The Central Kuskokwim Region, Alaska

By W. M. CADY, R. E. WALLACE, J. M. HOARE, *and* E. J. WEBBER

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An account of its geography, geology, geomorphology, and mineral resources including the occurrence and mining of quicksilver

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By W. M. Cady, R. E. Wallace, J. M. Hoare, and E. J. Webber

ABSTRACT

The central Kuskokwim region as described in this report is an area of about 10,000 square miles crossed by the middle course of the Kuskokwim River in southwestern Alaska. White men, Russian explorers and traders, first entered the region in 1829. American exploration began in 1898 and reached its greatest intensity in 1940 to 1946.

The region is dominated by the Kuskokwim Mountains, which trend northeastward through the center of the region and into central Alaska. The Kuskokwim River passes through the region from east to west in a gorge that transects the Kuskokwim Mountains. East of the mountains is the basin of the Holitna and upper Kuskokwim Rivers, and to the west are the basins of the Aniak and lower Kuskokwim Rivers and of the Yukon River. The Nushagak Hills lie southeast of the upper Holitna River.

Forests are restricted chiefly to river-bottom lands at altitudes of less than 1,000 feet. Upland areas are barren except for a covering of lichens. All of the major groups of vertebrate animals except reptiles are represented in the region. Insects appear to be the most abundant of the invertebrates.

The climate is subarctic; the winters are characteristically long, dry, and cold, and the summers, short and rather wet.

About 300 people, who are mostly natives and whose chief means of livelihood are fishing and trapping, live in the region. There are 4 villages with more than 20 inhabitants, all located on the Kuskokwim River. Most of the people live in family settlements of 1 or 2 cabins, scattered along the river bank.

The region is accessible to heavy goods by way of the Kuskokwim River from the Bering Sea. Passengers and light perishable goods are commonly transported by airplane from Anchorage and Fairbanks. Local travel and transport are by small boats in summer and by dog sled in winter.

The central Kuskokwim region lies at the center of the mobile belt of mountain building and volcanic activity that trends east-west through central and southern Alaska. This belt is bordered on the north by the stable North American continental platform and on the south by the equally stable Pacific Ocean floor.

The mobile belt was predominantly a zone of subsidence and geosynclinal deposition during the Paleozoic and early Mesozoic eras, and during this time it was characterized by basaltic to andesitic marine volcanism that spread progressively northwestward in western Alaska. The mobile belt became a zone of mountain building and intrusive igneous activity beginning with middle Mesozoic time. Geanticlines, raised in the mobile belt during the first phase of mountain building and intruded by granitic batholiths, established the structural framework of Alaska. Geosynclinal deposits, chiefly graywacke, formed in the intervening areas during the late Mesozoic. In the earliest Cenozoic these geosynclinal deposits were folded and were intruded by igneous rocks of several kinds during a second phase of mountain building. The present mountain levels were produced by vertical uplift that began in middle Cenozoic time and has continued to the present. Extrusion of basaltic volcanic rocks and intrusion of quartz monzonite stocks accompanied these later movements, and extensive faults formed where differential uplift was pronounced. Most of these features of the mobile belt are to be found in the central Kuskokwim region.

The bedded rocks of the central Kuskokwim region include both sedimentary and volcanic rocks that make up a very thick section of probably 60,000 and possibly more than 100,000 feet, deposited chiefly in marine water. Seven divisions of these are described in this report. The Holitna group is composed of limestone of early and middle Paleozoic age. It is succeeded by the Gemuk group which is made up of siltstone and chert accompanied locally by basaltic and andesitic volcanic rocks. This group is of late Paleozoic and early and middle Mesozoic age. The Holitna and Gemuk groups are marine geosynclinal deposits. The Kuskokwim group comprises 40,000 to 65,000 feet of interbedded graywacke and shale of late Mesozoic age. It is a secondary geosynclinal deposit, predominantly marine, that is regionally unconformable on the older rocks and is overlain disconformably by the volcanic Iditarod basalt, also of late Mesozoic age. This basalt is probably the first of a succession of volcanic rocks deposited in a continental environment. The Getmuna rhyolite group and the Holokuk basalt are volcanic rocks of early to middle Cenozoic age. They are separated from the older rocks by an angular unconformity. The Waterboot basalt is a volcanic formation of late Cenozoic age and is believed to lie on an old-age surface, equivalent to the Georgetown summit level, which intersects the Holokuk basalt.

The surficial deposits include residual soil and rubble; gravel that occurs on rock benches, in terraces, and buried beneath other surficial deposits; glacial till and outwash deposits; windblown silt; and the flood-plain deposits of existing streams. All occur immediately beneath or are deposited upon denudational surfaces that were formed at altitudes lower than the Georgetown summit level, and all are of late Cenozoic age. Most of the residual deposits are at the late-mature Sleetmute upland surface and are of Pliocene to Recent age. The gravel deposits are commonly at grade with the Sleetmute surface and underlie the silt deposits; they are probably of Pliocene and early Pleistocene age. The glacial deposits occupy glacial troughs and are succeeded by the flood-plain deposits of existing streams; they are of the Wisconsin stage of the Pleistocene. The silt deposits, which are probably also of Wisconsin age, are spread widely on the residual and gravel deposits. The flood-plain deposits are chiefly in the youthful Boss valleys that intersect the Sleetmute surface and are of early Pleistocene to Recent age.

The principal types of igneous rock in the region are, in general order of their formation: andesite, biotite basalt, albite rhyolite, basalt, quartz monzonite, and quartz diabase. Most of the andesite and basalt, and some of the rhyolite, are extrusive and are part of the sequence of bedded rocks with which they are included in the text of this report. The rest are intrusive rocks and are

emplaced chiefly in the Kuskokwim group, but some basaltic dikes are probably hypabyssal phases of the basaltic volcanic rocks. The rhyolitic volcanic rocks are believed to be extrusive phases of the hypabyssal albite rhyolite.

Biotite basalt forms small hypabyssal intrusive bodies, chiefly dikes and sills, probably of early Cenozoic age. Albite rhyolite occurs in rather large hypabyssal intrusive bodies, chiefly sheets and dikes, also of early Cenozoic age. Quartz monzonite and related granites and granodiorites form stocks of probable middle Cenozoic age. The stocks are slightly alkalic. Quartz diabase and related basalt, norite, gabbro, and andesite form hypabyssal intrusive bodies, both dikes and sills, some of which are closely associated with the quartz monzonite stocks. These intrusive rocks are probably of about the same age as the stocks. The biotite basalt and albite rhyolite are believed to be syntectonic, inasmuch as they are commonly oriented parallel to beds or folds in the bedded rocks. The quartz monzonite stocks and quartz diabase dikes, and also some basalt dikes believed to be a hypabyssal phase of the basaltic volcanic rocks, transect the folds in the bedded rocks and are therefore posttectonic. The stocks and quartz diabase dikes also cut the volcanic rocks that lie unconformably on the folds.

Two types of metamorphic effects are represented in the region, both produced by alteration of the interbedded graywacke and shale of the Kuskokwim group. Argillite occurs near bodies of albite rhyolite and hornfels in contact-metamorphic zones adjacent to the quartz monzonite stocks.

Geanticlines and geosynclines, folds, and faults are three principal categories of structural features. The Kuskokwim geosyncline, which occupies most of the region, is bordered to the southeast by the Alaska-Yukon geanticline and to the northwest by the Aniak-Ruby geanticline, both of which plunge southwest. The geanticlines, which are of middle to late Mesozoic age, compose the framework of the region. A system of folds, referred to as the Kuskokwim Mountain orogen, which was formed in earliest Cenozoic time, trends northeast through the region. These folds are chiefly in the late Mesozoic bedded rocks of the Kuskokwim group, deposited in the Kuskokwim geosyncline. Faults strike east-northeast across the Kuskokwim Mountain orogen, and intersect the Alaska-Yukon geanticline in the region to the northeast of the central Kuskokwim region. The faults are chiefly of late Cenozoic age and are apparently still active.

The principal geomorphic processes that have affected the region are frost weathering and stream and glacial erosion. Frost weathering predominates, but it has been exceeded by glacial erosion in the higher mountains, and has been succeeded in rather extensive uplifted areas by the downcutting of rejuvenated streams. Several denudational surfaces are recognized. They are partly successive and all of late Cenozoic age. The Georgetown summit level probably marks the position of an old-age surface evolved in the late Tertiary. The Sleetmute upland surface is a late-mature terrain, formed by denudation below the Georgetown level, which was begun in the late Tertiary. The Boss valleys are youthful stream valleys eroded below the Sleetmute surface since the beginning of the Quaternary. Glacial troughs that in the higher mountains intersect both the Sleetmute surface and the Boss valleys are probably of the Wisconsin stage of the Pleistocene epoch.

The recorded geologic history of the central Kuskokwim and adjacent regions began with the formation of the crystalline continental platform and adjacent mobile belt in pre-Cambrian time. Subsidence of the mobile belt beneath the sea began in the pre-Cambrian and continued intermittently through the Paleozoic and early and middle Mesozoic. The mobile belt appears to have encroached on the platform in the late Paleozoic and early Mesozoic, and earlier deposition of limestone in the central Kuskokwim region was succeeded by the deposit of siltstone and mafic to intermediate volcanic rocks. The geanticlines raised in the late Mesozoic shed clastic sediments, and interbedded graywacke and shale succeeded locally by basalt flows were deposited in the intervening geosynclines. The contents of the geosynclines were folded and intruded by hypabyssal biotite basalt and albite rhyolite in the earliest Cenozoic. The rocks were then uplifted and eroded, covered widely by basaltic volcanic rocks, and intruded by quartz monzonite stocks by middle Cenozoic time. Subsequent erosion reduced the land to an old-age surface upon which basalt flows were locally extruded. The old-age surface was destroyed late in the Cenozoic era, in response to differential uplift above base level, which has continued to the present time.

Quicksilver is the chief mineral product of the central Kuskokwim region. Gold is second in importance; tungsten, third. Copper, antimony, silver, tin, and molybdenum are known but have not been exploited commercially. The ores of these metals were probably all deposited in the Cenozoic era; they occur as lodes in veins that intersect igneous rocks, all of which are intruded in folded late Mesozoic strata. Three episodes of lode mineralization are recognized: gold-quartz-tungsten, copper-sulfide-gold-silver, and quicksilver-antimony.

The quicksilver mineral, cinnabar, commonly associated with the antimony mineral, stibnite, occurs most abundantly in fracture zones and joints in and near the borders of silica-carbonate rock formed by the hydrothermal alteration of biotite basalt sills and dikes. These deposits, which diminish with depth, are located at or a little beneath rolling terrains characteristic of the region, but they have not been found in areas of more sharply dissected topography, from which they have presumably been eroded. Production of mercury during the ten-year period 1940 to 1950 amounted to about 5,000 flasks; previous production was negligible. The principal mines are the Red Devil mine in the Sleetmute area and the DeCourcy Mountain mine in the DeCourcy Mountain area.

Commercial gold deposits occur as placer concentrations in existing streams, in bench gravel, and in buried gravel. Most of the gold placer deposits are close to sheets and dikes of silicified and sericitized albite rhyolite; near the contacts of some, traces of gold have been found in quartz fracture fillings and breccia zones. The largest concentrations of placer gold are in pay streaks immediately above bedrock, but smaller concentrations occur on a "false bedrock" commonly formed by a "hardpan" of interlayered clayey silt beneath the deposits of existing streams and above buried gravel. The most productive placers occur in areas of rolling topography whose gentle stream gradients have prevented dissipation of gold downstream.

Tungsten occurs in various associations; marketable ore, principally scheelite, has recently been recovered at one locality from a placer accumulation that was derived from quartz fracture fillings in a silicified and sericitized shear zone. The alteration effects are like those of rocks in the vicinity of the albite rhyolite intrusives, and it is inferred that, although not exposed at the surface, such an intrusive body probably exists at depth.

Copper-bearing metallic sulfide and associated gold, silver, and tin occur in fissure veins and breccia fillings within and near the border of one of the quartz monzonite stocks, but they have not been developed commercially.

It is emphasized that in the central Kuskokwim region one of the most useful guides to the selection of areas in which to prospect, for both quicksilver lodes and placer gold, is rolling topography, not a sharply dissected one; rolling terrains may very likely be the sites of buried gold placer gravel not yet discovered.

INTRODUCTION

LOCATION AND AREA

The central Kuskokwim region is in southwestern Alaska, about halfway between the headwaters of the Kuskokwim River, in central Alaska, and its mouth, about 450 miles to the southwest, on Bering Sea. The Kuskokwim River flows westward through the region and drains most of it. The area included in this report and covered by the accompanying geologic map (pl. 1) extends northward about 125 miles from the headwaters of the Holitna River, a southern tributary of the Kuskokwim River, to the Iditarod River, which drains to the Yukon River. The width of the region between the Aniak River on the west and the eastern tributaries of the Holitna River on the east is about 80 miles, and its area is about 10,000 square miles. The approximate geographic limits of the central Kuskokwim region as it is described here are meridians 156°45′ and 159°30′ west longitude, and parallels 60°30′ and 62°15′ north latitude; its position in Alaska is shown in figure 1.

PREVIOUS WORK

EARLY EXPLORATIONS

The first white men to enter the central Kuskokwim region were Russian explorers and fur traders based in the Bristol Bay region to the south. In 1829 an expedition under Vasilief of the Russian-American Company portaged from the head of the Nushagak River and descended the Holitna and Kuskokwim Rivers. In 1832 Kolmakof followed Vasilief's route and left his interpretor, Lukeen, to establish a trading

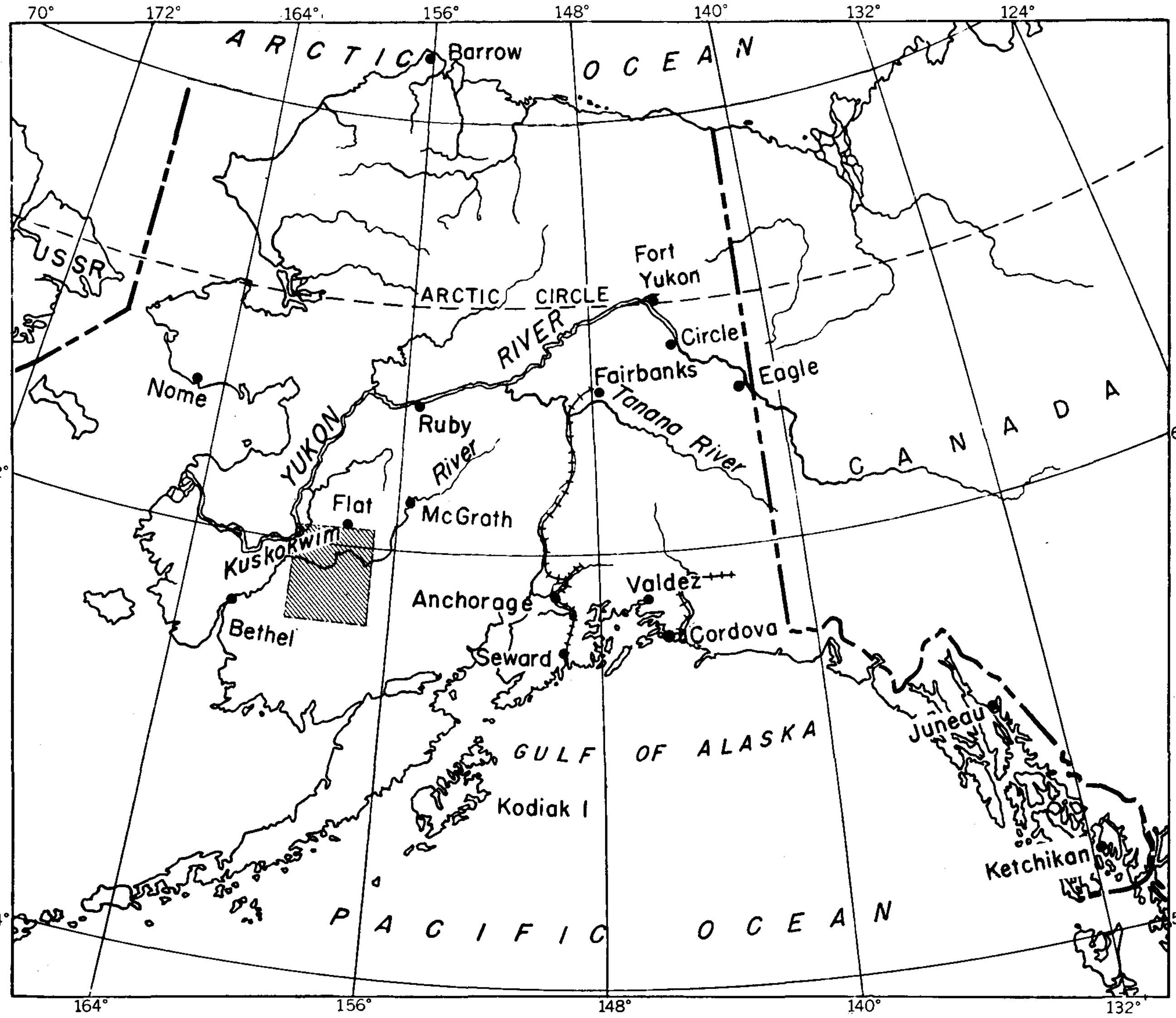

FIGURE 1.—Index map showing location of the central Kuskokwim region, Alaska.

post on the Kuskokwim River, about 100 miles downstream from the mouth of the Holitna River. This post, known as Lukeen's Fort, was later destroyed, though it was replaced by Kolmakof's Redoubt, a blockhouse built a few miles farther down the river. The Kuskokwim River drainage was first mapped by Lieut. Zagoskin in 1844.

Russian America was acquired by the United States in 1867, but little additional information concerning the Kuskokwim River region was obtained until 1898, when J. E. Spurr and W. S. Post of the United States Geological Survey descended the Kuskokwim River from the Alaska Range to Bering Sea. This party, with Spurr in charge and with Post as topographer, consisted of 6 men, provided with 3 canoes and supplies for the entire trip. The party left Cook Inlet late in May, crossed the Alaska Range near Rainy Pass, and reached the headwaters of the Kuskokwim River in the middle of July. The mouth of the Kuskokwim was reached late in August, and the return to the east coast of the Alaska Peninsula, by devious courses along the shore and by river, was accomplished late in October. The geologic data gathered on this remarkable journey were soon published (Spurr, 1900).

In 1902 and 1903 William R. Buckman, a prospector, visited parts of the Holitna River basin in search for valuable minerals. He prepared and transmitted to the Geological Survey a map, based on compass and paced surveys, that was the principal source of information about the southern part of the central Kuskokwim region until the present investigation.

LATER SURVEYS

By 1910 a scattering of prospectors had settled the Kuskokwim region and later surveys were conducted in an atmosphere of rather intense local interest, particularly in gold, to a smaller extent in quicksilver.

In 1914 a Geological Survey party, with R. H. Sargent as topographer in charge and P. S. Smith as geologist, entered the area of the present study near Sleetmute, en route with pack train from Lake Clark to the Iditarod River near Flat. The line of this traverse followed the summit ridge, between the Kuskokwim River and the South Fork of the George River, from Sleetmute nearly to Georgetown, thence north by way of the Georgetown Trail along the divide between the George River and Crooked Creek. Smith's studies included an investigation of the quicksilver deposits at Parks, northwest of Sleetmute, now known as the Alice and Bessie mine, and areal geologic investigations along the route (Smith, 1917; Smith and Maddren, 1915, p. 272–280, 286–291).

During the same summer A. G. Maddren of the Geological Survey investigated several mineral localities in the central and lower Kuskokwim regions (Smith and Maddren, 1915, p. 280–286; Maddren, 1915). Those in the central Kuskokwim region included placer gold deposits on Donlin, Crooked, and New York Creeks, a quicksilver prospect near Kolmakof, and copper lodes in the Russian Mountains.

Little more was published on the geology and mineral resources of the central Kuskokwim region for about 30 years.

A topographic party of the Geological Survey mapped the Holitna River basin in 1940. The United States Bureau of Mines trenched and sampled all of the known quicksilver deposits in the central Kuskokwim region and adjacent portions of southwestern Alaska during the period from 1942 to 1946, and the final results of these explorations were reported in 1947 (Webber and others, 1947).

Numerous private and semiprivate mineral investigations have been conducted in the region during the past 40 years, but none of the findings have been published.

PRESENT INVESTIGATION

SCOPE OF REPORT

The present report contains an account of the geography and a detailed description of the geology and mineral resources of the central Kuskokwim region. The report is accompanied by a geologic map and cross section of the region (pl. 1), and by more detailed geologic maps and sections of certain mining areas and some of the individual mines. Moreover an attempt is made to show the setting of the geologic features on a tectonic map of southwestern Alaska (pl. 2), in order that their mode of origin and relationship to the geologic features of other regions, both nearby and at a distance, may be placed in a perspective as nearly correct as possible.

METHODS OF WORK

The methods of geological investigation used in the central Kuskokwim region varied with the accessibility of the areas studied, with the base maps available, and with the amount of detailed knowledge desired in areas of special interest. Travel and supply in the field were the most difficult problems. The average field season began in early June and closed late in September.

