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GEOLOGY OF THE EAGLE-CIRCLE DISTRICT, ALASKA

BY

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GEOLOGY OF THE EAGLE-CIRCLE DISTRICT, ALASKA

By J. B. Mertie, Jr.

INTRODUCTION

LOCATION OF THE AREA

The district here designated the Eagle-Circle district lies between meridians 140° 45′ and 144° 15′ west longitude and parallels 64° 30′ and 66° north latitude and comprises a nearly square area of about 10,000 square miles. (See fig. 1.) The Yukon River runs diagonally across the area from the southeast corner to the northwest corner. This area is geographically the connecting link between the Fortymile mining district, to the southeast, and the Circle mining district, to the northwest. It embraces the Seventymile district and the American Creek, Fourth of July Creek, and Woodchopper Creek precincts.

PREVIOUS WORK

This region has interested prospectors and geologists for many years. Gold placer mining was begun in the Fortymile district in 1887 and in the Circle district in 1894, and mining operations have continued in these two districts up to the present day. In view of their productiveness it was but natural that the attention of prospectors should be directed to the intervening area south of the Yukon. A great deal of prospecting has been done, and in the aggregate a considerable amount of gold has been recovered in the last 25 or 30 years, although no large mining camps have so far been established. The Geological Survey, also, has been greatly interested in this intervening area because of its potential importance to the mining industry and its unique geologic features.

The area considered in the present report may logically be divided into two parts; one, which comprises some 40 per cent of the total, lies northeast of the Yukon, and the other lies southwest of the Yukon. The northeastern part is unmapped, both topographically and geologically, except for the work of the international boundary survey along the international boundary and the observations of workers who have traversed the Yukon. The southwestern three-fifths, because of its potential economic significance, has been mapped almost completely, both topographically and geologically, on the reconnaissance scale of 1:250,000.

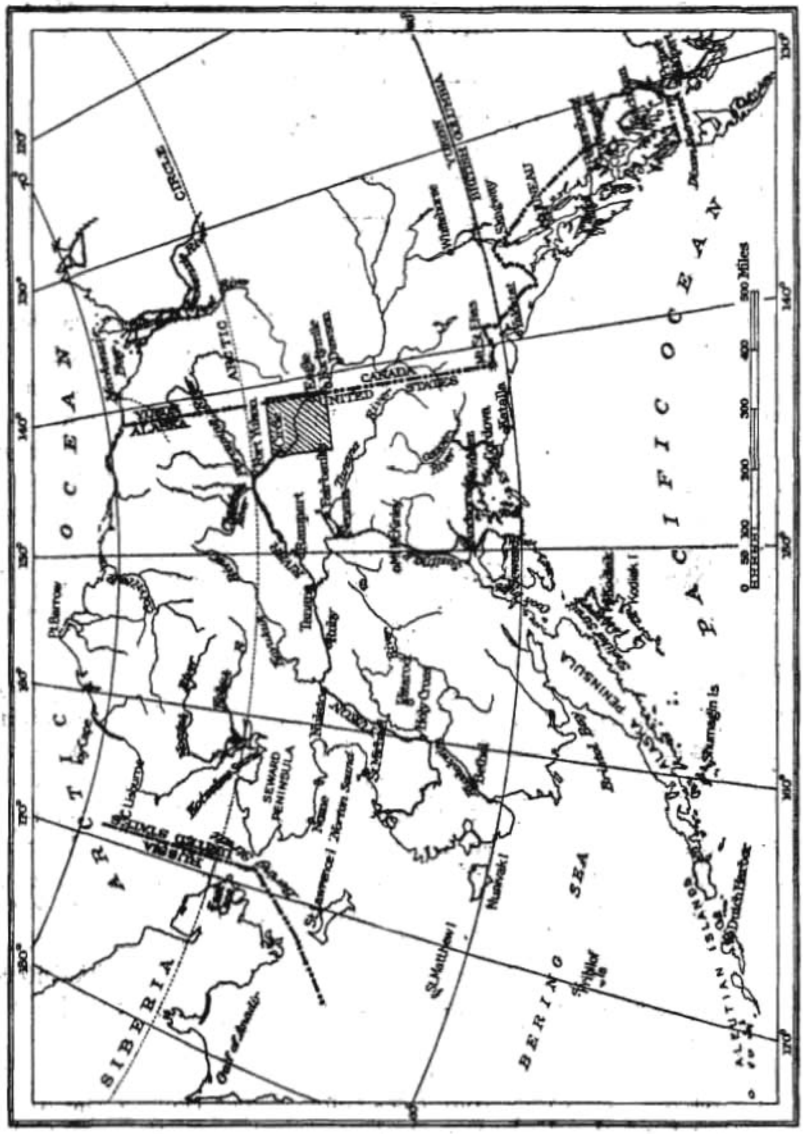

FIGURE 1.—Index map showing location of area covered by this report

Much of the initial work of the Geological Survey in a new region is concentrated in the environs of mining districts, in order to give to prospectors and miners the obvious benefits of good topographic and geologic maps and to correlate the facts of mining and geology for a better understanding of the processes of mineralization. This procedure, of course, is most desirable; but geologically it is often disappointing, because regions in which intensive mineralization has occurred are likely to be regions of more than ordinarily complex geology. Under such circumstances the geologist undertakes to decipher the geologic record under the least favorable conditions, and instead of working from the simple to the complex he is obliged to work in the reverse order. The area here considered is an excellent example of this condition. The southwestern part is a region composed largely of metamorphic rocks, and although a considerable amount of geologic work has been done there, the total results are somewhat disappointing. The northeastern part contains geologic formations of the same general age as those south of the river, in a relatively unmetamorphosed condition, but it is practically an unknown land so far as the geologist is concerned. The answers to numerous unsettled geologic problems mentioned in this paper will ultimately be found through study of the hitherto neglected territory north of the Yukon.

The earliest geologic notes on this stretch of the Yukon, from Circle to the international boundary, were made in 1888 by McConnell,[1] in the course of an exploratory trip from the Mackenzie River across to the Porcupine, down that stream to Fort Yukon, and up the Yukon to the confluence of the Pelly and Lewes Rivers. Ogilvie,[2] also in 1888, made a traverse up the Tatonduk River and over to the Porcupine, taking some geologic notes upon the rocks in the Tatonduk Valley. In 1889 Russell[3] made a rapid trip up the Yukon River from St. Michael to the headwaters. His observations, however, were more concerned with the surficial features of the region than with the hard-rock geology.

Systematic geologic work in this region was first attempted in 1896, when a Geological Survey party under the leadership of J. E. Spurr[4] traversed the Yukon from its headwaters as far downstream as Nulato, visiting on the way the mining camps contiguous to the river. The report embodying the results of this expedition is of great interest in so far as it relates to the history of exploration and early mining activities, and many of the geologic observations also are useful. Three of Spurr's formation names, Birch Creek "series," Rampart "series," and Tahkandit "series," have been redefined to

[1] McConnell, R. G., Report on an exploration in the Yukon and Mackenzie Basins, Northwest Territory: Canada Geol. Survey Ann. Rept., new ser., vol. 74, pp. 134–139D, 1890.

[2] Ogilvie, William, Exploratory survey of part of the Lewes, Tatonduk, Porcupine, Trout, Peel, and Mackenzie Rivers, Canada Interior Dept., 1890.

[3] Russell, I. C., Notes on the surface geology of Alaska: Geol. Soc. America Bull., vol. 1, pp. 99–156, 1890.

[4] Spurr, J. E., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 87–392, 1898.

fit later knowledge of the stratigraphic and lithologic conditions and remain in common usage, these being now designated, respectively, Birch Creek schist, Rampart group, and Tahkandit limestone.

The first topographic mapping in this region was done in 1898, when E. C. Barnard made a reconnaissance topographic map of the Fortymile quadrangle. The northern part of this quadrangle includes the Yukon River and contiguous territory from the international boundary downstream to the Tatonduk River, as well as the Seventymile River and American Creek Basins, and this map remains still a suitable base for geologic mapping in the southeast corner of the area under consideration.

Some further geologic observations were made in 1899 by Brooks,[5] in the course of a traverse from Lynn Canal to Eagle.

The accumulation of detailed stratigraphic data was begun in 1902 by Collier,[6] who traversed the Yukon from Dawson, Yukon Territory, to the Yukon Delta, giving particular attention and study to the Mesozoic and Tertiary coal-bearing terranes. During 1903 Arthur Hollick visited the same general region, in order to make more extensive collections of fossil plants from the coal-bearing beds.

In 1903 Prindle began a systematic study of the geology and mineral resources of the Yukon-Tanana region, which continued intermittently until 1911. Coincidentally with this geologic work, a reconnaissance topographic map of the Circle quadrangle south of the Yukon was prepared in 1903, 1904, 1905, and 1908, by T. G. Gerdine, D. C. Witherspoon, R. B. Oliver, J. W. Bagley, and G. T. Ford. Prindle, in these years, outlined the fundamental geologic features of this region and laid a lasting geologic foundation for subsequent work. Prindle's traverse of 1903 from Eagle to Fairbanks by way of Circle and the traverse in 1911 by Prindle and the writer both cover a part of the area here described and form a part of the groundwork for the following publications:

Prindle, L. M., The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska: U. S. Geol. Survey Bull. 251, 1905.

Prindle, L. M., The Yukon-Tanana region, Alaska—Description of Circle quadrangle: U. S. Geol. Survey Bull. 295, 1906.

Prindle, L. M., The Fortymile quadrangle, Yukon-Tanana region, Alaska: U. S. Geol. Survey Bull. 375, 1909.

Prindle, L. M., and Mertie, J. B., jr., Gold placers between Woodchopper and Fourth of July Creeks, upper Yukon River: U. S. Geol. Survey Bull. 520, pp. 201–210, 1912.

Prindle, L. M., A geologic reconnaissance of the Circle quadrangle, Alaska: U. S. Geol. Survey Bull. 538, 1913.

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[5] Brooks, A. H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including a description of the copper deposits of the upper White and Tanana Rivers: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 331–391, 1900.

[6] Collier, A. J., Coal resources of the Yukon Basin: U. S. Geol. Survey Bull. 218, 1903.

An important contribution to the geology of this area was made in 1906 by Brooks and Kindle,[7] who made a boat traverse from the international boundary to Circle, spending about two months in a study of the section exposed along the river. Their paper not only contained additional stratigraphic data of great value but also attempted for the first time a general correlation of the geologic terranes of interior Alaska.

In 1911 and 1912 the International Boundary Survey prepared a topographic map embracing a strip 2 to 3 miles wide on each side of the boundary from the Yukon River to the Arctic Ocean. A geologic survey along the boundary was also made, and for this purpose the strip was divided into a northern section extending from the Porcupine River to the Arctic and a southern section extending from the Yukon River to the Porcupine. The southern part of the southern section is within the area here described. The geology of the southern section was studied by Cairnes,[8] representing the Geological Survey of Canada. One of the interesting results of Cairnes's work was the discovery in this area of a well-developed sequence of lower Paleozoic rocks, including rocks of Cambrian age.

The triangle bounded on the east by the international boundary, on the northwest by the Porcupine River, and on the southwest by the Yukon River contains unquestionably the most complete Paleozoic section in Alaska, but it is as yet almost unexplored. Wishing, if possible, to obtain additional data on this Paleozoic section, A. H. Brooks, chief Alaskan geologist of the United States Geological Survey, in 1915 dispatched Eliot Blackwelder upon a boat trip from the international boundary to Circle. Blackwelder spent perhaps a month in this work, and from the data so collected he prepared a geologic report on this river section. His report was never published but was available to the writer, both in the field and in the office, and was of great assistance in the preparation of the present report.

Further paleontologic field work was done in 1918 by G. H. Girty, of the Geological Survey, who made extensive fossil collections from the type Mississippian and Permian localities along the Yukon at Calico Bluff and at the mouth of the Nation River, respectively.

SCOPE OF THE PRESENT REPORT

During the summer of 1925 the writer, assisted by M. M. Knechtel, made another boat traverse from the international boundary to Circle, for the purpose of correlating the work of earlier investigators.

[7] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, pp. 255–314, 1908.

[8] Cairnes, D. D., The Yukon-Alaska international boundary between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, 1914.

This trip differed from previous boat trips down the Yukon, in that an attempt was made to penetrate as far back from the river as possible, in order to obtain some idea of the areal distribution and regional trend of the geologic formations. Side trips were made up the Eagle, Seventymile, and Tatonduk Rivers and Fourth of July, Coal, Woodchopper, and other creeks, and much of the country several miles back from the river on both sides was visited. The present report, however, is based also in considerable measure upon the reports of earlier workers in this region, chiefly Collier, Prindle, Brooks, Kindle, Blackwelder, and Girty, and is an attempt to interpret all available data in the light of the writer's experience in this and other parts of the interior of Alaska.

GEOGRAPHIC FEATURES

RELIEF AND DRAINAGE

The Eagle-Circle district is a part of the great central plateau province of interior Alaska, which is bounded on the south by the Alaska Range and on the north by the Brooks Range. The Alaska Range is a continuation of the Coast Range province of the Cordilleras; but the Brooks Range, to the north, may represent either the Rocky Mountain Range of the Cordillera, bending northwestward into Alaska, or a separate mountain range of Arctic rather than of Pacific affinity. The term plateau, as applied to the great interior province, is somewhat misleading, as this province itself includes high areas that almost qualify as mountain ranges. The Ogilvie Mountains, which cross the international boundary just north of the Yukon, are apparently an integral part of the Rocky Mountains proper, but they extend only a short distance northwest into Alaska. Similarly, other small mountain groups that enter Alaska from Yukon Territory—for example, the Keele Mountains, just south of the Porcupine River, and other small unnamed mountain groups between the Yukon and Tanana Rivers—may be considered parts of the Cordilleran system, but their exact physiographic and structural placement in that system can not at present be given. If the Brooks Range represents the Rocky Mountains as developed along the east side of our western Cordillera, the interior province corresponds areally, though not necessarily physiographically or structurally, with the Great Basin province of the Western States. If, however, the Brooks Range represents an Arctic system of mountains, the interior province must represent the residuum of the western Cordillera minus the Coast Range. Under either interpretation it will probably be found that the conventional threefold division of the Cordillera into Coast Range, Great Basin, and Rocky Mountain provinces will require modification in Alaska.

The central plateau province in this longitude has a width from north to south of 350 to 400 miles, through the center of which flows the Yukon River in a northwesterly direction. The Porcupine and Tanana Rivers are the two largest tributaries of the Yukon, the former flanking the Brooks Range on the south and the latter flanking the Alaska Range on the north. The Yukon River proper, however, is the master stream of the area here described, the Porcupine and Tanana Rivers lying beyond its limits. The larger tributaries of the Yukon between Eagle and Circle, on the north side, named in order downstream, are Eagle Creek, the Tatonduk River (Sheep Creek), Hard Luck Creek, the Nation River (Tahkandit River), and the Kandik River (Charley Creek); those on the south side named in the same order, are Mission Creek, the Seventymile River, Trout Creek, Michigan Creek, Fourth of July Creek, Logan (Jewett) Creek, Washington Creek, the Charley River, Sam Creek, Coal Creek, Woodchopper Creek, Webber Creek, and Thanksgiving Creek.

The Yukon River at the international boundary is about 800 feet above sea level. A number of ridges in the Circle quadrangle have altitudes of 4,000 to 5,000 feet, and one unnamed mountain at the headwaters of the Charley River rises to an altitude of 6,340 feet. The maximum relief south of the Yukon in this district is therefore 5,500 feet. North of the Yukon, where the Ogilvie Mountains cross the international boundary, several mountains are known to exceed 5,000 feet in altitude, and it is very probable that a topographic survey will show within this district, west of the boundary, mountains 6,000 or even 7,000 feet high. The relief north of the Yukon is therefore at least as great as that south of the Yukon and possibly greater. The general aspect of the Yukon Valley as seen downstream from the international boundary is shown in Plate 1, *A*.

SPECIAL PHYSIOGRAPHIC FEATURES

The ridge tops in the Yukon-Tanana region are rather flat, and many of the spurs leading laterally from the ridges are also flat-topped, as well as extraordinarily long; this form, together with a noticeable tendency toward uniformity of ridge altitude in certain districts, has led earlier workers to regard this entire area between the Yukon and Tanana Rivers as a great dissected peneplain. This physiographic classification is not altogether proper. To be sure, the base-level of erosion in this region has been lowered since the Pleistocene epoch, as shown by the river-cut benches along the Yukon and its tributary streams. But the belief does not seem warranted that erosion in the Yukon-Tanana region had progressed prior to the regional lowering of base-level, to such a stage that a peneplain, in the ordinarily accepted use of that term, had been developed. It is now well known that much of the flatness of the tops of ridges and spurs and the abnormal elongation of the spurs are due to erosional processes peculiar to a sub-Arctic climate, such as solifluxion, nivation, altiplanation, and the like. The ground in much of interior Alaska is perpetually frozen, and much of the present movement of débris is accomplished by the processes named, which depend primarily upon the fracturing and heaving caused by alternate freezing and thawing. Moreover, the rugged mountains of this region are by no means isolated monadnocks surrounded by lower country of nearly uniform relief. If a peneplain is a land surface that has been worn down almost to some base level, then the Yukon-Tanana region is not a peneplain. It should rather be regarded as an area in which a mature but not old topography had been carved prior to the late lowering of the base level.

The stream-cut benches constitute another topographic feature that has attracted the attention of every geologist who has visited this region. These are particularly well developed on a number of the streams tributary to the Yukon from the south. On the Fortymile, Seventymile, and Charley Rivers, for example, a well-developed bench about 500 feet above the level of the present streams forms a very prominent topographic feature. This bench, though very prominent, is only one of several such old valley levels. Along the Seventymile River just above the falls a low bench about 12 feet high is seen on the north side of the valley; then after another rise of 4 or 5 feet a great flat stretches northward to the hills. On the south side of the Seventymile River remnants of similar low benches are seen, succeeded to the south by a prominent bench about 125 feet high, which is in turn succeeded by flat gravel-covered spurs 1,500 feet long and 500 feet above the present valley level. The 125-foot bench is very persistent. It follows down the south side of the present Seventymile Valley to the point where the river turns northward toward the Yukon, then veers off to the east. This turn indicates that the lower part of the old valley of the Seventymile River had a somewhat different course from the lower part of the present valley and suggests an old confluence with the Yukon somewhere above Calico Bluff. The valley of the Seventymile River is but one of many in this district that show well-developed benches, and such topographic forms are evidence of an interesting physiographic history that will eventually be deciphered when large-scale topographic maps are available and detailed studies can be made.

The Yukon River also has river-cut benches, but these seem to be developed in greater number and perfection farther upstream, in Yukon Territory above Dawson. Near the mouth of Woodchopper Creek, however, where the Yukon flows for some distance in a relatively narrow channel, there is a well-developed rock-cut terrace about 700 feet above the present river level. A part of this sharply defined terrace along the south side of the river, above and below the mouth of Woodchopper Creek, is shown in Plate 1, *C*. A similar bench at the mouth of Washington Creek is shown in Plate 1, *B*.

In general, the plateau province of interior Alaska has not been glaciated, but locally in some of the higher mountain groups alpine glaciation on a small scale has occurred. In the headwaters of the Charley River, for example, within the limits of the area shown on the accompanying map, Prindle[9] and the writer in 1911 mapped two small areas of morainal deposits. Other areas in the valleys of the Charley and Salcha Rivers were also mapped, and detailed work would doubtless reveal many others. These areas of glaciation are confined principally to the granitic rocks, which constitute the country rock on and near the Yukon-Tanana watershed. One of the best examples of this local alpine glaciation may be seen near the head of the Charley River, in the valley of a creek called by Prindle and the writer Moraine Creek. This creek heads against a mountain 6,284 feet high that lies between two forks of the Charley River and somewhat north of the main Yukon-Tanana divide. The valley has the typical U-shaped glacial form, with a floor about 500 feet wide. At its lower end is a terminal moraine about 400 feet thick, which extends downstream 1¼ miles into the main valley of the Charley River, where it thins gradually to 100 feet. Here the morainal material extends downstream to an altitude of somewhat less than 3,000 feet. The glaciated valley of Moraine Creek, the confluence of this creek with the main fork of the Charley River, and the morainal material from Moraine Creek that has nearly filled the main valley are shown in Plate 2, *A*.

SETTLEMENTS AND POPULATION

The two principal settlements within this district are Eagle and Circle, both on the southwest bank of the Yukon River, the former a few miles west of the international boundary and the latter about 120 miles in an air line downstream. Eagle is a picturesque little settlement built upon a terrace that is well above the high-water level of the Yukon even at times of severe flooding after the spring break-up. It undoubtedly occupies the best town site of the upper Yukon in that it is safe from floods and yet is located alongside a deep channel of the river, which favors the landing and departure of river craft. Eagle is the supply point for the Fortymile, Seventymile, and American Creek mining districts and is also the port of entry in coming downstream from Yukon Territory. The permanent

[9] Prindle, L. M., A geologic reconnaissance of the Circle quadrangle, Alaska: U. S. Geol. Survey Bull. 538, pp. 34–35, 1913.

summer white population is perhaps 40 people, but the winter population is larger, owing to the fact that some of the miners from the near-by mining districts spend the winter in Eagle. On the Seventymile River and on American Creek, adjacent to Eagle, there are 20 to 30 people engaged in mining, and just upstream from Eagle is a settlement of natives.

Circle is at the upper end of the Yukon Flats, upon a great river flood plain. It is the supply point for the Birch Creek mining district, to the south. It has at present a summer population of less than a score of white people, but, like Eagle, it has an augmented winter population, which is derived from the near-by Birch Creek mining district. There are also a considerable number of natives living permanently at and near Circle.

Between Eagle and Circle are two smaller settlements, Nation and Woodchopper, the former on the southwest bank of the Yukon about 2 miles below the mouth of the Nation River and the latter on the same side of the river just above the mouth of Woodchopper Creek. Only two men live permanently at Nation, but 8 or 10 others are engaged in mining on the near-by Fourth of July Creek. Similarly at Woodchopper the population consists mainly of the 15 or 20 men engaged in mining and prospecting on Woodchopper, Coal, and Sam Creeks.

A few trappers and prospectors also live along the river between Eagle and Circle, but the total white population of this district immediately contiguous to the Yukon, not including the Fortymile and Birch Creek mining districts, is probably less than 100.

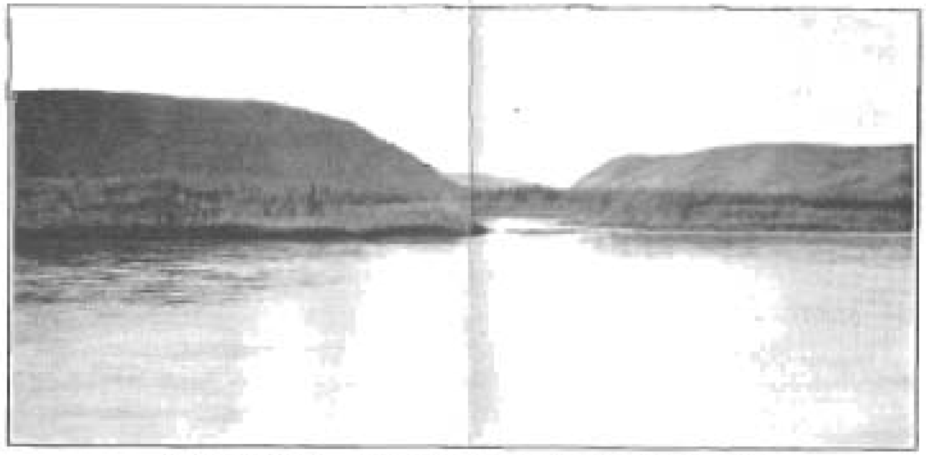
TRAILS AND TRANSPORTATION

The Yukon River is the arterial highway of this region, being traversed by river craft in summer and by dog sleds in winter. Few summer roads have yet been made in this part of Alaska. A wagon road connects Eagle with American Creek and extends on southward as a pack trail to the Fortymile district, another extends out from Circle to the Birch Creek mining district, and during the summer of 1925 a short road was being constructed from Nation up Fourth of July Creek. Much of the freighting is done in winter by horse and dog sleds, but these winter trails are of little use for summer transportation.

Supplies for this region, including the Fortymile and Birch Creek districts, are received mainly by way of Skagway and Whitehorse and thence down the Yukon through Canadian territory by river boats. The Alaska Railroad does not serve the upper Yukon region, and the costs of passenger and freight transportation are high. A new summer road has recently been built to connect Fairbanks with

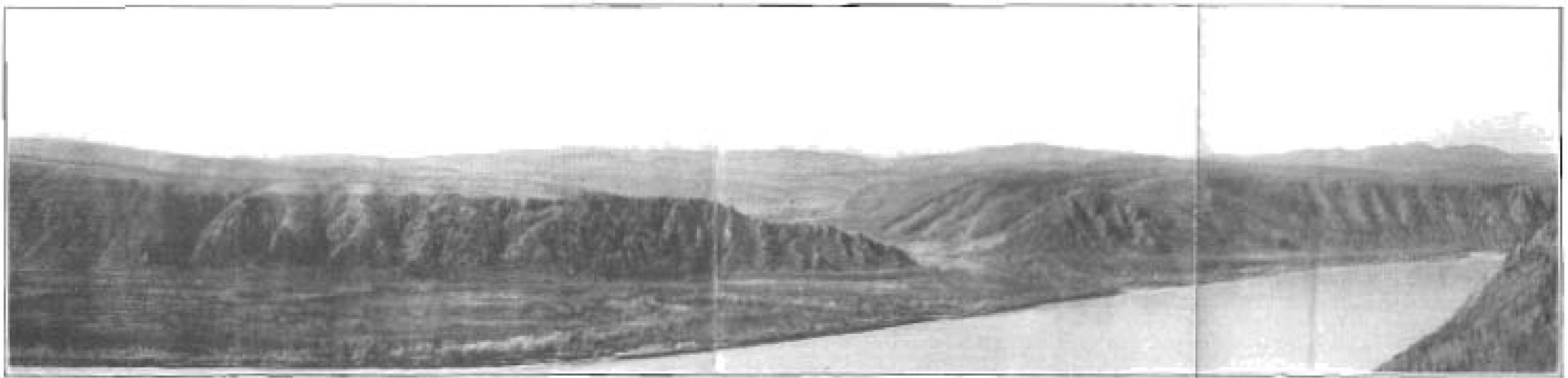
A. YUKON VALLEY, LOOKING DOWNSTREAM FROM INTERNATIONAL BOUNDARY

Showing Eagle and the mouth of Mission Creek.



B. YUKON RIVER AT THE MOUTH OF WASHINGTON CREEK

Showing bench about 750 feet above present river level.

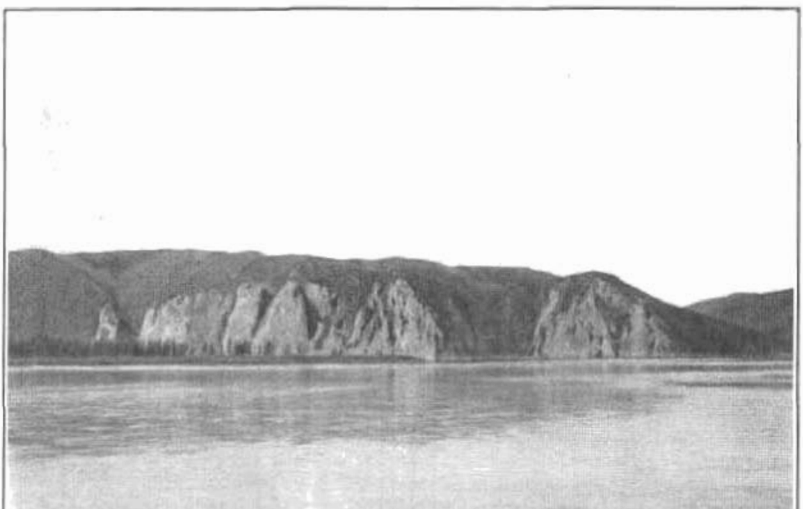


C. PANORAMIC VIEW OF THE NARROWS OF THE YUKON RIVER AT THE MOUTH OF WOODCHOPPER CREEK

Looking downstream. Shows 700-foot terrace on south side of river. Photograph by Eliot Blackwelder.

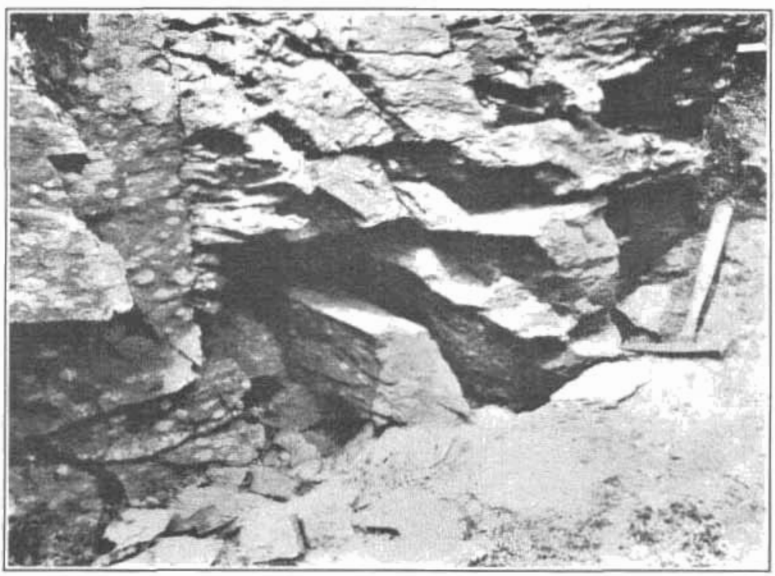
A. VALLEY NEAR THE HEADWATERS OF THE CHARLEY RIVER

Showing the effects of local alpine glaciation. U-shaped valley of Moraine Creek at left; morainal fill in the main valley.



B. UNDIFFERENTIATED (POSSIBLY UPPER SILURIAN) LIMESTONE ALONG THE WEST BANK OF THE YUKON RIVER JUST ABOVE TAKOMA CREEK

A. CONTORTED FELDSPATHIC QUARTZITE IN BIRCH CREEK SCHIST



B. AUGEN GNEISS INTRUSIVE INTO BIRCH CREEK SCHIST

Circle by way of Chatanika, and this road should be of great benefit to the Circle district, but no steps have yet been taken to connect the Fortymile district with the Tanana Valley.

CLIMATE

The climate of the Yukon-Tanana region as a whole is characterized by long, cold winters and short, relatively warm summers. The extremes of temperature are from 80° below zero in winter to 90° above zero or perhaps higher in summer, with an annual mean temperature of about 24°. At Eagle, according to the United States Weather Bureau,[10] there are on the average 56 days during the year when the maximum temperature exceeds 70°, 255 days when the minimum temperature is less than 32°, and 120 days when the minimum temperature is less than zero.

The mean maximum temperature from May 15 to September 15 is about 65° and the mean minimum about 40°; the mean maximum from November 1 to April 1 is about 10° and the mean minimum for the same period about −15°. Commonly, the alluvial deposits are permanently frozen to great depths and thaw only a few feet at the top during the summer. A marked exception to this condition exists along the banks of the larger streams, where circulating ground water has in places thawed the ground for several hundred feet back from the river banks. In winter ice freezes on the lakes and quiet ponds to a depth of 5 feet or more. The permanently frozen ground is believed to be evidence of a previous geological epoch, in part Pleistocene, during which the regional climate was even more frigid than at present. This deep frost may, therefore, be regarded as an inorganic fossil record of a preexisting climatic condition.

The larger streams, such as the Yukon, usually begin to freeze over about the middle of October, and the ice breaks up about the middle of May. The smaller streams freeze earlier in the fall and open later in the spring. In the higher country killing frosts are rare in midsummer but begin in the middle of August and sometimes continue throughout May. In the lower country, as along the Yukon, the season free of frost is somewhat longer.

The average annual precipitation at Eagle, based on observations made over a period of 18 years, is 10.4 inches. The average winter snowfall, based on observations over a period of 12 years, is 51 inches. Without doubt, both rainfall and snowfall are somewhat greater in the mountains away from the Yukon, but the region as a whole is semiarid. On account of the frozen substrata, the circulation of

[10] Summary of the climatological data for Alaska, by sections: U. S. Weather Bureau Bull. W, 2d ed., vol. 3, 1926.

deeper ground water is restricted. A heavy surficial covering of sphagnum moss tends to limit the run-off and to hold much of the precipitation near the surface. This wet ground favors the growth of vegetation, so that the semiarid nature of the region is not at once apparent to the casual observer.

VEGETATION

The common trees are spruce, cottonwood, and white birch, of which spruce is the most plentiful. Black birch and tamarack are also found. Spruce trees a foot or more in diameter may be seen in the bottoms of the larger valleys, but on the ridges and spurs the trees are small, both in height and girth, though in places very densely spaced. Timber line is at about 2,500 feet on most of the ridges, but on limestone ridges and in the heads of the larger valleys it may be several hundred feet higher.

In addition to the trees, a variety of other vegetation thrives. Along the smaller streams grow dwarf willows and alders, which in some places are almost impenetrable, and on many of the spurs, just below and above timber line, the dwarf black birch forms a dense undergrowth. Many smaller plants and shrubs also abound. Partial lists of these plants have been made by different observers, usually in connection with some other work, such as geology, but no comprehensive study of the flora has yet been attempted. Several species of moss are very common, covering the ground in the lower valleys and extending well up on the ridges. Toward and above timber line the lichens become more prevalent. These constitute one of the sources of food for the herds of caribou that roam through the country, particularly in winter, when the brush and other flowering plants are dormant.

Grass for horses is abundant in most of the river valleys and on the lower spurs. On the upper slopes of many spurs a moderate quantity of bunch grass suitable for stock may be found. Along the river bars a horsetail rush grows in great abundance, and locally the pea vine; both of these, particularly the pea vine, are eaten by horses. Stock can therefore find pasturage during June, July, and August.

Many varieties of berries grow wild, of which the blueberry and low-bush cranberry are the most abundant and useful. Red raspberries, red and black currants, high-bush cranberries, and other berries are also found. At Eagle, Circle, and other places along the river gardens are planted, and all the hardy vegetables, including potatoes, turnips, cabbage, lettuce, rhubarb, beets, carrots, and radishes, are grown without difficulty.

ANIMAL LIFE

The larger animals include caribou, moose, bear, and sheep. Many thousands of caribou live in this region and form an important source of food for the white and native population. The caribou assemble in large bands in August and begin to migrate across country. One of the impressive sights of the region is the spectacle of such a passing band, whose transit sometimes takes several days. Moose also are fairly plentiful, but their numbers would be counted in hundreds rather than thousands. Bears also are fairly numerous, the black bear being more common. In the higher hills, however, the great brown grizzly bear, with the light-colored back, is seen. Sheep are found only in the highest mountain ranges and are relatively scarce.

The fur-bearing animals include chiefly fox, lynx, marten, muskrat, squirrel, weasel, beaver, mink, land otter, wolf, and of late years coyote. Other animals, such as porcupines, rabbits, tree and ground squirrels, and mice, are also found.

The native game birds are ptarmigan and grouse, but in summer ducks, geese, and other waterfowl inhabit the country. Other birds include the loon, tern, gulls, owl, hawks, kingfisher, raven, swallows, sparrows, junco, thrushes, warblers, waxwing, jay, and shrike.

Grayling are found in nearly all the streams and trout in a few. Salmon run up the larger streams, and other fish, such as whitefish, pike, pickerel, and lake trout, are also present in the lakes and rivers.

DESCRIPTIVE GEOLOGY

PRE-CAMBRIAN ROCKS

BIRCH CREEK SCHIST

DISTRIBUTION

Proterozoic or pre-Cambrian rocks have so far been recognized definitely only in the southern half of the area covered by this report. The distribution of these rocks as shown on the accompanying geologic map (pl. 12) should be regarded only as a provisional mapping that may be materially changed by later work. One reason for this uncertainty is the presence near by of metamorphosed lower Paleozoic rocks, which in reconnaissance work are difficult to distinguish from the pre-Cambrian rocks. It is possible and even probable that the band of rocks mapped as Birch Creek schist around the Glacier Mountain massif, as well as the bands on the Seventymile River and on the Middle Fork of the Fortymile River, may later be found to be Paleozoic rocks that have suffered contact metamorphism as a result of their proximity to the great mass of granitic rocks which they border. The rocks on the South Fork of Birch Creek and thence westward, however, are almost surely of pre-Cambrian age.

LITHOLOGY

The name Birch Creek schist, as used in this report, is a designation for all the definitely pre-Cambrian sedimentary of rocks of this region. The term was introduced originally by Spurr [11] in 1898 as Birch Creek "series," to characterize the oldest rocks of sedimentary origin in the Birch Creek and Fortymile districts, although Spurr stated that "there are also found, although rather sparingly, schists of igneous origin, being dikes which have intruded into the sedimentary series previous to the shearing." As the name is used at present, however, the igneous rocks, although not separated from the sedimentary rocks on the map, are not considered a part of the Birch Creek schist. It is expected that the mass will eventually be subdivided, when more detailed work is done. Even at present the more distinct lithologic units are recognized, but no attempt has yet been made to delimit these units on a geologic map. It is possible that the Tindir group may prove to be of pre-Cambrian age, and in that event the Birch Creek schist would represent only the basal part of the pre-Cambrian sequence.

Most of the rocks of the Birch Creek schist are either schistose or gneissoid. They include quartzite, quartzite schist, quartz-mica schist, mica schist, graphitic schist, crystalline limestone, and calcareous schist. The associated metamorphic igneous rocks include granitic and dioritic gneiss, amphibolite, hornblende schist, and a certain proportion of sericite and chlorite schists. Nearly all these rocks are recrystallized, but in some of them traces of the original sedimentary or igneous fabric can still be seen.

Among the schistose rocks quartzite schist is perhaps the most common, followed closely by quartz-mica schist, quartzite, and mica schist. The quartzite schist and quartzite occur for the most part in beds 1 foot to several feet thick and weather into blocky talus piles. Plate 3, *A*, shows a typical exposure of quartzite in the Birch Creek schist. In many places these quartz-rich rocks are covered by a black lichen, which gives the outcrops a dark, forbidding appearance from a distance. Both muscovite and biotite occur with the quartz in these rocks, but the biotite is perhaps the more common. The presence of these micas affords one criterion for distinguishing these pre-Cambrian rocks from the metamorphosed lower Paleozoic rocks, for the latter, even where schistose, are likely to contain a larger

[11] Spurr, J. E., The geology of the Yukon gold district: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 140–145, 1898.

proportion of the hydromicas, brittle micas, and chlorite. At several localities, as for instance at the head of Woodchopper Creek and in the headwaters of the Salcha River, the difference in the character of the micas constituted the main basis for the separation of the Birch Creek schist from younger rocks.

Graphitic and calcareous schist and crystalline limestone are found to some extent throughout the Birch Creek mass, but for the most part such rocks are localized in their distribution in such a way as to suggest that they characterize the upper part of the sequence. No large bodies of limestone occur in the Birch Creek schist; the beds or zones range in thickness from a few inches to 100 feet. One of the unsolved problems of these older rocks is the definite identification of the carbonaceous and calcareous members as integral parts of the unit. Even without an exact determination of age, sufficient lithologic differences exist between these rocks and the older pre-Cambrian rocks to afford the basis for a cartographic differentiation whenever more detailed work can be attempted.

Among the igneous rocks associated with the Birch Creek schist granitic and dioritic gneisses, particularly the former, are conspicuous. In general, these rocks appear to invade the Birch Creek schist but like it have undergone sufficient metamorphism to acquire a gneissoid and in places a schistose texture, with the resultant formation of new minerals. Albitization of the feldspars, with the production of calcite, and alteration of the dark minerals to epidote, chlorite, and secondary hornblende or mica are the more common secondary processes. One of the more striking types of these metamorphosed intrusive rocks is augen gneiss, in which feldspar augen as large as 2 inches in diameter have been observed. Plate 3, *B*, shows a typical exposure of the augen gneiss. Sericite and chlorite schists of uncertain origin are also included with the Birch Creek schist as mapped. Some of these schists are of igneous origin, derived probably in part from lavas and fine-grained intrusive rocks of acidic and intermediate character, and therefore do not properly constitute a part of the Birch Creek schist. Others are undoubtedly derived from argillaceous sedimentary rocks and are closely related to the sedimentary mica schists. These rocks present a difficult problem, for their cartographic differentiation will have to be made on lithologic rather than genetic differences. These schists, like the carbonaceous and calcareous metamorphic rocks, belong in the upper rather than the lower part of the sequence and would have to be included there in any except the most detailed type of geologic mapping.

The associated amphibolite and hornblende schists, produced in large measure by the metamorphism of intermediate, basic, and ultrabasic igneous rocks, form another possible mapping unit. These rocks in some localities, as at the falls of the Seventymile River, occur with crystalline limestone and quartzite in such a way as to suggest at least the possibility of a sedimentary origin. They are also found at many places, however, in close association with the gneissoid rocks and are locally intruded by those rocks. The origin of all these rocks can not be stated with assurance, but their field relations to the gneisses and to adjacent sedimentary rocks suggest that most of them are recrystallized dike and sill rocks that were related genetically to the ancient granitic magma that produced the gneisses.

STRUCTURE AND THICKNESS

The pre-Cambrian rocks have been subjected to diastrophism during many periods and have unquestionably been intensely deformed in several stages. They therefore probably reflect in their present structure the combined effects of close and open folding, together with thrust and normal faulting, repeated several times and accentuated by proximity to intrusive rocks. Original bedding planes, except in the more massive quartzites and quartzite schists, are quite obliterated, and the present visible structure exhibits a multitude of diverse cleavage planes and of close or even recumbent folds, which give little idea of the original sequence of deposition. It is believed that the Birch Creek schist has a structure almost if not quite as complex as the pre-Ordovician schists of Seward Peninsula, and neither of these groups of rocks is likely to be understood structurally for many years to come.

In addition to the regional metamorphism, portions of the pre-Cambrian rocks have been subjected also to intense contact metamorphism caused by granitic intrusions of at least three eras. The pre-Cambrian (?) granite gneiss represents the earliest of these, the Mesozoic granite batholiths the second, and the Tertiary granitic intrusive rocks the third. It is difficult without detailed work to assign to each of these intrusive periods its proper share in the contact-metamorphic effects now visible, but the Mesozoic granitic rocks have unquestionably produced a large part of the contact metamorphism.

Garnetiferous schists are common near the contact with the great granitic batholith that stretches from Glacier Mountain westward to the Salcha River, and the Mesozoic granite itself at places shows the effects of its intrusion by a primary gneissoid fabric. At the heads of Woodchopper and Coal Creeks, near the contact with the Mesozoic granitic rocks, Prindle [12] and the writer in 1911 noted also a stauro-

[12] Prindle, L. M., A geologic reconnaissance of the Circle quadrangle, Alaska: U. S. Geol. Survey Bull. 538, p. 24, 1913.

litic garnetiferous schist, in which crystals of staurolite as much as half an inch in length were especially abundant. Mica, particularly biotite, is also prominent in the schist near its contact with the granite. It is apparent that the schists have received by injection a considerable amount of material from the granitic intrusions, for the schists near the contacts are locally feldspathic and have even in some places themselves been changed into augen gneiss much like the older metamorphosed granitic rocks. The schistosity has also been accentuated by contact metamorphism. These contact-metamorphic effects, however, are sporadic rather than universal and can not therefore be said to characterize the schist-granite contacts as a whole. As the Mesozoic intrusions must have affected the Paleozoic as well as the pre-Paleozoic rocks, it is altogether likely that contact metamorphism has been mistaken for regional metamorphism at some localities, resulting in the mapping of altered Paleozoic rocks as pre-Cambrian.

Veins of quartz in greater or less number are of course present in nearly all the geologic formations of this region, but the Birch Creek schist, because it is the oldest terrane, contains more vein quartz than any of the younger formations. The quartz is diverse in character, owing to differences in age and mode of formation. Much of it is a white vitreous quartz that ranges from tiny seams to veins several feet thick, but some, particularly in the smaller seams, is almost colorless and transparent. Little of the porous quartz with crystal outlines that is so characteristic of the gold lodes of the Fairbanks district has been found. It was the presence of so much quartz that led mining men as well as the earlier geologic workers in this region to believe that areas of Birch Creek schist were the most favorable localities for prospecting. Locally, to be sure, the quartz is mineralized with sulphides, chiefly pyrite, and also gold, but most of the quartz in the Birch Creek schist is barren. As it is now known that the granitic rocks are the ultimate sources of the gold, the Birch Creek schist can no longer be regarded as the mother lode, except in so far as it has been directly mineralized.

As the Birch Creek schist is the oldest terrane recognized in this region, its base has not been seen, and at present its upper limit is also indeterminate. These facts, together with the intensely complicated structure, make it impossible to hazard any exact estimate of the thickness. It suffices to state that at least several thousand and perhaps many thousand feet of strata are represented in this complex of metamorphic rocks.

AGE AND CORRELATION

The Birch Creek schist is here classified as pre-Cambrian in age. The oldest fossils found in this region by Spurr in 1896 were of

Devonian age, and as the Birch Creek schist antedates the rocks in which those fossils were found it was designated originally pre-Devonian. Subsequently, in 1909, Prindle[13] discovered Middle(?) Ordovician fossils in the White Mountains, in a limestone that is younger than the Birch Creek schist. A great thickness of rocks, however, lies between the known Ordovician beds and the Birch Creek schist, and Prindle suggested at that time the probability that the Birch Creek was pre-Cambrian. Blackwelder collected Lower Ordovician fossils from the White Mountain district in 1915, further strengthening this conviction. Meanwhile Cairnes,[14] in 1911 and 1912, had found Upper Cambrian fossils along the international boundary, and during the summer of 1925 and again in 1928 the writer collected Middle and Upper Cambrian fossils along the Yukon below Eagle. The Birch Creek schist is therefore now definitely known to be older than Middle Cambrian, and as two other formations that are not a part of the Birch Creek schist appear to lie between it and the Middle Cambrian beds, assignment of the Birch Creek schist to the pre-Cambrian seems now to be fully justified.

Some of the igneous rocks associated with the Birch Creek schist, notably the gneissoid rocks of granitic affinity, are definitely intrusive in character and may or may not have been formed prior to the Cambrian period. Evidence that at least some of the gneisses are of Paleozoic age was discovered by the writer[15] in the Chandalar district of northern Alaska in 1923. In that region the Paleozoic rocks up to and including the Silurian are metamorphosed to a greater or less degree, and in them the intrusive gneiss was found within a few feet of Silurian (?) fossils. This gneiss is believed to be of late Silurian or early Devonian age. Similarly, a chlorite schist believed to have been originally a lava flow of Silurian age was found adjoining the great middle Silurian limestone of this region. Doubtless, rocks of similar character are included with the Birch Creek schist as mapped and will some day have to be separated from it.

The Yukon-Tanana region is the type locality of the Birch Creek schist, for it is in this region that these rocks are best exposed and in this region only that their pre-Cambrian age has so far been demonstrated. There has been a tendency to correlate schistose rocks seen elsewhere in Alaska and Yukon Territory with the Birch Creek schist, merely on the ground that such rocks are greatly metamorphosed. Many such metamorphic rocks, however, are probably of Paleozoic age and have been altered to their present condi-

[13] Prindle, L. M., A geologic reconnaissance of the Fairbanks quadrangle, Alaska: U. S. Geol. Survey Bull. 525, pp. 38–39, 1913.

[14] Cairnes, D. D., The Yukon-Alaska international boundary between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, pp. 63–65, 1914.

[15] Mertie, J. B., jr., Geology and gold placers of the Chandalar district: U. S. Geol. Survey Bull. 773, pp. 243–244, 1925.

tion either by intense local dynamic disturbances or by contact metamorphism. Age assignment on degree of metamorphism alone, without contributory evidence, leads directly to such fallacies. One of the most striking examples of relative differences in degree of metamorphism may be seen along the Tanana River near Hot Springs, where slightly metamorphosed pre-Silurian rocks may be seen on the east side of Baker Creek, and semischistose Lower Cretaceous rocks on the west side of the same creek. Contact metamorphism has been the cause of this anomaly.

Various names have been proposed to designate the metamorphic rocks of Alaska and Yukon Territory. Spurr [16] in 1896 proposed the name "Birch Creek series" for the oldest rocks and the name "Fortymile series" for an assemblage of metamorphic rocks which he considered to overlie the Birch Creek schist. This dual nomenclature, however, has not survived, and the term "Fortymile series" has been abandoned, the rocks comprising that so-called "series" being now assigned in part to the Birch Creek schist and in part to the Paleozoic.

Brooks,[17] in 1898, used the name "Nasina series" to describe the schistose rocks of the lower White River and the term "Tanana schist" for the schistose rocks of the upper Tanana and differentiated a group of granitic gneisses which he believed to be older than either of these. In 1899 Brooks [18] used the term "Kotlo series" to designate the metamorphic rocks of the White River Basin and apparently included under this name both the "Nasina series" and the "Tanana schist." He indicated, however, that the "Kotlo series" probably included metamorphosed lower Paleozoic as well as pre-Cambrian rocks. None of these three names have persisted in the United States Geological Survey nomenclature, but the beds to which they were applied include in part at least the Birch Creek schist, though they may be in part younger.

