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THE BONNIFIELD REGION

ALASKA

BY

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PREFACE.

By Alfred H. Brooks.

The Bonnifield district, described in this report, has long been known as a field of some productive placers as well as extensive lignitic coal deposits. Its annual gold output up to the present time has been much smaller than that of most of the other Yukon camps and its coals are entirely undeveloped. For this reason the survey of this district was deferred until the more important regions had been mapped. Meanwhile, several Geological Survey parties have traversed parts of the region and some knowledge has been gained of its mineral resources. The present report can be considered by no means exhaustive in its treatment of the geology and mineral resources, for the field season was limited to 100 days, during which time the party mapped 3,100 square miles.

In spite of the hasty character of the field work Mr. Capps has been able to subdivide the metamorphic rocks into two formations. An older, the Birch Creek schist, is made up chiefly of altered arenaceous and argillaceous sediments. This formation is similar to the typical Birch Creek schist so extensively developed in the Yukon-Tanana region to the north, as well as elsewhere in the Yukon basin. Its assignment to the pre-Ordovician is based on work done outside of the Bonnifield region. The younger group of metamorphic rocks, called the Totatlanika schist, is made up chiefly of altered rhyolites but includes subordinate amounts of sediments. The assignment of the Totatlanika to the Silurian or Devonian is by no means definitely established. There are many gneisses and crystalline schists in the Yukon-Tanana region, to the north, which in the hand specimen bear a considerable resemblance to the Totatlanika schist. These rocks, for the most part, have been regarded as granite porphyries intruded into the Birch Creek schist and later intensely deformed. No evidence of their Paleozoic age has been found.

In the earlier reports these gneisses were represented as belonging to a basal complex and provisionally assigned to the Archean. The Totatlanika schist also closely resembles the rocks of McConnell's

Klondike series,[1] which are typically developed in the Klondike district. These have been described as altered quartz and granite porphyries. The distribution of the Klondike "series" corresponds closely to that of the "basal granite" as represented by Spurr [2] on the first geologic map published of the Yukon basin. It seems probable, therefore, that the Totatlanika schist may represent the formation formerly termed "basal granite" or "basal gneiss."

The Tertiary of this field, made up of loosely cemented gravels and sands and clays or shales, with intercalated lignitic coal beds, resembles certain phases of the coal-bearing series, widely distributed in Alaska, which has usually been referred to the Kenai formation and, on the basis of the plant remains, assigned to the Eocene. Arthur Hollick is now engaged in a study of the flora from the beds which have been referred to the Kenai in different parts of Alaska. His work is not completed, and the results are not published, but they point to the conclusion that part of the lignitic coal-bearing series of the Bonnifield region is to be correlated with some beds exposed near Rampart, on the Yukon, which are probably of post-Eocene age and therefore younger than the typical Kenai formation of the Cook Inlet region.

Mr. Capps regards the extensive elevated sands and gravels termed by him the Nenana gravels as of preglacial age. The writer,[3] who traversed the west end of the Bonnifield region in 1902, considered these deposits as having been laid down by the flood waters which accompanied the retreat of the main ice sheet. Mr. Capps had opportunity to study these deposits in far greater detail than did the writer, and the evidence he obtained must have great weight. On the evidence at hand it seems reasonable to correlate the Nenana gravel with the great sheet of unconsolidated deposits that mantles the piedmont region of the Alaska ranges which have been glaciated. Much of this material seems to have been pretty definitely proved to be of postglacial origin. Therefore, viewed in these broader relations, the Nenana gravel would seem to be of postglacial age. It is possible that the apparently contradictory character of the evidence may be explained by supposing that there was an older period of glaciation than that recorded in the moraines described by Mr. Capps (pp. 38–39) as of post-Nenana age.

Both the Totatlanika and Birch Creek schists are locally mineralized and were undoubtedly the ultimate source of the placer gold. The two localities in this region where auriferous lodes have been

[1] McConnell, R. G., Report on the Klondike gold fields: Ann. Rept. Geol. Survey Canada, vol. 14, pt. B, 1905, pp. 156–226.

[2] Spurr, J. E., Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1897, Pl. XXXVIII.

[3] Brooks, A. H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 135–136.

found are not far from granitic intrusives, suggesting a genetic relation to igneous rocks, such as has been established in other parts of Alaska. The gold of the developed placers has been derived in part by reconcentration from the Nenana gravel, in part directly from the mineralized schists. The wide distribution of gold in the alluvium suggests that other commercial deposits may be found. An all-important question to the future of the district is whether the Nenana gravel, known to be auriferous, carries commercial quantities of gold. This matter is now being settled, for one locality at least, by a hydraulic plant which has been installed on Gold King Creek.

The lignitic coal reserves of this region have been estimated by Mr. Capps to be nearly 10,000,000,000 tons, which exceeds by nearly 3,000,000,000 tons the estimate[1] made a few years ago, on the information then available, of the total lignitic coal tonnage for the entire Territory. Though Mr. Capps's estimates are made on a very conservative basis, they indicate that the coal tonnage of the Bonnifield region is greater than that of all the other surveyed fields of the Territory.[2]

Although the quantity of the coal is enormous, it is all of lignitic character and therefore can not be considered available for shipment to distant markets. It will probably be chiefly valuable for use in the mining camps of the Yukon-Tanana region, especially Fairbanks, when the depletion of the timber supply and the installation of large plants create a market for fuel. These coals could be made available for Fairbanks by building about 60 miles of railway or by erecting a power plant and transmitting their energy in the form of electricity.

[1] Brooks, A. H., Alaska coal and its utilization: Bull. U. S. Geol. Survey No. 442, 1910, pp. 36-39.

[2] It should be noted that only about one-fifth of Alaska has been surveyed, and only a small part of the surveyed coal fields has been examined in sufficient detail to permit tonnage estimates.

THE BONNIFIELD REGION, ALASKA.

By Stephen R. Capps.

INTRODUCTION.

HISTORY.

The region lying south of Fairbanks between Tanana River and the crest of the Alaska Range has been the scene of placer-mining operations since 1903, and after the stampede to Fairbanks in 1904 a large number of prospectors visited the many creeks which flow northward from these mountains. The area has long been known as the " Bonnifield district," having been named for John E. Bonnifield, who was one of the first men to locate in this part of Alaska. The name was at first applied to the foothill area in the neighborhood of Wood River and the creeks near by, to the west, but has since been used to cover all the country between Nenana and Delta rivers on the west and east and the crest of the range and Tanana River on the south and north. It includes portions of both the Fairbanks and Tanana recording districts.

The Bonnifield region was explored and prospected by men who worked southward from Fairbanks and the Tanana, and the first gold recovered was taken from Gold King Creek in 1903. From that year until 1906, prospecting was actively carried on by a large number of men, and interest in this country was sustained by the hope of striking another camp like Fairbanks, the great richness of which had been established. Since 1906 the production has remained about stationary and the list of creeks now producing is much the same as then, but the population has gradually diminished, the prospectors who were unsuccessful having been drawn to other more promising fields. In 1910 interest was revived by the preparations to exploit the high gravels on a large scale by hydraulic methods. The feasibility of this venture remains to be proved, but if it succeeds its success will, without doubt, mark the beginning of a new era of active mining and may place this among the important producing camps. In 1908 an extensive mineralized lode containing much iron sulphide and some gold was discovered in the basin of Wood River. Developments on this lode are at present insufficient to determine definitely the value of the discovery, but it is possible that a large quantity of low-grade ore is present. This discovery has encouraged prospecting for lode mines, and many claims have been staked. It remains for future developments to show the possibilities for lode mining in this region.

The placer-gold output of the region, though not exceeding $50,000 in any one year, has been steady, and considerable areas of placer ground have been found which are not now workable but which, with decrease in cost of transportation and easier access, will doubtless be added to the list of producing camps. Attention has also been attracted to the very extensive deposits of high gravels which are said to carry gold, and several projects are now under way to exploit these low-grade gravels on a large scale. In addition to the placer ground large lode deposits have been found in the basin of Wood River which are reported to carry gold sufficient to justify mining. The extensive fields of lignitic coal, though nowhere developed yet, have as a future source of power a value which may sometime overshadow even that of the precious metals.

PREVIOUS GEOLOGIC WORK IN THE REGION.

The first information in regard to the geology of the Bonnifield region was obtained by Brooks and Prindle in 1902, and the results of their work are contained in a report recently published.[1] At that time they visited only the western edge of the area, in the vicinity of Nenana River. Prindle again visited the area in 1906, at which time he examined the placer camps and coal fields as far east as Wood River. A brief summary of his conclusions, with descriptions of the placer camps, has been published.[2] The notes, manuscript, and traverses of both of these investigators have been freely drawn upon by the author of this bulletin, who has also been greatly aided by them in frequent personal conferences in the office.

WORK HERE REPORTED.

With the past production and the future possibilities of this country in view a party was organized to map it topographically, with J. W. Bagley, topographer, in charge.

Mr. Bagley connected his work with D. A. Reaburn's traverse of Nenana River on the west and with the work of D. C. Witherspoon and C. E. Giffin on the south and east, the area covered during the season being more than 3,100 square miles. The writer was detailed

[1] Brooks, A. H., The Mount McKinley region, Alaska, with descriptions of the igneous rocks, and of the Bonnifield and Kantishna districts, by L. M. Prindle: Prof. Paper U. S. Geol. Survey No. 70, 1911.

[2] Prindle, L. M., The Bonnifield and Kantishna regions: Bull. U. S. Geol. Survey No. 314, pp. 205–226.

to investigate the mineral resources and the geology of the area mapped.[1] The party, consisting of 6 men, with 12 pack horses, the usual camp equipment, and provisions for 60 days, left White Horse on the opening of river navigation, June 11, 1910, and arrived at Nenana, by way of Yukon and Tanana rivers, on June 19. Arrangements had previously been made for supplies for the remainder of the season, to be delivered at the mouth of Little Delta River. Actual field work began on the arrival of the party at the foothills, some 30 miles south of the Tanana, on June 27 and was completed on September 13, covering a field season of 79 days. As no steamboats had been run up the Tanana to Washburn by August 15, the provisions for the later part of the season were not delivered, and the party was able to continue work only through the kindness of several miners and prospectors who shared with its members their scant supplies of provisions, and through the abundance of game and berries. At the close of the season the party proceeded to Valdez over the military trail.

GEOGRAPHY.

TOPOGRAPHY.

The Bonnifield region, as the term is here used, occupies an area between 145° 40′ and 149° 20′ west longitude, and 63° 30′ and 64° 50′ north latitude. This includes a large area in the lowlands of the Tanana Valley, which heretofore has not been commonly understood to belong to the "Bonnifield region," but which is shown on the accompanying map (Pl. I, in pocket). The region covered by the map consists of three sharply defined east-west belts, each of distinct topographic character—the Tanana lowlands on the north, the foothills belt, and the high mountains on the north slope of the Alaska Range.

The Tanana Flats extend southward from Tanana River to the foothills. As Tanana River makes a broad loop to the north between the mouths of Nenana and Delta rivers, and as the front of the foothills forms a nearly straight line, the lowland belt is of varying width, being about 30 miles wide along Nenana River, 50 miles wide in the longitude of Fairbanks, and 20 miles wide along Delta River. This great lowland area is of slight relief, sloping gently from the foothills on the south to the Tanana on the north, and from east to west, down the valley of the Tanana. Its surface is broken only by a few isolated hills which rise above the general level of the plain. Much of this flat is covered with a dense growth of spruce, and the drainage is so poor that numerous lakes and marshes make summer

[1] A brief abstract of the portion of this report which treats of the mining developments and of the mineral resources of the region has already been published (Bull. U. S. Geol. Survey No. 480, 1911, pp. 218–235).

travel over most of it impossible. Only the larger streams from the hills to the south maintain definite channels across the flat, and the water from the smaller streams is absorbed into the gravels and reappears as clear meandering creeks, which eventually find their way to the Tanana. No valuable mineral deposits have so far been discovered in the flats, and their future value probably lies in their timber resources and agricultural possibilities, although, as will be shown later, they may contain extensive deposits of coal.

Along its northern border the Tanana lowland ends abruptly, giving place to a belt of foothills which stretches southward 15 or 20 miles beyond the flats, where it in turn gives place to the higher mountains. The foothills consist of minor east-west ranges, which lie parallel to the main range and which have for the most part rounded summits and long, smooth, connecting ridges, ranging in elevation from 2,500 to 3,500 feet, although here and there hills with somewhat sharper peaks rise to heights of 4,000 or 5,000 feet. Between the ranges of hills and parallel with them there are in places broad structural valleys which have little relation to the present stream courses, as some of them send their waters into two or three different drainage systems. Up to the present time the entire gold production of the region has been from the foothill belt.

The third belt, the rugged mountains of the Alaska Range, here trends nearly east and west, and though not so high as that portion which lies west of the Nenana, in the Mount McKinley region, its loftier peaks reach the elevation of perpetual snows and support many vigorous glaciers. The highest peak, Mount Hayes, with an altitude of 13,740 feet, is a conspicuous landmark throughout much of the Tanana country. Both Nenana and Delta rivers flow through the main range in broad, low passes, so that communication between the Tanana Valley and the Susitna and Copper River valleys is not difficult. Between the Nenana and the Delta the range is unbroken by low divides except one between the valleys of Wood River and Yanert Fork. The higher parts of the range are accessible, however, through the valleys of Yanert Fork and of Wood and Little Delta rivers, but these parts have been visited by only a few white men and no systematic prospecting has been done in them, so that almost nothing is known in regard to their mineral resources.

The drainage from the entire region here described is tributary to Tanana River, which flows along its northern border. The larger streams rise in the high mountains to the south and flow northward, and their valleys, cutting the foothill ranges transversely, have formed sharp canyons through the series of schist ridges. The courses of the present drainage lines must have been established in earlier geologic time, under conditions very different from those now existing, for the streams pass repeatedly from low, basin-like areas of little-consolidated deposits into deep canyons cut in hard rocks, although easier courses could have been found which would have avoided crossing the hard ridges. The streams probably follow the courses of earlier streams which flowed northward over a filling of gravels, the remnants of which are still present even on the tops of some of the higher schist hills, and their present courses were established as they gradually lowered their old valleys. Many of the low basins between the foothill ranges contain east-west tributaries which drain to the north-south trunk streams, and these by headward growth are gradually capturing some of the old drainage and taking it by easier routes to the Tanana. The most important streams of the area, from west to east, are Nenana River, Totatlanika and Tatlanika creeks, Wood River, Dry Creek, Little Delta River, Delta Creek, and Delta River.

Nenana River, which flows northward along the western edge of the Bonnifield region, is a large stream which drains a considerable part of the Alaska Range. It heads in the high mountains in the vicinity of Broad Pass and receives drainage from many glaciers, including some which lie on the south side of the range and which would be expected to drain southward to the Pacific. Its largest tributary, Yanert Fork, heads far to the east toward Mount Hayes and occupies a little-known valley which lies parallel to the trend of the mountain range. Below the mouth of Yanert Fork the Nenana flows for a few miles through a narrow canyon, from which it emerges to traverse a board flat-floored valley to the Tanana. As a result of the glacial origin of much of the Nenana water, during the summer the stream is subject to rapid fluctuations in volume and its water is heavily charged with débris. In parts of May, June, and July the melting snows and glaciers flood the stream so that it is often difficult or impossible to cross by fording. The heavy load of gravel and silt which the stream carries has caused it to build up its floor below the canyon, and as it flows through this flood plain it breaks up into an intricate series of channels. It is swift and unnavigable for large boats. Some small boats have been used to run downstream to the Tanana, but the swift current and abundant sweepers make even this dangerous for 30 miles above the mouth. During the winter, like most glacial streams, the Nenana decreases greatly in volume and its water becomes clear.

Totatlanika and Tatlanika creeks receive little glacial drainage and their water is clear throughout the year. They also show less tendency to split up into numerous channels than the glacial streams. Below the point where these streams reach the Tanana Flats their courses lie through a thickly timbered country and are not well known. Dry Creek is similar in character. It is said to join Wood River in times of flood, but during low water it sinks into the gravels and disappears.

Wood and Little Delta rivers, Delta Creek, and Delta River are all of glacial origin, and are turbulent and show the same tendency to fluctuate rapidly in volume and to break up into numerous channels as the Nenana. The Delta, like the Nenana, heads in glaciers on the south side of the range and then flows northward through a broad pass across the mountains.

TRAILS AND ROUTES.

