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THE BROAD PASS REGION, ALASKA

BY

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WITH SECTIONS ON

QUATERNARY DEPOSITS, IGNEOUS ROCKS AND GLACIATION

BY

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PREFACE.

By Alfred H. Brooks.

Broad Pass was discovered in 1898 by George H. Eldridge and Robert Muldrow, of the United States Geological Survey, in the course of their exploratory survey of the Susitna Valley.[1] The Indians had, of course, long known the Broad Pass region as a hunting ground, and some white prospectors had reached the upper Susitna basin before 1898, but so far as known the Eldridge party was the first to reach Tanana waters by this route. Worthy of record is the journey into this region of a party of prospectors, among whom W. G. Jack was the leading spirit. This party sledded up Susitna River in the spring of 1897 to the vicinity of Broad Pass and searched the neighboring district for placer gold.

The salient geologic and topographic features of the Broad Pass region were determined by the Eldridge party, as was also the feasibility of a railway route into the interior by this wide gap. As a result, a railway was planned through this pass and surveys for it were made in 1902.

The increased interest in railway routes from the Pacific seaboard created a demand for further information about this region, and plans for a supplementary survey were formulated in 1912 but had to be abandoned after supplies had been sledded into the interior because of delay in the appropriation. This plan was successfully carried out in 1913 by a geologic party under the leadership of F. H. Moffit and a topographic party under leadership of J. W. Bagley. The fact that a region so large and so remote as that described should have been mapped in one season reflects great credit on Mr. Moffit and Mr. Bagley and their assistants.

The results set forth in this report bring much additional evidence of the availability of Broad Pass as a railway route into the interior. They also show that, though no commercial mineral deposits have been found in the region, yet what is known of the geology gives hope that such deposits may be found. Since these

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

surveys were made prospectors report the discovery of ore bodies in the Broad Pass region, and, as has been pointed out, this was to be expected from the geologic survey.

The official announcement of the choice of Broad Pass as the route of the proposed Government railroad is made about the time this report is sent to press. This railroad is to run from Seward to Fairbanks. Broad Pass is about 310 miles from Seward and about 150 miles from Fairbanks by the proposed route. It is therefore to be expected that the Broad Pass region will now be the scene of much prospecting, and there is good hope that it may afford profitable mining development.

THE BROAD PASS REGION, ALASKA.

By Fred H. Moffit.

INTRODUCTION.

Broad Pass is a wide glaciated valley (Pl. III, *A*) between the head of Chulitna River and a tributary of the Nenana named Jack River. It is commonly regarded as one of the passes through the Alaska Range, but in reality is part of an east-west valley connecting the heads of the Chulitna and Susitna rivers. The headwaters of Nenana River once flowed westward through it to the Chulitna. The Broad Pass region, as the term is here used, includes the headwater tributaries of Chulitna and Nenana rivers and the heads of some streams flowing into Susitna River.

Previous exploration.—The vicinity of Broad Pass was first visited by Government exploring parties in 1898. In that year G. H. Eldridge and Robert Muldrow, of the United States Geological Survey, accompanied by five others, ascended Susitna River to the mouth of Indian Creek, whence packing their equipment on their backs, they made their way up Indian Creek and through an unnamed valley paralleling the main Chulitna Valley to a pass which they called Caribou Pass and which led them to the upper Jack River Valley. Descending Jack River and the Nenana they reached the mouth of Yanert Fork, where lack of provisions and the lateness of the season compelled them to abandon their hope of reaching Tanana River and to retrace their steps to the Susitna.[1]

The same year (1898) Sergt. William Yanert, Eighth United States Cavalry, with one white companion and an Indian guide, crossed the mountains between Indian Creek and Chulitna River and ascended the Chulitna Valley to Broad Pass and Jack River where, probably through fear of the Tanana natives, the guide refused to accompany him farther. In his report[2] to Capt. Glenn, Yanert states that he was directed by the Indian to cross the "tributary of the Tanana," Jack River, which he then thought to be the Cantwell

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

[2] Compilation of narratives of explorations in Alaska, Washington, pp. 677–679, 1900.

(Nenana) and was told that a trail would be found on the other side. He soon discovered the trail and after following it a short distance came upon tracks of white men that he rightly conjectured to be those of the Eldridge party, for they had passed that point only a few days before. The lack of all food except game, the loss of his shoes, and the knowledge that the Eldridge party was ahead of him, led Yanert to give up any further attempt to reach the Tanana and to return to the Susitna.

In 1902 an exploring party under Brooks crossed the Alaska Range from Cook Inlet by way of Rainy Pass, at the head of Skwentna River, and made its way northeastward along the flanks of the range to Nenana River and thence to the Tanana and the Yukon. The party crossed Nenana River above the mouth of Yanert Fork, but was obliged to ascend the fork for more than 20 miles before they could find a ford. Although the members of this expedition visited only the border of the Broad Pass region, they added something to the geographic and geologic knowledge of it.[1]

In 1902 and 1903 a reconnaissance survey for a railroad from Seward to Tanana River was made by private persons, who followed the Susitna and Chulitna river valleys up to Broad Pass and thence went down Nenana River to its mouth. As is common in such work, the information collected by the engineers during this survey did not become generally known.

Most of the information concerning the Broad Pass region obtained prior to 1913 was collected by members of the four expeditions already mentioned. Yet many white men—prospectors and hunters—have visited the region, coming into it for short periods and going away without leaving permanent record of their presence.

Topographic and geologic reconnaissance surveys were made by the United States Geological Survey in the adjacent Bonnifield[2] and Valdez Creek[3] districts in 1910. That work carried earlier surveys in the Copper River basin westward to Susitna River and like surveys in the Tanana Valley southward into the Alaska Range, so that with the completion of surveys in the Broad Pass region, a wide section of the range, extending westward from Delta to Nenana River, has been mapped.

Surveys in 1913.—Two parties were sent into the Broad Pass region in 1913; one, a topographic party of six men, was in charge of J. W. Bagley; the other, a geologic party of five men, was in charge of the writer.

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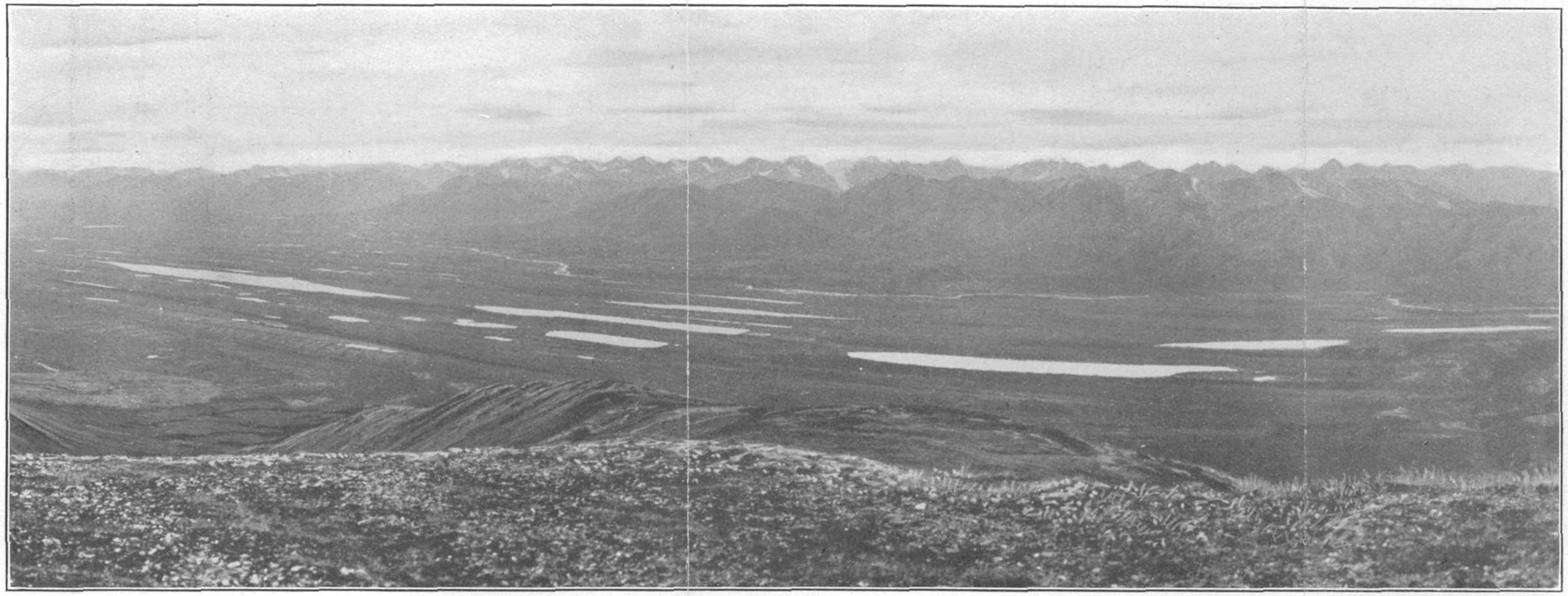
[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, 1911.

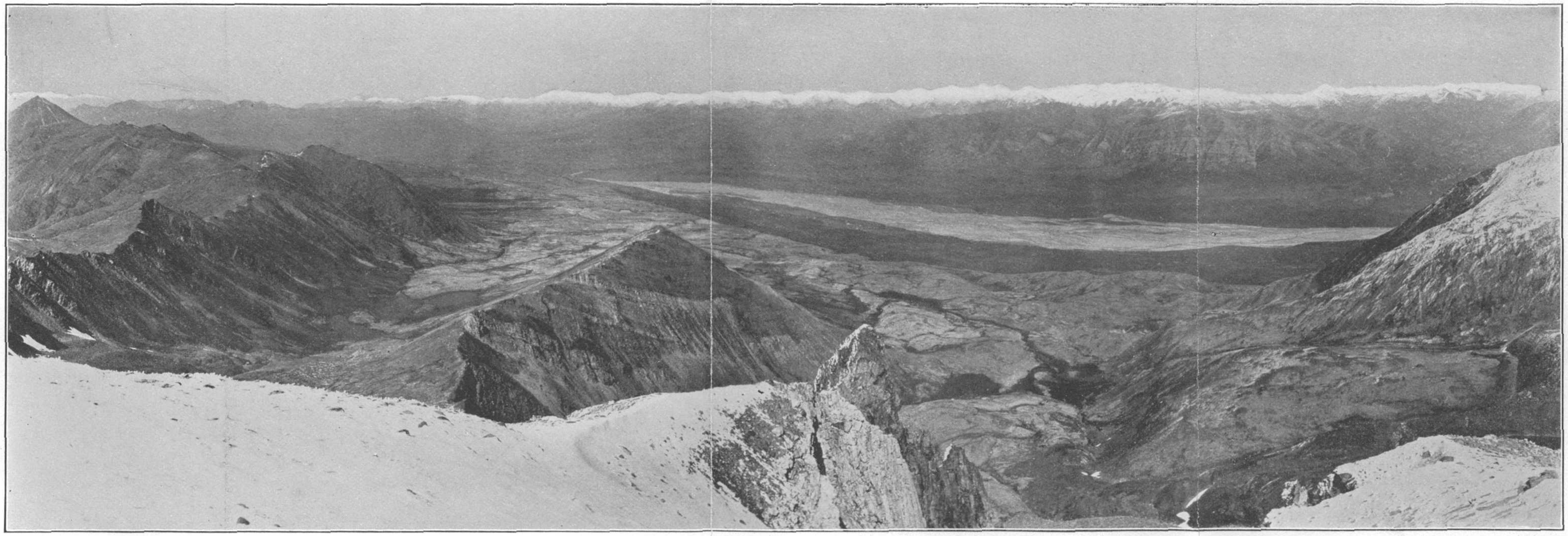
[2] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, 1912.

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



A. VIEW NORTHWARD ACROSS BROAD PASS.

Alaska Range in the background.



B. VIEW NORTHWARD ACROSS THE YANERT FORK OF NENANA RIVER.

Shows structure of the Cantwell formation.

Provisions for both parties were sent to Valdez Creek in March, 1912, but could not be used during the following summer because the appropriation for work in Alaska was made too late to be available that year in a region so remote. The work that had been planned for 1912, therefore, could not be carried out and was postponed to the next season. In the early months of 1913 more provisions were sent to Valdez Creek to replace such of the old supplies as were believed to be unfit for use. The two parties started for Valdez Creek June 8, after spending several days at Chitina in repairing the pack and camp outfits. The parties first followed the military road to Meiers Roadhouse, 124 miles from Chitina. At this place it was thought best, on account of the lateness of the spring and the consequent scarcity of grass, to leave the road and go westward to Maclaren River through a country lower than that of the trails leading westward from Paxson or from Yost's road house. Crossing Gulkana River at the foot of Gulkana Lake, the parties ascended the Middle Fork of the Gulkana and Lake Creek to the Tangle Lakes, and then followed the usual route across the two branches of Maclaren River, down Coal Creek and past the Roosevelt Lakes to the placer camps on Valdez Creek, where they arrived June 28. A number of days were employed at Valdez Creek in preparing for the work ahead. Provisions were separated out and sacked for use during the summer and on the return trip to the coast; a boat was built after the necessary lumber had been whipsawed; and finally the provisions, camp equipment, and horses were taken across Susitna River July 8, just one month after the parties started from Chitina.

The two parties worked near each other for a few days, then separated and did not meet again until the season's work was completed. The course followed by both was first to the southwest, then to the west, the north, and back to Valdez Creek. About 55 days were devoted to topographic and geologic mapping, but the work was interrupted by frequent rains during the summer and was ended finally by a heavy fall of snow from August 26 to 28. Both surveys were of a reconnaissance nature. The photographic method was employed in topographic mapping, Mr. Bagley being assisted in the photographic work by L. G. Steck. By using this method the topographers were able to survey a much larger area than they could have otherwise covered. The area mapped topographically is about 2,500 square miles.

About 1,700 square miles was mapped geologically. The writer was assisted in the field by Joseph E. Pogue, who also prepared the geologic map in the office and, in addition to writing the sections on the Quaternary deposits, igneous rocks, and glaciation, has done much other work connected with this report.

GEOGRAPHY.

Location and area.—The topographic map (Pl. I, in pocket) accompanying this report represents a mountainous area whose limits are defined by parallels 62° 57′ and 63° 51′ north latitude and by meridians 147° 25′ and 149° 15′ west longitude, and which comprises about 3,700 square miles. This area lies at the northernmost bend of the great arc formed by the Alaska Range. It includes the axis of the range, but in the main it lies south of that axis, embracing

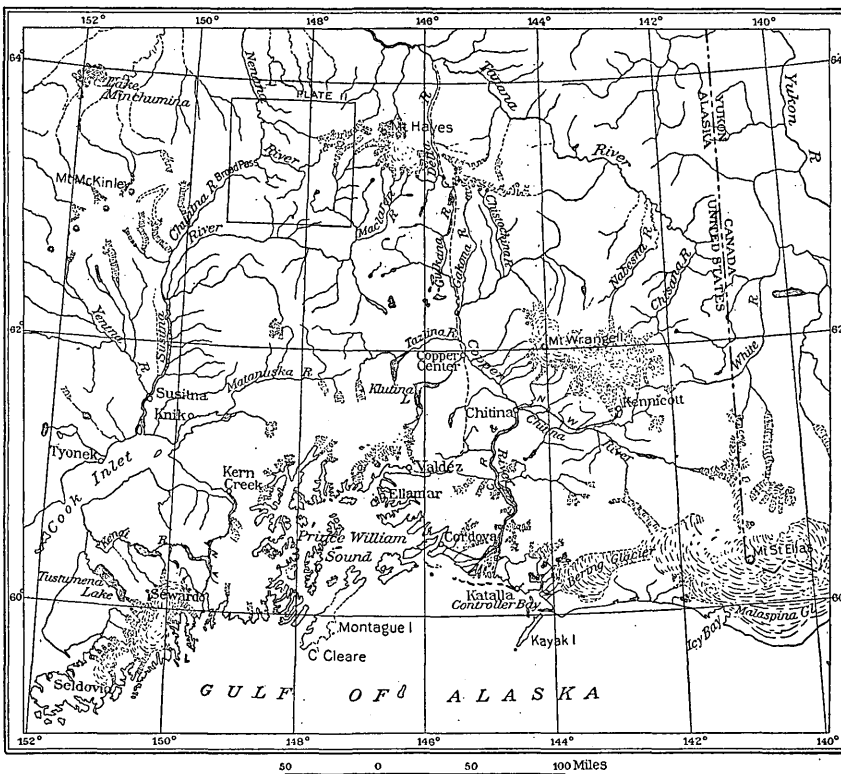
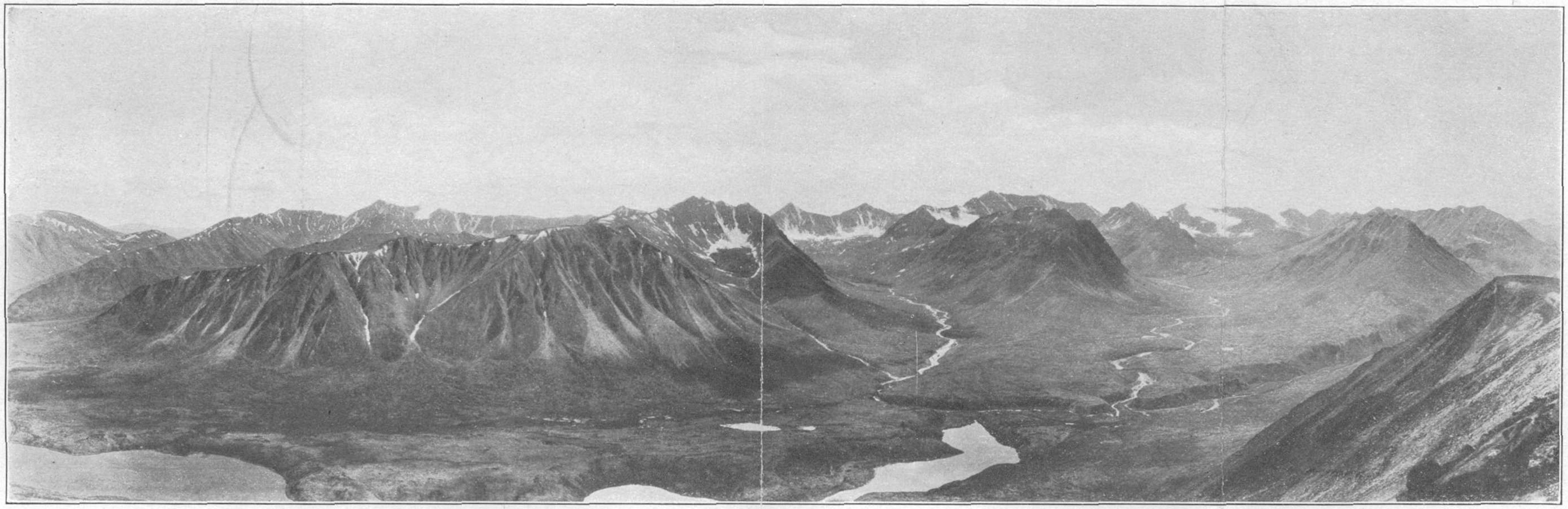


FIGURE 1.—Outline map of a part of southern Alaska, showing the area represented by Plates I and II (in pocket).

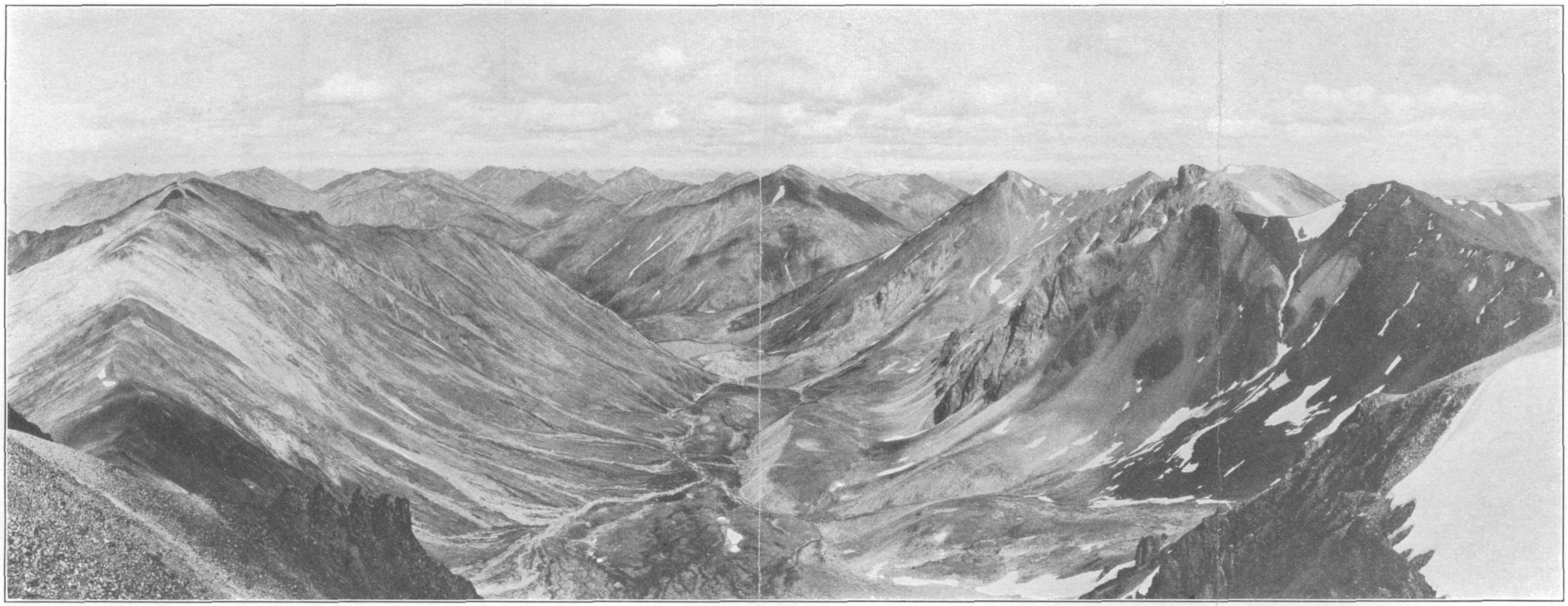
part of the mountainous country between the Alaska Range proper and Susitna River. The location of this area is shown on figure 1.

