest shows the type of broad, smooth ridge which probably characterized the whole region before the glaciers modified its topography. Craigie Creek valley is a fine glacial trough, which has six or more small tributary cirques on its south side but none on the north. The Willow Creek Glacier at the time of its greatest development joined the Great Susitna Glacier.

RETREAT OF THE ICE.

After the ice fields had reached their maximum thickness and size the climate gradually changed. The mean annual temperature probably increased a few degrees and perhaps the precipitation diminished somewhat. From whatever cause, the conditions for ice formation became less favorable and the edges of the glaciers began slowly to withdraw. The retreat, like the advance, was probably by no means continuous, but as the result of numerous recessions, pauses, and readvances the area of the ice fields became gradually smaller and land surfaces which had been covered by ice were again bared. As the main glaciers in the larger valleys became shorter and narrower many tributary ice streams from lateral valleys were detached, and these in turn retreated up their valleys and were separated into a great number of smaller valley glaciers, many of which melted away and disappeared completely.

Although the conditions for ice accumulation are now much less favorable than they were during the period of maximum glaciation, many parts of the high mountains that border the Susitna basin are still occupied by large and active glaciers, the remnants of the much greater ice fields that existed at the time of great glaciation. Knik Glacier, at the head of Knik River, within plain sight of the southern part of the Willow Creek district, is a large valley glacier which extends down to an elevation less than 200 feet above sea level. The Chugach, Kenai, and Chigmit mountains and the Alaska Range support large ice fields, and in the higher parts of the Talkeetna Mountains there are many smaller but still vigorous valley glaciers. Within the Willow Creek district there are five small glaciers, all lying in the basin of Little Susitna River. Two of these drain into Archangel Creek and two into Reed Creek. The one which forms the source of Little Susitna River is the largest, and when most active discharges enough silt to cloud the waters of the river. The others are small and inactive.

GLACIAL DEPOSITS.

The rock waste transported by glaciers is ultimately dropped by the ice, and it may be deposited as glacial moraines or may be fed to the streams discharging from the melting ice and deposited as glacial outwash gravel and silt. The ridgelike accumulations of detritus at the front edge of a glacier are known as terminal moraines and their characteristic hummock and hollow topography, many of the hollows being occupied by lakes, may be seen in many places in the lowlands between Knik Arm and Susitna River. Within the mountains of this district terminal moraines are not developed, and their absence has been noted in a number of severely glaciated mountain ranges of Alaska. A study of many active valley glaciers which terminate in narrow valleys has shown that almost every stream at the lower end of the glacier where the rock waste is most rapidly deposited, is directed by the slope of the valley walls against the edge of the glacier, and is admirably placed to remove the morainic material as fast as it is dropped by the ice. The absence of terminal moraine ridges in this district is best explained by assuming that they were never conspicuously developed. Lateral moraines deposited along the sides of the glaciers near their lower ends were seen in a few favorably situated places. These locally appear as benches, and there may be several, one above the other, the highest having been built first and the lower ones at a later stage, during the retreat of the ice. (See Pl. VIII, *B*, p. 26.)

When the ice was thickest and its movement was most rapid, the mountain glaciers doubtless severely eroded and deepened their channels, but at a later period, when the ice had thinned, erosion gave place to deposition. Much of the rock waste incorporated in the glaciers was deposited beneath the ice as glacial till upon the bedrock, which had before been worn and eroded. The glacial till is composed of a mixture of all the detritus carried by the ice and consists of a tough clay in which are incorporated bowlders, pebbles, and angular pieces of rock, the whole assemblage being free from any such assortment as characterizes deposits laid down in water. The areas of morainal deposits, as shown on Plate III, are covered with glacial till, but include only those parts of the district in which the glacial materials are thick enough to hide completely the underlying hard rock formations. Over many other parts of the area there are smaller accumulations of moraine, but wherever they were too small to mask the underlying bedrock topography they were not mapped. The lowlands on the south border of the district are covered with glacial materials, and the bedrock of the mountain front is overlain by moraine up to an elevation of about 2,000 feet. Similar deposits cover many square miles of the basin of Little Susitna River above the canyon, and few bedrock exposures occur either in the valley bottom or on its sides below a height of 2,500 feet. The present gorge of the river above the canyon and the steep inner valley of lower Fishhook Creek have been cut deep into the glacial material without exposing the underlying rocks. A few of the tributary valleys contain considerable accumulations of moraine, but in most of the surrounding cirques the bedrock is exposed at many places. The valley floors of Willow Creek and some of its larger tributaries are likewise covered with a mantle of glacial deposits, but the covering is there comparatively thin and has in places been removed by stream cutting.

Here and there within this district deposits of stream-washed gravels are associated with the glacial till, but they are not of great extent, and on the map (Pl. III) they have not been separated from the morainal deposits. Most of the stream gravels of glacial origin were carried beyond the borders of this district and deposited in the lowland areas.

POSTGLACIAL EROSION.

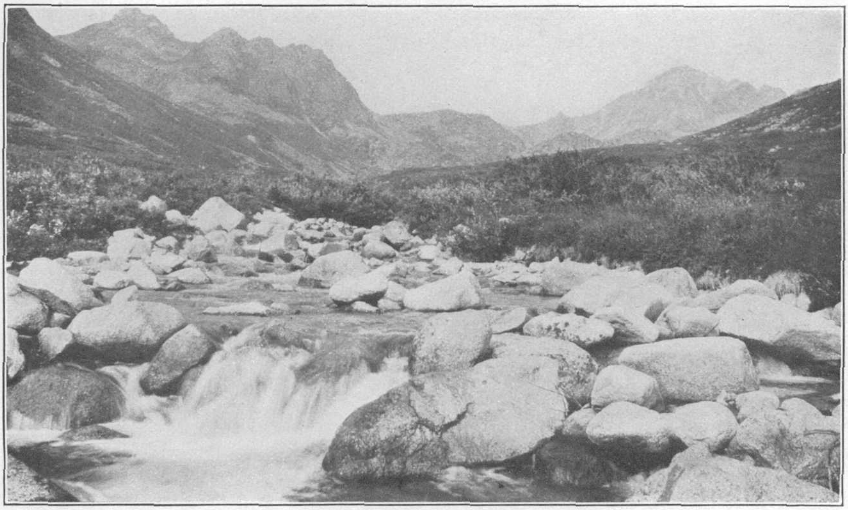
When the glaciers retreated and bared the valleys which they had first eroded and then partly refilled with unconsolidated deposits, the valley gradients were no longer adjusted to the streams. For some stretches the stream grades were steeper than they had formerly been, or the streams flowed upon easily eroded glacial deposits where formerly they had flowed over hard rock. In other places the gradients had been flattened. Each stream, in again occupying a regraded and changed valley, set about the task of reestablishing a normal stream gradient adapted to the size of the stream, the character of the material, and the amount of load. Under postglacial conditions the tendency of most of the streams in this district has been to intrench themselves.

The length of the period which has elapsed since the glacial ice disappeared and during which the surface has again been exposed to weathering and stream erosion is not the same for all parts of this district. A few small glaciers still survive, and their basins may be said to be still in the glacial epoch. The glaciers remained at the valley heads of the higher mountains long after the lower parts of their basins were free of ice. This whole district, however, gives one the impression that glaciation there has been comparatively recent. It is only along the stream courses that postglacial erosion has destroyed the shape of the surface as left by the ice. The greatest amount of postglacial erosion is to be seen at the canyon of Little Susitna River, where that stream has cut a gorge several hundred feet deep through the glacial deposits and into the Tertiary arkosic rocks. Above the canyon the stream has intrenched itself in the glacial materials, and the high benches on either side show the position of the valley floor as left by the ice. The amount of postglacial deepening of the valley decreases upstream, and in the cirque heads the stream cuts are shallow or completely lacking. That part of Fishhook Creek that flows at right angles to Little Susitna River is sharply intrenched in the moraine for the grade there is steep and the current rapid. Between the mouth of Fishhook Creek and the canyon the steep gulches tributary to Little Susitna River, both from the east and west, have been cut into the glacial deposits, and on the east much of the unconsolidated materials have been removed. In the Willow Creek basin postglacial erosion has accomplished little. The main creek has cut a shallow canyon for a part of its length, but the broad U shape of the valley has been little changed. Shorty, Craigie, Wet, Grubstake, and Homestake creeks have cut sharp canyons through the glacial deposits into hard rock for short distances near their mouths, where the stream gradients are steepest.

Throughout the district as a whole the surface forms are to-day much the same as when first uncovered by the ice. Relatively small stream trenches and gullies and rather inconspicuous accumulations of talus are the measure of weathering and erosion in postglacial times.

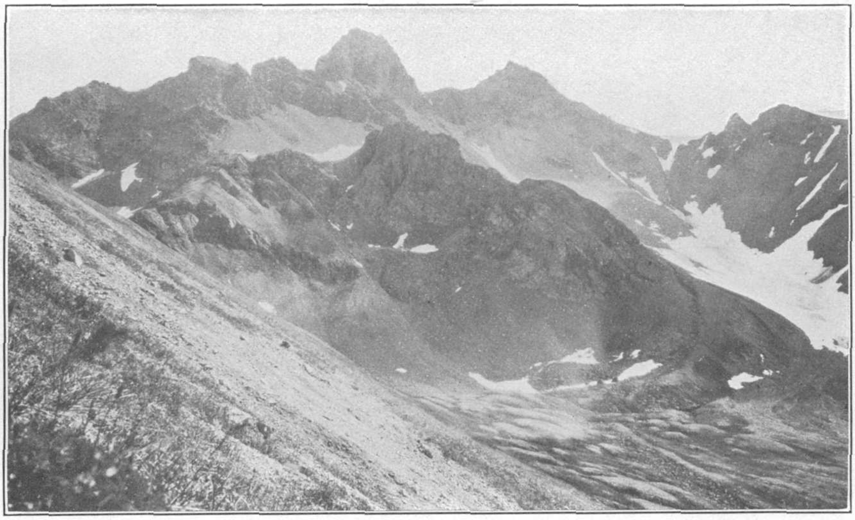
PRESENT STREAM GRAVELS.

Since the great ice fields retreated from this district the streams throughout most of their courses have been lowering their channels into the deposits left by the ice, and stream deposition has been unimportant. The present stream gravels are therefore in most places



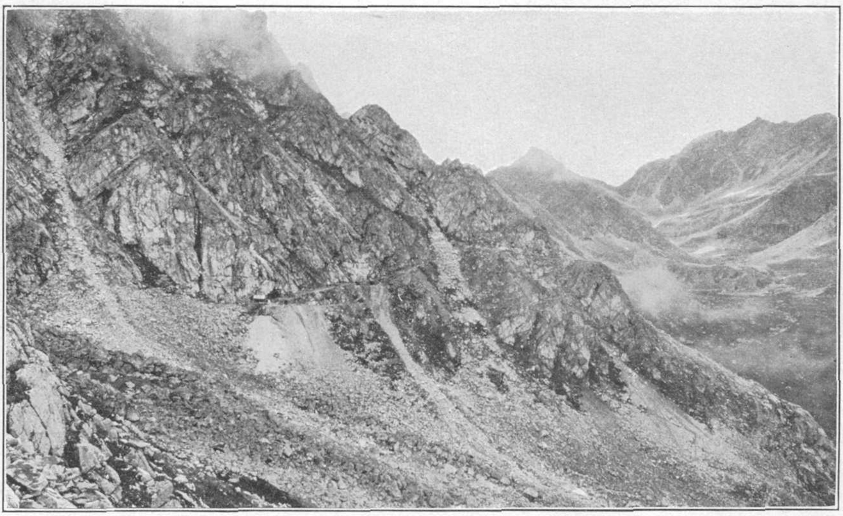
A. BED OF REED CREEK.

Bowlders are quartz diorite.



B. PEAKS OF ALTERED AND SOMEWHAT GNEISSIC DIORITE ON DIVIDE BETWEEN LITTLE SUSITNA RIVER AND MOOSE CREEK.

A. BLOCK OF GNEISSIC DIORITE CUT BY VEINLETS OF QUARTZ.



B. TUNNEL OF ALASKA GOLD QUARTZ MINING CO. ON GRANITE MOUNTAIN.

Shows two prominent sets of joints in quartz diorite. The veins lie along joints of the set which dips to the left.

not much wider than the streams that flow over them and are thus too small in area to be shown on the accompanying map (Pl. III, in pocket). Through the canyon Little Susitna River flows at the bottom of a rock-cut gorge, and the only stream-washed materials are the large bowlders with which the channel is filled. From the head of the rock canyon to the mouth of Fishhook Creek the channel is cut into glacial deposits, and in this stretch the stream flat at few places exceeds 100 feet in width, and the stream gravels consist of bowlders derived from the glacial till. Above Fishhook Creek the stream flat is somewhat wider, although the width of the narrow strip of alluvium shown is somewhat exaggerated on Plate III. The stream gradient in this district is so steep that the finer material derived from stream cutting has been quickly removed, and only the coarser material, consisting of coarse cobbles and large bowlders of diorite, arkose, and conglomerate, has remained. None of the tributaries of Little Susitna River have important recent gravel deposits, and all of them flow through channels filled with large bowlders. (See Pl. XI, *A*.)

Willow Creek has built up a valley floor of stream gravels below the mouth of Homestake Creek, and the stream flat gradually increases in width toward the west. The low gradient of the valley here has permitted the deposition of gravels derived from the postglacial cuts of the stream above. The stream deposits consist for the most part of cobbles, finer gravel, and sand, but include numerous bowlders a foot or two in diameter and a few larger bowlders. Grubstake and Wet gulches contain considerable deposits of stream-laid material in the intermediate portions of their valleys between the steep lower stretches and the cirques in which they head.

IGNEOUS ROCKS.

GRANITIC AND GNEISSIC ROCKS.

DISTRIBUTION.

As has already been stated, the northern half of this district consists of granitic intrusive rocks, which are a part of the great intrusive mass that comprises a large portion of the Talkeetna Mountains. As mapped by Paige and Knopf[1] the area in which these rocks predominate measures about 35 by 50 miles, and the Willow Creek district lies on its southern edge. The upper basins of Shorty, Craigie, Willow, and Fishhook creeks lie within this area; the basins of Archangel and Reed creeks contain no other rocks, and probably the entire headward portion of Little Susitna Valley is eroded into the intrusive mass, for all the stream bowlders were derived from granitic rocks. Between the head of Willow Creek and the east edge of this

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, Pl. II, 1907.

district the granitic rocks merge, along their southern border, into gneisses, which have been carved into a rugged topography resembling that of the unaltered diorite mass. (See Pl. XI, *B*.) In places this transition from unaltered granitic rocks to gneisses appears to be gradual, but where best developed the gneisses are notably different in appearance from the unaltered diorites. Isolated areas of gneisses have been mapped along the summit of Bald Mountain Ridge, on Government Mountain, and in the gulches tributary to the Little Susitna from the east, and well-developed gneisses occur east and south of that river, above the mouth of Reed Creek.