Difficulties of supply and lack of adequate base maps complicated geologic reconnaissance mapping, yet, as aerial photographs taken by the United States Air Force in 1941 became available, many difficulties met by earlier parties in Alaska were diminished. By utilizing aerial photographs, chosen from those previously used for the preparation of map manuscript by the trimetrogon method of photogrammetry, it was possible to select, before entering the field, the most likely areas for geologic study, the best routes of travel through rugged mountain areas and swampy and brush-covered terrain, and campsites at which firewood and tentpoles could be obtained. Most of the major geologic features could be distinguished on the photographs, which were therefore utilized in the field for mapping geologic formations and structures in areas off the traverse routes.

The aerial photographs were carried in the field and the location of each point of observation was plotted as the traverse progressed. These points, or appropriate geologic symbols based on data recorded in the field notebooks, were then plotted on field copies of the base maps, usually upon completion of a traverse. The base maps used in the field were all on a scale of about 1:100,000. All the base maps, except those used in the Georgetown – Horn Mountain – DeCourcy Mountain–Donlin Creek area and in the Holitna River basin area, were planimetric sketches traced from the original map manuscript compiled from trimetrogon aerial photographs. The base map of the entire central Kuskokwim region was prepared after field work was completed.

Travel and transportation of supplies was by poling boat, canoe, and on foot with packboards. Poling boats powered with outboard motors were used on the larger streams, and on some trips the motor was taken off and the boat poled and lined into headwater areas where the streams are too shallow and tortuous to allow for the use of a motor. On two occasions a canoe was transported in a poling boat and was used to travel in the smaller headwater tributaries. All of the geologic work away from the navigable streams was accomplished on foot traverses, commonly of several days' duration, by a party of two geologists. The longest such traverse, from near the forks of the upper Holokuk River almost to Flat Top Mountain and back by a circular route, a distance of 60 to 70 miles, was accomplished in 12 days. Geologic traverses of the streams were commonly made on the downstream or outgoing trips, when the boats required less attention than when they were fully loaded and running against the current.

The surface exposures of the quicksilver deposits were mapped by planetable methods. Maps of the various underground levels of the operating mines were commonly available as a base upon which to plot geologic data obtained underground. Where such maps were not available, particularly at prospects and abandoned mines, the geologists constructed a similar base by tape and open-sight alidade method.

About 1,200 specimens of rock and ore were collected in the central Kuskokwim region for petrographic study; of these, thin sections were prepared from about 500, and polished sections were made from about 12 ore specimens, for microscopic study. Some of the thin sections were polished and the cover glass left off to enable examination by reflected and transmitted light, which was found particularly advantageous for the study of quicksilver-antimony ore minerals because of the relatively large amount of nonopaque material that accompanies these minerals. Five of the rock specimens and 2 composite rock samples were analyzed chemically, and about 140 ore samples were collected and assayed.

Nearly 400 photographs were taken in the field by Cady and Wallace. These are filed in albums in the photographic library of the Geological Survey, in Washington.

The field and laboratory work was supplemented by a study of all accessible geologic literature on Alaska, Yukon Territory, and northeast Asia, as a basis for understanding the regional geologic setting. The principal sources were official reports of field investigations, too numerous to mention here. Some of the information gained in this study has been utilized in the compilation of the tectonic map of southwestern Alaska (pl. 2) and the geotectonic map of Alaska and vicinity (fig. 3). Included in the study were the discussions and interpretations of interregional geology presented by several authors as follows: Brooks (1906, p. 200–296), Dawson (1891), Eardley (1948; 1951, p. 44, 46, 57, 61, 255–272, 506–507, 511, 512–540), Frebold (1942), Gundlach (1942), Kay (1951, p. 7, 11, 35–49, 73–74, 76, 96), Kropotkin and Kheraskov (1939), Kropotkin and Shatalov (1936), Lord, Hage, and Stewart (1947), Martin (1926), Mertie (1930), Payne and others (1951), Saks (1937), Smith (1939), Spencer (1903), and Stille (1940, p. 44–48, 172–173, 191–197, 229–232, 257–258; 1945, p. 273, 274, 277, 279, 282, 283, 284, 286, 288, 290, 298, 299, 305).

ITINERARIES AND PERSONNEL

The investigation began as a detailed geologic study of the quicksilver deposits and nearby surrounding areas. As the work progressed and new deposits were examined in widely separated areas, the intervening tracts were mapped geologically to bring out the general relationships. Figure 2 shows the routes of traverse in the intervening areas.

Geologic mapping of the quicksilver deposits of the Sleetmute area began in the summer of 1941. W. M. Cady, assisted by R. V. Cushman, mapped the Red Devil, Alice and Bessie, and Barometer mines and the Willis prospects. Several other small prospects were examined briefly, and a geologic reconnaissance of the Sleetmute area was begun.

In 1942 R. E. Wallace, assisted part of the time by S. F. Johnson, continued detailed geologic mapping of the quicksilver deposits of the Sleetmute area, in co-

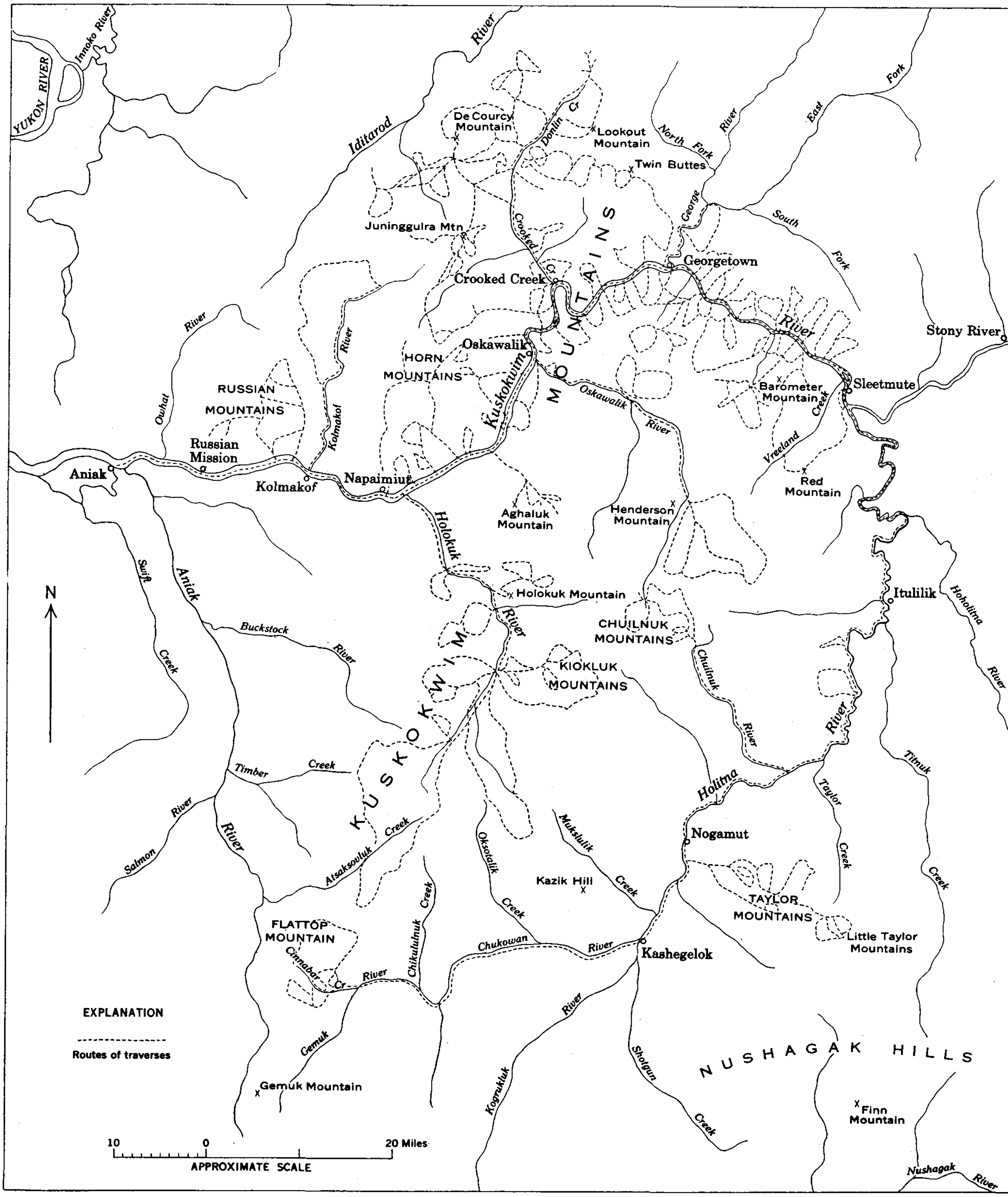

FIGURE 2.—Sketch map of the central Kuskokwim region, showing routes of traverse of Geological Survey field parties during the years 1941 to 1945.

operation with a field party of the U. S. Bureau of Mines which was engaged in trenching and sampling the mines and prospects. Newly opened trenches were mapped at the Red Devil, Alice and Bessie, and Barometer mines, and at the Willis and Fairview prospects. At the same time Cady, assisted by Johnson, was engaged in the areal geologic mapping of the Sleetmute area. Wallace participated in the latter work as time permitted. E. J. Webber joined the party in the middle of the summer and he and Cady went immediately to the DeCourcy Mountain quicksilver mine northwest of Crooked Creek, where Webber remained until the end of the field season. While there, Webber made a preliminary geologic map of the mine and began a geologic reconnaissance of the surrounding country.

Emphasis changed to areal geologic reconnaissance of the central Kuskokwim region in 1943, and three field parties were organized under the general supervision of Cady.

Webber returned to the DeCourcy Mountain area where, assisted by J. M. Hoare, he continued detailed geologic mapping of the DeCourcy Mountain mine, in cooperation with a party of the U. S. Bureau of Mines engaged in trenching and sampling operations. As time permitted, Webber and Hoare continued the geologic reconnaissance of the DeCourcy Mountain area and adjoining areas in the northern part of the central Kuskokwim region, from Little Creek east to the Georgetown Trail and south to Getmuna Creek and Bell Creek (pl. 1; fig. 2).

Wallace, assisted by George Gryc, mapped most of the area west of Georgetown to the Horn Mountains, and north of the Kuskokwim River to Bell and Getmuna Creeks and south to the Oskawalik River.

Cady, assisted by C. A. Hickcox, made a geologic reconnaissance of the Holitna River, Chuilnuk River, Chuilnuk Mountains, Chukowan River, Gemuk River, the Cinnabar Creek area, and Flat Top Mountain, and returned to Sleetmute in the middle of the summer. While in the Cinnabar Creek area they made detailed studies of the Lucky Day and Broken Shovel quicksilver lode prospects and the Cinnabar Creek quicksilver placers. Late in the summer Cady and Hickcox joined the other two field parties, and Cady and Gryc then traversed the Georgetown Trail from Georgetown to Donlin Creek and visited the DeCourcy Mountain mine. Cady and Hoare returned to the Kuskokwim River below Crooked Creek by way of Juninggulra Mountain and the Horn Mountains, completing the geologic reconnaissance of the northern slopes of the Horn Mountains on the way.

In 1944 Wallace and Webber continued the areal reconnaissance down the Kuskokwim River, mapping west from the Horn Mountains to the Russian Mountains, thence southward up the Holokuk River to Holokuk Mountain. They also made detailed studies of a quicksilver occurrence near Kolmakof and of copper prospects in the Russian Mountains. Cady and Hoare ascended the Holitna River to the Kulukbuk Hills and Taylor Mountains, where they continued reconnaissance mapping until the middle of the summer. After that they returned to the Kuskokwim River and traversed the Oskawalik River and adjacent terrain nearly to the foot of the Chuilnuk Mountains, and made a short traverse of the east slopes of the Russian Mountains and adjacent country.

The field work was brought practically to a close by Cady and Hoare in 1945. At the beginning of the field season they ascended the Holokuk River by boat and placed a base camp at the mouth of Girl Creek. From this camp they covered Girl Creek, the Kiokluk Mountains, Egozuk, Boss, and upper Mukslulik Creeks, the head of the Holokuk River, upper Atsaksovluk Creek, and the heads of Oksotalik, Chikululnuk, and Timber Creeks, and the Buckstock River. They returned to the Kuskokwim River in the middle of the summer, and during the second and third weeks in August traversed the Kolmakof River to its headwaters and continued on over the divide to the head of the Iditarod River. The DeCourcy Mountain mine was revisited late in August and the detailed geologic studies begun by Webber and Hoare were brought up to date with more recent mining operations. Similar studies were made at the Red Devil mine in the Sleetmute area early in September. A geologic reconnaissance of Red Mountain and the upper Vreeland Creek area was made late in September.

Hoare returned to examine new openings at the Red Devil mine in 1946, and at the DeCourcy Mountain mine in 1946, 1947, and 1948.

Since 1945 Hoare, who was later joined by W. L. Coonrad, has been engaged in areal geologic mapping of the region west and southwest of the Aniak River to Cape Newenham, and Togiak and Goodnews Bays. Hitherto unpublished information obtained in the latter regional study has been used in compiling the tectonic map of southwestern Alaska (pl. 2), and is referred to at several points in the text of the present report.

Laboratory and office studies continued each winter season, as the field work progressed, under Cady's supervision. Gryc, Wallace, and Webber assisted with petrographic studies. Hoare and Wallace assisted with the compilation of the areal geologic map and structure section (pl. 1) from field maps and notes. Cady examined the geologic literature of Alaska and vicinity in connection with study of the regional geologic setting. The tectonic map of southwestern Alaska (pl. 2) was compiled by Cady and Hoare. Cady wrote the report and prepared the illustrations. Hoare and Wallace made preliminary drafts of the discussion of geography, and Wallace wrote the first draft of the discussion of metamorphic rocks. The writing of the report and preparation of illustrations continued at intervals, as time from other work permitted, during the years from 1946 to 1951. Hoare, Wallace, and Webber reviewed the first draft of most of the manuscript as writing progressed.

The photomicrographs figured in the report are by J. A. Denson. Chemical analyses not previously published are by J. G. Fairchild and J. E. Husted. J. J. Fahey analyzed quicksilver and antimony ore samples. Fossil identifications and statements of their geologic age were furnished by R. W. Brown, R. W. Imlay, Edwin Kirk, and J. B. Reeside, Jr.

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GEOGRAPHY

The central Kuskokwim region is dominated by the Kuskokwim Mountains, which trend northeast from the southwestern part of the region for 300 miles and extend 175 miles beyond its northern border. The Kuskokwim Mountains exceed an altitude of 3,000 feet only locally, but they form a continuous belt that contrasts with the adjacent lowland areas, whose altitudes are commonly less than 500 feet. East of the Kuskokwim Mountains, the Kuskokwim River, second in length in Alaska only to the Yukon River, flows southwestward as far as the central Kuskokwim region, where it turns west through the mountains and flows southwestward through the lowlands to Bering Sea. The basin of the Yukon River lies northwest of the Kuskokwim Mountains and merges on the southwest with that of the lower Kuskokwim River.

Most of the upland area is barren of vegetation except for a carpet of lichens and mosses. Forested areas are restricted almost entirely to the river bottom lands and adjacent slopes at altitudes of less than 1,000 feet. Swampy slopes and bottom lands are covered with thick sphagnum moss. Animal life is varied and fairly abundant. The climate is moderately warm and wet in summer, but the winters are cold, dry, and long.

The principal settlements are located along the Kuskokwim River, which is the chief route of travel and transport. The inhabitants are engaged chiefly in fishing and trapping.

Many of the names applied to physical and cultural features on the maps, particularly the names of the numerous streams, are new in the sense that they have not previously appeared on a map. This is particularly true of the southern part of the region, of which no maps were available until 1942. Most of the names were supplied by natives, familiar with local usage, who accompanied the field parties of the Geological Survey as boatmen. In some instances the native name, or a simplified version of the native name, has been used in preference to English words, such as "salmon" or "swift", already in local use, but employed so widely and repeatedly in Alaska as stream names that they are confusing.

DRAINAGE AND RELIEF

The central Kuskokwim region may be divided conveniently into four geographic units. They are, beginning at the southeast, the Nushagak Hills, the lowland of the Holitna River basin and the upper Kuskokwim River, the Kuskokwim Mountains, and the lowlands of the valleys of the Aniak and lower Kuskokwim Rivers. South of the western headwater tributaries of the Holitna River, and at the headwaters of the Aniak River, is another mountain province that has been referred to in an earlier report as the Tikchik Mountains (Mertie, 1938, p. 14–15). The northern edge of these mountains, which compose a large area of glacially eroded peaks in the region to the south, is included on the map of the central Kuskokwim region (pl. 1). It is south of the area covered by field work, however, and its geographic features will not be discussed further.

The Kuskokwim River, the master stream, flows generally west-southwestward through the northern part of the region in a relatively narrow gorge through the Kuskokwim Mountains. The Holitna River drains nearly all of the area southeast of the Kuskokwim Mountains, except the southern slopes of the Nushagak Hills, flows northeastward, and enters the Kuskokwim River at the point where that river enters its gorge. The Aniak River, which drains much of the west slope of the Kuskokwim Mountains, flows north and enters the Kuskokwim River near the western end of the Kuskokwim River gorge. The Owhat River flows southwest and then south and enters the Kuskokwim River from the north, a little upstream from the mouth of the Aniak River. The Iditarod River, whose headwaters are opposite those of the Owhat, flows northeastward. The latter two streams are at the northwestern boundary of the area included in the geologic map of the central Kuskokwim region. Northwest of the Owhat and Iditarod Rivers is a narrow upland area that separates these rivers from the broad basin of the Yukon River, included in the northwest corner of the base map.

NUSHAGAK HILLS

The Nushagak Hills (Mertie, 1938, p. 13) are on the divide between the headwaters of the Nushagak River on the south and of the Holitna River on the north. They are low, smooth hills devoid of distinctive landmarks, and their higher summits rise to altitudes of about 2,400 feet. The area as a whole has an average altitude of about 1,500 feet. The Chichitnok River, the main headwater tributary of the Nushagak River in the central Kuskokwim region, is a swift clear-water stream that flows close along the base of the hills on the west side of its valley. Below the mouth of the Chichitnok River the Nushagak flows in an open valley. Above the mouth of the Chichitnok it is swift in places and flows over a gravelly bed, split into numerous small channels blocked with sweepers, snags, and log jams that make navigation of small boats dangerous. The valley floor is an abandoned flood plain and is dotted with hundreds of small lakes not shown on the map. Shotgun, Kiknik, Taylor, and Titnuk Creeks, which flow northward from the Nushagak Hills to the Holitna River, are swift clear streams like the Chichitnok River.

The Taylor Mountains are a small group of higher mountain peaks, whose summit altitude is 3,363 feet, that lie at the northern edge of the Nushagak Hills. Their U-shaped valleys and sharply serrate peaks indicate that they have been glaciated (pl. 6). A similar group of peaks, known by natives in the Holitna River basin as the "Mukhailinguk" or south mountains, lies at the southern edge of the region shown on the map, between the heads of Shotgun Creek and the Kogrukluk River.

HOLITNA RIVER BASIN

The Holitna River basin and adjoining areas along the upper Kuskokwim River include a broad, flat valley bottom adjacent to the rivers at altitudes of less than 500 feet and, at the edges of the basin, gentle slopes that rise to an altitude of about 1,000 feet. In its middle course, northeast of the mouth of the Chuilnuk River, the Holitna River passes through a belt of hills whose altitude is about 1,000 feet and which trend northwest across the trend of the basin. The Kulukbuk Hills, at the northeastern edge of this belt, are somewhat higher. High, smoothly rounded hills, much like the Nushagak Hills in appearance, are found in the southwestern part of the Holitna basin northeast and southwest of the Chukowan River and lower Oksotalik Creek. Kazik Hill, an isolated sharp pinnacle about eight miles northwest of Kashegelok, is one of the well-known landmarks of the region.

The Holitna River meanders freely on the valley bottom throughout much of its course. At Kashegelok and Nogamut it impinges for short distances against hills to the southeast, and near the mouth of the Chuilnuk River and at the Kulukbuk Hills it flows against the foot of limestone bluffs that overlook it from the northwest. The Kuskokwim River upstream from the mouth of the Holitna River flows on the northwestern edge of its valley bottom.

The Holitna River and its tributaries are large streams; it is said that in times of high water small barges may be pushed up as far as Kashegelok. Many of the side streams are accessible to poling boats powered with outboard motors. One of the field parties of the Geological Survey ascended the Chuilnuk River to the foot of the Chuilnuk Mountains and the Chukowan and Gemuk Rivers to the mouth of Beaver Creek, in a 30-foot poling boat equipped with a 22½-horsepower outboard motor. These localities are both at an altitude of about 1,000 feet and at, or only a little below, timber line. The Chukowan River flows in a fairly deep gorge from the mouth of Bairo Creek to the mouth of Oksotalik Creek but, though swift, the river is deep enough that powered boats can be used easily. The Gemuk River, on the other hand, comprises many anastomosing channels, filled with tree stumps and log jams against which a boat may easily be swamped or crushed by the current, if the power is accidentally cut off and headway lost in fast water.