Topography.—Most of the area considered is rugged and of high relief. It lies near the highest part of the Alaska Range east of Mount McKinley and includes many high peaks. On the other hand, it embraces also the lowest pass through the range. Cathedral Mountain, 13 miles east of the boundary of the area, stands 12,340 feet above the sea; Mount Hayes, 16 miles farther east, is 13,740 feet high; the highest mountain within the mapped area reaches an elevation of 9,000 feet. The highest mountain south of Broad Pass within



A. VIEW SOUTHWARD ACROSS A VALLEY OCCUPIED BY BRANCHES OF BRUSHKANA CREEK AND JACK RIVER.

The lake, only part of which is shown, lies near the summit of the divide.



B. SMALL, RECENTLY GLACIATED VALLEY OF STREAM TRIBUTARY TO THE LARGER EASTERN BRANCH OF JACK RIVER.

the area mapped stands about 6,700 feet above the sea, but in general the mountains between Broad Pass and Susitna River do not exceed 6,000 feet and are therefore at least 1,000 feet lower than those of average height in the main range to the north. The mountains about Butte Creek, in the southeastern part of the area, reach elevations over 6,000 feet. Broad Pass itself is about 2,500 feet above the sea, or practically the same elevation as Susitna River at the mouth of Valdez Creek. Yanert Fork at its mouth is 2,000 feet above the sea. Therefore the maximum relief of the areas, as is shown more clearly on the topographic map, is nearly 7,000 feet.

The mountains of the northern, western, and southern parts of the area have the rugged outlines of a recently glaciated mountain region. High-walled cirques (Pl. IV, *B*), truncated spurs (Pl. VII, *A*, p. 18), straightened valleys, and oversteepened valley slopes are characteristic features of the topography. On the other hand, the mountains of the eastern and central parts show smoother contours and are separated by lowland areas dotted with glacial lakes and strewn with morainic débris (Pl. V, *A*).

Drainage.—The Broad Pass region is drained primarily by Nenana and Chulitna rivers. A part of the drainage, however, passes to the east and south into Susitna River.

Nenana River and its principal tributary, Yanert Fork, originate in glaciers descending from the west slopes of Cathedral Mountain. The upper Nenana may be regarded as belonging properly to a drainage basin south of the Alaska Range, either the Chulitna or the Susitna, and Yanert Fork as belonging to the drainage north of the range. Yanert Fork is fed by a great glacier (Pls. V, *B;* VI, *A* and *B*, p. 16) flowing directly west from Cathedral Mountain, but the Nenana receives its headwaters from a small glacier on the ridge running southwest from the main peak and forming the divide between the two streams. Most of the ice streams on the south slopes of Cathedral Mountain unite to form the great West Fork Glacier of Susitna River. At its beginning Nenana River takes a southerly course, but it soon turns to the west and flows for 25 miles in a wide valley connecting the heads of Chulitna and Susitna rivers; then, instead of holding its westerly course and joining Chulitna River, it turns abruptly north through a minor ridge of the range, resumes its westerly course for a few miles, and finally flows northward in a deep narrow valley (Pl. VII, *B*, p. 18) through the Alaska Range.

Nenana River in its upper course, below the place where it first turns westward, flows sluggishly and meanders widely through open country. On the other hand, in its course from the place where it first turns northward into the mountains to the place where it crosses the axis of the range it runs in deep canyons or in narrow valleys.

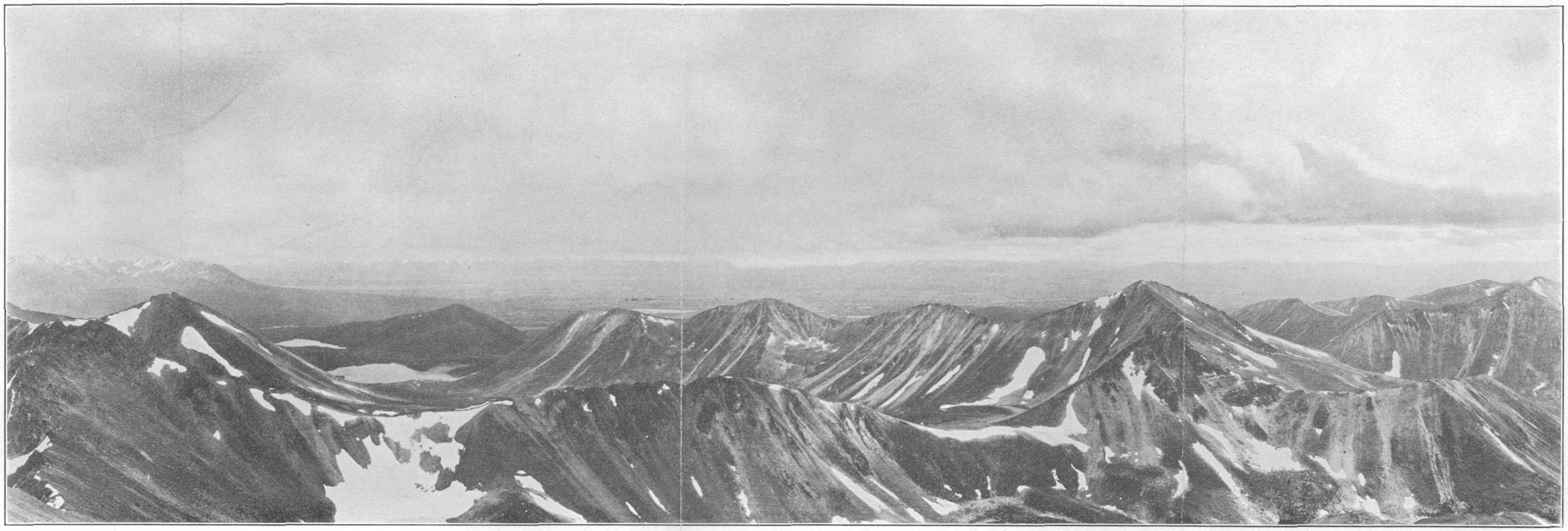
Its current, although swifter in this lower course than above, is not so rapid as that of Yanert Fork or of Delta River, which cuts through the range in a similar way farther east.

The principal tributaries of Nenana River, aside from the Yanert Fork, are Wells Creek on the north and Jack River and Brushkana Creek on the south. The eastern branch of Wells Creek, which joins Nenana River about 15 miles above the mouth of Jack River, and the Nenana itself for 5 or 6 miles above Jack River, lie in a minor intermontane valley that extends westward from the Nenana Glacier. Brushkana Creek, which is as large as the Nenana at the junction of the two streams, drains the central part of the area mapped and flows for the most part in a lowland country covered with marshes and small lakes. Jack River, on the contrary, is surrounded by high mountains (Pls. IV, *A* and *B*, p. 12). Its principal branches flow in deep, rocky canyons and its current is swift. The waters of Jack River, like those of the Brushkana, are clear.

Chulitna River drains the western side of the area. It is a large stream, but only the upper part of two of its branches lie within the area here mapped. It receives the water from many large glaciers in the vicinity of Mount McKinley, as well as from several eastern tributaries, and unites with Susitna River about 75 miles from the coast.

Butte, Watana, and Deadman creeks are the largest tributaries of Susitna River that rise within the area mapped. They can hardly be considered as belonging properly to the Broad Pass region, but they lie within the area of the summer's work. Butte Creek flows from Butte Lake, the largest lake shown on the map.

Routes and trails.—The Broad Pass region has been reached by three routes. The earliest explorers and prospectors approached it from the south through the Susitna and Chulitna valleys. Later hunters and prospectors came into it from the Tanana Valley through either the Nenana River or the Wood River valley. Others approached it by way of Valdez Creek and over the trails leading westward from the Military Road. All three routes have certain advantages and all offer difficulties. For summer use the route from the east is probably the best. At the outset it offers the advantage of a good wagon road from Valdez or Chitina, and farther on, between the road and Valdez Creek, of trails that are being traveled more and more each year. In contrast to this, the route from Cook Inlet is little used. No trails have been marked out in the valleys of Indian Creek or the Chulitna and no means of transportation have been established on Susitna River. The route from the Tanana Valley is traveled occasionally by hunters and less often by prospectors, but no trails have been made.



A. VIEW SOUTHEASTWARD FROM THE DIVIDE BETWEEN THE EASTERN BRANCH OF WELLS CREEK AND NENANA RIVER.

Glacial topography. Mountains on the left are granite.

B. VIEW SOUTHWARD ACROSS YANERT FORK GLACIER.

In winter the Susitna and Chulitna rivers, Nenana River, and the upper Susitna River afford practicable routes for freighting such supplies as would be required by prospectors in the Broad Pass region. Most of the supplies and mining equipment taken to Valdez Creek since 1907 have been sledded over the ice of Gulkana and Susitna rivers, yet in some of these years a part of the supplies has been brought from Fairbanks on the Nenana and Susitna rivers.

In the Broad Pass region travel has been so slight, and the visits of white men have been so infrequent and their wanderings so variable, that no usable trails have been established. In places the Indians, passing from one hunting ground to another, have followed trails that can be traced readily for short distances. In places also wandering caribou and moose have left trails that are still more conspicuous but that for the most part are of little benefit to travelers. It is evident, then, that all who now go into the region must choose their own ways. Travel, however, is not difficult for either horses or men where courses in the higher ground can be used. The best going is generally above timber line, at elevations between 2,800 and 3,500 feet above the sea. At such elevations trees and brush are absent, soft ground is less common, for the steeper slopes give better drainage, and grass for horses is most plentiful and of the best quality. The supply of firewood is less abundant than in the lower valleys, but willows for cooking and for tent poles can usually be found at elevations below 3,200 feet. In the lowlands the swamps and lakes make travel slow and tiresome.

Some of the larger streams offer difficulties to travel both because of their depth and swift currents and because of quicksand. Nenana River and Yanert Fork may be difficult or even impossible to ford at times of high water, but on cool days later in the summer may be forded safely if care is used in choosing the place. A few of the small streams are so full of granite bowlders that horses are likely to have trouble in fording them.

Railway routes.—Broad Pass offers one of the most favorable railway routes from the Pacific seaboard to the Tanana and Yukon basins and has been chosen for the route of the Government railroad from Seward to Fairbanks. The Chulitna, flowing into the Susitna on the south, and Jack River, flowing into the Nenana, a tributary of the Tanana, on the north, both head in Broad Pass. It therefore marks the watershed between Cook Inlet and Yukon drainage. The waters of the Nenana in the past ran through Broad Pass into the Chulitna, but were diverted by the glacier that formerly occupied the region. Since the disappearance of the ice the drainage has not reverted to its preglacial course.

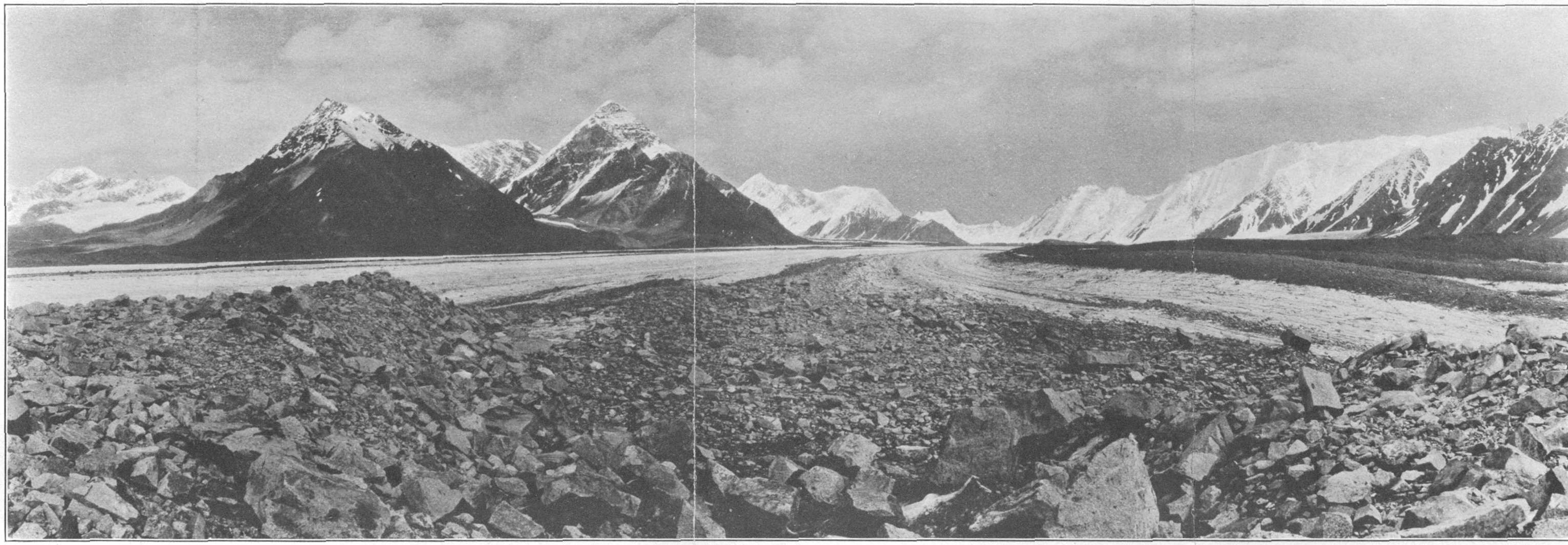
The approach [1] to Broad Pass from the south, along the headwaters of the Chulitna, is, so far as known, a gradual ascent, and a railway route of comparatively low grade could probably be found. The pass itself is a flat about 4 miles wide, presenting no engineering difficulties. It stands about 2,500 feet above sea level, which is about 700 feet lower than Isabelle Pass, on the route from Valdez and Chitina to Fairbanks. North of Broad Pass the railway route would be down the valley of Jack River to the Nenana, and here, too, a good grade could probably be found. The main Alaska Range would be traversed by the valley of Nenana River, which for about 10 miles flows through a steep-walled canyon.

Though Broad Pass probably affords the most feasible railway route, because it is most direct, there are other low divides leading from the Susitna into the Nenana basin. Thus a gravel-floored flat connects the upper Susitna Valley near Valdez Creek with Nenana River. Another low pass lies between the headwaters of Deadman Creek, flowing into the Susitna on the south, and Brushkana Creek, flowing into the Nenana on the north.

Climate.—A lack of records of rainfall, temperature, or other meteorologic data makes it impossible to discuss the climate of the Broad Pass region in other than general terms. The climate is that of a high mountainous country of abundant rainfall, with moderate summer heat and with winter temperatures that occasionally go lower than 40° below zero. The precipitation is much less than that of the southern coast of Alaska, but probably more than that of the Copper River basin and the Nenana Valley. Old choppings in several places along the Tanana River show that the snow was 2 or 3 feet deep when they were made. This does not indicate the total winter snowfall, but it probably gives a fairly correct idea of the average depth of snow in the main valleys in middle or late winter. Snow persists in deep gulches on the high mountains during most of the summer—occasionally throughout the year—but it probably is not correct to say that any of the peaks within the area mapped rise above the summer snow line. New snow is seen on the high mountain tops after almost every summer rain and sometimes comes well down on the mountain sides.

The length of the placer-mining season in the Valdez Creek district, except for underground work, has been regarded as 90 to 100 days. The season's length is governed in some measure by the necessity of leaving Valdez Creek while there still is grass for horses on the trail to the coast, and is therefore shorter than it would be if transportation facilities were more favorable. In 1913, by placing

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



A. VIEW UP YANERT FORK GLACIER.

Shows medial moraines and character of surrounding mountains. Photograph taken in August.

B. VIEW SOUTHWARD ACROSS THE YANERT FORK GLACIER.

Shows some of the lateral tributaries. Photograph taken about three miles from western end of the glacier.

feed at different points along the trail between Valdez Creek and Paxson, the miners were enabled to continue work almost until the 1st of October.

Climatic conditions in 1913 were somewhat different from those of most years since mining began in this district, for the early part of the season was unusually dry and a deep snow came very early in the fall. Little rain fell from the time when the snow began to melt in the spring until after the 1st of July, as a result of which fires were numerous and interfered much with the topographic work. The rainfall was considerable during the rest of the season and the rainy days were cold and disagreeable. A severe storm extending over much of Alaska began in the last week of August and continued for several days. Between the 26th and 28th of August from 18 to 24 inches of snow fell in the Broad Pass and Valdez Creek regions. The survey parties left Valdez Creek early in September, but it was learned that most of this snow had disappeared from the lower valleys by the beginning of October.

Vegetation.—In a discussion of vegetation of this region the distribution of timber and the supply of grass for horses are the particulars most likely to be of interest to travelers. A sketch map (fig. 2) is presented to indicate where spruce timber is found. It shows, further, that most of the region is above timber line, for all the area not covered with timber is above the elevation for that locality at which spruce grows. The elevation of timber line is not constant; it varies in different localities and ranges from 2,500 to 3,000 feet above the sea.

Spruce is the only valuable timber in the region, although cottonwood grows on many of the river bars, especially those of Jack and Nenana rivers, and might be used for some purposes if spruce could not be obtained. The best spruce timber seen in the region is on Butte Creek and is the source of supply for the miners of Valdez Creek. The largest trees cut there would furnish timbers a foot square and 16 feet long. Spruce of fair quality and size grows in places on Susitna River and on the lower part of Jack River, but in the rest of the timbered area the trees are scattered and scrubby, and although excellent for fuel would either make a poor quality of lumber or be altogether unsuited for that purpose.

Willows large enough for tent poles and firewood grow on nearly all the smaller streams up to an elevation of about 3,200 feet above the sea. As a rule they do not thrive on the bars of the larger creeks where unprotected from exposure, but seek the small tributary streams that have incised their channels deep into the gravel deposits or bedrock or that flow in narrow valleys between the mountains.

It thus happens that many good camp sites are hidden away in places where at first it seems as if none could be found.

Alders are not common on the upper Susitna, but are fairly plentiful along stretches of Nenana River, although very much less so than on the lower Copper and Susitna rivers and on the southern coast of Alaska.

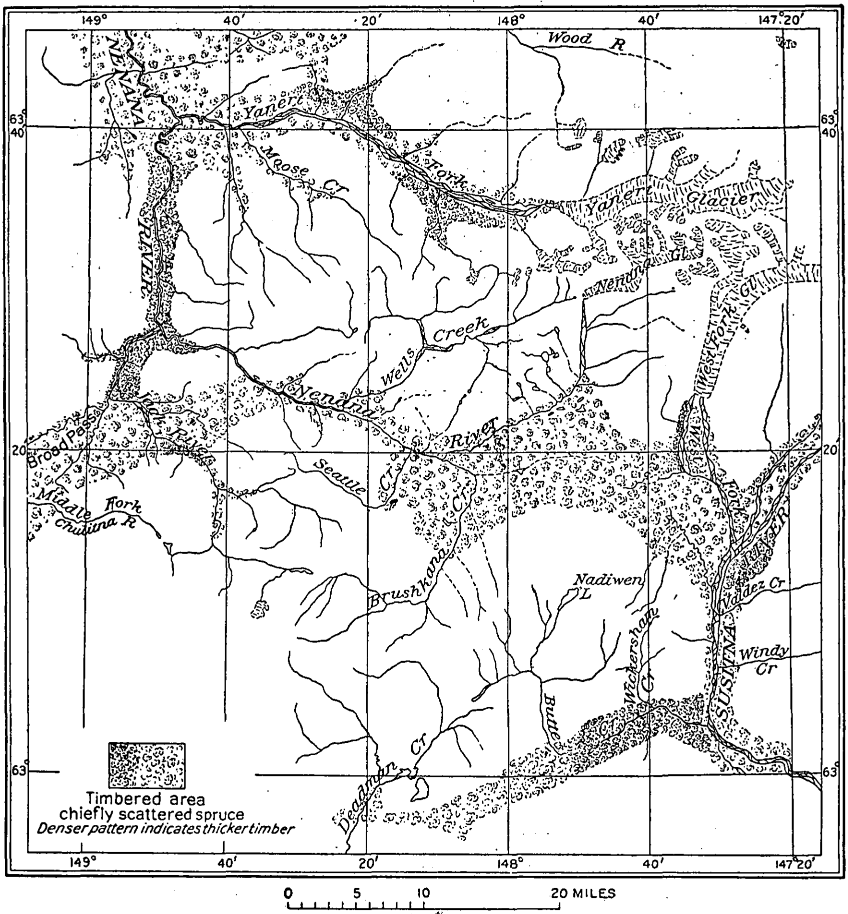
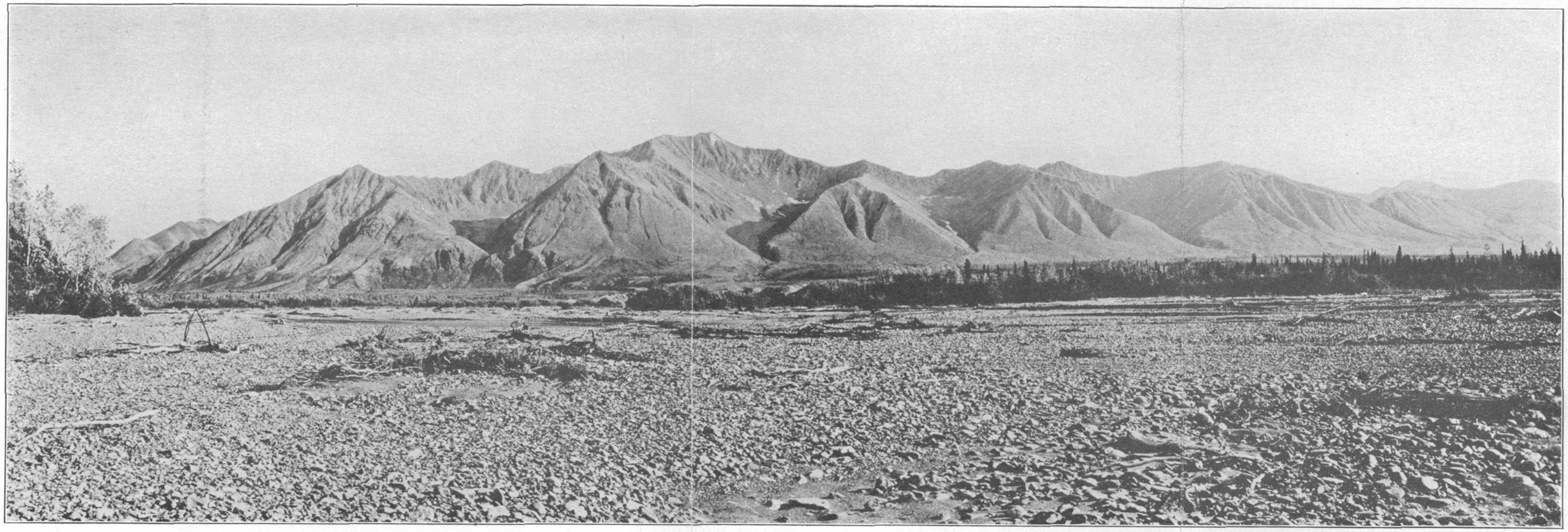