CHARACTER OF DIORITES.

As determined by a microscopic study of the rocks in thin section, the granitic rocks were found to consist for the most part of quartz diorites. These range from rocks in which plagioclase feldspars occur to the exclusion of the alkaline feldspars to types in which the two classes of feldspar are approximately equal in amount and which might be called quartz monzonites or granodiorites. Sections examined include unquestioned diorites, quartz diorites, and diorites with monzonitic tendencies, but for the purposes of this description the narrower subdivisions have been omitted, and the rocks of this general type are all designated quartz diorites. They have undergone various degrees of alteration and grade into the gneissic and schistose types, but in most thin sections the original dioritic character of the rock can still be recognized. Certain rocks show in the field a coarsely crystalline mass, including irregular bodies of a rather fine-grained grayish material, quite different in appearance from the surrounding coarse diorite. Microscopic study, however, shows that both the coarse matrix and the finer-grained inclusions have the same petrographic composition, the difference in appearance being altogether due to the size of the crystals that compose the mass.

The principal minerals of the quartz diorites are hornblende, feldspars, quartz, and biotite, some chlorite, and pyroxene, and smaller amounts of accessory minerals. These minerals are described individually below:

Hornblende.—The hornblende commonly occurs as anhedral, subhedral, or ragged prisms or long laths, predominantly dark green but varying to light green and yellowish or bluish green. Many of the crystal edges are penetrated by crystals of feldspar and quartz, and these also may be poikilitically included within the hornblende. The hornblende often shows twinning, and in places contains shreds of biotite and grains of magnetite and quartz. In many specimens areas of chlorite, calcite, and magnetite probably represent altered hornblende crystals.

Feldspars.—The feldspars are predominantly plagioclase, ranging from albite through oligoclase and andesine to labradorite. Carlsbad, pericline, and albite twinning is common, and many of the crystals contain kaolin and shreds of white mica. White mica is a common alteration product. Orthoclase or microcline is present in varying amounts in many specimens.

Quartz.—Quartz grains of irregular outline appear in most of the diorites, though in varying amount. Undulatory extinction or strain shadows characterize the quartz in areas in which the rocks have been metamorphosed.

Biotite.—Strongly pleochroic biotite in brown and greenish colors is generally present in shreds or leaves. It has been locally altered to chlorite.

Chlorite.—Scattered patches and shreds of green pleochroic chlorite were seen in a number of specimens.

Pyroxene.—Monoclinic, faintly pleochroic pyroxene, of pale-green color, with an extinction angle of about 31°, was seen as scattered grains and irregular crystals in one specimen.

Accessory minerals.—The most common accessory minerals are apatite, magnetite, and titanite, with occasional small crystals of zircon and epidote. It is worthy of note that the granitic intrusives of the Coast Range of southeastern Alaska are characterized by a large amount of titanite, and this mineral has also been frequently observed in the granites and diorites of the Alaskan Range.

CHARACTER OF GNEISSES.

When studied in thin section the gneisses are found to consist almost exclusively of rocks which might well have been derived by metamorphic processes from quartz diorites. Many specimens taken from areas in which a strong gneissic structure was evident were found to be composed of somewhat altered diorite, differing from the more massive forms principally in their content of the more abundant alteration products. The hornblende has in part been altered to chlorite and magnetite, and the feldspars to kaolin and white mica, both of which contain considerable secondary chlorite, magnetite, and epidote. The quartz is somewhat crushed and shows strain shadows. The metamorphism has locally resulted in the development of a large amount of hornblende, certain phases of the gneiss being coarse-grained hornblendites containing only small amounts of other components. On the south flank of Government Mountain the gneisses show the greatest degree of metamorphism, and some of them might well be called hornblende schists. One specimen of this character is composed of subhedral to anhedral hornblende prisms of green and yellow tones, more or less aligned and separated by irregular grains of quartz and feldspar carrying apatite needles. The feldspar is much altered but appears to be plagioclase. Magnetite occurs in scattered grains.

AGE AND RELATIONS.

The relations of the diorites and gneisses to the associated rocks are shown diagrammatically in the geologic cross sections A–B, C–D, and E–F on Plate III (in pocket). The granitic rocks and the gneisses, although quite distinct in the areas of their typical development, in places seem to grade into one another, and in the field work on which this report is based it was found to be impracticable to draw a sharp line of separation between them. In the accompanying geologic map (Pl. III) those areas in which gneissic rocks occur have been indicated by an overprinted pattern. In spite of the fact that the edges of the granitic mass at some localities show considerable metamorphism and are gneissic, the rocks of the typical gneiss areas, as on Government Mountain and Bald Mountain Ridge, as well as the rocks that immediately underlie the arkoses east of Little Susitna River, are highly metamorphosed, have a banded appearance, and in places contain an intricate network of quartz veinlets (Pl. XII, *A*), so that they are possibly older than the main granitic mass. The close relations between the gneisses west of Little Susitna River and the mica schists of that area also lend weight to the supposition that the typical gneisses are older than the rocks of the main granitic intrusion and were metamorphosed before its magma was injected. On the other hand, the borders of the great intrusive mass have certainly suffered some metamorphism, and it is possible that the metamorphism was most intense just south of the border of the intrusive rocks, and that the gneisses are the metamorphic equivalent of the granitic rocks. As has been shown, the gneisses when studied microscopically seem to consist for the most part of altered diorites or of rocks that might have been derived from diorites by metamorphism. If, therefore, they are older than the massive diorites, there must have been two periods of dioritic intrusion, and no definite evidence that there were two periods has yet been found in this region. More detailed work will be necessary to settle this question.

The gneisses are certainly younger than the mica schists, for they lie upon the schists and are less severely metamorphosed than those rocks. It may be that the contact between the gneiss and the mica schist is a fault contact, but this was not determined. At any rate, the lesser metamorphism of the gneiss indicates that it is younger than the schist. The gneisses were formerly more widely distributed than they are now, for pre-Tertiary erosion stripped them away from parts of the underlying mass of mica schist, and the later Tertiary arkosic rocks cover much of the gneiss area. The granitic rocks are also younger than the mica schists and may be younger than some of the gneisses, for they distinctly cut the mica schists and perhaps are intrusive into a part of the gneisses. Both the gneisses and the granitic intrusives are considerably older than the Tertiary rocks. The arkosic rocks, which here form the base of the Tertiary system, were laid down upon a comparatively level erosion surface formed of mica schist, gneiss, and granitic rocks, contain recognizable pebbles of the underlying formations, and are believed to be composed almost exclusively of material derived from this surface by disintegration. The contact between the Tertiary rocks and the underlying formations is in this district a depositional contact and lies parallel to the bedding of the sediments. The evidence obtained in this district therefore shows that the gneisses and the granitic rocks are older than the base of the Tertiary and younger than the mica schists, the age of which is not known.

The age of the great intrusive mass of granitic rocks can, however, be determined more definitely by comparison with other areas in which more conclusive evidence has been obtained. In the upper Matanuska Valley Paige and Knopf [1] found Jurassic rocks containing bowlders of similar composition to the main granitic intrusive, although a smaller outlying granitic intrusive cuts rocks that were then considered Middle Jurassic but are now assigned to the Lower Jurassic. They therefore regarded the great Talkeetna Mountain batholith as Middle Jurassic. It has not yet been proved, however, that the intrusive which cuts the Lower Jurassic is contemporaneous with the main Talkeetna intrusive, so their conclusion is still open to question. Martin and Katz [2] determined the age of a part, at least, of the granitic rocks in the Iliamna region as late Lower Jurassic or early Middle Jurassic, and as this determination coincides rather closely with the conclusion reached by Paige and Knopf, the great Talkeetna intrusion is provisionally assigned to the early Middle Jurassic.

GABBROS.

In the eastern part of the district here considered, near the southern edge of the area of intrusive rocks, there are local patches of intrusive rocks of gabbroic character. Some of these are massive and little altered; others have been severely metamorphosed and have become somewhat gneissic. A study of one of the more massive gabbros in thin section showed a few stout, irregular, nearly colorless augite pyroxene prisms, some of which were partly altered to hornblende, showing a granular nucleus of pyroxene surrounded by hornblende.

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, p. 20, 1907.

[2] Martin, G. C., and Katz, F. J., A geologic reconnaissance of the Iliamna region, Alaska: U. S. Geol. Survey Bull. 485, p. 76, 1911.

Hornblende in brown to green anhedral prisms is more abundant than augite, and much of it is probably derived from the augite. The rock contains rounded areas composed largely of a mixture of serpentine and magnetite, which may represent altered olivine crystals. Another somewhat metamorphosed gabbro contains monoclinic pyroxene, probably augite, of a pale-green color, and plagioclase feldspars, dominantly andesine, though some orthoclase may be present. Accessory minerals are represented by apatite and magnetite.

DIKES.

Though not abundant, dikes that cut the diorites, the gneisses, and the mica schists were seen in many parts of the district, but most of them are only a few feet wide and occur in places where their longitudinal extent can be traced for only short distances. Their areal extent is small, and none of those seen were large enough to justify their representation on a map of the scale of Plate III. The dike rocks differ considerably in appearance from one another, but most of them are of much the same mineralogic composition and were probably derived from the same magma that formed the quartz diorite intrusions. Most of the dikes may be classified as alaskite, being fine-grained aggregates of quartz and feldspar that include only small amounts of dark minerals. The quartz occurs as fine, irregular granules, many of them showing strain shadows, interlocked with anhedral and subhedral feldspars. Most of the feldspars are orthoclase, though some are plagioclase, and many are dusted with kaolin. Shreds of chlorite and minor amounts of apatite, epidote, and clinozoisite occur in some dikes, and one showed numerous scattered, irregular crystals of tourmaline.

A more basic dike cuts the quartz diorite on the property of the Gold Bullion Mining Co. This dike contains abundant laths and prisms of greenish-brown, moderately pleochroic hornblende, which is associated with a little magnetite and shows many twinned crystals. The hornblende is set in a groundmass whose constituents can be determined with difficulty, but which is probably for the most part feldspar. Owing to the uncertainty in regard to the composition of the groundmass, the rock can not now be classified.

LAVA FLOWS.

At several localities within the district basaltic lava flows are interbedded with the Tertiary sediments. (See p. 33.) Their areal extent, so far as it could be determined, is shown on Plate III (in pocket). The individual flows have covered only small areas, and none of them is much more than 50 feet thick. That they were actually flows rather than intrusive sills was proved, in one place at least, by the occurrence of fragments of lava in a conglomerate that lay immediately above the flow.

The Bald Mountain trail, at a point a mile southwest of the summit of the ridge, crosses a lava flow that is interbedded in the Tertiary rocks. The lava consists of a basalt having diabasic tendencies and of less completely crystallized amygdaloidal basalts. A thin section of the diabasic phase showed the presence of plagioclase, pyroxene, olivine(?), magnetite, and serpentine. The plagioclase feldspar occurs as laths of labradorite arranged at random in an ophitic matrix of ferromagnesian constituents, and shows albite and carlsbad twinning. Some larger laths may be regarded as phenocrysts. The pyroxene, which occurs in grains and anhedral prisms of pale-violet color, is more or less penetrated by the feldspars and in places fills interstices between them. It is probably a titaniferous augite. Scattered areas now composed principally of serpentinous material may represent original olivine crystals. Grains of magnetite occur here and there. A few areas of concentric fibers of serpentine may represent altered interstitial glass, and in addition there is much greenish, granular to platy serpentinous material.

West of the mouth of Fishhook Creek there is another lava flow, also interbedded with arkose (Pl. III). It, too, is a basalt, but is more andesitic. The abundant plagioclase, which occurs in small lath-shaped crystals, is set in green serpentine and includes grains of magnetite and epidote. The serpentine represents an alteration of pyroxene, probably augite. The rock contains considerable epidote and abundant rounded amygdules, most of which are lined with green serpentine in radiating fibers, but one filled with a granular aggregate of epidote with some magnetite was seen. The rock is so much altered that it is difficult to determine whether it should be classified as an andesite or a basalt, but in the apparent absence of olivine it is here called an andesitic basalt.

The stratigraphic position of these lava flows, interbedded with Eocene sediments, shows definitely that they are of Eocene age. They resemble in field appearance the basaltic lavas of the lower Matanuska Valley,[1] but clearly antedate those, which are possibly of post-Miocene age.

MINERAL RESOURCES.

HISTORY OF MINING.

Although placer gold was discovered on Cook Inlet in 1848 by an expedition of the Russian American Co. and a few ounces of gold was recovered, at that time mining did not prove to be commercially successful and was discontinued. Forty years later, in 1888, American prospectors discovered gold on Turnagain Arm, near Hope, and

[1] Martin, G. C., and Katz, F. J., Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500, pp. 54-55, 1912.

by 1895 the mining industry in that district was firmly established. The spectacular rise of the Yukon gold camps in 1897 and 1898 brought a great influx of prospectors to the region, and their activities were spread over a great area of previously unknown country. Prospectors working northward from Cook Inlet first visited the Willow Creek district in 1897, and the first placer claims were staked that year. Placer mining in this district has so far been confined to a small area on Grubstake and Willow creeks, and the history of developments there is given on pages 52–55 of this bulletin.

In most parts of Alaska the efforts of the earliest prospectors were directed exclusively to the search for placer gold, for placer gold can be quickly recovered by primitive means and with the investment of little capital. The search for lode deposits almost always follows somewhat tardily after the placer prospecting, for the development of a lode mine requires a considerable investment in the driving of shafts and tunnels in rock, in the purchase and transportation of supplies and machinery, and, except for free milling gold, in the reduction and marketing of the product.

Gold quartz claims in the Willow Creek district were first located in the basin of Fishhook Creek, on September 16, 1906, by Robert Hatcher, who had come into the district to trap and prospect. These, together with others located later, developed into the mine of the Alaska Free Gold Mining Co. In July, 1907, the first claims of the Gold Bullion Mining Co. were staked, and soon afterward the veins of the Alaska Gold Quartz Mining Co. were located. These three properties have since supplied almost all the production of the district. In 1909 prospecting was actively carried on and many claims were staked, most of which were later abandoned without much development work. One or two veins staked that year were, however, considered to be of sufficient promise to warrant the driving of adit tunnels. Of these the property of the Matanuska Gold Mining Co. has since been prospected vigorously, and a number of tunnels were driven, but the company became involved in litigation and has so far produced nothing. In the years 1910 and 1911 prospecting in the district was continued, but none of the discoveries then made have since been developed. In 1912 at least two promising discoveries were made, and others in 1913.