In Yukon Territory adjacent to Alaska McConnell [19] has divided the metamorphic rocks into two main groups—a lower and older series, called by him originally the Indian River series and later redesignated the Nasina series, a name earlier applied by Brooks [20] to other rocks in the lower valley of the White River; and an upper series called the Klondike series. The Nasina series of McConnell

[16] Spurr, J. E., The geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 140–155, 1898.

[17] Brooks, A. H., A reconnaissance in the White and Tanana River Basins, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 460–470, 1900.

[18] Brooks, A. H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including a description of the copper deposits of the upper White and Tanana Rivers: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 357–358, 1900.

[19] McConnell, R. G., Report on the Klondike gold fields: Canada Geol. Survey Ann. Rept., vol. 14, pp. 10B–23B, 1905.

[20] Brooks, A. H., A reconnaissance in the White and Tanaa River Basins, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 465–467, 1900.

consists mainly of quartzite and quartz-mica schist but includes also certain green schists of igneous origin and beds of crystalline limestone. The Klondike series consists principally of light-colored sericite schist and subordinately of darker-colored chlorite schist, both believed to be of igneous origin. Associated with and constituting, in fact, a subdivision of the Klondike series of McConnell is a group of ancient rocks of gneissic character that are believed to have intruded into his Nasina series and are probably the deep-seated equivalents of the sericite schist of the Klondike series. These rocks are known as the Pelly gneiss, a name which, according to McConnell,[21] was applied originally to them by Brooks, although the name does not appear in Brooks's report on the White and Tanana River Basins. Another cartographic unit recognized by McConnell [22] is the Moosehide diabase, composed mainly of altered diabase and supposed to be nearly contemporaneous with the Klondike series. Of these units, the Nasina series alone is regarded as correlative with the Birch Creek schist, as redefined in this report.

Subsequently Cairnes,[23] in 1914, introduced the term Yukon group to include "all these older metamorphosed, schistose, and gneissoid rocks of both sedimentary and igneous origin." He further defined the Yukon group as pre-Cambrian in age. This term, therefore, would include not only the Birch Creek schist but all the associated metamorphic rocks of igneous origin here mapped with the schist. No general term, similar to Yukon group, to include all the pre-Cambrian rocks, is at present recognized in the United States Geological Survey nomenclature. Unfortunately, as shown on page 33, Cairnes included in his mapping of the Yukon group certain Paleozoic rocks, some of which are as young as Devonian. This, however, should in no wise detract from the use of the term Yukon group as defined by Cairnes.

Cockfield,[24] in the most recent geologic work done in Yukon Territory, has used the general term Yukon group, but has divided the group into four subgroups—the Nasina series, at the base; the Klondike series, overlying the Nasina; the amphibolites, unnamed, overlying the Klondike; and the Pelly gneiss, which invades the Nasina and Klondike series as well as the amphibolites. It seems to the writer rather likely that parts of the Klondike series, of the amphibolites, and of the gneiss may later turn out to be of Paleozoic age.

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[21] McConnell, R. G., op. cit., footnote p. 13B.

[22] Idem, pp. 22B–28B.

[23] Cairnes, D. D., The Yukon-Alaska international boundary between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, p. 40, 1914.

[24] Cockfield, W. E., Sixtymile and Ladue Rivers area, Yukon: Canada Geol. Survey Mem. 123, 1921.

CAMBRIAN OR PRE-CAMBRIAN ROCKS

TINDIR GROUP

DISTRIBUTION

The term Tindir group was applied by Cairnes to groups of similar rocks at four distinct localities, as follows: Along the Porcupine River where it crosses the international boundary; along the international boundary between Fort and Orange Creeks; along the international boundary between Tindir, Cathedral, and Hard Luck Creeks; along the international boundary southeastward from the mouth of Eagle Creek. The first two localities lie outside the area covered by this report and will not be further discussed. The rocks of the fourth locality are here called the slate-quartzite group and for lack of definite paleontologic evidence have been assigned to the group of undifferentiated noncalcareous Paleozoic rocks. (See p. 34.) The rocks of the third locality, though not seen by the writer, come within the area shown on Plate 12 and will now be considered.

As mapped by Cairnes, the rocks of the Tindir group extend from the Cambrian limestone at Jones Ridge northward in a solid block for 5 or 6 miles to Cathedral Creek, thence northward in a narrow zone up a tributary of Cathedral Creek and on to the northwest and north of Mount Slipper. A small outlying mass lies on the north side of Tindir Creek about 4 miles north of Mount Slipper. Because of the proximity of these areas to Tindir Creek, it seems best to regard them as the type locality for this group of rocks. Here certainly is the best available evidence for evaluating the age of the Tindir group.

LITHOLOGY AND STRUCTURE

As the Tindir group in its type locality has not been seen by the writer, the description given by Cairnes,[25] referring to the Tindir, Cathedral, and Hard Luck Creek areas, is quoted here:

The Tindir section exposed still farther south along Tindir Creek and between Ettrain and Hard Luck Creeks particularly resembles that observed along Porcupine River, the members including mainly dolomites, limestones, quartzites, slates, shales, and greenstones. Here, however, the greenstones are developed to a much greater extent than to the north of Orange Creek and along the Porcupine, and the quartzites instead of being dominantly white to grayish include more greenish, reddish, and dark-colored members, even quite black quartzites being prominent in some places.

The dolomites weather characteristically rough and reddish to brownish as elsewhere and are generally bedded, the strata ranging in places from a fraction of an inch to a foot or more in thickness. They also include numerous bands of chert 1 to 2 inches thick. Intercalated with these dolomites also are

[25] Cairnes, D. D., op. cit., pp. 52–53.

occasional grayish limestone beds and also some of black slate. These dolomites appear to be at least 700 feet in thickness.

Mount Slipper is capped by Devono-Cambrian limestones and dolomites, which are underlain by the members of the Tindir group. Thus around the western and southern faces in particular of this mountain a splendid section of a part of the Tindir rocks is exhibited. There these beds include mainly dark to black calcareous shales, limestones, and quartzites, all invaded by greenstones which occur both as dikes and sills. The quartzites are dominantly thinly bedded and nearly black but weather in places to a dark reddish or reddish-brown color. The limestones are prevailingly also thinly bedded and dark to nearly black in color and grade into very soft, thinly bedded, friable black calcareous shales, the beds of the upper 500 feet at least of the section being very calcareous. The Tindir beds exposed here on Mount Slipper evidently constitute the upper portion of the Tindir group in this locality and very closely resemble the shale member comprising the upper 1,000 feet in the section measured along Porcupine River.

A typical member of the Tindir beds south of Tindir Creek also is a finely laminated rock consisting of alternating white and black bands, there being on an average about 20 laminae to the inch. The light bands consist dominantly of quartz and the dark bands of argillaceous shaly material.

Certain shales and quartzites also exhibit considerable hematite, and in places portions of these beds contain up to 30 per cent or even possibly 40 per cent metallic iron.

The greenstones are dominantly diabases and occur in sills, dikes, and irregular intrusive masses and in places constitute a considerable portion of the entire formation. The sills are in places as much as 100 feet and the dikes 200 feet in thickness. Since these intrusions were rarely noted intruding the overlying Devono-Cambrian limestones and dolomites, it is concluded that they are dominantly at least older than these rocks.

The Tindir rocks here, in the vicinity of Tindir Creek and between Ettrain and Hard Luck Creeks, as farther north, are characteristically much indurated, folded, and contorted, and are also brightly and varicolored, black and shades of red, gray, and yellow being conspicuous. A single side hill in places may exhibit reddish to brownish dolomites, yellow to black quartzites, gray limestone beds, gray, red, or black shales or slates, and black to bright-red iron ore containing beds all ribboned and intersected by irregular brownish-weathering greenstone dikes and sills. The hills on which these rocks outcrop are dominantly lofty and irregularly distributed and are characterized by long, sharp, steep-sided ridges, with smooth slopes covered with a fine talus. The bright and contrasted colors which they exhibit also constitute one of the most striking pictorial features of the landscape of the district.

AGE AND CORRELATION

The assignment of the Tindir group by Cairnes to the Lower Cambrian or pre-Cambrian was made for the following reasons: The Tindir group underlies the Devonian-Cambrian limestones and dolomites between the Black River and Fort Creek (north of the area here considered); the Tindir group underlies the Devonian-Cambrian limestones at Mount Slipper, north of Cathedral Creek; along the north side of Jones Ridge the Tindir beds were observed to underlie unconformably a limestone-dolomite series in which Cambrian fossils were found.

It is not believed by the writer that a continuous Devonian-Cambrian limestone sequence exists along the boundary. Unquestionably Devonian, Silurian, Ordovician, and Cambrian fossils have been collected from massive limestone and doubtless also at many places where it is impracticable to map separately the different limestone series. But all the stratigraphic data from the Paleozoic rocks of Alaska indicate that such limestone series are separated from one another by thick groups of essentially noncalcareous rocks and also by one or more unconformities. The great unconformity between the upper Silurian and the Middle Devonian rocks, as seen elsewhere in central and northern Alaska, is an example of such discontinuities of sedimentation. Hence the statement that the Tindir group lies beneath a Devonian-Cambrian limestone sequence implies so much doubt with regard to the areal distribution and interrelations of the several limestones within that range of age that such a statement fails to be convincing. The first two reasons above given are therefore discounted at the outset.

At Jones Ridge, however, a different condition appears to prevail. There only Cambrian fossils were found in the limestone along the south flanks of the Tindir group, and Cairnes saw the Cambrian limestone resting unconformably upon the Tindir. Also two recorded strikes and dips on Jones Ridge within the Cambrian limestone area show the limestone striking in a general northerly to northeasterly direction and dipping east to southeast, and this attitude of the beds, if continued to the Cambrian-Tindir contact, would undoubtedly place the Cambrian stratigraphically above the Tindir. Hence it seems reasonably sure that the rocks mapped as Tindir group north of Jones Ridge in fact underlie the Cambrian limestone of Jones Ridge. Cairnes's Cambrian fossils, however, have been determined as essentially Upper Cambrian in age, with one lot questionably Middle Cambrian. But if, as seems likely, the Middle Cambrian is definitely represented at Jones Ridge, and Middle Cambrian limestone rests unconformably upon the Tindir group, it seems probable that the Tindir group is, as stated by Cairnes, Lower Cambrian or older. Cairnes, evidently believing that this unconformity represents a discontinuity of major magnitude, was inclined to stress the possible pre-Cambrian age of all or at least a part of the Tindir group. This interpretation, though by no means proved, is a most suggestive one and is fraught with far-reaching consequences in connection with early Paleozoic and pre-Cambrian correlations. Cairnes suggests, for example, the correlation of the Tindir group with the Tatalina group, of the Fairbanks district, and this correlation, if made with the lower part of the Tatalina group, seems indeed to be a very logical one, for the Tatalina includes rocks of Lower Ordovician and probably of Cambrian and pre-Cambrian age. If the Tindir group should finally be proved to be pre-Cambrian in age, it would naturally be correlated with some part of the Algonkian system; and if the Tatalina group should also be found to include rocks of that age, the Birch Creek schist, which has heretofore been regarded merely as undifferentiated pre-Cambrian, would probably come to be regarded as Archean. Much, therefore, hangs upon a definite age determination of the Tindir group in its type locality, and future geologic work along the boundary should have this for one of its most important objectives.

RED BEDS

DISTRIBUTION

So far as known, the red beds, which are here regarded as underlying the Middle Cambrian, have been seen only at one locality, in the valley of the Tatonduk River about 3 miles downstream from the international boundary. They crop out on both sides of the valley, ending sharply to the east against Silurian and later Paleozoic rocks; to the north or northeast, however, along the strike, they appear to continue for a number of miles into the heart of the Ogilvie Mountains.

LITHOLOGY

These rocks may be described collectively as red beds. As seen in the bluffs along the Tatonduk River they consist of red sandstone and sandy shale, with layers of almost pure red hematite as well as layers of hematitic breccia. The fragmental material of the breccia consists of poorly assorted subangular to angular pebbles and cobbles that range in diameter from a few inches to a foot. The red shale is well indurated in the outcrops along the valley walls, but it disintegrates rapidly on exposure to the weather and is seen on the gravel bars downstream at many places as lumps or mounds of red clay or mud. On the slopes along the south side of the Tatonduk River it was found that the red beds contained a large proportion of conglomerate. At an altitude of 1,400 feet above the valley floor on this south side of the valley a massive bed of red conglomerate perhaps 75 feet thick was seen continuing up the spur from the creek. It consists of angular pebbles of quartz, chert, slate, and phyllite. This conglomerate is followed by red sandstone and slate, which in turn are succeeded at 1,600 feet above the creek by another bed of red conglomerate about 100 feet thick, composed of subangular to well-rounded pebbles, cobbles, and boulders, the largest of which are 2 feet in diameter.

Most of the fragmental débris is silicified limestone that resembles in part a white quartzite and in part chert. The matrix of this upper conglomerate is brown rather than red. From this point to the top of the ridge the rock is a brown-weathering quartzite, at places somewhat conglomeratic, mingled with some brown-weathering limestone. This section, as given, ranges downward in the geologic column in going up the spur, and the conglomeratic beds are therefore at or near the base of this section.

Doubtless other phases of this formation are present in this neighborhood. Cairnes[25] observed the same formation in much the same general locality and describes it as follows:

> This conglomerate is at least 700 or 800 feet in thickness and consists dominantly of a firm, somewhat dense, finely textured reddish argillaceous matrix, in which are embedded angular to subangular pebbles and boulders ranging in size from microscopic to 3 or 4 feet in diameter. The matrix appears to have approximately the composition of a boulder clay, and the greater number of the pebbles and boulders are composed of limestone or dolomite, but some were noted composed of other sediments such as sandstone, conglomerate, and shale.
>
> The prevailing red color of the matrix is due mainly at least to the considerable amount of iron contained in the matrix, which has in places the general appearance of a hematite ore. The conglomerate, where exposed on a small tributary of Tatonduk River, is quite unstratified and has the general appearance of a consolidated and iron-stained boulder clay. The pebbles and boulders are irregularly distributed and are often quite isolated and completely surrounded by the matrix, instead of resting upon one another as in the case of a normal conglomerate.
>
> This conglomerate is thus undoubtedly of terrestrial origin—the term terrestrial being used to imply deposition on the land in contrast to deposition in the sea or on the seashore. Land deposits may, however, be formed in numerous ways, mainly by the action of lakes, rivers, winds, glaciers, and volcanoes, as well as by weathering, creepage, or sliding. Of these, considering the thickness of this conglomerate, its unstratified condition, and the irregular distribution, composition, angularity, and size of the pebbles and boulders, the only two modes of origin which appear to at all satisfy the field observations are glacial action and creepage or sliding.
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> In general composition this conglomerate appears to much more resemble a boulder clay than it does slide material, but on the other hand its prevailing reddish color and the fact that this conglomerate has not been previously described as occurring in Yukon or Alaska, so far as the writer is aware, and is thus probably not very extensive would tend to disprove the glacial theory of origin. Also, no striated pebbles were found; this may, however, be due to the fact that since the pebbles are dominantly composed of soft materials such as limestones and dolomites, the scratches, even if they ever existed, might readily have become obliterated. Further, due to peculiar circumstances, the writer was able to examine this conglomerate in only one very limited area and could devote only a few hours to the examination; thus striated pebbles may well occur and not have been found. Pebbles having faceted surfaces, much resembling "soled" pebbles, were, however, noted to be somewhat plentiful. Due to its prevailing color, also, this conglomerate

[25] Cairnes, D. D., op. cit., pp. 91-92.

could be seen to extend for several miles to the west of the area examined, showing it to be somewhat extensive for slide material. This, taken in conjunction with the thickness of the conglomerate, rather favors the glacial theory again. Thus, until more evidence has been obtained, the origin of this conglomerate must remain an open question.

Cairnes apparently, from the above quotation, was rather inclined to regard this formation as glacial in origin but admitted that the evidence was inconclusive. An enthusiastic searcher for tillites might lean even more strongly toward the glacial hypothesis, for some of the characteristics of glacial origin appear to be present, such as faceted pebbles and the heterogeneity of assemblage of the fragmental material comprising some of the beds. On the other hand, faulting, landslide activity, soil creep, or fluviatile ice action in winter might also account for the soled pebbles observed by Cairnes. Some peculiar conditions of sedimentation appear to have existed to form beds of the character of some of these. The generally restricted character of this formation, however, is regarded as rather strong evidence against the glacial hypothesis of origin. It seems to the writer that one or more of a variety of terrestrial conditions of accumulation might just as easily explain the origin of this formation. Little is really known, however, about terrestrial accumulation of sediments in early geologic time, when the conditions of the atmosphere and lithosphere may have been materially different from those observable at present. It seems best, therefore, to defer judgment as to the origin of these red beds pending the accumulation of more general data about such matters and more specific information about these particular beds.

STRUCTURE AND THICKNESS

The upper part of this formation is well exposed in red bluffs along both sides of the Tatonduk River, but the lower part can be seen only imperfectly on the hillside slopes of the valley. Where seen along the valley floor these rocks strike in a general northerly direction and dip about 20° W.—that is, downstream. As a result of this relatively low inclination they project as a downstream wedge into the overlying rocks. The accompanying map is not on a sufficiently large scale to show this geographic expression of their structure.

Near the eastern geographic limit of the formation, as seen on the spurs above the valley, both the strike and dip are inconstant, although the dip appears to be prevailingly westward. At the contact with the undifferentiated limestone to the east (upstream) the red beds and the limestones are all greatly disturbed. It is conceived by the writer, therefore, that a fault of considerable magnitude forms the boundary line between these red beds and the limestone area to the east. Cairnes [27] did not recognize this zone of faulting, but his observations appear to confirm the general westward-dipping structure of the red beds, for he states:

This conglomerate overlies the Devono-Cambrian limestone-dolomite beds and appears also to overlie Carboniferous shales and the Devono-Ordovician shale-chert group and to correspond stratigraphically to the Nation River formation, but of this the evidence is not conclusive.

In other words, the red beds apparently dip to the west. Cairnes, of course, in assigning these beds to the "Permo-Carboniferous," did not know of the presence of Middle Cambrian formations still farther down the Tatonduk apparently overlying the red beds.

The red beds form a belt that is about a mile wide where it crosses the Tatonduk River, below the boundary. The structure shows only at the west side of this belt, along the walls of the valley, but if it is assumed that the structure is the same all the way across the strike, the resulting thickness may be about 1,700 feet. This figure in reality means very little. Deduction for reversals in dip at the east side of the formation might materially reduce it, but on the other hand, if the fault postulated at the eastern border has concealed some of this formation, its thickness may be greater. It will perhaps suffice to state that the rocks of this formation actually visible in the Tatonduk River, with the reversals in dip evaluated, aggregate possibly 1,200 feet.

AGE AND CORRELATION

The evidence regarding the age of this formation is far from conclusive. Cairnes suggested a "Permo-Carboniferous" age because he believed that these rocks overlie his group of Devonian-Cambrian limestones. As previously pointed out, however, this eastern contact is believed by the writer to be a fault contact; and the structure at the western limit, so far as known at present, leads to the belief that these beds not only underlie the Middle Cambrian limestone but are separated stratigraphically from it by another group of rocks. The sequence, then, is as follows:

Middle Cambrian limestone (top of section).
A limestone-argillite formation.
A red-bed formation (bottom of visible section on the Tatonduk River).

One significant fact should be emphasized. The limestone-argillite formation and the red-bed formation are well and continuously exposed at their contact on the Tatonduk River, and it is reasonably sure that although materially different in their lithology these two

[27] Cairnes, D. D., op. cit., pp. 92-93.

formations grade into each other. Field conditions indicate that the limestone-argillite and the Middle Cambrian limestone also grade into each other, but their contact is not so well exposed, and the evidence is therefore somewhat weaker. In other words, if any stratigraphic break should be postulated in this sequence of three formations it should more reasonably be assumed to exist at the base of the Middle Cambrian limestone. However, as no fossils have been collected in the two lower formations, and no definite structural data have been collected by the writer that will serve to prove or disprove the existence of any discontinuity of sedimentation in these three formations, they can merely be represented on the geologic map as a succession of beds of which the Middle Cambrian limestone is the top and the red beds the basal part.

These structural uncertainties and the lack of fossils make it difficult to assign definite age labels in the explanation that accompanies the map. If a continuous sedimentary sequence exists, all three of these formations are probably of Cambrian age; but if, as thought by Cairnes, an unconformity exists at the base of the Middle Cambrian limestone, it is easy to conceive that the two lower formations are of pre-Cambrian age. This uncertainty has been registered on the map in the designation "Middle Cambrian or older" for the limestone-argillite formation, and by the designation "Lower (?) Cambrian or pre-Cambrian" for the red beds. The interrogation point in the expression "Lower (?) Cambrian or pre-Cambrian" is intended to indicate the possibility that the red beds may be of Middle Cambrian age.

So far as correlation with other rocks is concerned little can be said, for Cambrian rocks have not been recognized in Alaska except along the international boundary. No rocks that are lithologically exactly similar in interior Alaska have been described, irrespective of geologic age. The nearest lithologic counterpart consists of certain red slates and phyllites and associated arkosic rocks that constitute a part of the Tatalina group, in the Fairbanks quadrangle. The Tatalina group lies stratigraphically between rocks of Middle Ordovician and pre-Cambrian age, and therefore this correlation seems a possible interpretation.

In Cairnes's description of the lithology of the Tindir group, which he assigned to the Lower Cambrian or pre-Cambrian (see extract, p. 22), he mentions the high hematitic content of some of the Tindir shales and quartzites. This is most suggestive and leads to the inference that these red beds will ultimately be found to be a part of the Tindir sequence. The geographic position of the Tindir group, which lies along the strike and 8 miles to the north of the red beds here described, may be taken as corroborative evidence of this correlation.

UNDIFFERENTIATED PALEOZOIC ROCKS

DISTRIBUTION

The undifferentiated Paleozoic rocks have been divided for cartographic purposes into two groups, of which one includes all the dominantly noncalcareous rocks and the other includes essentially the calcareous and dolomitic rocks.

The dominantly noncalcareous undifferentiated Paleozoic rocks are found chiefly in the valley of Slate Creek, a tributary of the North Fork of Fortymile River; in the headwaters of the Charley and Salcha Rivers; in a zone extending from the head of the Seventymile River to the southeast corner of this district; in a bifurcated belt that extends eastward from Thanksgiving Creek to Washington Creek and northwestward into the Crazy Mountains, south of Circle; along the international boundary in an irregular zone that extends from the valley of the Tatonduk River northward to Hard Luck Creek. Some smaller areas included with this group of rocks are a small belt of slate-quartzite rocks that crops out along the north bank of the Yukon above Eagle and extends southeastward up the Yukon Valley; certain areas on the north side of the Yukon below Calico Bluff; and a belt extending along the south bank of the Yukon from Fourth of July Creek downstream intermittently to Glenn Creek. The group that extends southeastward from the head of the Seventymile River continues up the Yukon River beyond the limits of the area shown on the accompanying map in the direction of Fortymile and comprises some of the rocks included by Cairnes [28] as part of his pre-Cambrian or Yukon group. The reassignment of these rocks from pre-Cambrian to undifferentiated Paleozoic is made on the basis of their lithology and of certain fossils found in them.

The undifferentiated calcareous and dolomitic rocks of the Paleozoic, because of their striking lithologic differences from the other undifferentiated Paleozoic rocks, are shown by a separate pattern on the accompanying geologic map. They occur chiefly as follows: A limestone belt crops out along the international boundary midway between Eagle Creek and the Yukon and continues southeastward up the Yukon Valley and northwestward from Eagle up the north side of Mission Creek; two great masses of limestone and dolomite are found along the international boundary, one cropping out in the valley of the Tatonduk River and extending northward to Hard Luck Creek, the other extending from Cathedral Creek northward almost to Ettrain Creek; a belt of limestone lies northwest of Nation, extending from Spring Creek northwestward across Bull Creek to Logan Creek; a small wedge of limestone crosses Woodchopper Creek about 3 miles from its mouth.

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[28] Cairnes, D. D., op. cit., map 140A.

LITHOLOGY

Paleozoic rocks of many types are here grouped together for convenience in mapping; some whose age has been demonstrated or for which separate delineation could be made on the basis of pronounced lithologic differences will be found separately listed elsewhere in this report. This grouping of rocks of diverse age and lithologic character has been rendered necessary for several reasons. First, little detailed work has been done in the Circle and Fortymile quadrangles, and practically nothing but exploratory mapping has been attempted as yet away from the Yukon River. Second, the undifferentiated Paleozoic rocks south of the Yukon have proved particularly difficult to subdivide into groups or formations because they are more than ordinarily metamorphosed and because they contain apparently none of the easily recognized horizon markers, such as the Skajit (Silurian) limestone of northern Alaska or its counterpart as seen in the White Mountains of the Fairbanks quadrangle. Finally, along the international boundary, where all the systems of the Paleozoic appear to be represented, as indicated by numerous fossil collections, Cairnes was unable, in the time available for the boundary survey, to differentiate and map them separately.

The differences in the Paleozoic section north and south of the Yukon in this longitude bring to mind another fact that is only beginning to be appreciated in the geology of interior Alaska—namely, that no one district appears to present a complete sequence of Paleozoic rocks. The Cambrian limestone, for example, is so conspicuous that it could scarcely have been missed, even in reconnaissance work. Yet no limestone corresponding to it has yet been seen south of the Yukon. Again, the Silurian limestone, which forms one of the most conspicuous horizon markers of northern Alaska and is almost as prominent in the Fairbanks quadrangle, is nevertheless not typically developed in the Circle and Fortymile quadrangles nor along the Yukon, although both older and younger formations that adjoin it elsewhere are here present. Still other examples might be cited. It is therefore becoming increasingly apparent that a complete Paleozoic section will be finally obtained only by piecing together the fragmental sections from all of interior Alaska, and the result will be a far greater thickness of rocks than has been formerly supposed.

The principal undifferentiated Paleozoic rocks south of the Yukon here grouped together are quartz-feldspar sandstone, or arkose, metamorphosed to a greater or less degree, quartzite, shale, slate, phyllite, chert and chert conglomerate, a little limestone, and greenstone, including serpentine, some of which has been separately mapped.

The arkose is composed of rounded to subangular grains of quartz and feldspar, in about equal amounts, commonly cemented by a matrix of quartz, feldspar, and argillaceous and ferruginous material. Locally such rocks have been metamorphosed, with the resulting development of sericite and a schistose fabric. Commonly, however, they are inclined to be massive and appear to have withstood the effects of metamorphism about as well as the quartzites. They occur in beds from 1 foot to several feet thick, interbedded with quartzite and slate, but they appear for the most part to be restricted to zones bordering or near the Birch Creek schist and are believed to have been derived in large measure from the sedimentary rocks of that group. By a decrease in the proportion of feldspar and a corresponding increase of quartz, the arkosic rocks grade into feldspathic quartzite.

The quartzites proper occur at several horizons in the Paleozoic and are therefore contemporaneous only in part with the arkosic rocks. Where the lower Paleozoic arkose and quartzite are appreciably metamorphosed, it is difficult to separate them from the Birch Creek schist.

Shale occurs at many places. It is usually drab, dark gray, or black, but the more metamorphosed varieties, such as the slate and phyllite, are inclined to be more conspicuously colored in hues of green, red, and purple. This difference in coloration, however, is not believed to be a function of degree of metamorphism but is due rather to original differences in the composition of the rocks. In other words, the more brightly colored argillaceous rocks, though they happen to be older than the shaly rocks proper and therefore are more metamorphosed, are believed to be also different in original composition.

Chert and chert conglomerate constitute a considerable part of the Paleozoic sequence at several localities in this area. Chert and silicified rocks approaching chert in composition are probably present in formations of different ages within the Paleozoic. Much of the chert and chert conglomerate, however, is of Devonian and Mississippian age, and where possible such rocks have been separately mapped. The rock here designated chert conglomerate is, so far as known at present, unique in that it is found only among the Paleozoic rocks. It is not just a conglomerate composed of chert pebbles but is a conglomerate made up of rounded to angular chert fragments in a chert matrix. It is so well consolidated that the rock commonly breaks across the chert pebbles. The chert conglomerate, as well as much of the chert, presents a peculiar problem in stratigraphic genesis, which is considered at greater length on pages 90–92 of this report.

No large bodies of limestone are included in the major grouping of undifferentiated noncalcareous Paleozoic rocks. Only a few small lenses of limestone and some larger bodies of calcareous shale were seen by Prindle and the writer in 1911. Such rocks occur usually in thin beds, varying in color from blue-gray to black, and show the results of metamorphism by their closely folded and locally recrystallized condition.

Basic and ultrabasic rocks, commonly designated greenstone and serpentine, are found at numerous localities in this region. Like the cherts, but to a greater degree, they are distributed throughout the Paleozoic sequence and may not in general be mapped as a lithologic unit without assembling rocks of very diverse age. Along with these basic igneous rocks are found more or less shale and chert, commonly in shades of light and dark green, not unlike the greenstones themselves, and probably of contemporaneous origin. Notwithstanding the undesirability of assembling together rocks of different ages, an attempt has been made to map these greenstones separately, so far as possible, with the hope that they may some time be further subdivided according to relative age. The undifferentiated greenstones are described further on pages 148–150. The prominent bluff on the Yukon just below Eagle, at the mouth of Mission Creek, is composed of undifferentiated greenstone. (See pl. 7, *A*.)

At the northeast side of the band in the Yukon, below Calico Bluff, and just east of the band of Upper Cambrian limestone that crops out along the river bank, the rocks are black, yellow-brown, and green shales, with numerous beds of hard black quartzite that alters to a rusty-colored rock. These rocks crop out for 200 feet or more along the beach, and fragmental material along the beach for some distance farther east indicates their presence higher up the hillside. These shales and quartzites, which dip southward, appear to underlie the Upper Cambrian limestone and to overlie the Middle Cambrian limestone farther up the hillside, but the obvious faulting in this particular area makes it hazardous to classify them definitely as part of the Cambrian sequence, though they appear to belong to that system.

A more conspicuous group of undifferentiated Paleozoic rocks occurs along the southwest bank of the Yukon, cropping out intermittently from a point just below Fourth of July Creek downstream to Glenn Creek. Just below Fourth of July Creek a mass that extends out into the river a short distance and projects above the water is known locally as the "Rock of Ages." About 4 miles below Fourth of July Creek the same rocks form a more extensive reef that projects a considerable distance into the river. This group consists essentially of thin-bedded black to light-gray dolomite, usually half an inch to 5 inches thick, interbedded with argillite, slate, and a few beds of limestone conglomerate. Much of the dolomite shows very fine alternating black and gray laminae, at some places as many as 50 to the inch. Some of the laminae are at an angle to the upper and lower surfaces of the beds and strongly suggest cross-bedding. All these beds are silicified to a greater or less degree, and some of the silicified argillite and slate is perhaps better designated chert. The fragmental limestone beds are of two types. The more common type consists of rounded limestone pebbles in a limestone matrix; some of these rocks show little or no silicification. The other type is an oolitic limestone in which the oolites are largely silicified to little balls of chert. Just above Glenn Creek this group of dolomitic rocks contains some altered intrusive rocks that were probably originally of basaltic or diabasic character but that now consist of secondary minerals, such as calcite and chloritic products, and are classifiable generically as greenstones. The rocks along the Yukon at the boundary, mapped by Cairnes [29] as the Yukon group and assigned to pre-Cambrian time, are in this report included with the undifferentiated Paleozoic rocks. Cairnes describes the Yukon group in general as composed of schistose amphibolites and quartzite and mica schists, with a few beds of limestone. He further states that these rocks are much folded, faulted, and distorted and are so highly metamorphosed in places that it is difficult or impossible to determine their origin or original character.

Along the ridge south of Fortymile the writer noted greenstone schist, quartzite schist, massive quartzite, graphitic schist, and several varieties of green schist, which correspond closely to the Yukon group as described. Such rocks continue downstream from Fortymile to the boundary, where they appear to be more consistently greenish and to contain a larger proportion of metamorphosed basic igneous rocks. In the river bluffs along the north side of the Yukon below Ogilvie's station are seen sheared, banded, and massive greenstones and some green and yellow rocks of sedimentary origin, within which are included several bands of marble, one of them 5 feet or more thick. Rocks of the same general character occur in the hills on the opposite side of the river, and in the interbanded marbles of this sequence, a short distance back from the Yukon, Paleozoic fossils were discovered in 1925. In rocks of the same type 13 miles south of Eagle, in the headwaters of Boundary Creek, Prindle in 1903 found Paleozoic fossils. These rocks, therefore, have in this report been included as a part of the undifferentiated Paleozoic sequence. This is not to be interpreted in any way as a reclassification of the age of the Yukon group as defined by Cairnes. It is merely a with-

[29] Cairnes, D. D., op. cit., pp. 39–44.

drawal of a certain portion of the rocks previously mapped as a part of the Yukon group, with a new assignment of them to the Paleozoic instead of to the pre-Cambrian.

To the north of these undifferentiated Paleozoic rocks, but separated from them by an overlapping band of Cretaceous and Eocene rocks, is a belt of limestone, which in turn is adjoined to the north by a group of rocks mapped by Cairnes as a part of his Tindir group, of Cambrian or pre-Cambrian age. This group of rocks consists essentially of drab shale and slate with some relatively thin beds of quartzite and conglomerate. Northwest of the mouth of Eagle Creek these rocks are well exposed along the north bank of the Yukon in a greatly disturbed fault zone and are there seen to contain also greenstone, probably of intrusive character. Except in this faulted zone the rocks of this formation are not so greatly metamorphosed as the undifferentiated Paleozoic rocks along the banks of the Yukon farther upstream, but this fact alone can not be regarded as decisive evidence of Paleozoic age. For reasons given later these rocks are not believed to be of Cambrian or pre-Cambrian age, as stated by Cairnes, and they are, therefore, here included as a part of the undifferentiated noncalcareous Paleozoic rocks.

Farther north along the international boundary, in several irregular areas from McCann Hill to Hard Luck Creek, Cairnes [30] maps a so-called "shale-chert" group, which ranges in age from Ordovician to Carboniferous. These rocks are mapped in this report as undifferentiated noncalcareous Paleozoic. With regard to their lithology, Cairnes makes the following statement:

This series consists dominantly or entirely of shales and cherts, which are prevailingly closely and finely interbedded. The cherts in places become really cherty shales or shaly cherts and occur in most places in beds ranging in thickness from 1 to 6 inches. Locally, however, they are more thinly bedded, and occasionally, on the other hand, they are in strata as much as 12 inches thick. They are also generally dark gray to black in color. The shales are also typically thinly bedded and in most places are soft and friable and gray to black or bluish black in color, the darker beds being in places decidedly calcareous in character. Occasional red shales also occur, however, locally intercalated with the darker strata, but these do not appear to be very persistent, or at least the color is not. Hard gray quartzitic shales are in addition somewhat extensively developed in places. These quartzitic beds contain locally sufficient iron to produce upon oxidation a bright-red to yellow coloration on weathered surfaces, but only rarely are these rocks red on a fresh fracture. These reddish beds decompose readily to form a red or yellowish sand or mud, which is a very noticeable feature of many of the hillsides on which vegetation is lacking.

Along Hard Luck Creek, where these shale-chert beds are well exposed, they have a red and black and in places even a decided ribboned appearance. The chert bands are generally from one-half to 2 inches in thickness and are finely interbedded with the shales. All the beds of the entire section are black or

[30] Cairnes, D. D., op. cit., pp. 31-44.

nearly so, but certain alternate layers weather red in places. The chert beds also in places become shaly or even friable when exposed to the atmosphere and decrepitate somewhat readily.

Cairnes also describes a "shale group," which he believed to be of Carboniferous age but mapped with his Ordovician-Carboniferous sequence. With regard to the lithology of these rocks, he states:

The shale group within the mapped boundary belt here being considered is developed at a number of points between Jones Ridge and Yukon River and wherever identified overlies the members of the Devono-Ordovician shale-chert group. Possibly the most extensive individual development of these Carboniferous shale beds occurs just to the north of Hard Luck Creek, where they compose the greater part of a low northeasterly trending ridge to the east of the boundary line and to the south and east of Jones Ridge. These beds were also identified on McCann Hill and at other points but become rapidly much less prominent to the south of Hard Luck Creek.

On the geological map to accompany this memoir these Carboniferous shale beds have been mapped with the members of the Devono-Ordovician shale-chert group, as except where fossils were obtainable it was in many places difficult or impossible in the field to distinguish certain members of these rock groups, as both contain beds that are lithologically practically identical.

This shale group consists dominantly of shales but includes also clays, cherts, calcareous sandstones, and thinly bedded limestones. The shales and clays are prevailingly soft and friable and range in color from light gray to black, but dark bluish-gray beds are possibly the most extensively developed. The cherts are dominantly dark gray to black in color but constitute a much smaller portion of this formation than the shale members. They occur prevailingly in beds having a thickness of less than 1 inch, but chert strata were noted which are as much as 3 inches or more in thickness. Calcareous sandstones and arenaceous clays are also developed in places and are typically grayish to brownish in color. The limestones generally occur in beds less than 12 inches thick and range in color from light gray to brown. This shale section has thus quite a decidedly striped or ribboned appearance, due to the frequently alternating shale, limestone, and sandstone beds.

The band of limestone south of Eagle Creek, which lies between the undifferentiated metamorphic Paleozoic rocks and the slate-quartzite group referred by Cairnes to the Cambrian or pre-Cambrian, is composed of a number of heavy plates of limestone separated from one another by greater thicknesses of thin-bedded limestone. The general appearance of this limestone belt, when viewed from a distance, would lead to the belief that the limestone is a white crystalline variety, but close inspection shows it to be in large measure a dark-gray noncrystalline thin-bedded variety. Even the thicker plates show well-developed bedding planes and are by no means typically massive limestone. One peculiar phase of this limestone belt is the presence of beds of limestone conglomerate and breccia. The fragments consist usually of pieces of noncrystalline limestone, of varying shades of light gray, commonly well rounded but in part subangular, embedded in a matrix of dark-gray noncrystalline limestone. The texture of the limestone and its numerous ripple markings lead to the inference that this formation is of near-shore and possibly estuarine origin. No dolomitic phases were seen. Some limonitic concretionary forms, simulating shells, were collected, but their organic origin is questionable, and no true fossils were seen, though two days was devoted to a search for them. The trend of this limestone, about N. 55° W., would carry it just north of Eagle and up the north side of Mission Creek, and there is little doubt that the undifferentiated limestone found at that locality is a continuation of this limestone, although it is more metamorphosed.

The two great masses of limestone, dolomite, and associated rocks along the international boundary from the Tatonduk River to Hard Luck Creek and between Cathedral and Ettrain Creeks, which were mapped by Cairnes as ranging in age from Cambrian to Devonian, are here mapped as a part of the undifferentiated calcareous Paleozoic sequence. With regard to the Cambrian-Silurian part of this sequence, Cairnes[31] gives the following lithologic data:

> These rocks are prevailingly white to light gray in color, but occasional beds occur having a dark gray to nearly black or even a pink or reddish appearance. Nearly everywhere, however, on weathered surfaces the different members have the peculiar grayish to bluish-gray rough appearance characteristic of limestones. The rocks are dominantly crystalline, and in places beds of particularly beautiful marble occur, which prevailingly range in color from pure white through various shades of gray, occasional reddish beds being, however, noted in places.
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> In texture these limestone-dolomite rocks vary from firm, dense dolomites to coarsely crystalline, almost pure limestones. They are also characteristically somewhat massive in appearance, due largely to the degree of metamorphism which they have suffered; but where the bedding planes are discernible the strata are dominantly from 1 to 6 feet in thickness, although much thinner beds from 1 to 6 inches thick are locally characteristic of the series. Beds of limestone having an oolitic structure also occur to the south of Tatonduk River and elsewhere, the oolitic grains being generally about one-tenth of an inch or less in diameter.
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> In composition these beds range from limestones to dolomites but appear to be all dominantly more or less magnesian. They are frequently tested in the field with cold acid, and only rarely was a member of this group found that effervesced freely, but nevertheless nearly all were more or less attacked. It would thus seem that these rocks are prevailingly transitional in composition between pure limestones and true dolomites, either of these forms being of somewhat exceptional occurrence. The more dolomitic beds are prevailingly harder and finer-textured than the limestones and are dominantly white to light gray in color, none of the very dark colors occurring, such as characterize the limestones in places. Further, the dolomites in places, as on Mount Marlow and elsewhere in Ogilvie Mountains, are more or less porous and contain numerous cavities, which are generally quite small but range in size from microscopic to several inches in diameter. These cause the containing rocks

[31] Cairnes, D. D., op. cit., pp. 58–61.

to be very rough on weathered surfaces. The cavities are dominantly lined with well-defined crystals, mainly of quartz and calcite, and are considered to indicate rather conclusively that the dolomites are of secondary origin and are derived from limestones, the amount of pore space representing the decrease in volume during the replacement process. Also, as fossils were very rarely, if ever, found in the dolomites and are quite plentiful in places in the adjoining limestones, this would seem to indicate that some change had occurred in the dolomite beds since originally deposited which destroyed any contained organic forms.

In a few places grayish, yellowish, to nearly black shales are intercalated with these limestone-dolomite beds, and at one point, on the western side of Mount Slipper, over 200 feet of thinly bedded shales occur, with dolomites above and below them. Shales, however, are of very minor importance quantitively in this Silurian-Cambrian terrane.

The entire series is prevailingly siliceous, and toward the south the beds contain a great amount of translucent to semitranslucent chalcedonic quartz or chert, which in places considerably exceeds the limestones and dolomites in amount. This chert has in places been deposited largely along the bedding planes of the containing rocks in seams ranging from microscopic up to 8 or 10 inches in thickness and thus gives the rocks in general a decidedly banded appearance. When somewhat regularly deposited along the bedding planes in this way the chert has in places the appearance of being contemporaneous with the containing beds, but when more closely examined it may be seen to intersect the strata; in fact, seams or masses of chert occur cutting the limestone and dolomite beds at all angles, and the smaller seams are frequently distinctly traceable back to larger seams or irregular bodies.

The Devonian part of this limestone sequence is described as follows:

The Devonian limestones resemble very closely the limestone beds of the Silurian-Cambrian group, and except where fossils can be found it is difficult or impossible in many places to distinguish these rocks from the older limestones. They are, however, as a rule somewhat more homogeneous and darker in appearance, being typically dark bluish gray in color. They are also in most places characteristically coarsely crystalline, and when broken they generally emit a strong oily odor, which was seldom noted in connection with the underlying formations. In places a heavy bed or series of beds of white to light-gray sugar-grained quartzite occurs at the base of this limestone series, as in the vicinity of Tindir Creek, but this quartzite appears to be only locally developed.

Another belt of limestone of unknown age begins in the hills west of Nation at Spring Creek and extends in a northwesterly direction 8 or 10 miles, as far as Glenn Creek. This limestone shows several variations. Some of it is dark gray to black and noncrystalline, some is light gray and finely crystalline, and some beds of silicified cherty oolite and also beds of limestone breccia were seen. The dip appears to be dominantly northward, but as the nearest good exposures of other rocks are some miles away, this apparent structure has little significance. As no fossils were found the age of the limestone is indeterminate. It resembles perhaps more nearly than any other rock the plate of limestone that crops out on the north side of the

Yukon about 2 miles below Calico Bluff, which is believed to be of Upper Cambrian age.

A similar belt of limestone crops out on Woodchopper Creek about 3 miles from the Yukon. This limestone also has a general northwesterly trend, but its extent along the strike northwest and southeast of Woodchopper Creek is not known. It is also varied in aspect. Some of it is black, noncrystalline, and carbonaceous and resembles the limestone south of Eagle Creek, and some of it resembles more closely the limestone west of Nation and that below Calico Bluff.

STRUCTURE AND THICKNESS

Structural observations on the undifferentiated Paleozoic rocks were made by the writer chiefly in the rock bluffs along the Yukon in the vicinity of the international boundary. The rocks in this zone, like most of the other undifferentiated Paleozoic rocks, lie northeast of a great mass of granitic rocks which are believed to have determined the degree of metamorphism and in large measure the dominant structure of the adjacent rocks. Although the observations are admittedly fragmental, they are nevertheless believed to represent conditions rather typical of the structure of all the undifferentiated metamorphic Paleozoic rocks lying northeast of the great Mesozoic batholith.

These rocks as exposed along the river and in the near-by hills north and south of the river are, as previously stated, closely folded and cleaved and show all the typical indications of intense compression induced by lateral thrusting. Except in some of the more massively resistant greenstones and in the easily recrystallized limestones, flow cleavage is commonly present. Nevertheless, bedding also can be discerned at many places, particularly in the thin beds of quartzite, and where such bedding was recognized close folding is also prevalent. Where the thrusting movements were localized, as along fault and shear zones, closely appressed and even recumbent folds are clearly visible.

Numerous observations of the attitude of the cleavage planes and of the axial planes, both of the drag folds in the less resistant rocks and of the more diagnostic appressed folds of competent beds, were made from Fortymile downstream to Eagle. Bedding planes also were recorded where visible. It can not be stated that any absolute uniformity exists in these observations. Nevertheless about 80 per cent of the cleavage planes and axial planes of the folds dip south at angles of 15° to 65°, with an average of about 30°. The strike of the dominant structural feature, which here is the cleavage, is about N. 70° W. The bedding planes, where visible, appear to dip both to the southwest and to the northeast, but it is worthy of note that the dip is prevailingly southward along the side of the river, where the rocks are most metamorphosed. In other words, cleavage and bedding in the metamorphic rocks are prevailingly parallel. These data suggest to the writer that the rocks have been thrust northeastward and overturned by enormous tangential forces acting from the southwest, and their degree of metamorphism is explained as a concurrent effect of this prodigious thrusting. The cause of the forces applied is believed to be a great batholith of Mesozoic granitic rocks that lies to the southwest.

At the boundary and just to the east are three groups of rocks, all mapped as a part of the undifferentiated Paleozoic sequence, that present a difficult stratigraphic problem; these are the metamorphic Paleozoic rocks along the river, the slate-quartzite group, and the band of limestone. Fossils found in the Paleozoic metamorphic rocks give some idea of the age of those rocks, but no fossils have yet been found in the other two formations, and the relative ages of the three must be deduced, if at all, from available structural data. The metamorphic rocks at this locality were regarded by Cairnes as pre-Cambrian and were included as part of his Yukon group; and the slate-quartzite group, which he believed to be of Cambrian or pre-Cambrian age, he correlated with his Tindir group, exposed farther north along the boundary; the limestone band was believed to be Cambrian. Cairnes's sequence, then, was metamorphic rocks at the base, overlain by the slate-quartzite group, overlain in turn by the belt of limestone.

The following data on the geologic structure may shed some additional light on this correlation. All three of these formations appear to be parallel to one another, trending about N. 55° W. The rocks of the Paleozoic metamorphic group are schistose, but where the bedding is visible or may be inferred the bedding planes also dip prevailingly southwestward. The angle of dip of the cleavage and bedding planes here, as farther upstream, averages about 30°.

Just below the mouth of Eagle Creek a well-developed fault zone may be seen exposed in the bluff along the north bank of the Yukon. This is not a clean-cult fault but rather a zone of dislocation along which adjustments consequent upon great thrusting movements took place. Doubtless numerous similar fault zones are present in this area, but it is doubtful if any will be discovered where the rocks are so well exposed and where the structural interpretation is so apparent. The rocks involved in this fault zone are the Paleozoic metamorphic rocks, which at this locality are greenstone and greenstone schist, and the rocks of the slate-quartzite belt. The strike of this fault zone is about N. 55° W., and the attitude of the axial planes of numerous drag folds shows that the thrusting came from the southwest. Figure 2 shows a thin bed of quartzite squeezed into an appressed fold whose limbs are practically parallel. Fragments of other beds of quartzite, surrounded by slate, are also visible, and on both sides of the quartzite and slate are relatively massive but nevertheless highly disturbed bodies of the recrystallized basic volcanic rocks of the Yukon group. This fault was traced 3 miles southeastward into the hills south of Eagle Creek. The small body of greenstone included in the limestone where the limestone formation reaches the Yukon lies within this fault zone and owes its peculiar environment to a dislocation attendant upon this thrust faulting. To the northwest the fault zone is apparent for 10 miles up the north side of Mission Creek, where its presence is inferred from the disturbed condition of the country rocks, as well as from fault breccias and an abnormal disposition of the geologic terranes.