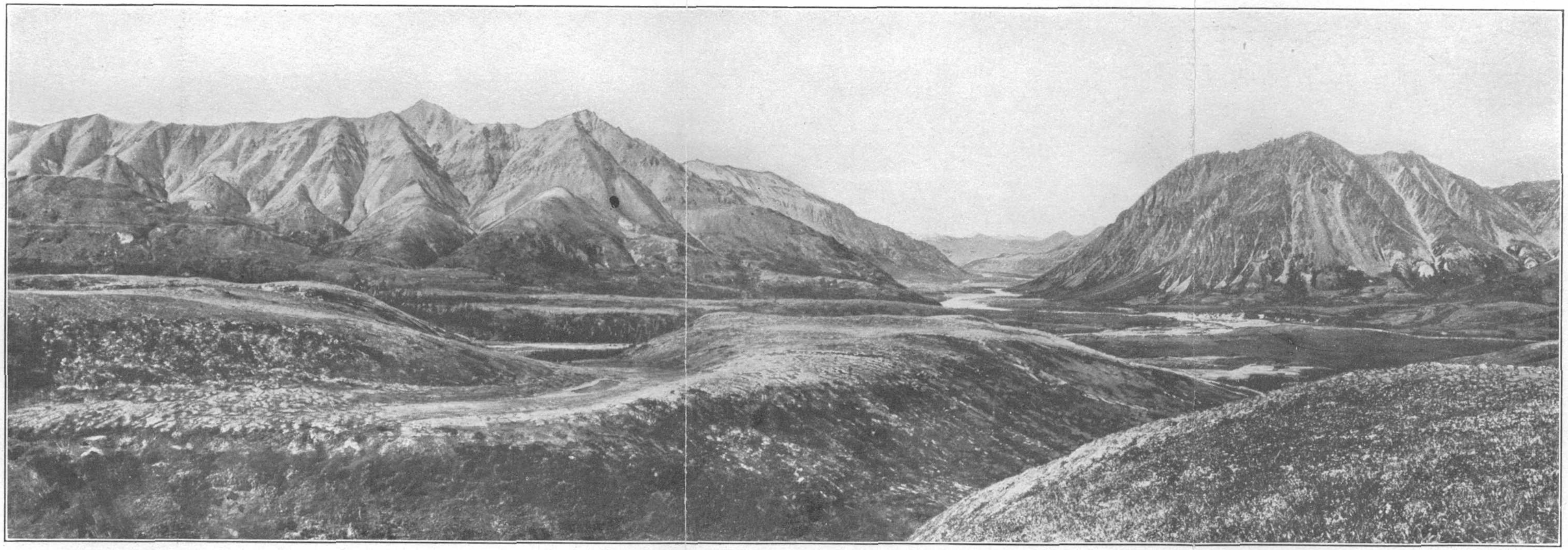
FIGURE 2.—Sketch map showing the distribution of spruce timber in the Broad Pass region.

Grass is abundant in the Broad Pass region in the places best suited to its growth. The lower parts of wide valleys and the gravelly flats of the larger streams are not such places, and grass is rarely found there in large amount. It grows luxuriantly, however, in many small valleys near timber line or at about the elevation where willows and alders thrive best. Steep banks along streams, the faces of benches on hill slopes, and the protected angles at their bases are commonly covered with a fine carpet of grass. On the western or



A. SOUTH WALL OF BROAD PASS VIEWED FROM THE BARS OF JACK RIVER.

Shows truncated spur produced by glaciation.



B. VIEW ACROSS JACK RIVER.

Shows the northward course of Nenana River through the Alaska Range.

Chulitna side of the area under discussion the tall grass called red top grows and forms the matted tangle of stems so commonly encountered in the Cook Inlet and lower Susitna region. It does not grow so luxuriantly, however, as in that region and is not so widely distributed on the eastern or upper Susitna side of the area.

Bunch grass, as it is commonly called, grows on many dry, gravelly flats. It cures on the stalk and is valuable as horse feed long after frost has killed the more luscious, ranker red top. The individual plants have the habit of growing somewhat apart from one another with bare spaces between, and in the spring the young blades come up through a base of old, dry, matted stems, building up a little clump of grass, which is raised above the surrounding ground level. This takes place year after year, and thus are formed the characteristic bunches from which the grass gets its name.

The date of the first appearance of grass in the spring depends on the locality and on the melting of the snow. It is a custom of the miners on Valdez Creek to turn their horses loose when the freighting is finished and the summer's wood supply is gathered, and to provide them with forage as long as they will return to the camps for it. The horses prefer the young, tender grass and rushes that they find on the bars of Susitna River to dry feed, and in most years will not return for hay and oats after the 10th of May or thereabout. The spring of 1913 was an exception to this rule, for the horses had to be fed for 10 days or 2 weeks longer than usual.

Grass grows rapidly in this region when it has once started, and by the 1st of July it is large enough to make good forage. It is killed quickly by the early fall frosts, so that by the 10th of September it is necessary to provide stock with feed other than that furnished by the country itself.

Several species of leguminous plants that are known by the general name "pea vine" grow on gravel bars of the larger streams and in a few places on the hill slopes. They furnish a most nourishing food for stock in the late summer and fall. Horses are exceedingly fond of pea vines and will leave any other forage for them, yet they will scarcely touch the plants early in the summer, before the seeds have ripened. Pea vines grow luxuriantly on the lower part of Jack River and are more abundant there than in any other place known to the writer.

Several kinds of berries are native to this region. Of these the blueberry is the most widespread and abundant. It thrives best near timber line and furnishes a welcome addition to the diet in August. A few currants and "low-bush cranberries" were found, but hardly in sufficient quantity to satisfy the appetites of the party at one meal. The scarcity of these two kinds of fruit was unexpected, for both are locally plentiful farther south, in the Copper River and Susitna River basins.

Game.—The list of game animals suitable for food or bearing fur in the Broad Pass region includes moose, caribou, sheep, bear, wolverine, and fox. Among the smaller fur-bearing animals are otter, mink, marten, muskrat, the so-called ermine (weasel), and the "parka squirrel." Ptarmigan are the chief game birds, although a few grouse are found in the timbered areas. Trout and grayling are plentiful in many of the clear-water streams and the lakes.

The Indians of the upper Susitna spend a large part of the year hunting on Jack River and on the Yanert Fork of Nenana River. These two localities are considered the choice hunting grounds of the region, and Yanert Fork is the better of the two. Formerly the lower Susitna natives also hunted in the Broad Pass region, coming into it by way of Chulitna River or the valley leading northeastward from the head of Indian Creek. Broad Pass itself seems to have been the northern limit of their territory.

Before the discovery of gold on Valdez Creek the upper Susitna natives depended on the country for most of their food and clothing. Valdez Creek was a favorite hunting ground; in fact, the native name for Valdez Creek (Galena, accented on the first syllable) signifies a river where game abounds. After mining began, however, large game practically disappeared from the creek and also from the head of the Susitna, where both moose and caribou were formerly common.

Moose are now found occasionally in the upper Chulitna Valley, and they sometimes come up Susitna River from the lowlands west of Copper River and travel between the Susitna and Chulitna rivers through the Nenana Valley. In Chulitna Valley they are rarely disturbed by white men.

Caribou travel over nearly all of the region and may be seen in almost any part of it at some time during the year, but according to the miners of Valdez Creek they rarely come to the Susitna flats of late years. Yanert Fork, Jack River, the valley between Yanert Fork and Nenana River and the vicinity of Broad Pass are favorite feeding grounds of the caribou.

Mountain sheep, within the mapped area, are almost restricted to the Yanert Fork of Nenana River and to the eastern branches of Chulitna River. It is not understood why they are more numerous on the north slopes of the Alaska Range than on the south slopes, but no sheep were seen on the south side of the range except on the branch of the Chulitna heading against the upper part of Jack River, where they appear to be numerous.

Several brown bears were seen on Yanert Fork and Nenana River by members of the Survey parties, but the evidences of bears were not plentiful in other parts of the region. Two wolverines were surprised one morning on the Middle Fork of Susitna River, an uncommon sight, for the wolverine usually manages to keep himself hidden in summer. Foxes were seen in different parts of the region, among them one black fox. The other fur-bearing animals that have been mentioned, except squirrels, which are numerous and widely distributed, are known from the skins in the possession of the white men and the natives.

Ptarmigan are abundant in all the Broad Pass region. They frequent the willow thickets in the upper parts of valleys and on hill slopes. Their peculiar cry was often heard during the summer, especially in the early morning. During the nesting season several broods of chicks were found almost every day.

Two kinds of fish, grayling and trout, abound in the clear waters of this region. Salmon does not ascend Susitna River above the falls a few miles east of Indian Creek—at least it is so reported by prospectors—and no salmon were seen in the upper Susitna by the Survey parties. It was not learned whether they ascend Chulitna River or whether there, too, they are prevented from doing so by some natural obstruction like the falls of the Susitna.

Most of the grayling caught during the summer were taken from deep, sluggish streams. They were large and very dark, almost black in color. The meat was white or pinkish and rather dry. Butte Creek, Deadman Creek, and Jack River are good grayling streams. Their waters are clear, for their sources are not glacial; fish avoid the milky glacier water.

Trout were taken from the clear-water streams but are most abundant and reach their greatest size in the deep lakes, such as Butte Lake, which has long been known by the Indians as good fishing water. A large trout from Butte Lake is reported to have weighed over 30 pounds. The tackle commonly used for these fish is a heavy hand line and a large hook baited with the tail of a grayling.

Population.—The Broad Pass region has no permanent settlements, either of white men or of Indians. About 25 whites were engaged in mining on Valdez Creek in 1913. These men stay on the creek for half the year and all but one or two go to the coast or out to the States in the fall. They, together with the prospectors of the Wood River district north of the Alaska Range, constitute the white population nearest the Broad Pass region.

The Indians who hunt on Jack River and Yanert Fork also have their cabins on Valdez Creek. Formerly they lived in the vicinity of Tyon River and the big bend of the Susitna, but within the last few years have moved to Valdez Creek and established themselves there in order to trade and obtain the white man's supplies more easily. Some of the miners on Valdez Creek take in extra supplies of groceries, tobacco, and ammunition for this purpose. Before the discovery of gold on Valdez Creek the Tyon River Indians were more independent and saw much less of white men than now. They made yearly trading expeditions to Cook Inlet and carried their contributions to the Russian Church or took their children to be christened by its priests. Practically all their supplies and clothing, except tea, sugar, ammunition, and a little cloth were obtained by hunting or fishing. The upper Susitna and the headwaters of Nenana River, together with the immediate vicinity of the Tyon Lakes and Tyon River, where the chief lived, belonged in their hunting grounds.

At present the natives stay in their cabins on Valdez Creek until early July and then leave for the hunting grounds to spend the summer and kill game for the winter. They start out with a small canvas for shelter and a few supplies like tea and sugar to supplement the diet of meat, fish, and berries that will constitute their chief food supply until they return.

Some of the younger men are employed by the miners on Valdez Creek for different kinds of work and are found to do fairly well except in the matter of attendance. It often happens that they are absent when most needed, even after they have promised faithfully to be on hand. Experience has taught the miners that Indians will not work contentedly unless they are given occasional opportunities to spend a day or two in hunting or fishing. Some of the younger men are inclined to gamble away their wages or to avoid work in the hunting season, feeling that inasmuch as most of the money they earn goes into the general family fund rather than into their own pockets, they receive no particular benefit from it. The older men are less disposed to work, a thing they have never been trained to do, but are more careful with the money they receive. They have been allowed to take what gold they can get by panning on certain of the Valdez Creek claims and obtain a considerable amount of the white man's supplies with the proceeds.

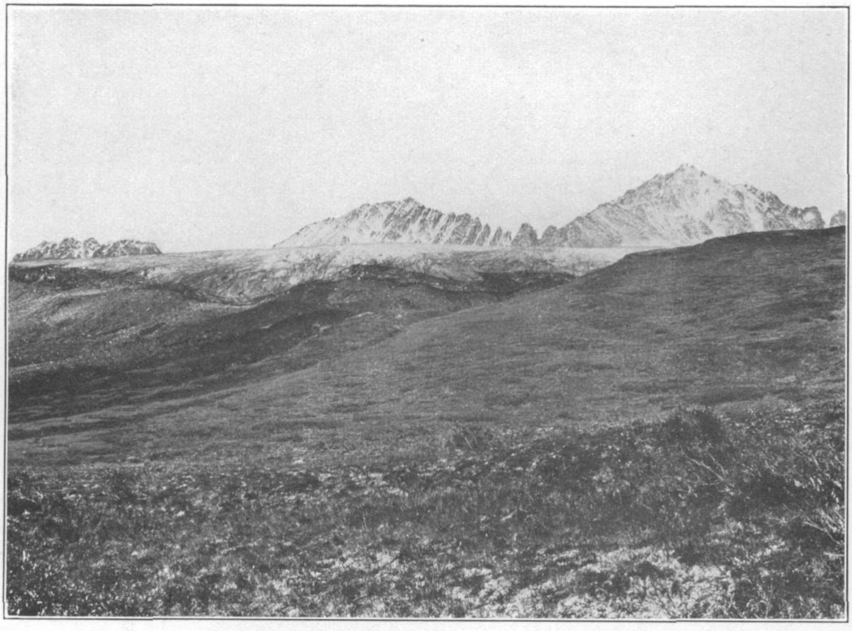
GENERAL GEOLOGY.

STRATIGRAPHY.

Geologic Map and Summary of Formations.

The distribution of geologic formations in the Broad Pass region is represented on the geologic map (Pl. II, in pocket) accompanying this report. Inasmuch as the field investigation was merely a reconnaissance, this map shows only the broad general features of formation distribution and lacks the detail that a longer period of work would have brought out. Yet it is believed that some of the forma-

A. TYPICAL EXPOSURE OF THE LIMESTONE AND ARGILLITE FORMATION (MESOZOIC?) SOUTHWEST OF NENANA GLACIER.



B. VIEW NORTHWARD ACROSS NENANA GLACIER.

Shows a lateral overflow of the glacier and vertical jointing of the granite mountains in the background.

tion boundaries are shown with almost as much accuracy as the scale of mapping permits. The earlier map by Brooks[1] has been used in extending the colors of the present map from the canyon a few miles below the Jack River on the Nenana to the mouth of Yanert Fork. This part of the region was not visited by the geologic party in 1913, although it was surveyed topographically by Mr. Bagley.

The geology of the Broad Pass region may be outlined as follows: The rocks consist chiefly of folded and more or less metamorphosed sediments intruded by large bodies of granular igneous rock and associated with extensive lava flows. The sediments include schist, slate, shale, sandstone, conglomerate, and limestone, all of which show metamorphism in some degree, expressed chiefly by schistosity and silicification, although parts of the oldest as well as of the youngest appear to be little altered. They range in age from Devonian to Eocene and possibly later Tertiary. All the consolidated sedimentary formations show folding and faulting, and some of the more recent show almost as much alteration as the oldest, so that metamorphism is not everywhere a safe guide in determining their relative ages.

The granitic rocks intruded into the sedimentary formations include granite, quartz monzonite, quartz diorite, and olivine gabbro. The granite is locally associated with coarse granite porphyry and with rhyolitic, trachytic, and andesitic lavas. Basaltic and andesitic lavas with tuffaceous beds having no evident connection with the granular intrusives are also present. The igneous rocks range in age from Jurassic or earlier to post-Eocene.

Much of the hard rock of the Broad Pass region is buried under unconsolidated deposits that include sand, gravel, morainal débris, and unsorted rock waste from many sources. This whole region has been profoundly glaciated and exhibits all the common evidences of glaciation in mountainous and piedmont areas. (See Pls. III, *B*, p. 8; IV, *A* and *B*, p. 12; and VIII, *B*.)

The stratigraphic positions of the sedimentary formations represented on the map are shown in the following table:

Geologic column of the Broad Pass region.

Quaternary:

1. Stream gravels, sands, silts, and unsorted rock waste.
2. Glacial gravels and morainal deposits.

Tertiary:

1. Shale, sandstone, and conglomerate, more or less indurated.
2. Cantwell formation, consisting of massive conglomerate, in part schistose, and finer-grained clastics, mostly sandstone, with intercalated beds of graywacke, argillite, carbonaceous shale, and slate carrying leaf impressions of Eocene age.

[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, pl. 9, 1911.

Undifferentiated Mesozoic (?):

Slates, argillites, graywacke, and thin-bedded limestone, differing widely in closeness of folding and degree of metamorphism; more or less silicified in part.

Jurassic (?):

Closely folded, dark-blue slate with beds of conglomerate, graywacke, and impure limestone, more or less altered; well exposed on upper Jack River and in the mountains south of Broad Pass.

Triassic (?):

1. Slate with intercalated beds of coarser sediments (graywacke, arkose, and similar rocks), closely folded and in part schistose (Upper Triassic?).
2. Basic lava flows with tuff beds.

Devonian:

Limestone, locally silicified and metamorphosed, with slate and mashed conglomerate (Middle or Upper Devonian).

Paleozoic Rocks.

DEVONIAN ROCKS.

CHARACTER AND DISTRIBUTION.

A belt of rocks consisting of limestone, slate, and a minor amount of altered conglomerate is exposed along Jack River in the lower hills and mountains that lie between the eastward-trending Nenana-Chulitna Valley and the main ridges of the Alaska Range. This belt is about 5 miles wide in this vicinity and lies parallel to the axis of the range, extending almost directly east and west. From Jack River it was traced eastward nearly to the Nenana Glacier and westward for 5 or 6 miles. Its continuation 10 miles or more farther west is inferred from the appearance and form of the mountains north of Broad Pass.

The limestone appears in large exposures, locally forming whole ridges, and is more or less metamorphosed in all places where it was examined, yet in some places is not altered enough to destroy or even to injure the fossils contained in it. The most thorough alteration observed is that by silicification, which in places has gone so far as almost to hide the identity of the rock. Recrystallization of the calcite into marble has not occurred extensively, if at all, not even near intrusive masses, where it might well be expected, although the metamorphism in such places is more pronounced than elsewhere.

Slates and conglomerate are associated with the limestone, the conglomerate being mashed and in places schistose, and these rocks have been closely folded and for the most part stand at high angles. The bedding planes are not recognized easily, but the general strike of the beds is indicated by the course of the limestone ridges and by that of the belt itself.

The Devonian rocks are intruded by granular igneous masses, which have probably caused the silicification of the limestone.

AGE AND CORRELATION.

The rocks that have just been described are classed together on account of their mutual structural relations and their positions with reference to adjacent formations. Fossils were found in a limestone bed on the east side of Jack River at the point where that stream turns westward after impinging on the end of a low ridge north of the old Nenana-Chulitna river valley. At this locality a vertical bed of limestone is included between walls of slate and in one place mashed conglomerate. The fossils collected were identified by Edwin Kirk, who pronounces them Devonian, to which period the limestone is therefore referred. Kirk's report follows:

Nos. F13 AP36; F13 AM1. Locality, right bank of Jack River, about 8 miles above mouth.

Cladopora sp.
Cyathophyllum sp.
Syringopora sp.
Diphyphyllum ? sp.
Martinia cf. maia (Billings).
Reticularia ? sp.
Loxonema sp.
Naticopsis sp.
Pleurotomaria sp.
Euomphalus sp.
Tentaculites sp.
Orthoceras sp.
Modiomorpha sp.
Leperditia sp.
Proetus (same as that referred by Kindle to *haldemani* Hall).

Owing to the rather poor preservation of most of the specimens and to the fact that in large part the fossils represented are undescribed, it is not possible to give specific determinations. The material renders possible, however, a fairly accurate age determination, and a rough correlation with other deposits in Alaska may be made.

This collection probably represents the same general stratigraphic horizon as that described by Brooks[1] in his report on the Mount McKinley region. Similar faunas have also been collected on the south side of Freshwater Bay, Long Island, and on Porcupine River. Identical species occur in this collection and in the collections made by Kindle[2] in the Salmon Trout limestone on the Porcupine. It is interesting to note that an apparently identical fauna has been found on the southern shore of Great Slave Lake. I have examined a small collection from this locality and it contains identical species.

The general stratigraphic horizon of the material is probably upper Middle Devonian, or else lower Upper Devonian.

Fossils were not found in any of the other rocks mapped as Devonian, and future work may possibly show that some of these beds belong to other systems than the Devonian. Possibly, too, some of the rocks in groups referred to later systems may be Devonian, but it is not believed that any great error of this kind has been made. Rocks of nearly the same character and age are found in the Alaska

[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 78, 1911.

[2] Brooks, A. H., and Kindle, E. M., Geol. Soc. America Bull., vol. 19, pp. 277–291, 1908.

Range southwest of Broad Pass, notably near the head of Kuskokwim River.[1] Such rocks have also been mapped between Yukon and Tanana rivers.[2] Devonian rocks have not been observed in the Alaska Range east of Susitna River, but they have been found[3] in the Nutzotin Mountains.

Mesozoic Rocks.

Two kinds of rocks in the Broad Pass region are tentatively referred to the Triassic. They are the basaltic lava flows in the southeastern part of the region and the slates that adjoin the lava flows on the north. Neither of these formations is known definitely to be of Triassic age; no fossils have been collected from them, and their provisional assignment to the Triassic is based on seeming structural relations and other considerations.

TRIASSIC (?) LAVAS.

CHARACTER AND DISTRIBUTION.

The lavas that are here tentatively assigned to the Triassic form the ridge of mountains south of Butte Creek in the southeast part of the mapped area. These mountains form the western end of a minor range of mountains that flanks the Alaska Range between Susitna River and the vicinity of Gulkana Lake. This range is made up principally of basaltic lava flows, with which are associated andesitic flows and beds of water-laid tuffaceous material.

