United States

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U.S. Geological Survey

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Geological Investigations

Naval Petroleum Reserve No. 4

Alaska

Special Report No. 43

REGIONAL INTERPRETATION OF THE GEOLOGY OF THE KONGAKUT-FIRTH RIVERS AREA, ALASKA

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by

Marvin D. Mangus

May 1953

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REGIONAL INTERPRETATION OF THE GEOLOGY OF THE KONGAKUT-FIRTH RIVERS AREA, ALASKA

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INTRODUCTION

In 1952 the National Park Service became interested in setting aside a large wilderness area in northeastern Alaska. The area is approximately 7,000 square miles in size, with boundaries as follows: beginning at Camden Bay south along the Katakturuk River to lat. 68° N.; then east to long. 144°33' W.; south to lat. 68° N.; then east to the Canadian Boundary. The two river areas which the Park Service is most interested in examining for ecology, botany, archeology, and geology are the upper Firth and Kongakut Rivers.

The U. S. Geological Survey has been asked to participate in this project, and it was decided before the actual field work was started that all the past geologic work on the area should be reviewed and integrated with the geologic investigations now being made in adjacent areas. The Navy Oil Unit, Alaskan Geology Branch, U. S. Geological Survey, has been conducting extensive geologic investigations in northern Alaska since 1944, and has been very interested in this area since the U. S. Navy's exploration program in Naval Petroleum Reserve No. 4.

An investigation would be of benefit for the following reasons:

1. It is now apparent from the detailed investigations of the Paleozoic strata in the vicinity of Lake Schrader-Peters and the upper Sheenjek River that if geologic work were done along the Firth-Kongakut Rivers, much needed information would surely be obtained to help interpret and give a better understanding of the regional geologic history. The geologic history would be an important key in defining structural highs as potential possibilities for petroleum reservoirs.

2. As most of the metalliferous deposits in northern Alaska occur in granitic rocks, it would seem advisable to examine the area for evidence of igneous activity. The eastern area contains the only large body of known granitic rocks on the north side of the Brooks Range, although other masses have been reported by earlier prospectors and explorers. It is possible that radioactive minerals may be associated with these igneous rocks. Small amounts of precious metals, mostly gold, have been reported along the drainages of the Firth and Kongakut Rivers.

Previous investigations.--Past geologic investigations by the U. S. Geological Survey in this 7,000-square-mile area have been very limited. E. de K. Leffingwell (1919) under private funds made geologic investigations in the area between the Canning and Okpilak Rivers in 1906-14. A. G. Maddren (Bull. 520, progress report) was assigned to study the geology in conjunction with the International Boundary Survey between Alaska and Canada in 1911-12. (No maps or final detailed reports on the results of this work were ever published.) J. B. Mertie (1927) made a reconnaissance survey along the southern fringe of the outlined area in the Chandalar-Sheenjek District. In 1914 the Canadian Arctic Expedition made a very limited geologic reconnaissance survey of an area 50 miles inland on the Firth River. In 1948 the Navy Oil Unit (Whittington-Sable, 1948) reexamined Leffingwell's area between the Sadlerochit and Okpilak Rivers. During the 1952 field season, Navy Oil Unit geologists made detailed geologic investigations in selected localities within the area now to be investigated by the U. S. Park Service (Brosge-Dutro-Mangus-Reiser).

Future Plans.--From examination of aerial photographs it appears that the Kongakut River would be the best river to descend--not only from a geologic standpoint--but for boat traverse. This river, as well as the Firth River, was used as a migration route by ancient and modern man. The biggest disadvantage of the Firth River is its great number of rapids for a distance of 30 miles where the river has incised itself deeply and is confined to a swift channel.

Maps

Available World Aeronautical charts of this entire area are published at the following scales: 1:1,000,000; 1:500,000; and 1:250,000. Partial maps made from trimetrogon photographs at a scale of 1:48,000 cover the area only as far east as the Jago River and south to approximately lat. 69° N. Excellent coastal maps and hydrographic coverage arebeing made from 1:20,000-scale vertical photographs and land triangulation by the U. S. Coast and Geodetic Survey.

Aerial photographs.--The photographic coverage of this area is limited, and although the entire area has been flown for mapping purposes, the photographs are unsuitable for geologic use. Below is a list of the available good photographs of this area:

1. U. S. Navy, Trimetrogon:

   a. BAR-345 photos 1-157.

   b. BAR-360 photos 1-54.

   c. BAR-364 photos 1-28.

These cover from Okpilak River to the Canadian border or approximately 69°10' to 69°40' N.

2. Royal Canadian Air Force:

   a. Roll 13 photos 74-79.

   b. Roll 13 photos 29-73.

   c. Roll 14 photos 101-136.

   d. Roll 14 photos 137-168.

   e. Roll 16 photos 154-202.

These cover from Herschel Island to the Firth River south of Mancha Creek and as far west as long. 141°31'.

GEOGRAPHY

The Firth-Kongakut Rivers area of Alaska is still very remote and inaccessible. The airplane is probably the most important means of Arctic and sub-Arctic transportation and without its use many of these scientific investigations would be next to impossible. Walking is very difficult in most of the area, but in many places is the only means of travel. Pack horses have been and can be used, but at great expense. Thus, during the summer months, boats are the most economical transportation for both men and equipment.

In this report northeastern Alaska will be divided physiographically into five provinces as follows:

1. Brooks Range province.

2. Arctic Foothills province.

3. Coastal Plain province.

4. Southern Piedmont province (the uplands on the south side of the Brooks Range).

5. Yukon Flats.

Brooks Range province

The Brooks Range, in the past sometimes called the Arctic Mountain System, has been considered both as the western extension of the Rocky Mountains and as a distinct mountain system. If the Range is a distinct mountain system (Brooks, A. H., 1916), it is connected to the Rocky Mountains by the lower, flat-topped Richardson Mountains which form the Mackenzie-Porcupine Rivers divide. The Brooks Range trends roughly west across northern Alaska. Along the 141st meridian the mountain belt is 60 miles wide, whereas along the 146th meridian it is approximately 100 miles wide. The average summit altitude of the Brooks Range between the 141st and 145th meridians is about 5,000 feet, with many peaks rising above 6,000 feet. Between the headwaters of the Okpilak-Hulahula and Chandalar Rivers a small group of mountains rises to an average summit height well over 7,000 feet, with several peaks over 9,000 feet.