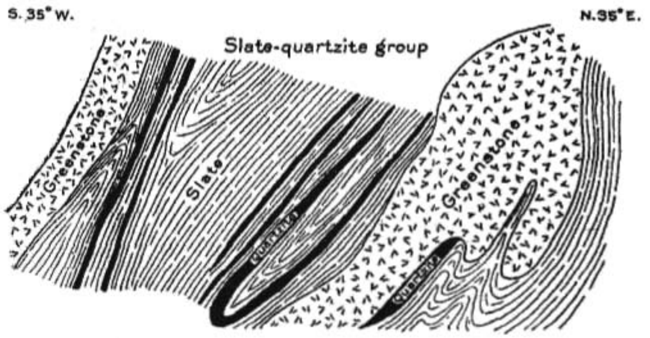

FIGURE 2.—Diagrammatic sketch showing structure of rocks in the fault zone on the north bank of the Yukon River 3 miles above Eagle

The belt of undifferentiated limestone, which lies at the international boundary northeast of the Paleozoic metamorphic rocks, is well exposed in the mountains south of Eagle Creek, but its contact with the Paleozoic metamorphic group to the southwest is covered by rocks of Cretaceous and Eocene age. To the southeast, however, farther up the Yukon Valley, rocks similar to the slate-quartzite group were seen on the southwest as well as the northeast side of the limestone belt. At the boundary the northeastern contact of the limestone with the slate-quartzite group is not a simple one but, northwest from the limestone, consists of a narrow zone of the slate-quartzite group followed by another plate of limestone, followed in turn by the main belt of the slate-quartzite group. This relationship, in the absence of a recognizable fault zone at this locality, suggests a stratigraphic gradation from the limestone to the slate-quartzite group. The structure of the limestone in this belt is complex, but as a rule the bedding planes are apparent. The southwestern flanks consist dominantly of thin-bedded limestone, which is much crumpled and shows numerous reversals of dip. The central and northern part of the limestone, however, contains numerous plates of more massive limestone, which dip consistently southwest at angles of 60° to 75°, though approaching verticality at some places. Appressed folds, in both the thin and the thick bedded parts of the limestone, are common, but these also dip usually to the southwest.

Relatively little is known of the structure of the slate-quartzite group of rocks that adjoins the limestone belt on the northeast and possibly on the southwest, because this formation along the boundary is not well exposed, even above timber line. At an altitude of 3,139 feet, at "Hog" station, and thence northwestward down the spur toward the mouth of Eagle Creek, these rocks crop out at intervals and show a cleavage plane which dips in general southwestward 30° to 60°, more commonly nearer 60°. Numerous wavy lines along this cleavage plane suggest deformed ripple markings, and these, together with sundry concretionary forms and marks suggestive of worm borings, lead to the belief that these cleavage planes also represent bedding planes. A northeastward dip was noted, however, at one or two localities on the ridge and also where the same rocks crop out in the fault zone along the river.

In weighing these lithologic, structural, and stratigraphic data, the greater degree of metamorphism of the rocks of the Yukon group should at the outset be discounted as absolute evidence bearing on the relative age of these three formations. Cumulative observations on the metamorphic rocks of Alaska have shown that degree of metamorphism alone, unsupported by contributory data, can lead to very erroneous conclusions; and in this area the greater degree of metamorphism of the Paleozoic metamorphic rocks may be discounted almost completely because of the known presence of a great granitic batholith to the south, from the direction of which tangential forces of great magnitude have been applied against the adjoining rocks to the north. The localized nature of this metamorphism is also emphasized by the occurrence of fossils of Silurian or Devonian age in these metamorphic rocks, whereas within a distance of 25 miles rocks of definite Cambrian age are found in an almost entirely unmetamorphosed state.

As has previously been stated, 80 per cent of the cleavage planes and axial planes of the appressed folds in the Yukon group dip southwestward, and the dominant dip of the bedding planes, where visible, in the more metamorphosed rocks south of the Yukon is also southwestward. In other words, cleavage and bedding in these rocks are more commonly parallel than otherwise. It seems almost evident, therefore, that tangential forces applied from the southwest have thrust the Paleozoic metamorphic rocks and to a less degree the limestone formation northeastward and have caused a general overturning of the whole sequence. Although both the limestone and the Paleozoic metamorphic rocks dip southwestward, the dip of the limestone is in general considerably higher than that of the metamorphic rocks, approximating verticality at the northeastern limit of the limestone. The hypothesis favored by the writer, therefore, postulates a great overthrusting movement of the rocks of this region from the southwest, the effects of which are naturally most evident near the northeastern border of the granitic batholith, where these thrusting stresses originated. As a result, the Paleozoic metamorphic rocks have been more or less completely overturned and metamorphosed and have acquired a southward-dipping cleavage. The limestone and the slate-quartzite formations have also been affected, but to a smaller degree, by the same forces, with partial overturning and the development of a similar cleavage.

This hypothesis explains the observed differences in metamorphism in these three formations but does not settle their relative ages. A number of different structural interpretations might be made. The limestone belt and the slate-quartzite formation may be part of either an overturned anticline or a syncline. The beds of the three kinds of rock may all lie on one side of such a fold, thus forming a continuous sequence; or any one of the three may lie in the axial plane of such a fold, thus changing the sequence; or any previously existing structure may have been materially modified by thrust faulting concurrent with the folding. It seems best, therefore, not to assign a definite sequence to these three formations.

The influence of thrust faulting with its attendant metamorphism can not be said to extend for any considerable distance north of the Yukon. Numerous faults are present, some of which were recognized in the field; but they seem to be of a different type. Cairnes shows one fault plane of low dip between Cathedral and Tindir Creeks at which the rocks of his Tindir group are brought into contact with younger rocks and which therefore indicates a thrusting movement of rocks from north to south, a relation diametrically opposed to that seen along the Yukon. This locality, however, lies on the north flank of the Ogilvie Mountains, where a different type of structure may prevail. This fault may also be either an earlier or a later structural feature than the dislocations attendant upon the Mesozoic granitic intrusion.

The obvious duplication of beds resulting from close folding, overthrusting, and faulting in the Paleozoic metamorphic rocks along the Yukon at the boundary and in the limestone belt and slate-quartzite group to the northeast precludes any accurate estimate of the thickness involved, even if the top and base of each of these three units were positively recognized. The upper limit of the metamorphic Paleozoic rocks along the Yukon is a fault zone, and the base is undetermined, so that it seems utterly useless to hazard even a guess as to the thickness of this part of the sequence. If the limestone band and the slate-quartzite group have about the same degree of complexity, the width across the strike indicates that these two units have thicknesses of about the same order. The limestone is better exposed than the slate-quartzite group and therefore affords a better basis for an estimate of thickness. Though not accurately measured, the total thickness of this limestone certainly can not exceed 3,000 feet, and when allowance is made for the probable duplication of beds due to folded structure, an estimate of half that thickness seems all that is warranted.

The following structural data are given by Cairnes with regard to the Silurian-Cambrian limestone and dolomite, here mapped as undifferentiated Paleozoic limestone:

> The rocks are all so much folded and faulted that only in a few places could the positions of the different beds within the series be even approximately determined stratigraphically; and unless fossils could be found it was impossible, even in these places, to draw the geological age boundaries, as no distinctive persistent lithological horizon markers could be distinguished. * * * These beds in the northern portion of the belt have an aggregate thickness of 4,000 feet and possibly very much more than this amount, but no section of them was at all closely measured at any one point, it being found very difficult to do so on account of folding and faulting. * * * To the south these beds do not appear to be so thick, but even there they have an aggregate thickness of at least 3,000 feet.

Cairnes's statement with regard to the thickness of the Devonian limestone, also mapped in this report as undifferentiated Paleozoic limestone, is as follows:

> These Devonian limestones appear to have an aggregate thickness of from 300 to 500 feet, and wherever a contact was observed with the underlying Silurian beds they overlie these unconformably.

AGE AND CORRELATION

Rocks of very diverse character and age are grouped on the map into two lithologic units, under the general assignment of undifferentiated Paleozoic. The evidence concerning the fauna and age of these rocks may conveniently be presented under three general headings, as follows: Undifferentiated metamorphic Paleozoic rocks along the international boundary and similar and associated rocks south of the Yukon; undifferentiated nonmetamorphic and essentially noncalcareous Paleozoic rocks along the international boundary north of the Yukon; undifferentiated Paleozoic limestone along the international boundary north of the Yukon.

Metamorphic rocks.—Only the three fossil collections noted below have so far been made from the undifferentiated metamorphic Paleozoic rocks within the area covered by this report.

3AP77. Valley of a headwater tributary of Boundary Creek, 13 miles south of Eagle; from a thin bed of crystalline limestone; collected by L. M. Prindle, 1903. These fossils were identified by G. H. Girty as crinoid columns and showed only that the rocks are of Paleozoic age.

Two other collections, made by the writer during the season of 1925, were found in the lower valley of a stream which empties into the Yukon on the same side of the river and about a mile upstream from Boundary Creek. The exact localities are:

25AMt52 (2059). West slope of Loop Mountain, in Yukon Territory, Canada, 2⅛ miles S. 40° E. of international boundary topographic station 112.

25AMt53 (2060). Boulder in creek, directly down hill from 25AMt52 and about 1.9 miles S. 40° E. of international boundary topographic station 112.

Both these collections consist of crinoid columnals. With regard to them, Edwin Kirk states: "These two lots are apparently of the same age. They are Paleozoic and not earlier than Silurian. They probably are Devonian." These crinoids are especially significant because they occur in rocks previously mapped as a part of the Yukon group. A part of the rock from which collection 25AMt53 (2060) was taken is shown in Plate 4, *B*.

To the south, however, beyond the area covered by this map but within rocks that are grouped with the undifferentiated Paleozoic rocks, L. M. Prindle made three collections in 1904, 1905, and 1907, all of which offer corroborative evidence of the Paleozoic age of this group of rocks. The numbers and localities of these collections are as follows:

4AP46. 40 miles west of Eagle.
5AP319. Dennison Fork, about 20 miles south of Chicken Creek.
7AP82. Fortymile River, one-fourth mile below mouth of Napoleon Creek.

Collection 4AP46 consisted of a coral doubtfully referred to *Zaphrentis?* sp., which suggested to E. M. Kindle a Devonian or Silurian age. Collection 5AP319 showed some striated plant stems which were referred by F. H. Knowlton to *Calamites radiatus* and indicated only a Paleozoic age. Collection 7AP82, from a somewhat schistose limestone, was identified by Kindle as crinoid stems of little diagnostic value.

In addition to such fragmentary paleontologic evidence, however, considerable is known of the age of this group of rocks from other fossil collections made in this same district and near-by districts, and from formations which, though belonging to the same group, have been in part differentiated into mappable units. The other fossil lists will be presented under the appropriate headings. The age of certain other parts of the undifferentiated Paleozoic assemblage that are unfossiliferous either here or elsewhere has been determined within fairly narrow limits from correlation with similar rocks in near-by districts where their stratigraphic relations to contiguous formations are better known. The feldspathic sandstone or quartzitic arkose, for example, which appears to adjoin the Birch Creek schist, is probably equivalent to part of the Tatalina group in the Fairbanks quadrangle, where such rocks have been differentiated into a separate unit. The Tatalina group, which lies beneath Middle Ordovician rocks and above the Birch Creek schist, includes not only the arkosic and quartzitic rocks above described but also many red, green, and purple slates, and it doubtless represents that part of the Lower Ordovician and Cambrian sequence which is present south of the Yukon, and it may extend down into the pre-Cambrian. It does not, to be sure, include a Cambrian limestone, but possibly its multicolored slates are in part at least the metamorphosed equivalents of the two formations that underlie the Middle Cambrian limestone in the valley of the Tatonduk River. It is therefore not too much to state that the base of this undifferentiated group of Paleozoic rocks may be as old as Cambrian.

The thin-bedded dolomites between Fourth of July and Glenn Creeks are particularly hard to place stratigraphically. The beds dip both southwest and northeast, showing reversals due to folding, but apparently the dominant dip is southwestward. They lie northeast of a belt of undifferentiated limestone of unknown age that crops out in the hills southwest of the Yukon. Farther northeast are Lower Cretaceous and Carboniferous rocks. The structure and surrounding stratigraphy therefore yield little information regarding their age. Lithologically, these rocks resemble more than any other the thin-bedded argillite and limestone that underlie the Middle Cambrian limestone of the Yukon and Tatonduk Rivers. They are included as undifferentiated Paleozoic rocks because the information at present available does not seem to warrant a closer age assignment.

The age of the slate-quartzite group just north of the Yukon at the boundary can not be stated definitely, inasmuch as no fossils were found in it or in the adjoining limestone. Even the stratigraphic sequence is doubtful, as previously pointed out. But as fossils not older than Silurian occur in the Paleozoic metamorphic rocks just to the south, and the rocks adjoining to the north are regarded as Middle Devonian, the apparent interpretation is that the age of the slate-quartzite group is somewhere between Silurian and Devonian. However, in an overturned sequence such as is believed to exist here the apparent interpretation is not necessarily the true one, and this suggestion is made with no dogmatic insistence of its absolute truth.

Metamorphosed basic igneous rocks of several different ages collectively designated greenstone exist in the Yukon-Tanana region. Fossils collected from the volcanic tuffs and other sedimentary beds associated with the lavas indicate the presence of a Middle Ordovician, a Middle Devonian, and a Mississippian sequence of basaltic rocks of greenstone habit. Another group of greenstones of ultrabasic character, which for reasons elsewhere stated in this report are considered to be of Devonian age, are also present. Each of these four Paleozoic greenstone formations has certain distinguishing characteristics that make possible a reasonable guess regarding the age in areas where the fossils are absent. From such data the greenstones of necessity included in these undifferentiated Paleozoic rocks are believed to be mainly of Devonian age. Likewise, some of the shales and thin beds of limestone are more likely to be of Devonian or late Silurian age than otherwise.

Chert occurs in varying amounts throughout the Paleozoic rocks, and two formations containing a considerable proportion of chert, of late Middle Devonian and lower (?) Mississippian age, have been separately mapped. The chert conglomerate, above described, may belong in either of these two formations, but the weight of present evidence favors its assignment to the lower Mississippian.

Upper Mississippian and Permian rocks constitute well-known geologic units along the Yukon and elsewhere in interior Alaska, but they are so extremely fossiliferous that it is inconceivable that their fossil content could be obliterated by metamorphism of the degree present in this undifferentiated group. It is therefore believed that practically none such rocks are included in this group.

It may be said, therefore, that the group of undifferentiated metamorphic Paleozoic rocks along the international boundary and south of the Yukon includes formations ranging in age from Cambrian to Devonian. It should again be emphasized, however, that the sequence included in this grouping represents only a part, and possibly only a small part, of the Cambrian-Devonian sequence.

Nonmetamorphic noncalcareous rocks.—The presentation of the evidence concerning the fauna and age of the essentially noncalcareous nonmetamorphic rocks along the international boundary north of the Yukon which were described and mapped by Cairnes is difficult because Cairnes published his faunal lists without giving exact locations; it is therefore impossible from his memoir alone to correlate the fossils with the geologic mapping. From Dr. E. M. Kindle, at Ottawa, however, the writer obtained a key to the locations of Cairnes's fossils, which, although obviously in error with regard to the placement of certain particular lots of fossils, gives the localities of most of them within a quarter of a mile.

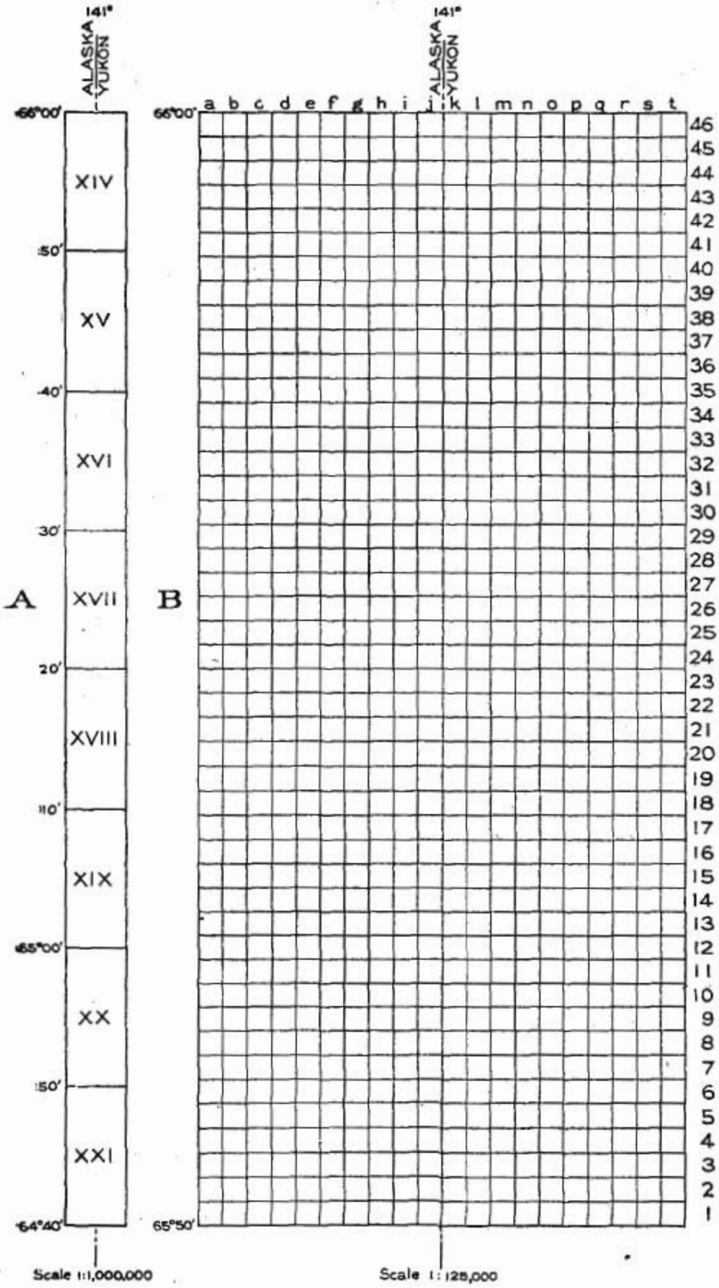

FIGURE 3.—Index to localities of fossils collected along the international boundary by the *Canada Geological Survey*, as listed by Cairnes. A, Key to numbering of main blocks; B, sample block showing method of indicating subdivisions

Cairnes's key is as follows: The strip along the international boundary is divided into blocks comprising 10 minutes of latitude and approximately 10 minutes of longitude, which are numbered from north to south with roman numerals. Each main block is subdivided into units approximately one-fourth of a mile square, designated from south to north by the numbers 1 to 46 and from west to east by the letters a to t. The main blocks falling within this area and the method of designating their subdivisions are indicated in Figure 3.

On the assumption that this scheme was used consistently and that no typographic errors are present in the numbers of the fossil collections given in Cairnes's memoir and after making the best possible adjustment of some of the obvious inconsistencies, the following lots of Cairnes's fossils are interpreted by the writer as having been collected from the essentially noncalcareous rocks, ranging in age from Ordovician to Carboniferous.

XX i 25:
- Dicranograptus cf. D. ramosus (Hall).
- Retiograptus geinitzianus Hall.
- Diplograptus foliaceus incisus Lapworth.
- Obolus sp.
- Ostracode.
- Ptychoparia sp.
- Isotelus? sp.
- Harpes? sp.

The three graptolites listed above were determined by R. Ruedemann to be of Lower Ordovician age, or, more specifically, equivalent to the Normanskill, the upper part of which, however, Ruedemann considers to be of early Black River (Lowville) age, which is commonly classified as Middle Ordovician. The other invertebrates were determined by L. D. Burling.

XXI o 44:
- Ostracode.
- Monticuliporoid coral.
- Atrypa? sp.
- Proetus-like trilobite.

The above collection, determined by E. M. Kindle and E. O. Ulrich, was referred with some hesitation to the Ordovician.

XV a b 35:
- Cladopora cf. C. dichotoma Hall.
- Phillipsastraea verneuili Milne-Edwards.
- Proetus cf. P. macrocephalus Hall.

This collection, determined by E. M. Kindle as Devonian but possibly different from the type Middle Devonian fauna, was obtained, according to the scheme of locations given in Figure 3, about 2½ miles west of the boundary and an equal distance south of the Kandik River, in an area believed to be composed essentially of Lower Cretaceous rocks. If no error in placement has been made, these fossils probably came from essentially noncalcareous Devonian rocks infolded into the Cretaceous.

L. D. Burling, who accompanied the boundary party in 1912, also made several Ordovician collections along the boundary north of the Yukon. These have been studied by R. Ruedemann, and the results of his study are given in the identifications below tabulated:

4636:

Cactograptus n. sp.
Callograptus cf. C. diffusus Hall.

4662:

Lingula n. sp.
Obolus n. sp. Strongly ribbed.
Paterula n. sp.
Caryocaris n. sp. Large form with fringed posterior extremity.
Sponge spicules.
Tetragraptus similis (Hall).
Didymograptus patulus Hall.
Didymograptus cf. D. extensus Hall.

4680:

Caryocaris n. sp.
Tetragraptus similis (Hall). Young specimen.
Didymograptus nitidus Hall.
Didymograptus extensus Hall.

4683:

Lingula n. sp.
Caryocaris n. sp.
Sponge spicules.
Tetragraptus similis (Hall).
Didymograptus nitidus Hall.

Three of the four collections above given include the genus *Caryocaris*. Ruedemann,[32] who discovered this little crustacean among the Burling collection, published a separate note thereon, as follows:

> In a collection of lower Ordovician praptolites from the Alaska-Yukon boundary sent to the writer by L. D. Burling, of the Geological Survey of Canada, for identification, a small number of specimens of *Caryocaris* were noted, one of which retains the abdomen in place. This fact as well as the presence of other characters hitherto unknown have suggested this note, the material having been kindly presented to the New York State Museum by Mr. Burling. * * * The Alaska-Yukon material is not obscured by an imperfect cleavage and leaves no doubt that the posterior margin of the carapace was indeed furnished with a fine comb of uniform bristles or teeth corresponding to the "fringe" observed in certain species of *Ceratiocaris*.

In 1928 P. S. Smith made a collection of Lower Ordovician graptolites from a bed just above the Upper Cambrian limestone, at the

[32] Ruedemann, R., Note on *Caryocaris salter:* New York State Mus. Bull., Nos. 227–228, pp. 97–98, 1919.

head of the North Fork of Shade Creek, which were determined by Edwin Kirk, of the United States Geological Survey, as *Diplograptus* sp. and assigned by him to the Normanskill. The exact locality (28AMt261) is 1 mile N. 17½° W. from "Hug" boundary triangulation station (McCann Hill). These fossils come from a narrow band of slate, directly above the Upper Cambrian limestone but directly below a group of rocks composed of argillite and chert, of Middle Devonian age. This Ordovician slate is too small to show on the scale of the accompanying map but can be discriminated and mapped on a larger scale. The occurrence is here recorded, for the benefit of later workers in this area.

Most of the Carboniferous fossils collected by Cairnes occurred in rocks that were dominantly noncalcareous, although some of the upper Mississippian rocks evidently contain thin beds of limestone, as they do at Calico Bluff, on the Yukon. The Carboniferous fossils of the boundary were studied originally by G. H. Girty, of the United States Geological Survey, and those collected from latitude 66° southward to the Yukon have recently been reexamined by him. Three of these collections from the vicinity of Ettrain Creek, which occur in limestone and are now referred by Girty to the Permian, are separately listed under the Tahkandit (Permian) limestone. (See p. 129.) All the others, as revised, are listed below:

XIV s 43:
- Favosites sp.
- Zaphrentis sp.
- Crinoidal fragments.
- Fenestella, several sp.
- Hemitrypa? sp.
- Spirifer cf. S. marcoui.
- Martinia? sp.

XV c 40:
- Fenestella sp.
- Polypora sp.
- Cleiothyridina cf. C. pectenifera.

XVI j 9:
- Zaphrentis sp.
- Marginifera? cf. M. involuta.

XVI k 10:
- Fenestella sp.
- Pinnatopora (Acanthocladia) sp.
- Cystodictya sp.
- Hustedia cf. H. indica.
- Zaphrentis sp.
- Fenestella sp.
- Productus cf. P. tenuistriatus.
- Productus cf. P. inflatus.
- Myalina cf. M. keokuk.

XVI 1 9:
- Fenestella sp.
- Chonetes sp.
- Marginifera? cf. M. involuta.
- Reticularia cf. R. lineata.
- Spirifer cf. S. nikitini.
- Spirifer sp.
- Aviculipecten sp.
- Aviculipecten? sp.

XVII a 38, 39:
- Chonetes sp.

XVII a, b 33:
- Batostomella sp.
- Productus cf. P. tenuistriatus.
- Productus cf. P. curvirostris.
- Productus sp.
- Leiorhynchus sp.
- Paraparchites sp.

XVII b 39:
- Zaphrentis.
- Chaetetes? sp.
- Lithostrotion? sp.

XVII e 27:
- Productus cf. P. curvirostris.
- Productus cf. P. pustulatus.
- Productus cf. P. cancriniformis
- Productus sp.
- Camarophoria cf. C. explanata

XVII j 30:
- Amplexus sp.
- Fenestella sp.
- Productus cf. P. gruenewaldti.
- Productus cf. P. juresanensis.
- Productus cf. P. tenuistriatus.
- Productus cf. P. porrectus.
- Marginifera? cf. M. involuta.
- Composita cf. C. trinuclea.
- Platyceras sp.

XIX b 3:
- Chonetes cf. C. variolatus.
- Productus cf. P. porrectus.
- Productus cf. P. humboldti.
- Productus cf. P. wallacianus.
- Productus sp.
- Spirifer cf. S. cameratus.
- Spirifer cf. S. nikitini.

XIX b c 35 to 37:
- Chonetes cf. C. variolatus.
- Productus cf. P. humboldti.
- Productus cf. P. wallacianus.
- Spirifer cf. S. nikitini.

XIX c d 30, 31, 32:
- Michelinia sp.
- Zaphrentis, 2 sp.
- Batostomella sp.
- Polypora, 3 sp.
- Derbya? sp.
- Rhipidomella sp.
- Chonetes sp.
- Productus semireticulatus.
- Productus cf. P. pustulatus.
- Productus cf. P. cancriniformis.
- Productus sp.
- Marginifera cf. M. involuta.
- Spirifer cf. S. fasciger.
- Spirifer cf. S. nikitini.
- Spirifer cf. S. tastubensis.
- Spirifer cf. S. condor.
- Squamularia cf. S. perplexa.
- Spiriferina sp.
- Cleiothyridiana cf. C. pectenifera.
- Hustedia cf. H. indica.
- Aviculipecten sp.
- Pleurotomaria sp.
- Amplexus sp.

XIX e 30:
- Favosites sp.
- Zaphrentis sp.
- Polypora sp.
- Batostomella sp.
- Lingula cf. L. albapinensis.
- Rhipidomella sp.
- Schuchertella cf. S. chemungensis.
- Chonetes cf. C. geinitzianus.
- Chonetes cf. C. variolatus.
- Chonetes sp.
- Productus cf. P. porrectus.
- Productus cf. P. cancriniformis.
- Productus cf. P. fasciatus.
- Productus cf. P. juresanensis.
- Marginifera? cf. M. involuta.
- Spirifer sp.
- Squamularia cf. S. perplexa.
- Aviculipecten, 2 sp.
- Pleurotomaria sp.
- Paraparchites sp.

XIX i 4:
- Chonetes cf. C. ostiolatus.
- Productus cf. P. humboldti.
- Camarotoechia sp.

Girty's latest statement regarding the probable age and correlation of the fauna above listed is given herewith:

I find it possible to repeat at this time most of what I wrote to Mr. Cairnes in 1912—something that does not always happen. As regards the age of this fauna, I am in a curious dilemma, owing to the recurrence in the late Pennsylvanian of Russia of types of fossils that are more or less restricted to the Mississippian of the United States. Judged by our standard the fauna would be late Pennsylvanian or even Permian; judged by the other it would be late Mississippian. Of course if an exact agreement were found with either, all uncertainty would instantly vanish, but nothing more is found than general resemblance. My identifications and comparisons as furnished to Cairnes would suggest a tentative preference for a Pennsylvanian or Permian age, though the formulas employed were in part at least merely descriptive and did not necessarily carry any strong implication of geologic age. My present feeling is the other way, that this fauna is probably Mississippian, though, I should add, it has scarcely any features in common with the typical Mississippian faunas of Iowa, Missouri, and other States. At present the only ground that is even approximately safe is that we apparently have two distinct faunas belonging in two distinct horizons. One horizon is the Alaskan Permian; the other is older. Unfortunately we know little or nothing about the stratigraphic relations of the Cairnes collections; such knowledge would doubtless be a great aid to us in the present difficulty. The true positions of this fauna in the time scale seemingly must be left to future investigations—probably to a recognition of it in other areas where its relations to other faunas have been determined.

I should perhaps add that because I have designated three collections as Permian, I would not imply that all the rest belong to the other questionable fauna. A number of the residual collections are so poor in species or in preservation that no disposition of them can be made.

The original faunal lists prepared for Mr. Cairnes are returned herewith. I have checked the lists with the collections, species by species, and made a few changes in terminology. In the original lists the species are compared with those of Tschernyschew's "Gschelian" fauna. If I attempted to embody my present idea in the lists I would perhaps try to find comparable species in our Mississippian faunas. This would entail a great many changes in the lists—would in fact give some of them an entirely new aspect. Under the conditions of uncertainty that exist, this seemed undesirable, and the names as they stand may well be taken to indicate specific resemblance without implying geologic age.

Limestone.—Cairnes, in his work along the international boundary, collected Cambrian, Ordovician, Silurian, and Devonian fossils from limestones of these ages but did not differentiate the limestones on his geologic map. Burling, in 1913, collected Cambrian and perhaps other Paleozoic fossils from limestone in the same area. Harrington, in 1909, collected Middle Devonian and Ordovician fossils from the limestone on the Tatonduk River near the boundary, and the writer in 1925 collected Middle Devonian and Silurian fossils from this same district. All the fossils from Paleozoic limestones that have not been differentiated in the geologic mapping are listed below.

Cambrian fossils collected by D. D. Cairnes:

XIX j 9:

- Obolus sp.
- Lingulella sp.
- Acrothele cf. A. coriacea Linnarsson.
- Acrotreta, 2 sp.

XIX j 9—Continued.
- Agnostus, 2 sp.
- Ptychoparia sp.
- Anomocare sp.
- Liostracus sp.
- Levisia sp.

XIX j 17, 18:
- Obolus (Westonia) cf. O. stoneanus (Whitfield).
- Lingulella sp.
- Acrothele cf. A. coriacea Linnarsson.
- Schizambon cf. S. typicalis Walcott.
- Undetermined trilobite.

XIX j 31:
- Foraminifera? undetermined.
- Obolus, 2 sp.
- Obolus (Westonia) cf. O. stoneanus (Whitfield).
- Lingulella, 2 sp.
- Dicellomus? sp.
- Curticia? sp.
- Acrothele cf. A. coriacea Linnarsson.
- Acrotreta sp.
- Orthoid.
- Coral?
- Ostracode.
- Agnostus sp.
- Eurycare? sp.
- Three unidentified trilobites.

XIX j 32:
- Micromitra (Iphidella) pannula (White)?
- Obolus, 2 sp.
- Obolella? sp.
- Acrothele cf. A. coriacea Linnarsson
- Acrotreta, 2 sp.
- Ostracode.
- Illaenus? sp.

XIX p 20:
- Obolus, 2 sp.
- Lingula sp.
- Acrotreta, 2 sp.
- Asaphus? sp.

XX c 29:
- Obolus sp.
- Acrotreta sp.
- Agraulos sp.
- Ptychoparia sp.
- Anomocare sp.
- Solenopleura sp.

XX e 39:
- Curticia? sp.
- Acrotreta sp.
- Agnostus sp.
- Dicellocephalus? sp.

XX i 34:
- Foraminifera.
- Hyolithellus? sp.
- Stenotheca, 2 sp.
- Conularia sp.
- Micromitra (Iphidella) pannula (White).
- Acrotreta, 4 sp.
- Ostracodes, 4 sp.
- Agnostus, 3 sp.
- Agraulos, 3 sp.
- Ptychoparia, 2 or 3 sp.
- Anomocare sp.
- Dorypyge? sp.
- Neolenus? sp.
- Solenopleura, 3 sp.

L. D. Burling, in 1912, made six collections:

4730, 4731, 4732, and 4733. Squaw Mountain north of Tatonduk River, international boundary.

4734 and 4689. Jones Ridge, north of Tatonduk River, international boundary.

C. E. Resser, of the United States National Museum, who has lately been studying this material, gave to the writer the following partial list of genera occurring in these collections:

4730, 4731, 4732, 4733, and 4734:
- Eoorthis sp.
- Westonia sp.
- Acrothele sp.
- Parobolus sp.
- Trilobites of several genera and species.

4689:
- Symphysurina sp.
- Eoorthis sp.

All of Cairnes's Cambrian fossils, with the exception of collection XX i 34, which was believed to be possibly of Middle Cambrian age, were referred by Burling to the Upper Cambrian, and so far as the writer is aware no later work has been done on this material. Collection 4689, made by Burling, is referred by Resser to the upper part of the so-called "Canadian system," or, in the United States Geological Survey nomenclature, to the Beekmantown group of the Lower Ordovician series. Collections 4730 to 4734, also made by Burling, are referred by Resser to the Upper Cambrian of Ulrich, which in United States Geological Survey nomenclature is the lower part of the Upper Cambrian. Hence it would seem that the Upper Cambrian series is rather fully developed as marine limestones along the boundary.

Cairnes collected Ordovician fossils along the boundary but not within the area covered by this report, and lists of those fossils are therefore not here included. The fossils of Ordovician age collected by Harrington in 1909 came from the gravel of the Tatonduk River near the boundary and consisted entirely of *Columnaria alveolata.* The presence of this species, of course, has little stratigraphic value, because the gravel in which it occurs may have been transported many miles.

Cairnes's Silurian fossils include 8 collections of middle Silurian age and 11 collections of upper Silurian age. Of the 8 middle Silurian collections, only 6 were obtained within the area covered by this report, and these are given herewith. The determinations were made by E. M. Kindle, of the Geological Survey of Canada.

XIX s 28:
- Pholidops cf. P. squamiformis Hall.
- Atrypa sp.
- Atrypa cf. A. marginalis Dalman.
- Orthis flabellites Foerste.
- Dalmanella cf. D. elegantula (Dalman).
- Whitfieldella cf. W. nitida Hall.
- Anoplotheca sp.
- Illaenus cf. I. armatus Hall.

XIX f 31:
- Stropheodonta sp.
- Rhipidomella n. sp.
- Gypidula? sp.
- Clorinda cf. C. fornicata (Hall).
- Sphaerexochus sp.
- Illaenus cf. I. imperator Hall.

XIX h 31:
- Stropheodonta sp.
- Orthis flabellites Foerste.
- Dalmanella cf. D. elegantula (Dalman).
- Meristina sp.
- Spirifer radiatus Sowerby.
- Spir fer sp.
- Sphaerexochus romingeri Hall.
- Illaenus cf. I. imperator Hall.
- Brontiopsis sp.

XIX m 6:
- Cladopora sp.
- Favosites sp.
- Zaphrentis sp.
- Camarotoechia? cf. C. acinus Hall.
- Camarotoechia? cf. C. indianensis (Hall).
- Atrypa sp.
- Atrypina sp.
- Nucleospira cf. N. pisiformis Hall.
- Trematospira cf. T. camura Hall.
- Sieberella n. sp.
- Mytilarca? cf. M. sigilla Hall.
- Platyceras sp.
- Orthoceras sp.
- Dalmanites sp.

XVII h 13:
- Camarotoechia cf. C. indianensis (Hall).
- Stropheodonta sp.
- Atrypa reticularis (Linnaeus) var.
- Spirifer radiatus Sowerby.
- Reticularia cf. R. proxima Kindle.
- Pterinea, small sp.
- Proetus sp.

XII l 30:
- Favosites gothlandicus Lamarck.
- Heliolites interstincta (Linnaeus).
- Halysites catenulatus (Linnaeus) var.
- Cyathophyllum sp.

Of the 11 upper Silurian collections made by Cairnes, only 1 was found within the area here described, and this is given as follows:

XIX t 27:
- Whitfieldella sp.
- Atrypa reticularis (Linnaeus).

The single Silurian (?) collection made by the writer from the limestone of the Tatonduk River was examined by Edwin Kirk, of the United States National Museum. The locality of this collection and its fauna, as given by Kirk, follow:

25AMt168 (2064):
- Diphyphyllum sp.
- Alveolites sp.
- Crinoid columnals.

Cairnes's Devonian fossils also were determined by Kindle. They include, within the area here treated, 15 collections, of which 12 were assigned definitely to the Middle Devonian and were correlated with the Salmontrout limestone of the Porcupine River. The other three collections were believed to belong to some other horizon in the Devonian. The Middle Devonian fauna is listed below:

XVII p 4, 5:
- Favosites sp.
- Camarotoechia sp.
- Pugnax cf. P. pugnus (Martin).
- Atrypa reticularis (Linnaeus) var.
- Leptaena rhomboidalis (Wilckens).
- Schizophoria striatula (Schlotheim).
- Reticularia sp.
- Anoplotheca cf. A. acutiplicata (Conrad).
- Platyceras sp.
- Cytherella sp.
- Cyphaspis cf. C. bellula.

XVII j 16, j 17, i 16, i 15:
- Atrypa reticularis (Linnaeus).
- Atrypa spinoza Hall.
- Schizophoria striatula (Schlotheim).
- Reticularia? cf. R. subundifera (Meek and Worthen).

XVII j 16, j 17, i 16, i 15—Continued.
Reticularia sp.
Athyris? n. sp.

XVII j, k 16:
Zaphrentis sp.
Favosites sp.
Stropheodonta sp.
Atrypa reticularis (Linnaeus).
Schizophoria striatula (Schlotheim).
Gypidula sp.

XVII h 19, i 19:
Crinoid stems.
Productella sp.
Atrypa reticularis (Linnaeus).
Reticularia cf. R. laevis (Hall).
Reticularia cf. R. subundifera (Meek and Worthen).
Nucleospira sp.
Fish bone.

XVII i 14, i 13:
Cyathophyllum sp.
Atrypa reticularis (Linnaeus).
Camarotoechia contracta Hall?
Stropheodonta arcuata Hall.
Reticularia sp.
Nucleospira n. sp.
Proetus sp.

XVII h, i, 18, 19:
Favosites cf. F. basaltica Goldfuss.
Favosites cf. F. canadensis (Billings).
Alveolites sp.
Schizophoria striatula (Schlotheim).
Chonetes sp.
Atrypa reticularis (Linnaeus).
Martinia cf. M. maia (Billings).
Nucleospira sp.
Proetus sp.

XIX h 19:
Zaphrentis sp.
Atrypa reticularis (Linnaeus).
Stropheodonta sp.
Camarotoechia sp.
Meristella? sp.
Meristella cf. M. laevis (Vanuxem)
Pugnax pugnus (Martin) var.
Gypidula sp.

XIX i 20:
Productella cf. P. spinulicosta Hall.
Stropheodonta sp. Indentical with Stropheodonta sp. in XIX h 19.
Atrypa reticularis (Linnaeus).
Schizophoria striatula (Schlotheim).
Gypidula sp.

XIX p 10:
Cyathophyllum? sp.
Atrypa reticularis (Linnaeus).
Leptaena rhomboidalis (Wilckens).
Spirifer sp.

XIX q 23:
Fenestella sp.
Atrypa reticularis (Linnaeus).
Atrypa cf. A. flabellata Goldfuss.
Stropheodonta cf. S. arcuata Hall.
Conocardium cf. C. cuneus Conrad.

XIX i, j, h, 23, 22:
Atrypa reticularis (Linnaeus).
Stropheodonta sp.
Schizophoria striatula (Schlotheim).
Cryphaeus? sp.

XIX d 22:
Cyathophyllum cf. C. quadrigeminum Goldfuss.
Crinoid stems.
Atrypa reticularis (Linnaeus).
Camarotoechia sp.
Gypidula sp.
Conocardium cf. C. cuneus Conrad.
Platychisma? sp.

The other three Devonian collections by Cairnes are:

XVII j 15:
Productella? sp.
Atrypa n. sp.?
Martinia cf. M. maia Billings.
Stropheodonta sp.
Proetus cf. P. macrocephalus Hall.

XVII p 4, 5:
Cyathophyllum cf. C. quadrigeminum Goldfuss.
Favosites sp.

XVII p 5:
Favosites sp.
Camarotoechia sp.
Hercinella? sp.

The localities and character of the Middle Devonian collections made by Harrington from the undifferentiated limestone of the boundary are as follows; the faunal determinations were made by Edwin Kirk:

736. 6.75 miles north and 3.5 miles east from intersection of one hundred and forty-first meridian and sixty-fifth parallel:
Crinoid columns.
Stropheodonta sp.
Camarotoechia sp.
Atrypa reticularis.
Conocardium sp.

738. Hard Luck Creek, 5.93 miles north and 0.33 mile west from intersection of one hundred and forty-first meridian and sixty-fifth parallel:

Fenestella sp.
Eatonia? sp.
Pugnax sp.
Atrypa reticularis.
Martinia cf. M. maia.

739. 6.75 miles north and 0.93 mile east from intersection of one hundred and forty-first meridian and sixty-fifth parallel:

Cyathophyllum sp.
Leptaena rhomboidalis.
Atrypa reticularis.

740. Hard Luck Creek, 5.93 miles north and 0.47 mile west from intersection of one hundred and forty-first meridian and sixty-fifth parallel:

Fenestella sp.

741. Hard Luck Creek, 5.93 miles north and 0.33 mile west from intersection of one hundred and forty-first meridian and sixty-fifth parallel:

Chonetes sp.

742. 0.55 mile north and 2.1 miles west from intersection of one hundred and forty-first meridian and sixty-fifth parallel:

Stropheodonta sp.

The locality of the collection from the Middle Devonian limestone of the Tatonduk River made by the writer and the determination of its contained fossils by Edwin Kirk, of the United States National Museum, are given below:

25AMt161 (2063). North bank of Tatonduk River, 0.38 mile N. 41½° W. of international boundary topographic station 104:

Alveolites sp.
Striatopora sp.
Acervularia cf. A. arctica (Meek).
Heliophyllum sp.
Favosites cf. F. polymorpha Goldfuss.
Gypidula comis Owen.
Atrypa reticularis (Linnaeus).
Atrypa near A. hystrix Hall.
Chonetes cf. C. pusilla Hall.
Camarotoechia sp.

Finally, it should be remembered that this wealth of paleontologic material comes mainly from a narrow zone along the international boundary, from the Yukon River northward to the Nation River, a distance of about 60 miles. Numerous stratigraphic horizons in the Paleozoic have already been recognized, and others are doubtless represented. When a topographic map shall have been made of the 600 square miles lying in the triangle between the boundary and the Yukon and Nation Rivers, the geologist will have before him probably the most interesting piece of geologic mapping of Paleozoic rocks that exists in Alaska. Cambrian, Ordovician, Silurian, Devonian, and Carboniferous rocks are all represented, and the recognition and mapping of all the formations in these five systems should lead to a vast amount of information regarding the history of the Paleozoic era in the Yukon Valley.

As no formational and little group mapping has been done along the boundary, not a great deal can be said as yet regarding the correlation of the rocks there with Paleozoic groups and formations elsewhere in Alaska. Paleontologically, however, certain correlations stand out strikingly, of which the Silurian, Devonian, and Mississippian faunas afford the best examples. One of the prominent horizon markers of central and northern Alaska is the great middle Silurian limestone developed in the White Mountains north of Fairbanks and from Kotzebue Sound eastward for 600 or 700 miles to the Chandalar River. To judge from the middle Silurian fossils collected by Cairnes and from the fact that Kindle [33] also collected middle Silurian fossils from the dolomite just above the lower ramparts of the Porcupine River, it would seem that this middle Silurian sequence is probably continuous with beds at the same horizon in northern Alaska. Similarly, the upper Silurian fossils collected along the boundary by Cairnes suggest the presence there of the upper Silurian (?) formation mapped by Smith and Mertie [34] in northern Alaska, correlative with a similar formation in central Alaska that overlies the middle Silurian limestone of the White Mountains.

The Middle Devonian fauna along the boundary may also be correlated with a similar fauna widely known in interior and northern Alaska. The type locality for this fauna in northern Alaska is on the Porcupine River at the mouth of the Salmontrout River in a limestone called by Kindle [35] the Salmontrout limestone. No fossils that were distinctly Upper or Lower Devonian were collected by Cairnes along the boundary. The absence of Lower Devonian fossils is to be expected, as such fossils have not yet been found anywhere in Alaska. But an Upper Devonian fauna, characterized principally by *Spirifer disjunctus*, is well developed in northern Alaska, and it is possible that some of the other Devonian collections made by Cairnes, which were believed by Kindle not to belong to the Middle Devonian sequence, may in fact belong in the Upper Devonian.

The Carboniferous fossils found by Cairnes along the international boundary may be correlated closely with Carboniferous faunas found elsewhere in interior and northern Alaska in that they can be split into two groups, one of late Mississippian and one of Permian age. The type upper Mississippian formation of interior Alaska is

[33] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, p. 324, 1908.

[34] Smith, P. S., and Mertie, J. B., jr., Geology and geography of northwestern Alaska: U. S. Geol. Survey Bull. 815, pp. 132–139, 1930.

[35] Kindle, E. M., op. cit., p. 329.

the Calico Bluff formation, on the Yukon, which is described on pages 101–106, and that of northern Alaska is the Lisburne limestone, most recently described by Smith and Mertie.[56] The type Permian formation for central Alaska is the Tahkandit limestone, at the mouth of the Nation River, described on pages 125–127 of this report; and for northern Alaska, the Sadlerochit sandstone, originally described by Leffingwell [57] as Pennsylvanian but later assigned by Girty to the Permian.

No great masses of limestone such as those that occur along the international boundary north of the Yukon are known along the Yukon between Eagle and Circle, but two small belts of undifferentiated limestone are found in this stretch of the river at Bull Creek and Woodchopper Creek. No fossils have been found in either of these, and their exact age is therefore unknown. The typical middle Silurian limestone as developed elsewhere in central and northern Alaska is so thick and so prominent that it is not believed that these small limestone belts can belong to the same horizon. The Middle Devonian limestone along the Yukon is associated with volcanic rocks, a condition which does not appear to exist with the belts of limestone under consideration. The Permian and Mississippian limestones are so extremely fossiliferous that it seems impossible that these undifferentiated limestones could belong to either of those horizons. There remain, so far as our present stratigraphic knowledge goes, the Cambrian, Ordovician, and upper Silurian limestone horizons, and of these the surrounding stratigraphy suggests more strongly the upper Silurian. The limestone bands crossing Bull Creek and Woodchopper Creek are therefore believed to be of possible upper Silurian age, but in the absence of conclusive proof they are mapped as undifferentiated limestone.

CAMBRIAN SYSTEM

For cartographic purposes the differentiated Cambrian and underlying rocks are shown in five units, as follows: An Upper Cambrian limestone; a Middle Cambrian limestone; a Middle Cambrian or older formation that underlies the Middle Cambrian limestone; a Lower (?) Cambrian or pre-Cambrian red-bed formation that forms the base of the visible stratigraphic sequence on the Tatonduk River; the Tindir group, as mapped by Cairnes, which is here interpreted as Cambrian or pre-Cambrian. The last two of these groups have already been described under the heading "Cambrian or pre-Cambrian rocks."

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[56] Smith, P. S., and Mertie, J. B., jr., Geology and geography of northwestern Alaska: U. S. Geol. Survey Bull. 815, pp. 168–185, 1930.

[57] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 113–115, 1919.

MIDDLE CAMBRIAN OR OLDER ROCKS

DISTRIBUTION

The rocks here described as Middle Cambrian or older constitute a mappable unit that lies geographically and stratigraphically between the red beds and the Middle Cambrian limestone. The known exposures are restricted to the Tatonduk River.

LITHOLOGY

This formation consists of beds of dark-gray limestone and dolomite from 6 inches to 3 feet thick, interbedded with shale and argillite, the latter perhaps somewhat calcareous. Much of the clay shale is nodular. There are also a few beds of limestone grit, a fine-grained phase of the limestone conglomerate described on page 66. Two such beds, the upper 25 feet thick and the lower 5 feet thick, separated by red shale, occur at the very base of this formation and show that the formation grades downward without a stratigraphic break into the red beds. The apparently concordant structure suggests that this formation also grades upward into the massive beds at the base of the Middle Cambrian limestone, but this relation can not be regarded as proved.

STRUCTURE AND THICKNESS

This formation is not continuously exposed in the bluffs along the Tatonduk River, but the visible exposures indicate a rather uniform westerly dip, ranging from 20° to 30°. Geographically, this formation occupies a belt along the Tatonduk about half a mile wide, measured across the strike, and the maximum thickness can not, therefore, much exceed 1,000 feet. This estimate, however, may be materially lessened if the structure should be found to be more intricate.

AGE AND CORRELATION

No fossils have yet been found in these rocks, and their age can therefore not be given on paleontologic grounds. They underlie the Middle Cambrian limestone and are thus Middle Cambrian or older. Much uncertainty is involved in a more definite age assignment, because of the possibility that an unconformity may exist at the base of the Middle Cambrian limestone. No positive evidence of such an unconformity was seen on the Tatonduk River, but Cairnes's data concerning conditions farther north along the boundary, particularly at Jones Ridge, suggest strongly that such an unconformity exists. Cairnes describes the rocks of his Tindir group along Tindir Creek and between Ettrain and Hard Luck Creeks as consisting of dolomite, limestone, quartzite, slate, shale, and greenstone. The lithology suggests that the formation here described as Middle Cambrian or older may be correlated with a part of Cairnes's Tindir group.