The lava flows south of Butte Creek were examined carefully at only one locality, south of Wickersham Creek, so that it is not possible to say with certainty that they correspond in all respects to the similar rocks east of Susitna River, but no reason is known for assuming that they do not. At the locality near the mouth of Butte Creek the mountains are composed of thick flows of basalt that has andesitic phases and that is in part amygdaloidal. Specimens from the outcrops of the rock are dark greenish, have a medium to fine-grained texture, and contain feldspar, pyroxene, and more or less olivine. Joint planes and slickensided surfaces are abundantly developed in the lavas. Loose blocks on the talus slopes show coarser phases of the rock than were seen in the outcrops. Some of this material has the appearance of gabbro, and some is amygdaloidal, the amygdules having maximum diameters of 1 inch and consisting of olivine, surrounded in places with a zone of zeolitic material. Serpentine is a common alteration product in the basalts, and

[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, pl. 9, 1911. Maddren, A. G., U. S. Geol. Survey Bull, 410, pp. 50–51, 1910.

[2] Brooks, A. H., op. cit. Brooks, A. H., and Kindle, E. M., op. cit.

[3] Capps, S. R., Mineral resources of the Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 622, pp. 189–228, 1915.

at many places appears as small veins. Fine-grained tuffs and tuffaceous conglomerates were not seen at this place. They are well developed south of the Roosevelt Lakes and at other places east of Susitna River studied by the writer in 1910.[1] By careful search tuffaceous beds may be found in the mountains south of Butte Creek.

The stratigraphic position of the basaltic lavas with reference to the slates north of Butte Creek has not been clearly determined, and the geologic conditions in this locality are unfavorable to exact determination, for the lavas and slates are separated by the wide valley of Butte Creek, and the contact of the formations is hidden under gravel deposits. If the slates north of Butte Creek can properly be correlated with the Triassic (?) slates and limestones south of the Roosevelt Lakes, the basalts may underlie these slates, for the best evidence indicates that they underlie the slates in the Roosevelt Lakes district.[2] On the other hand, the lava beds south of Butte Creek have a gentle southeasterly dip at the locality visited, which does not appear to corroborate the evidence found in the Roosevelt Lakes district, and suggests either a fault between the lavas and slates or a reversal of dip of the lava flows in the part of the Butte Creek valley floor that is buried under the gravel deposits. The inclination of the lava beds, however, furnishes a suggestion as to the thickness of the flows exposed in this locality. A calculation based on the assumption that the gentle dip remains fairly constant in the northern part of the mountains south of Butte Creek and on the known elevation of the highest mountains gives a thickness of 3,500 feet for the flows in this locality.

As has been stated, the lava flows at a number of places east of Susitna River are associated with argillites, tuffs, and tuffaceous conglomerates, indicating that repeated outpourings of lava were separated by intervals of time in which water-worn material as well as angular material produced during volcanic outbursts was deposited. Possibly some of the lavas may have been poured out and cooled under water, but of this no direct evidence was obtained.

AGE AND CORRELATION.

The age of the basaltic lavas has been determined from evidence afforded by other regions and is not certainly known. Near the mouth of Eureka Creek, a tributary of Delta River, the lavas seem to overlie Carboniferous sediments.[2] In the district between Clearwater Creek and the Roosevelt Lakes the lavas seem to overlie sediments of probable Upper Triassic age. In both these places the uncertainties arise not from the present positions of the rocks, but

[1] Moffit, F. H., Headwater regions of Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, p. 29, 1913.

[2] Idem, p. 30.

from difficulties of interpretation caused by folding and faulting. The evidence cited indicates that the basaltic lavas of the Gulkana-Valdez Creek region were extruded either in late Carboniferous or early Mesozoic time, before the Upper Triassic sediments were deposited.

In the region south of that under discussion most of the northern half of the Talkeetna Mountains is made up of rocks, largely volcanic, which are described by Paige and Knopf[1] as consisting of andesitic greenstones, dacites, rhyolites, and associated tuffs. Brooks[2] correlates these rocks with the Skwentna group of Spurr. Their Lower Jurassic age is indicated by fossils[3] collected from similar tuffs in the Matanuska Valley. Lithologically the lava flows south of Butte Creek resemble the flows to the east more than those of the northern Talkeetna Mountains, but the nearness of these mountains and the fact that Lower Jurassic time is known to have been characterized by volcanic activity in this part of Alaska make it necessary to consider the evidence carefully. The basalts of Butte Creek bear a close resemblance to the Nikolai greenstone of Chitina Valley and to greenstones exposed in some other parts of the Wrangell Mountains. The Nikolai greenstone is a great series of basaltic lava flows, at least 4,000 feet thick in the Nizina district. Its upper age limit is determined by the Chitistone limestone, which overlies the greenstone and was deposited in Upper Triassic time.[4] The lower age limit is unknown, but evidence has been presented tending to show that it can not be below the uppermost part of the Pennsylvanian, in which case the Nikolai greenstone is of late Carboniferous or Triassic age. Some reasons appear, therefore, for correlating the Nikolai greenstone and the basaltic flows of the Gulkana-Valdez Creek, region, but no evidence has been found in either region which would warrant a definite assignment of the lavas to either the Carboniferous or Triassic period. In discussing the geologic column of the upper Susitna-Gulkana district the lava flows were described as of Carboniferous or later age,[5] but the uncertainty concerning the relative stratigraphic positions of the lava flows and slates on Butte Creek makes it advisable here to include the lavas among the Mesozoic formations rather than to assign them to the Carboniferous.

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[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, p. 16, 1907.

[2] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 85, 1911.

[3] Martin, G. C., and Katz, F. J., Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500, pp. 29-32, 1912.

[4] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, p. 27, 1909. Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, p. 23, 1911.

[5] Moffit, F. H., Headwater regions of Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, p. 22, 1913.

TRIASSIC (?) SEDIMENTS.

CHARACTER AND DISTRIBUTION.

The sedimentary rocks tentatively assigned to the Triassic consist prevailingly of dark-blue and black slates, but include interstratified beds of arkose and graywacke. Although no section of these rocks was measured, their thickness is probably considerable, possibly amounting to several thousand feet. They are closely folded and show different degrees of metamorphism. Locally the argillite and arkose have been changed to phyllite and schist. Dikes of granitic and andesitic rock cut the beds and large masses of granite and diorite invade them. The Triassic (?) sediments form a belt 5 or 6 miles wide, separated from the lava flows on the south by the valleys of Butte Creek and the eastern fork of Watana Creek. They are regarded as a westward extension of the Triassic slate exposed in the Valdez Creek district.[1]

Dark-blue or black slate is the predominating rock of this group. Most of it has well-developed slaty cleavage, and splits with a smooth plane surface. There is some variation in the perfection of cleavage, however, for in places the rock shows little tendency to split and in others it splits with a more or less uneven crinkly surface. With increase in size of the constituent particles the slate grades into arkose or graywacke. Such gradations are most noticeable where the strike of the beds is crossed, yet if individual beds are traced along the strike for a considerable distance the change in coarseness or fineness of grain would probably be seen to take place in that direction also.

The coarser sediments are distributed through the slate in comparatively thin beds. They are finely granular and dark gray. Most of them are made up of small fragments of quartz, feldspar, and dark minerals of several kinds, but in places the dark minerals are lacking or are present only in small amount, so that this phase of the rock should be called arkose rather than graywacke. Locally the graywacke beds have become schistose. A specimen of schistose graywacke collected near Butte Creek was found under the microscope to contain grains and granulated areas of quartz interlaced with sericite. Associated with the quartz and sericite are subangular fragments of feldspar, both orthoclase and plagioclase, and a few shreds of biotite and altered hornblende. The quartz shows undulatory extinction.

It is not yet possible to determine even approximately the thickness of this group of beds of slate and graywacke, for pressure has

[1] Moffit, F. H., Headwater regions of Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, pl. 2, 1912.

thrown them into close folds and faulting has still further complicated their structure. The observer crossing their strike probably meets the same bed several times, yet beds of this group doubtless measure hundreds or, more likely, thousands of feet.

The pressure that folded these beds gave rise to other metamorphic changes, which, however, are not constant throughout the formation, as may be seen in the lack of cleavage in some of the rocks and the schistose nature of others. The folding of the beds was accompanied also by more or less faulting, but how important a part faulting plays in the structure of the beds and their relation to other formations is not known.

Quartz veins were developed locally in the slates and graywackes. They show little or no mineralization, but may contain a small amount of gold, for the stream gravels within the slate area commonly yield a little placer gold when panned.

A wide variation in the strike of the beds was noticed. The compass readings range from N. 20° E. to N. 80° E., but in general are about N. 70° E., which is the trend of the belt itself. There is some difference, however, between the prevailing strike of the beds in the eastern and western parts of the mapped area, for in the western end of the belt the strikes become a little more southerly. The prevailing dip of the bedding is northwestward and is steep, about 80°. The observations suggest a series of close folds, slightly overturned to the southeast and having the same general trend as the Alaska Range in this region.

The exposed Triassic (?) sediments are separated from the lava flows on the south by a wide gravel-floored valley and are bounded on the north either by intruded granitic rocks or by gravel deposits, so that no contact between them and older or younger sedimentary formations was seen. Some evidence has been advanced to show that the Triassic sediments of Coal Creek and Clearwater Creek in the Valdez Creek district rest unconformably, either by deposition or because of faulting, on the lava flows.[1] If the unconformity in that district is one of deposition, then the conditions are different from those in the Chitina Valley, where in many places Triassic sediments of the same age as those of Coal Creek rest conformably on the underlying lava flows and give no apparent evidence of an erosion interval between the two formations. The known facts clearly do not warrant a definite statement regarding the relation of the Triassic sediments to the older formations. If the belt of lava flows crossing the Valdez Creek and Broad Pass regions proves to be of Carboniferous age, the Triassic (?) sediments probably lie on them unconformably. On the other hand, if the lavas are of Triassic

[1] Moffit, F. H., Headwater regions of Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, pp. 30, 31, 1912.

age, then a similar relation of sediments to lava flows as that in the Chitina Valley may be found.

The slate and graywacke of this group has been intruded by dikes of granite and, less commonly, of andesitic rock. Small pegmatite dikes were seen in mashed and partly silicified slates at one place near the monzonite intrusion north of Wachana Creek (Pl. II, in pocket). The slate here is extensively mineralized with pyrite and probably carries a little gold. A mile to the southeast, at the border of the monzonite mass, the metamorphosed slates contain dikelike intrusions of fine-grained biotite-hornblende granite, dioritic phases of the same rock, and rhyolite porphyry. A large dike of diorite crosses Wickersham Creek about 3 miles from the mouth, and as it is more resistant than the inclosing slates, it has formed a waterfall. These dike rocks and the large intrusive masses of granite and monzonite, with which they are probably closely connected, will be discussed in the section on igneous rocks.

AGE AND CORRELATION.

The slate and graywacke formation immediately north of Butte Creek is the westward continuation of a formation well exposed east of Susitna River in the mountains south of Valdez and Roosevelt creeks, about the head of Clearwater Creek, and on the head of West Fork of Maclaren River. Fossils collected from limestones and shales in the lower part of this formation show that the beds were laid down in Upper Triassic time and are equivalent in age to the Chitistone limestone and McCarthy shale of the Chitina Valley[1] and to the Triassic limestone of the Nabesna River region.

The Upper Triassic sedimentary deposits of the Chitina Valley, the Chitistone limestone and McCarthy shale, have a thickness of at least 5,500 feet in the Nizina district. The McCarthy formation, which overlies the limestone, has a thickness of not less than 2,500 feet and is composed almost entirely of shale or, more accurately, of slate, except a comparatively small part at the base, which is made up of thin alternating beds of limestone and shale. The known Triassic rocks of the Nabesna district are limestone, but the limestone is associated with a great thickness of Mesozoic slate, graywacke, and conglomerate that is in large part of Upper Jurassic age, but may perhaps include Triassic deposits also. Triassic deposits are not known in the Talkeetna Mountains, but Upper Triassic sediments are well developed on Kenai Peninsula and in the Alaska Peninsula.[2]

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[1] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, pp. 21, 28, 1911. Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, p. 27, 1910.

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

JURASSIC (?) ROCKS.

CHARACTER AND DISTRIBUTION.

The rocks tentatively referred to the Jurassic are typically exposed in the mountains south of Broad Pass and west of Jack River. These mountains are made up of closely folded dark-blue and black slates interbedded with graywacke and conglomerate. Impure limestone, more or less altered, is interstratified with the slate and graywacke east of Jack River, but was not seen at Broad Pass. The thickness of the beds is unknown, but is probably several thousand feet. The relation of the group to older formations, too, has not been determined, yet is believed to be that of unconformity. In addition to being folded, faulted, and more or less metamorphosed these sedimentary deposits are intruded by large masses of granular igneous rock of granitic and monzonitic character, with which are associated rhyolitic lavas and coarse granite porphyry.

Slate is the predominating rock throughout the group within the region mapped. The conglomerate, graywacke, and limestone, however, are not equally developed in all parts of the area assigned to the Jurassic. Limestone is more common in the eastern part and graywacke and conglomerate in the western part, there being apparently a progressive increase in the coarseness of the sediments from the east toward the west in this area.

The slate for the most part is dark blue, but in places is black or dark gray. Locally it is carbonaceous. It shows different degrees of metamorphism, ranging from almost unaltered argillite to phyllite or schist. Much of it has a well-developed slaty cleavage, which is prevailingly parallel to the bedding but crosses it in places, probably in the bends of the folds. A much smaller proportion of the rocks called slate might possibly be described more accurately as schist. By an increase in size of the constituent particles the slate grades into graywacke.

The conglomerate occurs in beds of relatively hard, dense rock, made up of well-rounded water-worn fragments of silicified slate, quartz, chalcedony, and altered lava, set in a groundmass of similar material cemented with quartz. It is dark gray and in places has undergone considerable metamorphism, the pebbles being stretched and the whole rock assuming some of the characteristics of schist. The pebbles are commonly small, ranging from one-fourth inch to 1 inch in diameter in most beds, yet reaching a diameter of 2 inches in others. On account of its denseness, hardness, and the large amount of quartz which it contains the conglomerate does not weather readily but breaks into angular blocks and fragments that resist chemical alteration yet are readily attacked by temperature changes and ice. Jointing plays a prominent part in the breaking down of the conglomerate beds.

The conglomerate, like the slate, grades into graywacke, all three types probably having derived their constituents from the same source in some near-by land mass. Few of the conglomerate beds, so far as observed, exceed 20 feet in thickness.

The graywacke is light gray to dark gray, and is made up of fine angular or subangular grains of quartz, feldspar, and dark-colored rock fragments. A hand specimen of it shows a rough surface and suggests a very coarse slate but differs from slate in its poorer cleavage and in the size of the constituent particles, which are readily distinguished by the eye alone. Isolated fragments of slate from an inch to several inches in length are sometimes seen on joint planes that cross the bedding of the graywacke. They attract notice through the contrast of their dark color and large size as compared with the particles of the fine-grained groundmass in which they lie. Locally the graywacke, like the slate and conglomerate, becomes somewhat schistose. The microscope shows that quartz fragments predominate over feldspar among the constituents and that sericite and chlorite are present. Feldspar of both the orthoclase and plagioclase varieties is also present. Among the rock types represented by fragments sufficiently large to be identified are slate, which is the most abundant, quartzite, and two or more kinds of igneous rock. Those beds of graywacke that became schistose lost much of their granularity and show the development of micaceous minerals such as sericite and chlorite. Undulatory extinction and shattering of the quartz grains are evidences of the pressure to which the rock has been subjected. The schistose phases of the graywacke, nevertheless, can usually be recognized as being derived from rocks like the more massive, less altered phases. The graywacke beds exhibit great variability in thickness, ranging from a few inches to a thousand feet or more. Study of the graywacke makes it evident that this rock differs from the slate and conglomerate with which it is interbedded chiefly in the size of the particles that compose it and that it represents the accumulation of fine undecomposed waste derived from a land mass not far distant, where the processes of degradation were proceeding rapidly.

Limestone forms thin beds interstratified with the slate and is least common in those parts of the group where graywacke and conglomerate are most abundant. It was not seen west of Jack River but may be present. The rock is impure and is dark gray or black, so that at a little distance it is not distinguishable from the slate. In the vicinity of intrusive rocks it has been silicified and impregnated with pyrite.

The thickness of this group of sedimentary beds is not known. It is evidently great, whatever interpretation may be placed on the structure of the group, and must be thousands of feet. The folding of the strata and the difficulty of determining reference beds made it impossible in the time available either to form a definite idea of the thickness of the beds or to make certain of their larger structure, including their relation to the older underlying formations. They probably lie in a succession of close folds, slightly overturned, so that the axial planes dip southward. The strike of the beds ranges from N. 50° E. to N. 70° E. and is approximately parallel to the axis of the Alaska range in this region. As has been pointed out the forces that gave rise to folding also produced a cleavage in the finer grained clastics that is more or less well developed in accordance with the character of the rock affected and with other conditions. Metamorphism, of which slaty cleavage is only one manifestation, although perhaps the most noticeable, is slight in some places, but proceeded so far in others that new minerals and new textures such as are seen in the schistose varieties of the slate, graywacke, and conglomerate, were introduced. Not much faulting was observed. This seeming rarity of faulting is probably not real and is due to the character of the rocks and the difficulty of recognizing faults rather than to their absence.

Stringers and veinlets of quartz cut the beds but so far as observation showed are not accompanied by notable mineralization.

The base of this group of slate, graywacke, and conglomerate was not observed and its stratigraphic position with reference to underlying formations was not determined. It seems probable, however, that if the group is correctly referred to the Jurassic its relation to the near-by Devonian formations is one of depositional unconformity, for rocks of the intervening periods are not recognized in this vicinity although they are known in the region.

Granitic intrusive masses of large size lie adjacent to the group of slate, graywacke, and conglomerate along the southern border. In addition, the sedimentary beds of this group are intruded by dikes of rhyolite porphyry. These dikes, however, are not common, and seemingly are offshoots of the larger intrusive masses. No basic dikes were found.

Between the head of Seattle Creek and Jack River the slates and graywackes lie adjacent to an area of acid lavas which also are believed to be directly related to the large intrusive masses of granite. The igneous rocks are considered more fully on pages 54–65.

The group of sedimentary formations just described is well exposed southeast of Broad Pass in the vicinity of Jack River. According to Eldridge[1] it extends southwestward from Jack River to

[1] Eldridge, G. H., A reconnaissance in the Sushitna basin and adjacent territory, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 15 and map No. 3, 1900.

Indian Creek and continues thence down Susitna River to a point about 15 miles above the mouth of Chulitna River. He gave it the name "Sushitna slates" and describes the beds as quartzitic and varying in coarseness from fine-grained to granular. He found the rocks extensively sheared, the shearing being accompanied by the production of a partial schistose or slaty structure, and noted that locally there had been a marked crumpling of the strata and a formation of numerous quartz veins, many of which contained pyrite. From this description limestone evidently forms little if any part in the group where Eldridge studied it.

These beds extend northeastward from Jack River, forming the front of the mountains south of the old Nenana Valley for about 10 miles, but giving way to gravels and igneous rocks a few miles west of the mouth of Wells Creek. Their continuation east of Wells Creek and north of Nenana River is in doubt, although the mountains southeast of Nenana Glacier, mapped as undifferentiated Mesozoic (?) (Pl. II, in pocket), may include some of this group. The mountains of this vicinity consist of slate and limestone, commonly occurring as thin beds interstratified with slate and forming a much larger proportion of the whole than the similar beds in the mountains east of Jack River and south of the Nenana.

The group of Jurassic (?) sedimentary beds that has been described indicates sedimentation under conditions that were unstable and changing with comparative rapidity, as is shown by the kinds of material laid down, the thinness of the beds, and the change, many times repeated, from conglomerate to graywacke, from graywacke to slate, from slate to limestone, or the reverse. The beds probably accumulated in comparatively shallow water near the shore of a land mass, where streams brought in a variety of material that underwent change in the manner of its deposition and in part at least accumulated as delta and flood-plain deposits.

AGE AND CORRELATION.

The sedimentary formations just described are referred tentatively and without the evidence of fossils to the Jurassic, as it is believed that they are to be correlated with rocks of known approximate age in near-by districts.

Previous work by Eldridge, Brooks, and Capps in the Susitna basin has shown that a belt of folded and more or less metamorphosed sediments extends along the flank of the Alaska Range from Skwentna River to Jack River. This belt may contain rocks of two or more periods, but it consists essentially of slate and graywacke in variable proportions with which are associated quartzite, sandstone, and limestone in minor amounts.

On the lower part of Kahiltna River, between Skwentna and Yentna rivers, Brooks found a belt of rocks "composed chiefly of black carbonaceous slate and phyllite, with some heavier beds of fine graywacke and grit."[1] In this belt the foliated rocks are much more abundant than the massive ones. Brooks refers all these rocks to the Paleozoic, but says that "it is by no means impossible that they may be Mesozoic."

Northwest of this belt is another belt of similar rocks, about 30 miles wide, the Tordrillo formation, which "consists of a series of closely folded and faulted grits, sandstone, and fine conglomerate, together with argillite and a few layers of limestone."[2] Massive grits and sandstone predominate in the lower part of the formation; argillite with subordinate sandstone members and a few limestone layers makes up the upper part. Middle Jurassic fossils were collected from beds of the Tordrillo formation. On the west the Tordrillo formation gives rather definite evidence of resting unconformably on the slates and phyllites of the Tonzona group (Devonian or Silurian). The Tordrillo formation also overlies the Paleozoic (?) sediments to the southeast and thus forms a broad synclinorium of closely folded Middle Jurassic sediments. Large masses of granite and granodiorite and numerous dikes and sills of monzonite and rocks of kindred type are intruded into the Tordrillo formation.

Capps found a series of slates and graywackes extending northeastward from Yentna River to the Chulitna.[3] He regards these beds as the northeastward continuation of Brooks's "undifferentiated Paleozoic" sediments of the Kichatna, and describes them thus:

> They consist chiefly of black to gray slates and phyllites, in many places carbonaceous, and beds of graywacke, which range from fine-grained to coarse gritty rocks. In some places the rocks are massive, with argillites instead of slates, but the foliated types are much more widespread than the massive types. It is difficult to estimate just what proportion of the whole series is formed by the graywacke beds. Many sections show great thicknesses of the slaty phases, with very little graywacke present. At other localities the graywackes preponderate, occurring in thick massive beds that show little foliation or schistosity and that are often mistaken by the miners for fine-grained dike rocks, which they closely resemble.