The Brooks Range in the area here described is subdivided into four mountain groups. These mountain groups are, from west to east: (1) Franklin Mountains, (2) Romanzof Mountains, (3) Davidson Mountains, and (4) British Mountains. There are three short structural ranges (geologic structure) that lie north of the main Franklin group. These are the Shublik and Sadlerochit Mountains, and the very narrow Third Range which lies between the Canning and Sadlerochit Rivers (Leffingwell, p. 51).

The Franklin Mountains, characterized by a very bold northern boundary, lie west of the Romanzof Mountains, and have a general relief of 2,000 to 3,000 feet with summit altitudes near 5,000 feet.

The Romanzof Mountains are a small group of very high, rugged, glacier-bearing peaks situated between the Jago and Hulahula Rivers; the general summit altitude is over 7,000 feet, with several glacier-covered masses rising over 9,000 feet. When viewed from a distance these mountains appear to be welded into one mass that stands above the intervening mountains, making a very prominent profile against the skyline.

The British Mountains, like the Franklins and Romanzofs, are entirely in Arctic drainage. These mountains begin east of the Kongakut River and trend S. 69° E. into Canada; they have much lower relief than the Romanzof Mountains, but are very rugged with a general summit altitude of 4,000 feet.

The Davidson Mountains form an abrupt, bold, escarpment with a general relief of 2,000 to 3,000 feet, and many individual peaks rise over 6,500 feet. These mountains lie south of the Kongakut River and are drained by the Sheenjek, Coleen, and Firth Rivers.

Arctic Foothills province

The Arctic Foothills province, formerly called the Anaktuvuk Plateau, (Leffingwell, p. 52; Maddren field notes, 1912; O'Neill, 1914, p. 112), lies north of the Brooks Range province and south of the Coastal Plain province. It consists of a series of relatively low rolling, tundra-covered hills and ridges with a general relief of 1,000-1,500 feet.

At the Canning River the Arctic Foothills province is approximately 20 miles wide, and broadens to 30 miles near the mouth of the Firth River, Canada.

Coastal Plain province

North of the Arctic Foothills province, the Coastal Plain province is a featureless, flat-lying, poorly drained, tundra-covered region that grades southward into the foothills. Near the Canning River the province is approximately 20 miles wide and narrows to several miles in width near the Firth River, where the narrow coastal plain changes very abruptly into the Arctic foothills.

Southern Piedmont province

The Southern Piedmont Province, approximately 50 to 70 miles wide, in the area of the Sheenjek-Coleen Rivers is an area principally of low, rolling hills that have a general summit altitude of 2,000 feet, although some are as high as 4,000 feet. Northward these hills rise abruptly into the Brooks Range.

Yukon Flats

To the south of the Southern Piedmont province are the Yukon Flats. This swampy, alluvium-filled country is practically devoid of relief, the general altitude of the "flats" being approximately 1,000 feet to 1,200 feet. The streams are very sluggish with an average gradient of 10 to 14 feet per mile (Mertie, Bull. 810, 1927).

Drainage

The northern part of the wilderness area is drained by 11 fairly sizable rivers. These rivers have a rapid run-off during the "breakup" and rise 5 to 10 feet above normal water level. In the mountains most of the rivers are confined to glacial troughs and rush out onto fairly flat plains, building extensive gravel flats along their course.

The names of the rivers from west to east are the Canning, Sadlerochit, Hulahula, Okpilak, Jago, No Name 1, No Name 2, Aichillik, Kongakut, Clarence, and Firth.

The southern slopes of the area are drained by three major streams: the East Fork of the Chandalar River, Sheenjek River, and Coleen River. The East Fork of the Chandalar River and the Chandalar River join, flowing directly into the Yukon River; the Sheenjek and Coleen Rivers are tributaries of the Porcupine River, which in turn flows into the Yukon.

North-draining streams.--The Canning River is the largest in this area (Gryc and Mangus, 1947), although it drains only the extreme northwest part. The Canning is approximately 110 miles long and flows mostly through glacial troughs for the first 60 miles. The mountains along its course rise to altitudes 2,500 feet to 3,500 feet above the valley floor. The Marsh Fork, which parallels the Canning for approximately 40 miles and cuts across the geologic structures, joins the Canning approximately 70 miles from its mouth. Where the two forks merge, the main river flows through large gravel flats three fourths of a mile to 1 mile in width; beyond the mountain front it flows through the Foothills province for 20 miles. The river then crosses the coastal plain, where its banks are extremely low, (1 to 5 feet high), and about 10 miles from the coast the river splits into two channels. The western channel or distributary is unnavigable during most of the summer, but the eastern channel is good for small boats.

The Sadlerochit River for almost half its course has two main branches: the western branch heads in the mountains several miles southwest of Mt. Chamberlain, and the eastern or Lake Fork (Neruokpukkoonga) drains two large glacial lakes and the northern slopes of Mt. Chamberlain.

The West Fork (which originates southwest of Mt. Chamberlain) makes its way across resistant geologic formations forming small waterfalls 3 to 6 feet in height (Whittington, Sable, 1948). These numerous falls and the lack of water make the stream unfit for traversing with a small boat.

The East Fork or Lake Fork heads from melting glaciers and flows 12 miles north through a narrow glaciated U-shaped valley before emptying into Lake Peters. The two glacial lakes, Peters and Schrader, are connected by a small channel about 30 feet wide, 100 yards long, and several feet deep. The altitude of the two lakes is near 3,000 feet; the surrounding mountains rise 3,000 to 4,000 feet above the lake. From the north end of Lake Schrader the East Fork tumbles violently across large glacial erratics and morainal debris, and twelve miles north of Lake Schrader the east and west streams join, making a river navigable for small boats. The river then swings northeast for 10 miles around the east end of the outlying Sadlerochit Mountains. Here during low water the river flows over glacial boulders, making it difficult for small boats to navigate. Once past the mountains it spreads out, running through gravel flats to the coast.

The Hulahula River flows northward in a straight line the entirety of its course. The river is 80 miles long, cuts across the strike of geologic structures, and is confined to a moderately narrow glacial trough. Along this narrow valley the mountains have a general relief of 3,000 feet. About 40 miles from its head, the river is confined to a single channel, a narrow constriction between 1 and 2 miles long in greenstone. Once the river passes through the greenstone canyon it immediately widens in the foothills province. About 20 miles inland from the coast the river banks become low (2-5 feet) and the stream flows across the rest of the coastal plain practically on the surface. The Hulahula is navigable by small boat from the "canyon" to the Arctic Ocean (Whittington, Sable, personal communication).