Fairbanks is the distributing point for both passengers and freight for most of the Bonnifield region. This city is reached in the summer by two main routes. That most used leaves the coast at Skagway, by way of the White Pass & Yukon Railway, which terminates at the town of White Horse. From this point river steamers ply down the Yukon to Fort Gibbon and then up the Tanana to Chena, a few miles from Fairbanks, it being necessary to transship both passengers and freight at Dawson, Fort Gibbon, and Chena. This route is favored by those who desire to reach Fairbanks as early as possible in the spring, for the break-up of the ice on the upper river usually permits the first boats to leave White Horse between the 8th and 18th of June, and passengers may reach Fairbanks between the 20th and 25th. The second route, from Seattle to St. Michael by ocean steamer and from St. Michael to Fairbanks by river boat up Yukon and Tanana rivers, can not be used so early in the spring, and passengers can scarcely expect to reach Fairbanks by way of the lower river before July 1. The passenger rates are the same either way, but freight can be brought to Fairbanks much more cheaply by the up-river route. In winter a stage line that carries passengers and the mail for interior points is maintained over the military road between Fairbanks and either Valdez, on the coast, or Chitina, on the Copper River & Northwestern Railroad. This road is also used to some extent during the summer by travelers between Valdez and Fairbanks.

In the absence of navigable streams, railroads, wagon roads, and even of good summer trails, supplies can be transported to the mining camps of the Bonnifield region much more cheaply by sledding in the winter than by pack train in the summer, and the freighting is almost all done during the winter season, when mining operations are at a standstill. In general, the stream courses are followed, as they offer the best grades to the several points. The cost of freighting naturally varies with the distance from the base of supplies and with the amount carried, but it is usually several times as much from Fairbanks to the creeks as it is from Seattle to Fairbanks. The summer rates from Seattle to Fairbanks vary with the route, as well as with the class of merchandise shipped, but range from 4 to 8 cents a pound. When to this is added the cost of delivery at the mining camps, it will be seen that the prospector or mining operator has a serious problem to meet in the cost of his supplies, and that only the richest deposits can be worked at present.

Access to the region is difficult during the summer on account of the marshy character of the Tanana Flats, which may, however, be crossed by pack animals at a number of places. Along the east bank of Nenana River an old Indian trail has been cut out and widened, but numerous forest fires during the summer of 1910 were followed by the falling of timber and much of this trail is now obliterated. It was used to reach the upper Nenana and the diggings on Moose Creek and in the basin of the Totatlanika. A trail from the mouth of Wood River to the camps on Tatlanika and Gold King creeks is passable during the summer months, and a feasible route to the Little Delta, Dry Creek, and Wood River basins follows the military winter road from Washburn across the flats and then swings to the southwest over the high gravel ridges. A fourth route, but little used, leaves the Valdez-Fairbanks military road near Donnelly's and follows the low hills to the west. It is also possible to approach the region from the Susitna basin by way of Broad Pass, though few persons have used this pass up to the present time. Most of the above-mentioned routes can scarcely be dignified by the name "trails," as they include stretches where no trail or tracks can be followed; they are merely lines along which ground sufficiently firm to afford footing for horses can be found. Less than 50 miles of well-defined trail was seen during the whole season. In winter the courses of most of the larger streams may be followed by sleds without the necessity of much chopping. A good winter trail has been cut from the diggings on Gold King Creek across the Tanana Flats to Fairbanks.

RAILROAD POSSIBILITIES.

When a railroad eventually penetrates to the interior of Alaska it will probably cross the Alaska Range either at Delta Pass or Broad Pass. Both of thes routes have been surveyed and a railroad is now in operation at the Pacific coast outlet of each. In the Copper River Valley trains are now running as far north as the mouth of Chitina River, where the railroad turns eastward. This point is about 100 miles from the coast. A line has been constructed from Seward to Turnagain Arm, a branch of Cook Inlet, and the projected line extends up the Susitna Valley. A railroad through either Broad Pass or Delta Pass would tap the Bonnifield region, and the decreased cost of freight and greater accessibility of the region resulting from its construction would greatly stimulate both mining and prospecting.

VEGETATION AND CLIMATE.

The Tanana lowland is well timbered and from it much of the lumber used in the Bonnifield region must be taken. Near Tanana and Nenana rivers, and in fact along all the principal drainage lines, spruce, which is much the most abundant tree of this country, reaches a diameter of 12 to 24 inches and furnishes a fair grade of lumber for sluice boxes and other uses of the miner. A good growth of spruce is also present along the lower slopes of the foothills, above the edge of the flat, and extends up the valleys of the larger streams for some distance. Some tamarack and poplar also grow in the low country, with birch on the drier hillsides. In the swampy, undrained portions of the flats the timber is scrubby and small and is useless except for firewood. The timber line varies with local conditions, but its average elevation is about 2,500 feet. Here and there bunches of spruce may be found at elevations of as much as 3,000 feet, but these are unusual. Even below 2,500 feet there are wide areas which have little or no timber. Willows sufficiently abundant for camping needs are in most places to be found at elevations 400 or 500 feet above the last spruce. In the foothills, where all of the placer mining has been done, timber sufficient for mining uses is to be found only in the valleys of the larger streams. Along the Totatlanika good spruce may be had within a few miles of the head of the stream, but for the camps on the Tatlanika and its tributaries and on Gold King and Portage creeks lumber for sluice boxes must be hauled many miles. In a few camps the outcrops of lignitic coal supply fuel for domestic purposes.

In the early days supplies were brought into this country from Tanana River during the winter on sleds drawn by dogs or by the prospectors themselves, and even yet some small outfits are brought in this way. Supplies for the more important camps are now freighted to the creeks over the snow on horse sleds, and some of the horses are kept through the summer and used for work in the diggings or for packing supplies. For winter work the entire supply of horse feed must be freighted in, as the country offers no winter forage. During the summer grass is abundant nearly everywhere, especially in the heads of draws near timber line. Horses feed freely on both of the most abundant grasses, known locally as "red top" and "bunch grass," but the "bunch grass" is the better feed, as it is still nutritious in the fall, after frost has rendered the "red top" useless. In a few places, especially in the valleys of Wood River and Delta Creek, there grows a small vetch, known as the "pea vine," which the horses eat greedily and which forms excellent grazing, even after frost in the fall. It was seen only on well-drained gravel benches and river bars.

No statistics are available as to the precipitation and range of temperature, but the Tanana region as a whole has a light precipitation, averaging not more than 10 inches a year. Most of this falls during the winter as snow. Placer-mining operations are to a large extent dependent on the water supply and a dry season always cuts down the output.

GENERAL GEOLOGY.

INTRODUCTORY STATEMENT.

The main facts with regard to the geology of this area and the relations of the different formations to one another were first recognized by Brooks and Prindle in their trip down the Nenana River Valley in 1902, and the distribution of the formations as then known, with additional data collected by Prindle in 1906, is shown in a recent publication by these authors.[1] With the completion of a topographic map on a scale of 1:250,000 (Pl. I, in pocket), and with additional study of the geologic notes made by these two men, it has been possible to make some corrections to the earlier map and to extend the areal mapping eastward as far as Delta River. The accompanying geologic map (Pl. II, in pocket) makes no pretense of accuracy except in its broader features, but it is believed to show the general distribution of the different formations with sufficient closeness of outline to aid the prospector in determining the areas which hold out the greatest promise in his search for valuable minerals. If future economic developments justify it, more detailed surveys can be made to work out the problems of distribution and structure which lie beyond the scope of a hasty reconnoissance such as the present conditions demand. In the schist formations no fossils have been found, and the age correlations of Brooks and Prindle, based on lithologic and structural grounds, have been accepted, the older schist being correlated with the Birch Creek schist and a new name (Totatlanika) being introduced for the younger schist.

The geology of the region is epitomized in the accompanying columnar section (fig. 1), and may be briefly outlined as follows:

The oldest rocks of the region, the Birch Creek schist, form the greater part of the high mountains on the north slope of the Alaska Range. They comprise a great series of metamorphosed sediments, which now appear as quartz and mica schists and phyllites, with schistose and micaceous quartzites. When deposited they consisted of shales, sands, and gravels. Later they were subjected to intense and long-continued metamorphism which altered the rocks into schists, phyllites, quartzites, and conglomerates and gave them

[1] Brooks, A. H., and Prindle, L. M., Prof. Paper U. S. Geol. Survey No. 70, 1911.

highly irregular and contorted structures, so that even a hand specimen may show complex systems of folds. This series, after a part at least of the metamorphism had taken place, became a land mass and was subjected to erosion for an unknown length of time. As mapped by Brooks,[1] the width of the schist belt from north to south is about 17 miles in the valley of Nenana River and increases to more than 25 miles farther east along Delta River. The area of the schists is, however, not so great as these dimensions would indicate, as there are within this belt large masses of younger igneous rocks which have been intruded into the schists. No evidence has been found in the Bonnifield region which would determine the age of this schist series, but from its relations with younger fossil-bearing formations in other places it has been provisionally determined to be of pre-Ordovician age.

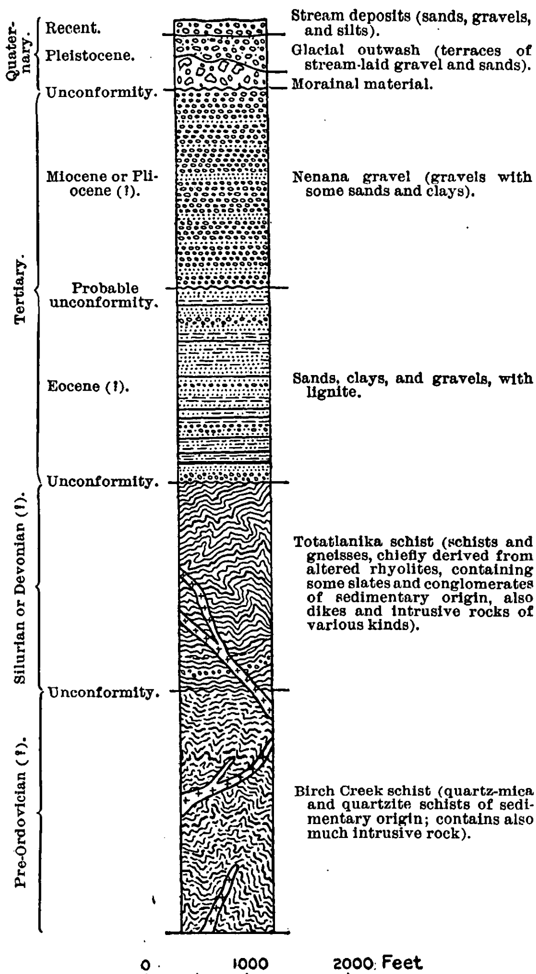


FIGURE 1.—Generalized columnar section of the rocks of the Bonnifield region.

Next younger than the Birch Creek schist, and forming the foothill ranges to the north of the main mountain range, is a thick series of quartz-feldspar rocks, to which the name Totatlanika schist is here applied, from typical exposures along the creek of that name. These are for the most part metamorphosed igneous rocks, but include some infolded beds of sedimentary origin. At the beginning of the epoch represented by these beds conditions for normal sedimentation existed, and gravels and shales were laid down. The deposition was, however, interrupted from time to time by extrusions of volcanic

[1] Brooks, A. H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, Pl. IX.

rocks, chiefly rhyolites, and the igneous material gradually increased in abundance so that in the upper part of the series the clastic beds are almost entirely lacking. The whole series was later folded, faulted, and greatly metamorphosed. Near Nenana River the schists appear at the surface across a belt 18 miles wide, although in places they are covered by younger deposits. Toward the east the belt is narrower, and at Delta River the gravels lie up against the Birch Creek schist and completely cover the Totatlanika schist, if, indeed, the latter formation extends east to this river. The quartz-feldspar schists and the associated beds of sedimentary origin are provisionally assigned to the Devonian or Silurian.

The period of metamorphism was succeeded by a long period of time during which the area here considered stood above the sea and was denuded to a surface of slight relief. Of this erosion period no record is left in the deposits of the Bonnifield region. The next younger beds are of lower Tertiary age (Eocene) and consist of loosely cemented conglomerates, sands, clays or shales, and lignitic coal occupying basins formed between ridges of the older schists. They were laid down in bodies of shallow water, which were probably fresh, as marine fossils are generally lacking. The surrounding land masses that furnished the clastic materials were of rather low relief, and the sediments are, in general, fine, though some beds of small gravels occur. The lower Tertiary beds, although locally folded and faulted, present a young appearance as compared with the schists on which they lie.

After the coal-bearing series was deposited the uplift of the Alaska Range began and the folding of the rocks formed a number of depressed basins in which the lower Tertiary beds were preserved. Between these basins and in the Alaska Range proper the uplift exposed the loosely cemented materials to erosion, and they were removed from much of the area which they had formerly covered. As the Alaska Range continued to grow in height the streams draining northward became swifter and discharged great quantities of material, the Nenana gravel, upon the flanks of the mountain area. These gravels after their deposition were uplifted, with some folding and tilting, and stream erosion made large inroads upon them, removing them entirely in some places and cutting deep, wide valleys in them in others. During the glacial epoch the ice advanced from the mountains down the valleys that had been cut through the foothills and in places laid down moraines and glacial gravels upon the Nenana gravel. On the retreat of the ice the streams attacked the glacial deposits as well as the earlier formations, and all these deposits have contributed materials to the gravels which the streams are now handling.

DESCRIPTIONS OF FORMATIONS.

BIRCH CREEK SCHIST.

CHARACTER AND DISTRIBUTION.

As has already been stated, the Birch Creek schist occupies a long belt on the north slope of the Alaska Range, extending from the east to the west border of the area here considered (Pl. II, pocket). It is also known to be present in the Kantishna country, southwest of Nenana River, and to extend into an unsurveyed region east of Delta River. Its limits to the south lie in the rugged snow peaks of the range and are not well known, but the formation has not been recognized on the south side of the range between the Delta and Valdez Creek. On the north these schists are cut off by several formations, among which are the Totatlanika schist, the Tertiary coal measures, and the high gravels.

The rocks of this series may be seen in numberless exposures in the headwaters of the many streams which rise in the main range. They have been described by Brooks [1] as seen in a tributary of Healy Creek, and, though showing many facies, the series as a whole is distinctive and easily recognized throughout its extent. The predominant rocks are highly contorted and fissile mica and quartz schists and phyllites of green, red, brown, and gray shades. In a few deep, newly made stream cuts where the rock was fresh, it appeared comparatively massive and the mica was not conspicuous. In these places the prevailing color is green, the red and brown coloring of the more weathered exposures being doubtless due to the oxidation of the iron pyrite which can be detected in many fresh specimens. On weathering the schist becomes more fissile, breaking into thin slabs, and the mica gives much of it a glistening, silvery appearance. The finer silts of streams which traverse the schists are in places largely composed of mica scales. The degree of schistosity is not constant, some of the rocks being rather massive and without any well-developed cleavage, while others contain a large percentage of mica and split into thin flakes. Interbedded with the mica schists here and there are strata of metamorphosed quartzite which show some schistosity and contain secondary mica, as well as dense beds of graywacke and fine black slaty schist. In the Kantishna country, west of Nenana River, the series consists largely of quartzite schists, with some crystalline limestone.[2] No limestones were seen associated with these rocks in the Bonnifield region. Quartz veins are present in most places and show a tendency to follow the foliation of the schists.

[1] Brooks, A. H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 56–60.

[2] Prindle, L. M., The Bonnifield and Kantishna regions: Bull. U. S. Geol. Survey No. 314, 1907, p. 206.

They are usually small leaf-like stringers or gash veins, but a few veins were found having a thickness of several feet. In certain localities the vein quartz cuts the schist intricately in all directions and forms a large percentage of the total mass of the rock. West of Little Delta River the quartz-mica schist predominates greatly, but to the east, in the neighborhood of Mount Hayes, the quartzitic and slaty schists become important members of the series in the higher parts of the mountains, as is shown by the abundance of these rocks on the stream bars and moraines of the valleys which drain them. The rocks here more nearly resemble those of the area north of Fairbanks from which they receive their name.

Pyrite in perceptible amounts was found in many of the quartz veins and stringers in the schist, as well as in the schist itself, and in places the vein quartz carries gold, galena, pyrite, and chalcopyrite. There can be little doubt that much of the placer gold of the Bonnifield region was originally derived from these rocks.

Intrusive rocks of a wide range of composition and texture are associated with the schists throughout their extent. They range from basic greenstones and hornblende rocks to acidic types, and from aphanitic, cherty-looking phases to coarse granite porphyries. Some have been metamorphosed with the inclosing schists to such an extent that they seem to be almost as old as the beds which they cut. Others are fresh and massive and show no traces of metamorphism. It will be seen, therefore, that the schists have been subjected to intrusions of various types and at different times throughout their history, and that an assemblage of the igneous rocks contained in these beds would include a great variety of materials. No attempt has been made to map the multitude of small dikes seen, and only those intrusive masses which have a large areal extent are shown on the geologic map (Pl. II, in pocket).