KUSKOKWIM MOUNTAINS

The Kuskokwim Mountains form a steep escarpment that overlooks the Holitna River basin (pl. 8). The Mountains stand 1,500 to 2,000 feet above the border of the basin at the escarpment. Northeast of Red Mountain, however, few nearby mountains stand more than 1,000 feet above the basin of the Holitna and upper Kuskokwim Rivers, and the escarpment falls away into low, rolling hills that slope gently down to the bluffs of the Kuskokwim River at and northeast of Sleetmute. The escarpment is also lost southwest of Oksotalik Creek, where the mountains are not so high and the adjacent part of the Holitna basin is more hilly.

The height of the southeastern escarpment of the Kuskokwim Mountains reflects closely the topographic character of various areas of the mountains northwest of the escarpment. The mountains at the escarpment are made up of sharply dissected peaks that reach altitudes of 3,000 to 3,500 feet, which typify the Kuskokwim Mountains from Red Mountain southwest to Flat Top Mountain. From Red Mountain, Henderson Mountain, and Aghaluk Mountain northward, however, the whole of the mountain belt, with a few notable exceptions, is made up of low, smooth, rolling hills devoid of distinctive landmarks (fig. 32), quite comparable to the Nushagak Hills. The higher summits are at an altitude of about 2,200 feet and the average altitude is about 1,500 feet.

Rising from the general summit level of the Kuskokwim Mountains are isolated peaks and groups of peaks. Most noteworthy are the glaciated serrate peaks of the Chuilnuk, Kiokluk, Horn, and Russian Mountains, whose summit altitudes range from 3,500 to 4,100 feet. These higher mountain groups are similar to the Taylor Mountains at the northern edge of the Nushagak Hills. Several smaller peaks, such as Barometer Mountain, Holokuk Mountain, Aghaluk Mountain, and Juninggulra Mountain, form smoothly rounded elongate ridges, covered with loose rock, on which grows a black lichen that gives the mountains a somber appearance. The higher peaks do not extend into the George River area east of Crooked Creek and north of the Kuskokwim River.

The Kuskokwim River flows in a gorge through the Kuskokwim Mountains from Sleetmute to Napaimiut. Between Sleetmute and Georgetown the river lies chiefly on the northeast side of the comparatively narrow valley bottom. This tendency to impinge on the right side of the valley may be traced downstream from Georgetown to Napaimiut, although it becomes less evident. Steep cut-banks and bluffs, commonly referred to as "ramparts" elsewhere in Alaska and northwestern Canada, characterize the gorge from Parks to Oskawalik. The average width of the Kuskokwim River in the gorge is a little less than a quarter of a mile. One of the most remarkable features of this part of the river is the big meander loop at the village of Crooked Creek. It is said that in the old days natives used to portage across this loop, particularly on trips up the river.

The principal secondary streams within the Kuskokwim Mountains, most of which are tributary to the Kuskokwim River are, in decreasing order of size, the George, Holokuk, upper Iditarod, Oskawalik, Kolmakof, Owhat, and Buckstock Rivers, and Crooked, Atsaksovluk, and Vreeland Creeks. Most of these are clear-water streams in contrast to the muddy Kuskokwim. The George River, Crooked Creek, Kolmakof, Iditarod, and Owhat Rivers, and other streams that drain the low, smooth hills north of the Kuskokwim River, flow in relatively broad, open valleys, commonly on the northwest sides of the valley bottoms. The streams south of the Kuskokwim River drain the more sharply dissected terrain of that portion of the Kuskokwim Mountains, and flow at the bottoms of rather deeply cut steep-walled valleys that have little or no bottom land. The gorge of the Holokuk River downstream from Chineekluk Creek is the best example of this.

ANIAK RIVER-LOWER KUSKOKWIM RIVER LOWLANDS

These lowlands form an L-shaped area that extends northward on the Aniak River from a point near the mouth of Atsaksovluk Creek to the Kuskokwim River at Russian Mission, and then west along the Kuskokwim. The lowlands slope gently upward to the Kuskokwim Mountains on the east and to mountains west of the Aniak River. Much of the bottom land is wet and swampy and numerous small lakes dot the area for a distance of 15 miles south of the Kuskokwim River. The Aniak River flows in several shifting channels that cross back and forth in a braided pattern; it is not as favorable for navigation with small boats as are most of the other large streams of the central Kuskokwim region. The Kuskokwim River flows on the north side of the lowlands from Napaimiut west, much as it does at the northwest edge of the Holitna-upper Kuskokwim basin and in the gorge between Sleetmute and Napaimiut. A little south of the present course of the Kuskokwim River are numerous oxbow lakes and swamps, left in abandoned channels of the river.

VEGETATION

The vegetation of the central Kuskokwim region is distinctive in each of four physiographic settings. These are the river flood plains, hill slopes, rounded ridge crests 1,000 to 2,000 feet in altitude, and higher peaks and ridges above 2,000 feet. The flood plains are commonly covered by extensive stands of spruce, including small amounts of tamarack. Large cottonwoods grow along river banks, around lakes formed in the flood plains, and on islands. Willows and alders form dense thickets, particularly on gravel bars. The hill slopes support open stands of mixed spruce, birch, and aspen; alder thickets; and a ground cover of blueberry, dwarf birch, cranberries, sphagnum moss, and lichens. The rounded ridge crests (fig. 32) are treeless except for a few stunted spruce; they are covered chiefly by various lichens, particularly caribou "moss"; mosses, including some sphagnum; and dwarf alpine flowering plants. The high rocky ridges and peaks are barren, except for lichens that cling to the rock surfaces and the scattered small plants that find a footing in what little soil is present.

The altitudinal zoning of vegetation, as described above, is typical of the central Kuskokwim region, but in regions to the west, where the land is not forested, such zoning is hardly apparent. West of Aniak the bottomlands of the Kuskokwim River are covered only by grasses, sedges, mosses, small willows, and alders. Lack of forest is characteristic of practically all areas within 100 to 150 miles of the Bering Sea coast.

The largest stands of timber in the region are on the flood plains south of the Kuskokwim River, between Napaimiut and Aniak. Spruce trees as much as 2 feet in diameter grow on the flood plains of the larger streams; and most of the flood plains of smaller streams, below an altitude of 1,000 feet, support small stands of spruce and other trees. Dense stands of trees follow some of the smaller gulches and draws up to an altitude of about 1,500 feet and spread out on the ridges where conditions are favorable. White birch and aspen predominate on southern slopes, particularly where there is also good drainage. Between the upper limit of the spruce on the hill slopes and the relatively barren ridge crests, there are in many places dense thickets of alders. The trunks of the alders are long and flexible and sweep downhill, roughly parallel to the ground, before turning upward. They grow to heights of 10 feet or more and present such difficult obstacles for the foot traveler that he experiences great relief when he has climbed over this zone onto the open ridges.

Blueberries grow in great profusion on the hill slopes; with the dwarf birch they form undergrowth from 2 to 4 feet high beneath and between the scattered trees. High-bush cranberries and small willows are also included in this undergrowth, beneath which lies a carpet of moss, commonly sphagnum. Salmonberries are common and raspberries occur in a few places.

Spongy polsters or cushions of fruticose lichens, chiefly the light gray-green caribou and reindeer "mosses", make up the conspicuous vegetation of the rounded upland slopes and summits. The rocky ridges and summits are covered by a black foliose lichen, which imparts a dark color to the peaks. This color has led to the misidentification of some of the peaks as basaltic volcanoes, by persons who observed them from a distance.

Great thicknesses of peat have formed locally on the lower slopes and flood plains, through the accumulation of sphagnum moss. Tall, lush stands of grass grow where village sites have been cleared along the river banks and are one means of recognizing abandoned village sites. Elsewhere, grasses are relatively uncommon and forage suitable for domestic animals is difficult to find.

Several garden vegetables grow rather well under cultivation on the flood plains along the Kuskokwim River. Lettuce and carrots are raised, for use during the summer, and cabbage, which may be stored for winter use. Potatoes are also grown, but the frost-free season, seldom longer than 90 days, is too short to allow them to mature satisfactorily.

Mr. A. J. Stewart, who was attached to one of the field parties during the summer of 1944, attempted to make a representative collection of the native plants of the region. The collection was sent to the University of California for study, and Professor Herbert L. Mason, Curator of the University of California Herbarium, kindly supplied the list of identifications given below. Most of the specimens were obtained along or near the Kuskokwim River between Oskawalik and Aniak, but a few are from the Horn and Russian Mountain areas.

A collection of plants from the central Kuskokwim region

[Identification by H. L. Mason; common names after J. P. Anderson (1943-52), except those shown in parantheses, which are local names or other well-known common names]

Polypodiaceae (fern family):
- *Cystopteris montana* (Lamarck) Bernhardi. Mountain-Cystopteris.
- *Dryopteris dilatata* (Hoffman) A. Gray. Spreading woodfern.
- *Gymnocarpium dryopteris* (Linnaeus) Newman. Oakfern.

Pinaceae (pine family):
- *Larix laricina* (DuRoi) Koch. Tamarack or American larch.
- *Picea glauca* (Moench) Voss. White spruce.

Cyperaceae (sedge family):
- *Eriophorum gracile* Koch. Slender cottongrass (squawgrass).

Juncaceae (rush family):
- *Juncus bufonius* Linnaeus. Toadrush.

Liliaceae (lily family):
- *Streptopus amplexifolius* (Linnaeus) De Candolle. Twistedstalk.
- *Tofieldia coccinea* Richards. Northern asphodel (lamblily).

Salicaceae (willow family):
- *Salix alaxensis* (Coville) var. *longistylis* (Rydberg) Schneider. Feltleaf-willow.
  - *arbusculoides* Andersson var. *glabra* Schneider. Littletree willow.
  - *bebbiana* Sargent. Bebb willow (beak-willow).

Betulaceae (birch family):
- *Alnus crispa* (Aiton) Pursh. Green alder.
  - *incana* (Linnaeus) Moench. Mountain-alder.

Polygonaceae (buckwheat family):
- *Polygonum alaskanum* (Small) Wight. Wild rhubarb.
  - *bistorta* (Linnaeus) subsp. *plumosum* (Small) Hultén Mountain meadow bistort (jointweed).
- *Rumex crispus* Linnaeus? Curled dock.

Portulacaceae (purslane family):
- *Claytonia sibirica* Linnaeus? Siberian springbeauty.

Caryophyllaceae (pink family):
- *Arenaria arctica* Steven. Arctic-sandwort.
  - *lateriflora* Linnaeus. Blunt-leaved sandwort.
- *Cerastium aleuticum* Hultén. Aleutian mouse-eared chickweed.
  - *arvense* Linnaeus. Field chickweed.
- *Dianthus repens* Willdenow. Northern pink.

Ranunculaceae (crowfoot family):
- *Aconitum delphinifolium* De Candolle. Delphinium-leaved aconite (monkshood).
- *Anemone narcissiflora* Linnaeus. Narcissus-flowered anemone (windflower).
- *Delphinium brownii* Rydberg. Larkspur.
- *Ranunculus purshii* Richards. (Buttercup).
- *Thalictrum venulosum* Trelease. Meadowrue.

Papaveraceae (poppy family):
- *Papaver radicatum* Rottboell. Arctic-poppy.

Cruciferae (mustard family):
- *Cardamine bellidifolia* Linnaeus. Alpine-cress (bittercress).
  - *pratensis* Linnaeus. Cuckooflower.
- *Descurainia sophioides* (Fischer) Schulz. Northern tansymustard.
- *Erysimum cheiranthoides* Linnaeus. Wormseed mustard.
- *Nasturtium obtusa* Nuttall.

Crassulaceae (stonecrop family):
- *Rhodiola integrifolia* Rafinesque. Roseroot (hen-and-chickens).

Saxifragaceae (saxifrage family):
- *Boykinia richardsonii* (Hooker) Gray. Richardson saxifrage.
- *Parnassia palustris* Linnaeus. Northern grass-of-Parnassus.
- *Saxifraga flabellifolia* Rendel and Britten.
  - *galacifolia* Small.
  - *hieracifolia* Waldstein and Kitaibel. Hawkweed-leaved saxifrage.
  - *serpyllifolia* Pursh. Thyme-leaved saxifrage.

Rosaceae (rose family):
- *Dryas drummondii* Richards. Drummond mountain-avens (yellowdryad).
- *Potentilla anserina* Linnaeus. Common silverweed.
  - *fruticosa* Linnaeus. Shrubby cinquefoil.
  - *monspeliensis* Linnaeus. Rough cinquefoil (barren-strawberry).
  - *uniflora* Lidet. One-flowered cinquefoil.
- *Pyrus* (*Sorbus*) *sitchensis* (Roemer) Piper. Sitka mountain-ash.
- *Rosa acicularis* Lindley. Prickly-rose.
- *Sanguisorba menziesii* Rydberg. Menzies greatburnet.
  - *sitchensis* C. A. Meyer. Sitka greatburnet.
- *Spiraea stevenii* (C. K. Schneider) Rydberg. Spirea (meadowsweet).

Leguminosae (pea family):
- *Hedysarum boreale* Nuttall.
- *Lathyrus palustris* Linnaeus. Wild pea (marshvetchling).
- *Oxytropis* sp. Oxytrope (locoweed).

Geraniaceae (cranesbill family):
- *Geranium erianthum* De Candolle. Northern geranium (cranesbill).

Empetraceae (crowberry family):
- *Empetrum nigrum* Linnaeus. Crowberry (black-crowberry).

Balsaminaceae (jewelweed family):
- *Impatiens occidentalis* Rydberg. Western touch-me-not.

Onagraceae (evening-primrose family):
- *Epilobium angustifolium* Linnaeus. Fireweed (blooming-Sally).
  - *latifolium* Linnaeus. Dwarf fireweed or riverweed (broad-leaved willow-herb).

Umbelliferae (carrot family):
- *Bupleurum americanum* Coulter and Rose. American thoroughwort.
- *Conioselinum cnidiifolium* (Turea) A. Porsild. Hemlockparsley

Cornaceae (dogwood family):
- *Cornus canadensis* Linnaeus. Bunchberry.

Ericaceae (heath family):
- *Arctostaphylos* (*Arctous*) *alpina* (Linnaeus) Sprengel. Alpine-bearberry.
- *Ledum* sp. Labrador-tea.
- *Moneses uniflora* (Linnaeus) Gray. Waxflower (woodnymph).
- *Phyllodoce glanduliflora* (Hooker) Coville. Yellowheather.
- *Pyrola asarifolia* Michaux. Liverleaf wintergreen.

Diapensiaceae (diapensia family):
- *Diapensia lapponica* Linnaeus. Diapensia.

Primulaceae (primrose family):
- *Dodecatheon latifolium* (Hooker) Piper. Shootingstar.
- *Primula* sp. Primrose.
- *Trientalis arctica* Fischer. Starflower.

Gentianaceae (gentian family):
- *Gentiana glauca* Pallas. Glaucus gentian.

Polemoniaceae (phlox family):
- *Polemonium coeruleum* Linnaeus. (Jacobs-ladder).

Scrophulariaceae (figwort family):
- *Castilleja purpurascens* Greenman? (Indian-paintbrush).
- *Mimulus guttatus* De Candolle. Yellow monkeyflower.
- *Pedicularis bracteosa* Bentham. Lousewort or bumblebee plant.
  - *euphrasioides* Stephan? Lousewort (eyebright pedicularis).
- *Rhinanthus crista-galli* Linnaeus. Rattlebox (yellow rattle)
- *Synthyris* sp. Kittentails.

Rubiaceae (madder family):
- *Galium boreale* Linnaeus. Northern bedstraw.

Caprifoliaceae (honeysuckle family):
- *Linnaea borealis* Linnaeus var. *americana* Rehder. Twinflower.

Valerianaceae (valerian family):
- *Valeriana sylvatica* Banks. Valerian (wild heliotrope).

Campanulaceae (bellflower family):
- *Campanula lasiocarpa* Chamisso. Mountain-harebell.

Compositae (aster family):
- *Achillea borealis* Bongard. Northern yarrow.
- *Antennaria umbrinella* Rydberg. (Cats-ear, ladystobacco, pussytoes).
  - *Arnica chamissonis foliosus* (Nuttall) Maguire.
    - *fulgens* Pursh.
  - *Artemisia arctica* Lessing. Arctic-wormwood.
    - *vulgarus heterophylla* (Nuttall). (Common mugwort).
    - *tridentata* Nuttall.
  - *Aster richardsonii* Sprengel? Siberian aster.
  - *Hieracium triste* Willdenow ex. Sprengel. Woolly hawkweed.
  - *Solidago corymbosa* Nuttall. Goldenrod.
  - *Tanacetum bipinnatum* (Linnaeus). Schultz-bip (tansy).

ANIMAL LIFE

All of the major groups of vertebrate animals except the reptiles are represented in the central Kuskokwim region. Amphibians are probably not common; yet a frog was heard by the authors at one place, and natives say that frogs are found. Insects, particularly mosquitos and gnats, which appear during the frost-free summer months, are the most obvious of the invertebrates, but no scientific study was made of them.

MAMMALS

The central Kuskokwim region supports a varied assortment of mammals. Among those that were seen by field parties of the Geological Survey or reported by local inhabitants are wolf, marten, weasel, otter, black bear, brown bear, wolverine, lynx, moose, caribou, reindeer, snowshoe rabbit, ground squirrel, pika, porcupine, marmot, mink, beaver, muskrat, red fox (including cross fox), and coyote.

Wolves are relatively plentiful, judging from the abundance of their tracks, but they are seldom seen except in winter. Scattered caribou are seen. Reindeer, which were introduced and herded in the region until 15 or 20 years ago, are scarce, and the nearest place at which they are now herded is on Nunivak Island in the Bering Sea, off the Yukon-Kuskokwim delta. Laplanders and natives who once herded reindeer in the Kuskokwim region have turned to fishing, trapping, and gold placer mining for a livelihood.

Black bears are probably the most common large game in the region. The black phase of this bear is predominant, and few have been seen that showed even partial tendency toward the development of a brown or cinnamon phase. The large Alaskan brown bear occurs south of the Kuskokwim River, principally in the

Chuilnuk and Kiokluk Mountains and farther south. Several large brown bears were seen by field parties in the latter areas. They have been reported as far north as Aghaluk Mountain, but natives claim that they are never found north of the Kuskokwim River. Their distribution follows closely the distribution of ground squirrels, which possibly is the controlling factor, since the ground squirrels are a favorite if not a principal food of the brown bear in this region.

Moose are the favorite big game of the hunter in the region and are plentiful enough that the small population of natives and whites is able to get as much game as is legally allowed during the hunting season each year.

Animals trapped for fur include beaver, marten, weasel, otter, mink, wolverine, lynx, red and cross fox, and snowshoe rabbit. Beaver fur is economically the most important because of its relative abundance and the consistency of the market, but marten brings higher prices and is therefore more highly prized. Wolverine fur is used in making parka ruffs because frost does not form on it.

Other smaller mammals are the pika, common in the rocky slopes above timberline, and porcupine and marmot, both of which are scarce.

FISH

According to Sam Parent, trader at Crooked Creek, the fish in the Kuskokwim River include king (chinook) dog (chum), and silver (Coho) salmon, pike, whitefish, sucker, chee (shee or cheet), "lush", and eels (lampreys). The following information concerning each type was supplied chiefly by him.

The king salmon have pink meat and a pink exterior, with dark spots, when they reach the upper rivers. The first migrants coming upriver to spawn arrive at Crooked Creek about the middle of June, and the run continues until about the second week in July. They migrate up the Kuskokwim to the Holitna River, where they leave the Kuskokwim and continue up the Holitna. The maximum size reported was one of 108 pounds caught near Kalskag on the lower Kuskokwim River. The average size is 10 to 30 pounds.

The dog salmon have pale pink meat, a mottled green-grey and white exterior, and an average weight of about 10 pounds. The first of these arrive at Crooked Creek with the king salmon, but they continue to come later in July.

The silver salmon are dark on the dorsal side, grading to silver on the ventral side, and weigh about 9 pounds. Instead of migrating up the Holitna River, they continue to the next major tributary, the Stony River, and ascend it to spawn.

Red salmon, also, occur in the Kuskokwim River. They weigh only about 6 pounds and may be further distinguished from the other salmon in that they have no spots.

The pike, whitefish, sucker, chee, and eels are common in the summer, but the "lush" are caught only through the ice in the wintertime. Grayling are plentiful in the clear-water tributaries of the Kuskokwim, but in the Kuskokwim they are caught principally where water from a tributary provides a clear zone in the otherwise muddy waters.

BIRDS

The central Kuskokwim region can be divided into five major ecological divisions which support different types of bird life. After each of the divisions listed below some typical bird inhabitants are given.