The Okpilak River is one of the finest examples of a glaciated stream in northern Alaska. It is about 70 miles long and heads from some of the many glaciers in the Romanzof Mountains. Here the mountains rise 4,000 to 4,500 feet above the valley floor. Near the edge of the mountains the valley floor is covered with large conspicuous talus fans and morainal benches that tend to confine the stream to one channel. The river flows through the mountains for 24 miles and then through the Arctic Foothills province. There the river is in a relatively narrow trough which is 1,000 to 1,200 feet below the summits of the foothills. The 9-mile stretch of river in the Coastal Plain is very braided, with low sand banks; near the coast it splits into several shallow distributaries. This stream can be navigated by small boats but with some difficulty. (Leffingwell, 1919, p. 58; Whittington, Sable, personal communication).

Untraversed streams.--The known Arctic drainages which have never been traversed by U. S. Geological Survey geologists were examined on existing aerial photographs. These rivers are between the Jago River and the Canadian boundary.

The Jago River is approximately 80 miles long and heads in some of the high glaciers in the Romanzof Mountains. It appears to carry about the same volume of water as the Okpilak River. For the first 40 miles the river is confined to a narrow, glaciated, U-shaped valley with its floor probably 3,000 feet below the average mountain top. From the mountain front the river flows through the Arctic Foothills province for 20 miles. Along the course of the stream rapids were observed which are due to glacial erratics. For the last 20 miles the Jago flows across the coastal plain in a braided channel. The river appears to be navigable with difficulty by small boats. According to Leffingwell (1919, p. 53) the Jago River was never travelled or hunted along by the natives until recently (1910-1912), because they thought it housed devils. A more logical reason is that there are few willows for camping use and no good passes into the Chandalar or Sheenjek Rivers area.

Approximately 40 miles northwest of the Canadian boundary a stream which appears to be larger than the Hulahula enters the Arctic Ocean. This stream is not named on existing maps, but will probably be named on the new U. S. Coast and Geodetic Survey maps now being compiled. For the purpose of this report the river shall be called No Name 1.

No Name 1 River is approximately 65 miles long and heads in the northeastern end of the Romanzof Mountains and against the headwaters of the Kongakut River. The river flows generally N. 15° E. and has two main branches that flow 25 miles through rugged mountains. Both forks are confined to glacial troughs flanked by mountains that appear to be 2,500 to 3,000 feet above the valley floor. The forks coalesce at the mountain front and the stream flows through the

Arctic Foothills province for a distance of 15 miles. The river then flows the remaining 20 miles through the coastal plain and appears to enter the ocean in one channel. The river could be navigated by small boat as far south as the two main forks.

Approximately 30 miles northwest of the Canadian border a stream which will be called No Name 2 River joins the Aichillik River several miles from the coast. Where the two rivers join on the coastal plain they build a large wide gravel flat with many small distributaries entering the ocean.

No Name 2 River is approximately the same size as No Name 1 and is about 50 miles in length. The river heads against the Kongakut River and has an almost perfect semi-oval course. The stream begins at the 142nd meridian, then flows northwest to long. 142°41' W., turns and flows northeast to the 142nd meridian where it empties into the ocean. The river flows for 20 miles through rugged, glaciated mountains that are lower than those along No Name 1 River. The stream appears to be navigable by small boat from the point where the river reaches the mountain front, bends and flows northeast. The river is confined to a gentle trough as it flows through the foothills province, and braids considerably when it reaches the coastal plain.

The Aichillik River, only 35 miles long, heads against the western tributaries of the Kongakut River. The ridges at the head of this stream would be placed by the writer in the Arctic Foothills province. The ridges appear to have an average relief of 1,000-1,200 feet. The stream is very braided and is too shallow for small boats. Contrary to earlier reports by natives to Leffingwell (1919, p. 58), there are low passes to the rivers east and west. About 16 miles from the coast the stream flows across the coastal plain through large gravel flats and joins No Name 2 River several miles from the coast.

About 5 miles east of Aichillik River a small braided stream heads in the higher ridges of the Arctic Foothills province. The stream is about 18 miles long and becomes practically dry during the summer months.

The Kongakut River, the largest between the Canning River and the Canadian border, was called the Turner River by Leffingwell (1919, p. 58). This river is approximately 100 miles long, but the airline distance from its head to the coast is 65 miles. It heads in the southeast and east end of the Romanzof Mountains against the Sheenjek and East Fork of the Chandalar River. For the first 25 miles the river flows due east through a structurally controlled valley of relatively unresistant late Paleozoic and Mesozoic sedimentary rocks. From aerial photographs it appears that this stream valley once drained southeast into the upper Firth River. The river then swings northeast across more resistant rocks through a deep glaciated valley. As the river cuts across the geologic structure it is joined by large tributaries that flow parallel to the strike of the rocks. In several localities the stream braids, dispersing the water into many shallow distributaries which are unnavigable for small boats. Just west of Mount Greenough the river is mostly confined to one channel and is navigable by small boat for the rest of its course. The general relief of the mountains from the valley is 2,500 feet to 3,000 feet. Where the river passes through the mountain front it makes a very marked northwest turn and it appears to skirt some geologic structures. The river flows for 15 miles, then is joined by two sizeable north-flowing tributaries that head against the Aichillik River. Here the river makes a right-angle turn, flows through the Arctic Foothills province for 8 miles, then onto the coastal plain where it splits into two braided channels before entering the ocean.

The Turner River (not to be confused with Kongakut River) is a small stream only 10 miles long that empties into Demarcation Bay 10 miles west of the Boundary. These stream has its headwaters in the northern fringe of the rolling foothills and appears to be too small for navigation.

The Clarence River is a small braided river that flows along the 141st meridian, and is about 25 miles in length. It heads in relatively low mountains with summit altitudes near 3,000 feet. It flows northwest for 16 miles where it then abruptly enters the coastal plain. Here the river swings northeast, splitting into several channels which in turn split into distributaries. After crossing 4 to 5 miles of an extremely well developed alluvial fan the wandering channels unite in one braided stream and flow north along the Canadian border for several miles. The river is deeply channeled for several miles before entering Clarence Lagoon.