The structure of the schists is intricate and can be solved only after much painstaking detailed work has been done. The beds have been so intensely metamorphosed that for the most part the original character of the material has been lost, and the schistosity and cleavage planes which have been developed obscure the old bedding planes. Strike and dip readings can be made only on the trend of the schistosity and may be quite different from the actual strikes and dips of the original bedding. Moreover, in places the bedding of certain schistose quartzites appears to be regular and easily determinable, but a careful examination may show that they have been subjected to intense folding and that the two limbs of the fold are closely compressed and parallel. Scattered strike and dip readings are therefore of little value in solving the larger problems of structure, as all possible dips and strikes may be found in a small area. When viewed in the large, however, the schists may be seen to form great folds roughly parallel with the trend of the range, the average dips over wide areas being 15° to 60° on the limbs.

ORIGIN.

The origin of the quartz-mica schists is still open to some doubt, although it is probable that they were derived from clastic materials. This conclusion is supported by their close association with quartzites and slates which are certainly sedimentary, yet which themselves contain quantities of secondary mica. The schists, however, contain members that are just as certainly of igneous origin, and these grade up into coarse, unaltered crystalline rocks, so that while most of the series may be considered to have originally consisted of sediments, it nevertheless contains beds of altered igneous rocks.

AGE AND CORRELATION.

The Birch Creek schist has so far failed to yield fossils, and definite proof of its age is lacking. Nothing is known about the rocks which underlie it in this region, but unconformably above it is a series of quartz-feldspar schists containing slates and a little limestone (Totatlanika schist), which are considered by Brooks[1] to be of Devonian or Silurian age, in which case the Birch Creek schist would probably be pre-Silurian. The greater metamorphism which the Birch Creek schist has undergone, however, suggests an age much greater than that of the overlying sediments.

From their general appearance and character the older schists of the Bonnifield region have been correlated with the Birch Creek schist of the area between Yukon and Tanana rivers, first described by Spurr[2] for the Birch Creek placer district. There now seems to be little doubt that such a correlation is correct. The rocks described by Spurr have further been correlated with a series of black slates and quartzites along Porcupine River which Kindle[3] has found to underlie beds that bear Ordovician fossils and which he therefore regards as pre-Ordovician in age.

TOTATLANIKA SCHIST.

DISTRIBUTION.

The name "Totatlanika schist" is here applied to the series of quartz-feldspar schists and gneisses which form much of the foothill ranges and portions of the higher mountains to the south, between

[1] Brooks, A. H., op. cit., pp. 59–60.

[2] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 140.

[3] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Bull. Geol. Soc. America, vol. 19, 1908, pp. 320–322.

Nenana and Delta rivers. Nothing is known of the extension of this belt beyond the limits of the Bonnifield region. There is little doubt, however, that these rocks occur west of Nenana River. As will be seen from the accompanying geologic map (Pl. II, in pocket), the Totatlanika schist forms the northernmost range of foothills in the vicinity of Nenana River and extends eastward to Tatlanika Creek. A second belt, to the south, stretches from the Nenana across the basins of Totatlanika and Tatlanika creeks and, dividing, forms a chain of foothills extending as far eastward as Dry Creek and a part of the Alaska Range to the basin of Delta Creek. The surface exposures of these rocks are cut off on the north by extensive gravel deposits which in many places lie directly upon the schists. In the higher mountains the Totatlanika schist is bordered on the south by the Birch Creek schist, or by masses of intrusive rocks which are younger than either schist.

CHARACTER.

The rocks included under the name Totatlanika schist have been briefly described, although not under this name, by Prindle [1] and by Brooks and Prindle.[2] They comprise material of a wide range of texture, due to the variations both in the original character of the rock and in the amount of metamorphism which the rock has undergone at different places. The most characteristic phase is a porphyritic schist or augen gneiss with phenocrysts of quartz and white feldspar, the feldspar forming the augen, which in places reach a diameter of over 2 inches and have sharply marked crystalline outlines. The matrix in which these crystals lie is a dark, fine-grained groundmass composed chiefly of mica and quartz. The quartz phenocrysts reach a diameter of half an inch. The lines of schistosity are well developed throughout the rock, and in places the quartz and feldspar crystals are orientated with their long axes parallel with the foliation. Excellent exposures of this phase of the schist are to be found in the lower canyon of the Totatlanika, in some of the tributaries of Tatlanika Creek, and in the mountain on Wood River just south of the mouth of Sheep Creek. From the coarse augen gneiss phase the rock grades through successively finer-grained materials with less conspicuous phenocrysts to a very fine grained white or cream-colored sericitic schist which shows little or no grit when broken and rubbed between the fingers. All gradations between these two extremes may be found. When fresh, the groundmass of the augen gneiss is dark in color, spotted by the white feldspar phenocrysts, but the weathering of the feldspar gives the rock a lighter-gray or whitish color. On weathered slopes and on the

[1] Bull. U. S. Geol. Survey No. 314, 1907, pp. 206–207.
[2] Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 149–150.

high ridges the surface is in places covered by fragments of feldspar crystals, left by the decay and removal of the groundmass.

The quartz-feldspar rocks are of igneous origin and have been derived from rhyolites or rhyolite porphyries, with perhaps some tuffs. These have been highly metamorphosed, have become schistose, and contain much secondary mica. From Prindle's description [1] of this series of rocks the following extract has been taken:

> The rock is composed essentially of angular quartz and perthitic orthoclase grains in a finely granular mass of quartz, feldspar, and sericite. It contains a few small grains of plagioclase (albite), apatite, zircon, magnetite, limonite (chloritic material), and in some specimens shows considerable carbonaceous matter.
>
> There are in general three varieties—a coarse-grained variety with feldspars up to 4 centimeters in diameter, a medium-grained variety (the most common) with feldspars 2 to 5 millimeters or more in diameter, and a fine-grained variety, which is a glistening sericitic schist containing only a few isolated grains of quartz and feldspar. At all localities the rock exhibits a greater or less degree of schistosity, but this is due rather to the arrangement of the fine materials than to that of the quartz and feldspar phenocrysts, some of which are conspicuously oriented, with their long diameters nearly at right angles to the general structure. The sinuous lines of fine material wind irregularly among the grains in directions governed by their presence. At some localities, through weathering, the coarse feldspars have been released from the groundmass and their crystal forms and edges are well preserved. Under the microscope the same is found to be true of much of the quartz, and both quartz and feldspar exhibit many cases of embayment. In the least-altered rocks the phenocrysts are still in the original relation to the groundmass and the structure of the groundmass is preserved; it is microgranitic, granophyric, or flow structure. In the rocks showing flow structure protoclastic phenomena are common.
>
> In the process of metamorphism the quartz and orthoclase have been fractured, and in every specimen observed where this has happened with the two in contact the quartz has yielded to the feldspar. Both quartz and feldspar have in many places been converted into augen by the physical and chemical shifting and deposition of material about their margins.
>
> A striking characteristic of these rocks is the universal presence of quartz-feldspar and feldspathic veins. Some of these are a foot or more thick, but most commonly they are but a few inches thick and of small extent. The minutest gash veins cutting the rock in various directions are of the same character. One such vein in thin section proved to be composed for the greater part of its length of feldspar alone. Toward the termination of the vein, however, the feldspar is limited to the margins of the vein, from which automorphic forms extend toward the middle of the vein, where they become embedded in granular quartz. The feldspar is perfectly fresh, has a lower index of refraction than balsam, and on sections cut at right angles to the positive bisectrix gave angles of 5° to 7° to the basal cleavage. No evidence of twinning was observed, and in composition it is probably a nearly pure potash feldspar. So far as noted there is no indication that these feldspathic veins are connected with intrusion, and their material has apparently been derived from the rocks in which they occur. They are unmetamorphosed. In the lack of detailed observations and studies of the veins any explanation can have but a tentative value, but it would seem that the inciting cause is to

[1] Prindle, L. M., Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 149–150.

be found in the process of metamorphism to which the rocks have been subjected.

So far as the evidence is available this assembling of gneisses and feldspathic schists comprises highly metamorphosed rhyolitic rocks, presumably flows, with possibly some associated tuffs and normal quartz-feldspar sediments.

Associated with the altered igneous rocks, especially in the lower part of the series, are commonly to be found beds of carbonaceous shales and schists and some quartz conglomerate, which are certainly of sedimentary origin. A thin lens of limestone was found by Prindle at one place near Jumbo Dome, and in the Wood River basin occurs a bed of impure crystalline limestone of considerable thickness. The carbonaceous schists are most common and extend in a fairly well-defined though discontinuous belt all along the contact between the two schist series. They are interbedded with the quartz-feldspar schists and are so closely folded and involved with them that it has been impossible in an investigation of this kind to separate the two. Indeed, it is probable that the laying down of the sediments was interrupted at times by the extrusion of the igneous rocks, so that they belong properly to the same time period. The beds of clastic origin are prominent only near the base of the Totatlanika schist; the quartz-feldspar schists in its upper portion contain little sedimentary material. The term Totatlanika schist is therefore used to designate a series consisting mostly of altered rhyolites but in its lower part containing much material of sedimentary origin. At one locality (p. 53) a part of this schist series has been found to be heavily impregnated with pyrite and to carry gold, so that the weathering of these rocks may have furnished some of the placer gold of the region, although most of it is supposed to have been derived from the rocks of the Birch Creek schist.

The complex structure of these rocks renders it difficult to gain a knowledge of their thickness. Valleys cut 3,000 feet below the peaks fail to show the base of the series, and much of its upper portion at these places may have already been removed by erosion. On the other hand, the apparent thickness at any particular place may be due to folding and duplication. Definite evidence of the real thickness is now lacking.

AGE.

In the absence of all fôssils from the Totatlanika schist, there is no certain evidence of its age. It overlies schists which are thought to be of pre-Ordovician age, and it has been correlated by Brooks[1] with his Tonzona group, which underlies beds that have been provisionally assigned to the Carboniferous. He therefore assigns it

[1] Prof. Paper U. S. Geol. Survey No. 70, 1911, p. 75.

provisionally to the Silurian or Lower Devonian. No further evidence of its age was found during the present investigation.

INTRUSIVE ROCKS.

Both the clastic and the igneous beds of the Totatlanika schist have been cut by intrusives at various times. Some of the dikes were injected when the rocks were comparatively young and have since been metamorphosed with them. Other intrusives came in much later and are still comparatively massive and unaltered. The intrusive rocks of various types are discussed more fully on pages 41–43.

TERTIARY SEDIMENTS.

EOCENE (?) DEPOSITS.

DISTRIBUTION.

After the deposition of the sediments included in the Totatlanika schist and the outpouring of the rhyolites from which the schists were formed there ensued a long period of time during the upper Paleozoic and the Mesozoic eras of which no sedimentary record appears in the Bonnifield region. The next younger beds that were laid down and have remained are the coal-bearing beds of early Tertiary (Eocene?) age. Beds of this age have been recognized in many parts of Alaska, and in all the localities they show many characteristics in common, their importance being especially due to the presence of lignite in them. The basin of Nenana River has for many years been known to contain an extensive coal field, as that river and two of its tributaries from the east have made deep cuts through the coal-bearing series, and the black coal beds stand in sharp contrast with the lighter-colored sediments with which they are associated. Brooks and Prindle, in 1902, were the first geologists to visit this field but at that time gained little knowledge concerning the extent of the sediments. In 1906 Prindle again visited this region and learned the more important facts in regard to the distribution of the coal beds between Nenana and Wood rivers. His results have already been published.[1] As these investigators have recognized, the Tertiary beds lie in shallow, warped basins bordered by the rocks of the two old schist series. That they were formerly much more widely distributed than at present there is little doubt, for wherever they lie against the bordering ridges they show the effects of vigorous erosion and the little-consolidated materials yield readily to the attack of streams. Even in the high mountains along upper Wood River some beds that are probably of this series still

[1] Prindle, L. M., Bull. U. S. Geol. Survey No. 314, 1907, pp. 221–226; also Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 169–175.

remain, and they may once have covered much of the area now occupied by the Alaska Range and extended northward to the present region of the Tanana Flats. The present distribution of the Tertiary, as now known, is much less widespread, the beds occurring in comparatively small areas surrounded by older rocks. The localities offering the best exposures are in the valleys of Healy and Lignite creeks. A better knowledge of the other fields may increase their relative importance, although the favorable natural exposures near Nenana River will always tend to make mining easier in that locality. The Healy Creek field extends up the valley of that stream for about 10 miles above its mouth. Joining it on the north is the Lignite Creek field, which extends to the head of that stream and eastward to the basin of Tatlanika Creek, a distance of 22 miles. Still farther north smaller fields of Tertiary beds occur in the basin of California Creek, south of Jumbo Dome, and in the basin at the junction of California, Rex, and Totatlanika creeks. In the basin of Tatlanika Creek the coal-bearing beds outcrop along the main stream and in the lower parts of its tributaries Hearst, Roosevelt, and Grubstake creeks, though they are for the most part covered by a later gravel deposit. Still farther east the Tertiary is found on Mystic and Coal creeks, tributaries of Wood River, and is reported from Kansas Creek, while beds of this age are found far up in the mountains, in the basin of Little Grizzly Creek. East of Wood River the coal-bearing beds show at the surface only in small areas in Dry and Newman creeks, in the basin of the Little Delta, and on Delta Creek, as they are mostly concealed by the widespread deposits of later gravels. Beds which may be of similar age have been recognized on the south front of the Alaska Range in Slate Creek and in the headwater region of Delta River. When these coals become of such economic importance as to justify more detailed investigation the area underlain by them will certainly be found to be much greater than that known at present.

CHARACTER.

The character of the coal-bearing series is rather uniform throughout the Bonnifield region. Most exposures show sections of only a small portion of the series, but in Healy and Lignite creeks the stream cuts are deep and the exposures excellent (Pls. VI, VII, and VIII, pp. 56, 58). At the base of the series, where it lies upon the older schists, there is in places a bed composed of smooth quartz and chert pebbles with a matrix of white sand or of kaolinic material. This member is locally 100 feet thick. It is conspicuous on account of its white color and may be recognized from a long distance. It is succeeded by alternating beds of sand, clay, and lignite. The coal is in general more firm and occurs in thicker beds toward the base of the series and thinner and more fibrous near the top. Single lignite beds with thicknesses of 12 to 20 feet are common, and some reach 40 feet or more. The sands, gravels, and clays are commonly but little consolidated, though here and there a thin bed has been cemented by iron oxide. In only one locality, on Little Grizzly Creek, in the Wood River basin, were the beds found to be uniformly cemented into rather firm conglomerates, sandstones, and shales. At this place the sediments of which the beds are composed contain an unusual abundance of dark carbonaceous material and the conglomerates and sandstones are gray or even black. Elsewhere the Tertiary is characterized by its light color. The pebbles of the gravel beds in this series are all of rocks which have been recognized in the Alaska Range, and the materials were probably supplied from that source.

STRUCTURE.

The coal-bearing series occupies shallow warped basins in the schists, the axes of the folding trending in an east-west direction, parallel to the structural trend of the main range of mountains and of the foothills. Each coal field, therefore, lies in a shallow syncline, the beds dipping from the south and north toward the center. In the Healy Creek valley the syncline is rather closely compressed, the beds having dips ranging from 20° to vertical. In the Lignite Creek field, as in most of the others visited, the beds have fairly steep dips along the margins of the basin but are approximately horizontal throughout most of the field. Some faults have been developed in association with the folding, and in one locality it is evident that duplication of the coal beds through faulting has given a greater thickness of coal in the section than is normal throughout this field. The folding has failed to metamorphose the beds noticeably, even where it has been most severe, and the sediments are still incoherent clays, sands, and gravels in places where the beds stand on edge. The only departures from this rule that were seen occur in the isolated patch of consolidated beds on Little Grizzly Creek and in those places where coal beds have been burned out. The burned-out beds are now represented only by masses of ashes and clinkers, but the adjacent sands and clays have been burned to a bright tile-red and are hard and brittle. The intrusive rocks were nowhere found to cut the Tertiary sediments, and it is presumed that they are all of earlier age.

AGE AND CORRELATION.