The first stamp mill to be installed in the district was a three-stamp prospecting mill, put into operation in 1908 on the property of the Alaska Gold Quartz Mining Co. The following year the Gold Bullion mill, equipped with two stamps, was completed. Additional units of five stamps at the Gold Bullion and one at the Alaska Gold Quartz mine were put into operation in 1911, and the Lane mill of the Alaska Free Gold mine started crushing ore in August, 1912. No mills were built in 1913, but two of the reduction plants were made larger in 1914.

The location of the more important mines and prospects is given on Plate III (in pocket), and the position of the same localities, together with a number of prospects not definitely located on the topographic sheet, is shown on the drainage map (fig. 3).

A number of publications which contain descriptions of the geology and mineral resources of this district have appeared from time to time. The earliest of these reports, issued before the discovery of

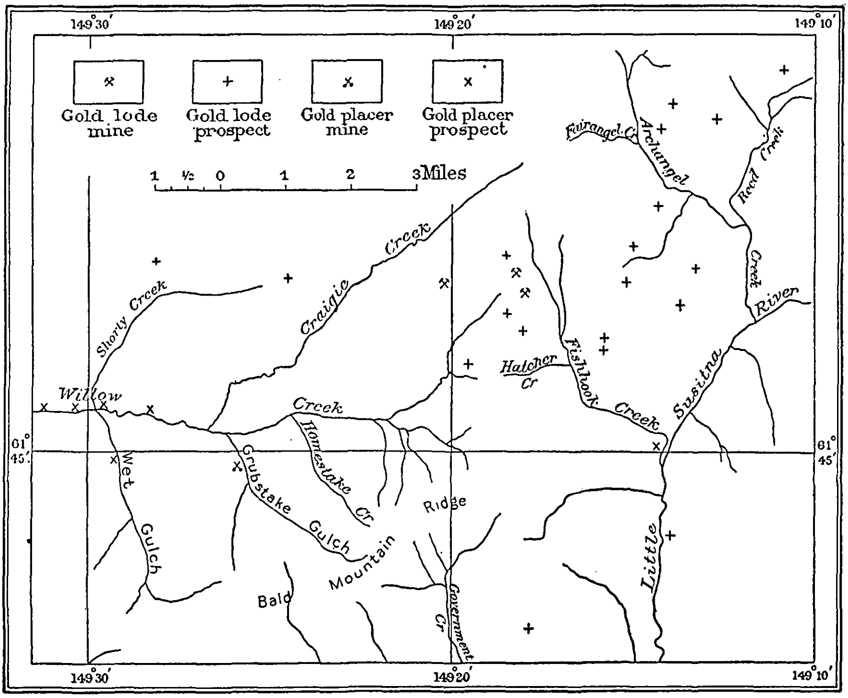


FIGURE 3.—Drainage map of part of Willow Creek district, showing location of mines and prospects.

gold quartz had been made, were by Paige and Knopf,[1] and described the development of the placer-mining industry at that time.

By 1909 the installation of two stamp mills and many reported discoveries of gold lodes had attracted considerable attention, and Brooks,[2] published a brief account, based on the reports of prospectors and others. F. J. Katz and Theodore Chapin, who visited the district in 1910, were the first members of the United States Geological Survey to study the gold lodes, and the results of their four days' visit were

[1] Paige, Sidney, and Knopf, Adolph, Reconnaissance in the Matanuska and Talkeetna basins, with notes on the placers of the adjacent region: U. S. Geol. Survey Bull. 314, pp. 116–118, 1907; also, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, pp. 65–67, 1907.

[2] Brooks, A. H., The mining industry in 1909: U. S. Geol. Survey Bull. 442, pp. 35–36, 1910.

published in 1911.[1] Short accounts of the developments in this mining district in 1911 and 1912 were published by Brooks, who visited a part of the district in 1912.[2]

GOLD PLACERS.

HISTORY.

Gold placer mining in the Willow Creek district began with the staking of the first claims on Willow Creek in 1897. From that time until 1899 pick and shovel mining only was carried on, but some fairly good ground was opened up, and this encouraged vigorous prospecting throughout the adjacent territory. At that time, however, placer ground was not considered sufficiently rich to justify mining unless it could be made to yield approximately $10 a day for each man. Many places were found on Willow Creek, both above and below the Discovery claims, and on its tributaries, where moderate amounts of gold could be recovered, but none of them, except the original claims and a few adjoining claims on Grubstake Creek, have proved rich enough to justify mining under present conditions. The greatest activity in placer mining was reached in 1904 and 1905, when a single hydraulic plant was successfully operated. Since 1905 activity has waned, partly on account of disputes as to the title to the ground, but principally on account of the exhaustion of the richest claims. With cheaper transportation, proper equipment, and careful management, some of the lower grade gravels could without doubt be profitably exploited.

GRUBSTAKE GULCH.

Practically all the placer gold that has been recovered from this district has been mined on Grubstake Gulch and on Willow Creek near the mouth of Grubstake Gulch. According to O. G. Herning, the first two claims were staked in 1897 by W. J. Morris and L. H. Herndon on Willow Creek at the mouth of Grubstake. In 1899 A. Gilbert staked two claims on lower Grubstake Gulch. In 1900 the Klondike & Boston Co. bought the claims on Grubstake and a number on Willow Creek, and for a number of years attempted to mine this ground. More than 6,000 feet of steel pipe, ranging from 9 to 24 inches in diameter, was placed on the ground and hydraulic methods were used. The most productive years for this company were 1904 and 1905. The company later became involved in financial difficulties and failed, and in 1908 its ground was relocated by O. G. Herning, who how holds 33 claims on Grubstake and Willow creeks.

[1] Katz, A. J., A reconnaissance of the Willow Creek gold region: U. S. Geol. Survey Bull. 480, pp. 139–152, 1911.

[2] Brooks, A. H., The mining industry in 1911: U. S. Geol. Survey Bull. 520, pp. 28–29, 1912; also, The mining industry in 1912: U. S. Geol. Survey Bull. 542, p. 39, 1913.

Grubstake Gulch, which enters Willow Creek from the southeast, is a hanging valley, glacial erosion having lowered the Willow Creek valley below the level of this tributary. A lateral moraine of the Willow Creek glacier was built across the mouth of Grubstake Gulch, and the stream has now cut through this material and has developed a steep, narrow canyon in bedrock beneath it. From the forks of the stream to the canyon, a distance of a little more than one-half mile, the stream falls about 200 feet. Through the canyon it drops about 150 feet within a short distance. Below the canyon an alluvial fan has been built out on the Willow Creek flat, and the stream is now somewhat intrenched into the alluvial fan.

The placer ground that has been worked includes part of the bars of Willow Creek below the mouth of Grubstake, a part of the alluvial fan of Grubstake Creek, the bed of the canyon, and the bars of Grubstake Creek for some distance above the canyon. The bedrock is mica schist, and the schistosity strikes across the creek and dips upstream at moderately steep angles, thus affording a rough bedrock surface admirably adapted to retain placer gold. The schist is cut in all direction by tiny stringers of quartz, and quartz veins that reach a width of 3 or 4 feet were seen at several places within the schist area.

The first placer production was made in 1898, the gold being recovered from the claims on Willow Creek at the mouth of Grubstake Gulch. It is reported that about $4,000 was taken out that year. In 1899 about $3,000 was recovered from above the canyon on Grubstake Gulch, and a small production was made from Willow Creek. During the next four years little active mining was done, but in 1904 and 1905, when the hydraulic plant had been installed, the production reached its maximum. For the last few years mining has been carried on in a desultory manner, and the production has been small. From what could be learned at the time of the writer's visit the largest area of ground mined lies immediately above the canyon, where, throughout the length of one claim, ground averaging about 200 feet wide has been worked out. The gravels averaged 2½ to 9 feet in depth. On the lower half of the claim the gold was recovered from the surface of a bed of clay about 1 foot above bedrock, but on the upper half of the claim the gold lay on the steeply dipping schist bedrock or in the cracks in it. About 1,200 feet of sluice boxes, 27 inches wide and 30 inches deep, built of 1½-inch lumber with 3-inch square frames, were set on a grade of 6 inches to the box length, the average grade of the bedrock. Water for hydraulic sluicing is brought from a dam at the forks of the creek through a ditch and steel pipe. The pipe is 24 inches in diameter at the intake but is reduced to 9 inches at the giant, and 3 and 4 inch nozzles are used. The head of water decreased as mining progressed upstream, but was 180 feet about half a mile below the dam. It is reported that the creek bed has been worked as far upstream as the dam. The gold is fairly coarse, and the largest nugget had a value of $14. A number of $5 nuggets were found, and pieces worth 50 cents to $1 were numerous. The gold is said to assay about $16.60 an ounce.

At the time of the writer's visit, late in August, 1913, assessment work on these claims had just begun. A giant was set about 1,300 feet above the canyon, and a cut was started to prospect the thick deposit of gravels on the east side of the creek. The gravels were there from 8 to 15 feet deep and thickened to the east, and the bedrock surface seemed to dip in that direction. Few large bowlders were found, and scarcely any rocks were uncovered which two men could not handle. The rocks were for the most part flat or somewhat rounded slabs of schist which did not move freely before the giant, and it was frequently necessary to remove them by hand, the larger ones being first broken with a hammer. Boxes 20 inches wide were in use, and two men were mining. It is reported that a good pay streak was discovered east of the present channel of the creek. The total placer production from Grubstake and Willow creeks is said to have been about $25,000.

The task of determining the bedrock source from which the Grubstake Creek placers have been derived presents some difficulties. Veins rich in free gold cut the quartz diorite on Craigie and upper Willow creeks and at once suggest themselves as an adequate source for the placer gold along Willow Creek. Upper Grubstake Gulch, however, lies entirely within an area of mica schist, and the richest placers are localized in this basin. It is therefore apparent that the placer gold above the Grubstake Canyon must have come from the schists, probably from the veins and veinlets of quartz, which are known to carry some gold. Below the mouth of Grubstake Gulch some gold from this gulch is unquestionably included in the gravels of Willow Creek. Placer prospects have been found on Willow Creek above Grubstake Gulch, and their gold was probably derived in part from veins both in the quartz diorite and in the schist. The absence of placers immediately below the outcroppings of the rich gold quartz veins in the quartz diorite is to be explained as the result of severe erosion by glacial ice, which removed any accumulations of gravel and the included gold and incorporated it in the glacial materials deposited farther downstream. The present placers are the result of postglacial concentration of gold from the glacial deposits and from the postglacial erosion of bedrock.

WILLOW CREEK.

Prospecting has been carried on at different places along Willow Creek since the first placer discoveries in 1897, but so far the only ground mined on this stream has been that just below the mouth of

Grubstake Gulch, already mentioned. The Alaska Hoosier Co. holds 32 claims on Willow Creek below the mouth of Wet Gulch, extending 2 miles downstream (see fig. 3, p. 51), but only assessment work has been done on them. Some years ago a ditch was built from Wet Gulch down the south side of Willow Creek valley for the purpose of hydraulicking some terrace gravels, but no considerable amount of mining was done. The ground has been prospected by pits and by means of a spring-pole drill. Holes have been sunk to a depth of 22 feet, but none in the valley floor have reached bedrock.

FISHHOOK CREEK.

In 1906 some prospecting for placer ground was done on lower Fishhook Creek. Encouraging prospects were found in many places, and the creek was diverted, at a point about half a mile above its mouth, into Little Susitna River. A 12-foot pit sunk into the channel showed fair returns, but no ground sufficiently rich to pay. The best prospects were found in the creek bed, and the gold decreased with depth. Bedrock was not reached. A 12-cent nugget was the largest found, and all the gold was fairly coarse, but large bowlders were so abundant that under the conditions which then prevailed the cost of mining would have been prohibitive. The placer gold along Fishhook Creek and Little Susitna River is doubtless a postglacial concentration of gold scattered through the morainal deposits, but the large number of great bowlders along these streams make it improbable that placer mining on them would pay.

GOLD LODES.

GENERAL FEATURES.

The present economic importance of this district is due in large measure to the deposits of gold quartz found in it. The important gold lode mines and prospects are described individually in the following pages, but a statement of the general conditions under which the lodes occur and of their geologic and structural relations seems desirable.

All the producing mines and the more promising prospects lie in the area of quartz diorite bordered on the south by Willow and Hatcher creeks and the east-west portion of Fishhook Creek, and on the east by Reed Creek and Little Susitna River above Fishhook Creek. Most of them are included in an area 6 miles long in an east-west direction and 5 miles from north to south. Within the narrow limits of this productive area the quartz diorite is for the most part massive and unaltered, though locally there is evidence of some shearing and its resulting alteration, and a few prospects lie within the somewhat gneissic phase of the granitic intrusion. Some claims have also been staked in the gneisses south and east of Government Peak, but these have not yet proved to be of economic importance.

Nearly all the mines and prospects are located high up on the mountain sides or near the ridge tops, probably because the mountain tops contain large exposures of bedrock and are free from deposits of glacial material rather than because of the absence of ore bodies at lower elevations. Any veins in the cliffs and crags of the high mountains are comparatively free from cover and are much more likely to attract the attention of the prospector than those whose surface outcrops are covered by moraine, talus, or vegetation. It is not unlikely that there are valuable veins in easily accessible localities in the valleys which may long remain undetected.

CHARACTER OF VEINS.

So far as determined in this investigation the gold-bearing lodes are without exception quartz veins which cut the quartz diorite. As shown in figure 4 the veins, when plotted for strike, are divided into two main groups, one striking in a northwest direction and the other in a northeast direction. Two veins that strike approximately east were observed. At any locality veins of only one of the two main groups occur, and the two groups are therefore not intersecting veins. In the direction of the dip the veins show a marked uniformity. Except the two which strike east and west, all but two dip to the west, the average angle being 39°. In places two or even three veins in the same mountain parallel one another though separated by distances of hundreds of feet.