MIDDLE CAMBRIAN LIMESTONE

DISTRIBUTION

The Middle Cambrian limestone crops out in the hills on the north side of the Yukon north of Calico Bluff and continues northward to the Tatonduk River and for an unknown distance beyond.

LITHOLOGY

The Middle Cambrian limestone is rather varied in character and appearance. Some of it seems to be pure limestone, but much of it is silicified to a greater or less degree. No dolomite was noted, but parts of the formation may have an appreciable content of magnesium. Textural varieties are also conspicuous, such as oolitic limestone and limestone conglomerate. The pure limestone is usually white and finely crystalline. The silicified varieties have the same general appearance but contain varying amounts of quartz or of chert. Where much secondary quartz is present the rocks simulate a granular white quartzite. At one locality the partly silicified limestone contains disseminated through the rock a shiny black conchoidally fracturing mineral that suggests a hydrocarbon similar to gilsonite.

This limestone formation is thin bedded at the top but very thick bedded in its lower half, making conspicuous cream-colored bluffs along the north side of the Tatonduk River. Viewed from the south bank of the river the limestone in these bluffs appears to grade upward into thin beds of gray chert, but the closer inspection afforded by swimming along the bluffs on the south side shows that on that side there is a sharp change from thin-bedded limestone to thin-bedded chert, with a covered zone a few feet wide that may conceal a dip fault parallel to the westward-dipping beds.

Where the Middle Cambrian limestone plunges southwestward toward the Yukon, north of Calico Bluff, a cold sulphur spring issues beneath the base of the limestone and discharges into a little gulch that drains southward to the river. This spring, which is about 100 yards from the Yukon, discharges from two vents some 20 or 30 feet apart, which are conspicuously colored with a white sulphurous deposit. The odor of sulphureted hydrogen is strong and may be detected 100 yards or more from the spring. A sample of the sulphur water was analyzed in the chemical laboratory of the United States Geological Survey by Margaret D. Foster, who reports the following composition:

Analysis of water from cold sulphur spring 11¼ miles N. 4¾° E. of Eagle, Alaska

	Parts per million
Silica (SiO_2)	14
Iron (Fe)	.24
Calcium (Ca)	274
Magnesium (Mg)	156
Sodium and potassium (Na+K) (calculated)	352
Bicarbonate radicle (HCO_3)	725
Sulphate radicle (SO_4)	544
Chloride radicle (Cl)	660
Nitrate radicle (NO_3)	Trace.
Total dissolved solids at 180° C	2,426
Total hardness as $CaCO_3$ (calculated)	1,325

It seems rather probable that a part of the contained solids of this water has been leached from the overlying limestone.

STRUCTURE AND THICKNESS

This limestone is not continuously exposed along the banks of the Tatonduk River, but exposures seen indicate a rather consistent westward dip at 20° to 30°. Southward from the Tatonduk River this limestone continues across wooded hills to the Yukon, bends sharply eastward, and finally veers northeastward, forming a well-defined anticline that plunges rather steeply toward the Yukon just north of Calico Bluff. The evidence at present available indicates that the east end of the anticline is cut off by a fault.

From the structural data available on the Tatonduk River the thickness is estimated at 800 to 1,200 feet, say 1,000 feet; but if the structure is more intricate than is now supposed, the thickness may be less. The top of the Middle Cambrian limestone, however, has not been definitely recognized, and it is possible that a complete section at some other locality will show a thickness greater than 1,200 feet.

AGE AND CORRELATION

Fossils were found in this limestone, apparently in the upper half of the formation, as follows:

25AMt148 (2062). Northeast side of Yukon River, at an altitude of about 1,400 feet above the river, 3.1 miles N. 2½° E. of Eagle:

Nisusia or Jamesella sp.
Dorypyge, 2 sp.
Albertella mertiell.
Stenotheca rugosa.
"Ptychoparia," 2 sp.
Ogygopsis sp.

These fossils were examined by C. E. Resser, of the United States National Museum, who determined them to be of lower Middle Cambrian age. Resser's report is as follows:

All of the foregoing species are quite similar or possibly identical with forms in the Langston limestone or the Ross Lake shale and hence belong to a horizon well down in the Middle Cambrian.

One part of this collection consists of a darker, more crystalline limestone, as compared with the whiter and finer-grained limestone which contains the more abundant fossils. Both apparently contain the same fauna, and in both the fossils silicify on weathering.

This material does not correlate with that secured by the Canadian Geological Survey along the international boundary. There are two distinct horizons represented by the Canadian material, the lower one possibly being a Cambrian horizon somewhat above Doctor Mertie's horizon; but the other is well up in the Ozarkian, containing a species or two of *Symphysurina*.

Of other collections made along the international boundary, Resser has seen only those of L. D. Burling, and it may well be that a reexamination of the Cambrian collections made by Cairnes will show that his horizons are more nearly equivalent to those of collection 2062, just described.

UPPER CAMBRIAN LIMESTONE

DISTRIBUTION

Limestone containing Upper Cambrian fossils has been recognized at two localities. The first is a thin plate of limestone that crops out along the north side of the Yukon north of Calico Bluff. The second occurrence is in the headwaters of the North Fork of Shade Creek at the top of the great mass of limestone that extends from Shade Creek northeastward to the Tatonduk River. The geographic position of these two limestones suggests that they may be continuous, but this relation has not yet been proved.

LITHOLOGY

The limestone along the north bank of the Yukon is a massive light-gray finely crystalline rock, with conglomeratic and oolitic phases, in general appearance not unlike the Middle Cambrian limestone farther up the hillside. (See pl. 4, *A*.) The conglomeratic phase of this limestone contains small pebbles of gray limestone and a few well-rounded pebbles of shiny black chert. The limestone at the head of Shade Creek consists of alternating thin layers of light and dark gray rock.

STRUCTURE

The limestone band north of Calico Bluff strikes about N. 30° W. and dips perhaps 60° SW., toward the Yukon. It was not measured instrumentally but appears not to exceed 300 feet in thickness. Evidently this limestone forms the uppermost bed of a pitching anticline, composed mainly of Cambrian strata and previously mentioned in connection with the Middle Cambrian limestone. It is overlain by beds of lower Mississippian age, and this relation is believed to be due to faulting.

The Upper Cambrian limestone in the head of the North Fork of Shade Creek strikes northwest and dips gently southwest. It lies at the top of a mass of undifferentiated limestone. It is underlain presumably by older Cambrian strata. On the other hand, the sequence is not continuously downward all the way north to the Tatonduk River, for both Silurian and Middle Devonian fossils have been found in the undifferentiated limestone on the Tatonduk River. The Upper Cambrian limestone is directly overlain by graptolite-bearing beds of Ordovician (Normanskill) age.

AGE AND CORRELATION

Two fossil collections have been made, as follows:

28AMt263. Limestone bluff along northeast bank of Yukon River, north of the north end of Calico Bluff:

Archaeocyathus? sp.

28AMt262. North Fork of Shade Creek, 1.15 miles N. 29½° W. from "Hug" boundary triangulation station (McCann Hill):

Acrothele sp.

Kirk's report on this material is as follows:

> No more definite age assignment of these lots of fossils is possible than to call them Cambrian. The fossil in lot 263 appears to be very like the Upper Cambrian forms referred to *Archaeocyathus*. Such scant evidence as there is would point to the Middle or Upper Cambrian age of the containing beds.

Archaeocyathus does not occur in any of Cairnes's Cambrian collections, but *Acrothele* is found in four of his eight collections, all four determined as Upper Cambrian. Lying apparently at the top of this mass of limestone at the head of Shade Creek, and being directly overlain by Ordovician beds, this *Acrothele*-bearing limestone seems therefore most logically regarded as Upper Cambrian. These two limestones, therefore, are believed to represent about the same stratigraphic horizon, and both of them are correlatable with the beds from which some of Cairnes's collections were obtained, notably with those on Jones Ridge.

ORDOVICIAN SYSTEM

Rocks of Ordovician age are known to be present along the international boundary but have not been recognized as such along the Yukon between the boundary and Circle. Cairnes [38] in his work along the boundary made several collections of Ordovician fossils, including one collection of graptolites. The invertebrates include forms from

[38] Cairnes, D. D., The Yukon-Alaska international boundary between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, pp. 66–69, 1914.

the Upper and the Lower Ordovician, and it is likely that Middle Ordovician horizons are also represented. The graptolites were determined as high Lower Ordovician, or more specifically as correlative with the Normanskill. Cairnes, however, was unable to differentiate the Ordovician rocks from the Devonian, Silurian, or Cambrian, so that no separate mapping of the Ordovician system is at present possible. His collections of Ordovician fossils found within the area covered by this report are therefore listed under the undifferentiated Paleozoic rocks.

Another collection of Ordovician graptolites was made in 1928, but as with Cairnes's the fossils occurred in such a manner as to preclude the separate mapping of the containing beds. These fossils have likewise been listed with those from the undifferentiated Paleozoic rocks.

A single fossil that resembles *Obolus* sp., according to Edwin Kirk, was found by Blackwelder on the north bank of the Yukon River about half a mile upstream from the mouth of Woodchopper Creek. The rocks near this locality, both upstream and downstream, are well known from numerous collections to be of Middle Devonian age. As the fossil was not found in place but in a talus pile, it may have been transported to the site where it was discovered by the action of river ice during the spring break-up. Faulting, of course, must be considered in any interpretation of the structure of the rocks above Woodchopper Creek, but if this fossil came originally from the cliffs above the talus pile where it was found, then faulting of far greater intensity and amplitude than have hitherto been suspected has probably taken place in this particular area.

Ordovician rocks, though not yet recognized as such along the Yukon, are known at a number of other localities in Alaska. Northwest of the area here considered, at a number of different places in the White Mountains of the Yukon-Tanana region, Prindle,[39] Blackwelder,[40] and the writer have collected fossils that were first determined as Upper Ordovician but were later referred to a horizon high in the Middle Ordovician. Middle Ordovician (Mohawkian) fossils have been found by Kindle[41] at two localities in the lower ramparts of the Porcupine River, some 25 miles below the Coleen River. Upper Ordovician and possibly also Middle Ordovician fossils, chiefly graptolites, were collected by Brooks and Prindle[42] in the Alaska Range region at the headwaters of the Kuskokwim River.

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[39] Prindle, L. M., A geologic reconnaissance of the Fairbanks quadrangle, Alaska: U. S. Geol. Survey Bull. 525, p. 42, 1913.

[40] Blackwelder, Eliot, unpublished manuscript.

[41] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, p. 323, 1908.

[42] Brooks, A. H., The Mount McKinley region, Alaska, with a description of the igneous rocks and of the Bonnifield and Kantishna districts, by L. M. Prindle: U. S. Geol. Survey Prof. Paper 70, p. 72, 1911.

Upper Ordovician (Richmond) fossils were found in the valley of the Sulukna River, some 50 miles west of Lake Minchumina, by Eakin [43] in 1915, and in the same general region, though somewhat farther southwest, by Brown [44] in 1924. In Seward Peninsula both Upper and Lower Ordovician fossils were collected in 1901 and later years by Collier, Washburne, Knopf, and Kindle, and most recently by Steidtmann and Cathcart.[45] Fossils of Ordovician age are known also in southeastern Alaska.

In the interior of Alaska, therefore, Ordovician rocks appear to be widespread, differing markedly in this particular from the Cambrian rocks, which are localized in one basin; and as Lower, Middle, and Upper Ordovician horizons are all represented it would seem that the Ordovician system is well developed, both areally and stratigraphically. In view of the conditions elsewhere and the great variety of geologic formations already recognized along the Yukon, it is altogether likely that subsequent detailed work will identify several Ordovician horizons among the undifferentiated Paleozoic rocks in the upper Yukon Basin along the international boundary and possibly also along the Yukon between the boundary and Circle.

SILURIAN SYSTEM

DISTRIBUTION

No rocks that can be definitely referred to the Silurian are known in this area, but a considerable portion of the undifferentiated Paleozoic rocks along the Yukon, including the undifferentiated limestones, may prove to be of this age. A belt of rocks believed to be of Silurian age lies along the west bank of the Yukon, beginning at a point about halfway between Thanksgiving and Takoma Creeks and extending north about 3 miles. It is not unlikely that the limestone that crosses Woodchopper Creek about 2½ miles from its mouth is also of Silurian age, but of this there is no direct proof. Silurian rocks are extensively developed along the international boundary but have not been differentiated there from the other pre-Mississippian Paleozoic rocks.

LITHOLOGY

The sequence below Thanksgiving Creek has been seen and described by several geologists, notably by Brooks and later by Black-

[43] Eakin, H. M., The Cosna-Nowitna region, Alaska: U. S. Geol. Survey Bull. 667, p. 25, 1918.

[44] Brown, J. S., The Nixon Fork country: U. S. Geol. Survey Bull. 783, pp. 103–105, 1926.

[45] Steidtmann, Edward, and Cathcart, S. H., Geology of the York tin deposits, Alaska: U. S. Geol. Survey Bull. 733, pp. 23–26, 1922.

welder. These rocks include massive and thin-bedded limestone, in part silicified, argillaceous, or calcareous, also siliceous shale, slate, and chert. About a mile below Thanksgiving Creek, on the west bank of the river, a little gulch empties into the Yukon through a timber-covered flat. On the south side of this gulch are the northernmost exposures of the Middle Devonian greenstone-limestone sequence. On the north side of the gulch the rock is a siliceous black slate, at places markedly graphitic, which continues downstream for perhaps 1,500 feet. This gulch is evidently in a fault zone, for the slate and a few associated calcareous beds are greatly sheared and show numerous fault striae. From this point downstream to the mouth of Takoma Creek, a distance of about half a mile, the rocks are well exposed in bluffs along the river bank and consist of massive and thin-bedded limestone with several beds of siliceous shale and slate similar to that just described. The massive limestone forms picturesque pinnacles and bluffs with numerous caves in the lower half. (See pl. 2, *B*.) It has the general aspect of a considerable sequence of thick limestone beds, but it contains several thin zones of interbedded shale and slate. The limestone for the most part is a fine-grained light-gray to black noncrystalline or cryptocrystalline rock, apparently without any dolomitic beds. It is much fractured and veined with calcite, and many of the calcite veins are closely folded, indicating the degree of deformation of these rocks, which is not otherwise so apparent in the massive beds.

From the mouth of Takoma Creek downstream these rocks continue to crop out on the west side of the river for a distance of about 8,900 feet. Some observations on the lithology are noted below. The measurements given are horizontal distances as paced along the beach.

Section of Silurian rocks on west bank of Yukon River, as traced northward from mouth of Takoma Creek

	Feet
Covered	200
Hard black limestone, quartzose at south end, in beds a few inches to 2 feet thick, interbedded with drab to black slaty shales. Strike N. 80° E.; dip nearly vertical	250
Covered	450
Interbedded black limestone and drab clay shale, with a few cherty beds at south end, grading toward the north into more massive beds of the same limestone with a little interbedded shale. Strike N. 75° W. at south end. A vertical fault striking N. 80° E. separates the more massive limestone from the thinner beds at the south end. North end shows folding and crumpling of the strata	500
Covered, except at point 900 feet downstream from mouth of Takoma Creek, where a thin-bedded shaly limestone crops out	1,450

	Feet
Thin-bedded black limestone. At south end strike is N. 80° E., dip 40° S.; dip changes to north at north end	220
Covered	230
Folded thin-bedded limestone and shale. About 150 feet below Takoma Creek there is a fairly open syncline; this is followed by a small appressed anticline and a syncline, which are faulted through the axial planes	350
Covered	350
Thin-bedded black limestone with beds of drab slate at south end, changing at north end to pellucid gray chert with some interbedded shale	500
Covered	350
Thin-bedded black limestone with beds of drab slate at south end, changing at north end to pellucid gray chert with some interbedded shale	500
Covered	200
Black slate, with some beds of limestone about 1 foot thick. Dip northerly	100
Covered	100
Thin-bedded limestone and slate. Strike N. 75° E.; dip 60° N	625
Covered	100
Limestone and slate at south end; followed by thin-bedded limestone that contains only a little shale and thus appears more massive; followed by more limestone and slate. An intensely crumpled zone at south end. Dip northerly throughout	1,075
Covered	180
Limestone and slate, with southerly dip at south end; the northern part is a crumpled zone bounded on its south side by a fault	350
Same material, with northerly dip at south end; the northern part is a crumpled zone bounded at its north end by a vertical fault striking N. 85° W	325
Slate with beds of the same limestone and three zones of clear chert, of which the farthest north is 75 feet across; stands vertical and strikes N. 55° E. The chert beds are from a few inches to 1 foot thick and weather to a yellowish-brown color, particularly in the shale partings	650
Thin-bedded limestone with little or no slate. Stands vertical at south end but dips south at north end	500
Covered	100
Thin-bedded limestone, with little or no slate. Much crumpled	100

STRUCTURE AND THICKNESS

The structure north and south of Takoma Creek is difficult to interpret. It is evident from the folding and faulting (see fig. 4) that there is much duplication of strata. The drag folds seen in the limestone south of Takoma Creek and in the thin-bedded rocks north of Takoma Creek give the impression that the sequence has suffered

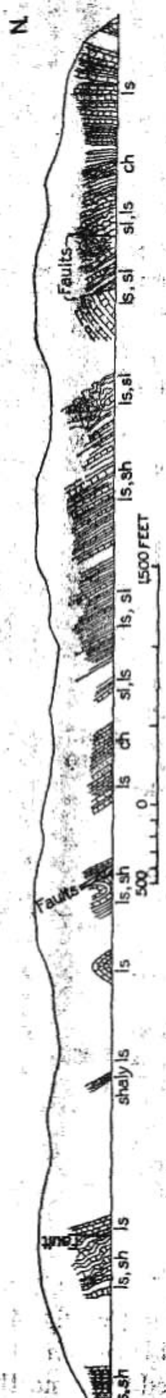

FIGURE 4.—Geologic section from Takoma Creek northward along west bank of Yukon River, showing structure of upper Silurian (?) rocks. *ls*, Limestone; *sh*, shale; *ch*, chert; *sl*, slate

compressional folding induced by pressure applied from the north. The faults do not appear to be particularly related to this tangential deformation but suggest rather a block faulting of later date. It may even be that the whole sequence, which apparently dips dominantly northward, is overturned, although of this there is no direct evidence.

With these considerations in mind, it is somewhat hazardous to make an estimate of the thickness of strata here present. Blackwelder's estimate [46] is 7,500 feet. The writer's estimate is considerably lower. Only one zone in this sequence appears to be relatively free of faults and folds. In this zone, which starts 4,000 feet north of Takoma Creek and extends for some 3,000 feet north along the beach, the rocks appear to have a monoclinal dip, and from this sequence it would appear that at least 2,500 feet of strata are present. Between this zone and Takoma Creek the rocks may consist of the same beds duplicated by folding and faulting. From this zone north to the end of the bluff exposures the rocks, though folded and faulted, are obviously of different lithologic character. If they belong to the same sequence, the thickness may be amplified by perhaps another 1,000 feet of strata, but it is by no means certain that the cherty rocks at the north end are even of the same geologic age. From their lithologic character, the writer is inclined to regard them as decidedly younger, perhaps correlative with the cherty rocks that directly underlie the upper Mississippian sequence at Calico Bluff. The beds south of Takoma Creek, including the massive limestone shown in Plate 2, *B*, should doubtless be correlated with this sequence, but their thickness also is subject to much doubt, on account of the close folding observed in the limestone and in the slate south of the limestone and on account of the faulted condition of the black slate. Perhaps another 1,000 feet of strata, mostly limestone, might be added to the sequence for the rocks exposed south of Takoma

[46] Blackwelder, Eliot, unpublished manuscript.

Creek. The total thickness, as estimated by the writer, is therefore probably about 4,500 feet, but if the cherty rocks at the north end of these exposures belong in part to a later horizon, the thickness may be as little as 3,500 feet.

AGE AND CORRELATION

A considerable Silurian fauna has been collected along the boundary from rocks which are not separately mapped, and this fauna has been listed in the section on the undifferentiated Paleozoic rocks.

In addition, five collections are tabulated below, of which three, Nos. 847, 173, and 174, came from the rocks near Takoma Creek. The other two, Nos. 848 and 849, were collected years ago and appear from the labels now with them to have come from the limestone on the northeast bank of the Yukon, north of the north end of Calico Bluff, which is now classified as Upper Cambrian. It is possible that this material may not originally have been in place, and it is also possible that the fossils may have become separated from their originally correct labels. As collections 848 and 849 are regarded by Kirk as Silurian, however, they are here included with the Silurian fauna.

Fossils from Silurian rocks along Yukon River between Eagle and Circle

	847	848	849	173	174
Diphyphyllum sp.					×
Favosites sp.	×			×	
Alveolites sp.	×		×		
Cladopora sp.					×
Syringopora sp.					×
Syringopora? sp.				×	
Crinoid columns				×	
Favositella sp.				×	
Indeterminable pelecypod		×			
Lepetopsis sp.			×		
Lepetopsis? sp.		×			

847. 12 miles below Woodchopper Creek, south bank of Yukon River. Collector, E. M. Kindle.

848. 2 miles below Calico Bluff, Yukon River, in ravine below bend. Collector, E. M. Kindle.

849. 2 miles below Calico Bluff, east bank of Yukon River. Collector, E. M. Kindle.

173 and 174. About 8 miles below Thanksgiving Creek, southwest bank of Yukon River. Collector, Eliot Blackwelder.

Collection 847 evidently came from the limestone horizon just south of Takoma Creek and is doubtless the collection referred to by Brooks.[47] This collection was regarded by Kindle as indecisive but indicative possibly of the Devonian. It has recently been redetermined by Edwin Kirk, who refers it questionably to the Silurian.

[47] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, p. 279, 1908.

Collection 173 was referred definitely to the Silurian. Collection 174 was referred questionably to the Devonian but is here included with the Silurian.

It is characteristic of many of the rather poor collections from this general horizon, both here and elsewhere in Alaska, that the determinations given are invariably "Devonian or Silurian," "Silurian or Devonian," "questionably Devonian," or "questionably Silurian." This uncertainty, of course, is due in part to the paucity and poor quality of much of the material collected, but there seems to be a horizon in interior Alaska which can not readily be assigned definitely either to the Devonian or the Silurian. This is all the more difficult to understand, inasmuch as the Lower Devonian appears to be absent in Alaska. Therefore, when fossils are determined as "Silurian or Devonian" or "Devonian or Silurian," one must place them, if further assignment is attempted, either in the lower part of the Middle Devonian or the upper part of the Silurian. It can not be said that any definite evidence is available along the Yukon to favor either assignment, but from the general experience of the writer in interior and northern Alaska it seems advisable at present to favor a Silurian age for these questionable fossils. The sequence of beds on the south bank of the Yukon below Takoma Creek is therefore here referred to the upper Silurian (?). The Silurian rocks along the boundary include beds of both upper and middle Silurian age.

The Silurian system is widespread in Alaska. In interior Alaska it is especially well developed in the White Mountains, north of Fairbanks, where middle Silurian fossils have been collected from a heavy limestone formation by Prindle,[48] Blackwelder,[49] and the writer. The same horizon is represented along the international boundary between the Yukon and Nation Rivers by the middle Silurian fossils collected by Cairnes, but this horizon has not yet been recognized as such along the Yukon between the boundary and Circle.

Schrader,[50] in 1901, described a great Silurian limestone in northern Alaska which he called the Skajit limestone; this formation has subsequently been traced eastward by the writer[51] from its type locality on the John River into the Chandalar Basin and westward

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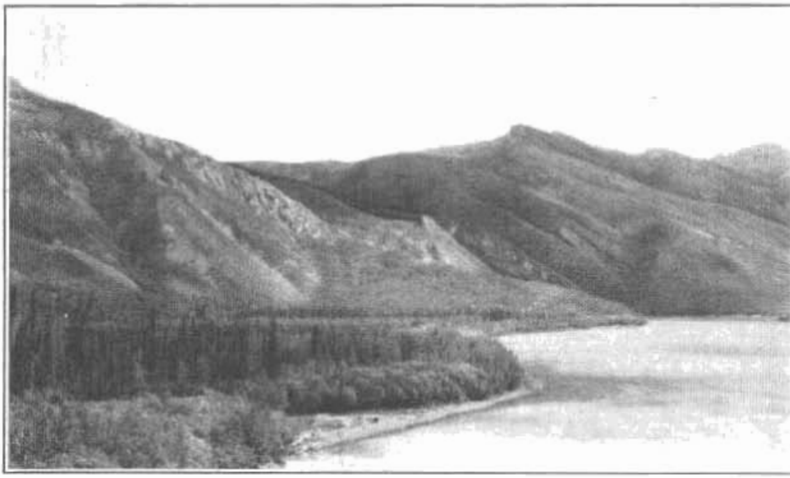
[48] Prindle, L. M., A geologic reconnaissance of the Fairbanks quadrangle, Alaska: U. S. Geol. Survey Bull. 525, pp. 39–45, 1913.

[49] Blackwelder, Eliot, unpublished manuscript.

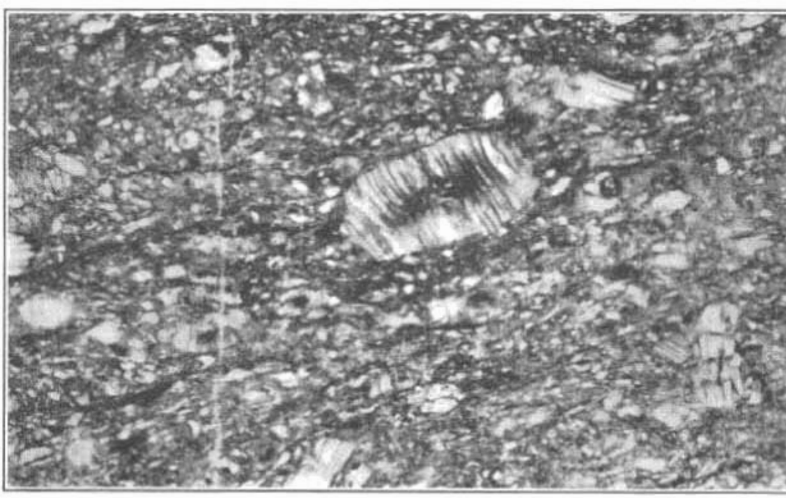
[50] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 56–58, 1904.

[51] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, pp. 229–233, 1925; Geology and geography of the Chandalar-Sheenjek region, Alaska: U. S. Geol. Survey Bull. —— (in preparation).



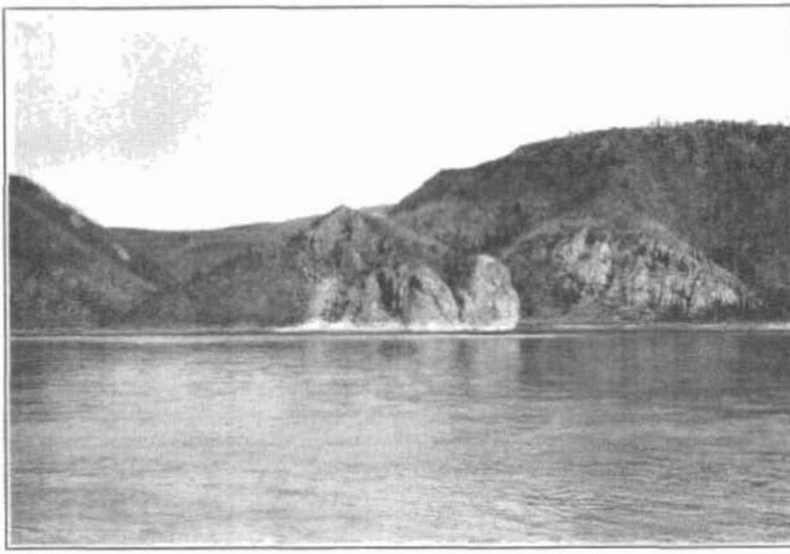
A. CAMBRIAN LIMESTONE AND ASSOCIATED ROCKS ON THE NORTH BANK OF THE YUKON RIVER JUST NORTH OF CALICO BLUFF

Looking upstream. Shows thin plate of Upper Cambrian limestone dipping toward the river in center and at left. Middle Cambrian limestone along top of ridge at right. Photograph by Eliot Blackwelder.

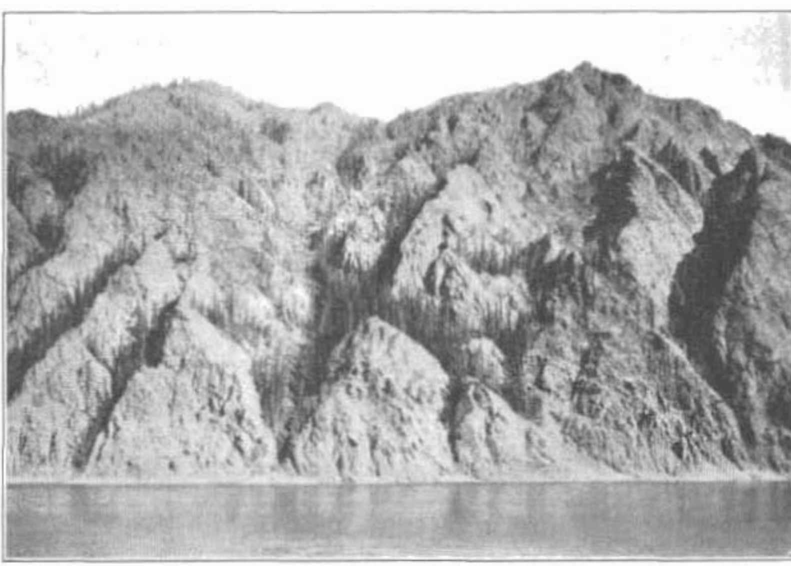


B. CRINOIDS IN CRYSTALLINE LIMESTONE OF SILURIAN (?) AGE FROM WEST SLOPE OF LOOP MOUNTAIN, YUKON TERRITORY

About four-fifths natural size.



A. FOSSILIFEROUS MIDDLE DEVONIAN LIMESTONE IN WOODCHOPPER VOLCANICS, AS SEEN ALONG THE NORTH BANK OF THE YUKON RIVER OPPOSITE WOODCHOPPER



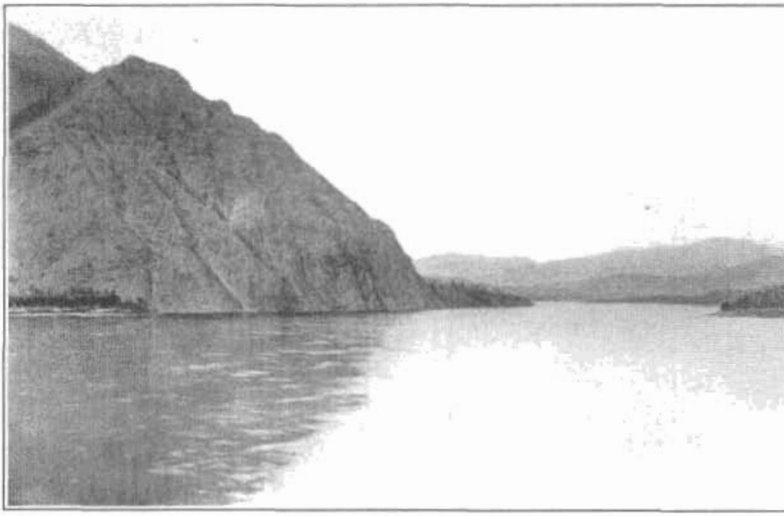
B. WOODCHOPPER VOLCANICS ALONG THE NORTHEAST BANK OF THE YUKON RIVER BELOW THE MOUTH OF WOODCHOPPER CREEK

A. LOWER MISSISSIPPIAN CHERT FORMATION ON THE EAST BANK OF THE YUKON RIVER JUST BELOW THE MOUTH OF SHADE CREEK

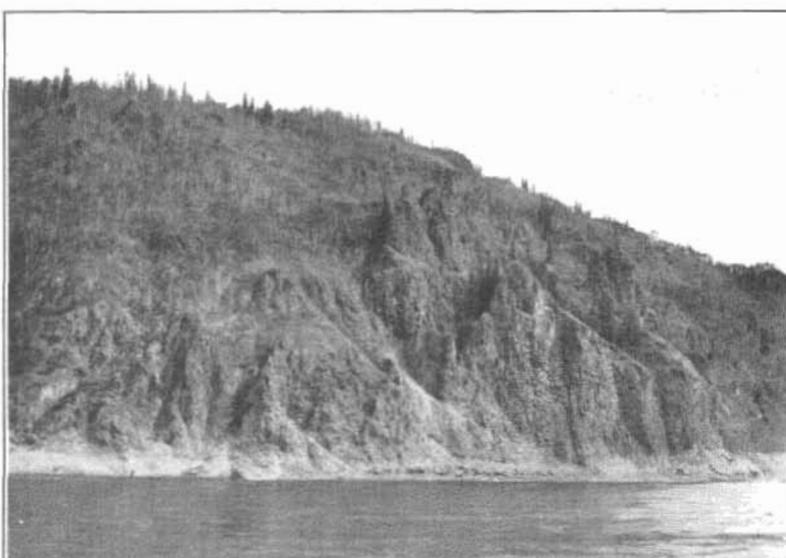
McCann Hill in background.

B. ELLIPSOIDAL GREENSTONE IN WOODCHOPPER VOLCANICS ON THE NORTH BANK OF THE YUKON RIVER ABOVE WOODCHOPPER

Photograph by Eliot Blackwelder.



A. UNDIFFERENTIATED PALEOZOIC GREENSTONE IN BLUFF ON THE WEST SIDE OF THE YUKON RIVER AT THE MOUTH OF MISSION CREEK



B. LOWER MISSISSIPPIAN VOLCANIC ROCKS ALONG THE EAST BANK OF THE YUKON RIVER ABOVE CIRCLE by Smith and the writer [52] into the valleys of the Alatna and Noatak Rivers. The Skajit limestone, which is believed to extend nearly or quite all the way across northern Alaska, is now believed to be mainly of late middle Silurian or early upper Silurian age. Above the Skajit limestone but below the Devonian sequence in northern Alaska lies another group of rocks which is composed mainly of noncalcareous beds but contains one or more prominent beds of limestone; this is believed to be of upper Silurian age. Similarly, along the Porcupine River, in northern Alaska, Kindle [53] found both middle and upper Silurian rocks, the middle Silurian consisting of a massive magnesian limestone and the upper Silurian of graptolite-bearing shale.

In general, the upper Silurian is more widespread in Alaska than the middle Silurian, though the latter is more conspicuous on account of its massive limestones. In addition to their occurrence in northern Alaska, upper Silurian rocks are found in Seward Peninsula, in the Nixon Fork country southwest of Lake Minchumina, at several places in the Yukon-Tanana region, along the international boundary north of the Yukon, and at a large number of localities in southeastern Alaska. The rocks along the Yukon that are assigned to the upper Silurian (?) are believed to be correlative with this general upper Silurian horizon or horizons.

DEVONIAN SYSTEM

The Devonian system is represented along the Yukon between the international boundary and Circle by a group of rocks of late Middle Devonian age, herein named the Woodchopper volcanics, and by another group of rocks, also called late Middle Devonian, to which no formational name has been applied. The typical Middle Devonian rocks and fauna of interior Alaska are found along the international boundary north of the Yukon but have not been separately mapped. Lower Devonian rocks have nowhere been found in Alaska.

MIDDLE DEVONIAN SERIES

WOODCHOPPER VOLCANICS

DISTRIBUTION

The late Middle Devonian rocks to which the name Woodchopper volcanics is here applied crop out along both banks of the Yukon

[52] Smith, P. S., and Mertie, J. B., jr., Geology and geography of northwestern Alaska: U. S. Geol. Survey Bull. 815, pp. 124–132, 1930.

[53] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, pp. 325–327, 1908.

from the mouth of Coal Creek downstream for 15 miles, extending on the south bank just beyond the mouth of Thanksgiving Creek.

LITHOLOGY

The Woodchopper volcanics between Coal and Thanksgiving Creeks consist essentially of basaltic lavas of greenstone habit and associated pyroclastic material, interbedded with massive limestone and more or less shale, slate, and chert. It is possible that some of the included argillaceous rocks may be infolded or infaulted parts of the Lower Cretaceous sequence, which borders this formation on the east, south, and west; the limestone, however, carries Middle Devonian fossils and is an integral part of the formation. This group of rocks, although essentially igneous in origin, is treated here among the sedimentary succession because of the bedded character of the lavas and because of the fossils found in the interbedded sedimentary rocks. Other basaltic rocks that crop out along the east bank of the Yukon above Circle were formerly included with this series but are now believed to be of later origin. The sedimentary members of the Woodchopper volcanics constitute a minor part of the total and are too small in areal extent to be separately mapped.

Along the south side of the Yukon the section of the Woodchopper volcanics begins somewhat indefinitely about half a mile below Coal Creek. The sequence of rocks as seen along the beach, going downstream, is as follows, the measurements given being distances along the river bank:

Section of Woodchopper volcanics on south bank of Yukon River below Coal Creek

	Feet
Lower Cretaceous slate exposed at mouth of Coal Creek.	
Covered. Probably top of Woodchopper volcanics	2,500±
Limestone, dark gray, rather coarsely crystalline, fossiliferous. Permian. Strike N. 35° E.; dip 50° SE	100
Greenstone and greenstone tuff, with some black chert and siliceous slate directly under the limestone	200
Covered	1,400
Greenstone, massive, basaltic. Shows numerous slickensided fault planes, marked usually by thin seams of calcite and epidote. These fault planes are low lying and dip very gently eastward	700
Covered along beach but exposed on hillside. Probably greenstone and tuff	1,600
Limestone. Seen only from river, but believed to be a part of the Woodchopper volcanics. Strike N. 35° E.; dip 60° SE	1,200

From this point down to Woodchopper Creek and for some distance below on the south side of the river there is an uninterrupted series of lavas and pyroclastic rocks. Plate 1, *C*, shows the bold bluffs in which these rocks are exposed, and Plate 5, *B*, shows a closer view just below the mouth of the creek.

Below Coal Creek, on the north bank of the river, the lavas were examined with some care for a distance of about 2 miles. The bedding of the flows is clearly apparent at many places, and numerous ellipsoidal flows were seen. Ellipsoids as large as 6 feet in diameter were noted. Much volcanic agglomerate or flow breccia and more or less tuff and tuffaceous sediments are also present interbedded with the lavas. Plate 6, *B*, shows typical ellipsoidal lava which crops out farther downstream. The lava itself is clearly basaltic in character, and some of it is amygdaloidal, with vesicular fillings of calcite. The original rock minerals, essentially plagioclase and augite, are now altered to chloritic products, and the accessory iron oxides are completely oxidized. More or less secondary pyrite and pyrrhotite are also distributed in these lavas.

From Woodchopper downstream massive beds of limestone, interbedded with the lavas, crop out at intervals in the bluffs along the river. Plate 5, *A*, shows two such masses of limestone on the north bank of the river opposite the Woodchopper road house. Numerous fossil collections have been made at this locality. Another prominent limestone occurs along the southwest bank of the river about 3 miles below Woodchopper. This limestone strikes N. 75° W. and dips 60° S. It is underlain by greenstone and overlain downstream by greenstone and tuff, mostly tuff. Limestone forms two bluffs about 6 miles below Woodchopper, on the same side of the river.

These limestones vary somewhat in appearance, the differences apparently depending more on the degree of metamorphism to which they have been subjected than on original differences in character. Some are light to dark gray dense noncrystalline or cryptocrystalline limestone, and others are partly recrystallized. An oily odor was detected when some of the limestone was fractured with the hammer, but this has no particular economic significance.

Beds of dark-gray to black slate and chert are found to the east of the limestone opposite Woodchopper road house and at some other places. Some of these rocks are doubtless an integral part of the sequence, but some of the slate, in the writer's opinion, is infolded or infaulted Lower Cretaceous slate.

STRUCTURE AND THICKNESS

The Woodchopper volcanics are complexly folded and faulted, and the resulting structure is most enigmatic. The assemblage of Lower Cretaceous, Permian, and late Middle Devonian (Woodchopper) rocks along the south bank of the Yukon below Coal Creek is certainly due principally to faulting. Similarly, along the north bank of the river above Woodchopper there appears to be a duplication of the limestone strata due to a distributed type of block faulting. The two bodies of limestone opposite Woodchopper road house are probably parts of the same band of limestone separated by faulting. Little is known of the true character of this faulting. Blackwelder[54] was inclined to regard the whole formation in the vicinity of Woodchopper as an assemblage of jostled wedges caused by folding under no great cover. This is as good an explanation as can be given at present and fits in with the writer's conception that the Middle Devonian Woodchopper volcanics at Woodchopper are folded into a major flexure of general anticlinal character. This hypothesis is based primarily on lithologic and areal relationships. A chert conglomerate, which crops out conspicuously, is believed to be the base of the next formation overlying the Woodchopper volcanics. This chert conglomerate is found up Woodchopper and Coal Creeks to the south of the Woodchopper rocks, and it also crops out in the hills about 3 miles north of Woodchopper. This symmetrical distribution of the chert conglomerate suggests an anticlinal arching of the Woodchopper rocks at Woodchopper, with an axial plane that strikes about N. 65° W. and veers more toward the north downstream from Woodchopper. Such a fold, though of greater amplitude, would be correlated rather closely with the observed anticlinal fold in the Cambrian rocks north of Calico Bluff. If this folding had been consummated when the Woodchopper rocks were fairly close to the surface, the wedgelike faulting postulated by Blackwelder would surely have ensued, and this interpretation seems at present the most logical one available.

In view of the observed complexity and the uncertain interpretation of the structure, it is useless to venture any exact estimate of the thickness of the Woodchopper volcanics. The belt is 3 or 4 miles wide from north to south, and it is rather likely that the thickness amounts to several thousand feet.

AGE AND CORRELATION

Seventeen collections of late Middle Devonian fossils have been made at various times by workers in this area, all of which have come from the sedimentary rocks interbedded with the volcanic flows near Woodchopper on the Yukon. A number of other collections have been made from the typical Middle Devonia rocks along the international boundary, but these have been noted in the discussion of the undifferentiated Paleozoic limestones of the boundary. The table below shows that 27 genera in the Woodchopper rocks are represented along the Yukon River. Edwin Kirk, of the United

[54] Blackwelder, Eliot, unpublished manuscript.

States National Museum, who has made most of these paleontologic determinations, regards this fauna as late Middle Devonian and very closely related to the Upper Devonian faunas.

Late Middle Devonian fossils from the Woodchopper volcanics along Yukon River between Eagle and Circle

	Collier 4, 5, 6	2AC60	2AC62	2AC90	2AC96	2AC97	2AC131	841	842	846	156	168	169	170	171	172	2085
Zaphrentis sp			×		×												
Cyathophyllum sp									×			×	×				×
Spongophyllum sp							×										
Favosites cf. F. hemisphericus												×			×		
Favosites cf. F. limitaris											×			×	×		
Favosites sp		×				×		×					×				
Alveolites sp													×				
Chaetetes sp					×												
Actinostroma sp													×		×		
Crinoid columns	×			×	×	×		×		×					×		
Fistulipora sp					×												
Monilopora sp				×													
Dalmanella sp									×								
Schizophoria striatula								×									×
Schizophoria sp					×									×			
Stropheodonta cf. S. calvini								×									
Stropheodonta sp										×				×			
Orthothetes? sp														×			
Chonetes sp								×									
Gypidula comis								×									×
Camarotoechia sp								×		×							×
Rensselaeria? sp									×								
Atrypa cf. A. flabellata																×	
Atrypa cf. A. hystrix								×	×								×
Atrypa reticularis									×	×	×	×		×			×
Atrypa reticularis?					×												
Spirifer sp									×					×			
Reticularia fimbriata var														×			
Reticularia sp																	×
Ambocoelia cf. A. umbonata									×								
Conocardium sp									×	×							
Cyclonema sp									×								
Diaphorostoma sp									×								
Proetus sp								×						×			×
Bollia sp								×									

Collier 4, 5, 6. Locality not recorded. Collector, A. J. Collier.

2AC60. Yukon River, east bank, 3 miles below mouth of Tatonduk River. Pebble from river gravel. Collector, A. J. Collier.

2AC62. Yukon River, east bank, 7 miles below mouth of Tatonduk River. Pebble from river gravel. Collector, A. J. Collier.

2AC90. Yukon River, north bank, opposite Woodchopper; upper end of a series of bluffs. Collector, A. J. Collier.

2AC96. Yukon River, southwest bank, 3 miles below Woodchopper Creek. Collector, A. J. Collier.

2AC97. Yukon River, southwest bank, 4 miles below Woodchopper Creek. Collector, A. J. Collier.

2AC131. Locality not recorded. Collector, A. J. Collier.

841. Yukon River, north bank, opposite Woodchopper road house. Collector, E. M. Kindle.

842. Yukon River, north bank, 2 miles above Woodchopper Creek. Collector, E. M. Kindle.

846. Yukon River, southwest bank, 2 miles below Woodchopper Creek. Collector, E. M. Kindle.

156, 168, 169, 170. Yukon River, north bank, 2 to 3 miles above Woodchopper Creek. Collector, Eliot Blackwelder.

171. Yukon River, southwest bank, about 2½ miles below Woodchopper Creek. Collector, Eliot Blackwelder.

172. Yukon River, north bank, opposite Woodchopper road house. Collector, Eliot Blackwelder.

2065. Yukon River, north bank, opposite Woodchopper road house. Collector, J. B. Mertie, jr.

The rocks along the Yukon (Woodchopper volcanics) containing the late Middle Devonian fauna differ from most of the other Middle Devonian rocks of Alaska in that they are mainly volcanic, though they include also some interbedded fossiliferous sedimentary rocks. The fauna, also, appears to be distinguishably different from the typical Middle Devonian fauna, such as that of the Salmontrout limestone. Therefore, although the stratigraphic limits of this formation can not be exactly given, the rocks and fauna as a whole appear to be sufficiently distinctive to warrant a name, and the term "Woodchopper volcanics" is proposed for this assemblage of rocks.

ARGILLITE, CHERT, AND CHERTY GRIT

DISTRIBUTION

The Middle Devonian rocks mapped as argillite, chert, and cherty grit are found at the head of the North Fork of Shade Creek and extend in a narrow belt both eastward and westward from the type locality. Rocks of the same lithologic character are also found in the valleys of Eagle and Last Chance Creeks, south of the type locality.

LITHOLOGY

The Middle Devonian rocks at the head of the North Fork of Shade Creek consist of argillite, slate, chert, and cherty grit. The argillaceous varieties are dark colored and everywhere more or less siliceous, at some places so much so that although cleaving like slate, they appear to be as hard as flint and might better be designated silica slate and silica argillite. Chert seems to be more abundantly developed in the upper part of the sequence. Probably the most interesting and certainly the most diagnostic lithologic type is a cherty grit that contains peculiar involute fossil forms by means of which it has been possible to correlate this formation at its type locality with similar rocks on Eagle Creek. This grit is in reality a sedimentary chert breccia, composed of angular to subangular fragments of chert, mainly black but subordinately gray, in a matrix of chalcedonic silica and some sandy material. The chert grains range from a quarter of an inch in diameter down to microscopic dimensions, and the contained involute fossil forms have a similar range in size.

In the hills north of Eagle Creek these rocks are imperfectly exposed along burned ridges and spurs and are overlain by rocks of the Nation River formation, which forms cappings on the higher hilltops. The exposures are too much separated to be pieced together into a continuous stratigraphic section, but the lithology shows the general character of this part of the sequence. Among the rocks seen were chert and siliceous slate, veined with secondary quartz; quartzitic graywacke; sandstone that weathers yellow-brown; fine-grained light-gray quartzite, probably a finely recrystallized chert; and fossiliferous cherty grit, which occurs near the Nation River beds and therefore high in the sequence of beds in the transitional formation. In going downhill toward Eagle Creek from the ridge that separates Eagle and Last Chance Creeks, much siliceous slate with beds of black chert is found cropping out along the spurs. The chert here as elsewhere in this formation weathers white, owing to the formation of a covering of opalescent material, which ranges from a thin veneer to a layer half an inch thick. The chert is interbedded with siliceous slate in beds 6 inches to 2 feet thick, and in places the bedding planes are emphasized by banding. The rocks exposed in the bluffs along Eagle Creek, which probably represent a lower horizon in the formation than the rocks above enumerated, include black shale that weathers brown, with numerous flattened ellipsoidal and reniform chert concretions along the bedding planes; nodular black sandy shale in beds from a few inches to a foot thick, containing pyrite nodules ranging from disklike forms to those approaching the frustum of a cone; soft thin-bedded dark-gray nodular sandy shale; bluish-gray hackly argillite, perhaps somewhat calcareous; siliceous slate in beds 1 to 4 inches thick; and chert like that seen farther up on the hill slopes. Apparently, therefore, these lower beds, as seen along Eagle Creek, are somewhat less siliceous than the higher beds seen on the hill slopes to the north and at the head of Shade Creek.