Capps traced these beds to Tokichitna River, within 10 miles of the slate-graywacke area east of Susitna River described by Eldridge, and believed that a correlation of the rocks of the two areas was justified.

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[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 67, 1911.

[2] Idem, p. 87.

[3] Capps, S. R., The Yentna district, Alaska: U. S. Geol. Survey Bull. 534, pp. 24, 25, 1913.

Eldridge traced the Susitna slate from a point opposite the mouth of Tokichitna River to Jack River, and says of it:[1]

The beds are essentially quartzitic, varying in coarseness of material from an extremely fine homogeneous rock to one of granular structure. In addition to quartz there are occasional orthoclase, plagioclase, biotite, muscovite, scattered grains of iron oxide, and minute fragments of slate—apparently of the same nature as the fine-grained slates of the series itself.

It is evident from this description and from his field notes that Eldridge included graywacke ("pyroclastic diorite," as he called it) under the term slate. The field notes also state that he saw no difference between the rocks in the vicinity of Indian Creek and Jack River except for some intrusive rocks near the head of Jack River.

A comparison of the formations in the districts described by Eldridge, Brooks, and Capps, and more particularly a study of the geologic maps made by them, appears to confirm Capp's correlation of his slate-graywacke series with the rocks of the lower Kichatna River and with Eldridge's Susitna slate. If this correlation is made it is necessary either to consider the slate, graywacke, and conglomerate formations of Jack River as Paleozoic or to present evidence in favor of the possibility suggested by Brooks, that the rocks of lower Kichatna River are Mesozoic rather than Paleozoic; and if they are Mesozoic, it is possible that they may be correlated with the upper or Tordrillo formation, and that the older Mesozoic (Triassic?) rocks of the Broad Pass region may be equivalent to the slate formations of lower Kichatna River.

The formations that make up the mountains south of Broad Pass are separated from the Devonian limestone on the north by a broad valley floored with gravel deposits and showing the underlying bedrock in few places only. One such place is on Jack River, where shale, sandstone and conglomerate referred to the Tertiary are exposed. The slate, graywacke, and conglomerate beds of these mountains differ from the Devonian rocks lithologically, in the intensity of their folding, and in the degree of metamorphism that they exhibit. They show less alteration than the Devonian formations, and except in the somewhat greater proportion of conglomerate that they contain resemble closely the slate-graywacke series of Capps and the Tordrillo formation described by Brooks. Lithologically the "undifferentiated Paleozoic" rocks underlying the Tordrillo formation appear to resemble the rocks of the Broad Pass region tentatively assigned to the Triassic, for they show a greater development

[1] Eldridge, G. H., A reconnaissance in the Susitna basin and adjacent territory, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 15, 1900.

of slate and less of the coarser sediments, such as graywacke and conglomerate.

Mesozoic rocks are widespread in Alaska south of the Alaska Range. Within the Susitna basin the Talkeetna Mountains are made up almost wholly of Mesozoic sediments intruded by igneous rocks, the only known exceptions being a small area of schist on Willow Creek, which Capps[1] assigns to the Paleozoic, and a somewhat similar area at the head of Matanuska River. Each year evidence accumulates to show that much of the Valdez and Orca groups, constituting a large part of the Chugach Mountains, are of Mesozoic and probably of Jurassic age. Triassic sediments are present in Chitina Valley, in the upper parts of Copper and Susitna River valleys along the south flanks of the Alaska Range, and in Kenai Peninsula. All the older associated formations whose ages have been determined are Carboniferous, yet some of the schists are believed to be older than Carboniferous. The Carboniferous and older rocks make up a comparatively small part of the whole complex of formations.

There is, then, a great area of Mesozoic sedimentary deposits south of the Alaska Range in south central Alaska, made up chiefly of slate, graywacke, conglomerate, and limestone, that as a whole are less metamorphosed than the older formations. The formations south of Broad Pass are of the same lithologic nature, and although there is no conclusive evidence at hand by which they can be definitely correlated with other formations of the region, the probabilities seem to be that they are more recent than Paleozoic, and that if they are the equivalent of either the Tordrillo or the underlying formations the correlation with the Tordrillo is more likely. This is the most important reason for assigning them to a particular part of the Mesozoic.

A great thickness of Mesozoic beds of similar character and in large part of Jurassic age is exposed in the Nutzotin Mountains, which form the eastern part of the Alaska Range.[2] Slate, graywacke, and conglomerate constitute the Jurassic part of this group, so far as is known. Triassic limestone and slate were seen at only a few localities, but probably are more widely distributed than the evidence at hand shows. The close lithologic resemblance and the evidence of fossils, so far as it goes, suggests the correlation of the formations of the Nutzotin Mountains with those of the Valdez Creek and Broad Pass regions.

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[1] Capps, S. R., The Willow Creek district, Alaska: U. S. Geol. Survey Bull. 607, p. 23, 1915.

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

UNDIFFERENTIATED MESOZOIC (?) ROCKS.

CHARACTER AND DISTRIBUTION.

The mountains south of the east fork of Wells Creek and about the lower half of the glacier in which West Fork of Susitna River rises are composed in large part of sedimentary rocks, chiefly slate and limestone. These rocks form a complex of beds that could not be differentiated in the time available and that differ considerably in aspect and in proportionate amount of different rock types from any of the formations already described, the difference being principally a much greater proportion of limestone, thin bedded and locally highly metamorphosed, interstratified with the slate. They lie in the strike of the Jurassic (?) sedimentary formations of Jack River, but because of their different lithologic character and their somewhat different structure it seems best to consider them separately, especially since it is thought possible, if not probable, that they may include Mesozoic rocks older or younger than Jurassic. These formations differ not only from other sedimentary formations of the region but also among themselves.

The northern half of the mountain mass between upper Nenana River and the east fork of Wells Creek is made up chiefly of alternating limestone and argillite beds, having gentle dip and showing distinct bedding. These sedimentary deposits were intruded by igneous rocks, but seemingly have not been greatly disturbed by them. Near the head of Wells Creek, where these sediments were examined with more care than at any other place, they comprise thin-bedded light-blue or light-gray white-weathering limestone, in part silicified and otherwise altered, interstratified with thin beds of dense, siliceous dark-blue argillite, much jointed and presenting a more or less iron-stained exterior. The contrasting colors of the rocks give their large exposures a variegated appearance, and in connection with the irregularities of erosion surfaces produce a complicated marking on bare mountain sides that immediately catches the eye. (See Pl. VIII, *A*, p. 22.) The limestone is cut by numerous seams of calcite, some of which is coarsely crystalline. A little pyrite is scattered through the argillite. Dikes and lens-shaped sills of rhyolite porphyry and medium to fine grained diorite are associated with the limestone and argillite. The bedding strikes about N. 80° E. and dips southeastward at angles ranging from 20° to 40°. It is estimated that the thickness of the exposed beds is at least 1,500 feet. These beds are probably part of a gentle fold, but are cut off from other terranes by igneous rocks and gravel deposits, so that they are not known to be a part of any neighboring formation on the north or on the south. Moreover, their open folding is discordant with the close folding of the other sedimentary formations near by.

A series of variegated, gently dipping sedimentary beds, composed chiefly of white silicified limestone, interstratified with thin beds of dark impure limestone and of dark-colored argillite, is exposed between the glacier of the two western branches of Susitna River. This series contains a greater amount of limestone, some of it in thick massive beds, than that south of Wells Creek, and the correlation of the two may be made only with a certain degree of reservation. These rocks are separated from the rocks on the south or southwest, to be described next, by a great fault.

The mountains between Nenana River and the glacier at the head of West Fork of Susitna River consist chiefly of closely folded slate, schist, and altered limestone. The limestone is thinly bedded, bluish-gray, and is locally silicified. Where it was impure pressure and chemical alteration brought about the formation of new minerals, such as mica, and gave the rock the appearance of schist. Black carbonaceous shale or slate and gray sericitic schist, composed of mashed graywacke, are associated with the limestone, and in fact make up most of these mountains. These beds have about the same strike as those south of Wells Creek, but, as already stated, are more closely folded and are more altered. Except for their greater proportion of limestone, they resemble part of the slate and graywacke series of Jack River.

AGE AND CORRELATION.

The age of these sediments is unknown. It is perhaps possible but does not appear probable that they correspond in part with some of the Devonian formations. On the other hand, it seems much more likely that they are of Mesozoic age, and are to be correlated either with the Triassic slates and limestones of the Valdez Creek district or with the Jurassic (?) sediments of Jack River. They may even include beds belonging to both of these groups.

Cenozoic Rocks.

TERTIARY SEDIMENTS.

CANTWELL FORMATION.

CHARACTER AND DISTRIBUTION.

The Tertiary sedimentary deposits of the Broad Pass region include the Cantwell formation and a small area of beds that somewhat resemble the rocks of the Cantwell formation but are not identical with them. The Cantwell formation consists of conglomerate beds, slate, shale, sandstone, quartzite, grit, graywacke, and highly metamorphosed equivalents of all these rocks.

In the vicinity of Nenana River, near the mouth of Jack River, the Cantwell formation shows open folding (see Pl. III, *B*, p. 8), but this folding becomes closer toward the east and is accompanied by a progressive increase in the degree of metamorphism, so that the little-altered rocks in the western part of the mapped area are represented in the mountains between the heads of Nenana River and Yanert Fork by mashed conglomerate and schist. The thickness of beds included in the formation can not be less than 2,700 feet and may be much more. These beds probably rest unconformably on the Devonian schist and limestone that limit them on the south.

The name Cantwell was proposed by Eldridge to designate a "series of conglomerates and coarse sandstones which was encountered in the banks of the Cantwell [Nenana] River, about 10 or 15 miles above the forks."[1] This name was adopted by Brooks, who studied the formation on the north side of the Alaska Range and traced it eastward from Muldrow Glacier to Yanert Fork.[2] It is applied here to the eastward extension of the beds included in the formation by Eldridge and Brooks.

The changing character of the Cantwell formation can be best shown by describing the beds observed at different localities between the mouth of Jack River and West Fork of Susitna River. A comparison of these localities brings out a number of features, some of which have just been mentioned and the most prominent of which are a progressive increase in closeness of folding and in degree of metamorphism and a decrease in the amount of conglomerate, with a corresponding increase in the relative amount of fine-grained sediments, from west to east. These descriptions apply to the southern border of the formation, for the character of the beds in the central and northern parts of the area occupied by the Cantwell is unknown except where it was studied by Brooks.

Just below the mouth of Jack River the Nenana in its northward course enters a narrow valley between black, rugged mountains whose upper parts are made up chiefly of massive conglomerate beds (Pl. VII, *B*, p. 18) that dip gently northward and rest on a narrow belt of granite which separates the conglomerate from the Devonian limestone and schist on the south. Inconspicuous beds of finer-grained rock (shale and grit), which in many places are hidden by a talus of conglomerate blocks, are interbedded with the conglomerate. These beds, when viewed from the vicinity of the mouth of Jack River, are seen to maintain their low northerly dip for several miles down the Nenana. The conglomerate is composed of well-rounded gravel and cobbles of quartz, quartzite, slate, and an acidic igneous rock set in a siliceous cement. Cobbles as much as 7 inches

[1] Eldridge, G. H., A reconnaissance in the Sushitna basin and adjacent territory, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 16, 1900.

[2] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 78, 1911.

in diameter were observed. Intercalated with the conglomerate are thinner beds of sandstone, quartzite, and dark-blue carbonaceous argillite. A contact of the Cantwell formation and the underlying granite showed the two rocks to be united as if fused together. The lowest part of the sedimentary formation in view at this contact exposes 4 feet of slightly mashed conglomerate, with closely spaced joints parallel to the contact, resting on the granite. This is overlain by 6 feet of closely jointed quartzite, which in turn is followed by massive conglomerate.

A small area of fine-grained dark-colored carbonaceous sediments, 3 miles east of the mouth of Jack River, lies in contact with limestone on the south and is separated from the conglomerate and associated beds on the north by a narrow tongue of granite that runs out from the large intrusive mass to the east. The rocks of this area are massive for the most part, but present schistose phases. The most abundant type of rock is dark-blue argillite, flecked with grayish scalelike spots. It is shown by the microscope to consist mainly of small quartz fragments associated with scattered feldspar grains and considerable black carbonaceous matter, in which are fairly abundant sericite shreds. Another phase of the argillite is schistose and merges into graywacke. The argillaceous beds of the area so closely resemble the argillaceous beds intercalated with the conglomerates of the near-by Cantwell formation as to warrant a correlation of the two and to justify the belief that they were separated by the intrusion of the granite. Yet this detached area of Cantwell rocks (if such it is) shows by the steep dips and variable strike of the beds a considerable structural discordance with the gently dipping beds of the main area. This locality is the only one where the Cantwell formation was seen in contact with the older sediments, yet the beds had been so much disturbed by pressure and movements as to make the interpretation of their relations uncertain.

Wells Creek has two main branches. The western branch is formed by three streams that head in an area of Cantwell sediments that forms the mountains of the divide between upper Nenana River and Yanert Fork. This area is separated from that to the west by an intruded mass of granite about 7 miles across from east to west. Its southern border was examined with some care at several places.

About a mile east of the western border of the area a section of the beds from the valley to the mountain top was studied. From the base of the mountain, at an elevation of 3,600 feet, to an elevation of 5,600 feet the beds consist predominantly of massive dark-gray, somewhat schistose graywacke, composed of subangular to rounded pieces of quartz and black slate, set in siliceous cement. Intercalated with the graywacke are beds of black carbonaceous shale or slate containing abundant leaf impressions, and siliceous conglomerate, locally somewhat schistose. Thin lenses of the conglomerate were seen in the graywacke, some of which, especially those in the more quartzose graywacke, contain angular and rounded slate fragments.

The mountain above an elevation of 5,600 feet is made up of thickly bedded conglomerate, mashed and in places so schistose that the original texture is nearly obliterated. Most of the conglomerate, however, retains a semblance of its original structure, the coarser components appearing as elongated lenses which the finer, partly micaceous constituents enwrap. The conglomerate at this locality is light greenish or yellowish and dips northward at angles ranging from 35° to 60°, which indicates somewhat closer folding than that on the Nenana below Jack River.

The next locality examined is near the westernmost branch of the west fork of Wells Creek. The following detailed section represents part of the Cantwell formation exposed in this locality:

Section of a part of the Cantwell formation as exposed on the western branch of Wells Creek.

	Feet.
Black shale with plant impressions, alternating with beds of massive graywacke, in some places approximating a sandstone	1,200
Massive conglomerate, somewhat contorted, composed predominantly of white quartz pebbles, the largest three-fourths inch in diameter	200
Thin bed of shale	50
Unexposed	several hundred feet.
Schistose conglomerate	15
Silicified tuff	15
Alternating schistose conglomerate and schistose graywacke, including beds of shattered black slate and lenslike intercalations of quartzite	50
Dense, light-colored tuff, very hard	5
Rather schistose conglomerate, grading into schistose graywacke, which in turn grades into schistose conglomerate, the whole group containing lenticular beds of tuff	15
Graywacke, with lenses of quartzite and shattered carbonaceous slate	30
Siliceous conglomerate, rather massive	2
Graywacke	3
Carbonaceous slate, much shattered and slickensided	8
Graywacke, slightly schistose	15
Crushed slate and schistose graywacke	5
Graywacke, fairly massive	5
Covered, probably mostly graywacke	20
Schistose and altered graywacke, injected with quartz stringers and lenses	10
Granite, exposed	30
Gravel deposits of the valley floor.	

The silicified tuff of this section loks like quartzite, but when examined under the miscroscope was found to be composed of small pieces of quartz, some orthoclase, and a little plagioclase, all distinctly fragmental, set in a dense microcrystalline ground.

A traverse was made up the west branch of the west fork of Wells Creek to the divide that separates the stream from Yanert Fork. For a distance of 2¼ miles south of the divide the rocks consist of alternating beds of mashed conglomerate and dark-blue to black slate, derived from the carbonaceous shale. Some phases of the slate have a crinkly surface and satiny luster. Many of the beds might properly be called schists. At one locality, 2 miles south of the divide, the carbonaceous plant-bearing shales contain seams of lignitic coal from 2 to 2½ inches thick. The formation as a whole has a black aspect, due in considerable degree to the large amount of carbonaceous matter contained in it. Southeast of the saddle at the head of this stream there are numerous dikes of rhyolite porphyry, which show well-formed phenocrysts of quartz and feldspar in a greenish ground. The stream gravels contain, in addition to the types of rock described, bowlders of fine-grained diorite porphyry, conglomerate of a different appearance from any seen in place, composed of oval cobbles of granite and other igneous rocks, and a plicated phase of the near-by mashed conglomerate.

Another traverse was made up the middle branch of the west fork of Wells Creek. Near the southern boundary of the Cantwell formation the stream has cut closely folded beds of slate, graywacke, and conglomerate, all considerably mashed, the conglomerate being altered almost beyond recognition. The slate is crushed and shows slickensided surfaces. In the schistose conglomerate are small, thickly lenticular masses composed largely of tiny pyrite cubes. The formation for 2 miles north of this place consists of slate, graywacke, and conglomerate. All these rocks have undergone regional metamorphism, but the graywacke and conglomerate have suffered most. Much of the slate, however, has a crinkly surface, a feature that is thought to have developed later than the cleavage and that shows something of the compression to which the beds have been subjected. Folding of the beds is also pronounced, and the dips are steep, ranging from 80° N. to 80° S. Numerous quartz veins, seemingly unmineralized, the largest a foot in thickness, were injected into the sediments. These rocks continue northward to the head of the stream and into the basin of Yanert Fork. As a whole, they are dark grayish to black in color and give the mountains which they form a dark somber aspect and rugged contours.

At the head of Nenana River another intruded mass of granite interrupts the continuity of the Cantwell formation for a distance of about 8 miles from east to west. The rocks east of this granite area and north of the glacier at the head of West Fork of Susitna River were not examined except from a distance, yet from their appearance and the morainal material brought down on the west side of the glacier it is believed that the Cantwell forms the mountains around the west side of the base of Cathedral Mountain. The beds consist of dark slates and mica schist, the schist representing the coarser grained, more altered members of the formation. The most common form of the schist is dark reddish to bluish gray and shows an iron-stained surface, the result of weathering. The cleavage planes glisten with mica scales, and the cross fractures show numerous thin quartzose lenses which represent the original pebbles in the rock from which the schist was derived. It is only after having traced the Cantwell formation through its progressive stages of alteration that an observer recognizes the schist of this locality as the mashed equivalent of the massive conglomerate so prominent in the mountains near the mouth of Jack River.

A comparison of the Cantwell formation, as it is exposed between Nenana River and the glacier of the West Fork of the Susitna with that part of it on the north side of the Alaska Range west of Nenana River, where it was examined by Brooks, shows some further characteristics of this group of sediments. According to Brooks:[1]

> The Cantwell formation includes a series of heavy conglomerates interbedded with a few shale layers and succeeded by finer conglomerates and red sandstones interbedded with gray and black clay shales.

Brooks says further that the name was applied by Eldridge to the coarser, basal part of the formation, and that when traced to the north and west the conglomerates and coarse sandstone are succeeded by reddish sandstone and gray, drab, and black shales. Some of the sandstones are bright red, but the color varies to brown or reddish brown. Both argillaceous and arenaceous shales are present, the arenaceous shales grading into shaly sandstone. Some of the shale beds contain a large amount of carbonaceous matter and include small coal seams. Brooks writes:[2]

> A typical section near the camp of August 9, on the West Fork of the Toklat, showed a basal conglomerate about 20 feet in thickness resting unconformably on the upturned edges of Paleozoic slates and limestones. This bed contains pebbles of the underlying rocks. Above it is exposed about 20 feet of carbonaceous shale, and this in turn is overlain by a heavy quartz and chert conglomerate containing sandstone lenses, which probably has a thickness of 100 to 200 feet and passes upward gradually into a grit and sandstone series with local conglomerate layers. This upper member is made up of heavy sandstone and grit, thin-bedded sandstone, and sandy shales which on weathering have an iron stain, together with considerable carbonaceous clay shale. The sandstone and shale member probably aggregates 1,200 feet in thickness at this

[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 78, 1911.
[2] Idem, p. 79.

locality. One small area of these rocks, made up chiefly of conglomerate and red sandstone, was found on the Tonzona, where they formed a syncline resting on the cherts and slates of the Tonzona group. The most extensive exposure of them occurs in a belt of unknown width stretching from the McKinley Fork of the Kantishna to the Nenana Valley and probably beyond. In this area, especially toward the Nenana, lava flows interbedded with the conglomerate are very prevalent. In some localities these volcanic rocks form over half of the thickness of strata exposed belonging to this formation. These lavas appear to be chiefly andesites, but also include rhyolites and basalts. That they were surface flows is indicated both by their stratigraphic relations and by the amygdaloidal and columnar structure that some of them exhibit. Some tuffaceous beds also occur in this formation. The Cantwell formation is cut by diabase dikes and some granitic stocks.

This description shows still further the complexity of the Cantwell formation. The part of it east of Nenana River, between the mouth of Jack River and Nenana Glacier, probably corresponds in large measure to that part of the formation which Eldridge described under the name Cantwell, but it should be borne in mind that this is not necessarily the base of the Cantwell, for the granite that forms the base of the mountains in this area was intruded into the sedimentary beds and may not everywhere have followed the contact of the basal beds and the underlying rocks. No such amount of volcanic material was seen along the southern border of the area as was found west of Nenana River by Brooks.

According to Brooks, the structure of the Cantwell formation west of Nenana River is characterized by broad, open folds, accompanied by faulting. Such folding is seen along the Nenana below Jack River, where the inclination of the massive conglomerate beds indicates a broad, open syncline pitching gently eastward.

A narrow belt of granite separates the lowest Cantwell beds from the adjacent Devonian limestone in this vicinity, and it is not evident whether the contact relation of the two is that of faulting or of depositional unconformity. The scarplike southern face of the mountains and the straight front of the ridge strongly suggest a great fault, yet no conclusive evidence of faulting was observed. The unconformable relation of the Cantwell and underlying Paleozoic formations farther west, however, is well established.