The age determinations of this series have been based largely on fossil plants, which are abundant in the Bonnifield region, although no invertebrate fossils have so far been discovered here. It has been difficult to procure good specimens for study, however, on account of the unconsolidated condition of the beds. The localities that have furnished the most satisfactory materials are those in which the burning of coal beds has hardened the overlying shales so that they can be handled; in such places some of the fossil leaf prints have been beautifully preserved. The best material which has been obtained was collected by Prindle in 1906 from the area in lower California Creek. The collection was examined by F. H. Knowlton, whose determinations are as follows:[1]

L. M. Prindle, No. 31. California Creek, tributary of Totatlanika. This is one of the finest and most satisfactory small collections of fossil plants that I have examined from Alaska. Although embracing less than 20 specimens, each individual is so far determinable that I have been able to distinguish a full dozen forms. They are as follows:

Taxodium tinajorum Heer.
Populus leucophylla? Unger.
Populus arctica Heer.
Quercus pseudocastanea Göppert.
Quercus? sp.
Myrica? probably new.
Betula prisca Ettingshausen.
Betula grandifolia Ettingshausen.
Betula cf. grandifolia or n. sp.
Juglans nigella Heer.
Hedera auriculata Heer.
Vitis crenata Heer.

Nearly all of these species are enumerated and figured in Heer's "Flora fossilis Alaskana," and I do not hesitate to refer them to the Kenai or so-called "Arctic Miocene," now generally considered Eocene.

C. S. Blair, No. 10. Roosevelt Creek, mouth of Tatlanika. This collection of only about a dozen specimens is interesting, although the material is not nearly so well preserved as the last. I do not recognize any species in this collection, but I note the genera Betula, Alnus, Corylus, Andromeda, etc. While I am not positive about it, my impression is that this material is younger—much younger—than the baked material from locality 31. In any event, there is not a single thing in common in the two localities, and this appears much more modern.

It will thus be seen that here, as in other parts of Alaska, the lower part of the coal series is of Eocene age. The fossils collected from California Creek were obtained near the base of the section at that place, although it is not certain that this is the equivalent of the base in other places. Those from the Roosevelt Creek locality are shown by both the stratigraphic and the paleontologic evidence to be from a much higher portion of the series. Larger and more numerous collections of fossils from the different fields would aid greatly in placing the beds in each place in their proper position in the series.

[1] The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 101–102.

NENANA GRAVEL.

DISTRIBUTION.

The name Nenana gravel is here applied to a widespread series of elevated gravels which covers a large area in the foothill belt of this region (Pl. II). They have received their name from the locality on Nenana River near the mouths of Lignite and Healy creeks, where they have great thickness and offer good exposures. This locality was visited by Brooks and Prindle in 1902. Prindle[1] described them briefly after having again visited the Bonnifield region in 1906, although he published no geologic map. His conclusions in regard to their age will be discussed in a later paragraph. Brooks grouped these gravels with the Pleistocene deposits and shows on his geologic map [2] the main facts in regard to their distribution as far east at Tatlanika Creek. With the completion of a larger-scale map it has been possible to differentiate the Nenana gravel from the glacial deposits, to make some changes in the Brooks's mapping of areas covered by the gravels, and to extend the known areas eastward to Delta River. The gravels also extend both west of Nenana River and east of Delta River into areas that have not been surveyed.

Between Nenana River and the eastern border of the Totatlanika Basin the Nenana gravel occurs in irregular patches, bordered for the most part by areas of older rocks but in places overlain by younger materials. The irregular outlines of the gravels are due in large measure to erosion. Scattered pebbles or even considerable patches of gravels on the tops of the schist ridges (Pl. III, *A*) show that at one time they covered the whole area between the Alaska Range and the Tanana lowlands. They have since been uplifted and attacked by the erosion of vigorous streams, and the underlying rocks have been exposed as the gravels were removed.

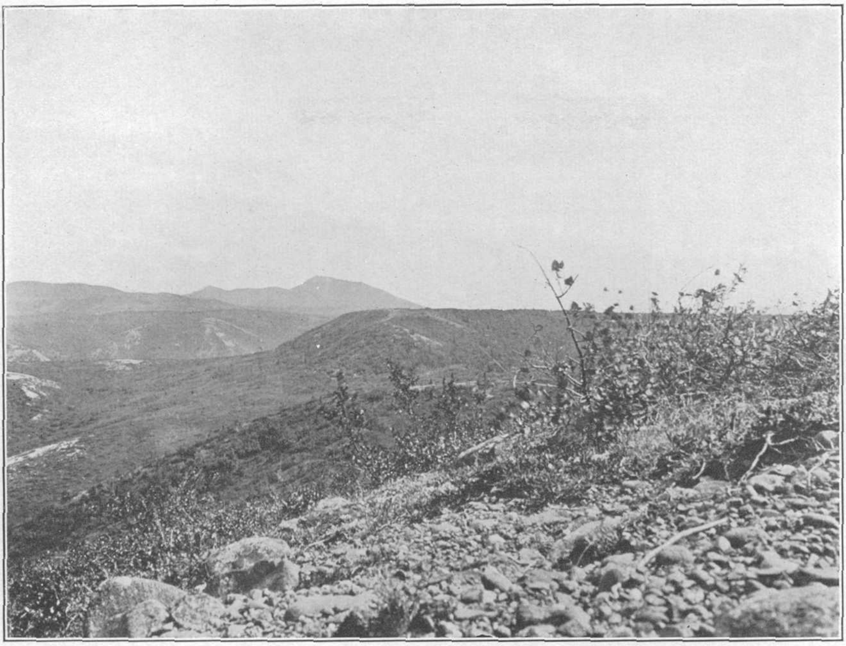
East of the Totatlanika the gravels reach their most extensive development, forming prominent ridges and ranges of hills as far east as Delta River. Gold King, Bonnifield, and the neighboring creeks have valleys which lie wholly or in large part within these gravels, and the high, smooth-topped ranges of hills east of Wood River and south of the main range are of this material. Their total area within the Bonnified region is more than 600 square miles.

CHARACTER.

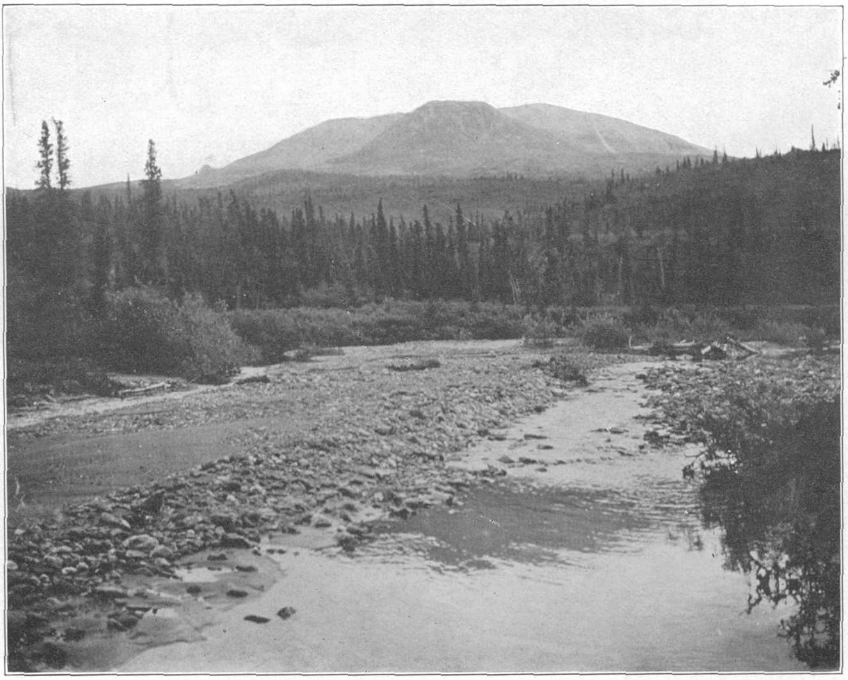
Although the Nenana gravel is so widespread in occurrence its surface forms are for the most part smooth, rounded ridges and hills without good exposures. The coarser gravels remain on the surface

[1] Prindle, L. M., The Bonnifield and Kantishna regions: Bull. U. S. Geol. Survey No. 314, 1907, pp. 205–226.

[2] Brooks, A. H.: Prof. Paper U. S. Geol. Survey No. 70, 1911, Pl. IX.



A. GRAVEL REMNANTS OVERLYING TOTATLANIKA SCHIST ON HIGH RIDGE BETWEEN NENANA RIVER AND CHICKEN CREEK.



B. JUMBO DOME FROM THE NORTH, LOOKING UP CALIFORNIA CREEK.

The dome is a mass of intrusive andesite, left in relief by the erosion of the surrounding schists and Tertiary beds.

and the finer material is removed, the impression being given that the materials are much coarser than is actually the case. Portions of the series are well exposed here and there in stream cuts, especially in the vicinity of Nenana River. The high hill north of the mouth of Lignite Creek shows exposures composed of bedded gravels, some of which reach diameters of 1 foot but most of which are much smaller. Some thin beds of sand and silt are present. The continuation of these beds downward toward Lignite Creek gives excellent exposures of fine gravels with some sand, the whole being oxidized to yellow and brown colors. The materials from which the pebbles were derived are schists, quartzites, granites, and other intrusive rocks, all abundant in the Alaska Range, from which, no doubt, this material was derived. East of Totatlanika Creek, above the lower canyon, benches occur which show beds of fine yellow gravel, with most of the pebbles 2 inches or less in diameter, but some beds containing large cobbles. The same yellow color, due to oxidation, is characteristic here, and some beds a foot or so thick have been cemented by iron oxide into hard brown grits or conglomerates. The many exposures seen to the east show the same characters, and although some bowlders several feet in diameter were seen, the gravels as a whole are fine and are everywhere composed of the rocks found in the mountains to the north.

STRUCTURE.

In all exposures examined the Nenana gravel gives evidence of having been laid down by streams. The arrangement of its materials is practically the same as may be seen in the bars of the present streams, where there is no question of the method of deposition. The gravels are rudely assorted and contain beds of sands and silts, but no fine laminated silts resembling those deposited in bodies of standing water. It is therefore believed that they were deposited as a great compound alluvial fan or apron along the north front of the range before the foothills were elevated to their present position, and that the beds as deposited had only a low dip of 1° to 4° N.

The present attitude of the gravel series shows that it has been subjected to considerable movement. In lower Lignite Creek valley the beds were seen to strike from east and west to northeast and southwest and to dip 10° to 15° N. Farther north, near Nenana River, high remnants of this series dip to the south. To the east, in the basin of Wood River, the dips are most commonly about 3° to 5° N., although many variations to this rule occur. For the most part the original attitude of the gravels has been little disturbed. Prominent tilting has taken place all along the north front of the foothill area, between Nenana and Wood rivers, and probably still farther east. Along this line the beds pitch sharply to the north, in places with angles of 30° to 45°, to disappear beneath the Tanana Flats. It is evident that this was an important line of movement when the foothill belt was elevated. These steeply tilted beds have been separated by erosion from the schist hills against which they lie, and they now form a line of low hills between the flats and the outermost range of schist foothills.

THICKNESS.

The greatest thickness of the Nenana gravel which has been seen in a continuous section and could be measured directly is that reported by Prindle from lower Healy Creek (fig. 3, p. 58), where 1,760 feet of gravel beds are exposed which lie upon and seem to be structurally continuous with the lower Tertiary sediments. In the valley of Gold King Creek the gravels probably reach an even greater thickness, although the exposures are not good. The stream is here 1,800 feet below the tops of the adjacent ridges, without having cut down to the base of the gravel deposits. Great thicknesses are also reached in the basin of Little Delta River. The average thickness over the areas mapped is much less than these measurements, as many of the beds thin out at the edges, and on many of the schist ridges they have not been mapped at all, as they are represented only by scattered pebbles. It is probable also that the beds as originally laid down varied greatly in thickness from place to place, being thickest near the base of the mountains and thinning out irregularly toward the north as the gravels were built up to cover a surface of uneven topography.

AGE.

There is still considerable doubt with regard to the age of the Nenana gravel, as it has so far failed to yield determinable fossils. As seen in the Healy Creek section examined by Prindle, it seems to be structurally conformable with the coal-bearing series and to have been deposited in continuous sedimentation upon it, and Prindle[1] was inclined to believe it to be either the upper part of this series or a later series which succeeded it with structural conformity. Brooks,[2] on the other hand, saw what he considers to be a part of the Nenana gravel lying unconformably on the Tertiary coal measures, and he grouped these gravels with the outwash laid down during a glacial advance. The writer, in studying the relations of the gravels to the coal series near Nenana River, frequently found the higher

[1] Prindle, L. M., The Bonnifield and Kantishna regions: Bull. U. S. Geol. Survey No. 314, 1907, pp. 221–222.

[2] Brooks, A. H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 135–136.

gravels to have dips similar to those of the underlying Tertiary beds and was inclined to think the two series continuous. Near Wood River, however, the gravels are but little deformed and lie unconformably upon the steeply dipping coal measures, so that part of the series at least is much younger than the coal series. It is entirely possible that the two series may be stratigraphically continuous at one place and have an unconformable overlap in another, as a long time period must have elapsed between the deposition of the lowest coal beds and that of the top of the Nenana gravel. The gravels as a whole, however, are less deformed than the coal series, and in view of the difficulty of detecting a stratigraphic break in beds of similar character, an unconformity might long escape detection in a region where the bedding of the two groups is nearly parallel. From the incomplete evidence now at hand the writer is inclined to believe the Nenana gravel to be considerably younger than the coal-bearing beds.

The difficulties of determining the upper age limit of the Nenana gravel are equally great. As already stated, Brooks has classed these gravels with the glacial deposits, but present knowledge as to how early glacial accumulation and ice advance became important in Alaska is most meager, and it has been the custom to include with the glacial deposits only those which were laid down during the last great advance of the ice. In the Bonnifield region there is considerable evidence bearing on the limits which the ice reached during the last great advance and at present no evidence that it has ever extended farther than it did at that time. This evidence will be discussed fully in the section on glaciation (pp. 36-40). In the three main forks of Little Delta River, as well as in the valley of Delta Creek, the ice at the time of its greatest known extent and thickness reached a height of at least 1,500 feet less than the level of the Nenana gravel near by. The moraines also show that the glaciers advanced down valleys which had previously been eroded into the high gravels. The topography of the gravels also shows a much longer period of erosion than has elapsed since the last great ice advance. It will thus be seen that the Nenana gravel is at least older than the outermost moraines of the last notable glaciation. Whether or not the glaciers at some earlier time reached a thickness which would bring them up to the level of the high gravels on Little Delta River, 1,500 feet above the present stream, is not known, but it appears improbable, for so extensive a glaciation should have left recognizable traces in the topography of the mountain valleys. It is true that in the type locality near the mouth of Lignite Creek, the Nenana gravel has on its surface a number of large bowlders, several feet in diameter, which are of much greater size than any bowlders seen in the deposits themselves. Similar bowlders were observed in the valley of Gold King Creek and at other places within the region. The significance of these bowlders is not certain. It has been suggested that they may be of glacial origin, but the fact that some of them occur many hundreds of feet above the upper limit which the ice is known to have reached and a number of miles away from the basin of any known glacier seems to militate against the theory that the bowlders were transported to their present resting places by glacial ice. On the other hand, they were seen only in places where at least the upper portion of the gravels had been removed by erosion, so they may have been originally distributed through a considerable thickness of beds and later concentrated by erosion upon the surface.

Near the mouth of Healy Creek there are bench gravels which lie unconformably upon the upturned edges of the Tertiary coal-bearing series (Pl. VI, *A*, p. 56). These gravels are probably of glacial or glacio-fluvial origin and may be correlated with the glacial terraces so perfectly developed on upper Healy Creek (Pl. V, *B*, p. 38). They are, however, decidedly younger than the Nenana gravel, which rises many hundreds of feet above them and which in places dips more than 30° N., whereas the bench gravels are approximately flat-lying and have been derived in part from the material eroded from the adjacent high gravels.

If the above-stated conclusions are correct, the Nenana gravel is separated from the coal series (Eocene) by an erosion unconformity, which is tentatively considered to represent Oligocene time. It also underlies glacial deposits which are probably of Pleistocene age. Before the glacial deposits were laid down the gravels had suffered extensive erosion, and broad valleys, more than 1,500 feet in depth, had been cut in them. If we consider this period of erosion to have been the Pliocene, the gravels must be of Miocene age.

QUATERNARY DEPOSITS.

PREGLACIAL CONDITIONS.