STRUCTURE AND THICKNESS

At the head of the North Fork of Shade Creek these rocks strike northwest and dip gently southwest. They overlie a wedge of Ordovician slates, too thin to be shown on the accompanying map, and underlie the rocks of the Nation River formation. No structural discordance between these rocks and either the overlying or the underlying rocks is apparent. About 3 miles northwest of the Shade Creek croppings, near the Middle Cambrian limestone, the contact between these Middle Devonian rocks and the overlying Nation River formation is exceptionally well exposed in the head of a gulch which drains southwestward to the Yukon. Here both these beds and the beds of the Nation River formation dip southward and, as elsewhere, no structural discordance is visible. Nevertheless discontinuities in sedimentation must be represented, both at the base and at the top of these Middle Devonian beds, because considerable parts of the stratigraphic sequence are absent at both horizons.

The rocks of this formation, as exposed in the valley of Eagle Creek, are highly disturbed, and numerous observations of the attitude of the beds yields little more than a general idea of the regional trend, which appears to be about N. 75° W. The beds are closely folded but not welded into flattened or appressed folds of the type seen in the older rocks to the south. The dip of the beds reverses at short intervals, in places within a few feet, so that little idea of the general dip can be obtained. The whole sequence consists of incompetent beds, and the idea naturally suggests itself that these rocks have been a place of readjustment for some of the tangential forces that produced the thrust faulting and overturning of the more competent older rocks to the south. In other words, the more massive rocks to the south have been a buttress against which most of the tangential forces from the south have been expended, but some of the compressional stresses have been transmitted northward into these weaker beds, producing the observed close folding. The rocks of this series that crop out along the northwest bank of the Yukon below Eagle continue N. 75° W. into the hills north of Mission Creek but are nowhere very well exposed. This belt of rocks is believed to be overlain unconformably to the north by the Nation River formation, of Pennsylvanian (?) age, but its contact with the older rocks to the south is probably determined by faulting.

AGE AND CORRELATION

The assignment of these rocks to the Middle Devonian is based on a collection of fossils made in 1928. The location and determination of those fossils are given herewith:

28AMt260. North Fork of Shade Creek, 0.72 mile N. 13° W. from "Hug" boundary triangulation station (McCann Hill):

- Favosites sp.
- Acervularia (?) sp.
- Zaphrentis sp.
- Leiorhynchus sp.
- Spirifer sp.
- Stropheodonta sp.
- Bactrites (?) sp.
- Orthoceras sp.

With regard to this collection, Doctor Kirk states: "All of this chert material is fragmentary and does not permit of closer identification. It is almost certain, however, that a high Middle Devonian horizon is represented."

In the valley of Eagle Creek no determinable invertebrates were collected but certain peculiar involute fossil forms were found, which occur also with the invertebrates above listed. The rocks of Eagle Creek and of the North Fork of Shade Creek are considered to represent the same stratigraphic horizon. The best collections of these obscure fossils, however, were made in the Eagle Creek Valley at locality 25AMt85 (2061), on the south flank of the ridge north of the creek, in Yukon Territory, three-eighths of a mile S. 23° E. of international boundary topographic station 108. The fossils occur in a cherty grit, which is really a fine-grained cherty breccia. In the hand specimens they appear in longitudinal section as elongated chalcedonic rods with a maximum length of a quarter of an inch, and in cross section as involute structures, some of which are so small that they can not be seen without the aid of a hand lens. They are shown in thin section in Plate 9. These fossils have been referred to a number of Paleozoic paleontologists, none of whom have been able to give any absolute determination of their character or age. Edwin Kirk, of the United States National Museum, to whom they were originally referred and subsequently referred again, has given the writer the following statement, which sums up concisely all that is known at present regarding them:

> The zoological affinities of these curious fossils are doubtful. From a study of their gross structure as well as their structure in thin section under the microscope it appears that the shells were originally chitinous, though now silicified. This, in connection with their elongate subconical form, suggests that the fossils are referable to the Pteropoda. The structure as indicated by available material is peculiar and problematical. Originally there appears to have been a sort of "cone-in-cone" structure, with the adjacent walls connected by irregular septa. In some of the specimens it appears that subsequent to the death of the organisms the horny sheaths were split longitudinally, and one free margin or both margins rolled inward, resulting in a secondary involute structure.
>
> The assignment of these fossils to the Pteropoda has in reality been made mainly by a process of elimination, although exactly comparable structures are not at present known in that group. Such types of pteropods indicate that the containing rocks are upper Paleozoic in age, but no correlation closer than this can be made.

This statement by Kirk, though it does not add materially to the stratigraphic placement of the containing beds, is in harmony with the other paleontologic evidence. Conversely, however, the invertebrates collected in 1928 make it possible now to state that these involute forms are characteristic of the Middle Devonian of this region, and this fact may be used to advantage at other localities where perhaps more diagnostic invertebrates are absent.

It is not possible to state definitely the stratigraphic position of these Middle Devonian argillite and chert beds with regard to the

Woodchopper volcanics. Both formations are regarded as late Middle Devonian, though Kirk feels that the paleontologic evidence is slightly in favor of placing these Middle Devonian beds above the Woodchopper volcanics.

Similarly the total thickness of these beds is not known, because the top of the sequence may have been removed by erosion. At the head of the North Fork of Shade Creek about 600 feet of strata are exposed.

The Devonian, next to the Carboniferous, is probably the most widespread of all the Paleozoic systems, not only in interior Alaska but in Alaska as a whole, and a tabulation of all the localities in Alaska where Devonian rocks are found would be quite beyond the scope of this paper. Three fairly definite horizons have been recognized, as follows:

Upper Devonian, characterized by *Spirifer disjunctus* and other Upper Devonian invertebrates. This is typically developed in the Brooks Range of Arctic Alaska and on Prince of Wales and Chichagof Islands in southeastern Alaska.

Late Middle Devonian, as seen in the sediments of the Woodchopper volcanics along the Yukon above and below Woodchopper Creek and in the argillite-chert beds of Shade and Eagle Creeks.

Middle Devonian proper, whose fauna is typically developed in the Salmontrout limestone on the Porcupine River. The Devonian fossils from the undifferentiated limestone along the boundary, collected by Cairnes, Harrington, and the writer, are a part of this Middle Devonian fauna. The same horizon is extensively represented elsewhere in interior and southeastern Alaska and has also been recognized on the Chandalar River in northern Alaska and in the Kuzitrin Valley on Seward Peninsula.

A horizon whose fossils have been variously referred to " Devonian or Silurian " and " Silurian or Devonian " is represented at numerous localities in interior and northern Alaska, but in this paper this horizon has been assigned to the Silurian system. No Lower Devonian sedimentary rocks are known in Alaska.

CARBONIFEROUS SYSTEM

Six groups of rocks that are believed to be of Carboniferous age are shown on the accompanying map as follows:

A group of volcanic rocks, here designated the Circle volcanics, which are correlated with the upper part of the Rampart group and are considered to represent the base of the Carboniferous system in this district; a formation of chert and slate, which underlies the Calico Bluff formation; the Calico Bluff formation, of marine origin; a transitional formation, believed to overlie the Calico Bluff formation and to underlie the Nation River formation; the nonmarine Nation River formation; and the Tahkandit limestone.

MISSISSIPPIAN SERIES

CIRCLE VOLCANICS

DISTRIBUTION

The rocks here classified as lower Mississippian and named Circle volcanics crop out for a distance of about 15 miles along the east bank of the Yukon upstream from Circle. This is the only known occurrence of these rocks in the area covered by this report, but rocks that are considered to be the same crop out at Fort Hamlin, at the lower end of the Yukon Flats, and continue downstream below Rampart. Plate 7, *B*, shows a typical occurrence of these volcanic rocks along the Yukon above Circle.

LITHOLOGY AND STRUCTURE

The rocks of the Circle volcanics are essentially basaltic lavas, of greenstone habit, not unlike the lavas of the Middle Devonian Woodchopper volcanics. They differ from the Woodchopper lavas in that they are cut by diabasic and gabbroic intrusive rocks, which, however, are not a part of the formation and on detailed work will be mapped separately. The formation contains also a certain proportion of interbedded sedimentary rocks, mainly chert and argillite, with some tuffs and flow breccias. Along the river above Circle the interbedded sedimentary rocks appear to constitute only a minor proportion of the formation, but farther down the river, below Fort Hamlin, they may constitute as much as half of the formation. It is particularly noteworthy that at neither of these two localities, nor southeast from Rampart, where these rocks have also been studied by the writer, have any limestones been found that are comparable with the limestones interbedded in the Woodchopper volcanics. Some thin beds of fossiliferous calcareous tuff have been found in this formation in the Rampart district, and one small lens of fossiliferous limestone was seen in 1923 along the north bank of the Yukon a short distance upstream from Rampart. Both the petrography and the lithology of this formation, therefore, distinguish it from the Woodchopper volcanics; and in addition the fossils found in these rocks in the Rampart area indicate that a part at least of this formation is younger than the Woodchopper volcanics. Little is known of the structure of these lavas and associated sediments above Circle. At their southernmost limit, 12 or 15 miles below Thanksgiving Creek, they appear to dip northwestward, thus apparently overlying other Carboniferous rocks which adjoin them on the southeast. From this point to a point 15 miles downstream, where the exposures on the east side of the river end, numerous reversals of dip were observed, and it is obvious that these lavas are much folded. The folds, however, are of the open type, probably owing to the competency of the beds. This formation is bounded on the north and also on the west by the alluvial deposits of the Yukon Flats, and its relation to adjoining hard-rock formations in these directions is therefore indeterminate.

AGE AND CORRELATION

These lavas and associated pyroclastic and sedimentary beds were originally grouped by Spurr [55] with those here separated as the Woodchopper volcanics, under the name Rampart "series," and were assigned to the Devonian on the basis of some obscure plant remains found in these rocks below Rampart; but fossils found in the calcareous tuffs interbedded with the lavas in the Rampart area by Overbeck in 1918 and by the writer in 1923 show that this part of the Rampart "series" is of Mississippian age. No fossils have yet been found in the typical Circle volcanics upstream from Circle, and the stratigraphic relation of these volcanic rocks to the rocks of the Devonian and Carboniferous systems is obscure. Hence their correlation and age assignment must be based mainly upon lithologic data and upon their relations to adjoining formations in neighboring areas where the stratigraphy and structure are more clearly revealed.

Lithologically the Circle volcanics correspond exactly with the Rampart group farther down the Yukon; and as the Rampart group seems definitely to be of Mississippian age these rocks also may be assumed to be Mississippian. But if the analysis of the Carboniferous stratigraphy in the Eagle-Circle district, as subsequently given, is correct, the Circle volcanics can not be high in the Mississippian sequence. The Calico Bluff formation is of upper Mississippian age, and the stratigraphic units both above and below it have been recognized and mapped. Above the Calico Bluff formation lie successively two younger formations followed by the Permian limestone, without a trace of volcanic activity; and conformably below the Calico Bluff formation lies another Mississippian formation, which at least in its upper part is likewise devoid of volcanic rocks. It would seem, therefore, that if the Circle volcanics belong in fact in the Carboniferous system they must lie well toward its base.

A formation in the type locality of the Rampart group in the Tolovana district was described by the writer [56] in 1916 as consisting

[55] Spurr, J. E., and Goodrich, H. B., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 155–169, 1898.

[56] Mertie, J. B., jr., The gold placers of the Tolovana district: U. S. Geol. Survey Bull. 662, pp. 239–244, 1918.

essentially of chert with a minor proportion of limestone and argillaceous rocks. This formation contains at the base a chert conglomerate. It rests upon rocks of Middle Devonian age and is in turn overlain by slates then supposed to be Pennsylvanian, but later the fossils of these slates were redetermined as Mississippian. In 1916 it was not determined whether the chert formation lay conformably or unconformably above the Middle Devonian rocks. The Rampart group was found to the north of the slates, but its structural and stratigraphic relations to the adjoining Carboniferous rocks were also adjudged to be indeterminate, although it was thought to underlie them. In 1918 and 1923 Mississippian fossils were found also in the Rampart group, but the available paleontologic data were still insufficient to place the Rampart in its proper stratigraphic relation to the Mississippian slates and the underlying chert formation. Thus it appears that neither in the Tolovana district alone nor in the Eagle-Circle district alone are the data available for assigning the Rampart group to its true stratigraphic position. But on considering jointly the data from both these districts a complete sedimentary sequence from the base of the chert formation to the Permian may be said to exist, in which there appears to be no place for a volcanic formation. Yet as shown by its fossils the Rampart group is of Mississippian age. Where, therefore, can it be placed stratigraphically except at the base of the Carboniferous system? Even under this interpretation a degree of uncertainty exists as to the exact relation between the Rampart group and the chert formation of the Tolovana district, for the Rampart group itself comprises a considerable proportion of interbedded chert, as seen along the Yukon below Fort Hamlin and in the North Fork of the Hess River, nor is the chert formation of the Tolovana district free of basic igneous material. It is not possible, therefore, to say definitely that in the Tolovana district the Rampart group in its entirety is older than the chert formation. Perhaps the two groups of rocks are in part contemporaneous. But in the Eagle-Circle district we are dealing only with the upper part of the chert formation, which underlies conformably the Calico Bluff formation and appears to be free of volcanic material. Without final commitment regarding the geologic history of the Rampart group and all of the chert formation, it seems safe to regard the Circle volcanics as older than the cherty rocks that lie directly below the Calico Bluff formation.

The question might be raised, however, as to whether the Circle volcanics could not properly be correlated with the Woodchopper volcanics and be regarded as Devonian. This, it must be admitted, is a possible interpretation, if the correlation of the typical Circle volcanics with those exposed along the Yukon below Fort Hamlin is denied, particularly as no fossils have been found either in the typical Circle volcanic rocks above Circle or in the cherty rocks underlying the Calico Bluff formation. This interpretation has been rejected for two reasons: (1) The lithology of the Woodchopper volcanics differs from that of the typical Circle volcanics above Circle; (2) the Woodchopper volcanics are Middle Devonian, and no Upper Devonian rocks have yet been recognized in central Alaska; hence a transition from the marine Woodchopper volcanics into the volcanic rocks farther downstream is not regarded as probable. Volcanism probably occurred in Upper Devonian time, but where igneous rocks are recognized, they are believed to be mainly intrusive and at least in part ultrabasic. Certainly no evidence exists for the belief that Upper Devonian volcanism was associated with the deposition of marine sediments, such as are found in the Woodchopper volcanics and the Rampart group.

From these considerations the Circle volcanics are correlated with the volcanic rocks of the Rampart group and are regarded as lower Mississippian.

CHERT FORMATION

DISTRIBUTION

The chert formation, which is tentatively referred to the lower Mississippian, occurs definitely at three localities and questionably at certain others. The type locality is at the north end of Calico Bluff, where these rocks are particularly well expressed. A second locality is in the bluff on the north bank of the Yukon, just below the mouth of Shade Creek. (See pls. 6, *A*, and 8, *B*.) Another small area is seen on the west side of the Yukon opposite the mouth of the Tatonduk River. Rocks correlated with this lower Mississippian formation, though probably equivalent to its base, are found in a belt crossing Coal and Woodchopper Creeks a few miles south of the Yukon, and a similar belt is seen north of the Yukon opposite Woodchopper Creek. The north end of the bluffs below Takoma Creek may also belong to the same sequence. (See pl. 8, *A*.) Two other areas of similar rocks which are correlated with this formation occur along the north side of the Yukon 10 or 12 miles below Thanksgiving Creek.

LITHOLOGY

At the north end of Calico Bluff the upper Mississippian Calico Bluff formation, which consists essentially of thin-bedded limestone and shale, grades downward stratigraphically into shale and chert of similar appearance, and finally, at the north end of the exposure, into nearly pure thin-bedded chert. This lower chert is mostly black but weathers to a yellowish-brown color that may be due in part to sulphur staining. It occurs in beds 2 to 6 inches thick, with thin partings of black shale. At the most northerly exposures it has been compressed into numerous sharp folds, though in general all these beds are fairly regular in their attitude. No distinct line can be drawn between the beds of the chert formation and those of the overlying Calico Bluff sequence, but three prominent bands of yellow-weathering limestone are seen at the north end of Calico Bluff, and the cherty rocks appear to become dominant just stratigraphically below these bands. This division between the two formations is a purely arbitrary one, but in the absence of any better one it is utilized for their cartographic separation.

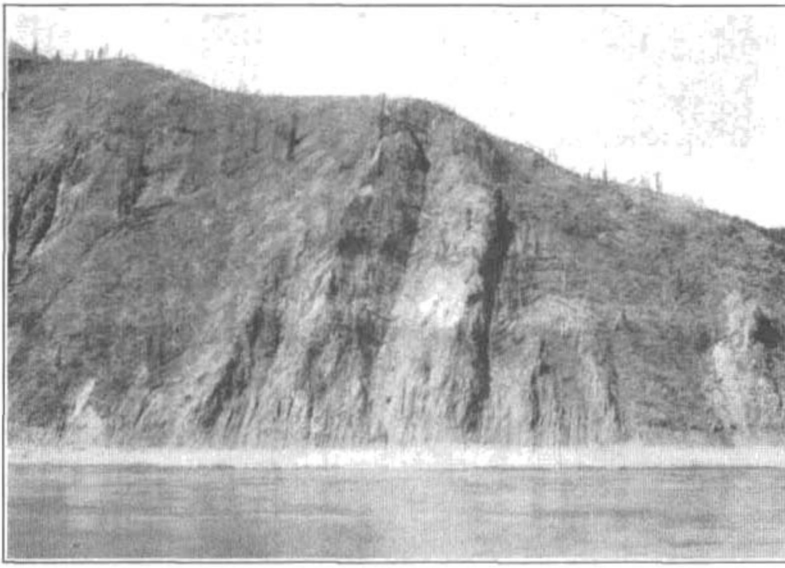
Southeast of Calico Bluff, at the mouth of Shade Creek, are other good exposures of the cherty rocks, which at this place consist essentially of siliceous slates. These slates are black and in part graphitic, as may be seen along some of the slickensided planes. They are, however, hard as flint and might better be called silica slates. Much yellow-brown iron staining is visible in the bluffs, as well as some white and yellow incrusted sublimates resembling gypsum and sulphur. The beds are from a fraction of an inch to 2 feet thick. A few rocks of other character were noted in these exposures, including true conchoidally fracturing chert, an exceedingly fine-grained quartzite, and a 2-foot bed of dark-gray oolitic limestone. The limestone has a strong petroliferous odor when fractured, but when tested in the chemical laboratory of the Geological Survey it yielded only a trace of oil.

South of the Yukon River, in the valleys of Coal and Woodchopper Creeks, is a formation that appears from the exposures along the creeks to be essentially a chert conglomerate or, more accurately, a chert breccia. This rock is only imperfectly exposed along Woodchopper Creek, but in the bedrock of Mineral Creek, a tributary of Woodchopper Creek, where placer mining is in progress, it has been exposed by the mining operations. The chert conglomerate may there be seen in unconformable contact with the much younger conglomerate of Upper Cretaceous or Eocene age. On Coal Creek chert breccia, chert conglomerate, and chert grit are intermittently exposed in bluffs along the west wall of the valley some 6 or 8 miles from the Yukon. Another good exposure occurs on the ridge about 900 feet above the Yukon River and about 2 miles S. 60° W. from the mouth of Coal Creek. The rock here is mainly a dark-gray chert, with a subordinate proportion of chert breccia. The mountain 3 or 4 miles north of the Woodchopper road house, at the head of Eureka Creek, is also composed of chert conglomerate and breccia.

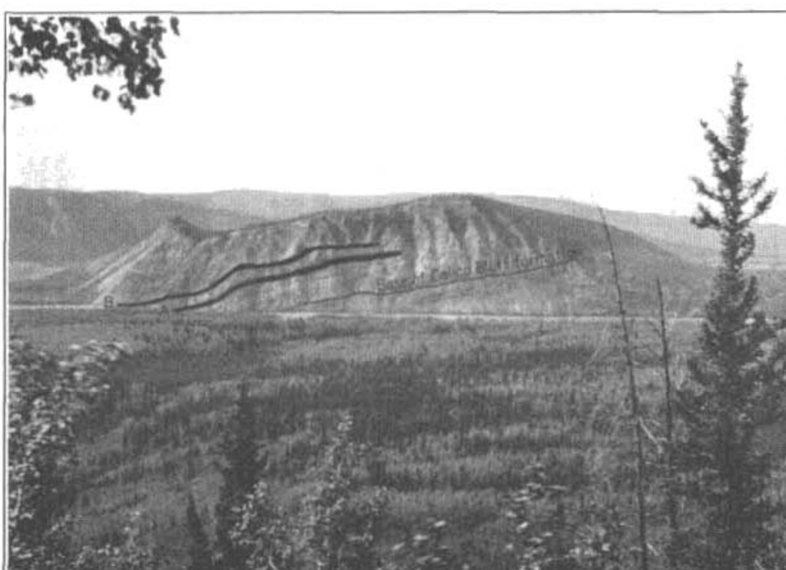
The northermost exposures of this formation of siliceous slate and chert are seen along the northeast bank of the Yukon about 10 miles below Thanksgiving Creek. Here the river swings in, at the lower end of some islands, to rock bluffs of Lower Cretaceous slate and quartzite. Upstream (southeast), along a slough behind these islands, the Lower Cretaceous rocks continue but a quarter of a mile and give place to a formation of siliceous black slate and chert which, still farther upstream, changes to shaly sandstone and black and green slate, with a few beds of chert. Farther up on the hillsides these rocks weather to tones of yellow and brown, giving a characteristic appearance which readily differentiates these hills from the hills composed of the Lower Cretaceous rocks. Downstream from the Lower Cretaceous bluffs intermittent outcrops of chert and siliceous slate may be seen at low stages of the river, and still farther down, just above the junction of the north and south channels, there are good exposures of vitreous pellucid chert and siliceous shale in shades of red, green, and gray. These rocks terminate downstream at a creek entering from the north, where the two channels of the river unite, and below this point is a thin unmappable zone of Lower Cretaceous rocks, followed by a great series of volcanic rocks. These two small areas of chert and siliceous slate should, with little doubt, be correlated with the other rocks of this formation.

The rocks of the chert formation near Woodchopper and Coal Creeks range in color from pearl-gray and cream color into darker shades of gray and jet-black. The constituent fragments range in size from particles too small to be distinguished with the naked eye up to pebbles 1 inch or more in diameter and are usually either angular or subangular. In granularity, therefore, these rocks might be classified as ranging from a chert sandstone or chert grit to a sedimentary chert breccia. The unusual characteristic is a matrix composed also of chert of the same general character as the pebbles. So well indurated are these rocks that they will always fracture directly across the pebbles when broken. Samples of this chert breccia may be seen in which the pebbles are so firmly welded to the matrix that the fragmental character is scarcely apparent; other samples resemble a breccia that might be produced by fracturing in a fault zone; but still others may be seen in which the pebbles are fairly well rounded from the action of water and the sedimentary character is unquestionable.

The writer has seen rock of this peculiar type at many localities in interior and northern Alaska, mainly at or near the top of the Devonian sequence or the base of the Mississippian, and the lithologic description given above would fit almost equally well any of the observed occurrences. The problem of their origin is a most interesting but very difficult one, in the consideration of which a number of facts must be evaluated. At the known localities in interior Alaska the pebbles are exclusively chert; in northern Alaska they include both quartz and chert; but the exact correlation of the two formations

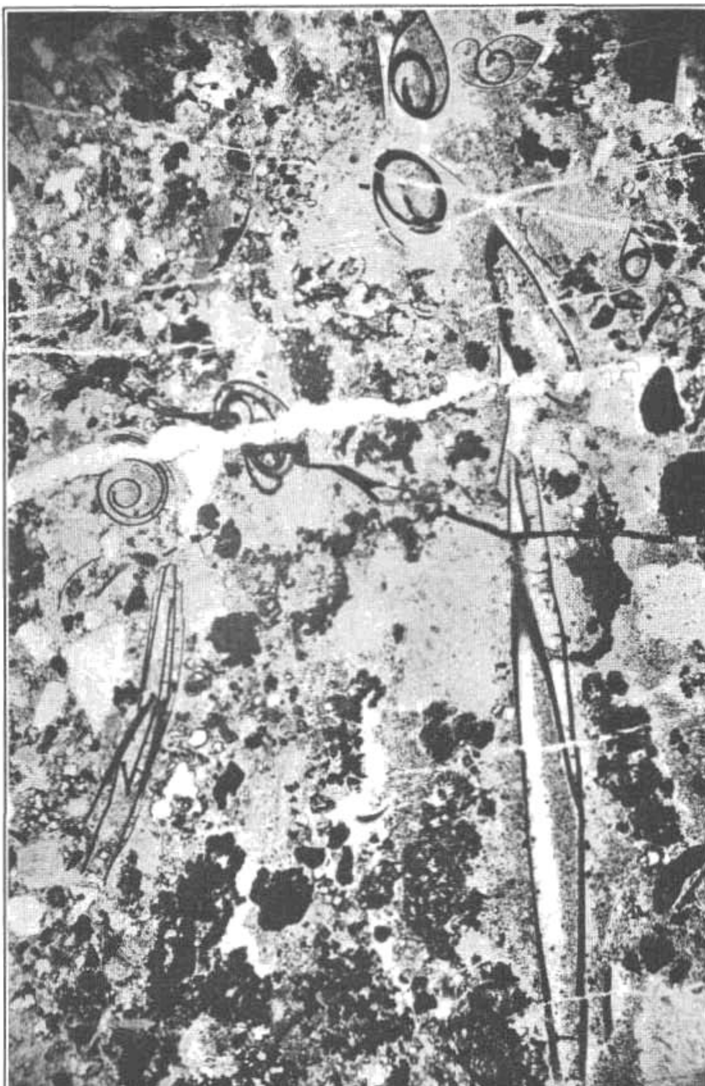


A. VERTICAL BEDS OF CHERT AT NORTH END OF BLUFF ON THE WEST SIDE OF THE YUKON RIVER BELOW TAKOMA CREEK



B. EAST SIDE OF CALICO BLUFF, ON THE YUKON RIVER BELOW EAGLE

Shows Calico Bluff formation underlain (at right) by lower Mississippian chert formation. A and B indicate two of the prominent beds. (See also fig. 5.)



ENIGMATICAL FOSSILS IN MISSISSIPPIAN OR PENNSYLVANIAN TRANSITIONAL FORMATION

Note transverse septa in the longitudinal sections. Enlarged about 15 diameters.

in interior and northern Alaska is inferred rather than proved. The pebbles are usually subangular. The matrix is also chert, and in interior Alaska pebbles and matrix are identical in composition. The rocks appear to have been originally siliceous, to judge from certain fossils found in them near Livengood. These fragmental cherty rocks occur at the base, not at the top, of a thick formation composed mainly of homogeneous gray to black chert, with some siliceous slate and limestone.

Cherts, to be sure, are found in the pre-Mississippian Paleozoic rocks, and one might assume that the fragmental material in the chert breccias and conglomerates originated in long residual accumulations of chert débris derived from these cherty beds in the lower Paleozoic. But an enormous amount of vein quartz, much of which was unquestionably formed in pre-Mississippian time, is also present in the early Paleozoic and pre-Cambrian rocks of interior Alaska, and as this vein quartz is at least as resistant to weathering as chert, it would be natural to expect to find vein quartz as well as chert among the fragmental material, if it is assumed that long-continued surface weathering destroyed the other less resistant type of country rock. But such is not the case. It is therefore necessary to conclude that the matrix and pebbles are syngenetic—that is, they are essentially contemporaneous, in terms of geologic rather than secular time units. The origin of the chert conglomerate and breccia is therefore tied directly to the question of the origin of the overlying chert formation.

The writer has stated in previous publications the belief that this chert is of primary and probably of marine origin, though no evidence of its marine character was definitely known when it was first described by the writer[57] in 1916. Subsequently, in 1918, Overbeck collected some coralline and crinoidal material from the chert in its type locality, some 12 miles west of Livengood, thus establishing its marine character. What, then, is the mechanism of the formation of such rocks? Some limestone conglomerate and primary limestone breccia have been proved to form more or less simultaneously with the massive limestones about them, by the eroding and sorting action of oceanic currents upon marine limestone reefs. Such reefs, it seems, could be either of coralline or inorganic origin. But the sharp angularity of many of these chert pebbles shows clearly that the original fragments must have already attained a considerable degree of cohesive strength at the time of their formation, or else they suffered practically no transportation or sorting by water. The

[57] Mertie, J. B., jr., Gold placers of the Tolovana district: U. S. Geol. Survey Bull. 662, pp. 239–244, 1918.

subangular character of most of this fragmental débris and the rounded character of some, however, favors the idea that the fragments were well indurated at the time of origin of the breccia but suffered some sorting or transportation by water.

The writer confesses his inability at present to formulate a satisfactory genetic hypothesis for these cherty fragmental rocks. The thesis here proposed, however, is that ordinary terrestrial processes of erosion and stream transportation had little if any direct part in the formation of either the cherts or the fragmental cherty rocks; that both the fragmental cherty rocks and the overlying massive chert are of primary marine origin; and that the fragments and matrix of the breccias and conglomerates are essentially syngenetic.

It is hoped that at some time a comparative study may be made of thin and polished sections of the cherts and chert breccias of this horizon from a number of localities in interior and northern Alaska. Specimens recently collected by the writer in northern Alaska show much vein quartz as well as chert among the pebbles of rocks that appear otherwise to be essentially the same as the rocks of this chert formation of interior Alaska. These variations may give rise to new ideas regarding the genesis of such rocks. In the meanwhile, it is hoped that field studies will continue to contribute stratigraphic and paleontologic data bearing on these questions.

STRUCTURE AND THICKNESS

The rocks of this formation exposed at the north end of Calico Bluff are relatively little deformed and constitute the lower beds of a synclinal basin that plunges gently about N. 30° W. The highest of these rocks underlying the Calico Bluff formation at the north end of the bluff are shown in Plate 8, *B*. The lowermost beds crop out downstream, north of Calico Bluff, for 6,000 feet in a low bench along the west bank of the river. The base of this sequence is nowhere exposed in this vicinity, and the assignment of the chert breccia and conglomerate farther downstream as the base of this formation can not be substantiated from any data obtainable along the river. This correlation is based on comparative stratigraphic studies made by the writer [58] at other localities in the Yukon-Tanana region, particularly in the Livengood district of the Fairbanks quadrangle.

Few structural observations of the chert breccia and conglomerate in the Woodchopper and Coal Creek areas are available, but the areal distribution of the two belts there present, one north and one south of the Middle Devonian Woodchopper volcanic rocks, suggests strongly the existence at this locality of an anticlinal fold whose

[58] Mertie, J. B., jr., The gold placers of the Tolovana district: U. S. Geol. Survey Bull 662, pp. 239–244, 1917.

major axis of elongation trends northwestward. Unfortunately a band of Lower Cretaceous rocks, overlying unconformably these basal Mississippian rocks, lies between the Middle Devonian and the lower Mississippian rocks on both Coal and Woodchopper Creeks, completely concealing the contact between the two formations. The hills, however, are low and the exposures poor in the Woodchopper area, and it is doubtful if much information regarding the stratigraphic relations could be gained even if the Lower Cretaceous rocks were absent. The great lithologic differences between the Middle Devonian Woodchopper and the Mississippian rocks, and the evident kinship of the chert formation with Mississippian rocks, as exhibited at Calico Bluff, favor the belief that a stratigraphic and perhaps a structural break separates the base of this chert formation from the underlying Middle Devonian rocks.

The rocks of this sequence 10 or 12 miles below Thanksgiving Creek appear to dip in a general northwesterly direction and are believed to underlie the volcanic series adjoining them downstream. It is possible that these rocks form the northwest end of the Woodchopper anticline, plunging northwestward at this point under younger rocks.

Only at the north end of Calico Bluff has it been possible so far to measure the thickness of these rocks, and there, of course, only a part of the sequence is exposed. Here about 1,700 feet of strata crop out below the arbitrary line which is assumed as the base of the Calico Bluff formation, but the base of the section is not exposed. Considering the amount of chert breccia exposed in Coal and Woodchopper Creeks, particularly in Coal Creek, it is probably safe to assume that the total thickness of this formation is several thousand feet, but any more exact statement is not warranted.

AGE AND CORRELATION

Formations consisting dominantly of chert and siliceous slate and argillite have been found at several localities in interior and northern Alaska and have in general been difficult to place stratigraphically, for the following reasons: They resemble one another lithologically; they are usually incompetent, so that critical structural data are lacking; they rarely yield diagnostic fossils; and they are so far separated from the standard sections of the United States that the ordinary stratigraphic nomenclature can at best be applied only in the most general way. The formation of chert and related rocks appears to have been more than ordinarily prevalent in Devonian and Mississippian time, and where such rocks occur at two or more horizons in the same general area, as in the Eagle-Circle district, their correct differentiation becomes difficult. The chert formation that underlies the Calico Bluff formation illustrates some of these difficulties. At its type locality its structural relation to the Calico Bluff formation is unequivocal, but its lower stratigraphic limit has not been recognized, and fossils are absent. Across the Yukon, below the mouth of Shade Creek, a few nondiagnostic fossils have been found, but the structural relations to overlying or underlying formations can not be discerned. And 75 miles to the northwest, in the Woodchopper area, occur more chert and chert conglomerate which with no fossil evidence and little stratigraphic evidence are interpreted as the base of this formation. Obviously, the correlation of these and other chert occurrences along the Yukon as a single formation is based more upon vague geologic interpretation than upon facts, particularly as at least one other chert formation, of Middle Devonian age, is also present in this same area.

The chert formation here considered is definitely known to underlie conformably rocks of upper Mississippian age. It is believed to be no older and perhaps younger than the Rampart group and Circle volcanics, which in this paper are considered to be lower Mississippian. Although elsewhere in Alaska similar cherty rocks have been termed Mississippian or Upper Devonian, the structural and stratigraphic relations of this formation to adjoining formations along the Yukon indicate a much closer kinship with the Mississippian than with the Devonian rocks of interior Alaska; and therefore this formation along the Yukon is referred to the lower Mississippian, not with the purpose of indicating a close correlation with the Waverly or Madison epochs of the United States, but merely to show that these rocks are younger than the Woodchopper volcanics, older than the Calico Bluff formation, and possibly in part contemporaneous with the Rampart group and Circle volcanics.

Fossils were found in the siliceous slate and chert at the mouth of Shade Creek by E. M. Kindle, in 1906. This collection (No. 844) has recently been examined by G. H. Girty, of the United States Geological Survey, and has been found to contain *Enchostoma* sp. and *Lingula* cf. *L. spatulata*. These fossils are regarded by Girty as possibly Devonian but more probably Mississippian. Inasmuch as such forms have not been found either in the Middle Devonian or in the upper Mississippian faunas of the Yukon, it would seem quite appropriate to regard them as lower Mississippian, to conform with the age assignment which the stratigraphic and structural relations indicate.

The rocks of this formation are correlated primarily with a similar "chert formation" in the Tolovana district,[59] about 225 miles to the west. At that locality the base of the formation was composed of

[59] Mertie, J. B., jr., Gold placers of the Tolovana district: U. S. Geol. Survey Bull. 662, pp. 230–244, 1918.

chert conglomerate and chert breccia, which may be correlated with the rocks seen on Coal and Woodchopper Creeks. The upper beds were mainly chert, with some siliceous slate and shale and silicified limestone; and this part of the sequence is believed to be the lithologic counterpart of the chert underlying the Calico Bluff formation. The "chert formation" of the Tolovana district was described originally as not older than Middle Devonian nor younger than Pennsylvanian, but fossils subsequently found indicate that it is Mississippian. Therefore it is correlative paleontologically also with the rocks at the north end of Calico Bluff and at the mouth of Shade Creek.

In northern Alaska a somewhat similar formation of chert conglomerate with interbedded layers of quartzite in the lower part and slate and shale in the upper part was described originally by Schrader [60] under the designation Stuver "series" and was considered pre-Devonian. Subsequently the Stuver "series" was shown by Smith and Mertie [61] to overlie the Upper Devonian rocks and to underlie the upper Mississippian rocks of northern Alaska and was therefore assigned to the basal part of the Noatak formation, of lower and upper Mississippian age. This basal part of the Noatak formation, previously called the Stuver "series," is therefore believed also to be approximately correlative with the chert formation of the Yukon. In this connection, however, it should be remembered that northern Alaska constitutes a different geologic province from interior Alaska, and it is therefore not surprising that the Noatak formation differs materially in lithology from rocks of similar age on the Yukon.

Other formations composed mainly or partly of chert are known elsewhere in Alaska, but accumulative data tend to show that rocks of several ages may be of this general lithologic character. The Upper Triassic chert of northern Alaska, described by Smith and Mertie, is a good example of one of the newly discovered chert formations that can not be correlated with the chert formation of the Yukon. The Middle Devonian cherty rocks at the head of the North Fork of Shade Creek constitute another example. Hence, in the future the burden of proof will bear heavily upon the geologist who attempts to correlate chert formations in Alaska upon lithologic evidence alone.

CALICO BLUFF FORMATION

DISTRIBUTION

The type locality of the Calico Bluff formation is at Calico Bluff, on the west bank of the Yukon River, about 8 miles due north of

[60] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 60–62, 1904.

[61] Smith, P. S., and Mertie, J. B., jr., Geography and geology of northwestern Alaska: U. S. Geol. Survey Bull. 815, pp. 155–157, 1930.

Eagle. (See pl. 8, *B*.) The rocks of this formation are also exposed in a narrow zone on the north bank of the Yukon north of Calico Bluff, and this zone apparently continues N. 30° W. into the lower valley of the Tatonduk River and beyond in the same general direction. Another narrow belt of the same rocks occurs just west of the mouth of the Seventymile River and also continues N. 30° W., cropping out again on the west bank of the Yukon about opposite the mouth of the Tatonduk.

LITHOLOGY

The rocks at Calico Bluff consist essentially of alternating beds of limestone and shale with some slate and, being only gently folded, afford an excellent opportunity for measuring a detailed section.

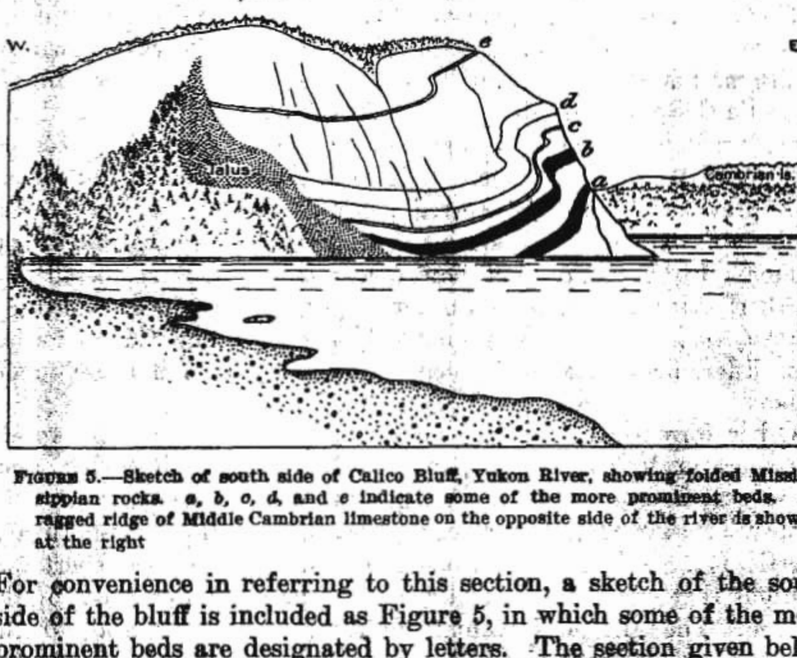


FIGURE 5.—Sketch of south side of Calico Bluff, Yukon River, showing folded Mississippian rocks. *a*, *b*, *c*, *d*, and *e* indicate some of the more prominent beds. A ragged ridge of Middle Cambrian limestone on the opposite side of the river is shown at the right

For convenience in referring to this section, a sketch of the south side of the bluff is included as Figure 5, in which some of the more prominent beds are designated by letters. The section given below was measured instrumentally from the base of zone *b* to the top of the bluff. The section from zone *b* down to the water's edge at the eastern point of the bluff was not measured instrumentally, but the thickness of beds involved was estimated by two roughly quantitative methods, which checked each other very closely. The limestone and shale are thicker at the base of the section and become progressively more thin bedded toward the top. As a result, the upper part of the section consists of a great number of thin beds of alternating limestone and shale, some of which have here been grouped together. It is doubtful whether any two sections of Calico Bluff made by different men would match, for much of the variation is more apparent than real, depending to a considerable extent upon differences in color, which are due to weathering and which do not persist laterally along the beds. The section from top to bottom is given herewith:

Section of Calico Bluff formation in south side of Calico Bluff, on Yukon River below Eagle

[Zones indicated by letters are shown in fig. 5 and pl. 8, *B*]

	Feet
Covered. Lower part composed of drab shale, with a few beds of limestone	60
Slope of gray shale, with a little limestone. Contains in the upper part two or three beds of sandstone that weathers a light ocherous yellow, each 3 or 4 feet thick	95
Calcareous shale, light gray or darker gray, weathering to a light gray. Upper 20 feet covered	194
Massive black limestone, noticeably carbonaceous. Weathers light gray. Zone *e*	8
Thin beds of black shale and limestone, both of which weather light and dark gray. These rocks are fossiliferous, but the shale contains invertebrates of genera different from those found in the limestone, indicating an oscillating condition of sedimentation and of marine life	215
A cliff-forming group of beds. Consists of thin-bedded limy shale that weathers to a chocolate color at the top; a 2-foot bed of white-weathering limestone in the center; and black shale at the base	14
Thin, fissile black shale that weathers to a bronze color, except in the middle of the sequence, where it appears chocolate-colored for 10 or 15 feet	119
Upper 56 feet is mainly thin-bedded limestone with some shale, weathering to a light chocolate color. Lower 27 feet is fissile black shale that weathers blackish brown. Zone *d*	83
Fissile black shale, weathering brown at base and red and yellow farther up, giving a general bronze color to the beds	48
Alternating thin beds of white-weathering limestone and fissile black shale. Fossils occur in a thin band at the very top	10
Dark-gray fetid limestone that weathers light gray. Fossiliferous at the base	4
Dark-gray fissile shale that weathers yellow-brown	15
Beds of limestone as much as 3 feet thick, alternating with shale. Contains about midway of the sequence a 2-foot bed of fossiliferous limestone	26
Dark-gray fetid limestone that weathers light gray. Fossiliferous. Zone *c*	14
Alternating thin beds of dark-gray limestone and thin, fissile black slate that is probably calcareous. Beds 2 to 8 inches thick	24
Black slate, somewhat siliceous. Near the top is a 6-inch bed of fetid, black fossiliferous limestone that weathers white. Zone *b*	39
Alternating beds of limestone and shale with some chert. Includes 1 thick zone of black siliceous slate, which is zone *a*. Thickness estimated	300

The base of this section, as here given, is about at the end of the point shown in Figure 5 as projecting into the Yukon. (See also pl. 8, *B*.) This basal line, as previously stated, is an arbitrary one, placed at about the level where, in going down in the section, the limestone and fossiliferous beds cease. This line therefore serves also as the upper limit of the lower Mississippian sequence, already described.

STRUCTURE AND THICKNESS

The structure of the rocks at Calico Bluff is that of an open syncline which plunges gently about N. 30° W. The other two belts of this formation to the northwest, one on the northeast side of the Yukon and one on the southwest side, are interpreted in a broad way as the northeast and southwest limbs of this same syncline. Strike faulting, however, has materially modified the synclinal structure. On the north side of the Yukon, north of Calico Bluff, occurs a rapid alternation of Upper Cambrian, lower Mississippian, upper Mississippian, and Upper Cretaceous rocks, standing practically on end. The lower Mississippian rocks are here repeated three times in the section, and the Upper Cretaceous rocks twice. Similarly, on the southwest side of the Yukon strike faulting is apparent, particularly opposite the mouth of the Tatonduk River, where the areal distribution of the lower and upper Mississippian rocks is exactly the reverse of what would be expected if normal synclinal structure were present. None of the four known upper Mississippian localities northwest of Calico Bluff, therefore, may be expected to contribute much stratigraphic evidence about this formation. The rocks at Calico Bluff, for some unknown reason, constitute a little stratigraphic island of relatively simple structure, surrounded on all sides by beds that are more intricately folded, as well as faulted, and all the structural and stratigraphic information available is concentrated at this one locality.

The northwestward plunge of the syncline is indicated on the south side of Calico Bluff (see fig. 5), where the strike of the rocks is east and the dip is 15°–35° N., averaging perhaps 20°. Minor crumpling is evident toward the east side of the bluff, but in general the rocks are little metamorphosed and show perfectly the original bedding planes, with incipient fracture cleavage only in some of the weaker beds.

The highest beds have been eroded at Calico Bluff, and it is therefore not possible to obtain a complete stratigraphic section. The thickness of beds from the arbitrary basal line to the top of the bluff at its south end is believed to be about 1,270 feet. The thickness from the base of zone *b* to the top, as measured instrumentally, is 968 feet.

In this connection it is of interest to examine the section made by Brooks,[62] who first studied in detail the rocks exposed at Calico Bluff and gave the following section:

Calico Bluff section

[As given by Brooks]

	Feet
O. Gray to blackish shale, with few bands of limestone	300
N. Gray limestone in 6-inch to 12-inch bands, interbedded with thin bands of black slate	500
M. Black shale and subordinate thin bands of limestone	60
L. Black carbonaceous shale	50
K. Gray chert and black shale	6
J. Dark-gray limestone full of *Productus*, etc	9
I. Dark carbonaceous shale	20
H. Gray cherty limestone	25
G. Soft fissile black shale	55
F. Gray chert	8
E. Fissile black carbonaceous shale	150
D. Black carbonaceous shale, with slaty cleavage developed in most beds	100
C. Black carbonaceous shales, with some thin black chert bands interbedded	40
B. Black cherts in 4-inch to 6-inch bands and interbedded black shale	55
A. Black carbonaceous fissile shale	150

From an inspection of this section it is fairly certain that zones L and G correspond, respectively, to zones *b* and *a* of Figure 5. Brooks's section, from the base of his zone L to the top of the bluff, is given as 910 feet, and when it is remembered that this measurement was made without instruments, it shows a remarkable similarity to the instrumentally measured section of the same sequence from the base of zone *b* to the top, which, as measured by the writer, is 968 feet.

AGE AND CORRELATION

Fossils are very plentiful at Calico Bluff, as well as at the other four upper Mississippian localities, and nearly every geologist who has gone down the Yukon, from the time of Collier's trip in 1902 to the present, has made collections at these localities. Some of the fossiliferous zones at Calico Bluff are indicated in the section above given, but others are doubtless present though not seen by the writer, for it was noticed that some of the fossiliferous zones had a rather slight lateral extent along the bedding planes, and any one section would therefore necessarily miss some zones. The writer, like his

[62] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, p. 288, 1908.

predecessors, collected additional fossil material from this unique locality at Calico Bluff. It has seemed best, however, to assemble and correlate all the collections, and the result is shown in the following table, which may be said to represent the intermittent collecting of seven geologists over a period of 24 years. A few of the earlier paleontologic determinations were made by Charles Schuchert, now of Yale University, but the great mass of determinative work has been done by G. H. Girty, of the United States Geological Survey. Girty himself made a trip down the Yukon in 1918 and collected some of the best of the material tabulated below. The localities are arranged roughly in the chronologic order of the collections. Although some of the locality descriptions are inadequate and some are slightly in error, they are published as given by the original collectors, with the exception that the terms right bank and left bank, as used in some of the locality descriptions, have been altered to north, east, west, or south bank, as the case may be. Interpretations of the locality made by the present writer are indicated in parentheses. Zones indicated by letters are those shown in Figure 5.