The veins are fillings of sharp, clean fissures in the quartz diorite. The rock is everywhere cut by several sets of prominent joints, and in every mine or prospect where the direction of jointing could be determined the veins lie parallel to a set of persistent joints and other intersecting sets cut the veins in different directions. The veins in any particular locality are more or less parallel to one another and to one set of joints, there being no quartz veins similarly related to the other joint planes. It seems certain that at the time the veins were deposited only a few of the present lines of fracture had formed, for solutions circulating through any of the openings under present conditions would have had free access to the other cracks of the same set and to the joints of other intersecting sets as well. Because of its homogeneous character the rock mass seems to offer similar conditions in all the passages, and possible precipitating solutions would also have circulated freely through all the openings that then existed. It is also difficult to conceive how the fissures could have been opened to receive their vein material without the joints having also been opened if the joints were in existence at the time the vein filling was introduced into the fissures. The noticeable restriction of the quartz fillings to a few widely spaced fissures of a single set seems therefore to indicate that the veins were filled at an early stage in the history of the granitic mass before much of the present jointing and that after the circulation of the mineralized quartz-bearing solutions through the fissures had ceased joints were formed, some parallel to the earlier fissures and others at divergent angles. These later openings contain no veins, but only careful prospecting can show which of the openings contain veins and which are barren. When once a

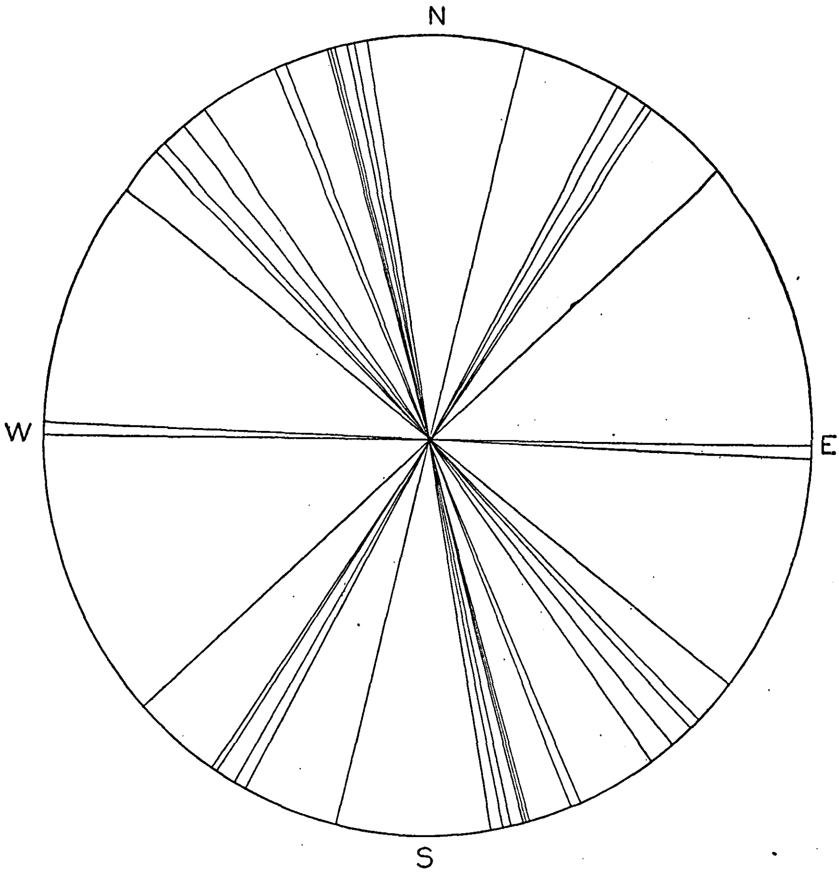


FIGURE 4.—Diagram showing direction of strike of the gold quartz veins in the Willow Creek district.

vein is discovered in any locality, however, prospecting on parallel openings seems to offer the greatest probability of success. It is believed that after the intrusion of the quartz diorite, at a considerable distance below the surface, the intrusive mass solidified and in response to stresses set up in it fissures were formed. At a time when only a few parallel fissures had developed hot aqueous solutions bearing quartz and gold and other metals circulated through the openings and deposited minerals along the passages through which the solutions were moving and fissure veins were formed.

The vein filling was distributed through a considerable period of time, during which some of the openings were filled and reopened a number of times, giving the veins a banded appearance. The gold content of the vein-depositing solutions was not everywhere and at all times the same but differed at different times and in different places. The resulting ores are therefore not of uniform value, but the richer shoots are confined to small areas within a given vein both along the strike and dip as well as to definite portions of the thickness of the vein.

Since the vein filling was completed, some movements within the rock mass have resulted in shearing and faulting. The movement has taken place along the later joints and the quartz-filled fissures and is attested by the development of slickensides on both the ore and the wall rock and by the presence of gouge along many of the veins. Some faults also cut the veins. In most places they are of small displacement and do not present serious difficulties in following the ore bodies. In one prospect, however, faulting has been more extensive, and the vein, which is cut off by a fault, had not been recovered at the time of visit.

At present too little work has been done in the district to determine definitely the extent of the ore bodies, either in length or depth. Developments show rather conclusively that one vein is continuous horizontally for a distance of 1,500 feet and another appears to be continuous for an even greater length, but on neither of these properties have underground workings actually opened ore throughout these distances. One tunnel has been driven 386 feet and another 240 feet on fairly continuous veins and veins have been shown to extend to a depth of 200 or 300 feet below the outcrop.

As the veins are fillings of clean fissures, the quartz commonly has well-defined regular walls. The ore, as a rule, breaks free from the walls, from which it is commonly separated by a layer of clayey gouge. Some veins show brecciated wall rock cemented by quartz, and horses of country rock surrounded by a quartz filling are not uncommon. The veins differ in thickness from place to place and are characterized by pinches and swells. The quartz is white to bluish gray, locally mottled with dark blue-gray patches, and in many places is banded. Near the surface croppings of the veins the ore is generally oxidized, and the visible metallic minerals consist chiefly of native gold and limonite. The oxidized ore is commonly full of cavities formed by the leaching out of the sulphides, and delicate crystals of gold extend into the cavities, showing that the gold was originally intergrown with pyrite. Oxidation, however, is confined to a shallow surface zone only a few feet in depth, and a short distance below the surface croppings the ore is unoxidized, and sulphides, particularly pyrite, are common. Along cracks and fissures in the ore oxidation extends to greater depth than in the solid ore.

The gold occurs for the most part free, some of it surrounded by quartz and free from pyrite but much of it adjoining or intergrown with pyrite crystals. Reports of gold tellurides from this camp have been common, but chemical analyses of ore collected by the writer from a number of mines and prospects have failed to reveal the presence of tellurium. One sample of ore, however, said to have come from this district, showed considerable tellurium, but the particles of this telluride were too minute to be identified. Besides free gold the following metallic minerals were identified in the quartz veins of the district: Pyrite, arsenopyrite, stibnite, chalcopyrite, bornite, chalcocite (?), galena, malachite, limonite, cinnabar, and an unknown telluride. Specimens of molybdenite associated with quartz have been obtained in this district, but no molybdenite was seen in the gold-bearing quartz veins, and the specimens may have come from pegmatite veins. The malachite and limonite are plainly secondary and are oxidation products, probably of chalcopyrite and pyrite. Cinnabar was seen at only one place, where it occurs as a filling of small fractures in the quartz. It was, therefore, introduced some time after the main vein filling had been deposited.

The assemblage of original vein-forming metallic minerals listed above seems to be characteristic of gold-bearing veins of deep-seated origin, deposited by aqueous solutions. Lindgren[1] includes gold, pyrite, chalcopyrite, arsenopyrite, galena, molybdenite, and tellurides as characteristic of veins formed under these conditions. Under Emmons's[2] classification also this assemblage could be found in veins deposited under deep-seated or moderately deep seated conditions. Most of the minerals listed are, however, not clearly diagnostic, as they may have a wide vertical range. The evidence produced by the underground workings in this camp is as yet too meager to serve as the basis for a final statement of the conditions under which the ore was deposited.

The evidence gathered in this district seems to indicate that the gold now present in the ore bodies which are being mined was originally deposited at the same time as the inclosing quartz and that there has since been no removal of gold by solution from the veins or addition of gold to them. In other words, the amount of gold in a given volume of any vein is the same now as at the time the quartz filling was completed. Oxidation has affected only a very shallow surficial portion of the veins, and in the oxidized portions only the

[1] Lindgren, Waldemar, The relation of ore deposition to physical conditions: Econ. Geology, vol. 2, pp. 105-127, 1907.

[2] Emmons, W. H., A genetic classification of minerals: Econ. Geology, vol. 3, pp. 611-627, 1908.

relatively soluble sulphides have been removed, and the gold, which is soluble with difficulty, has been left behind. It is true that mill tests of the surface portions of the veins often show larger content to the ton than is recovered from deeper portions of the same veins, but this is in part due to the fact that after the sulphides have been removed the specific gravity of the ore is reduced, and a larger volume of vein matter with its included gold is required to make a ton. Then also some residual gold from the eroded vein outcrops may find its way into the ore and thus the recovery is in excess of the true gold content of the original vein material. The mill concentrates from unoxidized ore carry considerable gold, probably in the form of free gold intergrown with pyrite. In the oxidized ore this gold has been freed by the removal of the pyrite and is recovered by amalgamation. Thus several factors tend to give a greater recovery of free milling gold from the surface portions of the veins than from the deeper unoxidized portions. Assay tests, however, which determine the gold content irrespective of the presence of sulphides, seem to show that in general the surface oxidized ores are no richer for the same volume than the deeper unoxidized ores. It can therefore be stated with much confidence that secondary enrichment of the ores by the solution and redeposition of gold has played no important part in the concentration of gold within the veins, and ores equally rich as those now mined at shallow depths probably extend as far downward as the cost of mining will permit the veins to be exploited.

MINE OF ALASKA FREE GOLD MINING CO.

The property of the Alaska Free Gold Mining Co. comprises a group of 13 claims lying on the bold mountain ridge which forms the west wall of the Fishhook Creek valley, north of Hatcher Creek (Pl. II, in pocket). The claims, which cover practically all the east slope of this ridge and include a part of the west slope near the summit, have been surveyed for patent, as has also a mill site on Fishhook Creek. The arrangement of the claims is shown on figure 5.

The company is organized as a stock company, but is now operated under an eight-year lease which began in 1912. It was on this property that the first discovery of gold quartz in this district was made in 1906. Since that time development work and mining have been carried on each summer. The improvements at the mine consisted at the time of the writer's visit of two inclined tunnels 50 and 85 feet long on the lower vein connected by drifts and stopes; a 95-foot adit tunnel on the main upper vein; numerous short tunnels, open cuts, and pits on the vein croppings on the different claims; a mill and blacksmith shop on Fishhook Creek and adjoining bunk and mess tents to accommodate about 30 men; and two main tramways and a branch tram which connect the mill with the ore bodies.

The Lane slow-speed Chilean mill (Pl. XIII, *B*), which is operated by a Pelton wheel working under a 35-foot head of water, is designed to turn about seven revolutions a minute and to crush to sizes from 40 to 60 mesh. It was first put in service about August 1, 1912. Its

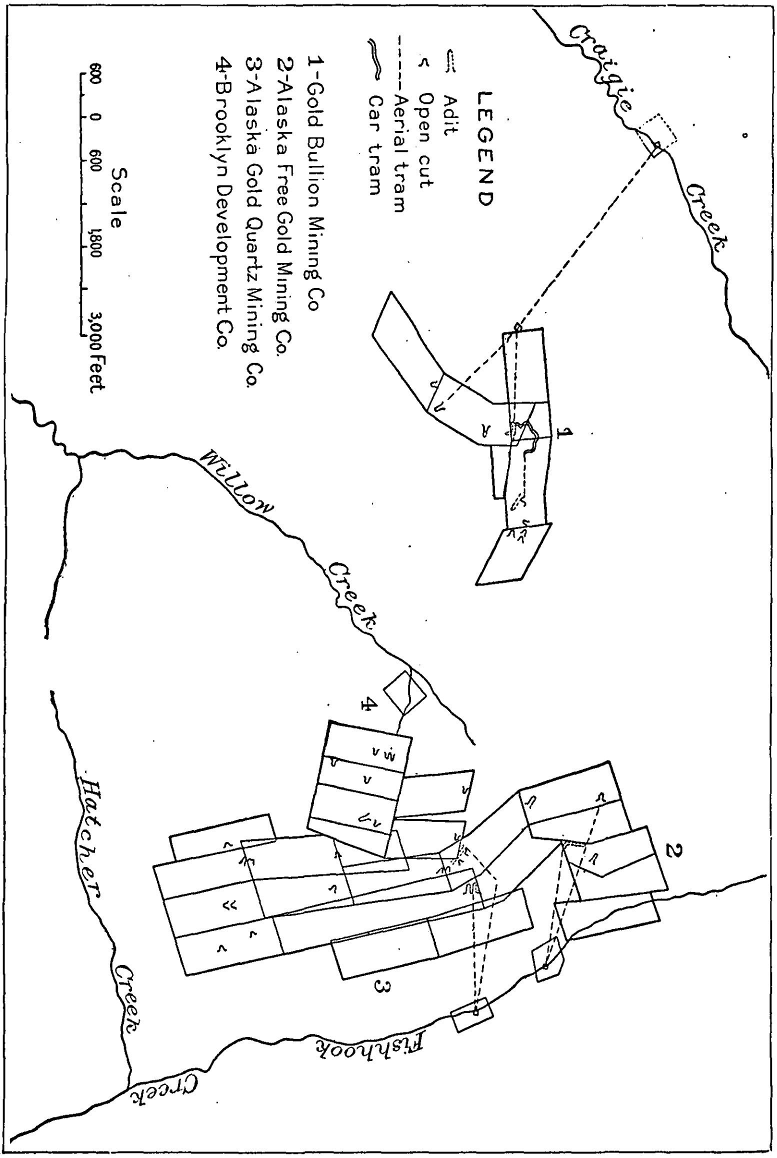


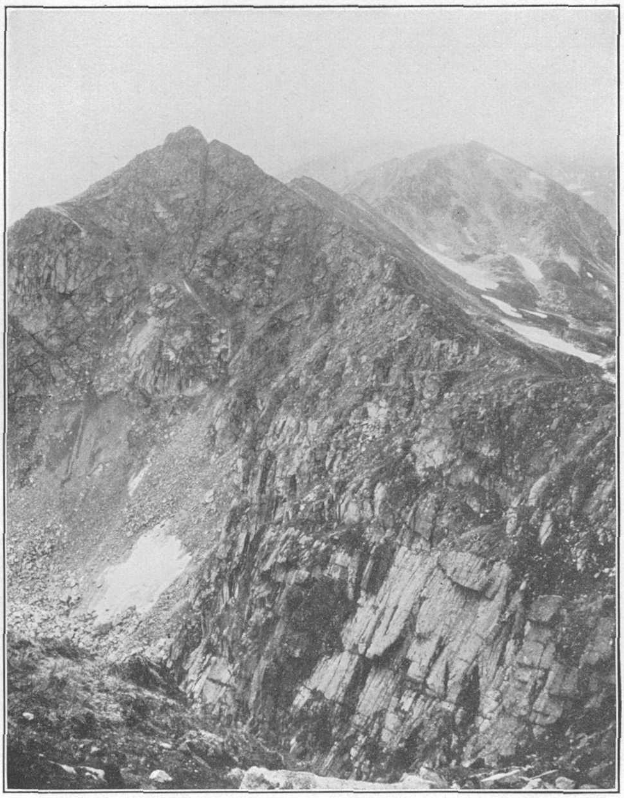
FIGURE 5.—Sketch map showing four groups of claims in Willow Creek district, surveyed by C. S. Hubbell and H. H. Waller.