After the deposition of the Nenana gravel the uplift which had been in progress for some time in the Alaska Range became of importance in the foothills also. West of Tatlanika Creek the northern edge of the area involved in the uplift is sharply marked by the topographic break between the Tanana lowland and the foothills. East of the Tatlanika observations are lacking. The line of movement may be a fault plane, although where observed the Nenana gravel shows a monoclinal tilting. During and after the period of uplift the gradients of the streams across the foothill belt were much increased, and all the larger streams which flowed from the mountains cut trenches through the gravels. As the gravels had been deposited over an uneven surface formed by the erosion of the Tertiary coal-bearing series and of the older schists, the down-cutting streams, whose courses had no relation to the bedrock, encountered the underlying rock at various depths. Through the higher rock ridges the streams cut canyons which are notable features of the topography to-day. Between the hard ridges erosion was more rapid, and broad, wide-floored valleys were excavated in the softer deposits. The larger topographic features, including the ranges of hills and the drainage lines, are believed to have been much the same at the time immediately preceding the great ice advance as they are now. The surface forms had been developed largely through the agencies of weathering and stream erosion, and the rocks in both the mountains and the foothills must have been deeply decayed and partly buried by a mantle of rock débris and soil.

GLACIAL EPOCH.

ADVANCE OF THE ICE.

Through a change in climatic conditions due to a lowering of the temperature or an increase in precipitation, or to both, a period of glacial growth and advance was started. The places in which snow must have first accumulated in quantities sufficient to form glaciers were in the heads of gulches in the high mountains. Large numbers of small independent glaciers were formed in favorable places, and as they grew they stretched farther and farther down their valleys and, like the streams whose courses they followed, finally merged in the trunk valleys.

At just what time the first glacial advance took place in Alaska, or whether there was more than one stage of glaciation, has not yet been determined. It has been shown that in the mountains of the Western States there have been at least two distinct advances of the glaciers, and in the Mississippi Valley five. Whether the mountain glaciation of Alaska represents only the last of these advances has not yet been demonstrated. On the top of the Nenana gravel of lower Lignite Creek there are certain large bowlders whose presence has not been satisfactorily explained. It may be that they were carried to their present position by floating ice at the time of an earlier glaciation, but this is only a suggestion. There is no convincing evidence that glaciation has ever been active in this region before the last great glaciation, of which we have abundant proof. Such evidence would probably not have been preserved, however, unless the earlier glaciation had been more extensive than the last, as the most recent glaciers in advancing would have erased or buried any traces of their predecessors, if they were coextensive. If, on the other hand, the valleys had formerly been filled by ice to a height in excess of that reached by the last ice flood, recognizable traces of such an invasion should still remain. No such traces have so far been found, and it is believed that at no time have the glaciers of this region reached a much larger size or occupied a much greater area than they did during the last important advance.

As the growing glaciers moved down their valleys and increased in thickness they found great quantities of talus, weathered rock, and stream gravels which they easily picked up and carried downward. Later, as the unweathered, hard rock surfaces were laid bare, the ice attacked these and wore them down by grinding them with the rock fragments embedded in it. The more prominent spurs, hills, and irregularities of the valleys suffered most, and by their removal the glaciers carved for themselves troughs which had a tendency to become U-shaped in cross section and free from the minor sinuosities which mark the courses of normal stream valleys in high mountains. These straight-walled, steep-sided, U-shaped valleys are characteristic of all mountains where glaciation has been severe. Without question the valleys were deepened as well as widened, though more detailed investigations will be required before the measure of this deepening can be determined in the separate valleys. It probably amounted to several hundred feet, at least, on some of the more important drainage lines.

EXTENT OF GLACIATION.

The northward extent of the several glacial tongues which came down from the mountains during the last great ice advance is shown by the position of the morainic deposits (Pl. II, in pocket). In the valleys of Little Delta River and Delta Creek the moraines are extensive and conspicuous, and their distinct outlines and the complete absence of similar deposits beyond certain sharply defined limits seem to mark these limits as the farthest extension of the last great glaciers, at least, if not of any previous glaciation. Additional evidence, such as the height of lateral moraines higher up the valleys and the height to which the rock valley walls have been glaciated, all seems to confirm the above conclusion. In the valley of Delta River a well-developed and characteristic moraine terminates some 10 or 15 miles south of the Tanana and is separated from it by a broad, level, gravel plain. Brooks,[1] in a hasty exploratory trip down the Tanana in 1908, saw what he considered to be moraine ridges near the river on the south side, between the mouths of Delta River and Delta Creek. It would take no great extension of the area covered by the glacier which deposited the conspicuous moraine farther south to reach the position of the moraines noted

[1] Brooks, A. H., oral communication.

by Brooks, and it may be that this glacier once extended entirely across the Tanana Valley, forming a dam behind which some of the alluvial beds of the upper Tanana were deposited. In the Nenana Valley the terminal moraine is not so conspicuous, and the northern limit of glaciation is still uncertain, though the ice must have moved as far northward as the edge of the Tanana lowland. In the Wood River valley the glacier reached some distance north of the mouths of Sheep and Coal creeks, though how far has not been determined. Dry and Tatlanika creeks were glaciated only at their upper ends, and the Totatlanika Basin contained no glaciers of notable size.

The northern limit reached by the glaciers of the Bonnifield region corresponds well with the edge of the glaciated area in the eastern portion of the Alaska Range. Here ice from the Wrangell Mountains pushed down the valleys of Nabesna and Chisana rivers to the north front of the range, but on reaching the Tanana lowland it spread out into broad lobes which did not extend more than a few miles beyond the face of the mountains.[1] Between Nabesna and Delta Rivers, however, the Tanana lowland narrows and the mountains extend northward almost to Tanana River, so that it is probable that glaciers from some of the mountain valleys pushed northward to the Tanana. The region on the north bank of the Tanana has been visited by a number of observers, all of whom have failed to find evidence that the Tanana Valley has ever been occupied by a large glacier, and in view of the fact that such evidence would almost certainly have been found if it existed, it is believed that the terminal moraines noted along the many streams entering the Tanana from the south mark the farthest northern extent of the ice from that direction.

The extent of glaciation on the north side of the Alaska Range is in sharp contrast to that of the south side and to that of the high mountains along the Pacific coast of Alaska. The Copper River basin is believed to have been filled by a great ice sheet, and glaciers from Copper and Susitna rivers certainly extended far out beyond the present mouths of these streams. Immediately south of the Bonnifield region, on the opposite side of the range, the glaciers were very much larger and of much greater thickness than on the north side of the mountains. As the temperature in these two regions could not have been greatly different, the differing intensity of glaciation must have been due to a heavier precipitation on the south side, just as the glaciers on the south side of the Chugach Mountains at present are much more vigorous than those on the north, on account of the greater snowfall along the coast.

[1] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska, with a section on the Quaternary by S. R. Capps: Bull. U. S. Geol. Survey No. 417, 1910, p. 28.

RETREAT OF THE ICE.

After the ice reached its maximum extent the climate changed, becoming less favorable for the maintenance of glaciers, and they gradually decreased in size. The retreat, like the advance, probably consisted of a series of oscillations, but the glacier fronts shrank farther and farther back into the mountains toward their present positions. Many lateral tributaries became detached from the trunk ice streams and in turn retreated up their valleys, eventually to disappear or to remain as small valley-head glaciers. The higher parts of the mountains are still glaciated. Nenana River is fed by glacial waters, but the ice tongues from which they flow lie in an unsurveyed area. The Wood River valley is known to support many small glaciers, although little is known about the head of the main fork. Little Delta River heads in at least one large ice tongue (Pl. IV) and several small ones, and Delta Creek is fed by two glaciers of large size. The Delta River basin contains at least four notable ice streams. The general appearance of all these glaciers shows that they are now in a state of slow retreat, although this may be only a temporary condition.

GLACIAL DEPOSITS.

As a glacier advances it forms moraines of the material dropped at its front edge or pushed before it, but these are destroyed when the ice moves forward over them. Only the moraines built at the time of the greatest advance, or during the retreat, are left undisturbed by the ice. Furthermore, moraines left in steep mountain valleys, where stream erosion is rapid, are likely to be quickly removed. The most perfectly preserved moraines, therefore, are those which were built by glaciers that advanced beyond the confines of their narrow canyon-like valleys to the flat lowland. The best examples of this type are to be found in the basins of Little Delta and Delta rivers and Delta Creek (Pl. II, in pocket). All these moraines have sharply defined borders and show the irregular hummocky topography and lake-dotted surface characteristic of such deposits. Farther up the valleys, above the terminal moraines, there are in some places remnants of lateral moraines, built along the sides of the glaciers, but these, so far as seen, are patchy and have suffered much from postglacial erosion.

Almost all the glaciated valleys contain terraces or benches of stream-laid gravels at a height considerably above the present level of the streams (Pl. V). A study of the streams now flowing from glaciers shows that many of them are turbid and heavily loaded with débris supplied by the glaciers and are gradually building up their valley floors with this material. During a period of more vigorous glaciation the same factors were operative, and transporta-

GLACIER AT HEAD OF EAST FORK OF LITTLE DELTA RIVER.

The ridge in the immediate foreground is granodiorite. The surrounding mountains are Birch Creek schist.

A. VIEW NEAR HEAD OF LAST CHANCE CREEK.

Showing remnants of glacial gravel benches above the present stream bars.

B. TERRACES CUT IN GLACIAL OUTWASH GRAVELS ON UPPER HEALY CREEK.

tion and deposition by the streams were more active than now, as the streams were of larger volume and were more heavily loaded. They therefore had a tendency to build up their beds, and as the ice commenced its final retreat the valley filling followed it upstream. As glaciation became gradually less intense, the streams which had been overloaded were relieved of the great quantities of material supplied by the ice, and instead of depositing they began to erode again, and so intrenched themselves in their own valley deposits, the remnants of the earlier filling being left as gravel terraces along the valley sides. In places several such terraces may now be seen, lying one above the other (Pl. V, *B*).

PRESENT STREAM GRAVELS.

The gravel deposits of the present streams are considered to have been laid down under conditions which were essentially similar to those of to-day. They form low gravel flats along all the stream valleys, which are still covered with water in times of flood, and include also the great flat gravel plain of the Tanana Valley. In some places the aggregate thickness of the present gravels is being increased annually, though in times of flood the streams may cut at these places, the filling taking place during lower stages of the stream flow. In crossing the foothill belt many streams are actively eroding their beds where they flow through rock canyons, but in the open basin-like areas between the canyons they have developed broad gravel flats. On their emergence from the hills upon the Tanana Flats the streams all deposit. Many of the smaller ones sink into the gravels and disappear, and all of the load which they carried is laid down. The larger streams which maintain their channels to Tanana River have all built up broad alluvial fans of low gradient. It is from these fans that Delta and Little Delta rivers and Delta Creek have received their names. The present course of Tanana River, which throughout much of its length flows along the north edge of its broad valley, may be due in part to uplift in the region to the south, but is also to an important degree due to a northward crowding by the vigorously depositing tributaries from the south. This general aggradation of the Tanana Valley may also be in part the cause of the heavy gravel filling so characteristic of the gold-producing streams in the vicinity of Fairbanks.

The character of the gravels varies greatly from one locality to another. In general the material is coarsest and most poorly assorted in the high mountains, where the streams are swift, and in the narrow canyons of the foothills. In the broad, open stretches the gravels are smaller and the material becomes progressively finer on the north toward the Tanana. In the lower courses of the tributary streams fine silty sand deposits, forming quicksands, are not uncommon.

The varieties of pebbles found also vary with the different streams and with different parts of the same stream. In the high mountains the pebbles are from the Birch Creek schist and the numerous varieties of igneous rocks which have been intruded into it. Farther north the rocks of the Totatlanika schist appear, as well as the reworked materials of the Nenana gravel beds. In those streams which cut the coal-bearing series the Tertiary sands and gravels have contributed to the recent deposits, and large quantities of coal in slabs, blocks, and fine, weathered particles may be found many miles below the coal outcrops.

POSTGLACIAL EROSION.

As glaciers still persist in favorably situated parts of the Alaska Range, while other portions of the Bonnifield region have, so far as we know, never been covered by ice, it is safe to estimate the amount of postglacial erosion only in those areas which were formerly glaciated, but now lie beyond the ice-covered areas, or in those places where there are deposits that were laid down as outwash from the glaciers. The outermost terminal moraines in the glaciated valleys have been longest exposed to the agencies of weathering and stream cutting and should show the largest measure of postglacial erosion, yet one is impressed, in traveling over these moraine areas, with the slight inroads that the streams have made upon them. They are commonly dotted with a multitude of lakes and ponds, many of which have no outlets. Two lakes were seen not more than 100 yards apart, one standing at least 30 feet above the other, with a low divide between. Neither had a stream flowing from it, and a slight cut would have drained the upper lake into the lower, yet no signs of any such connecting gully were seen. Only along the courses of the larger streams have the moraines been trenched and short drainage lines established. Farther upstream, in the gorgelike valleys, the erosion of the glacial materials has been greater. Recognizable terminal moraines are almost entirely lacking in these valleys, except at the ends of glaciers, and in many places the glacio-fluvial gravels have been so far removed that only isolated patches remain as benches or terraces. The greater erosion of these materials in the higher parts of the valleys, compared with that of the outer moraines, which are older, is due to the concentration of the stream flow in the bottoms of the narrow valleys, at the points where glacial deposits would naturally be left, while most of the outer moraines were laid down in wide lobes beyond the mountain gorges, in a comparatively level country, where the streams, after having once established channels, would tend to follow the same courses and leave the remainder of the moraine undisturbed. The erosion of the hard rocks of glaciated valleys by streams in postglacial time has in most places been unimportant. Some small canyons have been developed, but the smooth-walled, U-shaped troughs left by the glaciers have been little modified. In the areas of the little-consolidated lower Tertiary deposits and of the Nenana gravel stream cutting has been more rapid, especially in the basins of Lignite and Healy creeks. These streams may have been rejuvenated by the glacial deepening of the Nenana Valley. At any rate, they are vigorously attacking the soft deposits of their basins. In the Lignite Valley especially the streams all flow in deep steep-walled gorges and have carved the coal-bearing series into hills which resemble in topography some of the badland areas of the western United States. In upper Healy Creek basin an elaborate set of terraces has been cut from beds which include lower Tertiary sediments, Nenana gravel, and glacio-fluvial deposits (Pl. V, *B*).

IGNEOUS ROCKS.

CHARACTER AND OCCURRENCE.

Granular intrusive rocks of various textures and compositions have cut the schists at many places throughout the Bonnifield region. For the most part they occur in the higher mountains and form areas, some of which are of large size, surrounded by the Birch Creek schist. At one place only, on the headwaters of Totatlanika Creek, was any considerable area of intrusives found to occur within rocks younger than the Birch Creek. Only the larger intrusive masses have been shown on the map (Pl. II, in pocket), such as those in the vicinity of Jumbo Dome, in central Wood River basin, in the Little Delta basin, and in the vicinity of Mount Hayes, although great numbers of dikes were observed throughout the region. It is also known that many areas of granular intrusive rocks occur in the glaciated and snow-covered portions of the Alaska Range, and although it has been impossible to map these rocks, their presence is made known through the materials found on the moraines of the glaciers which come out of the high mountains.

The most common type of intrusive rock is a gray, fine to medium grained granodiorite, containing feldspars ranging in composition from orthoclase to labradorite, quartz, hornblende, biotite, and accessory minerals in smaller amounts. This rock in many places shows inclusions of darker material, consisting mostly of hornblende, biotite, quartz, and feldspar. The inclusions probably represent fragments of basic segregations of the magma, which were later caught up and included in the more acidic material.

Other intrusive rocks, which may be related to the granodiorites, range in composition from true granites to typical diorites. In the valley of Virginia Creek, in the Wood River basin, is an area occupied by granite which is mottled by aggregates of tourmaline. A tributary of Delta River from the west has on its bars large bowlders of a light-gray granite containing crystals of biotite up to half an inch in diameter, while in the same part of the area were found fragments of a gabbroic rock containing quartz, feldspars ranging from orthoclase to labradorite, biotite, hornblende, pyroxene, and olivine.

Jumbo Dome, at the head of the Totatlanika Basin (Pl. III, *B*, p. 30), is a mass of hornblende andesite, a black rock composed largely of hornblende crystals and phenocrysts of plagioclase feldspar, with some augite and olivine visible under the microscope. To the east, in the Platt and Totatlanika basins, this intrusive mass grades into a dacite containing quartz.

The dike rocks found in the two schist series are also of a wide range of composition, all phases from porphyries of the composition of a diorite to diabasic rocks being found, the dark-colored diabasic varieties being most common.

AGE.