1. The Kuskokwim River, its banks and river bars: Semipalmated plover, spotted sandpiper, glaucous-winged gull, pintail duck, American merganser, violet-green swallow.
2. Flood plains of the Kuskokwim River: Gambel's sparrow, Swainson's thrush, gray-cheeked thrush.
3. Spruce and birch-covered hill slopes, in many places burned over: Gambel's sparrow, junco, gray jay, spruce grouse.
4. Rounded ridge tops above timberline, covered with caribou and reindeer lichens, commonly not over 2,000 feet above sea level: Water pipit, rock ptarmigan, Alaska longspur.
5. Isolated clusters of rocky arêtes and horns, peaks rising 3,500 above sea level: Hepburn's gray-crowned rosy finch, snow bunting.

Another division of the region into three large areas is also possible. South of the Kuskokwim River there are varieties of birds as well as mammals that are not found north of the Kuskokwim River. The fox sparrow, Arctic tern, and bald eagle occur chiefly to the south. Most of the ducks and geese, the common gull, whistling swan and lesser sandhill crane, inhabit the extensive lake-covered bottomlands near Aniak.

Birds are plentiful along the Kuskokwim River. Among the commonest seen is the glaucous-winged gull, which nests on the sand bars that are above river level during times of low water in June and July. Dead fish that are washed up on the banks make excellent food for these scavengers. Of the water birds, the red-breasted merganser is most frequently seen, and various other ducks are also present. The semipalmated ringed plover and spotted sandpiper are common wading birds. During May, June, and July four species of swallows—the violet-green, tree, bank, and cliff—skim the river's surface and sometimes flutter around one's head to feed on the swarms of mosquitoes present. The violet-green is the most abundant of the four.

In the thickets along the shore, and also farther up on the brush-covered hillslopes, Gambel's sparrows are plentiful. Swainson's and gray-cheeked thrushes nest in alder thickets along the river. Juncos are often flushed from the brush-covered slopes, and it is there that robins, chickadees and gray jays are most commonly seen. Pipits, ptarmigans, and longspurs inhabit the lichen-covered ground above timberline. In one valley flocks of rock ptarmigans of 20 to 50 individuals seemed to be in the air continually, and in one day it was estimated that more than 1,000 individuals were seen in an area of about 4 square miles. Arctic terns nest in the valleys south of the Kuskokwim River.

The nesting season is short. All the birds that were established in the area were apparently nesting at the time the field parties arrived each year, in the latter part of May or early June. Violet-green swallows are reported by local inhabitants to arrive at Georgetown very nearly on the eighth of May each year. About the middle of July the various species of swallows gather in flocks, which in 1942 were last seen on the 24th of July. During 1943 the majority of the swallows left on about the 29th of July, but stragglers were seen during the first week of August. Ducks and geese were seen in flocks by July 15th and during the latter half of the month migration was well under way. A few ducks, however, were seen as late as September.

From the last part of July on, many of the migratory groups, including warblers, flycatchers, kinglets, and sparrows, were noticeably moving northeastward upriver. Some of the ducks and geese, however, were flying downriver. The birds that fly northeastward probably have to travel around the northern limit of the Alaska Range, which lies to the east of this area, and presumably join the Central flyway, whereas those that fly downriver probably join the Pacific Coast flyway after reaching Bering Sea.

During the last week in August one of the most spectacular events of the year takes place when the lesser sandhill cranes pass in their northeastward migration. Flocks of 50 to 75 individuals circle on upcurrents of air until great elevations are reached, then they coast on the next upcurrent of air and repeat their circling. Often their rough croaking cries could be heard, even though the birds were too high to be seen with the unaided eye. The cranes in their migration follow the trend of the Kuskokwim River only in a general way; they fly across country in flight paths that are much straighter than the flow of the river.

By early September, after the last of the cranes are gone, few birds are left. Those that were seen during the fast-shortening days of early fall were apparently regular residents such as the gray jays, chickadees, ravens, grouse, and rock ptarmigan. On frosty September mornings grouse came down from the brush-covered slopes and congregated on the pebbly banks of the river, for the purpose of picking up gravel, difficult to obtain elsewhere when the ground is frozen at higher elevations.

The following checklist of birds in the region, with the exception of one or two species, was compiled by R. E. Wallace, during June to September of the years 1942 to 1944 and in June and July of 1945. With the assistance of Frederick C. Lincoln of the U. S. Fish and Wildlife Service, the list has been arranged and edited in conformance with the nomenclature of the fifth edition of the American Ornithological Union checklist, still in manuscript form.

Checklist of birds observed in the central Kuskokwim region.

Common loon. *Gavia immer.*
Red-throated loon. *Gavia stellata.*
Cackling canada goose. *Branta canadensis minima.*
Whistling swan. *Cygnus columbianus.*
White-fronted goose. *Anser albifrons.*
Mallard duck. *Anas platyrhynchos.*
Pintail. *Dafila acuta*
Baldpate. *Mareca americana.*
Green-winged teal. *Nettion carolinensis.*
Shoveller. *Spatula clypeata*
Canvas-back. *Nyroca valisineria*
Lesser scaup duck. *Nyroca affinis*
Western harlequin duck. *Histrionicus histrionicus pacificus.*
White-winged scoter. *Melanitta deglandi*
Surf scoter. *Melanitta perspicillata.*
American merganser. *Mergus merganser americanus.*
Red-breasted merganser. *Mergus serrator.*
Marsh hawk. *Circus cyaneus hudsonius.*
Red-tailed hawk. *Buteo borealis.*
American rough-legged hawk. *Buteo lagopus.*
Bald eagle. *Haliaëtus leucocephalus.*
Osprey. *Pandion haliaëtus.*
Peregrine falcon. *Falco peregrinus.*
Spruce grouse. *Canachites canadenis.*
Rock ptarmigan. *Lagopus mutus.*
Willow ptarmigan. *Lagopus lagopus.*
Lesser sandhill crane. *Grus canadensis canadensis.*
Semipalmated ringed plover. *Charadrius hiaticula semipalmatus.*
Surfbird. *Aphriza virgata.*
Wilson's common snipe. *Capella gallinago delicata.*
Greater yellowlegs. *Totanus melanoleucus.*
Least sandpiper. *Erolia minutilla.*
Spotted sandpiper. *Actitis macularia.*
Solitary sandpiper. *Tringa solitaria.*
Wandering tattler. *Heteroscelus incanus.*
Baird's sandpiper. *Erolia bairdii.*
Long-tailed jaeger. *Stercorarius longicaudus.*
Glaucous-winged gull. *Larus glaucescens.*
Common gull. *Larus canus.*
Arctic tern. *Sterna paradisaea.*
Horned owl. *Bubo virginianus.*
Hawk owl. *Surnia ulula.*
Belted kingfisher. *Megaceryle alcyon.*
Three-toed woodpecker. *Picoides tridactylus.*
Hairy woodpecker. *Dendrocopos villosus.*
Flycatcher. *Empidonax* sp.?
Olive-sided flycatcher. *Nuttallornis borealis.*
Say's phoebe. *Sayornis saya.*
Horned lark. *Eremophila alpestris* subsp.?

Violet-green swallow. *Tachycineta thalassima.*
Tree swallow. *Iridoprocne bicolor.*
Bank swallow. *Riparia riparia.*
Cliff swallow. *Petrochelidon pyrrhonota.*
Gray jay. *Perisoreus canadensis.*
Raven. *Corvus corax.*
Black-capped chickadee. *Penthestes atricapillus.*
Boreal chickadee. *Penthestes hudsonicus.*
Robin. *Turdus migratorius.*
Varied thrush. *Ixoreus naevius.*
Hermit thrush. *Hylocichla guttata.*
Swainson's thrush. *Hylocichla ustulata.*
Gray-cheeked thrush. *Hylocichla minima.*
Ruby-crowned kinglet. *Regulus calendula.*
Water pipit. *Anthus spinoletta.*
Sprague's pipit. *Anthus spragueii.*
Greater waxwing. *Bombycilla garrulus.*
Great shrike. *Lanius excubitor.*
Orange-crowned warbler. *Vermivora celata.*
Alaska myrtle warbler. *Dendroica coronata hooveri.*
Blackpoll warbler. *Dendroica striata.*
Water-thrush. *Seirus novaboracensis.*
Pileolated warbler. *Wilsonia pusilla.*
Pine grosbeak. *Pinicola enucleator.*
Hepburn's graycrowned rosy finch. *Leucosticte tephrocotis littoralis.*
Common redpoll. *Acanthis flammea.*
Snow bunting. *Plectrophenax nivalis.*
Pine siskin. *Spinus pinus.*
Savannah sparrow. *Passerculus sandwichensis.*
Slate-colored junco. *Junco hyemalis.*
Tree sparrow. *Spizella arborea.*
Chipping sparrow. *Spizella passerina.*
Gambel's sparrow. *Zonotrichia leucophrys gambelii.*
Golden-crowned sparrow. *Zonotrichia atricapilla.*
Fox sparrow. *Passerella iliaca.*
Song sparrow. *Melospiza melodia.*
Alaska longspur. *Calcarius lapponicus alascensis.*

CLIMATE

The climate of the central Kuskokwim region is subarctic and characteristically cold and dry, but less extreme than at more interior points such as Fairbanks. Temperatures are more moderate than in the interior and precipitation is greater, owing to the closer proximity of the ocean. The summers are short and rather wet, and the winters long, dry, and cold. In summer, nights are comparatively warm; the sun is above the horizon 20 hours daily in June, and it is never darker than twilight from late May through July. On the other hand, the nights are 20 hours long in December and early January, when the sun cannot lessen the deep cold even at noontime.

Although uplands are commonly several degrees colder than the bottom lands during the summer, there is frequently an inversion of temperatures in the winter, when the valley bottoms are colder than the uplands, because of the settling of the heavier cold air. The growing season in the lowland areas begins about the second week in June and ends about the first week in September, but in some years it has been cut short in the middle of the summer by killing frosts. Growth is greatly hastened however by the long summer days. Thunderstorms occur frequently during June, on otherwise clear bright days when the wind is from the north. As the summer continues, however, and winds blow from the south and southwest, cloudy and rainy weather of several days' duration becomes more prevalent.

Weather observations have been taken for several years at Sleetmute, a lowland station whose altitude is about 240 feet. Here the mean annual rainfall is about 20 inches and snowfall about 80 inches. The mean temperature in July, the warmest month, is about 56°F, and in January, the coldest month, about −10°F. The highest temperature officially recorded at Sleetmute is 90°F and the lowest −58°F.

SETTLEMENTS AND POPULATION

Three hundred people live on the 120-mile section of the Kuskokwim River included in the present study. This is almost the entire population of the region, because only one or two families and a few prospectors live in areas distant from the Kuskokwim River. The density of the population of the region as a whole is therefore about 0.03 person a square mile. Only four villages have more than 20 inhabitants; most of the people live in family settlements of one or two log cabins scattered along the river bank.

The chief means of livelihood in the region is fishing; trapping is second in importance. Fish are the principal item of food of the human inhabitants and are the sole food of sled dogs used chiefly for winter trips to trapping grounds. Trapping is almost entirely for furs to be used in trade. Money gained from the sale of furs is used to buy groceries, outboard motors and gasoline, hardware, and various luxury items such as radios. Large quantities of fish, chiefly for dog food, are also sold in trade. Trading is a means of living for one or two persons in each community, who commonly also operate a roadhouse where travelers can obtain rooms and meals. The larger villages have a school teacher. Woodcutting, lumbering, dog-team and boat transportation, gardening, mining and prospecting, and serving as postmaster or weather observer are part-time occupations.

The largest community is Aniak, at the mouth of the Aniak River, which is the site of an airfield operated by the U. S. Civil Aeronautics Administration. Several people are employed at the airfield on communication and maintenance crews. The village also supports two stores, a roadhouse, a post office, and a school operated by the U. S. Bureau of Indian Affairs. About 40 to

50 natives and 30 to 40 white people lived at Aniak in 1944 and 1945 when the field parties of the Geological Survey were in its vicinity.

Crooked Creek village, on the north side of the Kuskokwim River near the mouth of Crooked Creek, has developed in two parts—an old village, situated downriver from the mouth of the creek and actually at the mouth of Village Creek, and the school, post office, and combined trading post and roadhouse, located upriver from the mouth of Crooked Creek. About 80 natives and people of mixed blood and 6 or 7 white people live at Crooked Creek or in the vicinity.

Sleetmute with its vicinity, near the mouth of the Holitna River, is populated by about 50 natives and 7 or 8 white people. A post office, a school operated by the Bureau of Indian Affairs, and a church are located at the village on the east bank of the Kuskokwim River, and trading posts are located about 1 mile upstream and 4 miles downstream from the village on the opposite side of the river. The Red Devil quicksilver mine is about 6 miles in an air line northwest of Sleetmute village, on the southwest side of the river.

Napaimiut is a small village on the north side of the Kuskokwim River, about 3 miles downstream from the mouth of the Holokuk River. Only about 15 natives and 2 or 3 white people live in the vicinity. This village supports 1 trading post, and the school operated by the Bureau of Indian Affairs is opened when there are 5 or more children of school age in the village.

In addition to these four villages, where post offices and schools are in operation, there are other more or less permanent settlements that form a part of the Kuskokwim River community. Several native families live on both sides of the river near Russian Mission, site of a church on the north side of the river in the vicinity of the Russian Mountains. Oskawalik, opposite the mouth of the Oskawalik River; Georgetown, near the mouth of the George River; and Eightmile, nearly opposite the mouth of Eightmile Creek, are villages now occupied by one family, but which at some time had larger populations. Native families that trade on the Kuskokwim River live at least seasonally at Nogamut and Kashegelok on the upper Holitna River. Itulilik, on the lower Holitna River, was not occupied when the Geological Survey party stopped there in 1944, but it did not appear to be permanently abandoned.

There are several abandoned village sites along the Kuskokwim River. Two of these, Kolmakof and Parks, are shown on the map because they are old landmarks of the region. Kolmakof, between Napaimiut and Russian Mission, is the oldest permanent white settlement in the interior of Alaska, founded in about 1834. Less than 40 years ago it was the site of a store, a church (since removed to Russian Mission), and a roadhouse, as well as the old Russian blockhouse, the ruins of which have been removed to the University of Alaska, at College, for preservation. Parks, about 9 miles northwest of Sleetmute, is the location of the former post office of Parks and also of the first quicksilver mine in the Sleetmute area. This mine, formerly referred to as the Parks mine, is now known as the Alice and Bessie mine.

At least 6 other village sites once occupied by natives are now almost completely obliterated by time. Repeated moving of families from one camp site to another and from one trading center to another, as well as a rather marked decrease in the native population over the past 100 years, have all contributed to the number of abandoned villages. Accounts of natives, corroborated by early Russian reports, indicate that there must have been well over 1,000 people in this region at some time within the past 150 years, although today the number of natives is less than 200.

The natives in the region are chiefly of Eskimo stock and speak dialects of the Eskimo language. Many families of mixed native and white blood live with the natives and speak their language; English is spoken by about one-half of the natives and people of mixed blood. The natives are known principally by their Christian names, which are chiefly of Russian origin.

The great decline in native population since the arrival of white people is probably directly attributable to the introduction of tuberculosis, and it is probably also the indirect result of many less tangible factors that have sapped both community and individual vitality. The majority of the natives have contracted tuberculosis, and many die of the disease each year. Few live to be more than 35 years old and, although the birth rate is high, infant mortality almost keeps pace with births. Apparently there is little racial immunity to tuberculosis among the natives, because most of the white people living among them do not contract it. As many of the natives as can be accommodated, and who can be persuaded to leave their homes and villages, are cared for at the hospital of the U. S. Bureau of Indian Affairs at Bethel.

The first white people to explore and live in the central Kuskokwim region were Russians. The earliest American settlers in this part of Alaska were, much as the present white inhabitants, traders, missionaries, prospectors, and trappers, who first appeared in the region in about 1880. The largest introduction of white people to the central Kuskokwim region occurred between 1905 and 1910, when men of practically every European nationality, as well as Canadians and Americans, came to prospect for gold. This movement ended with an overflow of several hundred from the rush to the Iditarod, who suddenly populated Georgetown in

1910 and as quickly departed. Most of the new inhabitants came to prospect the quicksilver and gold deposits of the region; but those who remained soon turned the greater part of their efforts to trapping and trading, which occupations have since become their chief livelihood. Despite the quickened activity brought about by two world wars and the advent of the airplane, the outboard motor, and radio communication, the general pattern of human existence, among both the natives and the white people, has remained the same.

ACCESS

The central Kuskokwim region is accessible chiefly by water and air transport. Heavy nonperishable goods are brought up the Kuskokwim River by riverboat from Bethel, a Bering Sea port near the mouth of the river, and into the side streams by poling boats that are powered with outboard motors. The chief traffic in passengers and light perishable goods is by airplane from Anchorage or Fairbanks.

Ground transport is very difficult, particularly in summer when the ground is thawed, since there are no roads and few trails within or approaching the region. Mining machinery and other heavy equipment have been moved into the region by tractor train during the winter months. Dog sleds are used by most of the inhabitants for winter travel and transport, but less for interregional travel than they were at one time. Trucks have been used on the frozen surface of the Kuskokwim River.

DESCRIPTIVE GEOLOGY

REGIONAL SETTING

The central Kuskokwim region is near the center of a mobile belt of mountain building and volcanic activity (fig. 3) that borders the Pacific Ocean and includes all but northern Alaska. Buried beneath younger strata in the northern regions, and in the adjacent portion of the Arctic Ocean basin, is a more stable platform of ancient crystalline rocks. The Pacific Ocean floor south of Alaska is another stable area.

Although the central Kuskokwim region is north of the centers of recent volcanism in the Aleutian Islands and the Alaska Peninsula, thick lava flows and volcanic ash deposits in the bedded rocks show the former wide extent of volcanic eruptions. Faults that intersect recently formed surficial deposits indicate that mountain-building movements are still taking place, although not so strongly as in the arc of the Aleutian Islands and Aleutian Trench at the south edge of the mobile belt. Folds, which in general reflect horizontal movements and a higher order of mobility than faults, are abundant in the bedrock and indicate a mountain-building activity much greater than at present.

The formations that crop out in southwestern Alaska range in age through most of the periods of geologic time since the beginning of the Paleozoic era and possibly include earlier deposits. There are six successive and contrasting types of bedded deposits in the stratigraphic section: (1) basement crystalline rocks, (2) marine limestone, (3) siltstone, chert, and interbedded basaltic and andesitic volcanic rocks that are all marine, (4) graywacke that is both marine and continental, (5) continental basaltic volcanic rocks, and (6) surficial deposits. All but the crystalline basement rocks are represented in the central Kuskokwim region. Other kinds of rocks, less abundant and less characteristic, are associated with each type.

The mobile belt was predominantly a belt of subsidence during the Paleozoic and the early part of the Mesozoic. The bedded rocks were deposited beneath the sea in a broad geosynclinal tract in the mobile belt. The deposits that contain interbedded basaltic and andesitic volcanic rocks were laid down principally in the southern part of the geosynclinal tract, away from the continental platform and nearer the Pacific Ocean floor. They spread progressively northwestward in western Alaska during the Paleozoic, and limestone, laid down at least as far south as the central Kuskokwim region in the early and middle Paleozoic, is succeeded in the late Paleozoic and in the early and middle Mesozoic by volcanic rocks, chert, and siltstone, whose area of distribution extends far to the northwest.

The mobile belt was a zone of uplift and less general subsidence during the late Mesozoic and the Cenozoic. Geanticlines that were uplifted in the Mesozoic established the structural framework of Alaska, and mark the first phase of mountain building that has been fairly continuous since that time. The geanticlines extend southwestward in southwestern Alaska as fingerlike projections of a much more extensive geanticlinal uplift, the Cordilleran geanticline of the western United States and Canada. The broadest of these, here designated the Alaska-Yukon geanticline, may be traced from the eastern part of the central Kuskokwim region (pl. 2) northeastward to central Alaska, and thence eastward and southeastward into Yukon Territory. Another geanticline is traceable northeastward from the western edge of the region, near Aniak, and crosses the Yukon River near Ruby.