maximum capacity is about 25 tons each 24 hours. The ore is passed through a rock crusher before entering the mill. The water supply is adequate to operate the mill during only part of the open season, and a 16-horsepower gasoline auxiliary engine has been installed to furnish power during periods of low water. From the mill the crushed ore passes to two sets of amalgamating plates and thence is fed to two Bartlett concentrating tables, operated by a small overshot water wheel. From 1 to 2 per cent of the ore crushed is saved as concentrates. From 70 to 75 per cent of the gold saved is said to be amalgamated in the mill, and the remainder is caught on the plates. At present the concentrates and tailings are not treated but are stored until the time when a cyanide plant is installed.[1]

Two principal ore bodies have been opened on this property, although there are openings at a number of places on veins which may or may not be continuations of these two main veins. The lower of the two veins has been opened at the head of the south tramway, at an elevation of about 4,300 feet, 900 feet above the mill, and will here be called the Homestake vein, as the principal workings are near the boundary between the claims known as the South Homestake and North Homestake. This vein outcrops at about the same elevation and has the same general strike and dip as the Granite Mountain vein of the Alaska Gold Quartz Mining Co., 1,500 feet to the north. It appears likely that the vein is more or less continuous between these two properties, although it has not yet been directly traced throughout the intervening distance. At the head of the tramway the vein is opened by two inclined tunnels 50 feet apart, one 85 and the other 50 feet long, connected at 50 feet from the surface by a drift. The ore was brought to the surface in a car tram operated by windlass. Most of the ground between these tunnels is stoped out for 25 feet below the outcrop. The average strike of the vein is here about N. 13° W., and the dip ranges from 30° W. at the surface to 42° W. at the tunnel face. The vein filling, which lies between quartz diorite walls, was 6 to 24 inches thick and was associated with some gouge and clayey matter. The vein cropping has been exposed for several hundred feet along the surface. To the north it has been traced as far as the north tramway and to the south it was followed to the edge of a large talus slide. It is said that it pinches out to a thin edge to the south. In 1912 a large part of the ore milled at this mine is said to have been taken from this vein. Several hundred tons of ore were treated, the gold recovered running from $15 to $30 a ton and averaging about $20 a ton.

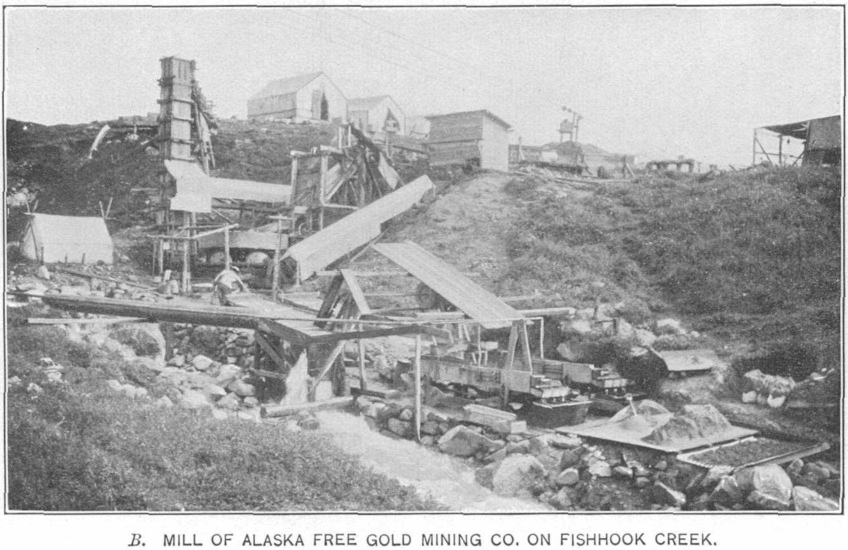
The upper main vein on this property, known as the Skyscraper vein, is opened by a tunnel at an elevation of 4,580 feet on the north slope of Skyscraper Mountain, near its top (Pl. XIII, *A*). These workings are at the head of an 850-foot branch of the aerial tram, which runs in a northeast direction and discharges at the head of the main north tram, 2,500 feet from the mill. At the time of the writer's visit the adit tunnel, which is equipped with a car tram, was 95 feet long and work was in progress in the breast. At 40 feet from

[1] Another mill and a cyanide plant were added to the equipment in the fall of 1914.

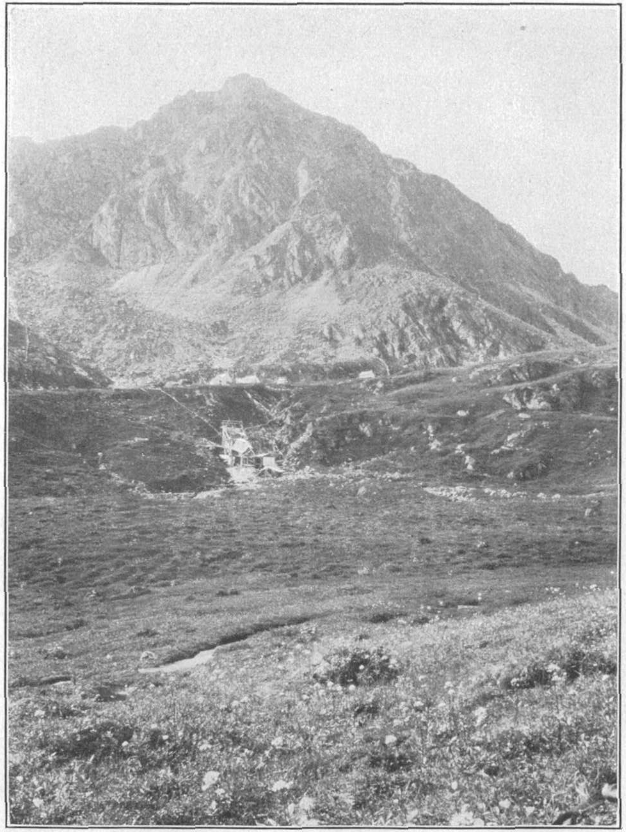


A. SKYSCRAPER MOUNTAIN FROM THE NORTH.

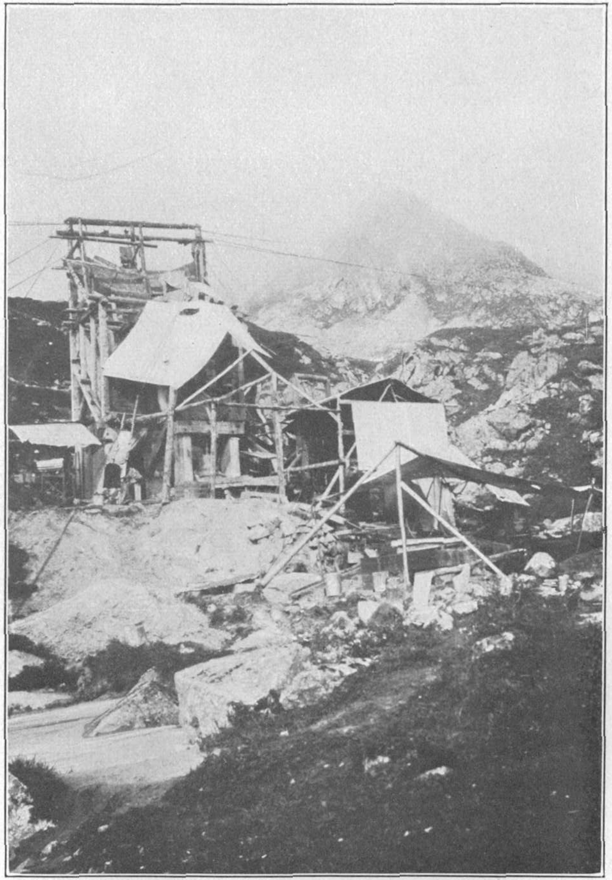
A conspicuous set of westward-dipping joints may be seen. The Skyscraper vein of the Alaska Free Gold Mining Co. lies along one of these joints. The tunnel mouth may be faintly seen below and to the left of the peak.



B. MILL OF ALASKA FREE GOLD MINING CO. ON FISHHOOK CREEK.



A. GRANITE MOUNTAIN, WITH THE MILL AND WORKINGS OF THE ALASKA GOLD QUARTZ MINING CO.



B. MILL OF ALASKA GOLD QUARTZ MINING CO. ON FISHHOOK CREEK.

the portal a raise reaches the surface 36 feet above. As opened by this tunnel, the vein ranges in thickness from 18 inches to 8 feet of solid quartz, associated with some gouge. The vein matter is generally free from the walls, and there is evidence that considerable movement has taken place along the walls. The vein pinches and swells, but the strike and dip are fairly uniform. The average strike is about N. 15° W. and the dip from 40° to 45° W.

A short distance southeast of the tunnel and above it, on the outcrop of the same vein, is a large open cut which supplied about two-thirds of the ore milled in 1913. In this cut the vein is split into two parts by a large horse of diorite 15 feet in thickness. Above the horse is said to be about 5 feet of milling ore and below it from 4 to 10 feet of ore. At a point 380 feet southeast of the mouth of the tunnel is another open cut on the same vein, showing about 9 inches of quartz. The tunnel is being driven toward this point.

The quartz of the Skyscraper vein is in general massive, although it locally shows a banded structure. In the open cuts it is rusty from iron oxide and full of cavities formed by the leaching out of the sulphides. A short distance from the surface, however, the sulphides have been oxidized only along cracks in the vein, and the massive quartz is light to dark blue-gray. It contains, besides native gold, rather abundant pale pyrite, some chalcopyrite, and a little galena. In places the cracks in the vein quartz and in the inclosing quartz diorite are filled with incrustations of epsomite or Epsom salt, a hydrous magnesium sulphate. The native gold occurs both as particles in the quartz not immediately associated with pyrite and also as intergrowths in the pyrite, as can be seen from the delicate crystals projecting into the cubical cavities from which the pyrite has been leached.

A third vein of proved economic importance outcrops on the Eldorado claim, about 3,000 feet south of Skyscraper Mountain. This vein has been developed by several large open cuts and by a 30-foot inclined tunnel, at an elevation of about 4,270 feet. The country rock is a much decayed quartz diorite. The vein ranges in thickness from 1 inch to 18 inches of solid quartz, associated with some clayey gouge. It strikes N. 24° W. and dips about 36° W. and is therefore nearly parallel with the other veins on Skyscraper and Granite mountains to the north. The quartz is oxidized and rusty, as is also the country rock, even at a distance of 30 feet from the surface. It is reported that in 1912 about 100 tons of ore from this vein was dragged down a trail to a point from which it could be trammed to the mill.

A number of other open cuts and short tunnels on this property expose quartz veins of different sizes and gold content, but none of them has yielded ore in commercial quantity.

In 1911 a few tons of ore from this property was milled in the mill of the Alaska Gold Quartz Mining Co., and yielded the first gold produced from this mine. In the spring of 1912 the Chilean mill was installed. In 1913 the mill was run to as great capacity as the water supply permitted and about 25 men were continuously employed during the working season.

MINE OF ALASKA GOLD QUARTZ MINING CO.[1]

The property of the Alaska Gold Quartz Mining Co. lies for the most part in the upper portion of the valley of Fishhook Creek, on the east slope of Granite Mountain (Pl. XIV, *A*). It comprises a group of five claims and a mill site, all of which have been surveyed for patent. The claims form an irregular tier extending from Fishhook Creek up the mountain to the west and include a portion of the divide between Fishhook Creek and the head of Willow Creek. The position and arrangement of the claims are shown on figure 5 (p. 61). The claims were located in 1907, and development work and mining have been carried on each year since. The improvements consist of a 4-stamp mill,[2] located on Fishhook Creek (Pl. XIV, *B*), two aerial tramways extending from the ore bodies to the mill, a group of tents in the valley, a blacksmith shop and car tram at the main tunnel, several hundred feet of adit tunnels and stopes, and a number of open cuts on the croppings of the ore bodies. The mill is operated by a small Pelton wheel, which works under a 120-foot head and develops about 15 horsepower. The mill equipment first installed consisted of a prospecting mill of three 500-pound stamps, manufactured by the Mine & Smelter Supply Co. Later a 1,250-pound Nissen stamp was added. The capacity of the four stamps was about 8½ tons in 24 hours with the small stamps dropping 98 times per minute and the large stamp 90 times. The ore is crushed to 40 mesh and passes from the stamps over amalgamating plates, and thence over a Wilfley concentrating table. The concentrates are said to bear a proportion of about 1 to 80 in the more or less oxidized portions of the vein and of about 1 to 40 in the unoxidized ore about 400 feet from the surface. The concentrates and tailings have been saved for future treatment, but so far all the production has been in free gold obtained by amalgamation in the mortars and on the plates. When the mill is running to capacity the plates are cleaned every 24 hours and the mortars once a week. Two 2-bucket aerial trams equipped with ⅝-inch cable lead from the ore bodies to the mill. The lower of the two, heading at the mouth of the main tunnel, is about 1,700 feet long and is supported by one tower near the mill. The other

[1] This property was taken over by the Independence Gold Mining Co. in 1914.
[2] This plant was enlarged in 1914.

tram is 2,460 feet long in a single span and has a vertical distance of about 1,100 feet between the ends.

Two principal ore bodies outcrop on this property. The main tunnel on the lower or Granite Mountain vein, which has furnished most of the production and which outcrops on the walls of a small cirque (Pl. XIV, *A*), is at an elevation of about 4,150 feet, or 500 feet above the mill. The upper or Independence vein lies high on the mountain, 620 feet vertically above the Granite Mountain vein, and at the time of visit had been prospected only by shallow openings. The country rock is everywhere the quartz diorite, which covers all the northern part of this district.

The Granite Mountain vein is developed by a main tunnel 386 feet long (Pl. XII, *B*), another tunnel 80 feet long, several short tunnels and open cuts, and several stopes, some of which connect the two larger tunnels with each other and with the surface. In general, the vein strikes N. 14°–20° W., the strike differing somewhat in different parts of the vein. The dip also is rather irregular, ranging from 10° to 42° SW., but averages about 20° SW. At the portal of the main tunnel the vein cropping shows only an inch or two of quartz, but in the tunnel the quartz vein matter ranges in thickness from 2 inches to 4 feet, rarely pinching to less than 8 inches and averaging about 22 inches. The vein pinches and swells abruptly and contains some horses of country rock, but is continuous throughout the tunnel. In one place a dip fault has displaced the vein about 4 feet.