The Firth River, which is probably equivalent to the Kongakut River in size, is 100 miles long. Two main forks join 65 miles south of Herschel Island, Canada. The northwest fork, Joe Creek, heads in the southwest slopes of the British Mountains against the east tributaries of the Kongakut River, and the main Firth heads in the northeast Davidson Mountains against the Coleen River to the southwest and the Old Crow River to the south. Joe Creek is 30 miles long and is essentially a structure-controlled stream confined to a narrow, partly glaciated trough, entirely within the Brooks Range province. The main Firth runs through a rather wide trough in the Southern Piedmont province. In one locality the river is extremely braided, and small boat navigation would be difficult or perhaps impossible. At the confluence of Joe Creek and the Firth River the stream becomes entrenched in what appears on photographs to be a rock-walled canyon 30 to 100 feet deep. Many rapids are present since the river cuts across the geologic structure and outlying glacial debris. This canyon is approximately 30 miles long and runs northeast through the Brooks Range province for about 20 miles, then through the Arctic Foothills province for 12 miles.

<u>South-flowing streams</u>.—The southern part of the area is drained by three large rivers, from west to east: the East Fork of the Chandalar River, the Upper Sheenjek River, and the Upper Coleen River.

The upper East Fork of the Chandalar River, which drains only a very small corner of the area, heads in the high glacier-ridden peaks of the southwest end of the Romanzof Mountains. Here the mountain peaks rise 3,000 to 4,000 feet above the valley floor, which is a deep glacial trough. In the headwaters the stream can be crossed on foot at almost any place. It is fed by melting glaciers and on warm summer days the stream becomes milky and swollen in mid-afternoon.

The lower Chandalar River area is not covered in this report, but was studied by J. B. Mertie (1927, p. 91).

The upper Sheenjek River is approximately 40 miles long, and heads in the southern slopes of the rugged glacier-covered peaks of the Romanzof Mountains. The valley is a broad glacial trough with adjacent mountains rising 3,000 feet to 4,000 feet above the valley floor. Above Star Lake (Brosge, Dutro, Mangus, Reiser, 1952) the stream is braided and can be crossed fairly easily by foot, but below Star Lake the river is essentially confined to one channel. Here the valley floor is covered with oxbow lakes, glacial lakes, and glacial moraines. In this area the river meanders slowly through the unsorted glacial debris. Where the river crosses morainal deposits small rapids are developed; in many places the moraines are 50 to 75 feet high and are excellent for walking. The lower Sheenjek River has been described in detail by Mertie (1927, p. 93).

The upper Coleen River, for which photo coverage is very poor, has never been visited by U. S. Geological Survey parties, but from the air it appears to be like the upper Sheenjek River. Although the relief is not as great nor the topography rugged as along the upper Sheenjek, glacial traces were noted, and a similar slow, meandering river and lake country is developed.

Springs.--There are three large springs in the area here discussed. The best known and probably the largest spring is at the southwest end of the Shublik Mountains and was named Shublik springs by Leffingwell (1919, p. 58). The spring flows from an orifice near the contact between the Sadlerochit sandstone and Lisburne formation. This spring flows all winter, and from all indications appears to be meteoric with a temperature of 40°-45° F.

The second spring is located in the northeast end of the Sadlerochit Mountains; it was first reported by the Canadian Arctic Expedition in 1914 (Leffingwell, 1919, p. 58). The temperature was measured in October of that year as 50° F. The writer has viewed the spring from the air in mid-April and it appears to be as large as, or even larger than, Shublik spring.

The third spring was noted by the author from the air in mid-April of 1952 on the east side of the upper Sheenjek, 3 miles north of Star Lake. This spring was flowing although the temperature was -30° F. The spring flows from several large "glacial pot" depressions, 25 to 50 yards in diameter. In mid-August of the same year the spring was visited and examined and was also found to be a meteoric spring. A large volume of water flows from the spring, but it is smaller than Shublik or Sadlerochit springs.

Climate.--Only a general statement will be made on the climate of the area. The part of the area north of the Brooks Range has the typical Arctic climate, consisting of long cold winters and short fairly warm summers. The average annual precipitation for this northern area is 7 to 10 inches. The annual snowfall is between 10 and 24 inches, with the snowfall deepest in the mountains. Rainfall is rather evenly distributed through the months of June, July, and August, with occasional light snows through the three summer months. The freezeup usually occurs in mid-October, and the breakup in late May or early June.

The southern part of the area has a sub-Arctic climate. Here as in the Arctic a semiarid to arid climate exists. The average snowfall is 36 to 54 inches a year with maximum fall in the mountains (Mertie, 1927, p. 103). The short summer months are noticeably warmer, with the breakup several weeks earlier and freezeup several weeks later than on the north side of the mountains.

It is thought that the source rain for this area comes from the southwest or Yukon basin, as the Arctic Ocean seems to be too cold for the air to carry much moisture.

ANIMALS AND PLANTS

The larger animals in the area are moose, caribou, sheep, wolf, grizzly, and black bears (black bears are predominantly in the timber of the south side). The smaller animals are the wolverine, fox, marten, weasel, ground squirrel, rabbit, lynx, porcupine, muskrat, beaver, and others. The porcupine, although seen several times on the north side of the Brooks Range, is usually confined to the southern slopes with the beaver, muskrat, otter, and lynx. The native game birds of the country are the grouse and ptarmigan, which seem to vary greatly in numbers from year to year. Many waterfowl, ducks, geese, swans, and cranes, nest in the Arctic lakes, rivers, and tundra during the short summer months. Fish are abundant in the streams, especially the grayling (sometimes called "Arctic trout"), lake trout, Arctic char, white fish, pickerel, pike, and the salmon, which are seen now and then on the north side.

Small plants too numerous to mention grow on both sides of the Brooks Range. Willows, ground birch, and some alders are present along gravel bars, while occasional groves of "Balm of Gilead" or poplar, and ground juniper are found. The poplar trees seem to grow in the warm protected south-facing valleys and sometimes attain a height of 45 feet and diameter of 14 inches breast high. On the southern slopes of the Range in this area spruce is the most abundant and

and important timber, although white birch, ground birch, alder, willow, and poplar grow. Along the northern limit of the tree line the spruce, and especially the poplar, is almost entirely restricted to talus slopes and glacial moraines because of the relatively permafrost-free nature of the gravel and talus.