Between the geanticlines are belts of secondary geosynclinal subsidence in which bedded rocks accumulated unconformably on the older formations (fig. 4). These were almost all marine deposits, chiefly graywacke, with some shale, sandstone, and volcanic rocks. Three such belts, the Yukon-Koyukuk, Kuskokwim,

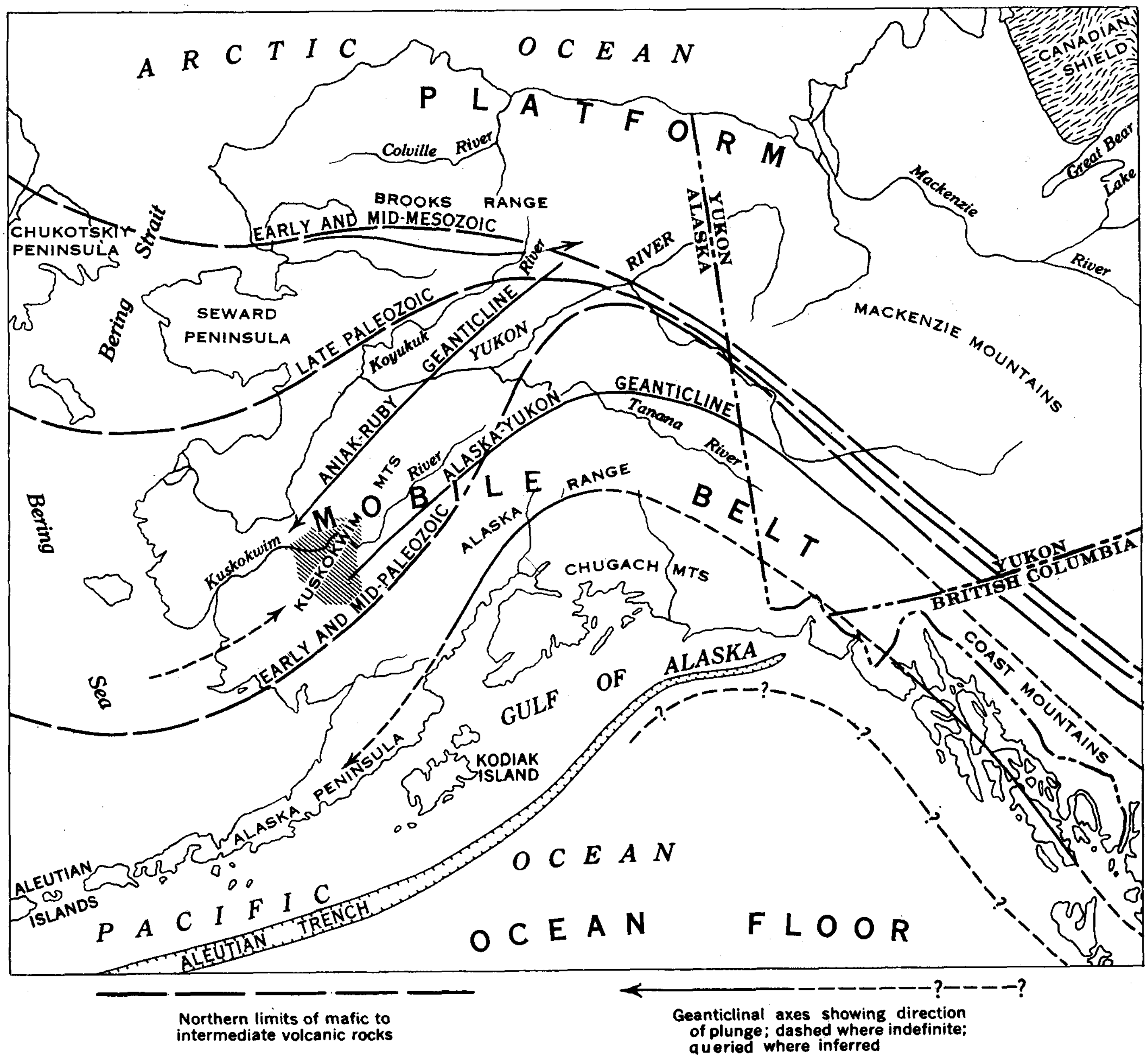


FIGURE 3.—Geotectonic map of Alaska and vicinity, showing northern limits of the mafic to intermediate marine volcanic rocks in early and middle-Paleozoic, late Paleozoic, and early and middle Mesozoic times, also distribution of geanticlines formed in the Mesozoic. Area of geologic map of central Kuskokwim region (pl. 1) shown by cross-hatched pattern.

and Alaska Range geosynclines, merge in the vicinity of the Central Kuskokwim region around the southwest-plunging ends of the Alaska-Yukon and Aniak-Ruby geanticlines. These geosynclines are the eastern estremities of a broad geosynclinal tract that passes beneath Bering Sea to the west.

The secondary geosynclines are the sites of the principal folding in southwestern Alaska. The systems of folds formed in each of the geosynclines are, in subsequent discussions, referred to as orogens and are designated by much the same geographic names used to refer to the geosynclines. The folds mark the second phase of mountain building and were probably formed in the earliest Cenozoic.

The Alaska Range orogen is the site of large granitic batholiths, sheets, sills, and dikes that were intruded in the early Cenozoic and late in the episode of folding. Granitic intrusive rocks are not nearly as voluminous in the other orogens. Biotite basalt sills and dikes and albite rhyolite sheets, dikes, and sills, the latter much like the smaller intrusives in the Alaska Range, formed at the same time in the Kuskokwim Mountain orogen.

The folds and the above-mentioned intrusive rocks are truncated by less steeply dipping terrestrial basalt

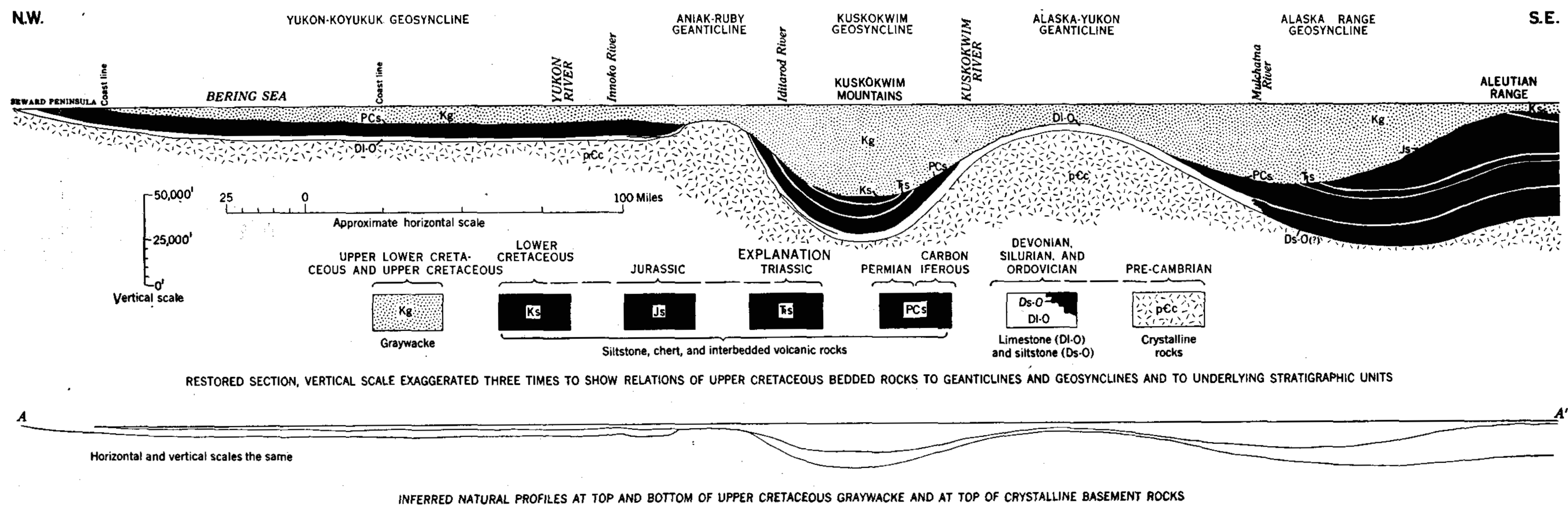


FIGURE 4.—Stratigraphic restoration of the bedded rocks of southwestern Alaska, showing their distribution at the end of the Cretaceous and before folding in earliest Tertiary time, and their relations to geanticlines and geosynclines formed in the Mesozoic. Line of section extends from southeastern Seward Peninsula southeast to the Aleutian Range, along line A–A' on the tectonic map of southwestern Alaska (pl. 2.)

flows and surficial deposits of Cenozoic age. The folded rocks and, locally, the basalt flows are intruded by stocks, commonly of quartz monzonite. The stocks are particularly abundant in the Kuskokwim Mountain orogen.

Most of the mountains of Alaska, with the exception of those formed by volcanic accumulation, attained their present altitudes by vertical uplift at various times in the middle and late Cenozoic, after folding. Connected with the mountain uplifts are extensive faults, many of which transect the geanticlinal framework in southwestern Alaska.

Formations associated with these final uplifts are chiefly horizontal basalt flows and various surficial deposits.

BEDDED ROCKS

GENERAL RELATIONS

STRATIGRAPHIC UNITS

Sedimentary rocks underlie more than 90 percent of the area of the central Kuskokwim region. Associated with them are lava flows and volcanic ash deposits that are part of the sequence of bedded rocks. The major rock types form stratigraphic units whose surface distribution is shown on the geologic map (pl. 1). The inferred subsurface distribution of most of these units is shown on the structure section that accompanies the map. The succession of stratigraphic units is tabulated below to show how the units fit into the general geologic time scale.

Summary of bedded rock formations and surficial deposits in the central Kuskokwim region, Alaska

Geologic age		Unit name	Character	Thickness (feet)
Period	Epoch			
	Recent.	Floodplain deposits.[1]	Gravel, sand, and silt.	0–50+(?)
Quaternary.	Pleistocene.	Silt deposits.	Silt, massively bedded, buff-colored.	0–100
		Glacial deposits.	Morainal till and outwash gravel.	0–100±
		Gravel deposits.	Gravel, and less sand and silt.	0–100+(?)
	Pliocene.	Residual deposits.[2]	Soil, rocky, and rubbly; talus.	0–100±
		Unconformity		
Tertiary.	Miocene.	Waterboot basalt.	Olivine basalt flows.	100±
		Angular unconformity		
	Oligocene	Holokuk basalt.	Basalt flows and water-deposited detritus.	3,000±
		?		
	Eocene.	Getmuna rhyolite group.	Rhyolite lava and tuff.	500–1,500
		Angular unconformity		
	Paleocene(?)			
Cretaceous.	Upper.	Iditarod basalt.	Basalt flows and sedimentary breccias.	2,000–3,000
		Disconformity		
		Kuskokwim group.	Graywacke and shale, interbedded.	40,000–65,000
		Unconformity		
	Lower.			
Jurassic(?)	Upper (?)			
Triassic.		Gemuk group.[3]	Siltstone and chert; local andesitic volcanic rock and limestone; basaltic greenstone.	15,000–25,000
Permian(?)				
Carboniferous(?)				
		Disconformity?		
Devonian.	Late or middle.			
		Disconformity		
Silurian.	Late or middle.	Holitna group.	Limestone, massive, locally dolomitic; overlain by thinner bedded calcitic limestone.	5,000–10,000
Ordovician(?)				
		Not exposed?		
Cambrian(?)				
		Angular unconformity		
Pre-Cambrian.		Basement rocks (not exposed.)	Schist, quartzite, greenstone, and crystalline limestone.	

[1] Range in age from early Pleistocene through Recent.
[2] Range in age from Pliocene through Recent.
[3] Information indicating that rocks of Jurassic age possibly are present was not obtained until after the maps (pl. 1 and fig. 38) were prepared.

The bedded rocks consist chiefly of terrigenous sediments, probably 60,000 and possibly more than 100,000 feet thick, most of which were deposited beneath marine water. These deposits were laid down in a broad geosynclinal belt of subsidence and local uplift south of the relatively stable platform. The gneiss, schist, quartzite, greenstone, and crystalline limestone that constitute the basement rocks of Alaska are not exposed in the central Kuskokwim region, but they crop out in adjacent regions, particularly to the north. Most of the units are apparently thousands of feet thick, but repetition in folds and lack of recognizable key horizons within the units make precise determination of their thickness impossible.

The limestone and dolomite of the Holitna group are made up of calcareous material, precipated directly from solution in sea water, or extracted by marine organisms and deposited as shells and small reeflike masses. They are coextensive with similar though thinner limestone and dolomite strata interbedded with clastic sedimentary rocks, which were deposited on submerged portions of the platform north of the central Kuskokwim region.

The formations of the Gemuk group consist chiefly of siltstone and chert, interlayered locally with thin limestone beds and basaltic and andesitic volcanic rocks. The Gemuk group is thicker than the Holitna group and its formations are subject to greater lateral variation in both thickness and texture. The predominantly clastic sediments are both volcanic and terrigenous. They were probably derived chiefly from linear belts of islands, comparable to the Aleutians, which were formed by accumulation of volcanic products and by local uplift within portions of the geosyncline at a distance from the platform.

The Kuskokwim group is an extremely thick sequence of rather coarse clastic sedimentary rocks, typically graywacke with shale interbeds, made up of unsorted mineral grains and rock fragments derived from all the various underlying formations exposed in the region, as well as from the crystalline basement rocks. The sediments of the Kuskokwim group are believed to have come from terrestrial sources on nearby geanticlines, and were deposited in the intervening secondary geosynclinal troughs. The Kuskokwim geosyncline trends northeast through the central Kuskokwim region and underlies the greater part of it, and the geanticlines from which its sediments were derived are both to the southeast and northwest (pl. 2; fig. 4). The limestones and dolomites of the Holitna group, in the southeastern part of the region, are at the axis of the southeastern or Alaska-Yukon geanticline, and correlatives of the Gemuk group, which crop out north of Aniak, lie along the southeast flank of the Aniak-Ruby geanticline. Basement crystalline rocks are exposed at the axes of these geanticlines north and northeast of the region.

The Iditarod basalt is made up chiefly of basalt flows, though it includes some sedimentary breccia. The basalt forms sheetlike accumulations that are believed to have erupted chiefly on land. The Getmuna rhyolite group was erupted explosively. The Holokuk basalt and Waterboot basalt are probably similar in origin to the Iditarod basalt.

STRATIGRAPHIC RELATIONS

The bedded rocks may be divided into at least four major sequences that are internally conformable and are separated by regional or angular unconformities. The first and lowest probably includes both the Holitna and Gemuk groups, the second comprises the Kuskokwim group and the Iditarod basalt, the third probably includes the Getmuna rhyolite group and the Holokuk basalt, and the fourth and uppermost is the Waterboot basalt.

The Kuskokwim group, believed to be mostly of Late Cretaceous age, is regionally unconformable upon the Ordovician(?)-Silurian-Devonian succession of the Holitna group and upon the Carboniferous(?)-Permian(?)-Upper Triassic-Upper Jurassic(?)-Lower Cretaceous succession of the Gemuk group. Thus strata that range in age from Late Devonian to Early Cretaceous are widely absent beneath this unconformity. The implied thinning of underlying strata against the unconformity is imperceptible, however, at individual exposures. The regional unconformity is most profound to the southeast, where the Kuskokwim group overlies the Holitna group near the axis of the Alaska-Yukon geanticline. This unconformity marks the onset of geanticlinal uplift near the close of the Early Cretaceous epoch. The beds of the Upper Cretaceous Iditarod basalt parallel those of the underlying Kuskokwim group, with which they form a structurally concordant unit. A basal breccia indicates a break in deposition, but the relations do not supply evidence of a major break.

An angular unconformity is visible beneath the Tertiary Holokuk basalt and is inferred to pass beneath the Getmuna rhyolite group. This unconformity records the principal episode of folding, in the earliest Tertiary.

A horizontal surface of angular unconformity beneath the flat-lying Waterboot basalt flows probably marks an episode of widespread erosion, approaching base-level, that was brought to a close by uniform regional uplift in the late Tertiary.

The unconformities extend far beyond the area of this study and mark major intervals of movement in Alaska. At least two unconformities that are reported elsewhere in Alaska have not been proved in this region. One is reported between the Silurian and Devonian systems in areas north and northwest of the Alaska-Yukon geanticline (Mertie, 1937b, p. 89). A disconformity in the Holitna group, indicated merely by the apparent absence of Lower Devonian strata, is possibly the only display of this unconformity in the central Kuskokwim region. Another of these unconformities, on the northern flank of the Alaska-Yukon geanticline (Mertie, 1937b, pl. 1), is beneath possibly Lower Cretaceous rocks (see also Imlay and Reeside, 1954, annotation 28, p. 236), which correlate with strata near the top of the Gemuk group, and penetrates rocks at least as low as the Middle Devonian. This unconformity records an episode of geanticlinal uplift that probably occurred sometime in the Jurassic. If present in the region under consideration it is hidden by the overlap of the Kuskokwim group on the Gemuk group, on the western flank of the Alaska-Yukon geanticline. An unconformity is reported, however, at about the same stratigraphic level on the southwest-plunging axis of the geanticline in the region to the south (Mertie, 1938, p. 53–54), which suggests continuity of the unconformity at depth in the central Kuskokwim region.

AGE

The age of the stratigraphic units is indicated chiefly by fossil animals and plants collected within the central Kuskokwim region. Fossils diagnostic of the Cambrian, Ordovician, Carboniferous, Permian, Jurassic, and Tertiary systems have not yet been found, but it is believed that some of these systems, particularly the Tertiary, are represented since rocks occur whose lithologic features and stratigraphic position are comparable to those of fossiliferous representatives in outlying regions.

The Cambrian and older rocks are apparently too deeply buried to crop out, but Ordovician rocks occur in nearby regions and part of the Holitna group may be of that age. Carboniferous strata are reported in the region to the south, and Permian rocks both to the south and west; it is possible that rocks of each of these systems may be represented in the Gemuk group. The Jurassic is reported in the region to the southwest, hence may also be represented in the Gemuk group. The concordance of the bedding of the Iditarod basalt with strata of the underlying Upper and Lower (?) Cretaceous Kuskokwim group suggests that the age of the basalt is Late Cretaceous. The angular unconformities between the Kuskokwim group and the overlying Getmuna rhyolite group and Holokuk and Waterboot basalts suggest Tertiary age for the latter formations. Portions of certain systems, specifically Lower Silurian, Lower Devonian, and Lower and Middle Triassic, are not known in the fossil record to date, and all of these except the Lower Triassic are likewise unreported from the rest of Alaska. Presumably strata were not laid down in these intervals, and where the strata above and below are essentially parallel, as in the central Kuskokwim region, the disconformity between them may not be recognizable in the field.

HOLITNA GROUP

AREAL DISTRIBUTION

A group of limestones which crop out in a hilly belt, about 20 miles wide, across the middle course of the Holitna River, southeast of the Kuskokwim Mountains, is here designated the Holitna group. The group is named for the Holitna River and is typically exposed between the mouths of Itulilik and Portage Creeks.

The limestone belt veers from a northwestward to a northward trend at and west of the Holitna River and ends at the Kuskokwim Mountains. The bedrock is rather thickly mantled with surficial deposits, hence the actual extent of the limestone belt is undetermined. The Kuskokwim group crops out southwest and west of the limestone, but to the northeast, as far as the Kuskokwim River, the bedrock is covered with surficial deposits. The best exposures of the limestone are in bluffs along the west side of the Holitna River, where they form cliffs several hundred feet above river level. Rather prominent light-colored outcrops, by which the limestone may be identified at a distance, are found along the ridgetops.

The limestone may be traced eastward and then northward, from a commanding viewpoint and with the aid of aerial photographs, far beyond the eastern border of the areal geologic map, where it forms high barren hills. These hills are the southern continuation of the Lime Hills (Smith, 1917, p. 50–57), which cross the eastern tributaries of the Kuskokwim River west of the Alaska Range. Comparable limestones, associated with various clastic rocks, are reported northeast of the central Kuskokwim region, northwest of the upper Kuskokwim River (Spurr, 1900, p. 123 124, 157–159; Eakin, 1918, p. 23–27; Brown, 1926, p. 102–105). The continuity of the latter with the limestone within the region is not apparent probably because the limestone in the intervening area is overlapped unconformably by the Kuskokwim group and is not exposed. The limestones in the two outlying areas referred to lie in the southeast and northwest flanks respectively of the Alaska-Yukon geanticline (pl. 2). The type locality of the Holitna group on the Holitna River is in the area where limestone crosses the southwestward plunging major axis of the geanticline.

LITHOLOGIC CHARACTER

The Holitna group includes various types of limestone that have been changed from an originally dense, fine-textured rock to more coarsely crystalline types. The recrystallized facies are partly dolomitic. The non-dolomitic limestone is gray on the freshly broken surface and weathers to lighter shades. The dolomitic facies are characteristically buff colored. Less commonly limestone and dolomite are closely intermixed and color tells little concerning composition. Massive rather than thin-bedded limestone predominates and forms many of the more prominent topographic features. The bedding of the massive varieties is so indistinct at most places that it is impossible to determine the orientation of the strata, although the strike may be suggested by the trend of the outcrop. Many such outcrops appear to be bounded by bedding joints 10, 50, or 100 or more feet apart. The more thinly bedded varieties fail to crop out prominently, but sandy and shaly partings are more common and bedding is readily distinguished in the outcrop. Fossils are better preserved in the thinly bedded limestones. Small reef-like masses, some as much as 5 feet high, were found in several places. Intraformational conglomerates and breccias, composed of limestone fragments in a limestone matrix, are common locally. Small fissures and vugs are to some degree characteristic. The constituent minerals, calcite and dolomite, are identifiable in hand specimens by simple chemical tests (Stevens and Carron, 1948, p. 34, 36).