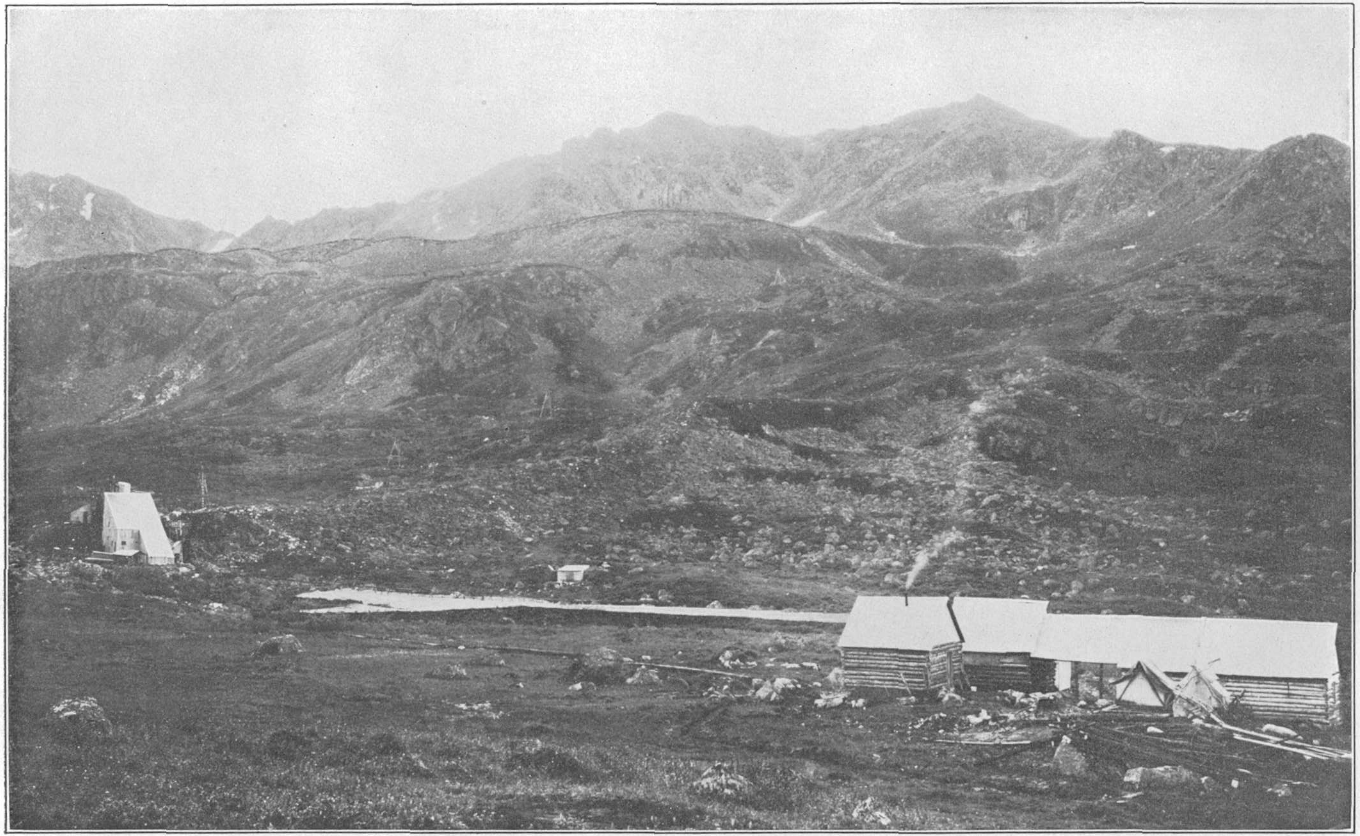
The vein walls are distinct and smooth, are generally slickensided, and are in most places separated from the vein by a layer of gouge matter a few inches in thickness. The quartz is characteristically massive, though it is banded in places; it is light gray to dark blue-gray, and where unoxidized shows, besides native gold, rather abundant pale pyrite, some chalcopyrite, and specks of some unidentified dark sulphide. The vein matter has been somewhat shattered and slickensided. Very near the surface the ore is rusty and most of the sulphides have been removed by oxidation. Farther underground iron oxide occurs along certain cracks in the ore, but most of the sulphides are unaltered a short distance from the surface. The better ore from this vein occurs in shoots, four of which were encountered in a distance of 386 feet along the strike of the vein. In general, an attempt has been made to keep the value of the ore milled up to at least $30 a ton, and the boundaries of the shoots as mined are therefore at about the point where the value falls below this figure.

The upper vein on this property is known as the Independence vein and is connected with the mill by an aerial tram at an elevation of 4,770 feet or 1,120 feet above the mill. The vein strikes N. 12° W., or approximately parallel to the Granite Mountain vein, and its average dip is about 42° W. Although its southward continuation has not been directly proved, it is without much doubt on the same plane as the Skyscraper vein on the property of the Alaska Free Gold Mining Co., and future developments are likely to show that the vein is continuous between these two properties. The developments at the time of the writer's visit consisted of an open cut about 100 feet long and a 15-foot tunnel at the head of the tramway and other open cuts on the vein both to the north and to the south. The vein, as seen at the several openings, is 2 inches to 2 feet in thickness, averaging about 12 inches, and is accompanied by considerable sheared matter and gouge. The walls consist of blue-gray quartz diorite, somewhat sheared near the vein. The vein near the tramway is forked, a portion of it cropping out about 30 feet below the tunnel. The vein quartz is less massive than that of the Granite Mountain vein, is generally banded, and consists of interlocking crystals of quartz containing free gold, a little pyrite, and small quantities of some other sulphides. Only a small quantity of ore from this vein had been mined up to the fall of 1913, but is was planned to build a cabin near the outcrop and run a tunnel on the vein that fall. It was reported that on September 3, 1913, this tunnel had been driven 34 feet on the vein and that approximately 4 feet of good ore showed in the tunnel face.

MINE OF GOLD BULLION MINING CO.

The Gold Bullion Mining Co.'s property is situated on the southeast wall of Craigie Creek valley, about 4 miles above the mouth of the creek. The first claims were staked in 1907 by William Bartholf, and the group now includes five full claims and a fractional claim, which have been surveyed for patent. The arrangement and position of the claims are shown on figure 5 (p. 61). The improvements consist of a group of buildings and a 7-stamp mill located in the valley (Pl. XV), two branch aerial trams supplying a main aerial tram to the mill, a short aerial tram and a car tram at the upper workings, which are provided with a stone mess house, blacksmith shop, and bunk tents, several hundred feet of tunnels and stopes, and numerous open cuts and strippings.[1] The main workings are connected with one another and with the mill by trails. Power for the mill is provided by a 12-inch Pelton wheel operated under a 28-foot head, about 25 horsepower being developed. Some power is also used to run the main tramway. Two 1,000-pound Hendy stamps were installed in 1909, and in 1911 five 1,000-pound Halladie stamps were added. The ore is first passed through a coarse crusher and then fed to the stamps, which are regulated to drop from 100 to 103 times a minute, crush to 40 mesh, and discharge over two sets

[1] A cyanide plant having a capacity of 45 tons daily was added in 1914.



MILL AND CAMP OF GOLD BULLION MINING CO.

The veins outcrop near the top of the mountains in the background. The impounded tailings may be seen below the mill.

of amalgamating plates, and thence over a Wilfley concentrator. The capacity of the stamps is about 21 tons of ore in three shifts of eight hours each, and the ore concentrates in about the ratio of 1 to 200. In 1909 the two stamps then installed were supplied with ore brought to the mill on pack horses, but the next year a cable tram was installed. The main tramway which now supplies the mill is a 2-bucket aerial tram, equipped with $\frac{7}{8}$-inch cable, and is 3,253 feet long, with a rise of 850 feet. It is supported on a number of towers. The buckets have a capacity of 400 pounds, and the tram is of sufficient capacity to keep the mill well supplied with ore. At the head of the main tram there are ore bunkers supplied by two trams, one about 1,600 feet long from tunnel No. 5 and one 1,450 feet long from tunnel No. 2, each equipped with $\frac{3}{4}$-inch cable and two buckets. These trams consist of single spans unsupported by towers. From the mouth of tunnel No. 2 a car tram 945 feet long follows the mountain slope to the northeast and is fed by an aerial tram 635 feet long, which heads at Discovery, on the Gold Dust claim.

The vein croppings on the Gold Bullion property occur near the summit of the ridge which separates the upper valleys of Craigie and Willow creeks. The workings are at elevations of 4,400 to 4,600 feet, and the mill in the valley bottom is 3,050 feet, or about 1,500 feet below the ore bodies. The discovery of the veins on this property in the high, craggy ridge top is, no doubt, due to the good exposures of bedrock which occur there. Below the workings most of the bedrock is so concealed beneath a covering of talus and of glacial deposits that prospecting is difficult.

The ore milled in 1909, which yielded the first gold recovered from this property, is said to have been obtained from the talus and from open cuts on the Gold Dust claim, the place of the original discovery. From 1910 to 1912 the ore milled was taken from tunnels Nos. 3, 4, and 5, No. 5 furnishing most of the production. In 1913 the production was largely obtained from open cuts and from tunnel No. 1 on the Gold Dust claim, from the same locality that was first mined.

At the time of the writer's visit access could be had to the many open cuts on the property and to adit tunnels Nos. 1, 2, and 4. Tunnels Nos. 3 and 5 had caved at the portals and were inaccessible. Active mining was in progress in open cuts near tunnel No. 1 and in that tunnel itself, which was 30 feet long, and a prospecting tunnel, No. 2, was being driven along the vein and had penetrated several hundred feet into the mountain. Between these two tunnels numerous open cuts and strippings have exposed the vein, and, although the exposures are not continuous, it is most likely that both tunnels, and No. 3 as well, are all on the same vein. Tunnels Nos. 4 and 5, though somewhat higher on the mountain than the projected dip of the vein from No. 2 would indicate, are in ground that has been somewhat faulted and disturbed, and it is not improbable that the veins on which they were driven are parts of the same ore body exposed in the other workings. The vein may, however, be somewhat displaced by faulting, or it may even prove to be a distinct ore body.

At tunnel No. 1 the vein strikes about N. 28° E. and dips 15° W. Open cuts show its continuation on the opposite side of the ridge to the south. At the time of the writer's visit the tunnel was 30 feet long, but it is reported that by October 15, 1913, it had been driven 184 feet. As exposed in the tunnel the vein is 3 to 7 feet thick and is composed largely of white or bluish quartz, rusty along the fractures. Sheared matter and gouge occur both above and below the vein, which cuts the quartz diorite. Many pieces of the ore contain visible particles of free gold, as well as small amounts of pyrite and chalcopyrite. Particles of some other finely disseminated sulphides are also present, and copper carbonate stains are common. Although both the country rock and the vein are much fractured, many of the fractures being filled with ice, the ore at even so short a distance as 30 feet from the portal of the tunnel is not greatly oxidized, except along fractures, and many of the sulphides are unaltered. The open cuts at this place have disclosed a large amount of oxidized and broken vein quartz mixed with the surface detritus, and this loose surface material supplied a considerable proportion of the ore milled in 1913. The surface portion of the vein seems to yield somewhat higher returns than the fresher material from the underground workings, probably as a result of the freeing of some gold by the oxidation of the sulphides. At present the only gold recovered is free gold, obtained by amalgamation. Tunnel No. 2 has yielded a little milling ore, but most of the tunnel has been driven in the hope of opening an ore body. The mouth is on the Golden Wonder claim, and the vein, which ranges in thickness from 5 feet to the vanishing point and averages about 2 feet, strikes approximately N. 30° E. and dips about 14° W. In the breast of the tunnel the vein had thinned out to a small stringer. It is reported that on October 15, 1913, the tunnel had been driven 240 feet and the vein had increased to a width of 3½ feet of paying ore.

Tunnel No. 3, about 400 feet west of No. 2 and presumably on the same vein, is now caved, but is reported to have yielded considerable good ore.

Tunnel No. 4 is said to be 300 feet long and the vein ranges in thickness from 2 feet down to a small stringer. No work was being done in it in 1913. In one place in this tunnel cracks in the vein quartz were filled with cinnabar, which had evidently been introduced after the vein had been filled. The amount of cinnabar is small, but the occurrence is of interest, as it is the only place in the district from which this mineral has been reported.

Tunnel No. 5, which is now caved and abandoned, furnished most of the ore milled in 1912. The vein is said to have had a maximum thickness of 14 feet, though averaging much less than that. In 1913 a small quantity of ore was recovered from the outcroppings of the vein near the site of the old tunnel entrance.

In the mill practice at this mine the only metal which has been recovered so far has been the free gold caught by amalgamation in the stamp mortar boxes and on the plates. In 1913, during the time when the mill was running 24 hours a day, the plates were cleaned up at the end of each 8-hour shift, and the mortars were cleaned every 48 hours. The concentrates from the Wilfley table have been stored separately and all the tailings have been impounded. About 4,000 tons of tailings are now stored ready for treatment, and plans are being made to install a 30-ton cyanide plant in 1914. The tailings are said to carry an average of over $16 a ton in gold. In 1913 the mill was run three 8-hour shifts a day, and two shifts were worked in the mines. About 30 men were continuously employed during the summer. In the fall the number of stamps in operation was reduced as the water supply diminished. The 5-stamp mill ran during the season for a total of 59 days and the 2-stamp mill for 72 days. It was planned to continue underground mining all winter.

MABEL MINE.

The Mabel mine is situated on the west wall of the Little Susitna Valley, 3 miles above the mouth of Fishhook Creek. The workings, at an elevation of 3,700 feet, are in a small gulch tributary to Little Susitna River, and the camp is near the same gulch, about 800 feet below the workings. The property comprises a block of 12 claims staked to cover the known outcroppings of the veins. The claims were staked in the fall of 1911, and a moderate amount of development work has been done since that time. In 1912 an open cut was made on the vein and an inclined tunnel driven down the vein for some distance, but water in this tunnel became troublesome and it was decided to drive an adit tunnel below to crosscut the vein. At the time of visit the open cut and inclined tunnel were badly caved and little could be seen, but in places a slip zone said to be on the vein and containing about 8 inches of gouge and a little quartz was observed to cut through the quartz diorite country rock. This zone strikes in a general northerly direction and dips about 45° W. The vein as opened in the inclined tunnel, is said to range from 2 to 18 inches in thickness. Ore taken from it showed a decided banding of white quartz with visible interlocking crystals and dark blue-gray fine-grained quartz.