East of Nenana River, as has been pointed out, the folding becomes more and more intense and the original character of the beds is much altered. At the head of Wells Creek the structure is much more complicated than on the Nenana. The beds dip steeply, some to the north, some to the south; the folds are compressed and complicated but not isoclinal, their axial planes dipping south or north in neighboring localities. A small fold on a branch of Wells Creek indicates the kind of folding that characterizes the formation in this vicinity. (See fig. 3.)

The width of the area occupied by the Cantwell formation also increases from east to west, but probably reaches a maximum somewhere between Nenana River and Wells Creek and decreases to the east. Near Muldrow Glacier the width of the area is about 2 miles, at Nenana River it is at least 20 miles, and at the lower end of Yanert Fork Glacier it is probably 17 miles, for Capps found coarse sediments at the head of Wood River that are thought to belong in the Cantwell formation.

Brooks found abundant evidence to show that, toward the west at least, the Cantwell rests unconformably on Paleozoic formations. No conclusive evidence of unconformity was seen east of Nenana River, for in most places the lowest exposed beds of the Cantwell are in contact with granite which is intruded into the formation. The one locality where rocks believed to be Cantwell are in contact with the older limestone is of such a character, owing to disturbing movements, that there is uncertainty as to the true relation of the two formations.

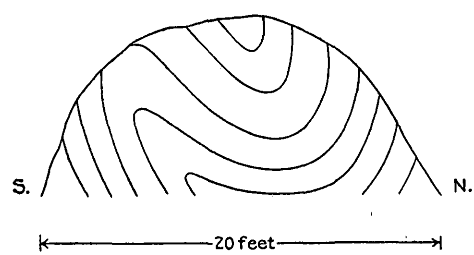

FIGURE 3.—Sketch of a small fold in beds of the Cantwell formation on a tributary of Wells Creek.

The thickness of the Cantwell formation can not be stated with accuracy. Much of the original deposit has been removed by erosion, and furthermore the survey of 1913 was not sufficiently detailed to furnish data for more than approximate measurements. Brooks found that the Cantwell at the head of Toklat River had a thickness of at least 2,000 feet, and noted that the thickness increased toward the east.

Near the mouth of Jack River the contact of the conglomerate and granite was observed at an elevation of about 3,100 feet above the sea. The mountain top is 5,860 feet above the sea. After making the necessary correction for the dip of the beds, it is found that this part of the Cantwell is approximately 2,700 feet thick; but it must be remembered that this measurement takes no account of a great thickness of overlying finer grained beds exposed farther north.

The Cantwell formation is intruded by great masses of granite and related granular rocks and is cut by light-colored porphyritic dikes. These intrusions must have had some disturbing influence on the rocks intruded, but so far as has been observed they have not produced conspicuous contact effects. The intrusive rocks are described on pages 57, 59, and 64.

The character of the sediments composing the Cantwell formation indicates continental deposition. This conclusion is suggested by the great thickness of conglomerate and the presence of intercalated beds of fine-grained, leaf-bearing material and of thin lignitic coal seams. Apparently the gravels were derived from an elevated land mass near by and were spread over a lowland occupied in part by marshy areas and bodies of quiet water. The accumulation of great thicknesses of conglomerate and graywacke made up of little-altered constituents is commonly regarded as indicating rapid degradation and deposition, such as might be expected in a region of cool and humid climate; but the fossil plants in the leaf-bearing deposits and coal seams of the Cantwell formation are those of a temperate or warm climate. Too little is known of the Cantwell formation to warrant a definite statement as to the location of the source of the material composing it, yet an examination of pebbles from the conglomerate beds along the southern border of the area and a comparison with older formations north and south of the range yields some evidence for assuming that the land mass lay in the south. Evidence of probably greater weight is found in the coarseness of the material constituting the southern border of the formation, but none of the evidence can be conclusive till a more detailed study of the whole area is made. Another account of the Cantwell formation has been given by Mr. Pogue.[1]

AGE AND CORRELATION.

The Cantwell formation is of early Tertiary (Eocene) age. This determination is based on the evidence of fossil plants collected in several places on the west fork of Wells Creek. The plant remains are contained in beds of shale or slate and sandstone interstratified with beds of conglomerate. Several collections were made, and the following forms were identified by F. H. Knowlton and Arthur Hollick:

Locality No. 6565. Ten miles east of mouth of Jack River.

Taxodium tinajorum Heer.
Taxodium dubium (Sternberg) Heer?
Sequoia langsdorfii (Brongniart) Heer?
Populus arctica Heer?
Daphnogene kanii Heer.

Locality No. 6567. Ten miles east of mouth of Jack River (near 6565).

Aspidium heerii Ettingshousen?
Taxodium dubium (Sternberg) Heer?
Ginkgo adiantoides (Unger) Heer?

Forms like three of the species in lot No. 6565 were collected by Brooks from a locality within the Cantwell formation in one of the upper tributaries of Toklat River.[2] The weight of other evidence,

[1] Pogue, J. E., The Cantwell formation, a continental deposit of Tertiary age in the Alaska Range: Jour. Geology, vol. 23, pp. 118–128, 1915.

[2] Brooks, A. H., op. cit., p. 82.

however, led Brooks to believe that the Cantwell must be older than Tertiary and that the beds in which his plants were found had been faulted into the Cantwell. The possibility of such conditions, either in faulting or in folding, is recognized for the Wells Creek localities, but is believed to be highly improbable. The Cantwell formation, then, is to be correlated with the widespread Eocene Tertiary sediments in Alaska that have been included under the name Kenai formation, although what has been called Kenai in some places is a complex that includes beds of Cretaceous age.

TERTIARY ROCKS ON JACK RIVER.

Jack River, after emerging from the mountains south of Broad Pass, flows for a mile or more through a canyon that gradually becomes wider and shallower till it finally disappears near the middle of the old Nenana-Chulitna Valley. The walls of this canyon consist of shale, graywacke, conglomerate, and sandstone. These rocks are altogether different from the Jurassic (?) formation on the south and are not identical with the members of the Cantwell formation to the north, although they have many features in common. They were seen only in the canyon and in the gulches tributary to it, so that the area known to be occupied by them is small. On the south side of the area these rocks consist of black shale containing a few thin graywacke beds, all dipping steeply northwest. The shale is followed on the north by massive conglomerate of grayish color which strikes northeast and dips 50°–60° SE. The contact of the shale and conglomerate was not seen. The conglomerate near the shale contains bowlders, the largest a foot in diameter, but is followed on the north by finer conglomerate that contains well-rounded pebbles of quartz and black flint, not more than half an inch in diameter. This finer conglomerate rests on yellowish-gray sandstone and shale beds that dip 30°–40° SE. These observations would indicate for the yellowish conglomerate and shale a thickness of not less than 2,000 feet, yet the exposures are such that this estimate can not be considered as wholly reliable. The shale and sandstone are soft, and the conglomerate, although well consolidated, weathers readily to gravel and sand.

No fossils were found in these rocks, but they are believed to be much younger than the slate, graywacke, and conglomerate of the mountains on the south and the near-by Devonian limestone and schist on the north. They probably represent some part of the Tertiary deposits, but their yellow color and slight metamorphism distinguish them from any part of the Cantwell formation examined by the writer.

QUATERNARY DEPOSITS.

By Joseph E. Pogue.

Much of the Broad Pass region is mantled by a covering of Quaternary alluvium, which consists of unconsolidated materials laid down by water and ice during the glacial epoch and those since deposited by the streams.

GLACIAL DEPOSITS.

The glacial deposits are primarily the result of a period of intense glaciation, characterized by transgression and coalescence of mountain glaciers into an ice sheet that covered all but the highest portions of the region. The extent of this ice mantle is now marked by silts, sands, gravels, and bowlders dropped during its retreat, laid down by streams escaping from its margin, and deposited in lakes left in its train. The structure and form of these deposits are fully discussed in the section on glaciation (pp. 66–73).

The distribution of the glacial deposits, as shown on the geologic map, conforms to the topography of the region, as relief was a controlling factor in their disposition. Their thickness is greatest in the broad valleys, whence they thin out on the gentler gradients and end against the steeper slopes in an irregular boundary, roughly concordant with the elevation contours. The maximum thickness of these sediments is nowhere disclosed in measurable section, but their topographic configuration indicates that their greatest vertical development is to be rated in hundreds of feet. Their thickness, however, is an exceedingly variable quantity, and in a broad way they must be regarded as a comparatively thin blanket or veneer, thinning out here and thickening there, with only general accordance to the underlying hard rock floor.

The surface configuration of the glacial deposits, except where channeled by present watercourses, has not been materially affected by postglacial erosion. About the borders of the gravel sheet, however, where slopes rise rather abruptly from its thin edge, special opportunity has been afforded for erosion, and such boundaries have not only been notched and serrated but have also suffered some downward migration, leaving a stripped belt of variable though unknown width in their wake.

RECENT DEPOSITS.

The recent deposits include alluvial material along present watercourses, rock débris of existing mountain glaciers, lake sediments, and colluvial deposits (those due to gravity) at the base of steep slopes. The first two classes of deposits only have sufficient areal development to appear on the geologic map.

The streams of the Broad Pass region comprise two groups—those heading in glaciers and laden with ice-ground rock flour, and clear-water streams, carrying no sediment except in time of rain. The first group, as represented by Susitna, Nenana, and Yanert Fork rivers and some of their tributaries, are torrential in summer and transport vast amounts of sediment. In their upper courses especially they are overloaded and divided into numerous braided and anastomosing channels spread over broad flood plains. These channels are constantly shifting, and material deposited in one season may be worked over and respread the next. Many of the clear-water streams are turbulent and narrow in their upper stretches, but where they emerge on the gravel floor of the broader valleys their velocity is checked and they develop flood plains on which sediments brought down in time of flood are deposited. These streams, however, nowhere form the intricate network of channels so characteristic of glacial rivers nor are their flood-plain deposits in all places sufficiently extensive to show on a small-scale geologic map. All clear-water streams eventually drain into the silt-laden glacial rivers, which carry much of their own burden beyond the confines of the region.

In character the flood-plain deposits consist of silts, sands, and gravels, showing distinct stratification and sorting. The gravels increase in abundance and in size of components toward the source, and especially near the glaciers the flood plain is covered with a cobble pavement, composed of rocks of the different types found in the drainage basin. Many of these pavements show a conspicuous accordance in size of individuals, and their development depends not only on depositation by swift and shifting currents, but also on subsequent removal of finer material by water of decreased velocity incompetent to roll the larger individuals.

The recent glacial deposits represent the rock débris brought down by the active glaciers and spread over their frontal lobes. This material, along with rock flour, is supplied to the streams that emerge from the ice masses, and is subsequently distributed over the broad flood plains that lie before the glacier fronts. These deposits and also the erosional activity of ice are treated more fully in the section on glaciation. (See pp. 66–73.)

Lakes are conspicuous features throughout the lowland areas of the region. (See Pl. III, *A*, p. 8.) Most of them are clear and limpid, but some form settlement basins for turbid glacial streams and in time of heavy rains all receive increments of mud. Many of these lakes have no outlets and ultimately disappear from the combined action of slow sedimentation and lateral encroachment of vegetation. In the aggregate lake deposits are not important in the region and are nowhere conspicuous, for a basin once silted up is obscured by a covering of vegetation and would not be observed until subsequently dissected by erosion.

A final type of deposit, of great local importance but of little areal extent, is one that depends on the pull of gravity exerted on rock fragments abundantly supplied through the agency of ice, frost, and the water that flows during thaws. These deposits include talus fans, rock slides, rock glaciers, and soil flows. The essential distinction of these is that they are not deposited in water. In a subpolar region like this one, where the temperature most of the year ranges below the freezing point of water, the surface rocks, especially where unprotected by a covering of vegetation, are rapidly disintegrated by the prying action of freezing water. This process, which is most active in spring and fall, results in the abundant development of rock fragments of different sizes, depending on the nature and structure of the rock. These fragments, according to their size and to the gradient and configuration of the slope, tend to migrate downward and give rise to deposits of diverse form. Where the slopes are vertical or precipitous the rock fragments, as they become detached, fall or slide rapidly downward until they become arrested on a flatter slope, where they accumulate in fringing aprons or coalescing fans, whose surface is inclined at the steepest angle at which the materials composing the mass will lie. In many places instead of being supplied uniformly from the top of such slopes, the fragments are concentrated by surface inequalities and develop symmetrical fans resembling in shape inverted half cones. Talus deposits of the kinds enumerated are especially conspicuous in those mountains that have been dissected by recent glaciation and now expose the steep slopes of their ice-carved amphitheaters or cirques, unprotected by ice, to the ravages of freezing and thawing. It is the finer material from such accumulations that is chiefly supplied in time of flood to the clear-water (nonglacial) streams and that is subsequently laid down on their flood plains.

Where the slopes are less precipitous they commonly show depressions in which the rock waste accumulates in longitudinal rock trains or slides, composed of a loose assemblage of angular pieces, ranging in size, according to the character of the rock, from small fragments to great blocks several tons in weight. The summits of many of the mountains can only be reached by climbing over such masses of incoherent rocks, for firmer paths of ascent are blocked by sheer cliffs. These bodies of rock, especially if made up of coarse components, have gentle slopes near their bottoms and increase in gradient toward their point of supply. In the course of their development their upper portions periodically reach a state of unstable equilibrium and adjustments take place, accompanied by a settling of the mass or by slides and avalanches. Such phenomena are less marked in bodies of finer material (such as those formed of slate fragments), since adjustments in these are frequent and gentle and their structure does not usually permit an overloading of the upper portions. Movement within these bodies is greatly facilitated by freezing and thawing, as well as by the presence of interstitial ice, and their progression, at least in their lower portions, is analogous to that of an extremely viscous material.

Generally these rock trains have little extent and are local features; they are everywhere abundant on the upper slopes of the mountains and are not uncommon at lower elevations. At favored localities, where several trains coalesce or the catchment area is especially large, the rock mass may take on a glacier-like form and extend a short distance down the valley. A few examples of this kind were observed, and they bear a partial analogy to the striking rock glaciers so typically developed in the Nizina district, as described by Capps,[1] though they are nowhere so extensive nor do they so completely simulate the character of an ice glacier. The rock glaciers described by Capps range to a maximum of 2½ miles in length. In the Valdez Creek region a rock glacier over a mile long was observed.[2] The longest rock glacier noted in the Broad Pass region scarcely exceeded one fourth of a mile in length.

On gentle slopes and the rounded tops of the lower mountains rock fragments tend to accumulate in thin sheets, which to some degree protect the underlying surfaces from disintegration. If the slopes be plane, the débris does not concentrate into trains or "streams," but slowly migrates downward as a uniform covering. That movement takes place is only inferential for the coarser material, but finer detritus in many places shows a marked streakiness of surface, owing to the arrangement of particles as a result of creep. The best example of this kind was noted near the top of the southern slope of a buttelike mountain west of Wickersham Creek. The underlying rock is slate, and the slope is covered with a thin veneer of slate fragments and soil, presenting a furrowed appearance, owing to alternate vertical strips a few inches wide of rock fragments and soil, the soil standing a bit higher than the rock.

Soil flow or creep is not confined, however, to the upper slopes, which are bare of vegetation, but takes place also on lower declivities covered with moss and grass, where it produces a surface configuration of peculiar character. Such slopes show a succession of roughly lobate areas, each thinning out upward and partly overlapped by another like shingles. These areas are caused by the gradual move-

[1] Capps, S. R., Rock glaciers in Alaska: Jour. Geology, vol. 18, 1910, pp. 359–375. See also Moffit, F. H., and Capps, S. R., U. S. Geol. Survey Bull. 448, pp. 52–59, 1911.
[2] Moffit, F. H., U. S. Geol. Survey Bull. 498, p. 41, 1910.

ment of the soil, under the influence of gravity, aided by the high moisture content and the action of freezing and thawing and restrained by the interlocking mesh of roots and fibers. They probably do not represent in themselves the total movement, but are rather the surface expression of steady creep, and the process may be compared to the flow of a viscous substance, such as pitch or asphalt, on an inclined plane. No examples at all comparable in fineness of development to the "soil flows" at the head of Valdez Creek[1] were seen in this area, though such phenomena are abundant in the mountains east and west of upper Butte Creek.

IGNEOUS ROCKS.

By Joseph E. Pogue.

SUMMARY.

Igneous rocks occupy large areas and have conspicuous topographic expression in the Broad Pass region. The geologic map (Pl. II, in pocket) shows that they fall into two main classes—granular intrusives that invaded the sedimentary formations and lava flows poured out on the surface. The granular intrusives include bodies of granite, granite porphyry, quartz monzonite, quartz diorite, olivine gabbro, and gneiss (probably an older intrusion altered by pressure). The lava flows include a series of acidic effusive rocks, principally rhyolites, trachytes, and andesites, which are closely associated with one of the large granitic intrusions, and a series of basic rocks, basaltic and andesitic, with interbedded tuffs, which show no connection with intrusive bodies. The sedimentary formations, moreover, are cut throughout by acidic dikes, whose increase in abundance toward borders of igneous masses suggest a genetic relation.

The igneous formations and their ages, so far as determinable, are summarized in the following table:

Igneous rocks of the Broad Pass region.

Post-Eocene	Amygdaloidal andesite.
Tertiary (in part)	Intrusions of granite, quartz monzonite, and quartz diorite, accompanied or followed by injection of granite porphyry and by extrusion of acid lavas.
Post-Jurassic (?)	Intrusion of olivine gabbro.
Pre-Tertiary	Gneiss (altered granular intrusive).
Triassic (?)	Basic lava flows with tuff beds.

[1] See U. S. Geol. Survey Bull. 498, pls. 5, *B*, and 6, *B*, 1912.

The Triassic basic lavas, because of their bedded character, the associated deposits of tuff, and their general structural analogy to the sedimentary formations, have been described with the sedimentary beds. (See pp. 26–28.)

GNEISS.

Southwestward from Butte Lake to the valley bordering Deadman Mountain there extends a belt of gneissic rock which forms rounded mountains of moderate elevation. This area is nearly surrounded by glacial gravels; on the south only it adjoins an intrusive mass of quartz diorite. Near the head of the east fork of Deadman Creek there are a few outcrops of a similar rock, evidently representing a prolongation of the belt beneath the gravels of the intervening valley.

The rock is a typical biotite gneiss, differing from place to place in coarseness, in the quantity of biotite it contains, and in degree of foliation. The average type is dark brown and closely foliated, carries considerable granulated quartz, and glistens with abundant mica. A specimen collected near Butte Lake, when examined under the microscope, was seen to be composed of a mosiac of quartz fragments, carrying orthoclase, plagioclase, and brown biotite associated with magnetite. Its characteristics are those of an igneous rock of granitic to monzonitic nature.

The dominant strike of the gneiss is about N. 50° E., and the dip is comparatively steep to the northwest. The area is intruded by dikes of andesitic porphyry and of a white alaskitic rock, which are probably related to the adjoining diorite intrusive. The metamorphism of the rock and its relation to the massive intrusive of probable Tertiary age (see p. 56) indicate a pre-Tertiary development for the gneiss. The gneiss accordingly is believed to represent a granitic intrusion of Mesozoic or Paleozoic time that became involved in subsequent metamorphism. In his study of the Mount McKinley region Brooks[1] refers to gneisses and gneissoid granites north of Tanana River which are older than the more extensive granite intrusions developed there.

GRANITIC INTRUSIVE ROCKS.

The sedimentary formations of the Broad Pass region are invaded by a number of granitic batholiths. Some of the rocks showing characters intermediate between granite and quartz monzonite correspond to granodiorite, but this term has not been used in this report. The intrusive rocks range from true granites through quartz monzonites to quartz diorites. In general, however, a single batho-

[1] Brooks, A. H., op. cit., p. 51.

lith does not exhibit this entire range in composition, but approximates the granite or the monzonite-diorite end of the series. It has been possible to apply these distinctions in the field, and the intrusives have been mapped, according to their dominant characteristics, as granite or quartz diorite, though each term, especially quartz diorite, must be understood as embracing monzonitic variations. Quartz diorite characterizes the eastern part of the region, where it is notably developed near Butte Creek and the glacier of the West Fork of the Susitna. The granite occurs in large areas west of the quartz diorite.

GRANITE.

Three large areas of granite have been mapped, one occupying the headwaters of Deadman Creek, Jack River, and Brushkana Creek; a second occupying a broad belt stretching northwestward from the region near the head of Nenana River and passing into the Alaska Range; and a third area adjoining the Nenana Glacier. The granite, broadly speaking, is a medium to coarse grained rock in which quartz in abundance, biotite, and feldspar can be readily recognized.

The large granite area that includes Deadman Mountain forms a series of rugged mountains bordered on the east by glacial gravels and ending on the north in an irregular contact against the Jurassic (?) slates of Jack River. This intrusive mass has not been traced southward and eastward to its limits. In its northern part the granite carries large areas of acidic lavas (see pp. 60–62) and of granite porphyry (see pp. 59, 60), which are probably later than the granite and represent a final expression of the magmatic intrusion. Throughout the formation there are scattered outcrops of rhyolite porphyry and of fine-grained diorite, regarded as dikelike intrusions injected at the close of or after the intrusion of the granite. It can not be affirmed whether the granite throughout the area under discussion represents a single batholith or several coalescing ones, though the rather constant character of the rock, so far as observations go, favors the first explanation. The average granite is a grayish medium-grained rock, showing about equal amounts of quartz and feldspar and carrying a subordinate sprinkling of biotite. A specimen from Deadman Mountain when examined under the microscope showed abundant quartz, a little biotite, and orthoclase predominating over acidic plagioclase.

The granite weathers rather readily to quartz feldspar sand, forming prominent talus fans of yellowish color which alternate with rock slides. This feature is especially prominent and characteristic toward the slate contact, east of upper Jack River, and suggests that the rock here has suffered hydrothermal alteration. The contact effects in this vicinity were studied in especial detail. The intruded slates and limestones near the igneous border show silicification, baking, and pyritization (see pp. 25, 31, 33) and the granite itself near the sedimentary boundary shows close jointing and chemical alteration. North of the head of Seattle Creek the contact is bordered by a band a few feet in width of a white fine-grained phase of the granite, composed of quartz, feldspar, and a minute amount of muscovite. The feldspar is shown by the microscope to be about equally divided between orthoclase (including microline) and oligoclase, and the rock is regarded as an aplite of monzonitic character. The contact has no topographic expression.