THICKNESS AND STRATIGRAPHIC RELATIONS

The Holitna group is estimated, from the few measurable sections exposed, to be at least 5,000 and probably closer to 10,000 feet thick. Approximately 1,300 feet of the thinner bedded facies were measured in the bluffs north of the Holitna River, 9 miles northeast of Nogamut at the southwestern border of the limestone belt, and at least as much more is probably covered by surficial deposits. There is a fairly continuous section of a little less than 1,000 feet of the thinly bedded facies in the western Kulukbuk Hills, near the northeastern border of the limestone belt. The thickness of additional covered or unexamined portions is possibly comparable to that of covered portions of the thinly bedded facies northeast of Nogamut. The more massive facies crop out through most of the intervening area of the limestone belt, between the Kulukbuk Hills and the exposures northeast of Nogamut, and appear to include the lower zones and the greater part of the Holitna group. The section northeast of Nogamut dips steeply to the west-southwest. The massive limestone in the bluffs along the Holitna River downstream (northeast) from the latter section are estimated to be at least 3,000 and possibly as much as 8,000 feet thick. It forms a broad anticline, the axis of which strikes north-northwest across the Holitna River, downstream (northeast) from the mouth of the Chuilnuk River. The thin-bedded limestone in the western Kulukbuk Hills dips eastward, apparently on the east flank of this anticline. The massive limestone reappears in the eastern ridge of the Kulukbuk Hills where its structural relationships are somewhat obscure, though available field data suggest that it forms a narrow anticlinal belt, in which 1,500 to 2,000 feet of strata are exposed.

Neither the basal nor the upper contacts of the Holitna group are exposed in the sections studied to date along the Holitna and Chuilnuk Rivers. It is inferred that the basal contact is probably northeast of the central Kuskokwim region, for the limestones along the Holitna River are at the southwest-plunging axis of the Alaska-Yukon geanticline. Surficial deposits lie at the axis of the geanticline in explored areas for a distance of several hundred miles to the northeast, and they cover all the explored areas of the geanticline between the flanking limestone belts; thus the precise location of the lower limits of the Holitna group in adjacent regions to the northeast are unknown.

The Holitna group is in fault contact with the overlying Kuskokwim group along the bluffs of the Holitna River 9 miles northeast of Nogamut. The contact is covered by surficial deposits in other areas explored, but it is rather likely that faults such as the one at the Holitna River mark the southwestern border of the Holitna group for a considerable distance both to the southeast and northwest. Faults may prove to be a characteristic feature of the contact over most of its length in and east of the central Kuskokwim region. The fault zone dips to the northeast, where observed, and reverse fault relations are indicated; that is to say, the Holitna group has moved up and southwestward over the Kuskokwim group. Because the uppermost beds of the Holitna group are not present at the contact and are probably completely eroded, both their character and their stratigraphic relations to the Kuskokwim group are unknown. Strata of the Gemuk group, which underlies the Kuskokwim group in the southwestern portions of the region, have not been observed anywhere to the east and northeast in the vicinity of the contact between the Holitna group and the Kuskokwim group, and it is inferred that they were not present there at the time the Kuskokwim group was deposited, rather than that they are cut out by a deeply penetrating fault. The fault or faults were possibly formed along the unconformable contact between the Holitna group and the Kuskokwim group, as a result of the greater structural competency, during deformation, of the massive limestone as contrasted to the relative incompetency of adjacent shale and graywacke.

The total thickness of the Holitna group is probably much greater than is apparent, if, as now seems likely, neither the base nor the top of the group is exposed in the central Kuskokwim region.

LOCAL DETAILS

The Holitna group was studied in some detail in the several exposed sections.

KULUKBUK HILLS

Massive limestone and dolomite crop out along the eastern ridge of the Kulukbuk Hills and are best exposed in several fairly prominent summits where they form large outcrops with little structural expression. Two sets of planar weathered surfaces, which intersect nearly at right angles and give outcrops a massive blocky appearance, are commonly the only recognizable features. These surfaces are believed to be those of bedding joints and joints that cross the bedding. The more pronounced and continuous surfaces are paralleled by zones of differential solution, presumably controlled by bedding, and are believed to be the surfaces of bedding joints. Bedding joints strike parallel to the eastern ridge, and on the east slope of the ridge overlooking the Holitna River they dip steeply east. The strata of this section appear to be about 1,500–2,000 feet thick. A few outcrops of thin-bedded conglomerate and breccia that dip west were found close to the river near the south end of the ridge, but their structural and stratigraphic relation to the massive limestone of the ridge crest is uncertain. Westward dips were found in the massive limestone west of the higher northern summits of the ridge. It is inferred that the major structure is an anticline the axis of which is coincident with the ridge crest.

The western ridge of the Kulukbuk Hills is formed on a homoclinal belt of thin-bedded limestone that dips 10° to 20° E. It is connected topographically with the eastern ridge through a low saddle in which there are a few outcrops of east-dipping thin-bedded limestone whose stratigraphic and structural relations to rocks on the eastern ridge are not clear because of intervening cover.

The thin-bedded limestone of the western ridge is fossiliferous. It grades stratigraphically upward from a gray, slabby, thinly laminated, partly dolomitic limestone that has a whitish gritty weathered surface, through buff, to brown, gray-weathering, locally crystalline limestone. The lower portions of this section are in the northern summits of the western ridge; the upper portions are in the southern summits. Together they probably total nearly 1,000 feet of strata; an equal thickness probably lies below the section examined, in the western slopes of the ridge.

BLUFFS NORTHWEST OF HOLITNA RIVER AND NORTHEAST FROM MOUTH OF CHUILNUK RIVER

Massive limestone and dolomitic limestone are exposed almost continuously in the river bluffs. These rocks appear less massive than the strata in the eastern ridge of the Kulukbuk Hills, probably because they are better exposed and bedding features are clearer. A conglomeratic facies, comparable to the conglomerate and breccia near the eastern base of the Kulukbuk Hills, is a fairly common feature of the lower portion of the section; it is apparently an intraformational conglomerate with limestone fragments and matrix. The conglomerate is overlain successively by massive crystalline vuggy dolomite and partly dolomitized noncrystalline limestone that is mottled buff and gray. Northeast of the conglomerate exposures the strata dip northeast, and southwest of the conglomerate they dip southwest; thus the section is exposed in a northwest-trending anticline that is transected by the Holitna River. The width of exposure on each side of the anticlinal axis is about 2 miles and the strata on each limb dip at angles that range from 15° to 50°. The mean dip is about 20°. The section is, therefore, probably 3,000 to 4,000 feet thick.

CHUILNUK RIVER SECTION

The Chuilnuk River flows past several isolated exposures of the Holitna group within 10 air-line miles upstream from its mouth. The northwesternmost exposures are less than 1 mile east of outcrops of the Kuskokwim group, in low bluffs southwest of and within the sharp bend of the middle course of the river. They consist of thinly laminated dense limestone that dips 25°–30° SW and is cut through by numerous thin calcite veins. The limestone is rather typical of the thin-bedded facies. Dolomitic limestone that dips 30°–60° E. is exposed in the same bluff between 2 and 3 miles downstream. Limestone northeast of the river, 2 to 3 miles downstream from the latter dips gently east and is partly dolomitic. The strata on the Chuilnuk River are not as massively bedded as those farther east in the Holitna River bluffs below the mouth of the Chuilnuk River, and are believed to be the stratigraphic equivalent of comparable rocks in the bluffs of the Holitna River above the mouth of the Chuilnuk River.

BLUFFS NORTH OF HOLITNA RIVER AND WEST OF MOUTH OF CHUILNUK RIVER

Exposures in these bluffs are at the southwest border of the limestone belt and about 9 miles northeast of the village of Nogamut. The fault contact between the Holitna group and the Kuskokwim group is exposed near the west end of the bluffs. The formation north of the contact is a very thin-bedded and fine-grained nondolomitic limestone with thin shale interbeds and sand streaks. The limestone laminae have an average thickness of ½ inch, and shale layers, ½ to ¾ inch. Calcite veins stand out on the weathered surface of the limestone, apparently because they contain quartz that resits weathering. The outcrop weathers a rusty yellow brown. The rocks at these exposures are comparable to the limestone, described in the preceding paragraph, that crops out less than 1 mile east of the Kuskokwim group along the middle course of the Chuilnuk River. Their structure is complicated by sharply crenulated drag folds that plunge northeast, subparallel to the dip of the fault plane at the contact, and that are apparently related to the formation of the fault rather than to the general structural pattern of the Holitna group.

The fault plane apparently projects above the bluff exposures in a covered interval to the east, near the middle portion of the bluffs, because farther east at a cut-bank only the shale and graywacke of the Kuskokwim group, too narrow to show on the map, are exposed. Near the east end of the bluffs, however, beyond another interval where the contact is hidden, a nearly continuous section of the Holitna group is exposed; the fault, if continuous, passes beneath river level. The section, about 1,300 feet thick, comprises limestone strata, locally dolomitic, that dip 60° to 80° WSW. Massive limestone strata, 1 to 3 feet thick, predominate, but near the east or stratigraphically lower end of the section sandy and shaly zones are interlaminated with the limestone. One such zone about 6 feet thick, contains abundant fossils; it is included in another zone, about 100 feet thick, that is more or less fossiliferous. The geographic position and orientation of the strata suggest that this section is stratigraphically above the southwest-dipping strata of the section in the Holitna River bluffs northeast of the mouth of the Chuilnuk River. There may, however, be considerable repetition of the section beneath the surficial deposits west of the mouth of the Chuilnuk River, as the latter area is in line of strike with strata along the lower middle course of the Chuilnuk River that dip northeast.

OTHER AREAS

Information concerning exposures of the Holitna group in other areas than those described above is based on the reports of prospectors and the study of aerial photographs. Prospectors report limestone along the Hoholitna River, and Titnuk and Taylor Creeks, and the bare limestone summits are distinguishable on aerial photographs. Noteworthy exposures of limestone observed by prospectors are those northeast of the forks of Taylor Creek, 10 miles northeast of the Taylor Mountains, and in the isolated hill west of Titnuk Creek and 15 miles east of the Taylor Mountains.

AGE

Fossils diagnostic of the Silurian and Devonian systems have been collected from the Holitna group. Seven collections from four different localities have been examined and the fossils identified by Edwin Kirk of the U. S. Geological Survey. These collections consist of the remains of marine animals, predominantly stromatoporoids and corals, accompanied by less abundant sponges, bryozoans, brachiopods, trilobites and ostracodes. Lists of these fossils are tabulated below. The collections are designated by Geological Survey locality numbers assigned by Kirk, and included fossils are indicated by the symbol (×).

Fossils from the Holitna group

[All collections by W. M. Cady and J. M. Hoare, 1944; field in parentheses below]

	2681	2683	2684	2685	2686	2688	2687
Sponge gen. ?							×
Stromatopora sp	×	×		×			
Favosites sp		×		×	×	×	×
Cyathophylloid coral		×					×
Monotrypa sp						×	
Atrypa sp							×
Spirifer sp., cf. *S. crispus*							×
(*emanuella*?) sp						×	
Athyris sp						×	
Productella sp						×	
Proetus sp						×	
Leperditia sp. (large)			×				

2681 (44ACa2). Kulukbuk Hills, 28½ miles south of Sleetmute and ½ mile west of Holitna River; summit of eastern ridge.
2683 (44ACa4), 2684 (44ACa6), 2685 (44ACa7), 2686 (44ACa8). Kulukbuk Hills, 28½ miles south of Sleetmute and 3½ miles west of Holitna River; summit of western ridge.
2688 (44ACa51). Kulukbuk Hills, 32 miles south of Sleetmute and 4 miles west of Holitna River; summit of western ridge (4 miles south of locality of collections 2683 to 2686).
2687 (44ACa48). Bluff north of Holitna River and 9½ miles northeast of Nogamut cliff overlooking slough near riverbank.

Kirk states that, except for the *Leperditia*, all of the genera in collections 2681, 2683, 2684, 2685, 2686, and 2687 range generally from the Silurian into the Devonian, but emphasizes the fact that the species represented indicate Silurian rather than Devonian age. He points out that the *Favosites* in collection 2687 is of Silurian type and states that he believes that it would be safe to assign these collections to middle or late Silurian age. He assigns collection 2688 to either late middle or early late Devonian. The only genus common to both Silurian and Devonian faunas in these collections is *Favosites*. Kirk describes the *Favosites* in the Devonian fauna as a small digitate form.

Collection 2681 consists of a fossil fragment collected from the more massive facies of the Holitna group.

Its stratigraphic position is somewhat uncertain. Collections 2683, 2684, 2685, and 2686 were taken from a section of rocks about 110 feet thick in the thinner bedded facies of the Holitna group. *Stromatopora* sp. is very abundant in this section, and the gray limestone of which the fossil is formed stands out sharply against a buff-weathered dolomitic matrix. The beds from which collection 2688 was taken lie 700 to 800 feet stratigraphically above a stromatoporoid zone quite like and probably the same as that in which collections 2683, 2684, 2685, and 2686 were found. The zone of collection 2688 is characterized by abundant brachiopods that can easily be separated from the matrix. This zone, and all the underlying strata between it and the stromatoporoid zone, are of the thin-bedded facies of the Holitna group. Field evidence for a stratigraphic break somewhere in the interval between the stromatoporoid and brachiopod zones was not discovered, but it is inferred from the disparity between the ages of these zones that strata representative of a large time interval, probably all of the Lower Devonian, are missing. The rocks from which collection 2687 was taken are so far from the localities of the other collections that their stratigraphic relationships to the rocks from which the other collections were taken could not be determined. Collection 2687 is from a sandy and shaly limestone zone about 6 feet thick, near the base of a 1,300-foot section of rocks exposed in the thin-bedded facies of the Holitna group. This zone is characterized by abundant brachiopods unlike those of collection 2688. It is inferred from Kirk's determination of the age of the fauna that the zone of collection 2687 is to be correlated with the middle or upper Silurian stromatoporoid zone of collections 2683, 2684, 2685, and 2686.

The age relationships of the Holitna group outlined above agree rather well with results of similar studies elsewhere in Alaska. The limestones in areas to the northeast of the central Kuskokwim region, in the northwestern flank of the Alaska-Yukon geanticline, contain not only Silurian and Devonian but also Ordovician faunas (Eakin, 1918, p. 25, 26; Brown, 1926, p. 103–105). It therefore seems quite possible that Ordovician faunas may yet be found in parts of the Holitna group of the central Kuskokwim region. This seems all the more likely inasmuch as the Silurian and Devonian faunas were collected only from the upper zones of the Holitna group. The lower zones may prove to be of Ordovician age. The inferred stratigraphic break between the zones of the Silurian and Devonian faunas is of added significance because it reflects a widespread condition in Alaska. Lower Devonian faunas are not known in Alaska, which suggests that marine strata of that age are absent throughout the Territory. Devonian strata overlie a metamorphic complex, possibly in part of pre-Cambrian age, in areas northwest of the Alaska-Yukon geanticline (Mertie, 1937a, p. 155–160) and in these areas a structural as well as a profound stratigraphic break is indicated.

GEMUK GROUP

AREAL DISTRIBUTION

The dark massive siltstone and interbedded chert, volcanic rocks, and limestone that crop out in several irregular areas near the axis of the Kuskokwim Mountains, southwest of the Kuskokwim River, are here named the Gemuk group after the Gemuk River. The type locality of the Gemuk group, and also the most favorable exposures, lie north of the lower middle course of the Gemuk River.

The largest mapped area of the Gemuk group extends northward about 15 miles from the northwest side of the Gemuk River valley into the drainage basins of Atsaksovluk and Chikululnuk Creeks, and thence northeastward about 15 miles into the headwater area of the main fork of the Holokuk River. The Gemuk group also crops out widely in the mountainous area near the headwaters of the Buckstock River and Timber Creek, where it forms a belt of exposure 3 to 6 miles wide that trends northeast for more than 20 miles. The northeasternmost exposures of the Gemuk group form a narrow belt along the northwest foot of the Kiokluk Mountains. This belt extends southwest about 15 miles toward the headwaters of the main fork of the Holokuk River. The extent of the Gemuk group in an intervening area, near the headwaters of the Holokuk River, is uncertain because of a cover of widespread surficial deposits. A few poor exposures and the general content of residual deposits in this vicinity suggest that the three major areas in which the Gemuk group is exposed are not connected through the upper Holokuk River valley.

The Gemuk group apparently extends far south of the southern border of the geologic map (pl. 1). Hoare has found rocks of equivalent age and lithologic character in areas south of Gemuk Mountain to Chikuminuk Lake, one of the Tikchik Lakes (see pl. 2; also Mertie, 1938, pl. 2). Probably the Gemuk group extends for a considerable distance southward and connects with comparable rocks in areas already described to the south (Mertie, 1938, p. 37–56).

Volcanic rocks, believed to be close correlatives of the Gemuk group and mapped with them, crop out north of the Kuskokwim River and west of the Owhat River near Aniak. They are largely altered to greenstone, but were probably originally basalt flows.

LITHOLOGIC CHARACTER

The Gemuk group comprises chiefly dense dark massive siltstone, with which are interbedded smaller amounts of chert and volcanic rock, and thin interbeds of limestone, graywacke, and breccia. The siltstone and breccia beds are made up of rock and mineral fragments that are unsorted as to size; they are closely allied to graywacke. The volcanic rocks consist chiefly of andesitic lava, which locally forms thick interbeds in the siltstone and chert. Much of the fine fragmental material in the siltstone is apparently derived from the volcanic rocks; the coarser fragments, chiefly quartz grains, are probably derived from unexposed formations beneath the Gemuk group.

SILTSTONE

The siltstone, which has the outward appearance of dark argillite, does not appear silty in hand specimens because it is formed of a massive, unsorted mixture of angular clay, to silt-sized grains in which the effect of granularity is much reduced, particularly by the tendency of the rock to fracture across the grains. The coarse siltstones grade into fine-grained graywacke. The rock is in essence a very fine grained microbreccia. Graywacke and pebble breccia, with rock and mineral fragments comparable to those of the siltstone, are locally interbedded.

These rocks are all dark, commonly black, but locally characterized by dark shades of green or red. Bedding features are scarce in the black varieties. The black rock surface weathers to a rather smoothly rounded rusty brown coating; both the massive outcrops and fresh hand specimens look like basaltic igneous rocks. The weathered surface of colored varieties resembles gunmetal finish. A conchoidal or subconchoidal fracture is characteristic of fresh specimens of the black variety and reflects the closely knit fabric of the rock. The colored varieties have a blocky fracture and bedding planes are distinguishable. Fossils were found at two places in the black siltstone.

The mineral and rock fragments in the siltstone are chiefly in the coarse silt sizes, which make up more than half the volume of the rock. The fragments have an average diameter of about 30 microns and occur as sharply angular though commonly equant grains, unsorted as to size and set in a poorly defined matrix of smaller silt- and clay-sized particles. There is actually no well-defined separation between matrix and fragments.

The fragments in the siltstone are as follows, roughly in decreasing order of size and abundance: quartz, plagioclase feldspar (apparently including albite), chert, shale, limestone, basaltic glass, chlorite, and sericite. The chlorite and sericite are chiefly in the clay-sized particle grades; with some of the smaller fragments of the rocks and other minerals they form the matrix of the rock. Minor constituents, some of which nevertheless considerably influence the depth of color of the rock, include magnetite, carbon, zircon, titanite, limonite, hematite and clay minerals. The black siltstone is probably colored by finely disseminated carbon; the red siltstone contains a relatively large amount of finely divided iron oxide; and the green siltstone owes its color to the presence of fairly large quantities of detrital chlorite, possibly the result of admixture of basaltic volcanic detritus. The chlorite and sericite of the matrix partly replace the other fine constituents and secondary alteration of former argillaceous material of the matrix has probably taken place.

The siltstone is silicified and carbonatized, in the vicinity of the quicksilver deposits in the Cinnabar Creek area, and altered to a pearl-gray rock.

CHERT

Chert commonly forms thin distinct beds that may locally grade into other lithologic types. It is varicolored. Gray to buff chert is the most common, but black (flint), red (jasper), and green chert are locally abundant. Most of the chert weathers to distinctly lighter shades. Some is banded, commonly gray and black, parallel to the bedding. A conchoidal fracture is characteristic. Many specimens are criss-crossed by a boxwork of fine veins of carbonate or silica. Such specimens break along the veins and the conchoidal fracture is less apparent.

The chert is composed almost entirely of a microscopic mosaic of chalcedony and very fine grained quartz. Minor constituents include sericite, chlorite, carbonate, carbon, clay, iron oxides, and amorphous silica. Calcite is abundant in limy chert, and sericite and angular fragments of quartz, also unidentified carbonate, are more common in the silty chert. Cross sections of spherical microscopic bodies, believed to be fossil remains of radiolaria, are distinguishable in the silty chert. The tests of the organisms are carbonatized and the central cavity, from which the silt is excluded, is commonly filled with spherulitic chalcedony that contrasts strongly with the outlying matrix which contains silt particles. The radiolaria are not readily distinguishable in the purer cherts, because this contrast is lacking, and because the tests are commonly recrystallized to a silica not easily distinguishable from that of the chert. Fragments of other microscopic fossils, apparently foraminifera, are scattered through the chert in which radiolaria occur. Fine veins that cut the chert contain both quartz and chalcedony.

VOLCANIC ROCK

Andesitic lava flows predominate; they are closely associated with tuffs of similar composition. These formations are distinguished from the massive siltstone by their rough weathered surfaces, greater depth of weathering, and lighter color that is due to secondary alteration. Vitric tuff is easily confused with chert in the field.