Several tons of quartz were obtained from the workings in 1912, and 6 tons was shipped to Tacoma for smelting.

In 1913 an adit tunnel was started 20 feet below the earlier workings and when visited had been driven 51 feet under cover. It was expected that the vein would be struck within a short distance. Near the mouth of this adit tunnel another quartz vein, cutting quartz diorite, strikes N. 52° W. and dips 55° SW. It is from 6 to 8 inches thick, and consists of massive rusty and oxidized quartz which breaks free from the walls and contains some horses of country rock. The sulphides have for the most part been removed by oxidation in this surficial portion of the vein, though some pyrite remains. It is probable that the amount of sulphides will be found to increase at no great distance from the surface. Visible free gold could be seen in many specimens of the quartz, and small pieces mortared and panned gave many colors of free gold.

A good horse trail has been built from the wagon road to the camp and also to the tunnel mouth. Plans were under consideration to construct an aerial tram from the tunnel to a mill site on Little Susitna River in 1914.

ARCH PROSPECT.

The Arch prospect is situated on the south side of Archangel Creek, about 1½ miles above the mouth of that stream, at an elevation of 3,200 feet, 550 feet above the valley bottom. This property, which consists of a group of four claims called the Arch group, has been generally known as the Fern, Taulman & Goodell prospect, but changed hands in the summer of 1913. At the time of the writer's visit there was no one on the ground, and the main tunnel was caved and partly filled with water, so that little could be seen. A good stone house and blacksmith shop have been built near the prospect, and a good trail extends from the cabin to the main trail in Little Susitna Valley.

The vein, which cuts quartz diorite, has been developed by a number of open cuts and by an inclined tunnel said to be 80 feet long. The tunnel follows down the vein, which in the somewhat disturbed ground through which the outer portion of the tunnel is driven strikes N. 33° E. and dips 21° NW. In the accessible portion of the tunnel the vein was 10 to 40 inches wide, and the filling was mostly a clayey gouge, with little quartz. It is said that farther within the tunnel a maximum of 12 inches of quartz was observed. The quartz, as seen on the dump, is banded and consists of interlocking quartz crystals surrounding pieces of altered country rock. Sulphides occur only in small amounts.

Under the new management an adit tunnel to crosscut the vein 180 feet below the old incline was started in the fall of 1913, and two other drifts are reported to have cut the vein, showing from 12 to 20 inches of quartz with an average gold content of $32 a ton. It was planned to install two small Lane mills on Archangel Creek in the summer of 1914, water for power being obtained from the tributary which joins Archangel Creek from the south near the mill site.

PROSPECT OF BROOKLYN DEVELOPMENT CO.

The Brooklyn Development Co.'s property consists of five mining claims and a mill site in the basin at the head of Willow Creek. The claims are said to have been located in 1909 and have been surveyed for patent. (See fig. 5, p. 61.) The developments consist of two buildings in the valley bottom, a large number of open cuts and trenches, and two tunnels. The upper tunnel, at an elevation of 4,400 feet, is 40 feet long, and is driven through quartz diorite. It was started on a quartz vein 6 to 8 inches thick, striking approximately east and dipping 15° S. A short distance from the entrance the vein was cut off by a fault, and the remaining portion of the adit shows little vein matter, although the diorite is seamed and fractured, and a little clayey material appears along some of the fractures. The quartz from the vein near the entrance is rusty and much fractured, and shows some banding. The vein is now for the most part concealed, but the few bits of quartz obtainable showed little mineralization.

The main adit, about 60 feet below the shorter one, is a somewhat crooked tunnel 180 feet long, and three 10-foot crosscuts extend from it to the south. On the surface there is said to have been a vein cropping of about 7 inches of quartz, but the tunnel follows a seam in the quartz diorite containing some clayey material but almost no quartz. In the breast of the tunnel there are a few small quartz stringers, and one crosscut shows 2 inches of clayey gouge with a little quartz. No ore body has been developed in this tunnel. The numerous open cuts and trenches on the property are caved and little could be seen in them.

A stamp mill for this property was purchased several years ago and freighted in to a point on Willow Creek 7 miles below the cabins, but has not been installed.

MAMMOTH PROSPECT.

A group of four claims, known as the Mammoth group, is located in the Willow Creek valley on the mountain which lies north of the pass between Fishhook and Willow creeks. The main workings lie at an elevation of 3,800 feet, or 450 feet above Willow Creek. Active development work was carried on during the winter of 1912–13, and a 200-foot tunnel, with 73 feet of crosscuts and a 12-foot raise, was driven. The vein at the tunnel entrance shows a large body of quartz 28 to 30 feet wide, striking approximately east and dipping 68° N. About 30 feet from the tunnel entrance a fault has cut off the vein abruptly, and the remaining 170 feet of tunnel on this level was driven on a slip zone full of clayey gouge, but the vein was not again encountered. The country rock is a somewhat gneissic quartz diorite which has been broken by slips in several directions. The walls of the slip zone on which the tunnel was driven are well defined, and although they show some rolls, the direction of the zone is fairly constant. The walls are smooth and in many places show slickensides, and the rock has been much altered. In the breast there is about 3 feet of clayey gouge and sheared, altered diorite, with good walls of solid rock on either side. A 35-foot crosscut to the north leaves the main tunnel 100 feet from the portal, and one or two other short crosscuts have been made, in none of which was the vein encountered. About 70 feet from the portal a 15-foot raise on a slip zone entered a body of quartz, but a 28-foot crosscut from the raise cut through the quartz body, which proved to be an irregular portion of the vein surrounded on all sides by faults. The faulted-off portion of the main vein has not been found in the underground workings.

The quartz is for the most part massive, white, and vitreous, mottled with patches of bluish gray. It shows scattered specks of pyrite and chalcopyrite with stains of copper carbonates. The assays that have been made show the vein to consist of ore which for this district is low grade. The vein is, however, the largest seen in the region, and if its underground continuation is established, and the tenor holds, there is here the possibility of a mine from which much gold might be recovered.

MINE OF MATANUSKA GOLD MINING CO.

The property of the Matanuska Gold Mining Co. is situated on the north side of a cirque in which Fairangel Creek has its head. At the time of the writer's visit there was no one on this ground, and only assessment work has been done for the last two years, as the property is now involved in litigation. The four claims of this group were staked in 1909, and considerable development work was done in 1910 and 1911. A good trail was built from the Little Susitna Valley to the workings, many open cuts were made, and tunnels aggregating over 200 feet in length were driven. The camp, consisting of several tents, is near the creek, at an elevation of about 3,500 feet. The country rock in this vicinity is a coarse gray quartz diorite with many inclusions of a finer-grained gray sugary diorite. The diorite is cut near the vein croppings by small aplite dikes, locally called "quartzite." The dikes are older than the vein fillings, for in places the quartz veins cut the dikes, and cracks in the dikes are filled with quartz.

The working nearest camp, at an elevation of 3,680 feet, is a 20-foot tunnel in diorite. No veins show in this tunnel, which was evidently driven to crosscut a vein that crops out on the slope 50 feet above. At the cropping a 22-foot adit shows two quartz veins in the breast, one from 1 to 3 inches thick, striking N. 22° W. and dipping 42° NE., and the other from 3 to 8 inches thick, striking N. 47° E. and dipping 71° NW. Above the tunnel the smaller vein has been exposed by stripping for a vertical distance of about 50 feet. At a point about 75 feet west of this exposure an adit tunnel, which is said to be 85 feet long, has been driven to intersect the larger of these veins. A cave-in has closed this tunnel about 60 feet from the portal, but it is reported that the position of the vein is believed to be about 10 feet beyond the breast of the tunnel. The tunnel is driven on a slip zone, from 12 to 18 inches wide, which contains much gouge and a little quartz and which strikes N. 44° W. and dips 72° NW., or approximately parallel to the vein in the tunnel. The vein matter, as seen in the tunnels and on the dumps, is 3 to 12 inches thick and consists of banded white and blue-gray quartz. The quartz contains some visible particles of free gold and considerable sulphides, mostly pyrite. Near the surface it is somewhat rusty and shows small cubical cavities containing iron oxide, the result of the leaching of the pyrite. The gold content of this vein is said to be high, averaging about $100 a ton.

At an elevation of about 3,930 feet, or approximately 250 feet above the vein just described, is another quartz vein closely associated with an alaskite dike. The vein is younger than the dike, the quartz cutting across the dike and filling fractures in it. A tunnel has been driven for 84 feet along the vein, which strikes N. 33° E. and dips 45° W. The vein is distinct on the hanging wall, there being in places 12 to 15 inches of solid quartz. Below this hanging-wall quartz a stockwork of reticulated quartz veins incloses fragments of diorite and contains some gouge. At many places the walls and the ore show slickensides. The same vein is exposed a short distance above the tunnel by strippings and by an open cut. Here the dike and the vein come together. The dike, which along its outcrop ranges in thickness from 1 to 6 feet, is at the cut about 6 feet thick, and the quartz lies parallel to it both above and below. The vein pinches and swells, but in places showed 30 inches in vein matter, mostly quartz, with small inclusions of altered diorite. Some caving has taken place in this cut, and the relations have thereby been partly obscured. The vein walls, the quartz filling, and the diorite fragments inclosed in the quartz all show fine specks of sulphides, mostly pyrite.

Another 24-foot adit tunnel on this property was driven on an alaskite dike locally called "quartzite." The dike rock contains disseminated pyrite, but assays did not show sufficient gold to warrant farther exploration.

MILLER PROSPECT.

The Miller prospect is on the east side of Little Susitna River, 1 mile below the mouth of Fishhook Creek, and about 60 feet above the river. The developments consist of two cabins on the west side of the river and a 30-foot tunnel driven from the bottom of a steep, narrow gulch. The tunnel follows a thick band of siliceous rock, which has been locally called a vein but which proves from study in thin section to be an altered alaskite dike. The "ore" is white to greenish-gray in color and in places contains considerable sulphides. The so-called "vein" is ill defined in outline, and little of it is exposed. The associated rock is coarsely crystalline, and belongs to the gneiss series. Only assessment work has lately been done on this property. Nothing definite was learned of the value of the ore, as assays are said to have given conflicting returns.

MOGUL PROSPECT.

The Mogul prospect comprises two claims situated on a high rock bench in upper Reed Creek valley, 2½ miles above the mouth of that stream, at an elevation of about 4,000 feet. The claims were staked in September, 1912, and have been developed by three open cuts about 15 feet from one another along the croppings of a quartz vein that cuts quartz diorite. The southernmost cut, about 10 feet long on the bottom, shows about 6 inches of clayey gouge with 2 inches of quartz. The middle cut shows 19 inches of clayey vein matter with 1 to 4 inches of quartz. The north cut shows 4 inches of quartz and gouge above, separated by 18 inches of altered diorite from a lower 12-inch vein of quartz. The vein quartz is very drusy, and small, slender quartz prisms project into the cavities. Much iron oxide is present, and some sulphides. The vein is reported to have given high assays in gold.

ROSENTHAL PROSPECT.

The Rosenthal prospect comprises the Sun, Moon, Morning Star, and Evening Star claims, all located on the high ridge which borders the Fishhook Creek basin on the northeast. The developments consist of two adit tunnels and a fair trail from the valley of Fishhook Creek. The longer tunnel, on the west side of the ridge, is about 95 feet in length and is driven along the vein which cuts the quartz diorite country rock. The vein, which consists of white, somewhat banded quartz, strikes N. 40° W. and dips 10° SW. It ranges from 1 to 3 feet in thickness and carries some visible specks of free gold and finely disseminated pyrite. This flat-lying vein is close to the mountain top, and the amount of ore, even if continuous in all directions, is necessarily small, as the projected plane of the vein comes to the surface in all directions within a few hundred feet of the main tunnel. On the east side of the mountain a 30-foot tunnel, driven on the same vein, is not now accessible. The gold is reported to be irregularly distributed, rich ore being closely succeeded by almost barren quartz. At the entrance of the longer tunnel is a pile of quartz, estimated to contain over 100 tons.

SHOUGH PROSPECT.

The Shough prospect is located on the Oregon group of claims on the west side of the Little Susitna Valley, 2 miles north of Fishhook Creek. The camp and workings are at an elevation of 3,550 feet, 1,800 feet above Little Susitna River. Development work on these claims was begun in the spring of 1913, and the improvements consist of a horse trail built from the main valley trail to the workings, an adit tunnel, which at the time of the writer's visit was 35 feet long, a shallow shaft, and several open cuts.

The shaft was sunk on "vein No. 1," a quartz vein which strikes N. 13° E. and dips 62° W. It is reported that the vein, which cuts a pinkish decayed diorite country rock, reached a maximum thickness of 15 inches. Remarkably rich assays, showing several thousand dollars a ton in gold, are said to have been made on ore from this vein. On the mountain slope below the shaft an adit tunnel was driven for the purpose of intersecting vein No. 1. In this adit another quartz vein with a greatest thickness of 12 inches was encountered and followed. The vein strikes in general about N. 36° W. and dips 45° E., but both strike and dip change greatly within short distances. The country rock near the tunnel breast is a dark blue-gray diorite, and the quartz is considerably shattered, and much stained with copper carbonate.

A third vein, imperfectly exposed in open cuts, is said to reach a width of 3 feet. Its general strike is east and its dip 68° N.

Notwithstanding the high assays reported from these veins, the vein matter shows little or no free gold and yields unsatisfactory returns when mortared and panned. The principal visible metallic minerals present are azurite, what appears to be chalcocite, iron oxide, and some galena. In the shallow depths reached, however, the quartz is more or less oxidized and the iron oxide probably represents original pyrite. Insufficient work had been done at the time the property was visited to determine the permanency of the veins. The presence of tellurides has been suspected but a small sample of ore failed to show tellurium on chemical analyses in the Survey laboratory.

The Shough prospects lie just east of the line of a fault zone cutting the diorite. This fault has been traced for a distance of more than 2 miles in a northeast direction, and several prospects have been located near it. The relation of this fault to the veins near it has not yet been determined, as little development work has been done along it, and the surface exposures are unsatisfactory. It may be, however, that the fault has offered a passage through which mineralizing solutions have circulated, and that the veins near it have a close genetic relation to the fault.

HATCHER PROSPECT.

The Hatcher prospect comprises three claims known as the Little Gem group, in the upper basin of Archangel Creek, about a mile above the mouth. The claims were staked in August, 1913, and were not visited by the Survey party, as no development work had been done at the time that portion of the area was mapped. It was reported in September that a tunnel 15 feet long had been driven on this property, disclosing a quartz vein from 1 to 10 inches thick, cutting the quartz diorite country rock. This vein is said to be traceable for 1,500 feet along the surface and to carry considerable gold. A large specimen from this vein showed abundant free gold in coarse specks. It is planned to install an aerial tramway and a 3-stamp prospecting mill on this property.