Mississippian fossils collected along the Yukon River between Eagle and Circle

	2637	1AC58	2645	2646	2642	2644	2644A	2644B	2651	2651A	843	845	1768	1768A	1768D	1767	1767A	1767B	1767C	1767D	1767E	1767F	1769	1768A	2279	2302	2303A	2303	2304	2342	2342A	2342B	2342D	2342O	2343
Coral					X																														
Cyathaxonia sp.													X																						
Hadrophyllum? sp.																									X										
Zaphrentis sp.	X				X			X								X												X							
Zaphrentis? sp.			X																																
Triplophyllum sp.																			X						X					X					
Triplophyllum? sp.																																	X		
Amplexus? sp.																									X										
Campophyllum sp.			X		X																				X			X		X		X			
Dibunophyllum? sp.																			X																
Lithostrotion? sp.																														X		X			
Favosites? sp.																			X																
Michelinia cf. M. princetonensis																									X										
Michelinia sp.			X																																
Aulopora? sp.																																		X	
Cladochonus sp.																			X						X			X							
Stromatopora? sp.																									X										
Serpula? sp.																									X										
Spirorbis sp.																									X										
Echinocrinus sp.								X																								X			
Fistulipora cf. F. excellens																									X										
Fistulipora sp.			X																																
Fistulipora? sp.																												X							
Batostomella sp.													X	X		X				X	X			X		X	X				X	X	X	X	
Leioclema sp.														X																					
Stenopora cf. S. carbonaria			X	X																															
Stenopora cf. S. ramosa																									X			X		X					
Stenopora sp.			X					X																							X				
Stenopora? sp.						X		X																											
Anisotrypa sp.																									X										
Anisotrypa? sp.																									X										
Fenestella sp.	X					X		X	X				X	X						X				X	X	X		X		X	X	X	X		
Hemitrypa sp.																X									X										
Polypora sp.						X		X		X										X	X				X			X		X					
Pinnatopora sp.								X						X																X					
Rhombopora cf. R. lepidodendroides			X	X																															
Rhombopora sp.	X					X		X	X					X	X										X			X	X	X	X		X		
Coelaconus sp.													X							X															
Ptilodictya sp.																																X			
Cystodictya cf. C. lineata																									X						X	X	X		
Cystodictya cf. C. pustulosa			X										X												X			X	X			X			
Cystodictya sp.	X					X		X	X					X	X									X											
Rhipidomella cf. R. penniana																									X										

Mississippian fossils collected along the Yukon River between Eagle and Circle—Continued

	[illegible]	24AC58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]A	[illegible]B	[illegible]	[illegible]A	[illegible]	[illegible]	[illegible]	[illegible]A	[illegible]B	1797	1797A	1797B	1797C	1797D	1797E	1797F	1798	1798A	[illegible]	[illegible]	[illegible]A	[illegible]	[illegible]	[illegible]	[illegible]A	[illegible]	[illegible]	[illegible]D	[illegible]E
Rhipidomella sp.			×																																
Schizophoria sp.								×																×	×										
Schizophoria? sp.									×																										
Orthotetes sp.																									×					×					
Orthotetes? sp.																																	×		
Derbya sp.																												×							
Derbya? sp.						×							×																						
Chonetes capax																									×			×							
Chonetes cf. C. capax																														×		×	×	×	
Chonetes choctawensis											×																								
Chonetes cf. C. choctawensis						×		×		×							×						×		×	×									
Chonetes cf. C. laevis																															×				
Chonetes sp.			×		×			×	×															×			×								
Chonetes? sp.																												×							
Productus cf. P. adairensis													×		×																	×			
Productus cf. P. adairensis var.																									×										
Productus cf. P. adairensis?																								×				×							
Productus cf. P. cherokeensis						×		×	×	×																									
Productus cf. P. inflatus						×																			×										
Productus cf. P. inflatus?																																×			
Productus cf. P. ivesi					×																														
Productus ovatus																									×	×						×	×		
Productus ovatus var.																																	×		
Productus ovatus?																				×	×														
Productus cf. P. ovatus					×			×	×	×			×			×																			
Productus cf. P. parviformis													×			×																			
Productus cf. P. parvus			×					×					×													×			×						
Productus cf. P. scitulus														×										×											
Productus semireticulatus																			×			×			×			×				×	×	×	
Productus semireticulatus var.			×		×																														
Productus semireticulatus?	×																				×			×											
Productus cf. P. semireticulatus								×		×																									
Productus cf. P. setiger						×			×				×																						
Productus cf. P. tenuicostus																													×						
Productus sp.			×		×	×		×		×			×												×				×	×	×			×	
Pustula cf. P. alternata																									×							×		×	
Pustula cf. P. biseriata						×		×	×				×	×										×	×		×	×		×	×	×	×		
Pustula cf. P. concentrica								×																											
Pustula hirsutiformis																										×									
Pustula cf. P. hirsutiformis						×		×	×	×															×			×				×			
Pustula cf. P. hystrix	×																																		
Pustula cf. P. indianensis														×		×									×								×		
Pustula cf. P. indianensis?													×																						
Pustula cf. P. oklahomensis																									×										
Pustula cf. P. oklahomensis var.																									×										

Pustula punctata															X																				
Pustula punctata?																				X				X											
Pustula cf. P. punctata						X																						X							
Pustula sp.																			X						X	X		X	X	X	X		X	X	
Avonia sp.																												X					X		
Strophalosia? sp.																									X										
Camarophoria cf. C. bisinuata																									X			X							
Camarophoria sp.																									X			X							
Leiorhynchus carboniferum	X	X					X			X	X	X													X			X				X	X		X
Leiorhynchus sp.						X																													
Leiorhynchus? sp.															X								X						X						
Moorefieldella eurekensis?																												X							
Pugnoides? sp.																									X										
Rhynchopora cf. R. beecheri																									X										
Rhynchopora sp.																																	X		
Rhynchonella sp.			X																																
Camarotoechia cf. C. metallica																									X			X							
Camarotoechia sp.								X																							X				
Camarotoechia? sp.								X																											
Dielasma sp.																									X										
Dielasma? sp.	X																								X										
Girtyella sp.																														X					
Spirifer cf. S. alatus			X																																
Spirifer cf. S. arkansanus																			X						X			X				X		X	
Spirifer cf. S. arkansanus var.																																X			
Spirifer cf. S. bifurcatus																									X										
Spirifer cf. S. bisulcatus						X		X		X																									
Spirifer cf. S. carinatus																									X			X							
Spirifer cf. S. keokuk						X		X																											
Spirifer cf. S. mortonanus																																X			
Spirifer cf. S. mosquensis																									X										
Spirifer cf. S. pellensis													X	X	X	X									X										
Spirifer cf. S. pinguis	X																																		
Spirifer cf. S. rowleyi																X																			
Spirifer cf. S. subrotundatus																										X		X				X			
Spirifer cf. S. sulcatus									X																										
Spirifer yukonensis																X									X			X							
Spirifer sp.			X		X	X			X															X	X							X	X		
Brachythyris cf. B. peculiaris																									X										
Brachythyris cf. B. suborbicularis																												X							
Reticularia cf. R. cooperensis																									X			X						X	
Reticularia cf. R. setigera						X		X					X																						
Reticularia sp.																										X									
Reticularia? sp.																																X			
Ambocoelia sp.																									X										
Ambocoelia? sp.								X																											
Martinia cf. M. rostrata										X																									
Martinia cf. M. sulcata																									X										
Martinia sp.																																X			
Martinia? sp.						X												X																X	
Spiriferina cf. S. spinosa																									X										
Spiriferina sp.																																	X		
Hustedia cf. H. mormoni																									X										

Mississippian fossils collected along the Yukon River between Eagle and Circle—Continued

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hustedia cf. H. multicostata																									×										
Athyris? sp.									×																										
Cleiothyridina cf. C. sublamellosa																									×								×		
Composita cf. C. trinuclea																									×								×		
Composita? sp.			×																											×					
Composita sp.	×												×																		×				
Sphenotus cf. S. branneriana																									×										
Sphenotus cf. S. meslerianus																									×										
Sphenotus sp.													×												×		×								
Edmondia? sp.																												×							
Solenomya? sp.																									×										
Cardiomorpha? sp.																×																			
Nucula cf. N. randolphensis																									×										
Nucula cf. N. rectangula																												×							
Nucula sp.																										×						×			
Nucula? sp.																×																			
Leda cf. L. bellistriata																										×									
Leda? sp.																																	×		
Yoldia sp.																										×									
Parallelodon cf. P. carbonarius						×																													
Parallelodon sp.								×																	×										
Leptodesma sp.																									×								×		
Leptodesma? sp.																					×														
Conocardium sp.																									×										
Pteria? sp.																												×							
Posidonomya sp.			×																																
Caneyella cf. C. vaughani																									×										
Caneyella cf. C. wapanuckensis																	×								×										×
Myalina sp.						×																													
Myalina? sp.																									×										
Pectinella? sp.				×																															
Schizodus sp.																									×										
Aviculipecten cf. A. batesvillensis																									×										
Aviculipecten sp.						×		×		×							×								×	×		×						×	
Streblopteria cf. S. hertzeri					×																														
Streblopteria similis?																									×										
Deltopecten cf. D. occidentalis																									×										×
Pleurophorus cf. P. subcostatus								×																											
Pleurophorus sp.								×																											
Pleurophorus? sp.					×																														
Cypricardinia cf. C. [illegible]																														×					
Cypricardinia sp.																									×			×							
Cypricardinia? sp.													×																						

Cypricardella cf. C. nucleata																									X										
Cypricardella? C. oblonga																												X							
Miscellaneous pelecypoda			X																																
Dentalium sp.									X																										
Laevidentalium cf. L. venustum																									X								X		
Chiton sp.								X																											
Patella sp.																									X										
Oxydiscus? sp.																									X			X							
Bellerophon cf. B. crassus			X	X																						X									
Bellerophon cf. B. sublaevis																									X			X							
Bellerophon sp.						X										X				X				X											
Bellerophon? sp.									X																										
Euphemus cf. E. randolphensis																																X			
Euphemus sp.																									X										
Bucanopsis cf. B. textilis																									X							X	X		
Pleurotomaria sp.	X							X		X			X			X								X	X	X		X				X			
Pleurotomaria? sp.									X																										
Phanerotrema? sp.																									X			X							
Baconospira sp.																									X										
Worthenia? sp.																									X									X	
Bembexia cf. B. mcchesneyana																									X	X		X					X	X	
Bembexia sp.																									X			X				X		X	
Bembexia? sp.																														X	X				
Trepospira sp.																									X								X		
Straparollus cf. S. spergenensis																									X			X		X		X	X		
Euomphalus sp.																											X				X				
Euomphalus? sp.										X																									
Cyclonema sp.																																X			
Cyclonema? sp.																									X										
Holopea sp.																												X							
Anomphalus sp.																														X		X			
Naticopsis cf. N. carleyana																														X					
Naticopsis cf. N. waterlooensis																									X										
Naticopsis cf. N. wortheni																									X										
Naticopsis sp.																X									X										
Naticopsis? sp.																																	X		
Meekospira sp.																									X					X			X		
Meekospira? sp.																												X							
Bulimorpha sp.			X																						X										
Zygopleura sp.																																X		X	
Aclisina sp.																																	X		
Aclisina? sp.																									X										
Trachydomia? sp.								X																											
Platyceras cf. P. acutirostre																									X										
Platyceras sp.																												X							
Eotrochus cf. E. concavus																									X										
Sphaerodoma sp.																									X										
Conularia sp.	X																																		
Miscellaneous gastropoda			X																																
Orthoceras cf. O. epigrus																																	X		
Orthoceras sp.							X			X	X														X	X									
Nautilus? sp.																	X																		
Gastrioceras sp.																									X										

Mississippian fossils collected along the Yukon River between Eagle and Circle—Continued

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gastrioceras? sp.																													×						
Goniatites sp.							×																					×							
Goniatites? sp.																													×						
Phillipsia sp.						×																						×							
Phillipsia? sp.				×					×																										
Griffithides sp.																									×	×						×	×	×	
Leperditia cf. L. carbonaria	×																																		
Paraparchites sp.																			×																
Ostracoda																																×			

5867. West bank of Yukon River 6 miles above mouth of Seventymile River (Calico Bluff). Collector, A. J. Collier.

2AC56. South bank of Yukon River 2 miles above mouth of Seventymile River. Pebble in conglomerate. Collector, A. J. Collier.

2645. North bank of Yukon River about 5 miles above Seventymile River. Collector, Arthur Hollick.

2646. West bank of Yukon River just above mouth of Sheep Creek (Tatonduk River). Collector, Arthur Hollick.

2647. Calico Bluff, Yukon River. Collector, Arthur Hollick.

2644, 2644A, and 2644B. Calico Bluff, Yukon River. Collector, A. H. Brooks.

2651 and 2651A. North bank of Yukon River above island near Star. (Star is an abandoned settlement at the mouth of Seventymile River.) Collector, A. H. Brooks.

848. Calico Bluff, Yukon River. Collector, E. M. Kindle.

845. North bank of Yukon River 1 mile above Seventymile River. Collector, E. M. Kindle.

1796, 1796A, and 1796B. North end of Calico Bluff, Yukon River. Collector, Eliot Blackwelder.

1797, 1797A, 1797B, 1797C, 1797D, 1797E, and 1797F. North bank of Yukon River at big bend north of Calico Bluff. Collector, Eliot Blackwelder.

1798 and 1798A. Calico Bluff formation, southwest of mouth of Sheep Creek, (Tatonduk River). Collector, Eliot Blackwelder.

5279. North bank of Yukon River nearly opposite Seventymile River. Collector, G. H. Girty.

5302. South end of Calico Bluff, Yukon River. Collector, G. H. Girty.

5302A. Base of Calico Bluff, Yukon River. Float specimens. Collector, G. H. Girty.

5303. North end of Calico Bluff, Yukon River. Collector, G. H. Girty.

5304. West bank of Yukon River opposite mouth of Sheep Creek (Tatonduk River). Collector, G. H. Girty.

5843 and 5843A. Calico Bluff, Yukon River. Just below base of zone B. Collector, J. B. Mertie, jr.

5843B. Calico Bluff, Yukon River. Zone C. Collector, J. B. Mertie, jr.

5843C. Calico Bluff, Yukon River. From 4-foot bed of limestone that lies 41 feet stratigraphically above top of zone C. Collector, J. B. Mertie, jr.

5843D. Calico Bluff, Yukon River. In the 215-foot zone (see section, p. 97) about 450 feet vertically above river. Collector, J. B. Mertie, jr.

5843E. Calico Bluff, Yukon River. Float specimens. Collector, J. B. Mertie, jr.

It will be seen from the faunal list above given that 117 genera have been identified, and it is likely that 250 or more species are represented. Girty's work on these collections has been of a general nature, with the purpose of determining the age of the several collections sent to him, rather than an intensive study involving complete specific identifications and the description of new species. Many new species are present in these collections, and a thorough and detailed paleontologic study of this material would probably reveal some interesting biologic data. This fauna is related more closely to the marine Asiatic faunas described by Tschernyschew than to the Mississippian faunas of the Rocky Mountain region, and this fact, together with the presence of many new species, has deterred Girty from correlating it very closely with the sections of the States. Girty believes the Calico Bluff formation to be of upper Mississippian age, though not necessarily correlative with the latest Mississippian rocks. Roughly the Calico Bluff formation can be correlated with the Chester group of the United States.

Mississippian rocks, like those of the Middle Devonian series, are widespread in Alaska. One of the most persistent zones of such rocks is found along the north slope of the Brooks Range, in Arctic Alaska, where an upper Mississippian group of rocks, known as the Lisburne limestone, extends from Cape Lisburne on the Arctic Ocean eastward almost if not quite continuously for a distance of 600 miles to the international boundary. This formation is composed of limestone and chert, and although lithologically it differs from the Calico Bluff formation, paleontologically it is very closely correlative. Stratigraphically below the Lisburne limestone in northern Alaska lies the Noatak formation, which is also known to be of Mississippian age, though not necessarily upper Mississippian. The Noatak formation is related more closely in age to the chert formation of the Yukon and to the Circle volcanics and Rampart group than to the Calico Bluff formation.

North of the Yukon, along the international boundary, Cairnes[63] collected a fauna similar to that of the Calico Bluff formation but did not differentiate the containing rocks as a separate formation. This fauna is presented in this paper in the discussion of the undifferentiated Paleozoic rocks. By plotting the localities of Cairnes's fossils, however, it appears that many of the upper Mississippian localities fall in his "shale-chert" group, of Ordovician to Carboniferous age, here mapped as undifferentiated Paleozoic, which lies just east of the boundary, between the Tatonduk River and Hard Luck Creek, and especially near to Hard Luck Creek. Hence it seems certain that the Calico Bluff formation reappears along the boundary some 15 miles northeast of its type locality at Calico Bluff.

Mississippian rocks are also known at the head of the White River and in the York district of Seward Peninsula. South of the Alaska Range another great series of basic volcanic rocks of greenstone habit, known as the Strelna formation, of Mississippian age, has an extensive development in the valley of the Chitina River. This formation, however, contains a larger proportion of interbedded sediments than the Rampart group. The Strelna formation is believed by the writer to continue southeastward into southeastern Alaska, and certain of the volcanic rocks of Lynn Canal are believed to represent this horizon. Farther southeast, in southeastern Alaska, a large representation of

[63] Cairnes, D. D., The Yukon-Alaska international boundary between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, pp. 93–103, 1914.

Mississippian rocks is known on Chichagof, Kuiu, and Prince of Wales Islands.

MISSISSIPPIAN OR PENNSYLVANIAN SERIES

TRANSITIONAL FORMATION

DISTRIBUTION

The rocks of a transitional formation of Mississippian or Pennsylvanian age are exposed on the north and south sides of the Seventymile River southwest of Calico Bluff, in a narrow zone north of the mouth of the Tatonduk River, and along the northeast side of the Yukon River northwest of Nation. Rocks at other localities along the boundary, which have been mapped in this report as undifferentiated, may later be shown to belong to this horizon.

LITHOLOGY

The rocks of this transitional formation consist essentially of sandy shale, argillite, slate, and some chert. On exposed hilltops and slopes, especially where old burns have bared the surface to view, these rocks are considerably weathered, so that the bedding and joint planes, particularly in the argillaceous varieties, are commonly covered with a very thin red film that is limonitic or perhaps in part hematitic, and the effect of this weathered fragmental débris is to give to the hillsides occupied by such rocks a bright-red appearance when viewed from a distance upon a sunny day. These brightly colored hillsides have been noted by many geologists going down the Yukon but apparently were not examined by anyone until the season of 1925. The vivid coloring has been noticed particularly in the hills northwest of Eagle and northwest of Nation. At the base of these hills near Nation, in a swamp, in the alluvium of the river valley, there is a deposit of bright-red clay, evidently derived from the red rocks farther up the slope. It is said that the Indians used to visit this locality to obtain red pigment for tattooing and other tribal uses.

The red-weathering beds northwest of Eagle, along the south side of the Seventymile River, consist of thin-bedded black carbonaceous shale, weathering to shades of gray and brown, calcareous shale, siliceous slate, siliceous limestone, chert, and some beds of conglomerate. The pebbles of the conglomerate are mainly chert. Some of these beds weather to a light reddish brown, which under the sun's rays appears bright red at a distance. Along the west bank of the Yukon about 1½ miles below Eagle this same formation, as seen in landslides, consists of beds of shale and chert. The same red-weathering, hematite-covered siliceous slate and chert were identified on the north side of the Seventymile River, in contact with the Calico Bluff formation.

The red-weathering beds northwest of Nation consist of cherty grit, quartzitic sandstone, and sandy shale and are in contact with the Nation River formation. The exposures along this zone are not good, as the area is mostly timber covered, but evidently the transitional formation exists here, although the area mapped as such may in fact include part of the Nation River formation.

At the locality north of the mouth of the Tatonduk River the rocks, as seen from a distance, are cream-colored rather than reddish. They appear to be at or near the base of the formation. This conclusion is drawn from the fact that the formation here contains both upper Mississippian marine fossils and obscure plant remains, a combination suggesting its transitional nature, and that it lies next or very close to the upper Mississippian rocks that are exposed a little farther east. These rocks are in part calcareous. No really good exposures of this formation were seen here, the outcrops being mostly weathered rubble on the hill slopes, and therefore nothing whatever is known regarding its structure or thickness at this locality.

STRUCTURE AND THICKNESS

There is no one locality at which the formation is completely developed from its base, as at present recognized, at the top of the Calico Bluff formation, to its top, just below the Nation River formation. Moreover, being a relatively nonresistant group of rocks, like the Upper Triassic series, it crops out on low, inconspicuous ridges, many of which are timber covered, and the exposures are both poor and discontinuous. Hence it is particularly difficult to formulate any ideas of the general structure or to evaluate the structural data in order to arrive at any estimate of thickness.

Along the north side of the Seventymile River near its mouth the rocks of this formation strike N. 40° W. and dip 70° NE., thus apparently plunging under the strip of Calico Bluff formation that adjoins them to the northeast. The rocks of both formations at this locality, however, constitute part of a faulted sequence, and the contact between the two formations is interpreted as a fault contact, probably one in the series of fault contacts that are exposed to the northeast, on the opposite side of the Yukon.

South of the Seventymile River this formation adjoins the Nation River formation. The beds are greatly disturbed and therefore very irregular in strike and dip but seem on the average to strike about northeast. The dips are high, ranging from 40° to 75°, both to the southwest and to the northeast, thus yielding little information regarding the structural relation of this formation to the adjoining Nation River beds.

It is believed that the rocks of this formation overlie the Calico Bluff formation and underlie the Nation River formation, but no data are available for stating definitely the structural relationships to either the underlying or the overlying rocks. The basal beds of the Nation River formation, however, as seen at the head of the North Fork of Shade Creek differ lithologically from the formation here described, and it is therefore inferred that these beds are more likely to grade downward into the Calico Bluff formation than they are to grade upward into the Nation River formation. If in fact these rocks are thus related stratigraphically to the Calico Bluff formation, it is likely that the Nation River formation may overlie them unconformably.

No reliable estimate can at present be made of the thickness of this formation, for neither its base nor its top is accurately known. It is believed, however, that its thickness is probably materially less than that of the Nation River formation, which is believed to be from 4,000 to 6,000 feet. Perhaps, from what is now known of this formation, 1,000 feet or at most 2,000 feet may be taken as a working estimate.

AGE AND CORRELATION

The stratigraphic evidence for the placement of this formation within the Carboniferous sequence has been sketched in the discussion of the lithology and structure. These rocks are evidently related to the Nation River formation, for at the two best-known localities—northwest of Eagle and northwest of Nation—they appear to adjoin areally the Nation River formation. It might, in fact, have been better to include them as a part of that formation, but their distinctive lithology and appearance have led the writer to treat them as a separate unit. This will at least focus attention upon them when this area is worked in greater detail at some subsequent time. G. C. Martin, in 1914, made a collection (Martin 81) of some obscure plant remains from a locality given as "east bank of Yukon River 2 miles below Tatonduk River," which may be the same as the locality noted by the writer north of the mouth of the Tatonduk. These plant remains have not been identified. At this locality the writer noted some imperfect marine fossils, which were not collected. The inference is that both marine and terrigenous conditions are represented at this locality.

The rocks at this locality, because they appear to adjoin the Calico Bluff formation, are interpreted as the basal part of the transitional formation, but the evidence for this is not complete and unequivocal. The importance of this locality, if the writer's stratigraphic assignment is correct, is that it may show a gradual stratigraphic transition downward into the marine Calico Bluff formation, of upper Mississippian age. Brooks,[64] in an earlier paper, without reference to any particular group of rocks, felt that an intermediate formation might well exist between the Calico Bluff and Nation River formations. He states:

> It is not improbable that detailed mapping may reveal a considerable thickness of strata lying between the Calico Bluff and Nation River [formations] as here described. Whether such strata, if found, should be included in one or the other of these formations or be mapped as a distinct stratigraphic unit must be left to the future to be determined.

It is conceived by the writer that this so-called transitional formation does, in fact, represent such an intermediate stratigraphic horizon; and the evidence at hand indicates that this transitional formation is more closely related lithologically and stratigraphically to the Calico Bluff than to the Nation River formation. Brooks also believed that an unconformity existed at the base of the Nation River formation, and no data have so far been acquired that controvert that conclusion. If such an unconformity does in fact exist, the evidence is even stronger for relating this transitional formation with the Calico Bluff formation. Nevertheless, all available evidence of the age of these beds is still inconclusive, and it has therefore seemed best on the geologic map to designate them simply Mississippian or Pennsylvanian.

Another possible assignment of at least a part of this transitional formation should not be overlooked. From the lithologic descriptions it will be noticed that some of these rocks, particularly those south of the Seventymile River, resemble very much the Middle Devonian sequence at the head of the North Fork of Shade Creek. It is thus possible, in the absence of fossil evidence, to correlate these rocks with the Middle Devonian argillite-chert sequence, and this possibility will need to be considered in future work in this area.

No similar rocks occurring in this portion of the stratigraphic column are known elsewhere in interior or northern Alaska, so that no stratigraphic correlations can be made at present. The most striking lithologic similarity is apparent in reading Cairnes's description [65] of his "shale-chert group," which he mapped as Carboniferous to Ordovician, and which in this report is assigned to the undifferentiated Paleozoic. Cairnes states in part:

> Hard gray quartzitic shales are in addition somewhat extensively developed in places. These quartzitic beds contain locally sufficient iron to produce upon

[64] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, p. 292, 1908.

[65] Cairnes, D. D., The Yukon-Alaska international boundary between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, p. 82, 1914.

oxidation a bright-red to yellow coloration on weathered surfaces, but only rarely are these rocks red on a fresh surface. These reddish beds decompose readily to form a red or yellowish sand or mud, which is a very noticeable feature of many of the hillsides on which vegetation is lacking.

This description fits very well the description of this transitional formation primarily given by the writer and suggests strongly that the rocks of this formation are also represented along the boundary north of the Yukon.

NATION RIVER FORMATION

DISTRIBUTION

The Nation River formation is exposed at two general localities along the Yukon. It crops out along both sides of the Yukon a short distance below Eagle and extends eastward up the valley of Shade Creek for an unknown distance, forming the bedrock at McCann Hill, a prominent dome-shaped hill along the international boundary. The other area consists really of two belts of the Nation River formation, separated by a zone of Permian limestone, which extend from the Yukon northeastward up the valley of the Nation River to and beyond the international boundary, although the distribution of this formation between the Yukon and the boundary is not exactly known. The belt south of the Nation River is believed to extend southwestward as far as the valley of Michigan Creek, but its limit has not been ascertained. A small anticlinal flexure brings the upper part of the formation to the surface in the middle of the Permian limestone just above the Nation River.

LITHOLOGY

The rocks of this formation consist of gray clay shale, sandstone, and conglomerate and resemble very much the Upper Cretaceous and Eocene rocks, from which, indeed, they are at some localities hard to distinguish. Where this formation crops out about 3 miles below Eagle it consists essentially of a drab sandy clay shale and sandstone, the sandstone in beds from a few inches to 10 or 20 feet thick. This sandstone consists of grains of chert, decomposed feldspar, and more or less quartz and carbonaceous material. It weathers to a dark-brown color. The beds are commonly ripple marked but only slightly cross-bedded and show numerous mud lumps and concretions, especially along the bedding planes. Conglomerate beds with a thickness as great as 10 feet are intercalated with the shale and sandstone. This conglomerate is dark colored. It is composed of chert pebbles, mainly light gray and dark gray but with some green, set in a sandy matrix. Below Boulder Creek the beds are coarser grained and consist dominantly of sandstone in beds from 3 inches to 6 feet thick, with some thin partings of sandy shale and numerous beds of a conglomerate that contains pebbles as much as half an inch in diameter. Above Boulder Creek much comminuted plant débris occurs in these rocks, and below Boulder Creek large carbonized stems, some of which are 2 inches in diameter and 2 feet long, were seen in the sandstone, but no plant remains of diagnostic value in determining the age of the rocks were seen. Plate 10, *B*, shows a typical exposure of the conglomerate and sandstone of the Nation River formation.

To the east of the Boulder Creek area, particularly on McCann Hill, Cairnes[66] observed a massive conglomerate 60 feet thick, which he believed to represent the base of the Nation River formation. Overlying this conglomerate he reported 230 feet of brownish to nearly black grit, overlain in turn by another bed of conglomerate 25 to 30 feet thick, above which came sandstone, shale, and intercalated beds of conglomerate, whose combined thickness here was not known. The mere presence of the conglomerate beds does not necessarily imply that this sequence represents the base of the formation, for beds of conglomerate are clearly intraformational throughout the sequence. But the structure of the Nation River formation in the McCann Hill area is relatively simple, and the writer is inclined to believe that the sequence given by Cairnes does in reality represent the base of the formation.

Much the same assemblage of rocks, including shale, sandstone, and conglomerate, is exposed along the west bank of the Yukon from Trout Creek downstream to the Permian limestone. At and below the Nation River, on the northeast bank of the Yukon, is the type locality of the Nation River formation. The rocks exposed in the bluff just below the mouth of the Nation River are essentially gray clay shale, interbedded with one thick bed and several thinner beds of massive conglomerate. The thick bed of conglomerate, which apparently forms the top of the hill, consists of gray, red, and green chert pebbles and a few pebbles of quartzite, some of which are as much as 4 inches in diameter, in a matrix that is composed of fine fragments of cherty and sandy material with a white, possibly calcareous cement. These conglomerates appear to be intraformational.

A feature of special interest is the occurrence of a bed of bituminous coal in this formation on the southeast side of the Nation River, about three-quarters of a mile from its mouth. With regard to this coal Collier,[67] in 1902, wrote as follows:

[66] Cairnes, D. D., op. cit., p. 89.

[67] Collier, A. J., The coal resources of the Yukon, Alaska: U. S. Geol. Survey Bull. 218, pp. 35–36, 1903.

Only one bed of coal has been found at Nation River. The mine workings are abandoned and, having caved in, could not be examined. The face of the bluff on which they are located is subject to local slides by which the outcrops of coal are covered. A recent prospect hole near the top of the bluff showed about 2 feet of crushed coal and shale standing nearly vertical.

W. E. Williams, who was superintendent of the mine, informed the writer that the coal here was never well defined. The coal was found in pockets and kidneys often as large as 8 feet thick and 13 feet long. When the mine was abandoned a large body of this kind that had been located was left unmined. Large pieces of this coal were found in the creek bed before the coal body was located.

The coal mined at Nation River is distinct in character from any other coal mined on the Yukon. It is a bituminous coal containing a low percentage of water and showing no traces of woody structure. If these coals prove to be of Kenai [Eocene] age, the differences in their composition may be accounted for by the greater degree of metamorphism which they have suffered. An analysis was made of a sample taken from a large pile, probably 100 tons, mined in 1898. It had been exposed to the weather on the river bank since that time, but apparently was not greatly altered. It had the following composition:

Analysis of coal (sample 68) from Nation River mine

[Analyst, E. T. Allen, U. S. Geological Survey]

	Per cent
Water	1.39
Volatile combustible matter	40.02
Fixed carbon	55.55
Ash	3.04
	100.00
Sulphur	2.98
Fuel ratio	1.39

This coal makes a good coke in the laboratory. A large part of the coal was dry and unfrozen and of good quality, while a smaller part was frozen and almost worthless as fuel. The distribution of the frost was probably due to the circulation of water through the bodies of coal.

In 1897 the Alaska Commercial Co. attempted to open a coal mine at this place, and about 2,000 tons of coal were mined and sledded to the Yukon, to be burned on river steamers or transported to the Dawson market. Owing to the irregularity of the coal deposit and the consequent uncertainty of the supply and to the expense of mining it was abandoned several years ago. During the summer of 1902 one man was prospecting and attempting to relocate the coal bed. This coal is of better quality than that of any other mine of the region, except for the large percentage of sulphur, but the disturbed condition of the seam makes it doubtful whether it can be worked at a profit.

The coal-bearing bed at the Nation River is now completely concealed, but if no fault is present it appears to be overlain by a body of gray clay slate with thin interbedded sandstones, which in turn is overlain by massive beds of conglomerate similar to that seen on top of the hill northwest of the mouth of the Nation River. Still farther up the hill slope to the east are exposed other beds of shale and sandstone.

On the opposite (southwest) side of the Yukon an anticlinal flexure within the Permian limestone brings to the surface the uppermost part of the Nation River formation, which here consists dominantly of a drab shale with some thin beds of quartzose sandstone. At this locality the evidence favors strongly the idea of a continuous gradation from the Nation River formation upward into the overlying Permian limestone.

STRUCTURE AND THICKNESS

Between Eagle and Calico Bluff the rocks of the Nation River formation are folded, in places rather closely. In the exposures below Boulder Creek one recumbent fold was noted. In general, according to Blackwelder,[88] the axes of the minor folds pitch gently N. 75° W., and this structure corresponds roughly, though not exactly, to the structure at Calico Bluff, where a well-defined synclinal basin pitches gently N. 30° W. Although the structure at Calico Bluff is unusually simple, so far as that general area is concerned, it would not be justifiable to extrapolate that synclinal structure for any great distance in any direction from Calico Bluff. The fault zone at and above Eagle, which might well be called the Eagle overthrust, lies only a few miles south of the Boulder Creek locality, and there is every reason to believe that other parallel faults are present trending in this same general direction. Unfortunately there is an alluvium-filled basin between the Boulder Creek locality and Calico Bluff as well as west of Calico Bluff, and in this zone important structural evidence is doubtless buried. On the east side of the Yukon, however, at low water the Nation River formation may be seen along the banks lying unconformably upon older rocks of undetermined age.

At the mouth of the Seventymile River and again on the west bank of the Yukon opposite the mouth of the Tatonduk River there is good evidence of faults trending in the same general direction—that is, N. 75° W. Both the regional structure and the distribution of formations northwest, west, and southwest of Calico Bluff therefore indicate the presence of a fault or perhaps a zone of faulting west of Calico Bluff which trends N. 75° W., and under this interpretation the Nation River rocks in the Boulder Creek area would be bounded on the northeast by such a fault zone.

The Nation River rocks in the valley of Shade Creek, including the McCann Hill area, seem to have a structure that is somewhat simpler and more nearly comparable with the type of folding at Calico Bluff. They may constitute a block of relatively slightly deformed rocks that extends from Calico Bluff southeastward up

[88] Blackwelder, Eliot, unpublished notes.

Shade Creek and is bounded by a fault zone on the southwest. On the northeast side of this area the rocks of the Nation River formation lie without apparent structural discordance upon Middle Devonian argillite and chert. This observation makes it necessary to postulate a discontinuity in sedimentation, if not an unconformity, at the base of the Nation River formation. If a structural unconformity does in fact exist, however, the evidence here indicates no great discordance in dip between the Nation River formation and the underlying beds.

The rocks of the Nation River formation south and east of the Nation River are also folded, but the larger structural relations are more evident. The distribution of the Permian limestone and the Nation River beds there suggests strongly the presence of a large anticline plunging southwest by west. The repeated minor folding of the Permian limestone at the Nation River, however, shows clearly that this is not a simple arch but an assemblage of minor folds welded into the larger anticline. Further evidence of this structure is present along the southwest bank of the Yukon between Montauk Cabins and the Permian limestone at the Nation River; for the rocks of the Nation River formation, which dip dominantly southeastward just below Montauk Cabins, are reversed farther downstream, as the formation plunges below the Permian limestone. (See fig. 6.)

At the Nation River locality the most striking structural feature of the Nation River formation and also of the Permian rocks is their regional strike or trend, which is about northeast and therefore nearly at right angles to the trend of the other Paleozoic formations farther up the Yukon. Such a structural trend might suggest that the Nation River and Permian sequence may not have been affected by the dynamic movements to which some of the older rocks were subjected, and this in turn suggests that the Nation River and Permian rocks may rest unconformably upon the Mississippian and older rocks. Brooks[69] was firmly of the opinion that such an unconformity existed. But 20 years ago the presence of the Nation

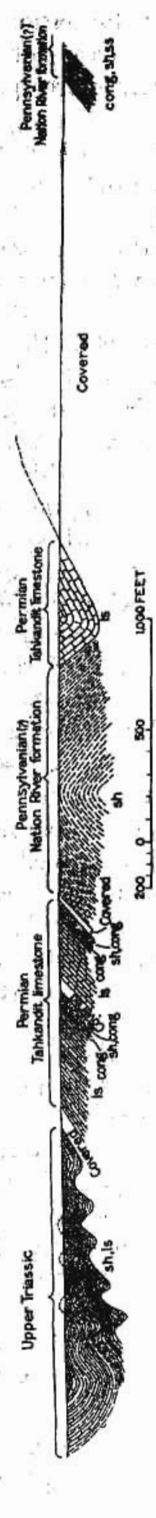


FIGURE 6.—Section along southwest bank of Yukon River opposite mouth of Nation River, showing structural relations of Upper Triassic rocks, Tahkandit limestone (Permian), and Nation River formation (Pennsylvanian?). sh, Shale; ls, limestone; cong, conglomerate; ss, sandstone.

[69] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, p. 294, 1908.

River formation and the underlying transitional formation in the Eagle area had not been recognized. As these two formations in the Eagle area partake of the structure possessed by the neighboring Paleozoic rocks, the variance in regional structure in the Nation River area loses the significance that it was formerly given. Insufficient work has yet been done to explain this variant structure, but at least it certainly does not necessarily indicate the presence of a structural unconformity at the top of the Calico Bluff formation.

The Nation River rocks are again exposed on the northwest side of the Nation River and continue up that stream in a northeasterly direction to the international boundary, but the field evidence indicates that this belt of Nation River beds is separated from the Permian and Upper Triassic beds to the southeast by a great fault, or perhaps a zone of faulting. Nothing whatever is known of the attitude of this fault plane or fault zone, but the assumption of its existence is indispensable to explain the occurrence of Nation River beds on both sides of the northwestward-dipping Permian limestone. Nor is the extent of the throw known, but the northwest is apparently the upthrown side, for Nation River beds now occur at the surface where Upper Triassic or younger beds should normally be exposed.

In general, therefore, from data at present available, it may be said that the Nation River formation at its top appears to grade upward without any marked stratigraphic break into the Permian rocks. At its base a discontinuity of sedimentation has been definitely recognized, and a structural unconformity may exist, but no marked discordance in dip between the Nation River formation and underlying beds has been recognized. If the Nation River beds represent the beginning of terrestrial sedimentation following the elevation of this area above sea level in post-Mississippian time, there would probably be a gradual transition from marine to terrestrial sedimentation, with or without a structural unconformity, depending on whether or not the underlying Mississippian rocks were deformed during the regional elevation. As a matter of fact, discontinuities in sedimentation have been recognized in the Carboniferous-Triassic sequence at many places in Alaska, but so far as the writer is aware no structural unconformity in this sequence has yet been recognized elsewhere in Alaska. This generalization indicates that the regional elevation in Alaska, which began in Carboniferous time and culminated in the Triassic, was accompanied by a minimum of rock deformation, and it constitutes evidence that must be given some weight in the consideration of this problem. Such evidence, so far as it goes, is opposed to the idea that the Nation River formation rests unconformably upon Mississippian rocks.

As no complete section of the Nation River beds has yet been found, the thickness of this formation is somewhat in doubt. In the Boulder Creek area the structure is complex, and the Nation River beds are bounded at least on one side by a fault zone. On the northwest side of the Nation River the structure is somewhat simpler, but the exposures are intermittent, and here also a fault zone lies at one edge of the formation. From Montauk Cabins down to the Nation River the sequence is perhaps the least disturbed, but everywhere the major structure is modified by minor folds; moreover, the base of the formation is not definitely exposed. Under these conditions no exact estimate of the thickness can be given. The areal distribution of the formation, however, interpreted in the light of its general structure, suggests a great thickness of rocks. Brooks [70] estimated the thickness of the Nation River formation at 3,700 feet. Cairnes [71] estimated its thickness, as seen along the international boundary, at 4,000 feet, but he evidently included with the Nation River formation some limestone beds of Permian age. Blackwelder [72] suggested the possibility that about 5,000 or 6,000 feet of strata are represented by this formation, but he was properly cautious with regard to the reliability of such figures. The writer has no data sufficient to favor any one of these estimates as against the others. All three are of the correct order of magnitude—that is, from about 4,000 to 6,000 feet. Brooks apparently did not recognize the presence of a fault zone up the Nation River, and his estimate might accordingly be rated as a little low. On the whole, Blackwelder's estimate of 5,000 to 6,000 feet is probably as nearly correct as can be given from the data so far collected.

AGE AND CORRELATION

The Nation River formation, so far as it has been studied along the Yukon by the writer and by American geologists who preceded him, appears to be nonmarine in origin. Many fragmentary plant remains are present in these rocks, though unfortunately no material of specially diagnostic character has so far been collected. On the other hand, no marine fossils have been found. This condition, considered in connection with the ripple marks, cross-bedding, and muddy concretionary forms, suggests that these rocks are of fluviatile origin. At the Nation River locality, however, they grade upward into marine deposits, and the conclusion is therefore reached that the place of their formation may have been at so short a distance from marine waters that a relatively slight shifting of the strand line

[70] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, p. 294, 1908.

[71] Cairnes, D. D., The Yukon-Alaska international boundary between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, p. 90, 1914.

[72] Blackwelder, Eliot, unpublished notes.

sufficed in early Permian time to change the conditions of deposition from nonmarine to marine.

Several collections of these fragmentary plant remains have been made by geologists, a brief summary of which is here given:

2970. Yukon River, east bank 2 miles below Tatonduk River. Collector, A. J. Collier. *Lepidodendron?* sp.

3AH7. Yukon River, west bank 3 miles above Nation River. Collector, Arthur Hollick. *Spirophyton* sp.

1655. Yukon River, northwest bank 5 miles north of Eagle. Collector, E. M. Kindle. Lepidophyte group.

Martin 81. Yukon River, east bank 2 miles below Tatonduk River. Collector, G. C. Martin. Specimens not identified.

Martin 89. Southeast bank of Nation River half a mile above mouth, at coal mine. Collector, G. C. Martin. Specimens not identified.

1501/19. Yukon River, 4 to 5 miles below Eagle. Collector, Eliot Blackwelder. Protolepidodendroid group. A variety of decorticated stems.

1507/L. Yukon River, north bank about 2 miles above Calico Bluff. Collector, Eliot Blackwelder. Indeterminate vegetal material.

1507/K. Yukon River, west bank 5½ miles above Nation River. Collector, Eliot Blackwelder. Indeterminate vegetal material.

1507/63. Yukon River, north bank 1½ miles below Nation River. Collector, Eliot Blackwelder. Bothrodendroid? group.

25AM127. Yukon River, northeast bank about 7½ miles N. 33° E. of Eagle. Collector, J. B. Mertie, jr. Specimens not identified.

David White, of the United States Geological Survey, who made the identifications noted above, is inclined, on the whole, to assign these plant remains to the lower Carboniferous, or Mississippian, but the material is so poor that little confidence can be placed in any age assignment that depends alone on the character of this flora. The stratigraphic relations therefore become of much more importance. It is fairly sure that the Nation River formation overlies the Calico Bluff formation and underlies the Permian limestone. The formation appears to grade upward into the Permian limestone on the west side of the Yukon just above the Nation River, but its relation to underlying formations is as yet obscure. Therefore the formation is apparently related more closely to the overlying Permian limestone than to the underlying upper Mississippian rocks. This Permian limestone, however, is so low in the Permian sequence that its contained fossils were originally identified by G. H. Girty as Artinskian and correlated with the Pennsylvanian rather than the Permian. The Nation River formation, therefore, may be in its upper part of earliest Permian age, but a better assignment for this thick sequence of rocks as a whole is believed to be Pennsylvanian. It is therefore here classified as Pennsylvanian (?).

No formation similar in character to the Nation River formation and of the same age is known anywhere else in Alaska. Collier[73]

[73] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, pp. 18–19, 1906.

has described a coal-bearing fresh-water formation which is said to lie at the base of the Mississippian sequence of rocks at Cape Lisburne, on the Arctic coast, about 700 miles northwest of the type locality of the Nation River formation, but these two formations do not seem to be specially comparable, either in lithology or in age. It is probable that the Nation River beds represent a phase of sedimentation related to some great drainage system similar to but not necessarily coextensive with the present Yukon Basin, and as such they would probably not have any exact counterpart elsewhere in Alaska.

PERMIAN SERIES

TAHKANDIT LIMESTONE

DISTRIBUTION

The Permian rocks herein designated Tahkandit limestone are restricted to four general localities. The type locality is along the Yukon just above the mouth of the Nation River (the old Indian name for which is Tahkandit), where a belt of such rocks crosses the Yukon, trending northeast. (See pl. 10, *A*.) Another belt crosses the valley of Trout Creek, a stream that enters the Yukon from the southwest about 8 miles above the mouth of the Nation River. A block of Permian limestone infaulted in the Middle Devonian volcanic rocks is exposed on the south bank of the Yukon a short distance below the mouth of Coal Creek. (See pl. 11, *A*.) Permian rocks are found also along the international boundary near Ettrain Creek and 25 or 30 miles northeast of the mouth of the Nation River. The rocks near Ettrain Creek were mapped by Cairnes as undifferentiated Carboniferous, but a reexamination of Cairnes's Carboniferous fossil collections has shown the presence of several collections of Permian age, the localities of which, when plotted on the map, fall in or near these areas of undifferentiated Carboniferous. Moreover, the rocks there are limestone similar to the Permian limestone. The writer has therefore inferred the presence of Permian rocks on Ettrain Creek and has so shown these areas on the accompanying map. It is probable that the Permian limestone continues intermittently up the southeast side of the Nation River and connects with the Permian limestone at Ettrain Creek.

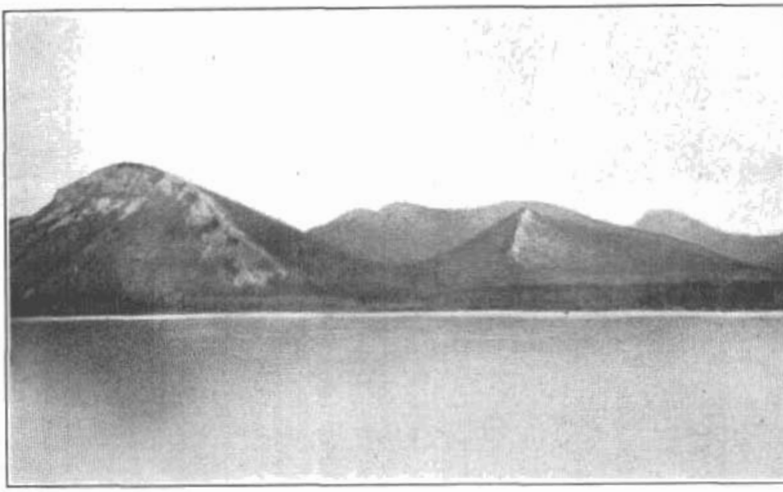
No formational name has previously been assigned to this Permian formation, but its lithology and fauna are so distinctive that a formational name is certainly warranted, notwithstanding the fact that the upper limit of the Permian sequence is not definitely known. This difficulty may be lessened by using the term "limestone" instead of "formation," in applying a formational name. The most fitting place name would have been Nation River, but this has already been used for a formation of Pennsylvanian (?) age. The next best place name is Tahkandit, the old Indian name of the Nation River, and this Permian limestone is therefore designated the Tahkandit limestone.

LITHOLOGY

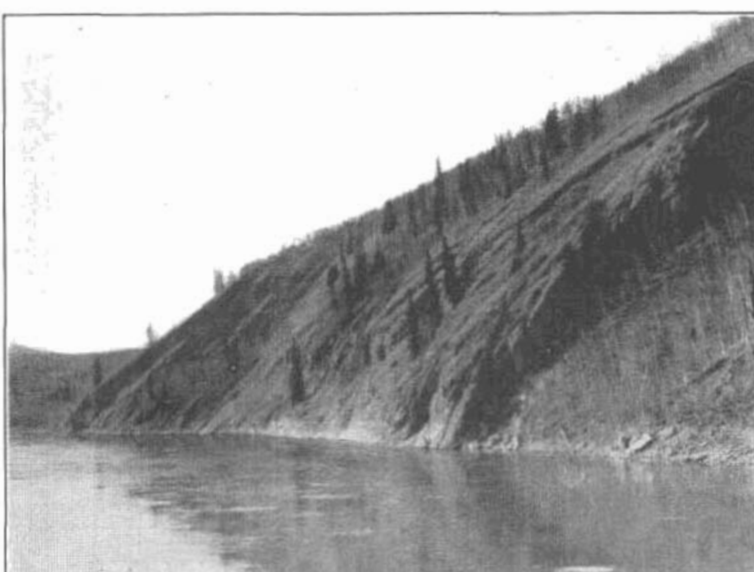
At the type locality along the Yukon River above the mouth of the Nation River the Tahkandit formation consists essentially of a cream-colored to white massive limestone, with some beds of conglomerate, sandstone, and shale in the lower half. The best section is seen along the southwest bank of the Yukon, where both the overlying and underlying rocks are exposed. (See fig. 6.) The section as measured by the writer along these bluffs, stated from the top downward, is as follows:

Section of Permian and Pennsylvanian (?) rocks on southwest bank of Yukon River above mouth of Nation River

	Feet
Tahkandit limestone:	
Massive cream-colored to light-gray limestone, containing numerous highly fossiliferous beds. Collection 5839	133
Massive limestone grading downward into fine conglomerate composed of gray and green chert pebbles. Collection 5839c	90
Conglomerate of gray and green chert pebbles. Highly fossiliferous	11
Thin beds of conglomerate alternating with green and brown shales. Lower half covered. Collection 5839b	76
Massive cream-colored limestone, grading downward into conglomerate. This part of the section shows a small vertical fault striking N. 55° W., along which rocks are downthrown 4 feet on southwest side	150
Fossiliferous conglomerate, which becomes coarser at base. Collection 5839a	20
Beds of conglomerate 1 to 2 feet thick, alternating with sandstone. The sandstone bed directly under the 20-foot bed of conglomerate shows on its top curious irregular imprints 4 to 12 inches long that resemble a ropy lava that was cooled while being agitated; these are believed to be of inorganic origin. This group of beds includes several fossiliferous zones; a 1-foot bed of green sandstone is particularly fossiliferous	47
Nation River formation (Pennsylvanian?):	
Drab shale with occasional thin beds of quartzose sandstone. Rocks are exposed for 1,000 feet along beach, but as they form an anticline, only about 300 feet of strata are present	300
Massive white limestone exposed in a syncline for 570 feet along beach	100

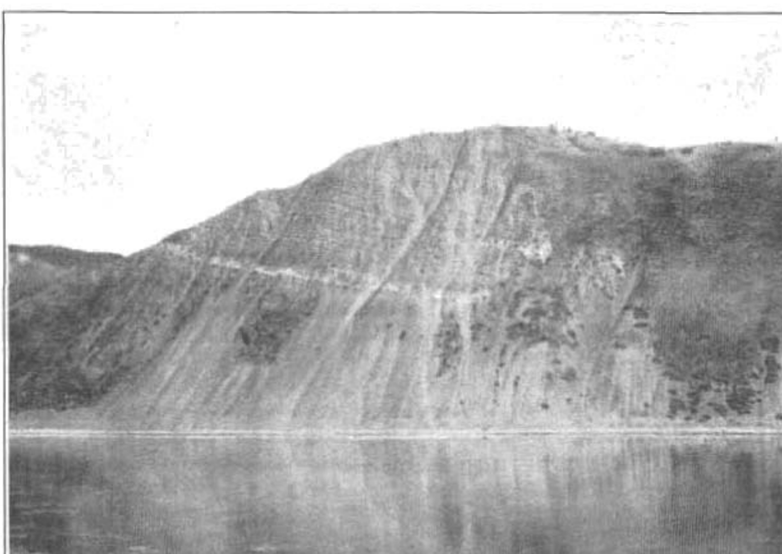


A. ANTICLINE AND SYNCLINE IN TAHKANDIT LIMESTONE (PERMIAN) ALONG THE NORTHEAST BANK OF THE YUKON RIVER JUST ABOVE THE MOUTH OF THE NATION RIVER



B. CONGLOMERATE AND SANDSTONE OF THE NATION RIVER FORMATION ON THE EAST BANK OF THE YUKON RIVER A FEW MILES BELOW EAGLE

A. INFAULTED BLOCK OF TAHKANDIT LIMESTONE (PERMIAN) IN MIDST OF WOODCHOPPER VOLCANICS (MIDDLE DEVONIAN) ON THE SOUTH BANK OF THE YUKON RIVER ABOUT 1 MILE BELOW THE MOUTH OF COAL CREEK



B. LOWER CRETACEOUS ROCKS (KANDIK FORMATION) IN BLUFF ON THE NORTH SIDE OF THE YUKON RIVER A FEW MILES ABOVE THE MOUTH OF THE KANDIK RIVER

Elsewhere in this area the lithology of the Permian is about the same as that seen at the Nation River locality. Along the Yukon below Coal Creek the Tahkandit limestone is bordered by basalt and tuff of greenstone habit, but these beds are believed to belong to the Middle Devonian sequence and to be faulted to their present position.