The granite belt north of Nenana River cuts diagonally across the eastward-striking sedimentary formations developed there, forming part of a front range of mountains and passing into the Alaska Range proper. This area is not distinguished topographically from the adjoining sediments. The mass as a whole is composed of a gray, medium-grained biotite granite with coarser phases of considerable development characterized by bluish quartz and pink feldspar. Microscopic examination of both phases shows that plagioclase is subordinate to orthoclase and that the rock is a normal granite, rather than a quartz monzonite. The granite of this area appears to have had remarkably little contact effect on the invaded sediments, some recrystallization and silicification in the Devonian limestone and pyritization in the Cantwell formation being the only important consequences observed. Attention has already been directed (p. 42) to the supposed rending effect of the granite on an area of the Cantwell formation lying about 3 miles east of the mouth of Jack River. Contact variations in the granite itself were noted at several points. About 2 miles east of the mouth of Jack River is exposed a contact of the conglomerate and the granite, parallel to which for 50 feet the granite exhibits close jointing but no textural change. At a contact with limestone a few miles southeast of here, however, the granite in less than 2 miles passes from a very fine grained phase through a medium grained to a coarsely crystalline condition.

West of Nenana Glacier the Cantwell formation is interrupted by granite, which extends back into the Alaska Range toward the Yanert Fork Glacier. This intrusion forms a rugged range of glaciated mountains that show prominent vertical jointing (Pl. VIII, *B*, p. 22) and that carry perpetual snow on their summits. The contact with the Cantwell is not topographically indicated, though easily recognized from the difference in the nature of the two formations. The rock, so far as examined, proved to be a normal medium-grained biotite granite. Between the Nenana Glacier and the glacier of the West Fork of the Susitna is a further extension of the granite, presumably a continuation of the same intrusion, although here the rock presents a gneissoid aspect. Under the microscope, however, it is seen to be composed of abundant quartz with orthoclase, a little microcline and acidic plagioclase, shreds and foils of biotite, and a few small crystals of green hornblende.

QUARTZ DIORITE.

Six areas of dioritic and monzonitic rock have been mapped, including one on either side of upper Butte Creek, an intrusion west of lower Butte Creek, a large body forming the southern portion of the sedimentary mountains bordering the glacier of the West Fork of the Susitna, an intrusion adjacent to Valdez Creek, and a body near Moose Creek. The absence of diorite from the western portion of the Broad Pass region is again emphasized. The diorite is readily distinguishable from the granite in that it shows in the hand specimen little quartz, considerable hornblende, scanty biotite or none at all, and scattered laths of feldspar in a feldspathic ground.

The quartz diorite area between upper Wickersham Creek and Butte Lake exhibits considerable variation within itself. The rock is typically a quartz-hornblende diorite, but its color ranges from dark to light, depending on the proportion of hornblende to feldspar. In the mountains immediately south of Butte Lake the rock carries titanite in conspicuous amount. This component is also prominent in the intrusives of the Coast Range of southeast Alaska.[1] Under the microscope the hornblende is seen to be a green, intensely pleochroic, iron-bearing variety. The plagioclase is mostly oligoclase and predominates over orthoclase. Quartz is fairly abundant and titanite is thickly distributed. Outcrops of a gray fine-grained phase, with components almost indistinguishable to the unaided eye, were noted near Wickersham Creek. This body invades the Triassic (?) slates, which near the contact are somewhat hardened and pyritized and carry foliated injections of the diorite magma.

The belt of gneiss that extends southwestward from Butte Lake is bordered by a body of quartz-hornblende-biotite diorite. A specimen collected from a tributary of Butte Creek is faintly gneissoid, though most of the occurrence is quite massive.

The intrusion west of lower Butte Creek invades the Triassic (?) slate formation, forming rounded mountains of moderate though conspicuous elevation among the gentler slopes of the sediments. The mass consists of medium-grained quartz-biotite-hornblende monzonite, fairly constant in character throughout, though locally presenting fine-grained dioritic phases. Microscopic examination of a typical specimen shows it to be composed dominantly of quartz, orthoclase, plagioclase, biotite, and hornblende, with magnetite and

[1] Iddings, J. P., Igneous rocks, vol. 2, p. 451, 1913.

apatite as accessories. Quartz occurs in rather abundant anhedral grains. Plagioclase slightly dominates over orthoclase; it ranges from oligoclase to andesine in character and shows carlsbad, albite, and pericline twins, many with zonal development. Biotite occurs in brown, strongly pleochroic shreds. The hornblende is green, pleochroic, and some of it is twinned. The rock is intermediate in character between granite and quartz diorite, and is classified as quartz monzonite. The adjoining sediments have been only slightly affected structurally by the intrusion, but in the vicinity of the contact they are injected with numerous dikes of rhyolite porphyry and fine-grained granite and show considerable silicification and pyritization. The intrusive area adjacent to the glacier of the West Fork of the Susitna is composed of a quartz-biotite diorite, with phases that have been mineralized with pyrite. The rock throughout this intrusion is massive.

AGE OF THE GRANITIC INTRUSIONS.

The granular intrusives of the Broad Pass region mark a period of batholithic invasion of unknown duration, but of notable development in Tertiary time, as indicated by the presence of both granite and diorite cutting Tertiary (Eocene) sediments. The massive character of much of the igneous material points also to late intrusion, but the gneissoid structure of some of the intrusions would seem to indicate that these occurrences are somewhat older than the massive ones. It might be argued also that because the intrusives are generally quite massive they came to place after the last period of intense folding to which the Alaska Range was subjected, the period of post-Eocene deformation, according to Brooks,[1] yet it must be remembered that bodies of resistant rock, such as igneous batholiths, may be involved in regional deformation without development of secondary structures. Attention has already been called (p. 55) to the belt of mica gneiss near Butte Lake and to the belief that this represents an older intrusive body, probably of Mesozoic age.

Granitic intrusions are prominent throughout the Alaska Range and are widely developed in southern and southeastern Alaska, as well as north of Tanana River. The evidence gathered by different workers goes to show that these occurrences are not all the result of a single period of intrusion, but rather of a succession of periods ranging possibly from Jurassic or earlier onward into Tertiary time.

GRANITE PORPHYRY.

East Fork of Jack River rises in a belt of granite porphyry and exposes fine sections of this rock in its upper canyon-like valley. The

[1] Brooks, A. H., op. cit., p. 118.

area lies within a large granitic batholith, adjoins a great body of acidic lavas and probably represents a special phase of the granitic magma. The rock is remarkable for the large size of its feldspar phenocrysts, its uniformity, and its great areal extent.

The granite porphyry was examined in greatest detail in a canyon carved by East Fork of Jack River between Seattle Creek and Brushkana Creek. It here forms great vertical cliffs, a hundred feet or more in height, of very striking aspect due to the abundance of white orthoclase crystals exposed on the surfaces. The feldspars, which average an inch in length though the largest measure $2\frac{1}{2}$ inches, are thickly set in a coarse ground of greenish aspect, composed of quartz, the largest pieces of which are one-fourth inch in diameter, biotite flakes, and dark altered hornblende. The rock is decomposed and crumbles under the hammer; on its surface the feldspars are more resistant than the groundmass, standing out as prominent white areas with crystal outline. The stream bed is covered with feldspar fragments, crystals broken by weathering. Small biotite flakes are included in zones about the periphery of many of the phenocrysts. The rock carries nodular segregations, the largest 6 inches in diameter, of fine-grained biotite granite. In places the feldspar phenocrysts are especially abundant, predominating areally over the groundmass. Under the microscope the groundmass of a typical specimen showed quartz, orthoclase, and acidic plagioclase, more or less altered, biotite partly changed to chloritic material, and a little brown hornblende.

The granite porphyry is cut by a few dikes of rhyolite porphyry and bluish-gray fine-grained andesitic rock. The relation of the granite porphyry to the adjoining granite is not certainly known, but the line of demarcation is apparently well defined and suggests injection of the porphyritic rock subsequent to the formation of the granite. The belt was not traced westward to its termination because of difficulties of travel in that direction.

ACIDIC LAVAS.

At the head of Seattle Creek, and near the belt of granite porphyry just described, the granite is associated with great masses of effusive igneous rocks. Time did not permit their areal delimitation in the field, as they are intricately interassociated, so they are mapped together as "acidic lavas." Smaller areas of similar rocks were observed near the head of Brushkana Creek and north of Soule Creek. Further work would probably disclose still other flows within the general area occupied by the same batholith, and detailed petrographic study of more abundant specimens would undoubtedly yield other rock types.

Microscopic study shows the lavas to consist mainly of rhyolite, trachyte, and andesite. The rhyolite is of at least two types. The most abundant phase is a reddish rock showing flow structure in alternate layers of red and buff color. In the hand specimen small crystals of quartz and feldspar may be distinguished. Under the microscope the rock is seen to be composed of phenocrysts of quartz, orthoclase, and plagioclase set in a fine-grained crystalline ground mass composed of an interlocking mass of quartz and kaolinized feldspar with a little magnetite and sericitic material. Quartz is the most abundant of the phenocrysts; it shows well-formed hexagonal and quadratic forms with here and there a corroded edge or corner. Orthoclase in euhedral to subhedral kaolinized tabular crystals predominates over plagioclase, which is not exactly determinable but of acidic character. A second and less extensive phase of the rhyolite was observed near the center of the largest lava area. This is a cream-colored rock showing on broken surfaces a conspicuous sprinkling of small, clear, quartz crystals. Under the microscope these quartz phenocrysts show both hexagonal and quadratic forms, with edges considerably rounded by corrosion; they are associated with orthoclase in tabular, rhombic, and triangular plates, some of which show twinning according to the Carlsbad law. The phenocrysts are set in a gray, fine-grained groundmass resolvable with difficulty under the highest power. Near their northeast border the lavas are associated with outcrops of a coarser-grained porphyritic rock showing well-formed crystals of quartz and feldspar in a granular groundmass of greenish aspect. The microscope shows the feldspar to be largely orthoclase and the groundmass to consist of a mosaic of quartz and feldspar carrying a little decompositional material. The rock is a rhyolite or granite porphyry and is judged to be a textural variant of the rhyolite.

The trachyte is typically a dark-gray rock, showing small feldspar crystals in a dense groundmass. Under the microscope the feldspars are seen to include both orthoclase and acidic plagioclase in nearly equal proportions, and the groundmass is resolved into a fine-grained mosaic composed chiefly of feldspar, with no quartz discernible. Ferromagnesian minerals are not notably developed. One specimen, resembling the trachyte in other particulars, carries in addition some small quartzes and seems to represent a transition into rhyolite.

Andesite is not so widespread as the more acidic lavas; it was noted at one point only—near the center of the principal area of lavas. It is a heavy dark-colored rock, in which laths of glassy striated feldspars are recognizable in a dark-blue fine-grained groundmass. Under the microscope the rock appears strikingly fresh. The dominant phenocryst is plagioclase, running into andesine in composition; it occurs in laths, rhombs, and tables and shows albite, Carlsbad, and pericline twinning. Orthoclase in subordinate amount occurs in tabular crystals, and the section contains a few euhedral crystals of augite. The groundmass is an aggregate of finely developed clear plagioclase laths, whose interstices are filled with pale-green augite grains and crystals.

The nature of these rocks indicates an origin in the form of effusive lavas. Their contact with the granite was not directly observed, but the general relations imply that they were poured out after the consolidation of the granite. They probably mark the close of the batholithic invasion.

OLIVINE GABBRO.

An intrusion of olivine gabbro invades the limestone-argillite series southwest of Nenana Glacier. The mass was examined in detail only near its western border, but the characteristics noted there probably hold for the entire batholith. The rock is hard, tough, and presents a weathered surface of reddish aspect. It is medium grained, and on fresh break shows an oily luster and red-gray tinge. Close examination of hand specimens reveals abundant glassy feldspars, associated with a brownish pyroxene and rather prominent plates of reddish biotite. At one point a coarse pegmatitic phase of the gabbro was noted, in which the pyroxene crystals attain a length of 2 to 3 inches.

Under the microscope the average rock is seen to be remarkably fresh. It consists essentially of a mass of plagioclase laths, carrying monoclinic pyroxene, biotite, olivine, and brown hornblende. The plagioclase is notably fresh and shows albite, Carlsbad, and pericline twinning; numerous measurements indicate it to be mainly labradorite. The monoclinic pyroxene is faintly greenish to pinkish in color and nonpleochroic. It occurs in stout, irregular crystals with borders more or less penetrated by the feldspars, and much of it is partly altered to fringing masses or included shreds of brown hornblende. Its highest observed extinction is 39°. The biotite is strongly pleochroic, from reddish brown to straw colored, and forms shreds and comparatively large, irregular plates inclosing the other minerals poikilitically. In places it shows partial alteration to pale-green chloritic material. The olivine occurs in grains of greenish color, showing the prominent cracks characteristic of this mineral; many grains contain areas and stringers of green serpentine, into which it is altering, accompanied by magnetite. Brown hornblende is present in small irregular crystals sparsely scattered through the section, in addition to that contiguous to the pyroxene.

The rock is in many respects similar to the olivine-pyroxene monzonite described by L. M. Prindle[1] from the Kichatna Valley in the Mount McKinley region, which is characterized by the minerals of the rock here discussed, together with more or less orthoclase.

No definite evidence is afforded as to the age of the gabbro intrusion; it is regarded, however, as the result of the general intrusive period that was dominated by granitic and dioritic invasions.

AMYGDALOIDAL ANDESITE.

About 6 miles above the mouth of Revine Creek an important flow of amygdaloidal andesite lies within the Cantwell formation. This area was not visited by the geologic party, and its limits are not precisely known. Its location and the character of the rock are based on information and specimens collected by J. W. Bagley, of the topographic party.

In hand specimens the rock shows a light grayish-green fine granular groundmass, carrying abundant rounded to elliptical amygdaloidal cavities, averaging 2 milligrams in diameter and partly to wholly filled with dark-green serpentine of radiating texture. Under the microscope the rock is seen to consist of an aggregate of altered feldspar laths set in green augite, changed almost completely to chloritic material. Feldspar phenocrysts of undeterminable character are scattered through the groundmass, together with grains of magnetite and a little ilmenite. The vesicles carry radiating aggregates of serpentine fibers. The feldspars, though not exactly determinable, are fairly acidic, and the rock accordingly is called an andesite rather than a basalt.

The age of the flow is probably late Tertiary, since it occurs within the Cantwell formation, of Eocene age.

DIKE ROCKS.

Dikes are fairly abundant in the sedimentary formations of the Broad Pass region and in the main seem to be genetically connected with the granitic intrusives. These bodies themselves also in many places carry dikes that probably represent the last expression of the intrusive period. On the whole the dike rocks of the area studied are distinctly acidic, few reaching the basicity of an andesite. The subject can be treated in the most general way only, because the reconnaissance character of the field work permitted the examination of but a subordinate number of the dikes actually present.

[1] U. S. Geol. Survey Prof. Paper 70, pp. 141–143, 1911.

The Triassic (?) slates are intruded by both acidic and basic dikes, the basic ones less abundant and of andesitic character. On a tributary of Deadman Creek, about 6 miles west of lower Butte Creek, a number of small pegmatite dikes are exposed in the stream bluff. In a fragment of the pegmatite were noted brown garnet, biotite, emerald-green mica, and specks of arsenopyrite. A mile southeast of this locality, and near the contact between slate and an intrusive body of quartz monzonite, the sediments are considerably metamorphosed and carry narrow dikelike intrusions of fine-grained biotite-hornblende granite, a fine-grained dioritic phase of the same rock in places porphyritic, and rhyolite porphyry, with well-crystallized quartz phenocrysts, the largest one-sixteenth inch in length, set in a rather dense cream-colored groundmass. On upper Wickersham Creek, a third of a mile above its largest tributary, a dike of hard massive dioritic rock crosses the stream, causing conspicuous falls. The rock carries numerous patches of pyrite and is composed of green hornblende, orthoclase, acidic plagioclase, and quartz, with biotite, shredded sericite, and tourmaline needles.

The Jurassic (?) slates of Jack River are injected by dikes of rhyolite porphyry, which are especially abundant near the granite contact east of Jack River, where the largest were 4 feet in width. No basic dikes were seen to cut this formation.

The belt of gneiss that extends southwestward from Butte Lake is intruded by dikes of white alaskitic rock and of andesite porphyry, which are apparently an expression of the diorite body that adjoins the gneiss on the south.

The limestone-argillite formation southwest of Nenana Glacier carries interbedded lenses and dikes of rhyolite porphyry and of medium to fine grained diorite that contains much biotite and presents pegmatitic phases with lath-shaped biotites, the largest of which are an inch in length.

The Cantwell formation at the head of Wells Creek is cut by abundant dikes of rhyolite porphyry that show well-defined phenocrysts of quartz and feldspar in a greenish ground. Under the microscope this rock is seen to be composed of phenocrysts of corroded quartz, irregularly rhombic orthoclase, acidic plagioclase, and hornblende almost completely altered to chloritic and serpentinous material in a groundmass of quartz and feldspar, most of it graphically intergrown. Bowlders and cobbles of gray, fine-grained diorite porphyry were noted in some abundance in the bed of Wells Creek, but this rock was nowhere seen in place. Diabase dikes were not found in those portions of the Cantwell examined, though Brooks[1] noted their presence in this formation west of Nenana River.

[1] Brooks, A. H., op. cit., p. 79.

In the large granite area including Deadman Mountain there are scattered outcrops of fine-grained diorite and rhyolite porphyry, which seemingly represent dikelike intrusions that closed or followed the intrusive period. A specimen of rhyolite porphyry collected near the head of Seattle Creek shows a conspicuous sprinkling of quadratic and hexagonal quartzes with white rectangular feldspar in a dense greenish groundmass, the rock having an aspect quite similar to that occurring in the Wells Creek area of the Cantwell formation. The granite porphyry adjoining the granite batholith also carries dikes of rhyolite porphyry that show small well-formed quartz and feldspar crystals and here and there also a dike of bluish-gray fine-grained andesitic rock.

STRUCTURE.

The known structural features of the formations in the Broad Pass region have been described in the preceding pages, but it still remains to consider these features together and so far as possible to show their relations. The structure in this region is difficult of interpretation, for it is complicated by masses of igneous rock that have invaded the sedimentary formations and interrupted their continuity; it is rendered still more complex and obscure by the large areas of unconsolidated deposits that cover most of the contacts between formations.

The sedimentary formations of the Alaska Range between Broad Pass and Susitna River and those of the region farther south lie in belts that extend in an easterly direction and that are approximately parallel to the range itself. (See Pl. II, in pocket.) For the most part the beds that compose these belts are closely folded, the axes of the folds being parallel to the axis of the range, yet locally they show open folding, and it will be seen from sections A–B and C–D on Plate II (in pocket) that the axial planes of the folds are not parallel but in some places dip to the south, in others to the north.

The Alaska Range in the vicinity of Broad Pass has a synclinal structure. On the north[1] and south (Pl. II, in pocket) Paleozoic or older formations are exposed; in the heart of the range only the gently folded Cantwell formation appears. Probably the simpleness of this structure is more apparent than real, however, for extensive faulting has affected other parts of the range, and, in fact, there is evidence that in this region the southern border of the Cantwell formation is a fault scarp. Eastward from Nenana River the folds of the Cantwell become more compressed, but the gen-

[1] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, pl. 2; 1912.

eral synclinal structure of the formation is maintained to the Yanert Fork Glacier at least. The structural relations of the formations south of the Nenana-Chulitna Valley are only imperfectly known, but as indicated on the geologic map and sections (Pl. II, in pocket), they are characterized by a northeastward trend and by close folding, with steeply dipping axial planes.

GLACIATION.

By Joseph E. Pogue.

DEVELOPMENT OF GLACIERS IN THE ALASKA RANGE.

Since the uplift of the Alaska Range in post-Eocene time, that mountain system has become the seat of active glaciation. This process reached its maximum intensity at a time when mountain glaciers on the south side of the range were so abundant and large that they coalesced into vast piedmont ice sheets which covered all but the highest of the front range of the mountains. At present the glaciers are receding and glacial activity is diminishing, though the higher and more rugged parts of the range are still undergoing glaciation. The Broad Pass region not only exhibits throughout unmistakable evidence of former transgression of ice over much of its area, but in its northern portion it still carries large and active glaciers.

PRESENT GLACIERS.

Yanert Fork, Nenana, and Susitna rivers head in large glaciers that fill great valleys and reach back into inaccessible portions of the Alaska Range. In addition to these prominent large-valley glaciers there are many small remnantal glaciers that occupy hanging valleys tributary to the main glaciers or that lie in the upper parts of cirques.

The Yanert Fork Glacier was not visited by the geologic party, but was surveyed topographically and its form and size are well shown on the topographic map (Pl. I, in pocket; see also Pls. V, *B*, p. 14, and VI, p. 16). In type it does not differ essentially from the glacier of the West Fork of the Susitna, described on page 67. It forms the source of Yanert Fork, which runs for miles in braided channels over a broad flood plain built up of rock débris supplied by the glacier.

The Nenana (formerly called the Cantwell) Glacier was examined only at its frontal margin. It descends from rugged mountains and abuts against a low rounded ridge, which was once overridden by the ice, but which now deflects its course westward to a place where it terminates in a débris-covered slope from which Nenana River springs. In the depression that borders the obstructing ridge on the east a low wall of ice forms a spillway from the main channel and feeds a small stream. (See Pl. VIII, *B*, p. 22.) Though time did not permit a detailed examination, the impression was gained that the glacier is retreating.