STRATIGRAPHY

Pre-Carboniferous rocks

A fairly thick sequence of predominantly metasedimentary rocks was noted by A. G. Maddren (1911, p. 308; field notes, 1912) along the Canadian boundary. From Maddren's lithologic and stratigraphic descriptions, these rocks are believed to be the same as the Neruokpuk schist in the Lake Peters-Schrader area, which is now though to consist of three distinct lithologic units. The lower unit is pre-middle Silurian to Middle Devonian, the middle unit is possibly Middle Devonian, and the upper unit is considered Late (?) Devonian age. (Brosge, Dutro, Mangus, Reiser, 1952, p. 3).

The main outcrop of Neruokpuk (?) schist occurs in a west-trending belt in the Arctic Foothills province. This belt is nearly 20 miles wide and is a series of tight, isoclinal folds; it can be traced reasonably well on aerial photographs to known outcrops of Neruokpuk schist along the Okpilak River. A second belt of schist occurs in an east-west band in the vicinity of Mount Greenough. This belt is approximately 12 miles wide and forms much higher mountains than the northern belt. This belt of schist can be traced west until it coalesces with the known Neruokpuk schists.

Approximately 2 miles north of Joe Creek in the vicinity of Tub Mountain, the Neruokpuk (?) schist is exposed along the core of what appears to be a west-plunging anticline. These rocks are estimated to be thick and consist of interbedded maroon and olive-gray-green pyritic phyllite, thin-bedded quartzite schist, crystalline limestone, chert, and quartzite (Maddren, field notes, 1912).

The upper part of the section consists mostly of intercalated maroon and olive-green phyllite, gray-brown phyllite, thin-bedded, dark-gray chert, and heavy-bedded (30-100 feet), fine-grained, medium-gray, quartzite schist which has a tendency to split into flat slabby plates. Interbedded with the quartzite schist is a medium-bedded, light- to medium-gray, recrystallized limestone. This section of metasediments Maddren referred to as the "Tub Mountain series," and it is here correlated with the upper unit of the Neruokpuk schist in the vicinity of Snake Creek in the area of Lake Peters (Brosge, Dutro, Mangus, Reiser, 1952, pp. 2-4) and the mapped Upper (?) Devonian chert-slate in the vicinity southwest of Old Woman Creek (Mertie, 1927, pp. 119-126).

Underlying the interbedded maroon and green phyllite, chert, and schist of Tub Mountain is a sequence of massive, thick-bedded, coarse-grained, light gray-green quartzite with minor amounts of interbedded gray-green phyllite. These rocks correlate very well with the heavy-bedded quartzite and phyllite of the lower units of the Neruokpuk schist in the vicinity south of Lake Peters (Brosge, Dutro, Mangus, Reiser, 1952, pp. 2-4).

Maddren (field notes, 1912) suggested that these quartzites were lithologically similar to quartzites of the Tindir group (Cairnes, 1914, pp. 44-58) (Eagle-Circle district), which were though to be pre-Cambrian to Cambrian in age.

Southwest of Yankee Ridge, Maddren noted a series of gray chert, ultramafics, and hard black quartzitic shale which he thought were older and beneath the "Tub Mountain series," but are though by the author to be equivalent to the upper part of the Neruokpuk schist. These black shales weather a striking bright red orange, and can be followed along strike for several miles on the barren hillsides. The black shale-chert sequence would seem to be equivalent to the rocks mapped by Mertie (1927, p. 119) as Upper (?) Devonian. Along the lower Coleen River a similar chert-shale-slate sequence was also tentatively designated as Upper (?) Devonian (White, 1952, p. 11).

Devonian rocks

Kanayut formation.--The Kanayut formation is not present in the extreme eastern Brooks Range. The formation has been mapped northeast to the Echooka River where it appears to pinch out (Brosge, Dutro, Mangus, Reiser, 1952, pp. 5-6). Whether or not the Kanayut formation was deposited in this locality and eroded away is not known. The Kanayut formation on the southern side of the Brooks Range was never examined on the ground, but was traced by aerial reconnaissance to the confluence of the Junjik River and East Fork of the Chandalar River. Here the Kanayut abuts against a thick, fine-grained quartzite-sandstone-slate series which has been mapped as Upper Devonian (Mertie, 1927, pp. 115-118). It is possible that this series is a finer facies of the Kanayut formation to the west. To the southeast of the Chandalar River in the Eagle-Circle district is another quartzitic pebble conglomerate similar to the Kanayut formation (Mertie, 1929, pp. 80-85), and which may be equivalent to it.

Mississippian rocks

Kayak formation.--The Kayak formation, one of the most distinctive lithologic units in northern Alaska, ranges in thickness from 400 to 1,200 feet.

In northeastern Alaska it consists of black clay shale, sandstone, pebble-cobble conglomerate, quartzite, and minor amounts of thin arenaceous limestone (Brosge, Dutro, Mangus, Reiser, 1952, p. 7).

In the vicinity of Tub Mountain, the Kayak formation overlies the Neruokpuk (?) schist with apparent unconformity and is conformably overlain by the Lisburne formation. In the Yankee Ridge area it was thought to overlie the Neruokpuk (?) schist with angular unconformity, and is conformably overlain by the Lisburne formation (Maddren notes, 1912).

In the vicinity of Tub Mountain the Kayak formation was estimated to be 600 to 900 feet thick, and consists of pebble-cobble conglomerate, quartzite, black slate, chert, and arenaceous, platy limestone. Here the basal pebble-conglomerate is at least 100 feet thick and is light gray, containing subangular to rounded pebbles of black, gray, and white chert. Maddren (field notes, 1912) described the conglomerate at a locality near Contact Creek as "an angular sub-aerial conglomerate member at least locally developed at the top of the Tub Mountain formation which is the basal part of the Carboniferous."

The Kayak formation, where it is thought to be near the nose or the north flank of the Tub Mountain anticline (?), is a series of crumpled black shale, quartzite, and fossiliferous, arenaceous limestone. The collected fossils were identified as lower Mississippian by Dr. Edwin Kirk (1912) and tentatively identified as Kayakian by J. T. Dutro, Jr., in 1953 (personal communication).

The upper part of the Kayak formation near Tub Mountain is similar to the Kayak formation at the type locality at the Kanayut River (Dutro 1952, p. 27-30) and the basal part of the section is similar to the pebble-cobble conglomerate of Lake Peters and Sheenjek River areas (Brosge, Dutro, Mangus, Reiser, 1952, pp. 7-10).