The evidence available in regard to the age of the various intrusive rocks of the region, though conclusive so far as it goes, still leaves the time of the igneous activity in doubt. In those areas in which the surrounding rocks are the Birch Creek schist, the intrusive rocks certainly cut the schists and are therefore younger. Furthermore, the schists have been intensely metamorphosed, but the intrusive rocks are in general little altered, so that the metamorphism of the schists must have taken place before the molten magmas were injected. At Jumbo Dome the andesites cut through the Totatlanika schist, which is younger than the Birch Creek schist. The andesite is fresh and unaltered and has been little affected by metamorphism. Overlying the borders of the andesite are beds of early Tertiary age (probably Eocene) containing lignitic coal. The coal is unaltered where it lies close to the intrusive mass and was laid down upon the andesite. From direct evidence, therefore, we find that the rocks of Jumbo Dome are younger than the Totatlanika schist (Silurian or Devonian?) and older than the Eocene. Their undeformed and unaltered condition indicates that they were probably intruded late in this intervening period. No intrusive rocks which cut the Tertiary beds were anywhere found in this region. From the relations of the granitic rocks in other localities, Brooks[1] has made the following general statement:

> The granites of the Alaska Range * * * are in part middle Jurassic, and it seems probable that the others represent about the same epoch of intrusion. It should be noted, however, that the granites cut the Upper Creta-

[1] Brooks, A. H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, p. 52.

ceous rocks of the Rampart region and that there is no proof that the granites of the upper Copper basin are later than upper Carboniferous. It is perhaps fair to assume that there was a general period of intrusion, beginning, possibly, in late Paleozoic time and in some parts of the province extending through to the Upper Cretaceous but having its maximum development late in the Jurassic period.

There are many dikes of various types of intrusive rocks, however, which cut the two schist series yet which have been deformed and metamorphosed with them. These dikes, therefore, are younger than the schists but older than the granitic masses, which are little or not at all metamorphosed.

MINERAL RESOURCES.

GOLD PLACERS.

GENERAL DESCRIPTION.

The localities in which placer gold in paying quantities has been found in this region all lie in the foothill belt between the Tanana Flats and the high schist range to the south. (See Pl. II, in pocket.) Furthermore, the placers all occur in the valleys of the smaller streams which were either north of the area invaded by ice at the time of the maximum glaciation or were themselves not occupied by glaciers. It may be that formerly there was a concentration of gold in the valleys of the main range, but if so this gold was removed by the ice and scattered throughout the moraine deposits, and post-glacial erosion has been insufficient to reconcentrate it or to form new placers. Colors can be found in almost all the streams of the foothills, but gold in paying quantities has so far not been found between Little Delta and Delta rivers. The streams between Wood and Nenana rivers are peculiar in that in their northward courses from the high mountains to the Tanana Flats they cross one or two, one of them four, hard-rock ridges into which they have cut deep canyons with steep rock walls. Between the canyons the valleys widen out and have developed broad gravel floors. Wide areas in the foothill belt are occupied by high bench gravels, the Nenana gravel, and scattered gravels on the crests of many of the schist ridges give strong evidence that the high gravels formerly covered all of this area north of the main range. It is in the streams which have cut their valleys into these gravels or which drain areas that were formerly gravel covered that all the workable placers have been found. The high gravels in many places carry a small amount of placer gold, and doubtless a reconcentration of the gold from these gravels has produced most of the present placer deposits, although some gold may have been contained in the early Tertiary beds and have been reconcentrated on their erosion along with that from the high gravels, and some may have been derived directly from the weathering of the schists.

With the exception of Moose Creek, a tributary of the Nenana, on which gold was first mined in 1909, the list of producing creeks is much the same as it was when visited by Prindle in 1906, and the total number of men engaged in mining or prospecting is smaller than at that time, being less than 50 in 1910. The beginning of active mining of the high gravels in the basin of Gold King Creek was expected to bring about an important increase in the mining population of the Bonnifield region in 1911. The creeks which were producing in 1910 are Moose; Totatlanika and its tributaries Homestake, California, and Rex; two tributaries to Tatlanika from the east, Grubstake and Roosevelt; Gold King; and Portage.

MOOSE CREEK.

Moose Creek is a small tributary of the Nenana from the east, joining that river about 10 miles above the Tanana Flats. It heads in a rounded schist ridge which was once capped by high gravels, and some remnants of these gravels still remain. The stream in its upper course occupies a valley cut in the schists, then cuts through beds of the coal-bearing series, below which it emerges upon the gravel flats of the Nenana. The first production of consequence from this creek was in 1909, when it was reported that 100 ounces of gold were recovered during the last three weeks of the season, the gold being taken from a gravel bench with schist bedrock. It seems probable that the gold is a reconcentration from the high gravels which once covered the schist but most of which have now been removed by erosion. Seven men are reported to have been mining on this creek during 1910.

TOTATLANIKA BASIN.

TOTATLANIKA CREEK.

Totatlanika Creek is a stream of considerable size, which enters the Tanana Flats about 16 miles east of the Nenana. It drains a basin in the hills about 275 square miles in area. It is formed by the confluence of a number of creeks which head in the high schist ridge north of Healy Fork. Below their junction it flows through a succession of rock canyons and broad, open areas, the stream floor being narrow and often difficult to travel in the canyons on account of the swift current of the stream, the steep rocky walls against which the stream cuts on one side or the other, and the accumulations of large bowlders and coarse blocky talcus from the walls above. In the more open spaces between the canyons the valley floor widens, having a breadth of several hundred feet in places, and is composed of cobbles, fine gravels, and sands. The more important tributaries which join the main stream are Homestake, Buzzard, and California creeks below its junction with Rex.

During the last six years a large number of men encouraged by "colors," which can be found in almost all parts of the valley, have prospected along this stream from its head to the mouth of the lower canyon, and most of it has been staked during this period. Especially in the canyons, where the gravels are shallowest, there are numerous old prospect pits and cuts. The stream in its course between the heads of its southernmost tributaries and the Tanana Flats flows across the Birch Creek schist, the soft coal-bearing beds, a belt of andesitic rocks, the Nenana gravel, and the quartz-feldspar rocks of the Totatlanika schist, so that the character of the bedrock varies from place to place and the stream gravels contain materials from all these sources. The gold is in places found scattered throughout the thickness of the stream gravels, but the most valuable deposits generally lie on bedrock, or even extend a foot or two into bedrock where it is broken and decayed. The gold is for the most part flat and worn smooth and although some nuggets worth a few dollars each have been found it is in the main rather fine. During 1910 all attempts to work ground on this stream had been abandoned except on a single claim 2 miles below the mouth of Homestake Creek, where five men were engaged in mining. It is reported that the ground worked was yielding considerably more than wages.

There is abundant water for mining purposes throughout this valley. In fact, the labor required in building wing dams and bedrock drains makes prospecting expensive even in periods of moderate run-off, and in times of high water the control of the stream is a serious problem to the prospector.

HOMESTAKE CREEK.

Homestake Creek is a small tributary of the Totatlanika from the southwest and joins that stream in its upper canyon. In accordance with a custom common among prospectors of giving different names to different parts of the same stream, the lower portion of this tributary is called Homestake and the upper portion Platt Creek. It heads in a broad, rolling depression bordered by schist ridges which extends between the Nenana and the head of Tatlanika Creek. This basin is underlain by the unconsolidated Nenana gravel and by the early Tertiary coal-bearing series. Two miles below its source the creek leaves the open country to enter a narrow, steep-walled canyon through andesite mountains, broadening again somewhat before it joins the Totatlanika.

This valley has been prospected throughout its length, but workable placer ground has been found only in the canyon and in the open part of the valley just above it. Above the canyon mining has been in progress since 1906. The gravels are about 6 feet deep and lie on a decayed schist bedrock. The gold occurs in a well-defined pay streak 30 to 60 feet wide, carrying reported values of about $3 to the cubic yard, being found either on bedrock or in thin beds of oxidized yellowish gravels and sands. The ground being worked at the time of visit evidently received its gold from a small tributary which came in at that point. The gold is somewhat rusty and rather coarse, numerous pieces valued at $3 to $5 having been found. The greatest drawback to mining this ground is the scant water supply, less than a sluice head being available through the summer, so that it is necessary to hold the water with a dam until enough has accumulated to give a good volume for ground sluicing and to supply the sluice boxes.

In the canyon of Homestake Creek, below the mouth of a small tributary called Ptarmigan Creek, three men were engaged in mining in 1910, having been at work on this ground since 1906 with the exception of the season of 1908. Here the gravels average about 6 feet in depth and lie on either schist or andesite bedrock. The gold occurs in a pay streak about 25 feet wide, and the gravels are reported to yield from $3 to $9 to the square yard of bedrock. A sluice head or more of water is available for a season of about 80 days. From the character of the gold and its distribution it seems probable that it has been derived from deposits of high gravels, most of which have now been removed by erosion.

It is estimated that the total production of Homestake and Platt creeks from 1906 to 1909, inclusive, has been about $50,000.

CALIFORNIA CREEK.

California Creek, which joins the Totatlanika at the head of its lower canyon, drains a considerable area in the vicinity of Jumbo Dome and has developed two canyons at points where it crosses schist ridges. Most of its course, however, is through a broad, open country of rounded hills, consisting of gravels, sands, and lignite beds. Colors can be found in many parts of the basin of this stream, although no information was obtained that gold had been produced in commercial quantities. During the season of 1910 work was being done in but a single locality, at the head of a canyon some 5 miles above the junction of California Creek with Rex Creek. Here two men had constructed a bedrock drain, in gravels about 6 feet deep, lying upon a schist bedrock. At the time of visit the gold content of the gravel had not yet been determined, though panning tests seemed to show fair values.

REX CREEK.

Prospecting on Rex Creek has been carried on intermittently since 1905 by a number of men, with but indifferent success. The creek, a tributary of the Totatlanika, heads in schist hills, some of which still retain portions of their ancient gravel capping. Some of its tributaries have sharp V-shaped valleys cut into the schist, but the valley of the main stream is broad and open and in its lower reaches lies in beds of sands, clay, and white quartz gravel, with some beds of lignite, which are thought to correspond with the base of the Tertiary as exposed in Healy Creek.

Both the gravels of the main stream and the low bordering bench gravels carry gold, which is here and there sufficiently concentrated to make mining profitable. The values, however, are unevenly distributed, especially on the benches, and no well-defined continuous pay streak has been found on them. On the main stream the difficulties of securing proper drainage have prevented thorough prospecting. The water supply on upper Rex Creek is too small for extensive workings, between one and two sluice heads being available during the summer.

The ground worked ranges up to 6 or 8 feet in depth, the gold all being found close to the bedrock, a decayed schist, into which the gold has penetrated to a depth of about a foot. The gold is bright and fairly coarse and the gravels contain no bowlders too large to handle. At the time of visit three men were engaged in mining, but it is reported that the returns were insufficient to justify the work and that operations were discontinued in the middle of the season.

TATLANIKA BASIN.

TATLANIKA CREEK.

Tatlanika Creek drains an area which lies east of the basin of the Totatlanika, the streams being 8½ miles apart at the points where they reach the Tanana Flats. It is formed by the union of Sheep and Last Chance creeks, both of which head well back in the high mountains. These streams after emerging from the main range both cross areas of much slighter relief and then enter gorges cut through quartz-feldspar schists; below their junction the Tatlanika enters a broad, open basin in unconsolidated sands, clays, gravels, and some lignite, through which the stream has developed a gravel floor many hundreds of feet in width. Through this broad basin the stream continues for more than 10 miles, suddenly entering another rock canyon, from which it emerges upon the gravel plain of the Tanana. In the basin above the lower canyon the Tatlanika receives tributaries from both the east and the west, those from the east being somewhat larger and having more deeply incised valleys. Three of the eastern tributaries, Grubstake, Roosevelt, and Hearst creeks, have yielded placer gold.

GRUBSTAKE CREEK.

Mining has been carried on more or less continuously on Grubstake Creek since 1905, though only a few men have been employed there at any one time. The valley of the creek lies along the line where the high gravels join the schist ridge to the south and the stream basin includes portions of both the schist and the high-gravel areas. Workable placers have been found only for a mile or two above the mouth of the stream, which has here cut a valley 200 to 300 feet deep through a wide gravel terrace into the beds of the underlying coal series. Where they are worked the stream gravels lie on a soft bedrock of clay, sand, or coal, most of the gold being found in the lower foot or two of the gravels or on the bedrock. The pay streak varies from 25 to 75 feet in width, and the gold is flat, well worn, and rather fine and contains few coarse pieces. Although the gravels contain some bowlders, of a large variety of rocks, derived both from the high gravels and from the schist, most of the material is small enough to be easily handled. About one sluice head only of water is available throughout the season, so that operations are restricted to small workings. In 1910 it was reported that two men were mining on this creek in ground that yielded a satisfactory return.

ROOSEVELT CREEK.

Roosevelt Creek joins the Tatlanika some 3 miles below the mouth of Grubstake Creek. It heads in a high ridge composed of unconsolidated gravels, sands, and clays and has no hard bedrock within its basin. The workable placer ground lies in the lower 2 or 3 miles of the valley, which is here comparatively shallow and open, without high bordering ridges. The placers occur in stream gravels derived by erosion from the high-gravel covering of the ridge in which the stream heads, and the placer gold is doubtless the product of the reconcentration of gold from the same high-gravel beds. In the absence of hard bedrock the gold is concentrated on a "soft bedrock" consisting of clayey or sandy layers of the coal-bearing series into which the stream has cut its channel. The ground worked is shallow and the gold is obtained from a pay streak 20 to 60 feet wide. The gold is flat and fine, and its worn appearance indicates that it has traveled far from its original source. An insufficient water supply has retarded developments on this creek, and the production for the last few years has been unimportant. During the season of 1910 mining was being carried on at one place on a small scale.

HEARST CREEK.

Hearst Creek enters the Tatlanika from the east, a little more than a mile below the mouth of Roosevelt Creek. Like Roosevelt, it heads in the unconsolidated deposits, and the lower part of its valley is cut into the sands and gravels of the coal-bearing series. In the absence of hard bedrock the gold has been concentrated upon the more favorable of the unconsolidated beds. Since 1905 a few thousand dollars' worth of gold has been recovered from this valley, but no information of mining there during 1910 could be obtained.

GOLD KING CREEK.

Gold King Creek is the first stream of importance east of the Tatlanika and flows through the foothill belt with a course somewhat east of north to the Tanana Flats, in which it joins Wood River. It heads in a high ridge of quartz-feldspar schists, through which it has cut a deep notch. From the schists it passes out into the area of high gravels, and its valley, 10 miles below its head, is incised 1,200 to 1,800 feet below the surface of the ridges to the east and west. These ridges were originally parts of a gently sloping plain built up of gravels from the mountains to the north, and in many places portions of the original surface of this plain are still preserved. The materials are for the most part well-washed gravels of moderate size, with some sandy and clayey beds, but portions of the deposit contain bowlders up to 2 feet or more in diameter. The bowlders and pebbles can all be recognized as having come from the mountains to the south. The stream was nowhere observed to have cut down into the coal-bearing series, which probably underlies the gravels.

Mining has been carried on in the stream gravels of Gold King Creek since 1903. The ground worked has ranged in depth from 2 to 8 feet, the principal drawback being the presence of many large bowlders, derived both from the rocks at the head of the valley and from the high gravels. The natural tendency for a stream cutting through gravel beds is to concentrate the large bowlders as well as the heavy metallic contents in the stream channel, while the finer and lighter material is carried away. The water of this creek is usually sufficient for small mining operations, three or more sluice heads being available even in periods of low water, while in wet seasons the flow of the stream is large. The gold is said to assay $17.82 an ounce and is flat, well worn, and rather fine. It is found either in the stream gravels or on a soft clayey bedrock. In 1910 mining operations were being conducted on two claims, Nos. 19 and 21, below Discovery, and the yield at both places was reported to be satisfactory.

In the valley of Gold King Creek, as well as at a number of points on adjacent creeks, large areas of ground have been staked by those who have in view the mining of the extensive deposits of high bench gravels into which the stream valleys are cut and which cover a wide area all along the foothill belt in this region. These gravels in the valley of Gold King Creek have a probable thickness of more than 1,800 feet, and no facts are known as to their depth in the valley bottom. For a number of years these high gravels have been known to be gold bearing, and from them many of the producing placers have been derived by stream concentration. Reports of men who have prospected in various parts of the high-gravel area show their gold content to range from fine "colors" to 3, 5, and even 15 or 20 cents to the cubic yard. The lower returns are usually derived from the gravels near the tops of the ridges; the higher values have been found along the lower slopes. This fact is of significance and probably indicates that the gold in the richer ground has been concentrated by erosion from the gravels above rather than that the actual gold content of the gravels is greater in the deeper-lying beds. Further evidence of the low average content of the high gravels can be obtained by comparing the amount of material eroded in those valleys which lie wholly within them and the richness of the placer gravels in these valleys. Although some of the gold derived from the high gravels might well be expected to have moved on down these streams, yet if the original gravels carried any considerable values it would be expected that the present stream gravels would be much richer than developments have so far proved them to be. In prospecting the high gravels, therefore, tunnels should be driven far enough into the deposits to reach undisturbed beds that have certainly not been enriched by gold from above. Only by careful sampling in this way can the actual gold tenor of the beds be determined.