The glacier of the West Fork of the Susitna heads in the heart of the Alaska Range and draws its supplies of ice from the perennial snows of lofty mountains. With its multitude of tributary glaciers it forms a dendritic assemblage, whose main trunk sweeps southward for about 25 miles in a graceful line of double curvature. Though it almost unites with the headward reaches of the Nenana and Yanert Fork glaciers, it differs from those bodies by contributing its waters to the Pacific Ocean drainage instead of to tributaries of Bering Sea. This glacier was examined at its lower end and viewed from its right bank 7 miles above. Its surface presents a rather uniform gradient from foot to head (about 100 feet to the mile for the lower 12 miles), and appears to be notably free from medial moraines and from topographic irregularities, such as ice falls, caused by unevenness in bedrock slope. Its lateral margin, where observed, terminates in an ice cliff that is separated from the steep valley wall by a channel or moat, partly filled with rock waste and occupied by a stream. The entire glacier for several miles above its foot is mantled with a thick covering of rock fragments, producing an extremely rough, hummocky topography and obscuring the ice from view. This débris, together with rock waste and flour incorporated in the ice itself and dragged along its bottom, is supplied to the streams that emerge from the ice front during the summer season. The abundance of this supply and the silt-laden waters point to the erosional activity of the ice, which by rasping, grinding, plucking, and undermining has worn down its channel and eaten its way headward into the heart of the highest peaks. Forward from the front of the ice, which has now withdrawn to the face of the range, stretch conspicuous lateral moraines nearly 1,000 feet in height, which mark the path of retreat of this glacier. The nature and disposition of the frontal débris suggest that the ice even now is slowly receding.

The smaller glaciers of the region require no individual description. Without observed exception they represent residual portions of more extensive ice bodies, and many present a crescentic shape with concave front, indicating incomplete nourishment and approach to dissolution. These residual glaciers are practically confined to the Alaska Range proper; in the mountains south of Nenana River few such bodies can now be found, though in sheltered spots snow banks survive the summer and would require only a slight increase in precipitation or decrease in mean temperature to become incipient glaciers.

GLACIAL DEPOSITS.

The mantle of rock débris that covers the lowlands and gentle slopes of the Broad Pass region includes unconsolidated materials in varied assortment and distribution. The character and form of these deposits indicate that they were laid down by receding ice, which once covered the entire area where such deposits are found. The most widespread of these materials is the ground moraine or till sheet that extends over the broad valleys and lowlands of the region. This sheet consists in the main of an unassorted assemblage of clays and sand, mixed with bowlders and angular pieces of rock. In the main this glacial sheet presents a gently rolling surface, dotted with lakes and traversed by sluggish streams. In many places, however, the surface is characterized by low, rounded hills and elongated moundlike masses, which represent morainal material dumped at the margin of the retreating ice. In Broad Pass, near Jack River, there are long sinuous mounds of glacial material, approximately parallel and extending northeastward. Though not accessible for detailed study, these bodies were undoubtedly shaped by the ice and indicate the direction of ice movement at this locality. (See Pl. III, *A*, p. 8.) In the smaller and higher valleys the drift invariably shows a rolling haphazard surface, which indicates deposition at a later stage in the glacial epoch, when the ice had receded from the piedmont slopes but still occupied these tributary valleys. Outward from most of these valleys extend well-defined lateral moraines, which mark the course of the valley glaciers that once filled them; the existing glaciers have invariably left such paths of their retreat. The drift sheet in general is associated with more or less stratified gravels, sands, and silts that result from the assortive action of water and that represent materials supplied by the ice but laid down about its margin as outwash plains or valley trains. The relative abundance of these fluvioglacial deposits is not known, as in many places they are covered by vegetation. Similar deposits are now being formed on river flood plains by waters opaque with glacial sediments.

GLACIAL EROSION.

The erosive effects of the ice are of two diverse kinds—those produced above the ice, which give rise to sharp, rugged topography, and those produced beneath the ice, which result in curved surfaces and rounded forms. No part of the Broad Pass region is free from one or the other kind of glacial erosion, for even the drift rests on an ice-scoured floor and the highest peaks owe their form to ice attack. The topographic map (Pl. I, in pocket) strikingly shows the angular outline of the higher mountains in contrast to the subdued and rounded relief of the lower portions of the area.

The mountain upland owes its rugged character to the development of glacial cirques—amphitheater-shaped basins of characteristic outline—each lying at a valley head and representing a catchment area of a former or existing glacier. These basins were carved by the ice itself at the beginning of glaciation, and some of them are not at the heads of preglacial valleys, for a cirque may develop in any slight depression where snow gathers. As glaciation proceeds and becomes more intense, the cirques are enlarged laterally, subsidiary cirques are formed, adjacent cirques merge, and cirques on opposite slopes finally intersect. In this way the glaciers literally eat their way headward into the mountains, leaving, if the glacial period continues long enough, no part of the upland free from their attack.

In the Broad Pass region the mountains are dominated by cirque topography, and so little time has elapsed since the development of these forms that subsequent erosion has scarcely modified their outlines. The most conspicuous feature of the landscape, however, is not the depressions themselves but the sharp ridges and pinnacles that remain between impinging cirques. Here topographic forms of the most rugged character abound—comblike and knife-edge ridges, sharp peaks, sheer cliffs, and steep declivities. These forms vary in contour, to be sure, according to the nature of the rock composing them, for although cirques are equally developed in mountains composed of different rocks, the formation being dependent only on altitude and precipitation, it is in massive rock, such as granite, that the most intricate and rugged relief is produced. The sharp ridges of the glaciated mountains form in horizontal plan an involved and branching pattern; in vertical section their roughly concordant elevation is frequently interrupted by U-shaped saddles or cols due to the intersection of two opposing cirques, and by higher peaks, some of them almost pyramidal in shape, the whole representing a cirque-scalloped remnant of a more extensive mountain. (See Pls. IV, *B*, p. 12, and V, *A*, p. 14.) The floors of the ice-abandoned cirques are now covered with rock débris, and here and there a lake, high perched in such a depression, remains to indicate the lack of erosion since the departure of the ice.

The topographic forms developed by the abrasion of slowly moving ice are very conspicuous in the Broad Pass region. The most common effect is the rounded outline, or U shape, imposed on the valleys by the ice streams that once traversed them. (See Pls. IV, *A*, p. 12, and V, *A*, p. 14.) The cross sections of these valleys are markedly different from the usual angular or V-shaped outline produced by normal stream erosion, a shape notably lacking in this region. Second in importance to these ice-shaped valleys are truncated spurs whose summits have well-defined triangular faces. These forms are likewise due to moving ice that impinged on lateral ridges and ground them down to a concordant plane. They furnish graphic and unmistakable evidence of ice transgression. In general, they occur in series, and a finely developed set forms the southern wall of Broad Pass. (See Pl. VII, *A*, p. 18, and the topographic map, Pl. I, in pocket.) A third feature illustrating the abrading effect of the ice is the so-called hanging valley, a lateral tributary valley that ends at a level above the bottom of the trunk valley and that results from overdeepening of the larger channel by the ice. Many of these valleys contain small streams which cascade in beautiful ribbon-like falls over the steep slopes to the main valley floor. Valleys of this kind are typically developed along upper Jack River. From such well-defined valleys there are gradations in size into hanging cirques, whose fronts are intersected by the main valley. Rounded rock surfaces are common throughout the region and require no notice here other than the observation that they locally carry striæ cut on them by ice-dragged fragments.

EARLIER GLACIATION.

The deposits and erosional forms just described indicate that glaciation, which is still in progress in the higher mountains of the Alaska Range, was formerly more severe and extensive and involved the whole Broad Pass region. The uplift of the Alaska Range in post-Eocene time established conditions favorable to glaciation. With increased precipitation or decreased temperature, or both, the mountain glaciers increased in size and number and, on emerging from the front of the range, coalesced in a piedmont ice sheet that was augmented by smaller glaciers that rose in the front ranges of the mountains until it covered the entire lowlands and overran the lower mountains to an elevation of at least 4,600 feet, the highest observed point of glacial erosion on a faceted spur south of Broad Pass. The region affords no evidence of more than one ice transgression. Certainly no conspicuous transgressions followed the major one, and preceding less extensive advances would be obscured by the maximum advance. The period of maximum advance is not precisely known, other than that it followed post-Eocene deformation and preceded the present waning glaciation; the lack of erosion on ice-shaped surfaces, however, points to a short lapse of time since their development. After the ice sheet reached its maximum development the climate became milder and the ice withdrew from the lowland and the piedmont slopes. Whether this withdrawal was continuous or whether it proceeded at intervals is not known, though such change would probably not be without fluctuations. Glaciers persisted in the mountains after the piedmont ice had disappeared, and a transition was thus effected to the present epoch of high-level glaciation.

The movement of the ice is not known in detail, but there is evidence that one part of the sheet moved southwestward through Broad Pass, whereas in the eastern part of the region the movement in general was southward. The topography of the region and the disposition of the present glaciers would seem to indicate that the ice advanced from two centers—one in the high mountains of the Mount McKinley group and the other amid the Cathedral-Hayes assemblage. During maximum glaciation the major lobes and the subordinate intermediate ones merged into one vast ice sheet whose movement was determined by the topography of the country in front of the mountains, but during the advance and retreat of the ice the lines of movement probably radiated from these two centers. During all stages of glaciation there were undoubtedly many conflicting ice currents, especially about the borders of the mountain masses, of which a single example is furnished by south-facing faceted spurs between the present glaciers of the West Fork and the Middle Fork of the Susitna, which indicate a transverse movement here, at the very front of the Alaska Range. The maximum thickness of the ice sheet, judged from the height reached by glacial erosion on the mountain slopes, is believed to have been more than 2,200 feet, a figure obtained by direct measurement of the height of certain faceted spurs south of Broad Pass.

CHANGES IN DRAINAGE DUE TO GLACIATION.

The drainage of the Broad Pass region, which was established by the uplift of the Alaska Range and conditioned by the topography then formed and by the structure and character of the underlying rocks, has been profoundly affected by subsequent glaciation. These subsequent changes in the drainage pattern are due (1) to deposits of glacial material left after the retreat of the ice, (2) to changes in topography due to erosion by ice, and (3) to the topography of the original surface of the ice itself.

The deposition of glacial drift over the low-lying portions of the Broad Pass region has produced areas marked by abundant lakes, by undrained and sluggishly drained tracts, and by streams that are errant, meandering, and discordant to the structure and lithology of the underlying rocks. The drainage has been lifted, so to speak, from its former bed and superposed on this mantle of unconsolidated material, so that now amid a region of high and rugged mountains a kind of drainage prevails that is normal only to regions of mature and subdued topography. This condition is locally striking, but is not of wide effect, for few of the larger drainageways have been entirely diverted from former courses by morainal deposition alone. The effect has rather been to convert an active stream into a sluggish one, a well-drained valley into a marsh, and only in exceptional places to reverse or change the direction of flow. Where a reversal or change in direction of drainage has apparently taken place the process seems, in most instances at least, to have been complicated by the manner of retreat of the ice, the disposition of the ice itself rather than deposits left by it having been the conditioning factor in directing postglacial drainage. An example of this condition is formed by the anomalous course of Butte Creek southward across the Triassic (?) slate formation, with its abrupt eastward sweep into the Susitna, in contrast to preglacial Butte Creek, which probably flowed southwestward from Butte Lake into Deadman Creek. Morainal damming alone seems incompetent to have caused this change, for the present stream cuts through a solid rock barrier of Triassic (?) slates at an elevation greater than the morainal deposits that form the divide between Deadman Creek and Butte Creek. The presence of ice at this locality, and especially the fortuitous manner of its retreat, are therefore assumed to have influenced the location of the present course of Butte Creek.

Erosion due to ice abrasion has modified stream gradients and developed local features, such as falls and rapids, but with the exception of Nenana River it has apparently had little broad effect on the drainage pattern. Hanging valleys with their frontal cascades form striking and picturesque examples of stream disturbance due to glacial erosion. The drainage of the upland regions, characterized by cirques, occupies depressions formerly filled with ice, but whether these lines were developed by the ice, in which event the present drainage is not superimposed on the preglacial one, or whether the ice merely deepened valleys initiated by normal processes of erosion, are questions that can not be satisfactorily answered here. The presumption is that both conditions are in part fulfilled in the Broad Pass region.

The course of Nenana River northward through the Alaska Range instead of southwestward through Broad Pass into the Chulitna basin is so discordant to structure and preglacial topography that it must have been due to unusual conditions. It is now well known that glaciation was and still is more intense on the seaward face of the Alaska Range than on its inland slope, a fact shown clearly on the geologic map of the Mount McKinley region.[1] The thick accumulation of ice in the Broad Pass region is thought to have found a northward overflow through a depression in the Alaska Range,

[1] U. S. Geol. Survey Prof. Paper 70, pl. 9, 1911.

which it overdeepened and left invested with the present Nenana River. This explanation derives additional weight from the fact that the course of the Nenana lies halfway between two centers of ice development—the high mountains of the Mount McKinley group and those of the group containing Cathedral Mountain and Mount Hayes, so that on the recession of the ice the eastward and westward drainage was probably blocked by waning ice lobes. Delta River, 90 miles to the east, which flows northward through Delta Pass, forms an example analogous to the Nenana, and a similar explanation has been advanced for its discordant course.[1] Two other explanations of the courses of these two rivers are possible—first, that they are antecedent streams, whose courses were maintained during the elevation of the Alaska Range, and, second, that they are due to headward erosion of streams which began on the north side of the range. These explanations, however, seem less adequate to meet the field condition than the one involving glaciation.

The principal changes in drainage caused by glacial deposition and erosion by ice have been indicated, and the suggestion has been made that some of these changes have been in part conditioned by the surface configuration of the original ice sheet and the manner in which this sheet receded. On the whole, the topography of the ice has apparently played an important part in determining the course of the present streams, though the precise way in which it exerted its influence and the places where it was most effective are difficult to ascertain. Inasmuch as the present drainage was developed at the edge of a waning ice sheet and was left in the path of its receding border, it appears that the disposition of the ice at its different stages must have fixed or controlled the position of the drainageways in many places where the original topography was insufficient to maintain control. The course of Butte Creek was apparently so determined. The explanation advanced to account for the northward course of the Nenana involves this principle. The diverging paths of Nenana and Susitna rivers, which head within a few miles of each other, are due to the fact that their sources were formerly more widely separated by an ice lobe of which their respective glaciers are remnants. The course of Jack River northward into the Nenana instead of through Broad Pass is probably due to the extension in the past of the glaciers near Mount McKinley across the upper Chulitna Valley, where they formed a barrier to southwestward drainage.

[1] Moffit, F. H., Headwater regions of Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, p. 51, 1912.

GEOLOGIC HISTORY.

The geologic history of the Broad Pass region can only be sketched, and very imperfectly, for the facts at hand are too meager to warrant a fuller or more detailed account. The first event of the geologic record, so far as is now known, is the deposition of argillaceous and calcareous sediments in Devonian time. These beds of Devonian slate, schist, and limestone are more highly altered and more intricately folded than the other sedimentary formations of the region, and they were probably folded and subjected to erosion before they were covered by later formations.

The next major event is in doubt. Apparently the lavas that form the mountains south of Butte Creek were poured out at this time, but the Triassic (?) slates of Butte Creek may have been deposited before the volcanic rocks were ejected. Facts bearing on the relative ages of these formations have already been given and need not here be repeated. What appears to be the upper part of the lava flows in the vicinity of the Roosevelt Lakes contains water-laid tuffs, and the near-by Triassic (?) sediments also contain tuffaceous beds. This evidence is interpreted as indicating an interval between periods of volcanic activity and normal sedimentation, during which the clastic material produced during volcanic outbursts and that due to erosion of a land surface were intermingled. No indication of volcanic activity during the deposition of the upper part of the Triassic (?) sediments has been found.

Little, if any, evidence is at hand to show what took place between the deposition of the Triassic (?) rocks and the group of slate, graywacke, and conglomerate on Jack River. This group is provisionally assigned to the Jurassic on rather slender evidence. The beds that composed it must have accumulated rapidly under rather unstable conditions, possibly in shallow water near a shore line. They are the youngest sediments of the region assigned to the Mesozoic. They were folded and intruded by igneous masses, and after being elevated were subjected to erosion for a long period, which probably extended into Tertiary time. If Cretaceous beds were ever laid down in this region they either have been unrecognized or have been entirely removed.

It is believed that when the conglomerates and sandstones of the Cantwell formation began to accumulate in early Tertiary (Eocene) time the area where the Alaska Range now rises had been reduced by erosion to a region of much lower relief than that of the present. A mountain mass, or at least a region of higher elevation, lay to the south and furnished material for the conglomerates, sands, and shales of the deposits that were being laid down along the front of the highland, not in the sea but on a marshy lowland, possibly near the sea. Deposition of the Cantwell sediments was followed in Tertiary time by mountain-building movements that finally gave rise to the Alaska Range as we see it to-day. The Cantwell and all the older formations were intruded by large masses of igneous rock, granite, diorite, and related types, and were folded together and elevated, permitting the revival of vigorous erosion.

It is not known when all the different igneous rocks of the region invaded the sediments. Probably intrusion went on intermittently throughout all the time between the deposition of the Devonian formations and the elevation of the Alaska Range. It is known, however, that widespread crustal movements and the intrusion of large masses of igneous rock took place some time after the Middle Jurassic epoch. According to Brooks,[1] the great batholiths of the Coast and Alaska ranges and of the Talkeetna Mountains were then intruded. Nevertheless it does not appear that the extent of Tertiary intrusion has been fully realized. The revival of the processes of erosion that began with the elevation of the Alaska Range led to the blocking out of the principal topographic features seen in the range to-day, but these features have been profoundly affected by other agencies than weathering and normal stream erosion, for the elevation of the range also gave rise to conditions that led to intense and long-continued glaciation of the region and great modification of the preexisting drainage and topographic forms. These changes have been discussed more fully in the section on glaciation (pp. 66–73).

ECONOMIC GEOLOGY.

MINERALIZATION.

Geologic conditions within the Broad Pass region are of a kind commonly regarded as favorable to mineralization. Wide areas of slate, shale, limestone, and other sedimentary deposits have been intruded at different times by granitic rocks of several types. Many such intrusions in other regions have led to extensive mineralization of the invaded rocks, but the results of the field work of 1913 show that the Broad Pass region is not so greatly mineralized as our knowledge of the other features of the geology would indicate. Many contacts of igneous and sedimentary rocks were examined with considerable care, yet without finding notable mineralization. At some places there is a small amount of pyrite, and the invaded rock has suffered such changes as baking and silicification, but otherwise the intrusive rocks appear to have produced little effect.

[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 117, 1911.

No mining is carried on in the Broad Pass region. Parts of the region have been prospected, chiefly for placer gold, in a hasty and imperfect way, but the results of prospecting were not encouraging, though gold, copper, and coal have been found.[1] The men who discovered the gold placers of Valdez Creek ascended Susitna River from the mouth of Tyon River, prospecting the tributary streams on both sides of the river as they went. They found coal on a western tributary of the Susitna which they called Coal Creek, and panned gold from the gravels of Butte Creek and some of the smaller unnamed streams.

GOLD.

The gravels of Butte Creek, Wickersham Creek, and several small streams that flow into Susitna River from the west in the vicinity of Valdez Creek contain placer gold. Gold prospects have also been found on some of the small streams west of the glacier at the head of West Fork of Susitna River, but no mining has been done. An attempt to recover gold from the gravels of Wickersham Creek and one or two of its tributaries did not turn out profitably.

All these localities are in areas of slate or schist. So far as is known to the writer placer gold has not been found within the areas of igneous rock, except in places where the gravel is derived in part from neighboring sedimentary formations.

COPPER.

Copper-bearing minerals have been found in the lava flows between Butte and Wachana creeks and Susitna River and are reported from localities on the upper part of Chulitna River. A rather large vein of chalcopyrite was found several years ago south of the eastward bend in Butte Creek. This locality was not visited by the Survey party, but a specimen of the ore furnished by Mr. Peter Monahan, of Valdez Creek, shows olivine basalt carrying disseminated chalcopyrite. No effort has been made to exploit the lode.

COAL.

Coal Creek joins Susitna River 3 or 4 miles above the mouth of Maclaren River. Coal was found on this stream in 1904, but no attempt has been made to use it. Little can be said about the occurrence of coal in this locality, for neither its thickness nor the character of the rocks associated with it are known.

[1] During the summer of 1914 reports of the discovery of valuable lodes in the Broad Pass region were widely disseminated. These were described as large deposits carrying ores of low value. The place at which these lodes were found is unknown, and there has been no authoritative confirmation of the discovery.

Seams of coal only a few inches thick are interstratified with carbonaceous shale in the Cantwell formation, but they do not promise to be of commercial value.

ECONOMIC CONDITIONS.

Most of the conditions that would affect prospecting and mining in the Broad Pass region have already been discussed under the head of "Geography," but further reference to one or two of them is desirable. Transportation is the most important, and might easily be the deciding factor in determining the profitableness of a mining venture in this region. Under present conditions ordinary supplies can probably be freighted to Broad Pass from Fairbanks more easily and cheaply than from any other point. Even now some of the miners on Valdez Creek bring supplies from Fairbanks, hauling them over the ice of Nenana River. The winter route from Cook Inlet, however, should be fully as good, although the use of this route would necessitate landing freight at the head of Cook Inlet before winter sets in.

On the other hand, most of the mining equipment and supplies used on Valdez Creek will doubtless continue for a few years to be hauled from Chitina, and the lesser cost of trail breaking by this route must be taken into consideration in calculating the cost of winter freighting into the Broad Pass region.

The transportation problems of the upper Chulitna, Susitna, and Copper River regions will probably be entirely changed in the near future. Since the passage of the Alaska railroad bill the different routes from the coast to the Tanana and Yukon valleys have been surveyed and that leading from Seward to Fairbanks by way of the Susitna, Chulitna, and Nenana valleys has been chosen as the route for the first railroad to be built in Alaska by the Government.

Construction work on this road has been begun, so that there is reason for believing that the Broad Pass region will soon be one of the parts of interior Alaska most easily reached.

The Broad Pass region, considered as a whole, is timberless. The sketch map shown in figure 2 (p. 18) indicates that spruce grows only along the principal watercourses and that the higher country is without timber. It is therefore evident that both lumber and fuel must be imported if required in considerable quantity. The lignitic coal that is so abundant in the Bonnifield region north of the Alaska Range may be used, yet the higher grade coal of Matanuska Valley is more likely to be employed when railroad communication with Cook Inlet is established.

The Broad Pass region may be said to be almost unexplored so far as a knowledge of possible mineral resources is concerned. It appears unlikely, however, that it contains important deposits of coal, for the principal coal-bearing formation of this part of Alaska is not widely developed south of the Alaska Range in this region.

Though no extensive mineralization was found here during the geologic field work of 1913, that work was not sufficiently detailed to warrant a sweeping statement as to the presence or absence of metallic deposits, particularly when the general geologic conditions appear favorable to their presence, and it is believed that a search for valuable metals may be justified.

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