In the vicinity of Ammerman Mountain, Maddren estimated the Kayak formation to be 900 to 1,000 feet thick. Here the formation consists of a series of chert-pebble conglomerate, quartzite, black shale, silty chert, and arenaceous, platy limestone. The pebble-conglomerate rests unconformably on the Neruokpuk (?) schist and is made up mostly of subround to round, gray, black, and white chert pebbles interbedded with a "millstone grit" quartzite. The upper part of the Kayak formation at this locality, from Maddren's description, appears to be similar to that of the type locality near the Kanayut River (Dutro, 1952, pp. 29-30), and the basal part is like the Kayak formation near Lake Peters.

Lisburne formation.--Along the Canadian Boundry the Lisburne formation is exposed in three main belts. The largest belt extends along the boundary for more than 40 miles north of Ammerman Mountain, with the exception of a small complex infold of Sadlerochit formation and Triassic rocks along Joe Creek. This Lisburne limestone can be traced west into the Coleen and Sheenjek River drainages to known Lisburne outcrops.

The second band of limestone is relatively narrow, is approximately 2 to 5 miles wide, and is near the head of Aspen Creek and the Malcom River. These beds can be traced (on photos) for some distance west of Mount Greenough.

The limestone in the northern belt, the Arctic Foothills province, crops out in relatively small scattered structures appearing to unconformably overlie the older rocks. These outlying ridges crop out over a belt approximately 12 miles wide, and can be followed easily east and west on aerial photos.

In the area north of Ammerman Mountain, although the contact was not seen, Maddren (notes, 1912) believed the limestone formation to be conformable with the Kayak formation. These massive limestones belong to the Lisburne formation and can be correlated with the upper part of the Lisburne formation on the Sheenjek River (Brosge, Dutro, Mangus, Reiser, 1952, pp. 10-19). Maddren estimated the limestone there to be 2,000 to 3,000 feet thick. This entire outcrop belt is lithologically similar throughout and consists of massive, light blue gray, dove-gray-weathering limestone intercalated with dark gray, thin- to medium-bedded cherty limestone. Near the base of the formation the limestone is cherty, and the chert is both bedded and nodular, mostly dark gray to black. This limestone was identified as Carboniferous from the collected fossil assemblages by Dr. Edwin Kirk (notes, 1912). The most abundant fossils were the Lithostrotion colonies and Productus gigantias which are now classified as Alapah age (Bowsher, Dutro, 1950) and were found in the localities of Shark Bluff-Firth River, Incog Creek, Turner Mountain, Joe Creek, and Grizzly triangulation station.

In the vicinity of Joe Creek the Lisburne formation was estimated to be 2,000 to 3,000 feet thick. Here the basal 500 feet consists of black, calcareous, slaty shale and dark arenaceous flaggy limestone with very minor amounts of chert. Overlying the dark limestone-shale sequence is several hundred feet of thin- to medium-bedded, medium-grained, black cherty limestone that contains brachiopods and corals. The remainder of the section is a coarse-grained, medium-gray, massive-bedded, pinnacle-forming crinoidal limestone. All the fossil assemblages examined from this locality are upper Mississippian (Alapah) age.

The northern belt of Lisburne formation is a massive, cherty, light-medium gray, fine to coarsely crystalline limestone that weathers the typical light gray of the Lisburne formation. These limestones are mostly in synclines and apparently overlain by the Sadlerochit formation as indicated by photogeologic evidence and Maddren's notes. From these limestones Maddren found only upper Mississippian fossils.

Permian rocks

Sadlerochit formation.--The Sadlerochit formation, which Maddren called Pennsylvanian, crops out in two main belts along the 141st meridian. The best exposures were examined along Joe Creek, 2 to 8 miles west of the boundary. The rocks consist of chert, sandstone, shale, and flat slabby silty limestone that form an outcrop belt 2 to 3 miles wide. The second belt, in the Arctic Foothills province, occurs mostly as small scattered canoe-shaped synclines over a north-south distance of 15 miles. Here the outcrops are mainly of shale, chert, and sandstone.

Maddren estimated the section at Joe Creek to be at least 800 to 900 feet thick (field notes 1912), and to be conformable with the underlying Lisburne formation. As he states in one place that the base of the Sadlerochit formation is sandstone, and in another that the base consists of slabby, silty, fossiliferous limestone, it is not exactly clear what the bottom beds are. Overlying the basal beds is a relatively thick section of interbedded dark-gray-black, soft, friable shale, siltstone, and minor chert. Above the predominantly shale-siltstone section are intercalated thin- to medium-bedded, hard sandstone, calcareous sandstone, and grit conglomerate.

Invertebrate fossil remains collected by Maddren from the Sadlerochit formation were first designated as Pennsylvanian by G. H. Girty (1912), but are now known to be lower Permian. The lower part of the Sadlerochit formation, which Maddren called the "Swagerina zone", is lower Permian; the middle shale-siltstone sequence contains middle Sadlerochit formation fossils, while the upper fauna, which was called "Artinsikian" by Maddren, is now thought to be approximately the same age as the "Nuka member" (Dutro, J. T., Jr., personal communication) of the Sadlerochit formation in the Kuna-Nuka Rivers area.

The Sadlerochit formation in this area is very similar to the Sadlerochit formation in the upper Sagavanirktok-Canning Rivers area.

The northern belt of the Sadlerochit formation, which Maddren reported as having a Mesozoic appearance, is composed mostly of shale, siltstone and sandstone.

Triassic rocks

Shublik formation.---The Shublik formation, a very distinct lithologic unit of Triassic age, crops out in the vicinity of Joe Creek 8 miles west of the Boundary, and in the upper Firth drainage near Aspen Creek (not shown on pl. 1). Here marine fossils of Upper Triassic age were found in thin-bedded black clay shale and black silty limestone. In both localities the rocks are so badly folded and crushed that their relation to older rocks could not be ascertained (Maddren, field notes, 1912; Bull. 520). Although no Triassic rocks were reported by Maddren on the north side of the Brooks Range, it is quite certain that they are present in the Arctic Foothills along the Kongakut River.

In 1914, along the Firth River, J. J. O'Neill (Leffingwell, 1919, p. 115-118) found *Pseudomonotis* in soft black shale, chert, and black silty, impure limestone. From both Maddren's and O'Neill's descriptions of the Triassic rocks, there is little doubt that they are the same composition as the Shublik formation along the Canning River (Leffingwell, 1919, p. 115-118).