STRUCTURE AND THICKNESS

The Permian (Tahkandit) rocks at the Nation River locality, like the rocks of the Nation River formation, are distinguished by a northeasterly trend, which is about at right angles to the trend of the other formations along the Yukon. They also are probably involved with the Nation River beds in a great arch, whose northwestern limb crops out just above the Nation River and whose eastern limb is seen in Trout Creek. The axis of this arch appears to trend about southwest by west. The arch is not simple but is modified by minor folds, which are perfectly exemplified by the Tahkandit limestone at the Nation River. Plate 10, *A*, a view of the northeast bank of the Yukon just above the Nation River, shows an anticline and a syncline in the Tahkandit limestone. This syncline is believed to be continuous with the syncline shown in Figure 6. The high butte shown at the extreme right in Plate 10, *A*, is an isolated outcrop of the limestone, which may represent the trough of another syncline lying parallel to the one shown in the center of the picture but farther northeast. These folds are evidently of the open type and appear to be fairly symmetrical.

The Tahkandit rocks are believed to grade downward into the Nation River formation, as indicated in Figure 6. The upper part of the Tahkandit limestone, however, has not been recognized, for the formation at the Nation River is overlain without apparent angular discordance by Upper Triassic rocks, and it is not possible to tell at this locality how much if any of the Tahkandit was eroded before the Upper Triassic sediments were laid down. Hence, no estimate of the total thickness of Tahkandit limestone can be given, but it may be stated with some assurance that about 527 feet of strata are exposed from the base of the Upper Triassic down to the shale that is believed to represent the top of the Nation River formation. Of this thickness 373 feet is limestone.

AGE AND CORRELATION

The Tahkandit limestone, like the Mississippian rocks, is very fossiliferous, and numerous collections have been made by geologists, including the writer, since 1896, when Spurr made his trip down the Yukon. This fauna has been tabulated and is presented below. The determination of the fossils, except in a few of the earlier collections, has been made by G. H. Girty. As with the Mississippian fossils, however, Girty's work has been more a rapid reconnaissance of the fauna with the object of determining its age than a detailed study involving the identification and description of new species. Many of the species are new and are apparently more closely related to Asiatic than to North American Permian forms. Nevertheless, 54 genera and at least 123 species have been recognized. This fauna was originally believed to be of Pennsylvanian age but is now assigned by Girty to a horizon low in the Permian. The arrangement of the localities in the table is more or less chronologic.

Permian fossils collected from the Tahkandit limestone along the Yukon River and its tributaries between Eagle and Circle.

	2444, 2444a [a]	2A C45 [a]	2443 [a]	2445 [a]	Collier 1902 [a]	2441	Brooks 12	2446	2447	2448	437	428	Martin 83	Martin 88	1799	1799a	1799b	1800	1800a	1800b	1801	2437	2437a	2437b	2438	2439	2440	2440a	2442	2442a	2442b	2442c	2442d	2443 [b]	2449	5330	5339a	5339b	5339c	5340	5341	5343
Globigerina? sp			X																																							
Zaphrentis sp								X					X	X																												
Zaphrentis? sp						X																																				
Triplophyllum sp																																					X			X		
Triplophyllum? sp																													X													
Amplexus? cf. A. zaphrentiformis	X																																									
Amplexus sp																										X																
Lophophyllum sp																									X											X						
Lophophyllum? sp																																			X							
Batostomella sp																				X	X	X							X						X	X						
Stenopora sp								X												X																						
Stenopora? sp											X										X																					
Polypora sp										X																																
Phyllopora sp																					X																					
Phyllopora? sp																													X													
Rhombopora sp										X																																
Cystodictya sp						X																																				
Lingula sp						X																X	X														X					
Lingulidiscina cf. L. utahensis														X																												
Lingulidiscina sp																								X							X											
Orania sp																																			X							
Orania? sp																																				X						
Orthotetes sp		X																																								
Derbya sp																													X													
Derbya? sp						X						X																														
Streptorhynchus cf. S. pelargonatus								X	X	X																X			X						X	X				X		
Streptorhynchus? sp											X									X																			X			
Meekella? sp																									X																	
Chonetes cf. C. geinitzianus																													X						X					X		
Chonetes cf. C. laevis			X																																							
Chonetes cf. C. morahensis								X			X												X	X		X		X		X	X	X			X	X		X		X		
Chonetes sp						X																X			X																	X
Productus cf. P. cora			X											X		X									X	X									X		X					
Productus cf. P. cora var																																	X									
Productus cf. P. cora (of Tschernyschew)																											X		X								X		X			
Productus cf. P. gruenewaldti														X				X																								
Productus cf. P. koninckianus								X	X	X													X		X				X	X	X				X	X	X	X	X	X		X
Productus cf. P. koninckianus var																									X	X	X															

[a] The fossils of these collections were determined by Charles Schuchert. [b] Collection misplaced, but fossils known to be of Permian age.

Permian fossils collected from the Tahkandit limestone along the Yukon River and its tributaries between Eagle and Circle—Continued

	2444, 2444 [a]	24C55 [a]	2443 [a]	2445 [a]	Collier 1903 [a]	2441	Brooks 12	2446	2447	2448	427	428	Martin 82	Martin 83	1799	1799a	1799b	1800	1800a	1800b	1801	2437	2437a	2437b	2438	2439	2440	2440a	2442	2442a	2442b	2442c	2442d	2543	2549	5839	5839a	5839b	5839c	5840	5841	5842
Productus longispinus	X																																									
Productus longispinus?	X																																									
Productus cf. P. longus																									X	X	X		X				X		X		X		X			
Productus cf. P. longus?																																						X				
Productus cf. P. mammatus								X				X								X		X	X		X	X	X		X		X		X				X	X	X			
Productus multistriatus	X																																									
Productus cf. P. multistriatus		X	X	X		X																																				
Productus semireticulatus	X																																									
Productus semireticulatus var.		X	X																																							
Productus cf. P. semireticulatus			X	X		X																																				
Productus cf. P. transversalis										X																																
Productus cf. P. undatus	X		X																																							
Productus sp.						X		X							X			X	X						X				X													
Pustula cf. P. fasciata							X																																			
Pustula cf. P. horrida								X			X	X							X									X	X						X	X						
Pustula cf. P. humboldti			X																																							
Pustula cf. P. irginae								X															X		X	X	X		X	X	X		X		X	X	X		X	X		
Pustula punctata var.	X																																									
Pustula cf. P. purdoni						X																																				
Pustula cf. P. wallaciana											X	X																														
Pustula sp.																													X						X	X						
Avonia cf. A. porrecta													X													X			X							X						
Avonia cf. A. porrecta?								X		X																																
Avonia? cf. A. porrecta																																								X		
Marginifera cf. M. aagardi								X	X	X	X	X						X				X	X	X	X	X	X	X	X		X	X			X	X	X	X	X	X		X
Marginifera cf. M. splendens								X																																		
Marginifera? cf. M. splendens									X	X																																
Marginifera typica var. septentrionalis																																			X							
Marginifera typica var. septentrionalis?																										X			X				X			X						
Marginifera sp.			X																																							
Marginifera? sp.																			X																							
Aulosteges sp.									X																				X						X		X					
Camarophoria margaritovi										X																																
Camarophoria cf. C. margaritovi																										X	X								X				X			
Camarophoria cf. C. pinguis			X																																							
Camarophoria sp.						X																														X	X					
Pugnoides sp.																																				X			X			
Rhynchopora cf. R. nikitini			X			X		X			X	X			X	X	X			X		X	X	X		X	X	X	X	X	X				X	X	X		X	X		X
Dielasma cf. D. elongata											X																															
Dielasma? sp.															X																											

Spirifer cf. S. cameratus						X				X																																
Spirifer cf. S. fasciger																																			X					X		
Spirifer cf. S. marcoui						X		X				X								X									X													
Spirifer cf. S. scobinus	X																																									
Spirifer cf. S. striatus		X	X		X																																					
Spirifer sp																																			X							
Spiriferella arctica			X	X		X		X	X	X		X	X		X						X																					
Spiriferella arctica var.																										X																
Spiriferella arctica?																				X																						
Spiriferella cf. S. arctica						X																																				
Spiriferella? arctica																									X				X						X	X	X			X	X	
Spiriferella? arctica var.																																	X						X			
Spiriferella cf. S. artiensis										X																																
Spiriferella? sp																			X																							
Reticularia cf. R. lineata			X																																							
Squamularia cf. S. perplexa								X		X	X											X	X		X	X	X		X				X		X	X	X		X			
Squamularia sp																															X											
Squamularia? sp																												X														
Martinia sp															X										X																	
Martinia? sp																										X			X													
Spiriferina sp																										X			X													
Hustedia cf. H. meekana						X																																				
Cleiothyridina sp								X																					X						X		X					
Composita subtilita?																				X																						
Edmondia? sp																										X			X													
Solenomya? sp																													X													
Pseudomonotis sp			X																																							
Pseudomonotis? sp																													X													
Schizodus sp								X																					X													
Aviculipecten sp	X					X		X		X												X							X						X		X					
Streblopteria sp			X																				X								X											
Streblopteria? sp																														X					X					X		
Deltopecten cf. D. occidentalis																									X																	
Deltopecten sp																		X																								
Pleurotomaria sp																						X			X						X					X	X	X				
Pleurotomaria? sp																										X			X													
Straparollus? sp															X																											
Schizostoma sp																									X	X			X						X							
Euomphalus? sp						X												X																								
Omphalotrochus sp								X																																		
Bulimorpha sp						X																																				
Gastrioceras? sp																																					X					
Bairdia sp																											X															
Fish tooth										X																																

a The fossils of these collections were determined by Charles Schuchert.

2444 and 2444a. Yukon River above Circle. (The description is inadequate but almost surely represents the Nation River locality.) Collector, J. E. Spurr.

2AC55. Yukon River, north bank 3 miles above mouth of Seventymile River. Collector, A. J. Collier. (No Permian rocks are known at this locality; either the locality is wrongly recorded, or the faunal and age determinations are incorrect.)

2443. Yukon River, west bank 3 miles above Nation River. Collector, A. J. Collier.

2445. Limestone mountain 1½ miles northeast from mouth of Nation River. Collector, A. J. Collier.

Collier 1902. (Ambiguous wording in description of locality. Interpreted by the writer to mean float found along the Yukon at the mouth of Washington Creek.) Collector, A. J. Collier.

2441. Yukon River, west bank 3 miles above Nation River. Collector, Arthur Hollick.

Brooks 12. Yukon River, southwest bank 1 mile below Tatonduk River. Collector, A. H. Brooks. (No Permian rocks are known at this locality, and the writer is inclined to believe that this locality also is wrongly recorded.)

2446. Yukon River, south bank 6 miles above Nation. Collector, A. H. Brooks. (This collection probably comes from the Trout Creek locality.)

2447. Yukon River, north limb of anticline opposite station 14. Collector, A. H. Brooks. (This collection is undoubtedly from the north side of the limestone band at Nation River.)

2448. Yukon River three-quarters of a mile below Coal Creek. Collector, A. H. Brooks.

427. Michigan Creek, west side about 6 miles from mouth. Collector, J. B. Mertie, jr.

428. Michigan Creek, west side about 3 miles from mouth. Collector, J. B. Mertie, jr.

Martin 82. Yukon River, south bank 2 miles above Nation River. Collector, G. C. Martin.

Martin 83. Yukon River, south bank 1½ miles above Nation River. Collector, G. C. Martin.

1799, 1799a, and 1799b. Yukon River, southwest bank 8 miles above Nation River. Collector, Eliot Blackwelder.

1800, 1800a, and 1800b. Yukon River, west bank above Nation River. Collector, Eliot Blackwelder.

1801. Yukon River, south bank just below Coal Creek. Collector, Eliot Blackwelder.

2437, 2437a, and 2437b. Yukon River, west bank opposite mouth of Nation River. Lowest part of middle outcrop of Permian sandstone, with 15 feet of shales, but from several horizons. Collector, G. H. Girty.

2438. Yukon River, west bank opposite mouth of Nation River. Middle outcrop of Permian limestone, above lots 2437, 2437a, and 2437b, but in transition beds below main white limestone. Collector, G. H. Girty.

2439. Same general locality as 2438, but from a more shaly stratum just above 2438. Collector, G. H. Girty.

2440. Same general locality as 2438, but from base of a heavy limestone 10 feet above 2439. Collector, G. H. Girty.

2440a. Same general locality as 2438, but from the very top of the white limestone as exposed. Collector, G. H. Girty.

2442, 2442a, 2442b, 2442c, and 2442d. Yukon River, west bank opposite mouth of Nation River. Talus from several horizons. Collector, G. H. Girty.

2548. Yukon River, south bank three-quarters of a mile below mouth of Coal Creek. Collector, G. H. Girty.

2549. Yukon River, west bank opposite mouth of Nation River. Various horizons in lowest outcrop of Permian limestone. Collector, G. H. Girty.

5839, 5839a, 5839b, and 5839c. Yukon River, southwest bank about 2¾ miles upstream from Nation. The positions of these four localities in the Permian stratigraphic section were closely determined. Collector, J. B. Mertie, jr.

5840. Southeast side of valley of Nation River about 1 mile northeast of Yukon River. Collector, J. B. Mertie, jr.

5841. Yukon River, southwest bank about three-quarters of a mile downstream from mouth of Coal Creek. Collector, J. B. Mertie, jr.

5842. Southeast side of valley of Nation River about 5 miles northeast of Yukon River. Collector, J. B. Mertie, jr.

In addition to the fossils tabulated, at least three of the fossil collections made by Cairnes along the international boundary are also now recognized by Girty as Permian. These are given below. (For explanation of numbers, see p. 48.)

XVI k 15:
- Chonetes aff. C. variolatus.
- Productus cf. P. aagardi.
- Rhynchopora cf. R. nikitini.
- Spiriferina sp.
- Aviculipecten? sp.

XVII f 42:
- Polypora sp.
- Chonetes sp.
- Productus cf. P. aagardi.
- Productus n. sp.
- Rhynchopora cf. R. nikitini.

XVII n 34:
- Chonetes cf. C. ostiolatus.
- Productus cf. P. aagardi.
- Productus n. sp.
- Rhynchopora cf. R. nikitini.

This lower Permian horizon is correlated paleontologically by Girty with the Artinskian of Tschernyschew and is known at many localities in Alaska. In northern Alaska this horizon has been recognized by Maddren [74] along the international boundary in the valley of the Firth River, not far from the Arctic. Farther west in Arctic Alaska rocks of the same horizon in the Canning River region have been described by Leffingwell [75] under the name Sadlerochit sandstone. This formation, which consists there of 300 feet of sandstone, was described by Leffingwell as Pennsylvanian but is now placed by Girty in the lower Permian. Maddren [74] found this lower Permian horizon represented by a calcareous tuff lying at the top of a lava

[74] Maddren, A. G., unpublished notes.

[75] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 113–115, 1919.

formation in the lower Kuskokwim Valley of southwestern Alaska, and Brown[77] found it represented by a limestone formation in the upper Kuskokwim Valley southwest of Lake Minchumina.

In the Alaska Range region Permian rocks are extensively developed. Rocks 6,000 to 7,000 feet thick in the headwater region of the Chistochina River were described by Mendenhall[78] under the name Mankomen formation. This formation consists of limestone, sandstone, and shale. Farther south, in southern Alaska, Artinskian fossils have been found by Capps[79] in a limestone on Skolai Creek, at the head of the White River, and it is possible that the Permian rocks continue on around the northeast side of the Wrangell Mountains to join with the Mankomen formation farther northwest. In southeastern Alaska Permian rocks were found first on Kuiu Island and are now known to be extensively developed on Kupreanof, Admiralty, and Suemez Islands, as well as at other localities.

TRIASSIC SYSTEM

UPPER TRIASSIC SERIES

DISTRIBUTION

In the Yukon Valley, as practically everywhere else in Alaska, the only part of the Triassic system present is the Upper Triassic, and in the Eagle-Circle district Upper Triassic rocks are known only at two localities. At the Nation River Upper Triassic rocks adjoin the Permian limestone on the northwest. In the valley of Trout Creek, about 12 miles farther up the Yukon, the Upper Triassic rocks lie southeast of the Permian limestone.

LITHOLOGY

At the Nation River locality Upper Triassic rocks crop out on both sides of the Yukon, but are somewhat better exposed, particularly at low stages of the river, on the southwest bank. A tape traverse from the farthest point downstream where such rocks are exposed upstream to the Permian limestone showed the following section. The distances given are horizontal distances along the river beach, but the general structure and thickness are shown graphically in Figure 6.

[77] Brown, J. S., The Nixon Fork country: U. S. Geol. Survey Bull. 783, pp. 105–106, 1926.

[78] Mendenhall, W. C., Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, pp. 40–51, 1905.

[79] Capps, S. R., Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, pp. 18–24, 1910.

Section of Upper Triassic rocks on Yukon River at the mouth of Nation River

	Feet
Fossiliferous black shale. Strike is N. 70° E. Dip is 70° S. in downstream part of section but becomes gradually less upstream. This shale contains some thin beds of dense argillaceous limestone about 1 foot thick. Collection 13423	150
Covered	720
Shaly limestone or calcareous shale. Fossiliferous. Collection 13425	40
Covered	18
Shale and a 5-foot bed of highly fossiliferous limestone, from which a part of collection 13425 was made	12
Imperfectly exposed bituminous shale and limestone showing so many reversals of dip due to numerous small folds that it is difficult to tell whether the dip of the formation as a whole is dominantly southeastward or northwestward. Contains several fossiliferous beds from which collection 13426 was made	567
Gray fossiliferous thin-bedded limestone. Strike N. 45° E., dip 30° NW. Collection 13427	17
Mostly covered; black shale imperfectly exposed. Rocks adjoining to the southeast are the uppermost beds of the Tahkandit limestone (lower Permian)	100

This section, imperfect as it is, shows that these Upper Triassic rocks consist essentially of black bituminous shale, interstratified with thin beds of gray to black limestone. Much of the black shale exposed at this locality is oil shale, but none of these rocks were tested quantitatively for oil.

The oil shale at Trout Creek was noted by P. J. Hillard, of Eagle, as early as 1901, and in October, 1915, he sent a sample to the United States Geological Survey. No distillation test of the shale was made at that time, however, the specimen being apparently of more interest on account of its contained fossils than on account of its bituminous nature. The shale from Trout Creek consists of a mat of closely compressed shells of *Pseudomonotis* and *Halobia* in a matrix of black shale. The fossil shells are so numerous and so closely compressed that not even the thinnest sliver of shale can be discovered without the impression of a shell upon it. A recent microscopic examination by Miss Taisia Stadnichenko, of the United States Geological Survey, indicates that the bituminous material originated from spores. A sample of this oil shale collected by the writer in 1925 was distilled in the chemical laboratory of the Geological Survey by E. T. Erickson, whose report is given below:

The sample as received appeared to have been exposed to weathering, which is likely to influence the character as well as the yield of the oil. For further chemical test the shale deposit should be resampled at a position unaffected by weathering.

A distillation test was made according to the oil-shale distillation method used by the Bureau of Mines[80] for determining the yield of crude shale oil. The total time required for the distillation was one and one-half hours; rate of oil distillation, 0.5 cubic centimeter a minute.

Upon comparison with other crude oils that were obtained from typical oil shales by the Bureau of Mines distillation apparatus, using a similar distillation rate, the crude oil obtained from the sample of shale from Trout Creek may be described as high in gravity and low in setting point. In these respects it is more nearly like the crude oil obtained from the Kentucky oil shale.

Results of distillation of samples of oil shale

	Trout Creek, Alaska	No. 2, DeBeque, Colo.	No. 18, Colorado	No. 11, Elko, Nev.	No. 12, Australia	No. 7, Kentucky	Scotland
Crude oil.......gallons per ton..	28	35.73	63.32	59.19	120.56	15.01	....
Specific gravity..................	0.934	0.913	0.894	0.867	0.877	0.948	0.864
Setting point..............° C..	—0.0	22	19	35	23	0.0	22

The chemical composition of oil shales has not yet been sufficiently investigated to compare them with typical petroleums, such as paraffin-base petroleum, which is low in specific gravity and high in content of paraffin series hydrocarbons; or a naphthene-base petroleum, which is largely composed of naphthene series and other cyclic hydrocarbons; or a mixed-base petroleum, which is intermediate in gravity and composition between paraffin-base and naphthene-base petroleums. The high gravity of the crude oil obtained from the shale of Trout Creek favors its commercial use for the production of lubricating oils. The low setting point indicates the absence of commercial quantities of paraffin.

Oil shale is also known at other places in Alaska. A shale phenomenally high in its content of oil has recently been found in the valley of the Christian River, about 75 miles north of Fort Yukon. This shale contains 122 gallons of oil to the ton of rock and is therefore of higher grade than any oil shale so far found in the United States. Another bituminous deposit, first noted by Ensign (now Rear Admiral, retired) W. L. Howard in his traverse down the Etivluk River, northwestern Alaska, in 1886, has recently been revisited by P. S. Smith.[81] This material has now been determined by David White, of the United States Geological Survey, as tasmanite. Similar material was also found by Smith on the Kivalina and Meade Rivers, in northwestern Alaska.

STRUCTURE AND THICKNESS

On account of the softness of this Upper Triassic shale and limestone the rocks of this formation crumble when exposed to the

[80] Karrick, L. C., A convenient and reliable retort for assaying oil shales for oil yield: Bur. Mines Rept. 2229, 1921.

[81] Smith, P. S., and Mertie, J. B., jr., Geology and geography of northwestern Alaska: U. S. Geol. Survey Bull. 815, p. 283, 1930.

atmosphere and are quickly eroded away. In addition the incompetency of these soft beds has rendered them particularly subject to deformation. The resulting poor exposures and accentuated folding make it difficult to obtain any satisfactory idea of the structure. The generalized section shown in Figure 6 conveys the writer's impression that these rocks are welded into a mass of small folds with a general northwesterly dip. A narrow covered zone separates the lowest of the Upper Triassic rocks from the uppermost Permian beds, but the two formations appear at least to agree in strike and dip. Little doubt can exist, however, that the contact between the two formations represents a great hiatus in sedimentation that corresponds geologically to Middle and Lower Triassic time and probably also to upper Permian time.

The top of the Upper Triassic sequence is not exposed, and therefore the total thickness of the formation can not be given. Martin,[62] who examined these rocks in 1914, estimated that at least 400 feet of strata are exposed along the beach opposite the mouth of the Nation River. Blackwelder,[63] in 1915, noted that the visible exposures indicated a thickness of 575 feet and possibly several times as much. The section given in Figure 6, though in part idealized, is plotted by the writer from the observed strike and dip and indicates that Martin's estimate is about correct, as nearly as may be judged from the available exposures.

AGE AND CORRELATION

Twenty fossil collections have been made from these Upper Triassic rocks, mostly from the Nation River locality. This fauna has been assembled by the writer in the table given below. T. W. Stanton, of the United States National Museum, has identified all this material.

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[62] Martin, G. C., Triassic rocks of Alaska: Geol. Soc. America Bull., vol 27, pp. 701–702, 1916.

[63] Blackwelder, Eliot, unpublished notes.

Fossils from Upper Triassic rocks along Yukon River near mouth of Nation River

	4054	8895	8896	8897	8898	8899	10266, 10267	9382	9383	9384	9385	9387	9388	9321	13423	13424	13425	13426	13427
Camarophoria? cf. C. crumena	×																		
Pugnax cf. P. osagensis	×																		
Pugnax sp	×																		
Rhynchonella sp		×								×	×								×
Rhynchonella? sp		×						×											
Dielasma? cf. D. bovidens (Tschernyschew)	×																		
Terebratula sp		×						×											
Martinia? sp	×																		
Spiriferina cf. S. laminosa	×																		
Spiriferina cf. S. simensis	×																		
Spiriferina sp		×								×	×								
Nucula sp	×																		
Pseudomonotis subcircularis						×		×							×		×		
Pseudomonotis subcircularis?																	×		
Pseudomonotis sp							×												
Pseudomonotis? sp														×					
Halobia cf. H. superba	×		×	×	×		×		×				×						
Halobia sp		×													×	×	×	×	
Halobia? sp										×									
Aviculipecten cf. A. parvulus	×																		
Aviculipecten sp		×									×								
Aviculipecten? sp	×									×	×								
Pecten sp										×									×
Modiomorpha? sp	×																		
Pleurophorus? sp										×									
Plagioglypta? sp	×																		
Pleurotomaria sp	×																		
Pleurotomaria? sp												×							
Natica? sp		×																	
Orthoceras sp										×	×								
Nautilus sp		×								×	×								×
Placites? sp											×								
Popanoceras (Parapopanoceras?) sp											×								
Trachyceras (Protrachyceras?) cf. T. (P.) leconti											×								
Trachyceras (Protrachyceras?) sp															×				
Clionites? sp					×							×				×			
Monophyllites? sp										×									×
Nathorstites sp																			×
Ammonite of undetermined genus		×																	
Ostracoda	×																		
Bone fragment												×							

4054. Yukon River a quarter of a mile northeast of mouth of Nation River. Collector, E. M. Kindle.

8895. Yukon River, southwest bank about 1 mile above Nation River. From a 10-foot bed of dark noncrystalline limestone, which is probably not more than 50 feet above the crystalline Permian limestone. Collector, G. C. Martin.

8896, 8897, 8898, and 8899. Yukon River, southwest bank about 1 mile above Nation River. 8896 is about 31 feet stratigraphically above 8895. 8897 is about 10 feet stratigraphically above 8896. 8898 is from float along river bank between localities 8897 and 8899. 8899 is about 300 feet stratigraphically above 8897. Collector, G. C. Martin.

10266 and 10267. Trout Creek about 3 miles from confluence with Yukon River. Collector, G. C. Martin.

9382. Yukon River, southwest bank southwest of Nation River. Collector, Eliot Blackwelder.

9383. Yukon River, southwest bank about 2 miles above Nation. Collector, Eliot Blackwelder.

9384. Yukon River, southwest bank opposite Nation River. Collector, Eliot Blackwelder.

9385, 9387, and 9388. Hillside one-third of a mile northeast of mouth of Nation River. Collector, Eliot Blackwelder.

9321. Trout Creek about 3 miles from confluence with Yukon River. Collector, P. J. Hilliard, of Eagle, Alaska.

13423, 13425, 13426, and 13427. Yukon River, southwest bank 2½ miles upstream from Nation. The relative positions of these four collections are given in the stratigraphic section on page 131. Collector, J. B. Mertie, jr.

13424. Southeast side of valley of Nation River near Yukon River. Collector, J. B. Mertie, jr.

The Triassic rocks of Alaska have been described in detail by Martin,[84] and it is unnecessary to include here a faunal and lithologic correlation of the Upper Triassic rocks of the Yukon with the other Triassic rocks. Upper Triassic rocks are known at many localities in Alaska, of which Martin lists the Nizina Valley, Kotsina and Kuskulana Valleys, Cooper Pass, upper Susitna Valley, Kenai Peninsula, west coast of Cook Inlet, Iliamna Lake, Alaska Peninsula, Kodiak Island, Admiralty Island, Kupreanof Island, Gravina Island, Firth River, Canning River, Noatak Valley, Cape Lisburne, and Cape Thompson. To these should be added the numerous areas of Upper Triassic rocks recently discovered in northwestern Alaska,[85] which, together with those at Cape Lisburne and on the Canning and Firth Rivers, in northeastern Alaska, indicate that a continuous Upper Triassic belt crosses northern Alaska from the Arctic Ocean to the international boundary. These Arctic Upper Triassic rocks differ lithologically, however, from those found along the Yukon in that they include a considerable amount of chert.

The rocks at the base of the Upper Triassic sequence at the Nation River contain certain genera of ammonites, such as *Placites*, *Popanoceras*, *Trachyceras*, *Clionites*, *Monophyllites*, and *Nathorstites*, which do not occur in the higher beds. These are accepted by Stanton as an integral part of the Upper Triassic fauna but are believed to represent a lower faunal horizon than the fossils found in the higher strata.

No Lower Triassic rocks have ever been found in Alaska; nor is the Middle Triassic represented, except possibly at one questionable locality at Brooks Mountain, in Seward Peninsula. In this connection, it should again be emphasized that the Tahkandit limestone, as well as the other Permian rocks in Alaska, represent only the lower part of the Permian sequence. Nevertheless, Upper Triassic rocks, wherever found in Alaska, appear to lie upon Permian, Pennsylvanian, or Mississippian rocks, without any angular discordance of bedding. It is believed that a gradual uplift of Alaska began in late Carboniferous time and culminated perhaps in the early Triassic, followed by submergence again in Upper Triassic time. The lack of any apparent angular unconformity between the Permian and Upper

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

[85] Smith, P. S., and Mertie, J. B., jr., Geology and geography of northwestern Alaska: U. S. Geol. Survey Bull. 815, pp. 185–194, 1930.

Triassic rocks leads to the belief that this uplift was of the plateau-forming type and was accompanied in Alaska by a minimum of warping and rock deformation; if any deformation took place it affected only the older, pre-Carboniferous rocks, which were more deeply buried. As this plateau-forming uplift in Carboniferous to Triassic time was not worldwide in extent, it follows that in areas adjacent to Alaska there must be a hinge zone, where this time interval will be found to be represented by deformed strata. Hence the postulate of an unconformity involving little or no rock deformation is intended to apply only to Alaska. It is believed that the deformation of the Carboniferous, Permian, and Triassic rocks, which resulted in the folding and faulting of these rocks, took place in one or more stages in post-Triassic time.

CRETACEOUS AND TERTIARY SYSTEMS

Jurassic rocks, though present in great thickness in southern Alaska and on the Alaska Peninsula, are unknown in the interior of Alaska and are very sparingly developed, if at all, in Arctic Alaska. The system next above the Upper Triassic in the Yukon region, therefore, is the Cretaceous. Two series of Cretaceous rocks have been differentiated in the upper Yukon Valley, of which the older is a well-developed Lower Cretaceous series. The younger is an Upper Cretaceous series, but as these rocks apparently grade upward lithologically into Eocene rocks in such a manner that it has not been possible to draw a line between the two series, they are herein mapped together and described under the heading Upper Cretaceous and Eocene series.

LOWER CRETACEOUS SERIES

KANDIK FORMATION

DISTRIBUTION

The Lower Cretaceous rocks in this area occur mainly at two localities which will probably later be found to form parts of one continuous belt. Along the Yukon these rocks crop out about 10 miles below the Nation River and continue on both sides of the Yukon downstream to Coal Creek, thence thinning to a narrow band which continues northwestward to Woodchopper Creek and for some undetermined distance farther. (See pl. 11, *B*.) The other area is along the international boundary from the neighborhood of Sitdown Creek northward for at least 25 miles. This area, which was mapped by Cairnes, was not differentiated by him as Lower Cretaceous nor in fact as exclusively Cretaceous; his cartographic designation was "Cretaceous and Upper Carboniferous." The inclusion of "Upper

Carboniferous" in his legend arose from the fact that the Nation River formation is so similar to the Upper Cretaceous rocks that at many places it is difficult to differentiate between the two. From the distribution of the Lower Cretaceous rocks along the Yukon, the writer surmises that much of the rock along the international boundary from Sitdown Creek northward to the 66th parallel is most likely also of Lower Cretaceous age. It is believed that between Sitdown and Ettrain Creeks, however, Cairnes's "Cretaceous and Upper Carboniferous" group is more likely to be the Nation River formation. Hence, on the accompanying geologic map the country rock from Sitdown northward to the limits of the map is shown as Lower Cretaceous, and from the Nation River southward to Ettrain Creek the Nation River formation is indicated, with a blank unmapped area between the two formations. Another minor outcrop of Lower Cretaceous rocks is seen along the northeast bank of the Yukon about 10 miles below the mouth of Thanksgiving Creek. This narrow belt may be the northwestward continuation of the narrow belt of the same rocks that crosses Coal and Woodchopper Creeks.

Blackwelder[86] has used the term Kandik formation in referring to the Lower Cretaceous rocks of the upper Yukon, and inasmuch as these rocks are typically exposed in the valley of the Kandik River, from the Yukon northeastward probably to the boundary, this formation name seems particularly fitting and is here formally applied. To be sure, neither the top nor the bottom of the Lower Cretaceous rocks has been recognized in this area, but as Jurassic rocks are absent in interior Alaska this formation is known to lie everywhere unconformably upon rocks older than Lower Cretaceous; it is also believed to underlie unconformably the Upper Cretaceous series. The term Kandik formation may therefore be regarded as a formational name that includes all the Lower Cretaceous sedimentary rocks of this area, of whatsoever lithologic character, although it seems highly probable that only sandstone, slate, and conglomerate are represented.

LITHOLOGY

The Kandik formation consists in the main of a monotonous sequence of black slate and thin beds of sandstone. The slates are carbonaceous, argillaceous rocks, which in some of the thicker beds show little stratification. No calcareous shale or limestone was seen, and the slates appear not to be bituminous or oily, thus differing markedly from the Upper Triassic shales. Moreover, no chert or siliceous slate appears in the sequence, which thus differs from the lower Mississippian (?) rocks. These argillaceous members are ad-

[86] Blackwelder, Eliot, unpublished notes.

visedly for the most part termed slate rather than shale, for in most of them fracture cleavage is well developed. Plate 11, *B*, shows a typical exposure of the Lower Cretaceous quartzitic sandstone and slate. The sandstone beds show no sign of such cleavage, although some of them are much jointed.

The sandstones occur for the most part in thin beds, from a few inches to 1 or 2 feet thick, but some thick massive beds occur in the sequence. One very thick bed of this type is exposed along the south bank of the Yukon just below Glenn Creek. The thinner beds of sandstone are usually dark gray on a fresh break but weather to a dull-brown color, which is due probably to their content of ferrous iron. They are composed essentially of grains of quartz, with little chert but with a certain amount of altered feldspar and ferromagnesian minerals. The thicker beds are inclined to be more purely quartzose, and some of them by partial recrystallization closely approach quartzite. In the Rampart district, where these same Lower Cretaceous rocks occur, the heavy quartzose beds served the writer to a certain extent as horizon markers, inasmuch as they make prominent hogbacks; they will probably be useful in a similar way along the Yukon when more detailed mapping is attempted.

Along the banks of the Yukon no conglomerate was seen in the Lower Cretaceous sequence. A few miles upstream from the Kandik River, however, on the north side of the Yukon, a great thickness of these rocks is exposed at Kathul Mountain. The top of this mountain is 2,400 feet above the level of the Yukon, and in the course of a trip up the mountain the writer observed that the upper three-fourths of the sequence was composed largely of sandstone and conglomerate, the conglomerate being particularly evident near the top. This conglomerate, however, is rather fine grained, and much of it might better be described as a grit, although some beds containing pebbles as large as 3 inches in diameter were seen. The component fragmental material is subangular to rounded and consists of quartz, chert, slate, and fragments of other dark-colored rocks, perhaps in part of volcanic origin. Except in the fineness of grain these conglomeratic beds do not differ materially from some of the conglomerates of the Upper Cretaceous and Eocene sequence. It is possible, indeed, that these conglomerates and grits may mark the base of the Upper Cretaceous, but the writer is inclined to believe that they form an integral part of the Lower Cretaceous series.

STRUCTURE AND THICKNESS

Little work was done by the writer on these Lower Cretaceous rocks. Such observations as were made, however, indicate that the rocks are considerably deformed, though the folds are for the most part of the open type and of large amplitude, so that considerable stretches of river bluffs show what appears to be homoclinal structure. Some steep dips were noted at places along the river, and these, considered in relation to the nature of the foldings, suggest the presence of some large unrecognized faults. Large unexamined areas of such rocks occur between Glenn and Coal Creeks, and it is rather hazardous to extrapolate the visible structure into such unknown areas.

The rocks at the west side of Kathul Mountain dip southeastward, and those at the east end dip northwestward, so that this mountain occupies approximately the center of a gentle syncline. As this mountain rises 2,400 feet above the Yukon, it is safe to say that at least 2,400 feet of Lower Cretaceous strata are present at this locality. Neither the top nor the base of this sequence has been recognized, however, and it is probable, therefore, that two or three times that thickness of strata may be present in this wide belt of rocks. No data are at hand for making any closer estimate of the stratigraphic thickness.

AGE AND CORRELATION

Fossils are rather scarce in the Kandik formation, but nevertheless a number of small collections have been made, which are adequate for determining the geologic age. This fauna, which has been determined by T. W. Stanton, of the United States Geological Survey, is listed below.

Fossils from Kandik formation on Yukon River

	2674	3783	3784	3785	9389	13428	13429
Pinna sp.		×					
Inoceramus sp.		×	×			×	
Inoceramus? sp.					×		
Aucella crassicollis	×			×			
Aucella cf. A. crassicollis							×
Aucella sp.			×				×
Aucella? sp.		×					
Pecten sp.		×					
Perisphinctes? sp.		×					
Belemnites sp.							×
Belemnites? sp.						×	

2674. Washington Creek 6 miles above mouth. Collector, A. J. Collier.

3783. Yukon River, southwest bank about 400 yards below Glenn Creek. Collector, E. M. Kindle.

3784. Yukon River, south bank about 1½ miles below Sam Creek. Collector, E. M. Kindle.

3785. Yukon River, north bank about 6 miles above Charlie Village. Collector, E. M. Kindle.

9389. Yukon River 8½ miles above Washington Creek. Collector, Eliot Blackwelder.

13428. Yukon River, southwest bank just below Glenn Creek. Collector, J. B. Mertie, jr.

13429. East side of Woodchopper Creek about 1 mile in a straight line from Yukon River. Collector, J. B. Mertie, jr.

In addition to the invertebrate collections above enumerated, Blackwelder in 1915 found remains of a plant which was identified by F. H. Knowlton as *Chondrites heerii* Eichwald. This was found along the southwest bank of the Yukon about 1½ miles above the mouth of the Kandik River.

Of the six genera of invertebrates that have so far been found in these rocks, *Aucella crassicollis* Keyserling may be said to be the type fossil. This fossil is particularly abundant at the locality on Woodchopper Creek, in beds of slate. Other undetermined species of *Aucella* are probably also present at this locality. Along the international boundary Cairnes[87] also made a number of collections of Lower Cretaceous fossils, from Sitdown Creek northward to the sixty-sixth parallel. These were determined originally by T. W. Stanton, of the United States Geological Survey. (For explanation of numbers, see p. 48.)

XIV k 25:
- Nucula sp.
- Astarte? sp.
- Panopaea? sp.
- Undetermined pelecypod casts.

XIV q 31:
- Aucella crassicollis Keyserling.

XV a 31, 32:
- Aucella crassicollis Keyserling.
- Astarte sp.

XV h 30, 31, and l 30:
- Aucella crassicollis Keyserling.

XV j 30:
- Aucella crassicollis Keyserling.

This Lower Cretaceous horizon is represented at many places in Alaska. The locality nearest to the Yukon is in the Rampart district, where a great thickness of *Aucella*-bearing slate and quartzite is found. In northern Alaska Schrader[88] found Lower Cretaceous rocks on both the south and the north sides of the Brooks Range, and he gave to these two groups of rocks the designations Koyukuk and Anaktuvuk "series." In the recent work in northwestern Alaska[89] the Lower Cretaceous rocks north of the Brooks Range,

[87] Cairnes, D. D., The Yukon-Alaska international boundary between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, pp. 105–107, 1914.

[88] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, 1904, pp. 74–77.

[89] Smith, P. S., and Mertie, J. B., jr., Geology and geography of northwestern Alaska: U. S. Geol. Survey Bull. 815, pp. 196–207, 1930.

roughly equivalent to the Anaktuvuk group, were shown to continue westward in a more or less continuous zone from the Anaktuvuk River to the Arctic Ocean. This group is probably closely correlative with the Kandik formation of the Eagle-Circle district.

In the Chitina Valley of southern Alaska two formations, the Kotsina conglomerate and the Kennicott formation, both believed to be in part at least of Lower Cretaceous age, were described originally by Rohn.[90] *Aucella*-bearing shales were found by Capps[91] at the head of the Chisana River and are also known to exist to the east at the head of the White River. They were also found by Mendenhall[92] in the valley of the Nelchina River, a stream which heads against the Matanuska River and flows eastward to the Copper River.

In southwestern Alaska, east of Kuskokwim Bay, rocks of Lower Cretaceous age are included in the group differentiated by Spurr[93] as the "Oklune series." The Herendeen limestone of the Alaska Peninsula, as mapped by Atwood,[94] is also of Lower Cretaceous age. Lower Cretaceous rocks are known on Admiralty and Etolin Islands, in southeastern Alaska.

UPPER CRETACEOUS AND EOCENE SERIES

DISTRIBUTION

Rocks of Upper Cretaceous and Eocene age crop out in a continuous belt 1 to 15 miles wide for a distance of 85 miles from the international boundary northwestward to Woodchopper Creek and beyond. This belt extends southeastward from the boundary for an unknown distance into Yukon Territory. Along the Yukon these rocks crop out only at few places north and northwest of Calico Bluff. A small area of rocks at the head of the Charley River mapped by Prindle in 1911 as Upper Cretaceous (?) is also included here.

LITHOLOGY

Little additional work was done on this group of rocks during the season of 1925; they were examined at several localities on the north side of the Yukon, in Yukon Territory, and the northern boundary

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

[91] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, p. 62, 1916.

[92] Mendenhall, W. C., A reconnaissance from Resurrection Bay to the Tanana River, Alaska: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 309, 1900.

[93] Spurr, J. E., A reconnaissance in southwestern Alaska: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 167, 1900.

[94] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, pp. 39–41, 1911.

of the group was modified in the area northeast of Eagle. So far as known, these rocks are all of fresh-water origin and represent conditions of sedimentation not unlike those that existed at the time the Nation River formation was laid down. In fact, these rocks are so similar lithologically to the rocks of the Nation River formation that it is difficult to differentiate between them at the localities where the two formations adjoin.

Where seen along the Yukon, the Upper Cretaceous and Eocene rocks consist of impure greenish-gray to almost black sandstone, graywacke, sandy shale, and beds ranging from grit to coarse conglomerate. A short distance above the international boundary, in the hills north of the Yukon, the conglomerate consists of pebbles from a quarter of an inch to 3 inches in diameter, in a brownish matrix. The pebbles here were mainly of vein quartz and chert, with some quartzite, quartzite schist, graphitic phyllite, and decomposed granitic or dioritic material. This is about the average character of the conglomerate. At some places, however, the conglomerate is coarser, and boulders as large as 3 feet in diameter have been observed. At most localities all these rocks are loosely consolidated and therefore by weathering form on top of the ridges gravel deposits that simulate high bench gravel. At places, however, as for example in the valley of the Seventymile River, these rocks have been more than ordinarily metamorphosed and occur as hard, well-indurated sandstone and conglomerate.

A small area of coarse conglomerate and sandstone is shown at the head of the Charley River. These rocks consist of gray more or less carbonaceous sandstone, interbedded with very coarse conglomerate containing boulders as much as 6 feet in diameter. Like most of the strata of this series, they carry plant remains.

The sequence of rocks in this series, as interpreted by Prindle,[95] comprises shale and sandstone with beds of lignite at the base of the formation, overlain by sandstone, shale, and conglomerate, with thick beds of conglomerate at or near the top.

The upper or conglomeratic beds appear to be the proximate though not the ultimate source of a part of the gold in the placers of the Seventymile River and of Fourth of July, Coal, Woodchopper, and other creeks along the south side of the Yukon between Eagle and Circle. This statement, which was made originally by the writer[96] in 1923, in discussing the origin of the gold deposits of interior Alaska, has not been clearly understood by some of the mining men of this district, who apparently have been led to believe

[95] Prindle, L. M., A geologic reconnaissance of the Circle quadrangle, Alaska: U. S. Geol. Survey Bull. 538, pp. 32–34, 1913.

[96] Mertie, J. B., jr., The occurrence of metalliferous deposits in the Yukon and Kuskokwim regions: U. S. Geol. Survey Bull. 739, p. 164, 1923.

that all the creeks which cut this formation ought therefore to have placer gold in the present stream valleys, derived from these conglomerates by recent erosion and stream sedimentation. This belief, of course, is incorrect. As examples may be cited Fourth of July and Crowley Creeks, south of Nation; the former contains workable gold placers, but the latter contains little or no gold in its stream gravel.

Two considerations must be borne in mind—first, no reason exists for believing that gold is universally distributed in those conglomerates, for here as elsewhere only certain streams or even certain parts of some particular stream draining from a mineralized area contain auriferous gravel; second, these rocks have been highly folded at many places, particularly in this zone south of the Yukon, with the result that even if the conglomerate beds had originally carried equally distributed deposits of gold, gold would no longer be equally distributed areally. The gold in this mineralized belt from Eagle to Circle came originally from mineralized rocks at the border of the granitic rocks and also, in part, from the granitic rocks themselves within the drainage basins of the streams, and it has continued to accumulate as stream placers ever since these mineralized rocks were exposed to surficial erosion. The indurated conglomerates are but one stage in this process. Gold placers may therefore exist in any of these streams within whose drainage basins occur bodies of mineralized rock, but the chances for the formation of gold placers may be said to be appreciably enhanced in the areas where these conglomerates now occur, for in such areas both the original mineralized rocks and the fossil placers of the conglomerate are available as sources of gold.

STRUCTURE AND THICKNESS

No studies have yet been made that are sufficiently detailed to warrant a structural section across this belt of rocks. The rocks are known, however, to be everywhere folded and at some localities intensely deformed. The structure of the Upper Cretaceous and Eocene rocks south of the Yukon is believed in general to be much more complex than that of the Lower Cretaceous rocks north of the Yukon, notwithstanding the fact that the Lower Cretaceous rocks are older and probably were subjected to deformational processes before the Upper Cretaceous and Eocene rocks were laid down. This apparent anomaly is due in reality to the closer proximity of the Upper Cretaceous rocks to the seat of volcanism farther south. The same conditions were observed in the Paleozoic rocks, those south of the Yukon being much more metamorphosed than rocks of similar age north of the Yukon. This interpretation of the structure of the Upper Cretaceous rocks involves axiomatically the idea that volcanism such as produced the great Mesozoic batholith to the south and led to the deformation of the late Paleozoic and Triassic rocks was renewed in Tertiary time. Evidence of Tertiary volcanism in southwestern Alaska has already been presented by the writer;[97] and although no stratigraphic evidence of invasion of Cretaceous rocks by granitic bodies has been recorded in the Yukon-Tanana region, the evidence from southwestern Alaska, based on the types of metallization, has been extrapolated by the writer[98] into the Yukon-Tanana region to prove that Tertiary intrusions of granitic magmas occurred in that region, particularly in the Tolovana and Rampart districts. Hence the idea of a period of deformation in Tertiary as well as in Mesozoic time is not at variance with present interpretations.