The andesitic lava ranges from black to dark greenish gray, depending upon the amount of alteration, and weathers brown. The glassy phases of the lava are light gray and weather a grayish white. The lava rarely appears porphyritic to the naked eye, but amygdaloidal zones that parallel the bedding, and at first glance look like porphyry, are common. A web of fine, irregular white veins contributes to the lighter shades of the altered rock. The tuff is finely banded parallel to the bedding, a feature that is particularly apparent on weathered surfaces.

The phenocrysts are amost exclusively subhedral to euhedral andesine without zoning. Some can be seen in hand specimens, though most of the laths are much less than 1 millimeter long and are not distinguishable. The texture of the groundmass is predominantly ophitic, and in the few specimens collected is characterized by a mesh of randomly oriented, mutually contacting andesine laths $\frac{1}{10}$ to $\frac{1}{3}$ millimeter long. The spaces between the andesine laths are filled with pyroxene or, more commonly, its alteration products. The glassy phases of the flows are composed of partly devitrified andesitic obsidian, which resembles vitric crystal tuff and contains angular fragments of quartz, plagioclase feldspar, shards of glass, and a few ophitic-textured igneous rock fragments. Accessory minerals of these volcanic rocks include ilmenite, titanite, and magnetite.

The lava in particular is altered to some degree. Practically all of the pyroxene is changed to chlorite and antigorite. The plagioclase is partly chloritized and altered to fine-granted mica. There is little evidence that the plagioclase has been albitized. Areas of a typical thin section may be indiscriminately silicified and carbonatized with the formation of fine-grained quartz and carbonates (chiefly calcite). The secondary minerals, principally calcite associated with minor amounts of quartz, chlorite, and antigorite, form the amygdules and the abundant veins in the rock.

LIMESTONE

Limestone occurs in thin single lenticular beds that are rather few and far between. Siliceous varieties of limestone may be confused with chert.

The limestone beds vary widely in character within the space of one outcrop. Colors of fresh surfaces range from dark gray brown to light gray. The darker beds weather reddish buff to buff, the lighter ones to a gray buff. Siliceous limestones have a sharply defined buff rind reminiscent of chert. The limestone is fine textured and resembles lithographic stone in this respect. Fossils were found at three localities. At each place they occur as a rather coarse accumulation of calcareous shell fragments set in a matrix of fine-textured limestone. These are typical coquinas. The few silty beds excepted, the typical limestone is commonly massive within the thickness of the characteristic single beds. This feature, coupled with the fine grain, causes the rock to break on subconchoidal fractures when chipped with a hammer. Limestone, like the chert, is commonly crossed by subrectangular patterns of fine veins, chiefly of carbonate, along which the rock is more likely to break than on a fresh fracture. Rather thick veins of coarse gray-weathered dark calcite form subparallel to the bedding of the limestone, which may give the rock a fluted appearance as a result of differential weathering of the veins and less soluble siliceous limestone.

The principal mineral constituent of the limestones is calcite. Hand specimens were given simple chemical tests (Stevens and Carron, 1948, p. 34, 36) by which dolomite was not identified. Siliceous, ferruginous, and argillaceous impurities are more abundant than in the limestones of the Holitna group. They are disseminated through the body of the fresh rock, although not in quantities large enough to prevent the acid test for calcite. Calcite, on the other hand, is apparently leached from the weathered zone, and here the less soluble residues are concentrated. Powdered fragments of these residues were studied microscopically. Most abundant and probably the least altered of the mineral residues are quartz and a little chert that derived from siliceous limestone interbedded with chert. Most obvious and also the most altered of the residues is the earthy ferruginous material responsible for the red-to-buff color of the weathered limestone. The argillaceous impurities are locally very abundant in silty limestone. Thin sections of some of the limestones show sharply defined, discontinuous limestone laminae a fraction of an inch thick, in abrupt and irregular contact with siltstone that contains admixtures of grainlike carbonate. These features suggest clastic origin of the limestone as well as of the siltstone.

THICKNESS AND STRATIGRAPHIC RELATIONS

The exposed portion of the Gemuk group is estimated to be 15,000 to 25,000 feet thick. A thick, steeply tilted succession of these rocks, comparatively free of minor folds and therefore favorable for determinations of thickness, occurs along Cinnabar Creek. The rocks strike south across Beaver Creek, a western tributary of the Gemuk River. Another fairly good section is in the upland area east of Flat Top Mountain.

The section along Cinnabar Creek comprises chiefly massive siltstone, 10,000 to 15,000 feet thick, that dips consistently about 60° SW. between the mouth of the creek and the zone of contact with the overlying Kuskokwim group, about 3 miles to the southwest. The dip flattens out near the mouth of Cinnabar Creek, and the strata that underlie the section pass over the crest of an anticline about ⅜ mile to the east. The latter anticline, and others to the east of it, form the anticlinal belt of the Gemuk anticlinorium, which trends north-northeast into the upland area east of Flat Top Mountain. Thinly bedded siltstone, stratigraphically beneath the massive siltstone along Cinnabar Creek, is exposed in this area. Between 5,000 and 10,000 feet of these lower strata is exposed in the southeast flank of the Gemuk anticlinorium, east of Flat Top Mountain. The succession of rocks studied commences a little east of the crest of an anticline that occurs near the head of a forked tributary of Atsaksovluk Creek, and it continues southeastward for at least 2 miles without apparent repetition of beds. The average dip is about 45° SE. Dips are more variable than in the Cinnabar Creek section.

The base of the Gemuk group is not exposed in the areas studied north of the Gemuk River, nor in areas recently examined by Hoare immediately south of the central Kuskokwim region near the upper Tikchik Lakes (pl. 2). Farther south, in the vicinity of the lower Tikchik Lakes (Mertie, 1938, pl. 2), correlatives of the Gemuk group apparently plunge southeast at the axis of a structure that is very likely the Gemuk anticlinorium.

The contact between the Gemuk group and the overlying Kuskokwim group is best exposed in the anticlinal mountainous area at the heads of the Buckstock River and Timber Creek. Here the contact is mapped at the surface trace of a zone of marked change, from siltstone, chert, and volcanic rocks below to graywacke above. The two groups seem structurally comformable in this area; there is no evidence of angular unconformity although siltstone well below the contact appears to be more highly deformed than the siltstone immediately beneath it, possibly because it is less competent. Elsewhere the contact with the Kuskokwim group either is covered by surficial deposits or occurs along a major fault. Field relations in the vicinity of covered contacts suggest, however, that the beds of the Gemuk and Kuskokwim groups are widely concordant. The volcanic rocks and chert in the uppermost zones of the Gemuk group are a fairly useful guide in the location of the contact in areas where it is covered. This contact marks a regional unconformity although there is no local evidence fur such a break.

The upper and lower contacts of the Gemuk group apparently converge rapidly toward the east, in that the Kuskokwim group is directly in contact with the Holitna group, and the Gemuk group is entirely missing, in the Holitna River valley. It is impossible to determine within the area of the present study, because of complete overlap by the Kuskokwim group, exactly how the Gemuk group terminates to the east. Either it converges internally and was not deposited farther east, or it was deposited and then eroded before unconformable overlap by the Kuskokwim group. Probably both nondeposition and erosion account for eastward thinning of the Gemuk group and are due to the emergence of the Alaska-Yukon geanticline. The Gemuk group appears to be continuous across the Aniak-Ruby geanticline in the latitude of the central Kuskokwim region.

LOCAL DETAILS

Fairly detailed studies of the Gemuk group were made in several areas.

CINNABAR CREEK AREA

The stratigraphic section in this area, mentioned in the general discussion of thickness and stratigraphic relationships, is in a homocline; it comprises about 10,000 to 15,000 feet of beds, chiefly massive siltstone and a smaller amount of volcanic rock, chert, and limestone. These rocks strike northwest roughly parallel to the valley of Cinnabar Creek, and dip about 60° SW. This homocline is bordered on the east by anticlines such as the one best exposed in the northern cut-bank of Beaver Creek, about ⅜ mile east of the mouth of Cinnabar Creek. The strata exposed in this anticline include siltstone that is less massively bedded than the siltstone to the west in the homocline. A zone of interbedded chert and siltstone, exposed over a surface width of about 1,000 to 1,500 feet, forms a linear hogback ridge east of Cinnabar Creek and passes southward beneath the creek about 1 mile upstream from its mouth. The cherty zone is bordered both to the east and to the west by massive siltstone. Discontinuous beds of extremely fossiliferous limestone lie near the center of the chert zone and are particularly well developed at a point about ¼ mile north of the creek near the crest of the hogback.

Volcanic rocks crop out intermittently in a zone 1,500 to 2,000 feet wide along the ridge southwest of Cinnabar Creek. They comprise at least 5 separate flows, locally as much as 200 feet thick, interbedded with cherty siltstone. Massive siltstone, stratigraphically beneath the flows, crops out in the slopes to Cinnabar Creek on the northeast. Interbedded chert and siltstone crop out to the southwest between the flows and the Kuskokwim group. The contact with the Kuskokwim group passes southeastward, along the valley of the tributary of Beaver Creek southwest of Cinnabar Creek, to within 1 mile of Beaver Creek, where it swings southward across a low spur before it crosses Beaver Creek. Its approximate position is shown by the superficial material; chert fragments are common in the soil over bedrock of the Gemuk group, whereas they are absent in terrain underlain by the Kuskokwim group.

The Cinnabar Creek section was not studied south of Beaver Creek, but prospectors report continuation of the cherty rocks as far south as the alluvial cover along the Gemuk River. The section was traced northward to the southern headwaters of Waterboot Creek, and the chert-limestone zone northeast of Cinnabar Creek was followed continously over the divide at the northern headwaters of Cinnabar Creek into the Waterboot Creek drainage. The volcanic rocks are not extensive to the north or south, where they apparently grade into cherty siltstone.

UPLAND AREA EAST OF FLAT TOP MOUNTAIN

The stratigraphic section in this area includes 5,000 to 10,000 feet of moderately massive siltstone that lies beneath the more massive siltstone of the Cinnabar Creek section. Red and green siltstone is thinly interbedded with black siltstone, in greater local variation than occurs in strata higher in the Gemuk group. Cherty siltstone and silty chert, which have the outward appearance of thinly bedded quartzite, form the thickest unvaried succession. Fossil radiolaria are preserved in the chalcedonic matrix and suggest its probable primary origin. Sharply defined beds of purer chert and limestone, such as those in the Cinnabar Creek section, do not occur. The overall uniformity of this section is remarkable, despite local lithologic variations; well-defined zones, such as those of the limestone or lava near Cinnabar Creek, are not apparent.

Terrains underlain chiefly by siltstone lie to the northwest and southeast of this area. To the northwest, along Atsaksovluk Creek, there is apparently a northeastward continuation of the homocline along Cinnabar Creek. The rocks to the southeast, in the basin of Chikululnuk Creek are less readily identifiable, because they are covered by widespread residual deposits. Siltstone is exposed, however, in the few outcrops crossed in a traverse of the Chikululnuk Creek-Atsakosovluk Creek divide, and the residual deposits contain abundant fragments of subconchoidally fractured black siltstone and less abundant chert. The rocks in the basin of Chikululnuk Creek are therefore believed to be the stratigraphic equivalent of those on Cinnabar Creek, but located on the southeast side of the anticlinal belt that passes northward and northwestward, a little east of Cinnabar Creek, into the upland area east of Flat Top Mountain. The rocks characteristic of the anticlinal belt trend northeast to Atsaksovluk Creek, where they appear to be faulted against the overlying siltstone.

HEADWATER AREAS OF ATSAKSOVLUK CREEK AND THE HOLOKUK RIVER

Lava, like that which occurs southwest of Cinnabar Creek, and associated with chert and cherty siltstone, crops out in a belt more than 2 miles wide that trends north-northeast from the eastern headwater tributary of Atsaksovluk Creek into the headwaters of the Holokuk River; the gentle dips of the lava probably explain its width of exposure. The lava is exposed within 1 miles west of shale and graywacke of the Kuskokwim group. It thus appears that here also lava flows lie near the top of the Gemuk group, and their correlation with the flows in the belt southwest of Cinnabar Creek is implied. The area west of the lava, along the main headwater fork of Atsaksovluk Creek, was not traversed, but the general low relief suggests that it is underlain chiefly by siltstone, probably beds stratigraphically beneath the lava. The lava is apparently cut off to the south by a fault that follows the middle course and eastern headwater fork of Atsaksovluk Creek, inasmuch as it is not found in the hills south of the latter fork, on the divide between Atsaksovluk Creek and Chikululnuk Creek. It has already been pointed out that the formation found along the latter divide is chiefly siltstone. The lava and associated chert may be traced northward less than 5 miles in the headwaters of the Holokuk River, where they are lost to view beneath widespread residual deposits. The general absence of chert fragments in the residual deposits suggests, however, that the Kuskokwim group forms the bedrock, and that the contact between the Gemuk group and the Kuskokwim group must swing to the west.

HEADWATER AREAS OF THE BUCKSTOCK RIVER AND TIMBER CREEK

The upper, chiefly volcanic, formations of the Gemuk group crop out at the core of a broad anticlinal tract that plunges northeast near the head of the Buckstock River and extends southwest nearly to the head of the southern fork of Timber Creek. Less than 1,500 feet of Gumuk strata are exposed in this anticline. The massive lower strata of the Kuskokwim group flank the anticline and also cap some of the higher peaks near the axis of the anticline. Beds of vitric tuff, 200 to 300 feet thick, that weather white like chert, lie a little beneath this massive cap rock. They are widely exposed on many of the lower summits, particularly in the southwestern part of the anticline between the forks of Timber Creek. The tuff formation can be seen from afar, because of the way it weathers, and is readily distinguished on the aerial photographs; thus it forms a useful guide in the mapping of the contact between the Gemuk group and the Kuskokwim group. Banded red, green, and black chert, as well as red, green, and black siltstone, are associated with the tuff. At one place, near the head of the eastern fork of Timber Creek, the tuff beds underlie about 300 feet of red siltstone that underlies roughly the same thickness of black siltstone. The latter in turn appears to grade up into the massive graywacke of the Kuskokwim group by interlamination. There might be some question here as to the position of the upper boundary of the Gemuk group, but at many other points the tuff is directly overlain by breccia and massive graywacke grit that contain fragments of the volcanic rocks, which suggests at least a slight erosional break. About 800 to 1,000 feet of black siltstone, interbedded with minor amounts of chert and graywacke, is exposed beneath the tuffs beds on the upper eastern fork of Timber Creek. It is probably to be correlated with the siltstone in the Cinnabar Creek area, above the limestone zone and below the volcanic rocks. The tuff beds descend the valley sides along the eastern fork of Timber Creek, and progressively smaller thicknesses of the lower strata are exposed toward the northeast in the direction of plunge of the anticline.

UPPER HOLOKUK RIVER–KIOKLUK MOUNTAIN AREAS

Siltstone, with scattered limestone lenses, crops out along the upper Holokuk River valley from near the junction of the three headwater forks northeastward to the vicinity of the mouth of Girl Creek. This belt continues northeast, along the north foot of the Kiokluk Mountains, at least to Kiokluk Creek. The rocks differ from those in areas previously described in that they generally lack chert and volcanic rocks. The limestone lenses are exposed chiefly in stream cut-banks where they form discontinuous red-buff weathered beds 1 to 2 feet thick. It is difficult to compare these limestones with those which occur in other areas of the Gemuk group, because the cut-bank exposures are fresher and less subject to weathering. Limestone found at two or three places back from the streams, however, is like that in the Cinnabar Creek area. Very thin coaly seams occur in the rocks associated with the limestone, as do also small, commonly somewhat curved, platelike fragments of aragonite, the fine columns of which are arranged at right angles to the tabular surfaces of the plates. The appearance of the plates suggest that of fossil shell fragments; they are differentially weathered and in cross section form rectangular pits, arranged subparallel to the bedding of calcareous siltstone. Locally they lie at an angle to the bedding and give the appearance of fine breccia, which they may be.

The rocks of this area are, with possibly one exception, bounded by faults or by surficial deposits that hide their stratigraphic relation to the adjacent Kuskokwim group. Interbedded limestone and siltstone, which crop out in the southeast facing slopes northwest of the mouth of Boss Creek, strike parallel to and closely adjacent to the massive graywacke and shale beds of the Kuskokwim group, which form the mountain summits along the divide between the upper Holokuk River and Girl Creek. The actual contact is covered, but there is no local evidence of faulting. Both formations are nearly vertical in dip, and they are therefore believed to be structurally conformable. The relation suggests that the rocks of the upper Holokuk River - Kiokluk Mountains belt lie near the top of the Gemuk group, but the absence of volcanic rocks and chert, such as are found elsewhere in a comparable position beneath the Kuskokwim group, must be explained. Possibly an eastern facies, formed beyond the range of distribution of the volcanic and related rocks, occurs here.

AGE

Fossils of Late Triassic and Early Cretaceous age were collected from the Gemuk group. Six collections from as many localities, four of which proved useful in correlation, were examined by J. B. Reeside, Jr., R. W. Imlay, and R. W. Brown of the Geological Survey. The collections contain chiefly the remains of marine shelled animals, most of which are pelecypods. One collection, from near the headwaters of Timber Creek, was made up of the remains of land plants—unidentifiable fragments of fossil wood, according to Brown. Another (45ACa65), from near the head of Chikululnuk Creek, shows indefinite markings that Reeside believes to be the borings of some animal. Reeside and Imlay report on the collections of marine fossil shells as follows:

Fossils from the Gemuk group

Locality No.	Field No.	Collector, year of collection, description of locality, identification, and age.
18927	(43ACa39)	W. M. Cady, 1943. Seven miles south of Flat Top Mountain, crest of spur of ridge east of Cinnabar Creek, about 1 mile northwest of mouth of creek. Coquina of *Monotis subcircularis* (Gabb); from Upper Triassic, "Noric stage".
19409	(43ACa28)	W. M. Cady, 1943. Seven and one-half miles south of Flat Top Mountain, on hill slope west of Cinnabar Creek, about 2 miles west of mouth of creek. Float fragments from burrow, containing *Halobia* sp. indet., *Myophoria* aff. *M. vestita* Albert, and *Mysidioptera?* sp.; from Upper Triassic.
19730	(45ACa70)	W. M. Cady, 1945. Near northwest cut-bank of Holokuk River, 1/10 mile north of mouth of Boss Creek. Float fragment on river bar; angularity suggests it has not been transported far, perhaps from cut-bank. *Aucella crassicollis* Keyserling; from lower Lower Cretaceous.
19731	(45ACa71)	W. M. Cady, 1945. Bluff along east side of Holokuk River, 3/8 mile southwest of mouth of Girl Creek. *Inoceramus* sp., fragment of a large species; *Serpula* sp. indet.; from Cretaceous.

The Late Triassic fossils were collected from the rocks of the homocline along Cinnabar Creek. Collection 18927 was obtained from the discontinuous beds of limestone associated with chert and cherty siltstone that crop out along the hogback ridge northeast of Cinnabar Creek. These beds lie in the lower middle quarter of the homoclinal section; thus the fossils come from a zone about 10,000 feet below the contact of the Gemuk group with the overlying Kuskokwim group. Collection 19409 is apparently derived from the massive siltstone that underlies the northeast-facing slopes southwest of Cinnabar Creek. The locality at which this collection was found is in about the middle of the homoclinal section, or about 7,500 feet stratigraphically beneath the top of the Gemuk group and about 2,000 feet below the volcanic zone in the upper middle quarter of the section.

The Lower Cretaceous fossils and those determined simply as Cretaceous are from siltstone of the belt along the upper Holokuk River and at the northeast foot of the Kiokluk Mountains. Their stratigraphic position in the rocks of this belt is not very well known inasmuch as the strata are folded and faulted in a manner too complex to permit a zonal study. Collection 19730 is derived from open-folded siltstone located at a point about half a mile southeast of the Kuskokwim group and northwest of the upper Holokuk River; thus, unless a profound fault intervenes, the fossils come from a zone probably much less than 2,000 feet below the top of the Gemuk group. Reasons for belief that the contact with the Kuskokwim group, here inferred, may be normal rather than faulted have already been indicated in the discussion of the local details of the upper Holokuk River and Kiokluk Mountain areas. Collection 19731 was taken from nearly flat lying calcareous siltstone and silty limestone, less than half a mile southeast of exposures of the Kuskokwim group near the mouth of Girl Creek, and are bordered on the southeast by a shear zone believed to be that of a large fault. The relation to the Kuskokwim group is also obscured by the valley-bottom cover of surficial deposits. Trace of a fault, such as is commonly apparent on the aerial photographs, was not noted along the northwestern border of the Gemuk group in this vicinity. It may very well be then that the collection comes from a zone in the Gemuk group not far stratigraphically beneath the base of the Kuskokwim group.

The information furnished by the fossils collected from the rocks along the upper Holokuk River assists in the correlation of the upper part of the Cinnabar Creek succession. The Early Cretaceous age of the upper Holokuk River rocks excludes them from correlation with the lower half of the section across Cinnabar Creek, since fossils of Late Triassic age were found as high as the middle of that section. It suggests, on the other hand, that the strata in the upper part of the section on Cinnabar Creek, particularly the volcanic zone and, by analogy, the volcanic rocks at the head of Atsaksovluk Creek and in the headwater area of the Buckstock River and Timber Creek, may be of Early Cretaceous age.