Undifferentiated Mesozoic rocks

Rocks of post-Triassic age were reported to overlie the Neruokpuk(?) schist unconformably at a locality 12 miles south of the Arctic Ocean along the Clarence River, and associated with the Shublik formation 8 miles west of the 141st meridian along Joe Creek. At the Joe Creek locality a crinoid bed bearing fragments of *Pentacrinus* was found. These crinoid remains are the same age as the crinoids in the Kingak shale (Leffingwell, 1919, pp. 119-120), (C. L. Harrington, letter). The rocks along the Clarence River are dirty, gritty, green-brown sandstone and black shale in which no fossils were found.

Quaternary deposits

The Quaternary sediments are separated into two types, both on the age and the kind of deposits. The older deposits are products of glacial erosion and probably are Pleistocene in age, whereas the younger deposits are talus slides along the mountain slopes, and the sand and gravel deposits along the streams, both formed from partial reworking of glacial deposits and as the products of stream erosion.

Most of the streams in the area, which are characterized by U-shaped valleys, were glaciated in the Pleistocene. During the period of maximum glaciation ice covered most of the Brooks Range; ice extended both north and south as piedmont glaciers, and at many of their extremities formed valley glaciers probably of alpine type. Many of the piedmont glaciers of the higher regions were thick, and in many places huge erratics are found on ridges 2,000 to 3,000 feet above the valley floors. The main divides between the ice were plucked into ragged cerrated crests, and the valley floors were scoured relatively clean. The streams on the south side appear to have more glacial outwash debris; most streams are restricted to one channel which meanders very slowly through outwash, whereas on the north side of the Brooks Range the rivers are not constricted and flow swiftly to the ocean.

It is believed that two or three glacial periods occurred during the Pleistocene epoch (Detterman, personal communication) (Mertie, 1927, pp. 131-132).

Present glaciers.--At present many of the higher peaks of the Romanzof and Franklin Mountains are covered with ice and snow which are very conspicuous from a distance. The glaciers are commonly the valley type; the larger ones on the Okpilak and Hulahula Rivers are 5 to 8 miles long and are probably several hundred feet thick. The sides of the glaciers usually grade into lateral moraines against the mountainsides, but in places the ice has been observed to be steeply convex along the sides. On the surfaces the glaciers are quite smooth and are speckled with fallen rocks. Along the heads of the larger glaciers deep crevasses are developed. At present, although no check has been made, the glaciers appear to be receding. Thus, it is assumed that the rate of melting is greater than precipitation.

Aufeis.--Thick deposits of ice, called aufeis, (Leffingwell, 1919, p. 158), are formed over the flood plains of the Arctic and sub-Arctic rivers. These ice deposits are formed by overflow water and springs which run all winter. After the first ice freezes over the river, it is broken by hydraulic pressure, heaving and cracking enough to allow the water to overflow. The overflowing water soon freezes and the action is again repeated. During this procedure the ice will build up in thickness from several feet to 15 feet. Many of these deposits are 3 to 6 square miles in area and are called "glaciers" by the miners and natives. Other names are "ice fields" and "flood ice".

These large deposits of aufeis are more or less seasonal, and their size depends on the amount of water overflow and the temperature. Most of the fields last well into the summer and may are perennial.

IGNEOUS ROCKS

Both ultramafic and granitic igneous rocks crop out along the 141st meridian. The largest mass, which is granitic, is in the vicinity of Ammerman Mountain. It is massive and intruded sedimentary rocks that are very schistose for a distance from their contact with the granitic mass. Clear quartz stringers about half a mile northeast of the contact in the country rock contain some pyrite but no important mineralization seems to have occurred.

The ultramafic rocks occur as small intrusive sills and dikes, and as lava flows. These dark-green, chocolate-weathering aphanitic rocks intrude the metasediments of the Neruokpuk (?) schist and were thought to be Devonian to Mesozoic in age (Maddren, field notes, 1912).

Along the crest of the British Mountains, in the vicinity of Monument Gulch (Maddren, 1912 notes) are local basaltic flows. The flows are dark green and weather various shades of chocolate and red brown. These lavas show many flow characteristics and were thought by Maddren to have been extruded on a land surface. These flows rest on a basal agglomerate which consists of well-rounded mafic pebbles and cobbles, volcanic bombs, and tuffaceous materials. The age of the lavas was thought to be late Carboniferous; the basal agglomerates rest on the Neruokpuk (?) schist and on lenses of gray crystalline limestone that contains unidentifiable corals. It is suggested by the author that these limestone lenses are Lisburne in age and that the flows are therefore much younger than the more folded underlying limestone. It has been suggested that these volcanics are the same age as the Mississippian volcanics in the Eagle-Circle district (Mertie, 1930, pp. 25-84), but this in unlikely because the volcanics near Circle are lower Mississippian. If the limestones on which the British Mountain volcanics rest are Lisburne in age, the flows could be no older than late Mississippian.

It is suggested by the author that these flows are probably the same age as the Hulahula "greenstones" and that they are much younger than Maddren had thought.

STRUCTURE

The main structural features of this area are the major fold axes and faults which strike approximately east, with some minor folds that strike north (O'Neill, 1914, p. 113), and a probable structural high that trends north-south. The east-west structures appear to be superimposed on the older structures, which were probably folded prior to the Devonian.

Pre-Carboniferous (?) structure

It is very possible that a regional north-trending high is present along the Canadian Boundary. It is believed that this high (?) is similar to the several north-trending highs in the Paleozoic rocks between the Sagavanirktok and Hulahula Rivers (Brosge, Dutro, Mangus, Reiser, p. 22, 1952), (Keller, Morris, 1952, pp. 14-16). It appears that the Neruokpuk (?) schist was folded and faulted before the deposition of the Kayak formation in early Mississippian time.

The age during which these structures were formed is not known; however, earlier geologists postulated that folding in areas to the southwest occurred in late Silurian or Early Devonian (Smith and Mertie, 1930, p. 267; Mertie, 1923, p. 249) because of the absence of Lower Devonian rocks in northern Alaska. Mertie suggested that, in the Chandalar River district, either in late Silurian or Early Devonian time, diastrophism took place in which the fold axes were oriented approximately N. 20° E. Mertie suggested this hypothesis from the combination of both the lobate outcrop pattern of the Silurian limestone and the oriented pattern of the small streams that drain in pre-Devonian rocks. The Silurian limestone forms large north-south reentrants into the overlying unconformable Middle (?)