MCCOY PROSPECT.

The McCoy prospect includes a group of 19 claims on the east slope of the mountain which lies west of the lower Reed Creek valley. The claims were located on June 28, 1913, and prospecting during the year was confined to digging open cuts to uncover the vein croppings. At the time the property was visited no one was working on the claims. About 20 open cuts were examined. None of these is large, and only a part of them reached undisturbed bedrock. Several of the cuts had a little quartz on the dumps, and one showed 4 inches of clayey gouge in place, containing a little quartz. The country rock on this mountain is all coarse quartz diorite, with some inclusions or segregations of a gray sugary phase of the diorite. It is reported that the best showing of quartz on the property is north of the cuts visited. There are said to be three veins, the largest reaching a maximum known thickness of 7 feet. The veins are reported to strike northwest and to dip southwest.

BARTHOLF-ISAACS PROSPECT.

The four claims of the Bartholf-Isaacs prospect are located in the upper basin of Archangel Creek, about a quarter of a mile above its mouth. They were staked in June, 1912, and only assessment work has been done on them. No one was working on these claims at the time the area was surveyed, and they were not visited by the writer. It is reported that five open cuts have been made which show the vein at its greatest size to contain 2 feet of quartz and 5 feet of gangue and to cut quartz diorite.

GRIMES PROSPECT.

The Grimes prospect comprises a group of eight claims, known as the Dolores group, situated on the north side of the ridge which divides the Fishhook Creek drainage basin from that of Archangel Creek. The ground was staked in 1912. The developments consist of a number of open cuts distributed throughout a vertical range of 300 feet and supposed to be on the same vein. The line of cuts strikes a little east of north, but little could be seen of the vein in place, as the sides of the cuts have caved. The lowest cut, at an elevation of about 3,600 feet, shows on the dump pieces of quartz from a vein at least 10 inches thick. The quartz shows some banding and contains bits of altered country rock but is for the most part rather massive white quartz, somewhat iron-stained. The country rock is quartz diorite, cut by a set of joints striking N. 15° W. and dipping 43° SW., and the vein is probably a filling of a joint of this set. Another cut, at an elevation of about 3,200 feet, has on the dump considerable rusty, banded quartz stained with malachite. The vein is evidently at least 6 inches thick. Another open cut above the two already described is said to expose 14 inches of quartz which carries sulphides and free gold.

RAE PROSPECT.

The Rae prospect consists of four claims called the Jennings group, situated on the divide between Fishhook Creek and Little Susitna River, 1 mile north of the east-west portion of Fishhook Creek. The claims lie in an area of more or less gneissic quartz diorite, which is cut by a considerable fault or shear zone. Two open cuts on the Fishhook Creek side of this property were examined. The larger of these cuts was dug from the bottom of a steep gulch, at an elevation of about 4,000 feet, or 1,100 feet above the valley floor, and extended 15 feet into the mountain side. The country rock is deeply oxidized and decayed gneissic diorite, and the cut was driven on a layer of sticky yellowish clay or gouge from 8 to 18 inches in thickness, striking in a general northeast direction and dipping 43° N. Some quartz occurs in the clayey material and contains free gold, chalcopyrite, pyrite, galena, and copper carbonates.

A second open cut, 20 feet above the first, shows the same altered country rock, with thin rusty seams. The little work done on these claims is insufficient to either prove or disprove the presence there of valuable ore bodies.

SAN JUAN PROSPECT.

The San Juan group of two claims is on the crest of the high mountain ridge which forms the west valley wall of Little Susitna River just north of Fishhook Creek. The open cuts on these claims were not seen by the writer, but it is reported that a ledge 9 feet wide has yielded encouraging assays. Pieces of ore said to have been taken from the property appear to be pegmatitic in character, with large quartz and feldspar crystals. If this rock proves to be workable ore, it is of different character from the other proved ore bodies of the district.

MISCELLANEOUS PROSPECTS.

A number of gold lode prospects have been staked in the district, about which little could be learned and which were not visited. Some large quartz veins of low gold content are reported in the upper part of Little Susitna Valley. A prospect on a high ridge at the head of Purches Creek, a northern tributary of Willow Creek, is said to contain quartz showing considerable free gold. Several hundred pounds of this ore was back packed by the owners to the head of the road on Fishhook Creek, in order to send it to a smelter. A vein on Shorty Creek about 2 miles above its mouth is said to have been stripped for 300 feet, and to show 3 feet of ore. Many other claims have been staked on which insufficient work has been done to demonstrate whether or not they will ultimately develop into mines.

SUMMARY.

PRODUCTION OF DISTRICT.

Of the three producing mines in this district one has been operated for six years, one for five years, and one for two years (in 1913). Two are equipped with stamp mills and one with a Chilean mill. All these mills can be operated only during the short summer season, and the total milling done is the approximate equivalent of 1 stamp of 1,000 pounds dropping for 150 months running time. From this small amount of ore treated, a total of nearly $600,000 worth of gold has been recovered, and nearly one-third of this amount came from ore mined in 1914. The total tonnage milled to the end of 1914 is about 17,200 tons, and the average recovery from the ore is approximately $34 a ton in gold, with some silver. This does not include most of the gold and silver contained in the concentrates or in several thousand tons of tailings which have been stored for future treatment. It is probable that the actual gold content of the ore crushed averaged at least $40 a ton. The production of the district by years is given in the following table:

Production of lode mines in Willow Creek district.

Year.	Gold.		Silver.[a]	
	Ounces.	Value.	Ounces.	Commercial value.
1908	87.08	$1,800	6.88	$3.64
1909	1,015.87	21,000	80.25	41.73
1910	1,320.15	27,290	104.29	56.31
1911	2,505.82	51,800	197.95	109.91
1912	4,673.02	96,600	369.07	226.97
1913	4,883.94	100,960	385.83	233.42
1914	14,376.28	297,184	1,330.00	735.00
	28,862.16	596,634	2,474.27	1,406.98

[a] The silver content recovered from the gold bullion is estimated.

In addition to the gold taken from the gold lodes, placer gold valued at about $30,000 was recovered in this district between 1897 and 1914.

FUTURE OF LODE MINING.

In both the number of tons of ore crushed and the value of gold recovered the year 1914 showed an increase over any preceding year, although the largest mill was not put in operation until the season was half over, a shortage of water throughout portions of the summer seriously curtailed mill operations in two plants, and the third was running only a part of the time on account of breakdowns. On two of the larger properties considerable reserves of ore have been opened up, and the prospects are bright for a prosperous season in 1915. Plans are underway for the installment of new machinery at one of the mines, and small mills will likely be installed on two or three properties not previously productive. It is therefore believed that the output from gold lode mines will tend to show a steady increase.

EXTENT OF MINERALIZED AREA.

As has already been stated, the area in which gold-bearing lodes have so far been found is so small that a circle 6 miles in diameter includes all the important mines and prospects. The location of the places where gold lodes have been found is shown on figure 5 (p. 61). It is by no means certain, however, that the lodes are confined to the small area indicated by the present discoveries. Prospecting has naturally been most vigorous near the producing mines, and later discoveries have each year extended the known limits of the mineralized area. Since all the proved lodes occur within the area of the quartz diorite intrusive mass, it is to be expected that the future discoveries will also be made in rocks of this type. Most of the lodes that have been discovered occur within a few miles of the southern border of the quartz diorite mass, but a reported find of rich gold quartz on the head of Purches Creek, a northern branch of Willow Creek outside of the area here mapped (Pl. II), tends to show that the gold-bearing veins are not confined to the borders of the intrusive mass but may occur well within it. Any extension of the limits of the district which contains quartz veins that cut quartz diorite will necessarily be in the directions in which the intrusive rocks occur, namely, to the north and east. In most of this region but little prospecting has been done. The unmapped area north and northeast of the Willow Creek district, including the headward basins of Purches and Peters creeks, Kashwitna River, and Montana and Sheep creeks, is thought to contain large masses of granitic intrusive rocks similar to those in which gold-bearing veins have been found and is believed to offer a promising area for prospecting. It is difficult of access, however, much of it lies far from timber, and even sufficient brush for camping purposes may in places be difficult to obtain. No trails lead to this area, but it may be approached in winter from the Susitna Valley by sled and horses may be taken into the region by following the mountain slopes on the east side of Susitna Valley north from Willow Creek. The upper basins of Moose, Granite, Kings, and Boulder creeks and Chickaloon River, all tributary to Matanuska River, lie in the area of granitic intrusives. Some of these valleys are known to contain placer gold, and they deserve careful prospecting for gold lodes.

DEPTH OF MINERALIZATION.

Only general information is available as to the depth below the surface to which the mineralized veins extend. Most of the prospects are high on the mountains, and mining has been conducted almost entirely by means of tunnels and stopes rather than by sinking. So far as is known to the writer, no single vein has been opened over a vertical distance of more than 200 or 300 feet below the outcrop. The veins all cut quartz diorites which so far as known have an indefinite downward extension. In these rocks the walls of the veins are everywhere of much the same chemical and physical composition, and no reason is known why the walls of the veins should exert a controlling influence on ore deposition at one level rather than at another. The character of the veins and the association of their metallic minerals is characteristic of veins deposited at considerable depth. The ores mined are composed of the original vein material and are practically free from alteration and from either enrichment or leaching. The mineralization in such primary veins has generally a considerable vertical range, and there is no reason to fear that in a country rock of uniform character, and with primary veins of deep-seated origin, mining operations will penetrate below the mineralized portions of the veins for some time to come, if the veins themselves are continuous downward, or that the character of the ore will change greatly within a rather wide vertical range.

MINING COSTS.[1]

The development of mining in the Willow Creek district is hampered by much the same adverse conditions as those which affect most inland mining districts in Alaska. The most far reaching of these conditions is the shortness of the summer season, which directly affects the cost of transportation, of labor, and of power. (See p. 18.) Freight can be placed at the mines more cheaply by sled in winter than by any means in summer, so that six months or more often elapse between the dates of shipment of freight from Seattle and its arrival at the mines. The total transportation cost of freight from Seattle delivered at the mines naturally differs according to the location of the delivery point and the bulk moved, but when taken in by the most economical methods ranges from $50 to $85 or more a ton. Surface mining and prospecting are limited by the weather to a period of 150 days or less, and wages for a short season are consequently greater than they would be if steady employment were offered. The ruling wages in the district for miners and laborers range from $100 a month to $5 a day. The present situation, both in regard to transportation costs and labor, will, however, be greatly improved when a railroad is constructed to pass near this district.

For those mines which obtain their ore by underground mining the length of the productive season is determined only by the duration of the time in which the stream flow is sufficient to furnish power for milling. The three mills now installed are all situated near the heads of the stream basins, where the discharge is small, and an adequate supply of water for even their slight power requirements can be obtained for a season of only about 100 days. This places the burden of carrying all the capital expenditures for the year on a very short productive season, necessitates higher wages during the period of operation, and greatly increases the cost of mining. One of the most serious problems which confronts the operators of the district, therefore, is the securing of cheap power which would be available all the year round. Coal occurs on Moose Creek, about 12 miles from the mines on Fishhook Creek, but transportation charges on coal brought from even this near-by locality would, under present conditions, be about $30 a ton, and the cost of this coal delivered at the mine on Craigie Creek would be even higher. Cordwood, delivered at the mines, is said to cost $40 a cord, and gasoline 70 cents a gallon.

[1] The conditions here described will change when railroad communication with Seward is established.

The railroad to be built from the Matanuska coal field to tidewater on Knik Arm will furnish coal for the Willow Creek district at less than the present cost. It may also be possible to obtain power at a considerably lower cost by building a tram road or an electric transmission line from the Moose Creek coal outcrops.

An increase of power from the present plants could be obtained by bringing the same volume of water to the mills under greater head. Most of the streams in the upper portions of their basins have steep gradients, and additional head could in most places be obtained at a rather small expense.

What appears to be the most feasible suggestion for power for the mines is the installation of a single plant on Little Susitna River near the canyon to supply hydroelectric power to all the mines of the district. The maximum power consumption for the whole district in 1913 was probably less than 75 horsepower during the running season, and the regular fall diminution of run-off caused the closing down of all the mills in September, yet a measurement of the flow of Little Susitna River at the canyon, on September 13, by R. W. Davenport, of the United States Geological Survey, showed sufficient run-off at that late date to develop 12 horsepower for each foot of fall.[1] The stream gradient is there quite steep, and even with a much smaller run-off than that measured it would be easily possible to develop several hundred horsepower, which would be available for a considerably longer period than can be obtained with the present installations. Although nothing is known of the winter discharge of the Little Susitna, it seems likely that the operating season could be almost doubled in length and enough power developed to provide for expansion for some time to come. If it seemed desirable, an auxiliary steam plant to furnish power in the winter could be provided, the coal to be brought from Moose Creek.

Timber for use in mines must be brought several miles, but fortunately not much is needed. Nearly all the tunnels need timbering near the surface, especially those driven through talus or loose surface material, but in the solid quartz diorite, beyond the area of surface disintegration, the rock holds excellently and very little timber is used.

Prospecting is carried on in this district by rather primitive methods. The gangue of the gold-bearing veins is predominantly quartz, and the prospector confines his attention to the search for quartz as float, or in place. The determination of gold in the quartz discovered is almost altogether made by means of mortar and gold pan. If the quartz does not contain visible particles of free gold a small piece is crushed in a mortar, and the pulp is panned. Quartz

[1] Ellsworth, C. E., and Davenport, R. W., A water-power reconnaissance in south-central Alaska: U. S. Geol. Survey Water-Supply Paper, in preparation.

which fails to show considerable free gold on panning is not deemed worthy of further attention. Until 1912 there was no assayer in the district, and it was often several months before the returns from samples sent either to Seward or Seattle for assay were available. Naturally therefore the prospector relied on the immediate information obtained from his mortar and pan. The presence of tellurides in a sample said to have come from this district indicates that assays may be desirable for certain of the ores.

FUTURE OF PLACER MINING.

Since 1905 the placer gold production of this district has been small. Although considerable prospecting was done, the only ground discovered that has proved rich enough to justify mining under present conditions was that first staked on Grubstake Gulch and below its mouth on Willow Creek. Nevertheless there are many claims on lower Willow Creek that yield encouraging prospects, and it is reported that areas there are suitable for dredging. When the railroad is completed to this district it will probably reduce mining costs so much that ground not now available can be worked at a profit, and the district may become the scene of a vigorous placer mining industry.

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