The evidence of the intense deformation of the Upper Cretaceous and Eocene rocks is cogent at numerous localities, particularly along the Seventymile River, where these rocks lie nearest to the volcanic rocks to the south. On Barney Creek, a tributary of the Seventymile, the conglomerate beds stand nearly vertical at places, and even farther north, in the valley of Fourth of July Creek, they are nearly vertical at one exposure. Along the south side of the Seventymile River below the falls, where these rocks strike about N. 55° W., they dip consistently south at angles from 30° to 70° and are highly indurated. They consist here largely of sandstone and conglomerate, with some lignitic beds, but farther up Crooked Creek from the Seventymile the bedrock changes by degrees to soft shale and sandstone. This sequence indicates, if Prindle's interpretation of the order of deposition is correct, that these beds along the Seventymile River, though highly deformed, are at least right side up, the conglomerate resting normally upon the stratigraphically underlying shale and sandstone.

The beds of heavy conglomerate, however, are apparently duplicated by folding and crop out repeatedly in the area between the Seventymile and Yukon Rivers. This duplication of beds by folding and perhaps also by faulting unquestionably explains the great distance across the strike of these rocks from the falls of the Seventymile to the Yukon. It is therefore entirely possible that no great thickness of rocks exists in this belt, even though the greatest distance across the strike is nearly 15 miles. On the other hand, all of the sequence may not be present in that portion of the belt where the distance across the strike is the least. Prindle[99] estimated the thickness of the sequence between the Seventymile and Yukon Rivers at

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[97] Mertie, J. B., jr., and Harrington, G. L., The Ruby-Kuskokwim region, Alaska: U. S. Geol. Survey Bull. 754, pp. 71–72, 1924.

[98] Mertie, J. B., jr., The occurrence of metalliferous deposits in the Yukon and Kuskokwim regions: U. S. Geol. Survey Bull. 739, pp. 156–158, 1923.

[99] Prindle, L. M., A geologic reconnaissance of the Circle quadrangle, Alaska: U. S. Geol. Survey Bull. 538, p. 33, 1913.

3,000 feet. This, it seems to the writer, is a minimum estimate and if subject at all to reconsideration should be increased rather than decreased. In view of the absence of detailed work done in this area it seems hardly worth while to hazard any other figure. It should be noted, however, that this estimate does not include the small area of rocks in the head of the Charley River to which Prindle assigned a thickness of 1,000 feet. From Prindle's figures, therefore, 4,000 feet may be given as a minimum thickness for the sequence of rocks here described as Upper Cretaceous and Eocene.

AGE

The proper age assignment for this group of rocks is a moot question. Martin,[1] who has made a comparative study of the Mesozoic rocks of Alaska, is inclined to favor the assignment of all these rocks to the Upper Cretaceous. Prindle,[2] on the other hand, depending upon numerous determinations of plant fossils by F. H. Knowlton, has described these rocks, with the exception of the small area at the head of the Charley River, as Eocene. Perhaps the answer to the problem is the same as in the Ruby-Kuskokwim region, farther down the Yukon, where the writer[3] collected Upper Cretaceous (?) invertebrates and Eocene (?) plants from the same slab of rock. The fossil remains may not be sufficiently diagnostic for reliable stratigraphic correlation; but it may also be that the Eocene in this region was not sharply separated from the Upper Cretaceous by the beginning of crustal movements and accompanying changes in conditions of sedimentation. Such a gradual transition from the Mesozoic to the Cenozoic might easily result in an equivocal intermingling of fossils.

In all, 20 collections of fossil plants have been made from this sequence of rocks, and many more could be gathered, for at certain localities the rocks are full of plant remains. Eight of these collections, which were found along the Yukon, are believed at present to be of Upper Cretaceous age. The other 12 collections, which were found at some distance south of the Yukon, have been assigned to the Eocene, but a number of genera and species are common to both groups. Arthur Hollick has recently studied these collections, and the results of his work when published may throw additional light upon this problem. Under the circumstances, and especially in view of the fact that the names of some of the species and even the genera

[1] Martin, G. C., The Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, pp. 387–390, 1926.

[2] Prindle, L. M., A geologic reconnaissance of the Circle quadrangle, Alaska: U. S. Geol. Survey Bull. 538, pp. 30–31, 1913.

[3] Mertie, J. B., jr., and Harrington, G. L., The Ruby-Kuskokwim region, Alaska: U. S. Geol. Survey Bull. 754, p. 40, 1924.

may later be changed, the writer feels that no good purpose will be served by publishing a mixed fossil list. As a matter of record, however, the localities from which these collections were made are listed here.

Upper Cretaceous (?) collections

2973. Yukon River, west bank 2 miles below Seventymile River. Collector, A. J. Collier.

2971. Yukon River, west bank 7 miles above Nation River. Collector, A. J. Collier. (This collection may have come from the Nation River formation.)

3243. Yukon River, west bank about 3 miles below Seventymile River. Collector, Arthur Hollick.

Kindle 11h. Yukon River 1½ miles above Seventymile River. Collector, E. M. Kindle. (It is partly upon the evidence afforded by this collection and partly upon the lithology that the writer has referred the rocks at this locality to the Upper Cretaceous, rather than to the Nation River formation, to which Blackwelder suggested that they be referred.)

Kindle 20. Coal mine, Washington Creek, 16 miles from Yukon River. Collector, E. M. Kindle.

7404. Yukon River, south bank at mouth of gulch 1½ miles below Seventymile River. Collector, G. C. Martin.

7408. Yukon River, south bank 2 miles below mouth of Seventymile River. Collector, G. C. Martin.

6815. Yukon River, south bank at mouth of draw 1½ miles below Seventymile River. Collector, G. C. Martin.

Eocene (?) collections

Spurr 3. Yukon River below Mission Creek. Collector, J. E. Spurr.

Collier 27. Coal Creek about 12 miles from Yukon River. Collector, A. J. Collier.

Collier 40. American Creek 100 yards below crossing of Eagle-Valdez trail. Collector, A. J. Collier.

3AP330. Wolf Creek, tributary of Seventymile River. Collector, L. M. Prindle.

3AP336. Branch of Wolf Creek, tributary of Seventymile River. Collector, L. M. Prindle.

3AP348, 3AP349, 3AP350. Bryant Creek, tributary of Seventymile River. Collector, L. M. Prindle.

3AP355. Mogul Creek, tributary of Seventymile River. Collector, L. M. Prindle.

3AP432. Mission Creek 2 miles above junction with Excelsior Creek. Collector, L. M. Prindle.

Atwood 10. Seventymile River half a mile below mouth of Mogul Creek. Collector, W. W. Atwood.

Atwood 11. Bryant Creek 3 miles above its mouth. Collector, W. W. Atwood.

Three other collections, which belong with these, were found in the Fortymile district, south of the area covered by this report; the first was determined as Cretaceous (?) in age; the other two as Eocene.

5AP178. Liberty Creek, tributary of O'Brien Creek. Collector, L. M. Prindle.
3AP224½. McDowell claim, Chicken Creek. Collector, L. M. Prindle.
3AP251. Chicken Creek. Collector, L. M. Prindle.

QUATERNARY SYSTEM

Unconsolidated sediments ranging in age from Pleistocene to Recent are present in all the stream valleys of this area, and the physiographic history of their deposition constitutes a geomorphologic problem of great magnitude, which has not yet been attacked in this area.

The Alaska Range, together with southern and southeastern Alaska, was intensely glaciated during Pleistocene time and probably during early Recent time. In fact, some of this territory has not yet really emerged from the glacial epoch, being still covered with great ice caps. The Brooks Range, which crosses northern Alaska, was also glaciated in Pleistocene time, though not nearly so severely or extensively as the Alaska Range, and it is now nearly free from glaciers. The great stretch of country lying between these two ranges, however, has not been glaciated except in certain groups of high mountains, where local valley glaciation of the alpine type has occurred.

While all this glaciation was taking place, both north and south of the Yukon Valley, climatic conditions of a peculiar type must have existed in the interior of Alaska. The mean annual temperature of this region, bordered on the north, east, and south by ice caps, must have been much lower than at present, and it is probable also that the annual precipitation was even less than at present. Rivers like the Tanana, which headed in large part in a glaciated area, handled and reworked great volumes of outwash material from the glaciers, which was subsequently redeposited to build up great alluvial plains like that in the present Tanana Valley, north of the Alaska Range. Streams that headed in essentially nonglaciated areas, however, like those between the Yukon and Tanana Rivers, went through a physiographic cycle which is as yet only imperfectly understood. Their deeply buried preglacial stream gravel, where uncovered by mining operations, is seen to be covered with great deposits of black muck, composed largely of silt and peaty material, with some beds of sand and layers of gravel. These are the sediments which were deposited during this physiographic cycle, and it was during the time of their deposition that numerous forms of preglacial life, such as the bison and mastodon, became extinct in this region, while other more adaptable animals and plants were modified to conform with the new environment. Where small areas were subjected to local glaciation, the emerging alpine glaciers built up a few morainal deposits. Two such morainal deposits in the southwest corner of the area covered by this report have been shown separately on the accompanying geologic map. All the other alluvial deposits, of both Pleistocene and Recent age, have been grouped together as a single cartographic unit.

As the glaciers began to retreat, climatic conditions began to change and to approach more nearly those of the present time. Stream erosion and sedimentation of the normal type were renewed; and the formation of alluvial deposits of silt, sand, and gravel which began then has continued to the present time. Evidence exists at numerous localities that this era was ushered in by a lowering of the base-level of the master stream of this region, which produced many changes in the disposition of preexisting drainage channels. Many interesting problems, including stream superposition, reversals of stream flow, "inlaid" gravel deposited on preexisting deposits of muck, terracing, and a multitude of kindred phenomena, are here represented and should sometime be studied in their physiographic and geomorphologic aspects.

IGNEOUS ROCKS

Five mappable units of igneous rocks are shown on Plate 12. These are undifferentiated Paleozoic greenstone; Middle Devonian greenstone interbedded with sedimentary rocks; lower Mississippian greenstone interbedded with sedimentary rocks (Circle volcanics); Mesozoic and Tertiary granite, diorite, and related rocks; and Tertiary lava flows, mainly rhyolite, but including some dacite.

The pre-Cambrian igneous rocks associated with the Birch Creek schist are described in connection with that formation on pages 15–16 and are not separated from the Birch Creek on the map.

The Middle Devonian and Mississippian volcanic formations, although essentially basaltic, have been described on pages 77 and 85 in connection with the sedimentary rocks, with which they logically belong because of their bedded character. So far as the other igneous rocks are concerned, no additional work was done by the writer during the season of 1925. The petrology of these eruptive rocks was described in considerable detail by the writer[4] in 1911. Several hundred thin sections were studied and described at that time, and all that seems necessary for the present report is a brief summary of that work.

UNDIFFERENTIATED GREENSTONE OF PALEOZOIC AGE

DISTRIBUTION

The principal areas mapped as undifferentiated greenstone are the Mount Sorenson massif, at the head of the Seventymile River, some

[4] Prindle, L. M., A geologic reconnaissance of the Circle quadrangle, Alaska, with a chapter on the igneous rocks by J. B. Mertie, jr.: U. S. Geol. Survey Bull. 538, pp. 37–48, 1913.

scattered areas farther east, and the greenstone that forms the bluff at Eagle and extends northwestward up the north side of American Creek. Certain small areas along the international boundary, mapped by Cairnes, are also included in this grouping.

PETROLOGY

The greenstone at Mount Sorenson is an ultrabasic rock of peridotitic character, which weathers reddish brown. In relatively unweathered specimens it is seen to be essentially a dunite consisting entirely of olivine, much of which is altered in part or wholly to serpentine. This mass of serpentine is undoubtedly intrusive. Similar serpentine is exposed on American Creek, forming the bedrock from the forks downstream for a mile or two. This serpentine evidently forms a narrow belt trending northeast, but it is included in the undifferentiated Paleozoic rocks because its extent in the direction of maximum elongation has not been determined. Other small areas of serpentine as well as greenstone of original basaltic character occur at a number of localities along the Seventymile between the Mount Sorenson massif and Mission Creek. The greenstone that forms the bold bluff at Eagle and continues northwestward up the north side of Mission Creek is essentially a basaltic greenstone, with which are interbedded flow breccia and tuff, also of greenstone habit, as well as more or less quartzite and crystalline limestone. This body of greenstone is mainly of effusive origin, though it may also contain some intrusive rock.

AGE

Greenstones are known at many horizons in the Paleozoic and pre-Paleozoic sequence of Alaska, and most of these rocks resemble one another greatly. Theoretically, the present grouping of undifferentiated greenstone includes all the Paleozoic basic and ultrabasic rocks of greenstone habit. The serpentine, however, which forms a large part of these rocks, is known to intrude the Silurian and Middle Devonian rocks of this region but has not been seen anywhere in rocks of later age. This does not definitely establish its age, for it may have been intruded at depths below the surface too great to reach the later Paleozoic rocks. But a stratigraphic discontinuity and perhaps angular unconformity of considerable magnitude is believed to separate the Middle Devonian rocks of this area from the overlying Carboniferous sequence, and with the idea in mind that such rock deformation is usually accompanied by volcanism, it seems possible that these ultrabasic rocks are Upper Devonian. The greenstone at Eagle may also be of Devonian age, but if so, it is more likely to be correlative with the Woodchopper volcanics and therefore to be late Middle Devonian. No data are available for determining the age of the sundry small areas of greenstone, mapped and unmapped, in this area. Where large areas of such rocks occur, as upstream from Circle, the lithology of the interbedded rocks may afford presumptive evidence for correlating the formation with similar rocks in near-by areas. But the age of the smaller areas of greenstone can not be assigned more closely than Paleozoic.

GRANITE, DIORITE, AND RELATED ROCKS

DISTRIBUTION

Granitic rocks occupy a zone in the southern part of this area 75 miles long and from 10 to 50 miles wide; and smaller outlying masses of similar rocks occur both to the north and south of this great massif. Only one new area, about 15 miles southeast of Eagle, in Yukon Territory, was recognized and mapped in 1925, all the other cartographic work on these rocks having been done in previous seasons.

PETROLOGY

The varieties of acidic intrusive rocks previously identified by the writer consist of muscovite granite, alaskite, muscovite-biotite granite, amphibole granite, tourmaline granite, epidote granite, and a little quartz monzonite. Among the subsilicic types are granodiorite, quartz diorite, and diorite. The basic rocks include gabbro, peridotite, and pyroxenite. The granitic and dioritic rocks, however, are the typical rocks of this group. Locally, primary granite gneiss is developed along the contact of these intrusives with the country rocks, but such gneiss is not to be confused with the older gneisses, which are of early Paleozoic or pre-Paleozoic age. Dikes of rhyolite, dacite, andesite, basalt, and diabase are commonly found near the intrusive rocks, but a part of these are of Tertiary rather than Mesozoic age.

AGE

The granitic rocks of this area have always been considered to be of Mesozoic and probably of late Jurassic age, and this generalization is doubtless true for the greater part of such rocks. Of late years, however, evidence has been accumulating that some of the granitic and particularly the monzonitic rocks of interior Alaska are of Tertiary age. Such Tertiary intrusive rocks are highly developed in southwestern Alaska and have been recognized up the Yukon as far as the Rampart, Hot Springs, and Tolovana mining districts. Where stratigraphic evidence of the presence of such Tertiary granitic rocks is lacking, the presence of cinnabar in the concentrates taken with the gold from the placers has been interpreted by the writer[6] as almost infallible evidence of Tertiary age. It is therefore of interest to record the fact that cinnabar has been found in considerable quantity in the placer concentrates on Canyon and Mogul Creeks, tributaries of the Seventymile River from the south. This fact suggests strongly the recurrence of volcanism in Tertiary time and leads to the belief that granitic rocks of Tertiary age are present in this area, though of course such rocks may not yet have been uncovered by erosion and therefore may be below the surface.

RHYOLITE AND DACITE

A number of flows believed to be of Tertiary age have been mapped in the upper valley of the Charley River. They consist mainly of rhyolite and dacite porphyries, which appear to cover the tops of a number of hills. These lavas are clearly flows, but the orifices from which they issued have not been recognized.

GEOLOGIC HISTORY

The pre-Cambrian and Paleozoic geology of this region is as yet only imperfectly understood, but enough information is available to sketch at least the main geologic cycles of sedimentation, erosion, mountain building, and volcanism. As no one area in the Yukon and contiguous territory appears to furnish a complete historical sequence, the writer has been obliged in the following outline to draw upon geologic data and experience acquired in other areas.

The oldest rocks known in the Yukon Valley are the quartzite and mica schist of the Birch Creek schist, which are of sedimentary origin. Such rocks constitute, then, the earliest evidence of sedimentation in Alaska, and their character indicates that the ordinary processes of erosion and sedimentation functioned then in quite the same manner as at present. As no fossils of any kind have been found in this pre-Cambrian sequence, it can not be stated with assurance that these arenaceous and argillaceous rocks were of marine or terrestrial origin, but such traces of original texture as may be seen in some of the quartzitic rocks indicate that they originated as well-sorted littoral sediments such as characterize the present eastern Coastal Plain of the United States. Later in pre-Cambrian time the sediments appear to have become more dominantly argillaceous and even to a degree calcareous, the resulting deposits being now represented by graphitic, sericitic, and chlorite schists and also by calcareous schist and crystalline linestone.

The pre-Cambrian also had its periods of volcanism, as indicated by granitic and dioritic intrusive rocks of gneissoid character and

[6] Mertie, J. B., jr., The occurrence of metalliferous deposits in the Yukon and Kuskokwim regions: U. S. Geol. Survey Bull. 739, p. 157, 1923.

by various metamorphosed basic and ultrabasic rocks, such as amphibolite, hornblende schist, and related rocks, which doubtless represent both surficial and deep-seated basic volcanism. A definite paragenetic assignment of the igneous rocks of the pre-Cambrian can, of course, not be made, but the gneisses have invaded the amphibolitic rocks, and the evidence at present available suggests that the acidic intrusives originated at a somewhat later date than the basic eruptives. It should be remembered, however, that some of the igneous rocks at present mapped with the pre-Cambrian Birch Creek schist are possibly of Paleozoic age.

The earliest record of a pronounced discontinuity in sedimentation is seen at the top of the Birch Creek schist, in the Fairbanks quadrangle. The field evidence is not that afforded by a visible unconformity but consists of three lines of circumstantial evidence that are believed adequate to prove the point; these are a sudden and pronounced change in the character of sedimentation, a slight but apparently real difference in the course of trend lines in the pre-Cambrian and overlying formations, and a marked difference in the degree of metamorphism. It is believed by the writer that at or about the end of the period of sedimentation represented by the Birch Creek schist the usual diastrophic sequence of elevation, stream rejuvenation, and accentuated erosion produced a great discontinuity in deposition, which was followed by renewed marine sedimentation. The unconformity that marks this break in deposition represents the lower stratigraphic limit of Alaskan geologic knowledge. What happened geologically before this diastrophic epoch is largely a matter of surmise and is likely to remain so for many years to come. The geologic record of succeeding events becomes progressively more intelligible, and additional work in Alaska should continue to contribute evidence.

It seems worth while to suggest the possibility at least that the gneissoid granitic and dioritic rocks of pre-Cambrian age may have originated contemporaneously with and have been one of the manifestations of the diastrophic events that produced this early unconformity. No positive evidence can be cited, but these gneissoid rocks invade some of the pre-Cambrian sedimentary rocks as well as some of the amphibolitic rocks, so that the evidence as far as it goes does not negate this as a possible hypothesis.

The sequence of events following the deposition of the Birch Creek schist is as yet somewhat uncertain. The Middle Cambrian rocks along the boundary lie unconformably above the Tindir group; and the hypothesis has been formulated that the Tindir group may possibly be correlated with the lower part of the Tatalina group, which overlies the Birch Creek schist in the Fairbanks district. These associations suggest the possible presence of a group of rocks of either Lower Cambrian or Algonkian age, or both, lying between the Birch Creek schist and the lowest known Paleozoic rocks. If this interpretation is accepted as a working hypothesis, the conclusion follows that both Archean and Algonkian rocks may be present in Alaska; that the unconformity at the top of the Birch Creek schist in the Fairbanks quadrangle represents a stratigraphic hiatus and period of deformation that separates the Archean from the Algonkian; and that another and similar unconformity exists between the Algonkian rocks and the earliest Paleozoic rocks.

The history of events that occurred during the formation of the rocks of the Tindir group is obscure, but these rocks, which in their type locality are little metamorphosed, indicate processes of sedimentation similar to those of later geologic periods. One distinguishing characteristic is the occurrence at certain horizons of hematitic beds, as mentioned by Cairnes and as described also by the writer in connection with the red beds on the Tatonduk River. The origin of these red beds has not been determined, but they evidently represent a specialized type of sedimentation, different from the ordinary processes of erosion and deposition, that characterized one or more epochs during the Lower Cambrian or Algonkian. Volcanic action is also recorded in the dikes, sills, and irregular intrusive masses of greenstone that appear to constitute an integral part of the Tindir group.

According to Cairnes, the Middle (?) Cambrian limestone of Jones Ridge lies unconformably above the Tindir group. Hence it should follow that a period of regional deformation occurred after the rocks of the Tindir group were formed, which was followed by an era of regional depression below sea level, when the Cambrian sequence of rocks began to be laid down. The writer's hypothesis, however, is that the early Cambrian sea, though possibly widespread at other localities to the southeast in the Rocky Mountain provinces of Canada, was restricted in Alaska to a relatively narrow embayment more or less coincident with the present Ogilvie Mountains but possibly extending some distance northward and westward. This localization of marine sedimentation would account for the apparent absence of early Cambrian rocks elsewhere in interior Alaska.

No evidence has yet been found in Alaska or in Yukon Territory that suffices to prove or even to suggest strongly any marked interruption of sedimentation in Cambrian or Ordovician time. Rocks of Middle and Upper Cambrian age and of Lower Ordovician age are known along the international boundary just north of the Yukon, apparently in conformable sequence; and in other parts of interior Alaska rocks of Middle Ordovician (Mohawkian) and Upper Ordovician (Richmond) age are also found. Hence it would seem that the Cambrian and Ordovician seas spread gradually over Alaska, reaching their maximum extent in the Upper Ordovician epoch, for such rocks have been found well down into southwestern Alaska and in Seward Peninsula. Minor unconformities undoubtedly exist, as, for example, the discontinuity represented in the White Mountains north of Fairbanks, where middle Silurian rocks rest with apparent discordance upon Middle Ordovician rocks; but no great stratigraphic hiatus, accompanied by regional deformation, has yet been identified in the Cambrian and Ordovician seuqence. Apparently volcanic activity was slight in the Cambrian and early Ordovician but became progressively greater in late Ordovician time, as indicated by the late Middle Ordovician basic volcanic rocks of the White Mountains and the Upper Ordovician greenstones in the Nowitna Valley of southwestern Alaska.

No rocks of lower Silurian age are known in interior Alaska, and this fact might be used as presumptive evidence that between the Ordovician and Silurian rocks a stratigraphic hiatus, possibly an angular unconformity, exists. The contact relations between the Ordovician and Silurian rocks, however, have not been studied, and the writer is not in a position either to affirm or to deny this hypothesis. If such an unconformity can be shown, it should prove a convenient horizon in the stratigraphic column with which to correlate the Totatlanika schist, a formation of metamorphosed rhyolitic flows and interbedded sediments of Silurian or Devonian age found between the Tanana River and the Alaska Range. Middle and upper Silurian rocks, however, are well developed along the international boundary and at numerous other localities in interior, northern, and southwestern Alaska; and these rocks, which include a large proportion of limestone, indicate strongly another long period of undisturbed marine deposition comparable with the Cambrian-Ordovician deposition. These marine beds appear to have been affected to a minor degree by volcanism.

Lower Devonian rocks, also, are unknown in Alaska, but the meaning of their absence is better understood than that of the absence of lower Silurian rocks. The hypothesis has been proposed and evidence therefor given by the writer[6] that a great structural unconformity exists between the Silurian and Devonian rocks of northern and interior Alaska. Perhaps the direct evidence so far adduced for this hypothesis is better in northern Alaska than in the interior, but it is believed by the writer to hold for all of Alaska. Equally good is the evidence presented by the writer[7] to show that the

[6] Mertie, J. B., jr., Geology and gold placers of the Chandalar district: U. S. Geol. Survey Bull. 773, p. 234, 1925. Smith, P. S., and Mertie, J. B., jr., Geology and geography of northwestern Alaska: U. S. Geol. Survey Bull. 815, pp. 144–145, 1930.

[7] Mertie, J. B., jr., op. cit. (Bull. 773), p. 244.

emergence from the Silurian sea and the regional deformation of the Silurian and older rocks were accompanied in some areas, though apparently not along the international boundary, by the intrusion of granitic rocks. The unconformity resulting from these processes is regarded as one of the critical tie points in the geology of interior Alaska.

Marine sedimentation began again early in the Middle Devonian epoch and continued without major interruptions, though possibly with minor ones, to the end of Devonian time, resulting in the formation of the beds described as a part of the Woodchopper volcanics. The extrusion of basic lava began sometime in the early Devonian, but its first definitely recognized products occur in the late Middle Devonian, as exemplified by the Woodchopper volcanics. A part at least of the Woodchopper flows were of submarine origin. Surficial outpouring of basic lavas seems to have continued intermittently into the Upper Devonian epoch, and it is believed by the writer that certain ultrabasic rocks of deep-seated origin in interior Alaska may also have originated at the same time, but of this belief there is no absolute proof. The Middle Devonian rocks at the head of the North Fork of Shade Creek were deposited either contemporaneously with or somewhat later than the Woodchopper volcanics.

The relation existing between the representatives of the Devonian and Carboniferous systems is not entirely clear. A considerable sequence of marine Middle Devonian rocks is known along the international boundary and in interior Alaska, but Upper Devonian rocks have not yet been identified except in northern and southeastern Alaska. Along the Yukon and the international boundary, therefore, the Upper Devonian, in the light of present knowledge, appears to be represented by a depositional discontinuity, though not necessarily by a structural unconformity.

The earliest known events in the Carboniferous are the extravastation of the Rampart group and Circle volcanics and the deposition, more or less contemporaneously with these lava flows, of the lower Mississippian chert and shale. The chert formation is believed to be of marine origin, but numerous matters relating to its origin as well as its correct stratigraphic placement are as yet unsettled. Some of the lavas of the Rampart group are probably of subaqueous origin, but some of these rocks are clearly of intrusive origin. The complete history of this early Carboniferous volcanism on the Yukon can not yet be written.

The deposition of the chert was followed, without any stratigraphic hiatus or deformational movements, by the deposition of a marine upper Mississippian formation, known on the Yukon as the Calico Bluff formation and in northern Alaska as the Lisburne limestone. These upper Mississippian rocks constitute very important horizon markers in interior and northern Alaska. After the deposition of the Calico Bluff formation, marine sedimentation continued but changed gradually along the Yukon and the international boundary to a terrigenous type of sedimentation, culminating finally in the deposition of a great thickness of fresh-water sediments known as the Nation River formation. These deposits were then submerged below the sea, and upon them was laid down the marine Permian limestone.

Although several marine formations and one terrestrial formation were laid down during Carboniferous time, no major structural unconformity in the sedimentary sequence is recorded during this interval. This lack of angular unconformities is regarded as one of the typical features of the late Paleozoic history. The transitional beds between the terrestrial Nation River formation and the overlying marine Tahkandit (Permian) limestone may be seen on the Yukon opposite the mouth of the Nation River, with no evidence at all to suggest any interruption in sedimentation or intervening deformational movements; and, although a discontinuity in sedimentation has been recognized at the base of the Nation River formation, no angular discordance in the beds was observed. It can not, of course, be maintained on the basis of such negative evidence that sedimentation continued in this region without interruption during the entire Carboniferous period. Indeed, the transition from marine to terrestrial and back again to marine conditions must certainly have been accompanied by movements of the strand line of considerable magnitude. Unconformities without angular discordance may therefore exist in this sedimentary sequence, but they are not very evident; and the presence of an angular unconformity of any considerable magnitude seems much less probable.

After the deposition of the Tahkandit limestone all of Alaska apparently was elevated above sea level, and as no Lower or Middle Triassic rocks have yet been found anywhere in Alaska it is believed that a land mass existed in much or all of Alaska until the sea again invaded it in Upper Triassic time. One of the vagaries of this regional elevation and the following submergence is that the Upper Triassic rocks of the Yukon are fine-grained sediments, shale and limestone, which appear to lie conformably upon the Tahkandit (Permian) limestone. Fossiliferous beds of early Permian and Upper Triassic age lie practically in contact with one another without divergence in attitude. Therefore a very considerable discontinuity in sedimentation does in reality exist, but it is hard to conceive of the conditions of sedimentation that might have produced such a result. Evidently the elevation and subsequent depression of the land represented by the Lower and Middle Triassic time interval must have been of the plateau-forming type, the land moving upward and downward, with an absence or minimum of tilting or deformation in the earth's crust. Possibly an oscillatory movement of the strand line due to variation in the ocean level might better fit the facts. At any rate, a stratigraphic discontinuity exists at this horizon not only along the Yukon but at other localities in Alaska, and this discontinuity appears to characterize the transition from the Paleozoic to the Mesozoic. In some parts of Alaska, particularly in southern Alaska, great extravasations of basaltic lava accompanied the regional uplift and subsequent depression. These eruptions attained their greatest development in the interval between the Permian and the Upper Triassic. Along the Yukon, however, no lavas of Pennsylvanian, Permian, or Triassic age have yet been recognized.

At the end of the Triassic period this region was again extensively uplifted above sea level, and it appears to have remained so during all of Jurassic time. Some time during the Jurassic also occurred the great batholithic intrusions of granitic and related rocks, of which the batholith in the basin of the Charley River is a most striking example. The Lower Cretaceous conglomerates show little or no granitic material derived from such intrusive rocks, so that it is likely that the intrusives were injected late rather than early in the Jurassic and had not been uncovered to any large extent by erosion at the time of the formation of the Lower Cretaceous rocks. Concomitantly with these Jurassic granitic injections came the earliest period of mineralization of which there is any definite record in interior Alaska; and during this period were formed many of the gold-quartz veins of interior Alaska from which the present placers were subsequently derived.

By subsequent sinking of the land marine sedimentation was again begun in Lower Cretaceous time, resulting in the formation of the sandstone, slate, and conglomerate that now constitute the Kandik formation. After this epoch of marine sedimentation the land was again elevated, and a great series of fresh-water deposits, which constitute the assemblage of rocks here grouped as Upper Cretaceous and Eocene, was laid down. It is likely that this mid-Cretaceous regional elevation was accompanied by deformational movements that folded the Lower Cretaceous rocks prior to the deposition of the Upper Cretaceous rocks, thus resulting in an unconformity between these two groups of rocks. The structural relations in the Rampart district indicate that such an unconformity exists, but along the upper Yukon the two groups of rocks are not in contact, so that the hypothesis can not be absolutely proved. Nevertheless the unconformity is accepted as the probable condition.

As pointed out in the discussion of the Upper Cretaceous and Eocene sequence of rocks, there appears to have been no stratigraphic or botanic hiatus at the end of the Mesozoic era, so that as well as can be ascertained at present the Cretaceous deposition seems to have merged gradually into the Eocene through a transitional epoch.

After Eocene time, however, the region was again uplifted, and it has not been subsequently depressed below sea level. Hence no Tertiary marine strata are present in interior Alaska. Along with this regional uplift in post-Eocene time came further intrusions of granitic rocks of the same general character as those injected in the Jurassic. These intrusives, however, appear to have consolidated fairly close to the surface and at some localities reached the surface, forming rhyolitic and dacitic lava flows, of which those at the head of the Charley River are examples. These post-Eocene granitic intrusions also gave rise to the second known period of mineralization in interior Alaska, forming the later gold quartz veins and cinnabar deposits and at some localities reopening and enriching the Jurassic vein systems.

The post-Eocene history of Alaska is recorded mainly in ancient fluviatile gravel, in the sediments deposited during the Pleistocene epoch, and in the Recent stream alluvium. The interpretation of this record in terms of elevations and depressions of the base level of erosion is largely a physiographic problem the solution of which has hardly yet been begun. One fact in particular should be emphasized, namely, that interior Alaska, except in some isolated areas along the Yukon-Tanana divide, was not glaciated during the Pleistocene epoch. Yet it was bordered on the north, east, and south by great glaciers, and these, together with the climatic conditions which produced them, must have had a potent influence upon the nature of sedimentation in interior Alaska. Great bodies of black peaty silt were found deeply burying the pre-Pleistocene alluvial material, and such deposits, locally known as muck, themselves constitute an important problem in sedimentation and are as well one of the most hopeful sources of data bearing on Pleistocene conditions. The fine nature of these sediments shows that ordinary abrasion and movement of detritus by stream action was not the most typical process. Probably the mean temperature was low and precipitation also low, resulting in unusual conditions of erosion.

Although the Pleistocene is referred to as a glacial epoch, it is believed that interglacial stages formed a part of that epoch in Alaska, as in the States, but the glacial geology of interior Alaska has as yet received but little attention. For such study, as well as for post-Pleistocene glacial study, detailed topographic maps will be required, and little detailed topographic mapping has yet been done in Alaska.

ECONOMIC GEOLOGY

The principal source of exportable mineral wealth in this region is gold. The Eagle-Circle district and more particularly the Fortymile and Circle mining precincts, which lie to the south and west of the area here described, have long been known as sources of placer gold. Deposits were discovered at Franklin Gulch, in the Fortymile district, in the fall of 1887; at Birch Creek, in the Circle district, in the summer of 1893; and at American Creek, south of Eagle, shortly after the discovery on Birch Creek. All these old placer diggings are still producing gold.

No other mineral deposits are known in this region which give promise of possible commercial development in the near future. Some low-grade coal deposits exist, and attempts have been made to utilize these locally for fuel, but without success. Oil shale also is known at several localities, but this also does not seem possible of exploitation at the present time.

GOLD PLACERS

DISTRIBUTION

The accompanying map shows that all the creeks hereafter mentioned whose gravel has been mined for its content of gold lie southwest of the Yukon River, also that the granite intrusive bodies occur on the same side of the Yukon. The country northeast of the Yukon has not yet, to be sure, been much explored geologically, but the gravel from the streams draining that region does not indicate the presence there of any extensive granitic intrusives close to the river. The smaller degree of metamorphism seen in the rocks northeast of the Yukon also tends to confirm this idea. It is believed that all the placer gold in this region came originally from these granitic masses, although the proximate source may be gold quartz veins, mineralized shear zones, or ancient placer deposits. This distribution of gold placers is therefore only what might be expected from what is now known of the regional geology. This statement is not intended as a general proscription of all the region northeast of the Yukon as a possible seat of gold mineralization and gold placers, for practically all of the triangle between the Yukon and Porcupine Rivers and the international boundary is as yet unmapped geologically, and it may contain granitic bodies that have mineralized the surrounding rocks. But along the northeast side of the Yukon in the zone between Eagle and Circle the known geology does not encourage the hope for finding commercial gold deposits.

The two most productive gold placer camps in this region are the Fortymile precinct, lying south of Eagle, and the Circle precinct, southwest of Circle. Both these camps lie without the area included in this report and therefore will not be described. The Eagle-Circle district, as the term is used in this report, includes mainly the area contiguous to the Yukon between the settlements of Eagle and Circle. Within this area gold placer mines are being worked on American Creek, on the Seventymile River and its tributaries, on Fourth of July Creek, and on Woodchopper and Coal Creeks.

SOURCES OF GOLD

In a previous publication the writer[8] has outlined the geologic occurrence of mineral deposits, including the gold lodes, in interior Alaska and has drawn therefrom such conclusions as may be useful for prospectors and miners in searching for lodes and placers in this region. The fundamental thesis advanced is that the gold ores have originated as a phase of granitic intrusion; and that therefore where bodies of granitic rocks are found the conditions in general are favorable for the occurrence of gold. It does not, of course, follow that all granitic intrusives have functioned as mineralizing agencies; but on the other hand it is of decided value to know that where such rocks or the quartz veins which resulted from their presence are absent the chances for discovering workable lodes or placers are poor.

One modifying factor in this working hypothesis should be mentioned. The magmatic fluids that carried in solution the metallic elements appear to have escaped from the molten granitic rocks at a late stage in their cooling and to have migrated upward to points at or near the apexes of the intrusive bodies before the metallic elements were precipitated to form the quartz veins and other types of mineralized zones. Now it will be observed that both large and small bodies of granitic rocks occur in the Yukon-Tanana region, but it is probable that if one could follow them downward to great depths some or all of them would be found to connect underground with one another. This simply means that the granitic rocks approached somewhat closer to the surface at some localities than at others and that in the process of their subsequent uncovering by erosion of the land surface some of the intrusive bodies that came closer to the surface have been more extensively eroded and exposed than others that lay at somewhat greater depths. Hence the occurrence of granitic rocks with large surficial extent suggests at once deep erosion into the lower parts of such intrusive bodies, with the attendant removal ages ago of the upper or apical zones. Hence, if the mineralization has been concentrated, as supposed, at or near these apical zones, such areas of large surficial exposure of granitic rocks are regarded as less favor-

[8] Mertie, J. B., jr., The occurrence of metalliferous deposits in the Yukon and Kuskokwim regions: U. S. Geol. Survey Bull. 739, pp. 149–165, 1923.

able for the possible occurrence of metalliferous lodes. On the other hand, bodies of granitic rocks with small surficial area are in general interpreted as the apical parts of larger underlying granitic masses; and as their upper zones have not been removed by erosion, such bodies are regarded as more favorable sites for mineralization. Hence, it is believed that the best places to prospect for possible metalliferous lodes in the Yukon-Tanana region are at or near small outcrops of granitic rocks that are not more than 2 or 3 miles in diameter. Conversely, large granitic bodies like the one which covers nearly all of the Charley River Basin are not regarded so favorably as possible seats of mineralization.

In much of interior Alaska, however, on account of the high costs of mining, metalliferous lodes have little present value unless they are of bonanza character; and such lodes are rare. Therefore the prospector is naturally more interested in placer deposits, especially in gold placers. Lodes must, of course, have existed at some time in order to produce the gold which subsequently became concentrated in the placers; hence the same generalizations that apply to prospecting for lodes apply also to prospecting for placers—that is, the streams best to prospect are those which drain areas where mineralization is known or may be expected to be present. In regions where extensive glaciation has taken place this generalization may not hold true, for the gold placers, if they were formed prior to the last advance of the glaciers, may have been destroyed and dissipated by the ice action. In the Yukon-Tanana region, however, practically no glaciation has occurred, so that this added complication does not enter into the matter.

In the Eagle-Circle district the gold of the placers on the Seventymile River and tributaries, Fourth of July Creek, and Woodchopper and Coal Creeks came originally from the granitic rocks that lie to the southwest. But the proximate source of some of this gold is in the coarse sandstones and conglomerates that extend from Eagle northwestward at least as far as Woodchopper Creek. This is not hard to understand when it is remembered that most of these granitic rocks were intruded during the Jurassic period, whereas the conglomeratic rocks were formed long afterward, in Upper Cretaceous or Eocene time. In other words, these conglomerates represent ancient gold placers, which originated so long ago that they have since become consolidated into rock. Moreover, it is probable that at the time of their formation the regional erosion level was much higher than at present and that only the upper parts of the big Charley River granitic body were then exposed to erosion. Hence the Charley River batholith, though now regarded as a not particularly favorable site for gold placers, was probably in Eocene time a more favorable area for lodes and for placer accumulation and probably did in fact supply the gold of the Upper Cretaceous and Eocene conglomerates. The recent streams in this area have therefore obtained a part of their gold from the destruction of the old fossil placers and have reconcentrated it in the present drainage channels. But the streams southwest of the conglomerate belt—for example, the tributaries of the Seventymile River above Barney Creek—have probably derived a part of their gold directly from the original gold lodes.

It does not follow, however, that all the streams that drain the Upper Cretaceous and Eocene belt are favorable sites for gold placers, for three reasons: (1) Some of these old conglomerates may consist of gravel laid down by streams that did not head far enough to the southwest to have tapped mineralized zones. (2) Even where the ancient streams drained out of bodies of mineralized country rock the gold was probably irregularly distributed in the old placer bodies, just as it is in many present-day gold placers. (3) The Upper Cretaceous and Eocene rocks have been greatly folded and otherwise disturbed from their original nearly horizontal attitude; this feature alone would make for irregular distribution of gold, even if the ancient streams had developed long, continuous pay streaks.

Therefore, although some of the gold which came originally out of the Charley River batholith may be preserved in these old conglomerates instead of being widely dissipated into larger stream valleys like the Yukon, yet the present irregular distribution of gold in the conglomerate belt adds an element of uncertainty to the problem of prospecting in the streams draining it that is not unlike the uncertainty that attends prospecting in recent stream gravel in glaciated areas. In other words, prospecting can be done more intelligently in the part of the area southwest of the Upper Cretaceous and Eocene belt, where, as in the Fortymile precinct, the gold placers have been derived for the most part directly from the original gold lodes rather than by reconcentration from earlier placer deposits.

PLACER-MINING OPERATIONS

No extensive study of the gold placer-mining operations on the streams between Eagle and Circle has been made by the writer, but most of the placer-mining plants were visited in 1925, in order to obtain a general idea of the character of the placers and of mining conditions. On American Creek the Upper Cretaceous and Eocene rocks extend from the mouth upstream for about 4 miles, but the placer-mining operations were confined to a zone beginning about 4 miles farther upstream, where the bedrock consists of schist, serpentine, and other metamorphic rocks. At this point American Creek is joined by Discovery Fork, which enters from the southeast.

One operator, who owns Discovery claim at the forks and five claims below and six above Discovery claim, on American Creek, was preparing for hydraulic operations on a large scale. The stream gravel which was to be worked ranged in thickness from 3 to 10 feet. Three other men were operating small plants on Discovery Fork. The gold from American Creek is said to yield $17.25 to the ounce at the mint but is accepted at $16.70 commercially at Eagle.

On the Seventymile River the largest operating plant was at the upper end of Discovery claim on Crooked Creek. The bedrock on Crooked Creek belongs entirely to the Upper Cretaceous and Eocene sequence, and much or all of the gold in the present placers has probably been reconcentrated from the ancient conglomerates. The stream gravel that was being worked is from 5 to 6 feet thick in the center of the cut but becomes thicker toward the east valley wall. The pay streak, where worked in 1925, was 240 feet wide, but it is probably narrower upstream in the direction in which operations were being extended. The ground here averages about 18 cents to the square foot of bedrock, and the gold is of fairly high grade, yielding about $18 an ounce in Eagle. The largest nugget so far found was valued at $3.50. This ground was being mined by hydraulic operations, the gravel being moved by two 2½-inch nozzles under a 100-foot head, and the tailings being stacked downstream by a 3-inch nozzle. The water for the nozzles was obtained from a ditch that taps Crooked Creek farther upstream, but as work progresses upstream a higher ditch will have to be dug in order to obtain the necessary head.

About 2 miles up the Seventymile River from Crooked Creek and on the same side of the river hydraulic placer-mining operations on a small scale were being carried on in 1925 at the mouth of a little creek called Broken Neck Creek, but this work proved unprofitable and was subsequently discontinued. The bedrock here, as on Crooked Creek, is the old conglomerate formation, and about 3 to 5 feet of gravel from 20 to 50 feet wide was being worked at the time of the writer's visit.

About 3 miles farther upstream, on the north side of the Seventymile River, another man was at work mining the river bars and prospecting. At this point the conglomerate formation lies to the northeast, and the country bedrock consists of quartzite schist, quartz-mica schist, amphibolite schist, and basalt and diabase of greenstone habit; but at one place along the river bank a piece of the conglomerate was seen faulted into the older schistose rocks. The Seventymile River at this point cuts through a short gorge in rapids which are known locally as "The Falls." The valley of the river here has a number of well-developed benches, one of which, about

12 feet high, shows well on the north side of the river and slightly on the south side. On the north side, at a level 4 to 5 feet higher than the 12-foot bench, a great flat extends to the hills. On the south side another prominent bench occurs about 125 feet above the river level. These benches, particularly the lower ones, are being prospected by hand methods.

Barney Creek, about 6 miles farther upstream and also on the north side of the Seventymile River, is an old placer-mining site, but no mining operations were being carried on there in 1925. This creek also flows entirely through the Upper Cretaceous and Eocene rocks, and the gold in the placers probably came from that source.

Two other mining plants were being operated still farther up the Seventymile River, on the south side, the uppermost of which, on Alder Creek, had been worked intermittently for many years. This is a hydraulic plant working stream gravel, but as the bedrock is composed entirely of the old schistose rocks, the gold has doubtless been derived directly from original mineralization in the valley of Alder Creek, produced by the granitic intrusives. The other plant, on Nugget Creek, was worked on a small scale, mainly by hand methods.

Farther down the Yukon, south of Nation, Fourth of July Creek is the site of another good-sized hydraulic plant, which had been in operation for several years. The lower part of Fourth of July Creek cuts across the Tahkandit (Permian) limestone, but in the upper part, where the mining operations were being carried on, the bedrock is the same Upper Cretaceous and Eocene conglomerate strata seen on the Seventymile River and on American Creek. The pay streak is about 500 feet wide and the gravel is 10 to 15 feet thick, covered by 2 to 7 feet of black muck. The gold lies in the lower foot of gravel, and in the bedrock, it being necessary at places to mine 2 feet of bedrock in order to obtain all the gold. The gravel in the placers ranges in size from 2 to 10 inches, but a few boulders as much as 2½ feet in diameter are encountered. The pebbles of the conglomerate bedrock are mainly flint and quartzite, with some vein quartz and rarely a piece of greenstone, and naturally the stream gravel is similar in character. Curiously enough, no granitic pebbles were seen at this locality either in the bedrock or in the overlying gravel. The gravel at this plant ranges in value from 20 to 30 cents to the square foot of bedrock.

The July Creek Placer Co. owns nearly 3 miles of claims on Fourth of July Creek, from claim 10 to claim 21 above Discovery, and plans to continue its mining operations for a number of years. Two ditches have been built, a lower one 2½ miles long, which taps the upper part of Fourth of July Creek, and an upper one 9¼ miles long, which takes its water from the head of Washington Creek. The discharge from the upper ditch enters Ruby Creek, a headwater tributary of Fourth of July Creek, and helps to feed the lower ditch farther downstream. The pay streak, 500 feet wide, is mined in cuts 250 feet wide, working for a distance of 100 feet and then returning for the other half. The muck overlying the gravel is first ground-sluiced off, then three 2½-inch nozzles under a head of 160 feet are used to move the gravel. A line of eight or ten 12-foot sluice boxes are used, with a steel shear board suspended longitudinally over them, thus making it possible to move gravel into the sluice boxes simultaneously from both sides of the boxes.

Little active mining is in progress on Woodchopper and Coal Creeks. The chief placer mining during the summer of 1925 was on Mineral Creek, a small right-hand tributary of Woodchopper Creek, about 5 miles from the Yukon. Here the baring of the bedrock by placer mining has revealed the contact between the lower Mississippian chert conglomerate and the Upper Cretaceous and Eocene conglomerate, the latter occurring upstream from the former. The pay streak is about 100 feet wide, and the gravel and muck are about 10 feet thick. Mining was being done by open cutting, aided by a small nozzle.

On Iron Creek, another eastern tributary of Woodchopper Creek, 2 or 3 miles above Mineral Creek, two men were at work in 1925, one on Discovery claim, at the mouth of Iron Creek, and another on claim No. 2 above Discovery. The work on Discovery claim was underground work done by winter drifting. The work on No. 2 above consisted of open cutting and shoveling in about 3 feet of gravel and 2 feet of muck, taking 8 feet on each side of the sluice boxes. The pay streak here is spotted and irregular, but the gold is coarse and of high grade, one sample sent to Seattle assaying $18.75 an ounce.

Three other men were at work farther up Woodchopper Creek, engaged in small-scale winter drifting and prospecting.

No placer-mining operations were in progress on Coal Creek at the time of the writer's visit in 1925, but this creek has been mined intermittently at a number of places in recent years. The bedrock at the mouth of Coal Creek and for 4½ miles upstream is the Lower Cretaceous black slate, which is followed upstream for 3½ miles by the lower Mississippian chert and chert conglomerate. Above this the Upper Cretaceous and Eocene rocks cross the creek. Two groups of claims on the creek are now held mainly by two men. The upper group lies at the lower end of the Upper Cretaceous and Eocene conglomerate, and the gold in these placers has probably been derived in part from the reconcentration of these ancient gold-bearing rocks. The lower claims lie mostly in the black-slate zone, and it seems likely that the gold in these placers may have been derived from a mineralized zone in the creek itself, for this lower gold is brighter in color, coarser, and higher in grade than the gold from the upper claims. The pay streak on the lower claims is 100 feet wide and the gravel from 12 to 20 feet thick. The ground worked by the owner has not yielded less than 75 cents to the square foot of bedrock, although placers of lower grade than this are undoubtedly present. These two groups of claims, which together comprise 7 miles of placer ground on Coal Creek, should be thoroughly prospected and if possible should be mined as a unit. This should make a good hydraulic venture for some company, for Coal Creek always has plenty of water, and mining would therefore not be at a disadvantage, as it is on some of the smaller gold-bearing creeks tributary to the Yukon.

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