Devonian rocks; these reentrants were suggested to be plunging anticlines and synclines. Stream tributaries in pre-Devonian rocks are oriented N. 20° E., and in the Devonian and post-Devonian rocks are roughly S. 70° E. This, of course, was not a hard and fast rule because in many places the structural complications are such that drainage patterns did not reveal the N. 20° E.-trending structures (Mertie, 1923, p. 249). It is possible that the pre-Kayak folding in the Neruokpuk (?) schist was of this north-south nature, causing the north-trending highs in the eastern Brooks Range. Another suggested cause for the present regional north-trending highs is differential compressional forces (Jurassic-Tertiary folding), that brought the older underlying rocks closer to the surface.

It is now known that in the eastern Brooks Range the Kayak formation lies unconformably on the Neruokpuk schist, which is considered to be Upper Devonian (Brosge, Dutro, Mangus, Reiser, p. 22, 1952). However, in the central Brooks Range between 5,000 and 6,000 feet of quartzite and conglomerate of the Kanayut formation were deposited during Late Devonian time. This alone suggests that a Late Devonian uplift took place in the eastern Brooks Range.

Pre-Permian diastrophism

Throughout the eastern Brooks Range the lower Permian Sadlerochit formation lies on the upper Mississippian Lisburne formation. The lack of Pennsylvanian sedimentary rocks in the area is evidence of post-Lisburne uplift, and in the vicinity of Lake Peters erosional relief of 100 feet has been proved (Brosge, Dutro, Mangus, Reiser, p. 23, 1952).

Post-Paleozoic structures

The prominent east-trending structures of the Brooks Range and of the younger northerly sedimentary rocks suggest Jurassic to Tertiary folding.

Many of the folds are overturned to the north with thrusting along the crests (Maddren, notes 1912). An imbricate thrust zone occurs between Joe Creek and the headwaters of the Malcom River; in this vicinity large blocks of Lisburne limestone are thrust upon each other, and south of Joe Creek the folds become more gentle.

GEOLOGIC HISTORY

In this eastern Brooks Range area a thick sequence of metasediments thought to be the Neruokpuk schist is tentatively broken down into two lithologic units: the lower unit is thought to be pre-middle Silurian to Middle Devonian and to be correlative with the lower units of the Neruokpuk schist in the Lake Peters area; the upper unit is thought to be Upper (?) Devonian and to be correlative to both the upper unit of the Neruokpuk schist at Lake Peters (Brosge, Dutro, Mangus, Reiser, 1952, p. 24) and the chert-slate sequence mapped southwest of Old Woman Creek (Mertie, 1927, pp. 119-125).

It is quite evident that a marked uplift occurred during Late Devonian or early Mississippian time in this extreme eastern area of the Brooks Range.

No Kanayut formation was reported by Maddren (notes, 1912) and it is assumed that if the Kanayut formation was deposited, it was eroded away during Late Devonian or early Mississippian time.

The Kayak formation, like the Kayak formation near Lake Peters, rests unconformably on the Neruokpuk (?) schist, the basal part being a pebble-cobble conglomerate. The Kayak formation was estimated to be 600 to 900 feet thick.

In all the localities mentioned (Maddren, field notes, 1912), the Kayak formation consists of clean basal conglomerate and quartzite. These clean, well-washed clastics suggest a long period of quiescence.

In this area Maddren (notes, 1912) collected no fossils from the lower part of the Lisburne formation (Wachsmuth). It will be assumed that this was an area of minimum deposition during Wachsmuth time, and that less sinking occurred, and as in the Lake Peters area, the Wachsmuth member could be equivalent in time to some of the Kayak shales (Brosge, Dutro, Mangus, Reiser, 1952, p. 24).

The great thickness of the Alapah member of the Lisburne formation tends to show that a more uniform rate of subsidence occurred at the time of its deposition. These limestones become (Maddren, notes, 1912) more clastic and coarser-grained near the top of the formation, indicating a faster rate of deposition.

Because of the absence of Pennsylvanian rocks in the area, the Sadlerochit formation is thought to be disconformable with the Lisburne limestone. During Pennsylvanian time an erosional surface was formed in the eastern Brooks Range. Although the general magnitude of the uplift is unknown, erosional relief of 100 feet was proved in the vicinity of Lake Schrader. In this eastern Brooks Range area the northward coarsening of the clastics of the Sadlerochit deposited on the Lisburne limestone tend to indicate a source area to the northeast (Whittington and Sable, 1948, pp. 8-11) (Keller and Morris, 1952, p. 3).

The Shublik formation in the eastern Brooks Range appears to be a thin blanket-type deposit. Phosphatic beds occur near the base of the Shublik formation where seen in northeastern Alaska; presence of phosphates usually indicates a long period of little deposition. Although Maddren (field notes, 1912) saw no normal contacts between the older rocks and the Shublik formation, it is thought that the contact with the Sadlerochit formation is conformable.

In one locality on the Clarence River, (12 miles south of the Arctic Ocean) Maddren (notes 1912) thought the Mesozoic sandstones and shales rest unconformably on the Neruokpuk (?) schists.

ECONOMIC GEOLOGY

Possible stratigraphic and structural petroleum traps may be present in the Lisburne formation in the eastern Brooks Range area. It is possible that traps may be present in the subsurface Lisburne formation which is believed to underlie younger rocks in the Arctic Foothills province. These stratigraphic and structural traps could be formed by the following conditions:

1. Folding of the Lisburne into favorable anticlines.

2. Fracturing and leaching of the limestone, making a favorable reservoir rock.

3. The unconformable relation of the younger overlying rocks to the Lisburne formation, causing a stratigraphic trap.

The most favorable area for these geologic structures would be between the Okpilak and Aichillik Rivers, where the outcrop belt of Mesozoic rocks is much wider.

Granitic igneous rocks, which are usually the source of metalliferous deposits, are very scarce in the eastern Brooks Range. The only sizable igneous masses are the granites in the vicinities of the Okpilak River and Amerman Mountain. The northern area has been practically unexplored geologically, and it is possible that more granite masses may be found east of the Okpilak River.

Small amounts of gold have been reported in the drainages of the Firth, Malcom, and Kongakut Rivers, but are of no commercial value. In the Okpilak River granites, 80 miles west of the 141st meridian, radioactive biotite was found with associated minerals (Whittington and Sable, 1948, pp. 14, 15). White suggested, after a radioactivity study of these granites, that they could possibly be a source of high-grade deposits of uranium, (White, 1952, p. 4) and further investigating should be done.

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