By far the largest project under way in the Bonnifield region and one which may have a most important influence upon its future development is that of the Berry & Hamil Co., which is making preparations to mine on a large scale the high gravels in which the basins of Gold King and Bonnifield creeks have been eroded. The company controls a large acreage of land in these two valleys. No mining has so far been done; but 45 men were employed during the summer of 1910 in building ditches and roads, erecting buildings, etc. It was expected that during the summer the ditches would be completed so that active mining might be commenced early in the spring of 1911. The ditches include one 2½ miles long and one 2 miles long to take water from the heads of Mystic and Moose creeks, respectively, and drop it into the upper end of the Gold King drainage basin; another 6½ miles long to take the water from upper Gold King Creek to the cut on claim No. 5 below Discovery; and a fourth a little more than a mile long from Gold King Creek to the cut. The long ditch, which is to supply water under pressure for the hydraulic giants, will carry 3,000 miners' inches of water and will give a head of 700 feet at the cut. This is more pressure than will be needed, but the ditch has been laid out so that its continuation will cross the ridge into the Bonnifield basin and will furnish sufficient water for operations on both streams. The giants, with 4-inch nozzles, have been set and the cut opened so that sluicing may be begun without delay. The timber for flumes, sluice boxes, building, etc., is sawed at the company's mill situated a few miles below the mine workings. Most of the upper portion of the valley is timberless. So far as could be learned on the ground, it appears that the deposit to be worked has not been extensively prospected, and its gold tenor can be accurately told only when some considerable body of it has been sluiced. Conditions should be favorable here for the handling of ground at a very low cost, as a very high gravel face will be available when the cut is run back into the hill a few hundred feet. Furthermore, although some large bowlders occur in the gravels, most of the material is fine enough to be readily handled by the giants, and with the high pressure available successful working is largely a question of water supply. If the ground proves to be rich enough to warrant it, mining will be established on a permanent basis in this region, as the gravels are practically inexhaustible and are so widely distributed that the water from a large number of streams could be used in their exploitation.

DRY CREEK AND LITTLE DELTA RIVER.

Dry Creek heads in the high schist mountains and flows north to the Tanana Flats, draining a basin which lies just east of that of Wood River. In the foothills the stream carries a large volume of water, but soon after reaching the flats much of its water is said to sink into the gravels and disappear. Above the mouth of Newman Creek, its largest tributary from the east, the valley is cut into schists. Below Newman Creek the stream flows for 5 miles in a wide valley cut through high gravels into the coal-bearing formation and then enters a schist canyon through which it flows for about 5 miles, emerging into the broad, flat valley of the Tanana.

The stream gravels of Dry Creek are known to carry gold, and the valley floor has been staked for a few miles above the mouth of Newman Creek and considerable prospecting done. The gravels are from 4 to 8 feet deep and lie upon schist bedrock. Returns as high as $3.50 to the square yard of bedrock have been obtained, but large bowlders are numerous and the ground proved too wet to work without establishing a bedrock drain, an undertaking which has so far discouraged the owners.

Caribou Creek, a tributary of Dry Creek from the west, about 7 miles below the mouth of Newman Creek, flows through a valley which is reported to lie in high gravels at its head and in schist in its lower portion. In 1909 two men made fair wages by working the stream gravels, but the ground appears not to have been rich enough to encourage them to return, and no work was done on this stream during 1910.

Newman Creek drains a basin which includes schists, the coal-bearing series, and high gravels. The stream gravels carry some gold and the high-gravel hills are also auriferous, reported prospects in the upper beds of the high gravels showing a tenor of 3 or 4 cents to the cubic yard and the values increasing somewhat in the lower beds. At the base of the high gravels, which are similar to those already described for Gold King Creek (p. 50), there is a bed of clean, rounded white quartz pebbles, locally known as the "white channel," on which there seems to be some concentration of gold. Newman Creek has so far not produced gold in commercial quantities, but a project is under way to exploit the high gravels on a large scale. One party has staked 125 association claims of 120 acres each in the basins of Newman Creek and West Fork of Little Delta River, water for hydraulicking to be taken from the latter stream. It was expected that the ditch would be surveyed during September, 1910, and active construction started in the spring of 1911.

Portage Creek is a small tributary of West Fork of Little Delta River and has a basin in the high gravels east of the head of Newman Creek. Placer mining of the stream gravels has been carried on continuously for the last five years at one place, the gold being concentrated on a clay bedrock. No hard bedrock occurs in this gulch. The total production of the creek to 1911 is estimated at $10,000.

LODE MINING.

The wide distribution of placer gold in the Bonnifield region has attracted the attention of many prospectors to the search for placer mines, yet comparatively few men have been seriously engaged in the search for the lodes which must have furnished the gold to the gravels. Both the geologic and the physiographic evidence at hand point to the high schist mountains of the Alaska Range as having been the ultimate source of much of the gold, and these mountains hold forth considerable promise to the hard-rock prospector. Associated with the schists of the main range, which have been correlated with the Birch Creek schist of the Fairbanks region, also cutting the quartz-feldspar schists to the north, are many intrusive granitic rocks, and there is some reason to believe that the mineralization of the schists may be due to these intrusions. The schists in the neighborhood of such granite and diorite masses are therefore, so far as known, the most promising fields for the search for mineral-bearing lodes. Lode prospecting has so far been largely confined to the basin of Wood River.

In addition to the gold-bearing lodes to be described in the following paragraphs, veins carrying copper and lead were seen at a number of places in the region. No development work has so far been done on these veins, and in the present lack of transportation facilities such deposits have only prospective value.

CHUTE CREEK.

Chute Creek is a tributary of Wood River from the east. It is about 6 miles long and flows in a deep, narrow-bottomed gorge through a complex series of schists cut by intrusive dikes of various kinds. In 1908 J. C. Rogers, a prospector, found a certain zone in the schist to be heavily mineralized with pyrite and to carry some gold. The lode is an altered rhyolite porphyry, which weathers to conspicuous red and yellow colors and is filled with extremely small cubes of finely disseminated pyrite. The same rock or a very similar one occurs in the valleys of Sheep Creek to the south and of Dry Creek to the east. In 1909 a 3-stamp mill was installed on Chute Creek and operated for about a month. The mineralization was observed to occur in a zone which has a width of over 100 feet, striking nearly north and south, and which has a high dip, so that a large body of pyritized rock is exposed. It is reported[1] that the average values recovered were equal to $5 in free gold to the ton of rock milled, and that assays of the tailings yielded about $4 a ton more. The average of a number of assays of the lode at its outcrop on Chute Creek is said to have been $9 a ton. In August, 1909, the mill was washed out by a freshet, and it has since been removed to another part of the country. A 30-foot tunnel driven into the ore body in 1910 showed no changes in the rock other than those due to protection from surface weathering. Assays of a similar mineralized rock from Chute, Sheep, and Dry creeks all showed traces of gold, although no attempt was made to sample any ore body. If further tests prove the average gold tenor of this mineralized zone to be anywhere nearly equal to the values reported, there is here an opportunity to develop mines in which the large supply of ore and the favorable conditions for mining should allow a liberal margin of profit over the cost of production. A lignite coal of rather good grade could be procured for power within 5 miles of the mineralized zone.

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[1] Brooks, A. H., Bull. U. S. Geol. Survey No. 442, 1910, p. 36.

KANSAS CREEK.

Kansas Creek is one of the larger tributaries of Wood River from the east. In its basin, as well as in that of Copper Creek, which enters Wood River opposite Kansas Creek from the west, there occur bodies of a black quartzitic rock associated with the schists, which are reported to carry gold. The only development work that has been done in these bodies is on Kansas Creek, where, it is reported, a 90-foot tunnel has been driven into a black quartzitic bed which shows disseminated pyrite. No report of the assay value of this rock was obtained.

GUNNYSACK CREEK.

A short distance above the Rapids Roadhouse, on Delta River, a small tributary stream from the east known as Gunnysack Creek has cut a deep gorge through the Birch Creek schist. About half a mile above the mouth of this tributary claims have been located upon a large quartz vein which strikes S. 33° W. (magnetic) and dips about 70° NW. This vein cuts the schists, which are here quartzitic mica schists of much-contorted and wavy structures. The main vein, which is irregular and branching, is in places more than 20 feet thick and consists of massive milky quartz, showing some rusty spots and vugs formed by the removal or oxidation of pyrite. A 30-foot tunnel in the schist footwall shows a stockwork of quartz stringers in the schist parallel to the main vein. Reports of rich assays from this vein led to some little excitement a few years ago, but further tests proved the gold content to be too low for profitable extraction under present conditions. The claims on this vein are reported to have been abandoned, and no work has been done on them for some time.

COAL DEPOSITS.

GENERAL DESCRIPTION.

The coal-bearing rocks, referred to frequently in the preceding pages, occupy a large area in the foothills north of the main range and have their greatest known development and offer the best exposures near the western edge of the area under discussion. The rocks as far east as Wood River were visited and their approximate distribution mapped by L. M. Prindle in 1906. During the summer of 1910 further information was obtained regarding the areal extent of this important series, and numerous exposures were found which extend the limits of the formation eastward to the neighborhood of Delta River. Reports from prospectors also show that coal, probably of the same age, occurs both east of the Delta and west of the Nenana, so that further investigation may extend this field to the east and west much beyond its limits as now known. It also seems highly probable that the coal series underlies parts of the areas of high gravels and of the Tanana Flats. From the facts now known no estimates can be made of the possible coal resources in the region where the formation is completely covered by later deposits, as the coal beds may there lie too far below the surface to be economically available, and the large supply of more easily accessible coal will certainly be used before an attempt is made to utilize the deeply buried coal.

The coal-bearing beds where best known lie in low troughlike areas between the east-west ridges of schists which form the foothills (Pl. II, in pocket). The series consists of sands, clays, gravels, and coal, the beds being usually but slightly cemented. The base of the series is composed of beds of pebbles and angular or partly rounded bits of quartz in a matrix of white sandy clay or of kaolinic material which where exposed is conspicious for its whiteness. These beds are succeeded by alternating sands, clays, and coal, the coal beds being in general thicker toward the base of the series and thinner near the top. One section shows an aggregate of 230 feet of coal, of which more than 200 feet is in beds 4 feet or more thick. In many other less complete exposures the total thickness of coal measured was from 50 to 130 feet, single beds reaching thicknesses of 20, 30, or even 40 feet. In many places, too, certain of the coal beds have been burned out, leaving the adjacent beds burned to a bright tile-red. Where this has occurred the beds immediately above are locally brecciated and much disturbed by caving down to fill the void left when the coal burned out (Pl. VIII, *B*, p. 58). The red baked beds are much harder than the associated unconsolidated deposits and have retained the imprints of fossil leaves which show the coal series to be of Tertiary age.

The coal beds of the Tertiary vary considerably in character, being firm, compact, and in places very thick lignite beds near the base of the section, but becoming thinner and more woody in the upper part. No openings were seen which would give an opportunity to collect fresh, unweathered samples for analysis, but the surface outcrops of the lower beds furnish a fuel which has had some small local use and which is said to burn freely and without much ash. Although probably of too low a grade to compete with the better coals of the coast for export, it would find a ready market for use in the interior of the Territory. It also offers exceptional opportunities for the development of power in the coal fields for electrical transmission to points in the Tanana Valley. Fairbanks is less than 65 miles from the nearest of these fields and well within the zone of economical transmission. An analysis of coal from Healy Creek collected by Prindle[1] is given below. The sample was taken from a weathered outcrop, as no openings showing fresh, unweathered coal had been made.

Analysis of coal from Healy Creek.

[E. T. Allen, analyst.]

Moisture	13.02
Volatile matter	48.81
Fixed carbon	32.40
Ash	5.77
	100.00
Sulphur	.16

This sample was not collected in an air-proof can, and the percentage of moisture given may therefore be less than the normal amount.

A heavy series of gravel beds, the Nenana gravel, overlies the coal-bearing series at many points and was probably once continuous over much of the foothill area, but erosion has now removed the gravels in many places where their former presence is shown only by small patches or by scattered pebbles. The exact stratigraphic position of this gravel series is still in doubt and can be determined only by more detailed investigation. No determinable fossils have so far been found in it. It seems to be distinctly older than the glacial deposits, occurs at elevations above those reached by the ice at its greatest known development, and is folded and tilted more than the glacial deposits. In the vicinity of the Nenana it seems to be structurally conformable and continuous with the top of the coal-bearing beds and was thought by Prindle to be a continuation of the coal-bearing series. At points farther east, however, it seems to overlie the Tertiary beds unconformably and the writer is disposed to think that an erosion interval elapsed after the deposition of the coal series before the high gravels were laid down. It is possible, however, that different conditions existed in different localities and that the gravels may be continuous and conformable with the coal-bearing beds in some places and unconformable in others.

In discussing coal fields which may in time become of great economic importance in the development of the Territory, it is desirable to estimate as closely as the information at hand will warrant the tonnage of coal contained in the field. Such estimates are made in the following pages for the more important coal fields of the Bonnifield region. It must be borne in mind, however, that these estimates contain many uncertain factors and can be considered as trustworthy only in indicating the order of magnitude of the true figures. Esti-

[1] Prindle, L. M., The Bonnifield and Kantishna regions: Bull. U. S. Geol. Survey No. 314, 1907, p. 224.

A. TILTED COAL BEDS ON LOWER HEALY CREEK.

The creek flows along the contact between the Birch Creek schist on the right and the Tertiary beds on the left.

B. CONTORTED COAL BED, UPPER HEALY CREEK.

mates which approximate accuracy can be made only after detailed surveys have determined more closely the areas of the fields, the extent and continuity of the individual coal beds, the structure of each field, and many other factors which are beyond the scope of a hasty reconnaissance such as that on which the present report is based.

The estimates of tonnage given below were made on the following basis:

1. No beds less than 4 feet thick were assumed to be workable or contributed to the tonnage.
2. The depth of workability was assumed to be 1,000 feet.
3. The tonnage was computed by the formula: Tonnage=area of bed to limit of workability (square miles)×thickness (inches)×specific gravity×72,600.
4. The specific gravity was assumed to be 1.30 for lignite.

LOCAL DESCRIPTIONS.

HEALY CREEK.

The valley of Healy Creek is occupied by the coal formation for about 10 miles above its mouth. In a general way these beds form a

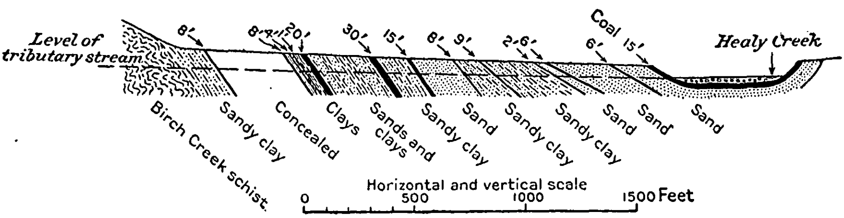


FIGURE 2.—Section of the Tertiary coal-bearing series on Healy Creek.

synclinal trough whose axis is parallel with the valley. The stream follows the trough of the syncline in its upper end, but lower down it crosses one limb of the syncline and flows along the contact between the coal-bearing beds and the schist (Pl. VI, *A*). The deposits occur in a basin in the schists, upon which they lie unconformably on both limbs of the basin, the dips of the coal beds ranging from vertical in a few places to horizontal at the bottom of the trough. In some places the beds have been contorted and faulted (Pl. VI, *B*). Near the east end of the coal basin Healy Creek flows for more than a mile in the trough of a coal bed which forms the banks of the stream on both sides. The folded coal beds have suffered vigorous erosion, both by streams and by glacial ice, and in upper Healy Creek much of the series has been removed. A measured section about 6½ miles above the mouth of the stream shows a thickness of about 1,500 feet of these beds (fig. 2), and here the upper part of the series is missing. Near the mouth of the stream a section which was carefully

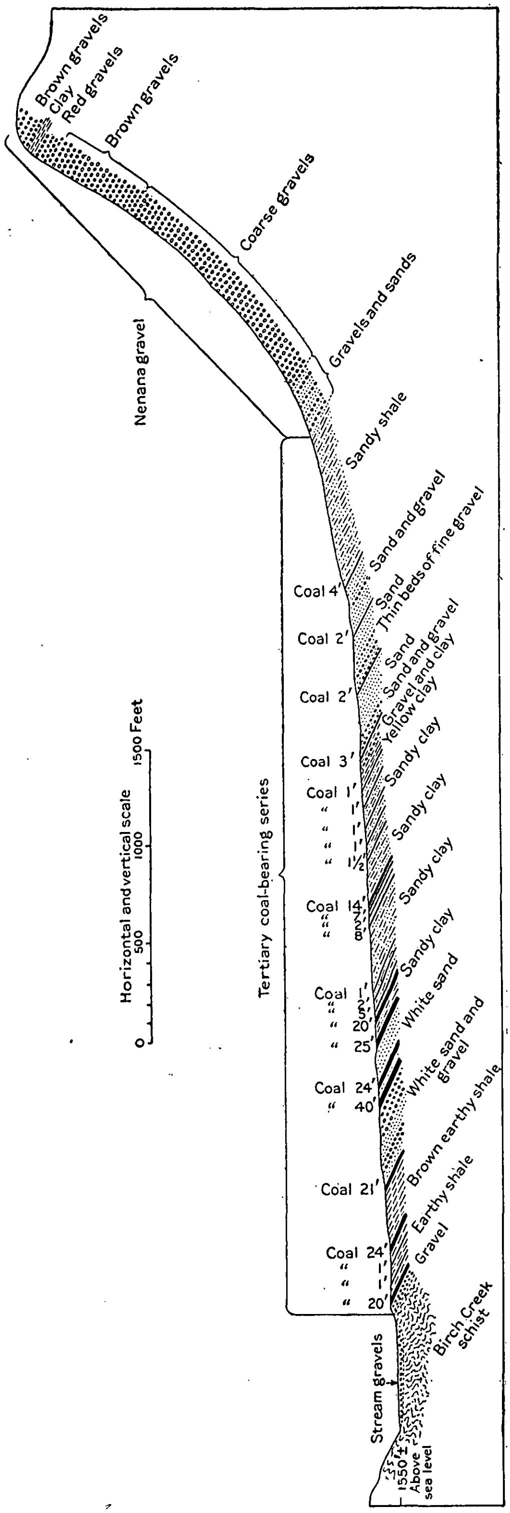
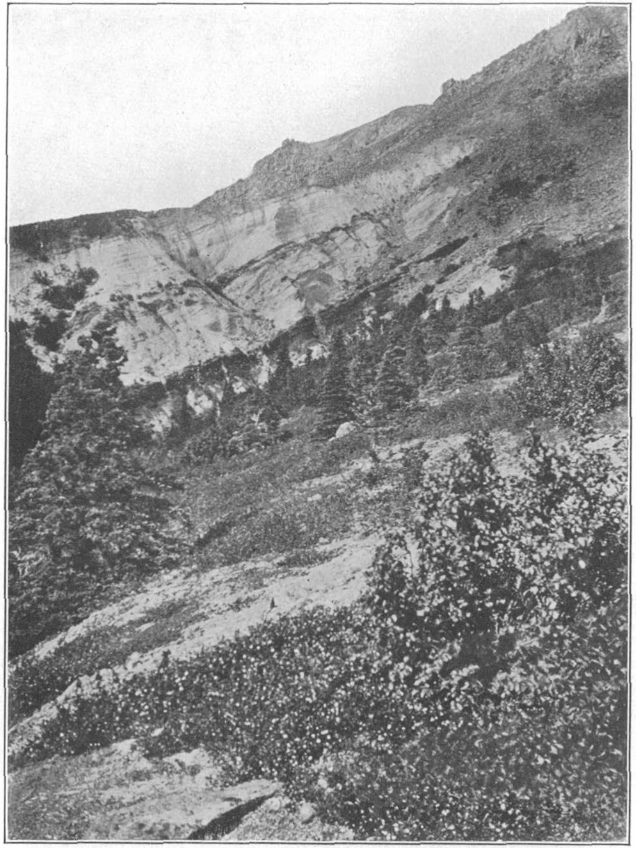


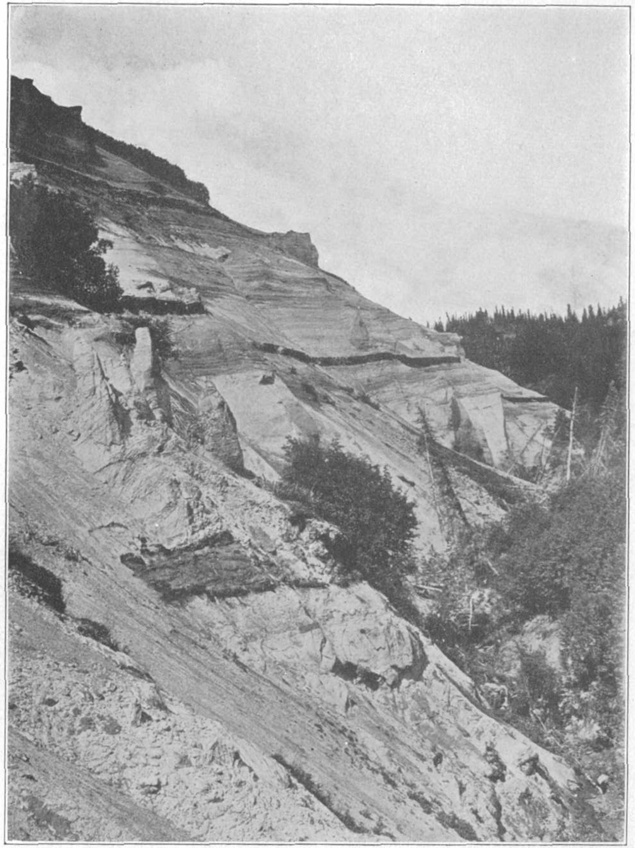
FIGURE 3.—Section of the lower Tertiary beds and the Nenana gravel near the mouth of Healy Creek.

measured by Prindle gave over 1,900 feet of the coal series, with about 2,000 feet of the overlying gravels (fig. 3). The coal series may or may not be complete at this point. The total thickness of coal found in a section near the mouth of the creek was 230 feet in 23 beds, of which seven beds contain 174 feet. A section 6 miles farther east showed 130 feet of coal, of which four beds contain 80 feet. These were the two places where measurements could best be made. As some beds of coal have been burned out in almost all sections examined, the above measurements probably fall short of the original thickness.

Between the mouths of Healy and Lignite creeks the coal-bearing series is covered by glacial deposits and by the Nenana gravel. This portion of the field has not been carefully studied, but it is highly probable that the coal series of rocks is continuous between these two creeks, beneath the beds of later gravels, so that any estimates of the area of the coal field must include portions



A. TILTED TERTIARY COAL BEDS LYING AGAINST THE SOUTH SIDE OF JUMBO DOME.

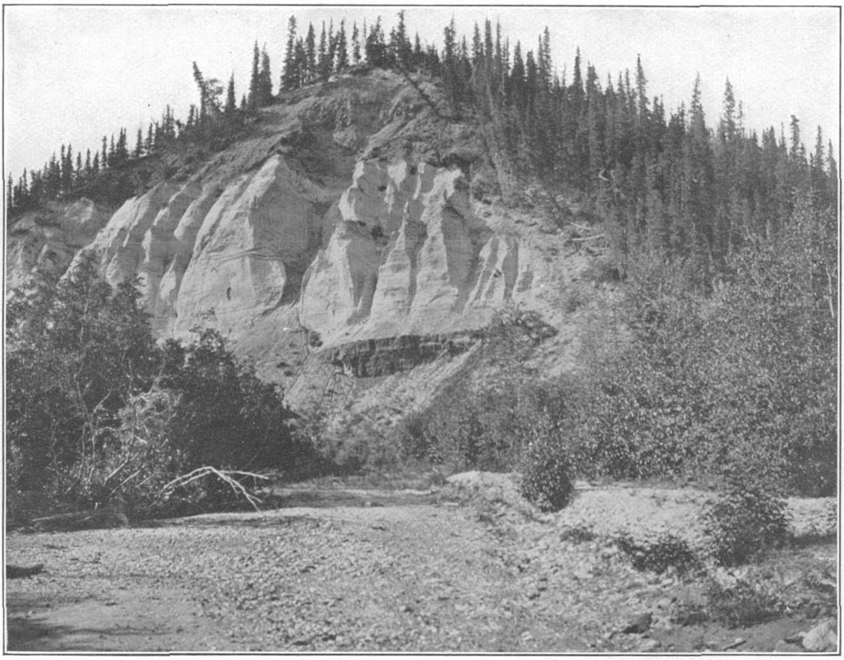


B. UPPER PORTION OF THE TERTIARY COAL-BEARING SERIES, LIGNITE CREEK.

The lignite beds near the top of the series are fibrous and woody and form a smaller proportion of the total thickness than those near the base.

A. A THICK BED OF COAL ON LIGNITE CREEK.

Twenty-one feet of coal, in a single bed (*a* to *b*), shows above the level of the stream.



B. TERTIARY COAL BED, 20 FEET THICK, ON LIGNITE CREEK.

The absence of bedding in the upper portion of the bluff is due to the burning out of a coal bed which lay just above the white sands.

of the areas mapped as gravels on the accompanying geologic map (Pl. II, in pocket). There is also every likelihood that the coal beds of this field extend west of Nenana River into a region which is as yet unsurveyed.

As already stated, a section near the mouth of Healy Creek and another 6 miles above the mouth showed 212 and 133 feet of coal, respectively, not including any beds less than 4 feet in thickness. As the field has its greatest width near the mouth of the stream, the mean of these two measurements, 172 feet, probably represents a conservative average thickness for the whole field. Calculated from this thickness and with an area of 20 square miles, the total lignitic coal content of the field would be more than 3,890,000,000 tons.

LIGNITE CREEK.

The Lignite Creek coal basin is separated from that of upper Healy Creek by a high schist ridge, but the two fields are probably continuous at their lower ends. The Lignite Creek field extends eastward beyond the head of Lignite Creek and includes areas on the headwaters of Totalanika and Tatlanika creeks. In its east end exposures are few and poor, as the streams have made only shallow cuts into the beds, but sufficient outcrops of coal were seen to place most of the basin among the known coal-bearing areas. By far the best exposures are to be found in the valley of Lignite Creek and its tributaries, which have cut sharp, steep-sided valleys as much as 600 feet into the coal-bearing beds, without, however, anywhere exposing the underlying schist in the center of the valley, so that the lower part of the series is not shown. The beds, like those in the Healy Creek valley, lie in a basin bordered by schist ridges and old intrusive rocks, dipping away from either border toward the center of the valley. Although at some points along the borders the dips are high, being as much as 45° on the south side of Jumbo Dome (Pl. VII, *A*), in general the coals of Lignite Creek lie much flatter than those of Healy Creek, and throughout most of the valley they appear to the eye to be horizontal. The beds consist of cross-bedded sands, soft blue shales, some fine, loosely cemented conglomerates and gravel beds, and coal. In the deeper exposures the coal is hard and dense and the beds are heavy (Pl. VIII), but in the upper beds the coals become woody and fibrous, with much shaly material, and the beds become successively thinner (Pl. VII, *B*). As the coal series of lower Healy and Lignite creeks is overlain by a thick deposit of gravels, its actual areal distribution is much greater than is shown by a map of its surface occurrence.

A section of the coal series measured by L. M. Prindle about 6 miles above the mouth of Lignite Creek gives 129 feet of coal in a total thickness of 726 feet of beds. Of this more than 100 feet occurs in beds 8 feet or more thick. Another exposure about 2 miles farther upstream shows 50 feet of coal in a section of 170 feet. Still other exposures, distributed throughout the field to its eastern edge, show thicknesses of 40, 70, and 20 feet of coal. None of the above-mentioned exposures extend to the base of the coal-bearing series, and it is highly probable that in each place there are important coal beds which do not show at the surface. An estimate of the coal tonnage of this basin was based on the average of the five incomplete sections measured and is doubtless much less than the actual coal content. By using 62 feet as the average thickness of coal throughout the 80 square miles of the field, the coal content is found to be more than 5,700,000,000 tons.

CALIFORNIA CREEK.

One fork of California Creek heads on the south side of Jumbo Dome, in the Lignite Creek coal field. North of this dome it flows through another area underlain by the coal-bearing series, which outcrops at the surface over an area of about 15 square miles. The beds have here the same structural relations as elsewhere, lying in a basin bordered by schist ridges and dipping toward the center of the basin. The dips, however, are gentle, and throughout much of the field the beds are nearly horizontal or lie in gentle wavelike swells. As the streams have nowhere made deep cuts through the coal series, the thickness seen is probably much less than the actual thickness and there may be many coal beds below, no surface outcrops of which were observed. The extent of the field is also greater than the surface distribution of the exposures, for along its western edge the coal beds are overlain by a heavy deposit of gravels. They are composed of sands, shales, and white kaolinic materials containing quartz fragments and pebbles, with beds of lignitic coal. Along the main stream for several miles a heavy coal bed 12 feet thick shows in the bluffs, in places dipping below the stream bars but in general lying nearly flat. Other outcrops of the same or a similar bed appear in tributary valleys to the east, so that it is probable that the field contains at least 12 feet of coal throughout its area. If a single coal bed 12 feet thick underlies the whole field of 15 square miles, the total coal content of this field is more than 200,000,000 tons.

In the basin at the lower end of California and Rex creeks the beds of the coal series cover an area of about 20 square miles. They are similar in character to those on upper California Creek and are conspicuous for the prominent white bluffs exposed along Rex Creek and for their bright-red color in many places where the coal has burned out and baked the adjacent beds. Some woody coal was seen on a small tributary south of Rex Creek, but no workable coal beds are known in this basin.

TATLANIKA BASIN.

On the east side of the Tatlanika Valley, in lower Grubstake Creek and between Roosevelt and Hearst creeks, the clays, sands, and coal beds of the coal series outcrop, and it is reported that similar beds occur as far north as the head of the lower canyon of the Tatlanika. Little is known of the amount of coal present, although a bed 12 or 15 feet thick is said to outcrop at the surface, dipping at a low angle to the east. No development of the coal has been attempted here, but its occurrence is of interest, as it affords strong additional evidence that the area of high gravels between Tatlanika and Wood rivers is underlain by coal. Too little is now known of the extent, quality, or thickness of the coal beds in this field to form a basis for any estimates of the amount of coal present.

WOOD RIVER BASIN.

In the valley of Mystic Creek and westward to that of Moose Creek the coal-bearing beds have an area of about 7 square miles. One section shows 30 feet of coal in two beds, and at another point the upper 10 feet of a coal bed outcrops. The coal has been used for cooking and heating in a camp of 25 men, with very satisfactory results. The total thickness of the series and of the contained coal beds is nowhere exposed. If the whole field is considered to be underlain by 10 feet of coal, it would contain more than 160,000,000 tons.

At the head of Coal Creek, which joins Wood River 4 miles below the mouth of Mystic Creek, the coal series is exposed, dipping steeply from the schist ridge to pass beneath the high gravels north of Coal Creek. No opportunity was had to study this section closely, but some 16 coal beds were seen, the aggregate thickness of which is more than 100 feet. It may be that in the uplift and crumpling of the beds the coals have been given a greater thickness here than they possess farther to the north, but unquestionably there is a valuable coal field beneath the high gravels, concerning the extent of which little is known.

DRY CREEK BASIN.

In the valley of Dry Creek, at the mouth of Newman Creek, 140 feet of the coal series is exposed beneath the high gravels. Coal beds at this place have been on fire for at least five years and are still burning. Prospect holes and coal outcrops, though giving little information in regard to the thickness of the coal beds, show that the series, with workable coal beds, lies beneath the high gravels on Dry Creek, but the present knowledge of the field is too meager to justify estimates of the coal tonnage.

AREA EAST OF DRY CREEK.

Isolated coal outcrops in the basins of Little Delta River and Delta Creek also indicate that the coal is widely distributed and may underlie large areas of the high gravels as far east as Delta River.

SUMMARY.

The Tertiary coal fields of the Bonnifield region are remnants of a series which was once much more widespread than now. It probably covered extensive areas in what is now the Alaska Range, but the unconsolidated condition of the beds favored their rapid removal by erosion, except in those places where they were protected by surrounding ridges of harder rocks or by overlying gravel beds, or where they were never uplifted sufficiently to expose them to stream cutting. The best-exposed beds are now found in warped troughs bordered by schists, the troughs lying parallel to the foothill ranges and to the Alaska Range. The coal beds are thickest and of the best quality near the base of the series. The surface area of the coal-bearing series, as mapped, is about 165 square miles between Nenana and Delta rivers, but this does not include wide extensions of the series that are overlain by later gravels and may exceed in area and in coal content the fields which, on account of their better exposures, can be more accurately investigated. The coal-bearing beds are also known to extend both east and west of the Bonnifield region into unsurveyed areas. Estimates which include only 122 square miles of the better-known coal fields give a coal content of 9,950,000,000 tons, and it is possible that this figure might be multiplied several times and still be within the bounds of probability, if the total coal content of the region is included.

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