The lower 5,000 to 10,000 feet of the Gemuk group, chiefly beneath the rocks of the Cinnabar Creek section and included in the terrain that extends from the lower course of Beaver Creek, through the uplands east of Flat Top Mountain to Atsaksovluk Creek, has yielded no fossils other than the radiolaria and possible fragments of other microfossils noted in studies of thin sections of certain of the silty cherts. The microfossils are recrystallized and of doubtful value in correlation. The 2,000 to 4,000 feet of strata within the Cinnabar Creek section, but beneath the lowest zone in which Upper Triassic fossils have been found, are probably also of Late Triassic age, because their lithologic features are comparable with those of strata in which Upper Triassic fossils have been found. The rocks below the Cinnabar Creek section, on the other hand, may be older than Upper Triassic, because they are lithologically different.

If so, they are probably of Carboniferous or Permian age, or both.

Rocks of roughly the same age as those of the Gemuk group occur in several other close-lying areas in southwestern and adjacent central Alaska. Southernmost of these is the Tikchik Lakes area in the Nushagak district, to the south of the Central Kuskokwim region, where, among others, strata of Carboniferous, Permian, Upper Triassic, and probable Lower Cretaceous age are reported (Mertie, 1938, p. 37–56). The northern edge of the geologic map in the Tikchik Lakes area (Mertie, 1938, pl. 2) is about 45 miles south of the type section of the Gemuk group northwest of the Gemuk River in the central Kuskokwim region. The apparent structural affinities of the Gemuk River and Tikchik Lakes sections, particularly their relation to the Gemuk anticlinorium, have already been pointed out. The stratigraphic units in the Tikchik Lakes section are also remarkably like those in the type section of the Gemuk group in both age and rock types. The chief difference seems to be in the fossils collected to date: Fossiliferous Permian limestone and associated volcanic rock such as those reported in the Tikchik Lakes section (Mertie, 1938, p. 46) are not known in the Gemuk group of the central Kuskokwim region. Conversely, fossils of Early Cretaceous age are yet to be discovered in the Nushagak district, although there are rocks in that district (Mertie, 1938, p. 49–56) whose type and stratigraphic position seem comparable to the fossiliferous Lower Cretaceous rocks of the Gemuk group in the central Kuskokwim region.

The rocks of the Nushagak district that are of possible Early Cretaceous age are reported to be structurally unconformable to both older (Mertie, 1938, p. 53–54) and younger (p. 58–59) strata. This relation, which is not shown in the exposures of the Gemuk group of the central Kuskokwim region, may be of considerable significance, for the Nushagak rocks lie at the southwestward plunging axis of the Alaska-Yukon geanticline. This fact suggests similar relations along the northwestern flank of the geanticline, where the Gemuk group is concealed by the Kuskokwim group of Upper Cretaceous age.

Most of the exposures of the correlatives of the Gemuk group in outlying regions are on the southeast flank of the Aniak-Ruby geanticline, where, in contrast to the condition noted adjacent to the Alaska-Yukon geanticline, they are not now overlapped by the Upper Cretaceous strata of the Kuskokwim group. These exposures are considered below.

Permian (Smith, 1939, p. 33), Upper Jurassic, and Lower Cretaceous rocks crop out in the lower Kuskokwim region southwest of the area of the present study. Hoare has found that the Upper Jurassic and Lower Cretaceous rocks of this region (see also Imlay and Reeside, 1954, annotation 37, p. 240), which crop out in areas west and southwest of the Aniak River, are lithologically similar to, and occupy the same relative position as, rocks believed to be younger than Triassic in the Gemuk group of the central Kuskokwim region. Exposures of these rocks west of the Aniak River are separated from rocks of probable Early Cretaceous age in the areas of the Gemuk group east of the Aniak River, by a northeast-trending synclinorial belt of Upper Cretaceous rocks about 25 miles wide. The rocks of Permian age crop out along the Kuskokwim River, west of the vicinity of Aniak. They possibly trend southwest beneath surficial deposits, in a belt that lies northwest of the belt of Jurassic and Cretaceous rocks west of the Aniak River. This distribution of Permian, Jurassic, and Cretaceous rocks suggests essentially a homocline that dips southeast toward the synclinorial belt at the Aniak River. The homocline is believed to include rocks of the same age span as the Gemuk group. The Permian limestones and associated volcanic rocks reported here (Smith, 1939, p. 33) are comparable to those reported in the Nushagak district (Mertie, 1938, p. 46). Although fossils of Late Triassic age have not been found in the section west of the Aniak River, the possibility that the Upper Triassic is represented in this section must not be excluded, particularly because of its relatively close proximity to the known Triassic rocks of the typical Gemuk group. The correlatives of the Gemuk group in the lower Kuskokwim region apparently differ from the typical Gemuk group chiefly in their greater volume of volcanic rocks.

Rocks comparable to those of the Gemuk group, but without reported fossils, crop out in the Kaiyuh Hills (Mertie, 1937a, p. 160–163) and in the Ruby district (Mertie and Harrington, 1924, p. 22–24) north and northeast of the central Kuskokwim region, in central Alaska. The formations in the Kaiyuh Hills, principally volcanic rocks, are believed to be Carboniferous because they are like Carboniferous strata to the northeast (Mertie, 1937a, p. 163). The formations in the Ruby district include "argillite", chert, and volcanic rock, which lie chiefly to the southeast of the belt of volcanic formations in the Kaiyuh Hills and are believed to be younger (Mertie and Harrington, 1924, p. 24). They compare favorably with the Triassic and Lower Cretaceous formations of the Gemuk group. Similar rocks are reported in two other areas northwest of the central Kuskokwim region, between Aniak and Ruby (Mertie and Harrington, 1924, p. 13, 23, 34).

near Tikloi

KUSKOKWIM GROUP

AREAL DISTRIBUTION

The interbedded graywacke and shale which underlie about 80 percent of the area covered by the geologic map of the central Kuskokwim region (pl. 1) are here named the Kuskokwim group. They are the principal rocks of the Kuskokwim Mountains and are typically exposed in the bluffs and cut-banks along the Kuskokwim River between Sleetmute and Russian Mission. They are named after the Kuskokwim River.

A broad belt of these rocks, which is more than 50 miles wide and follows the trend of the Kuskokwim Mountains, enters the region from the northeast and continues southwest for almost 90 miles to the Kiokluk Mountains, where it is divided by the centrally located exposures of the Gemuk group. The portion southeast of the Gemuk group expands rapidly, from a width of about 15 miles to a width of at least 40 miles, in a broad swing to the southeast through the Nushagak Hills, southwest of the exposures of the Holitna group. The portion northwest of the Gemuk group continues southwest across the Aniak River in a tapering belt. The Kuskokwim group extends for an unknown distance into the unexplored area northwest of the Iditarod River. At the Owhat River, however, southwest of the headwaters of the Iditarod, it adjoins and probably is faulted against rocks in the vicinity of Aniak that are believed to be correlatives of the Gemuk group. The latter continue westward north of the Kuskokwim River.

The Kuskokwim group may be traced far outside the area of the central Kuskokwim region, as well as in areas off the routes of the ground surveys within the region, because its characteristic rolling terrain is recognizable at great distances on the ground and in aerial photographs. This feature has been of particular assistance in geologic mapping of the headwaters of the George River, in the northeastern part of the region, where ground surveys were not attempted. The Kuskokwim group in the basin of the George River was thus traced on the photographs into areas to the north and northeast of the region, for at least 125 miles along the axis of the Kuskokwim Mountains and through the upland area between the Innoko and upper Kuskokwim Rivers (pl. 2), where comparable rocks are reported (Mertie and Harrington, 1924, p. 24–41). The Kuskokwim group is similarly traceable from the Nushagak Hills, in the southeastern part of the central Kuskokwim region, southward into the basin of the Nushagak River, and also eastward and northeastward beyond the area of the map into the basins of the Mulchatna, upper Hoholitna, and Stony Rivers, where similar rocks crop out west of the Alaska Range (Smith, 1917, p. 58–77). Recent studies undertaken by Hoare in the lower Kuskokwim region show the southwestward continuation of close correlatives of the Kuskokwim group, beyond the Aniak River and nearly to the Goodnews River, 125 miles distant.

The characteristic smoothly rounded contours of the upland are accentuated by an almost continuous veneer of surficial deposits composed of frost-weathered fragments of bedrock. Actual outcrops are not numerous, but the attitude of the bedding is shown by faint ridges and furrows in the uplands, and by the contrast in shade between terrain underlain by graywacke beds and that underlain by shale. The graywacke forms the ridges and weathers to relatively coarse fragments, many of them overgrown with black lichens, whereas the shale is in the furrows and disintegrates to fine fragments commonly covered completely by light-colored lichens. These contrasts in relief and shade give the terrain a streaked appearance that shows the bedding much more effectively at a distance than close at hand.

LITHOLOGIC CHARACTER

Graywacke and closely related rocks make up practically all of the Kuskokwim group. The rocks referred to as graywacke are a variety of sandstone. The shales, which are about half as abundant, are a siltstone facies of the graywacke that is intimately interbedded with the sandstone (fig. 5). They differ from the graywacke chiefly in the generally smaller grain size; rock fabric and, to a lesser degree, composition are essentially the same. Breccias and conglomerates, which also form facies of the graywacke similar to the sandstone, although coarser grained, are present in a few localities. All the rocks are dark. They are altered to hornfels in the contact-metamorphic zones adjacent to stocks.

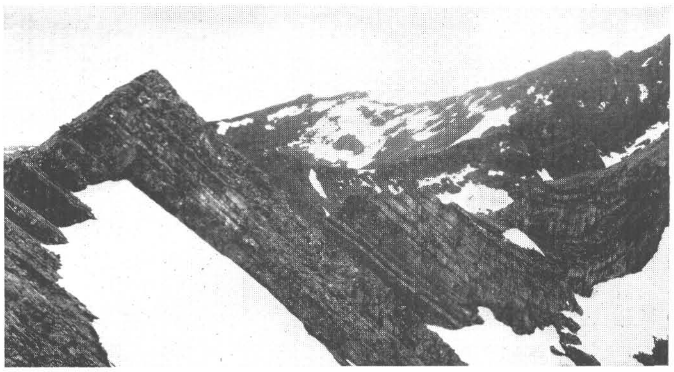


FIGURE 5.—Interbedded graywacke and shale of the Kuskokwim group, on eastern slopes of Kiokluk Mountains.

In general, angularity of grain and poor sorting of grains characterize the group. Large fragments, randomly oriented, are scattered in a poorly defined matrix

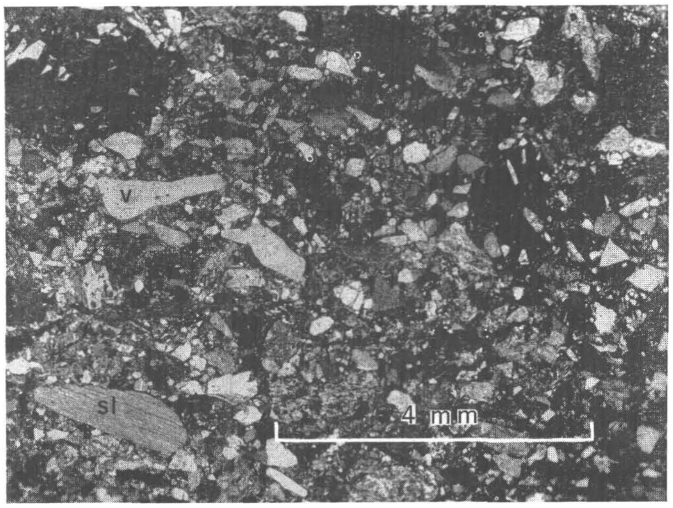


FIGURE 6.—Photomicrograph of typical graywacke, on south bank of George River near mouth. Fragments shown include microlitic volcanic glass (*v*) and slate (*sl*). Plain light.

of small particles (fig. 6). Tabular fragments are subparallel to the bedding. The composition of the fragments varies with closeness to source rocks; thus fragments of volcanic rocks and plagioclase feldspars predominate in the lower part of the Kuskokwim group, directly above the volcanic zones of the Gemuk group, whereas limestone or dolomite fragments are common in the eastern areas, where the Kuskokwim group overlaps the Holitna group. Resistant fragments, chiefly chert, quartz, and quartzite, which are abundant in the higher zones of the Kuskokwim group, are apparently farther from source rocks. Some of the small particles, chiefly of phyllite, have probably also come from a distant source, as the formations that underlie the Kuskokwim group in the central Kuskokwim region are not phyllitic.

The most likely source of the phyllite, quartzite, and chert fragments are formations such as those reported in the Ruby district (Mertie and Harrington, 1924, p. 13–17, 22–24); where metamorphic rocks, and overlying chert and "argillite" that are probably correlatives of the Gemuk group, are exposed.

Finely divided carbon is disseminated in fragments of phyllite, slate, and shale included in the graywacke and is largely responsible for its dark shades. The carbon is not necessarily abundant, but the fragments which contain it are evenly distributed through the rock and produce an effect of greater quantity. Rocks in which fragments of coarse light-colored opaque chert, feldspar, and limestone are more abundant are not so dark. The finer grained rocks, characteristically the shales, are commonly the darker; they contain disseminated carbon apparently fixed in them at the site of deposition, as well as the carbon introduced in rock fragments.

The rocks near the base of the Kuskokwim group are nearly all massive and include local basal conglomerate and breccia and several thousand feet of graywacke and shale in beds hundreds of feet thick. There is an almost imperceptible upward gradation from coarse to fine facies in this part of the group that is apparently unbroken except by local breccia beds, some of which contain large volumes of fragments derived from the underlying Gemuk group. The graywacke beds in the lower part of the group also thin southeastward and shale takes their place in the belt that borders the Holitna group.

The upper nine-tenths of the Kuskokwim group is composed almost entirely of interlaminated graywacke and shale. The graywacke beds, ranging in thickness from a few inches to 1 or 2 feet, are commonly separated from the thinner beds of shale by sharply defined bedding planes. Some of the shale beds pinch out laterally between graywacke beds in the width of a large exposure. Dark pebbles and coarse black grains of shale in the graywacke beds are lithologically similar to the interbedded shales and apparently were derived from them. Small-scale crossbedding occurs in zones that contain these fragments of intraformational origin but rarely throughout a graywacke bed. The thicker graywacke beds are massive and ungraded, but the thinner ones show gradation of grain size from coarse at the bottom to fine at the top. Intraformational folds and faults, produced by subaqueous sliding of the sediments before they were lithified and before the younger layers were deposited, are fairly common. Ripple marks are few.

Recent investigations (Kuenen and Migliorini, 1950; Pettijohn, 1950) have indicated that graywacke and related rocks formed from sediments that accumulated first in the shallow shore zones of geosynclinal troughs; later, while still in an unconsolidated state, these sediments descended by gravity in subaqueous mudflows and also were transported in turbidity currents of high density generated by mudflows, or by other means, into deep water, where they were redeposited below the superficial zone of wave and current action. Varying sequences of such processes seem to account for the deposition of the rocks of the Kuskokwim group.

The strata that bear crossbedding, ripple marks, and other evidence of deposition in shallow water are found chiefly in the upper part of the group, but they are not common.

GRAYWACKE

The graywacke, although a variety of sandstone, commonly does not show the characteristic granularity of sandstone, because of its greater proportion of highly indurated interstitial material, which makes for durability and comparatively smooth fracture across grains. These features, coupled with the dark color and massive uniformity of the graywacke beds, lead to their confusion in the field with mafic igneous dike rocks, particularly where contacts with interbedded shales are not exposed. The sedimentary origin of coarse-grained graywacke is shown, however, by irregularly angular fragments.

The graywacke ranges in color from medium gray to black. The finer grained types are of more uniform, commonly darker color, whereas the coarser types are mottled and have a characteristic "pepper and salt" aspect, produced by the scattered lighter colored rock and mineral fragments in the relatively fine-grained dark matrix. The extremely coarse breccia and conglomerate facies of the graywacke contain abundant intraformational shale pebbles, which produce the opposite effect of dark fragments in a generally lighter matrix. A faintly greenish tinge may indicate a relatively large percentage of the detritus of basaltic igneous rocks. The weathered color of the graywacke is highly varied, depending upon the rock and mineral constituents. Browns as opposed to grays are favored by the presence of basaltic material.

The way in which a fresh specimen of graywacke breaks is related to its structural setting. Folded, steeply dipping strata are more highly indurated than the flat lying, and the fracture, though possibly irregular in fine details, is roughly subconchoidal. Some of the less indurated and also coarser rocks show a slight tendency to break around as well as through the grains and an irregular fracture is produced. Fractures can rarely be produced parallel to the bedding within the typical massive graywacke bed, but smooth, even breaks along shale partings between the graywacke beds are readily formed by striking with the hammer, if not already developed as bedding joints.

Mineral and rock fragments of several different kinds are recognizable in the coarser grained hand specimens. Shale is most readily distinguished because fragments are generally large and black, and some are slab shaped. Fragments of feldspar and limestone (or dolomite) are light colored. The feldspar can be distinguished readily from the limestone in places where it forms rectangular cleavage fragments, or where fine micaceous alteration products are detectable with the point of the knife blade. The limestone is commonly buff and effervesces where acid is applied. Fragments of chert and basaltic igneous rock are of neutral shades and commonly are not noticed at first glance. Some of the chert is as dark as the shale fragments but can be distinguished in large fragments by its translucent fracture flakes. Much of the chert, however, is as light as the fragments of limestone and feldspar, from which it can be distinguished by its greater hardness and curved fracture. The basaltic rock fragments also vary in shade with degree of alteration. Commonly they are granular and have a greenish tinge. Quartz grains are not as apparent in the hand specimens as they are in thin section, partly because the grains are commonly smaller and partly because the vitreous luster is masked by abrasions on the surface of the durable unfractured grains. Many specimens contain scattered flakes of rather fine white mica that is visible with the unaided eye or hand lens. In hand specimens fragments of quartzite cannot be distinguished from chert, nor phyllite fragments from the finer matrix of the rock.

Fragmental fossils are occasionally found in thinly bedded graywacke. They commonly occur in intraformational breccia and pebbly zones, and the fossil fragments, like the shale fragments associated with them, are apparently derived from shale interbeds in which they were first deposited.

The mineral and rock fragments in the graywacke are chiefly of sand size. They are about ¼ to ½ millimeter in diameter, though fragments several millimeters in diameter are conspicuous in many specimens. Silt-sized particles, many less than 1/10 millimeter in diameter, occur throughout. The sand-sized fragments are angular and commonly tabular or bladed. They are unsorted as to size and are set in a poorly defined matrix, which is comprised of equant though angular silt-sized grains, which are also poorly sorted.

The major constituent fragments are, in generally decreasing order of abundance: siltstone and slate, phyllite, chert, quartz, quartzite, mafic to intermediate

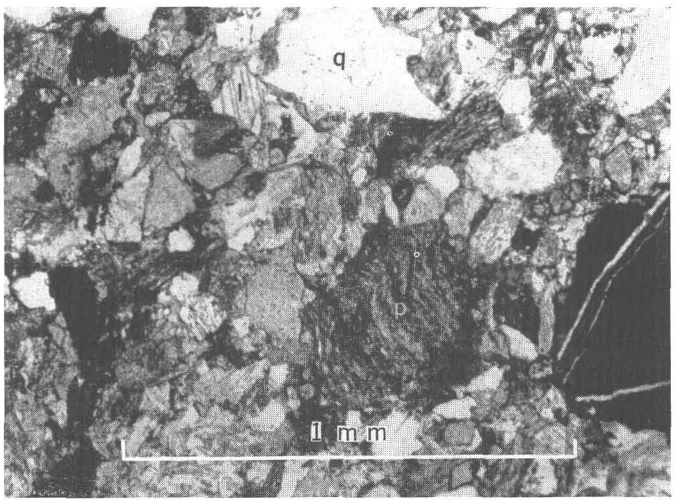


FIGURE 7.—Photomicrograph of phyllite fragment in graywacke, on Georgetown Trail near Twin Buttes. This fragment (*p*), which lies a little to the right of the center of the picture, includes a crinkle in the schistosity of the phyllite; the dark fragment at the extreme right, cut by fine veins of chalcedony, is probably a very ferruginous volcanic fragment; other fragments are quartz (*q*) and carbonate probably from limestone (*l*). Plain light.

and spilitic volcanic rocks, feldspar (chiefly albite), shale, limestone, mica (chiefly muscovite), and chlorite.

The phyllite fragments are tabular or bladed, and subrounded, and they are abundant in the finer sizes. The phyllite is composed principally of quartz and sericite, has a crinkled structure (fig. 7), and is carbonaceous; the carbon forms numerous small dark specks visible in thin section. Some of the smaller fragments of phyllite are compacted and bent into interstitial positions between larger and more competent fragments; thus they look superficially like a matrix material though they may be no smaller than fragments of other constituents. Some of the phyllite fragments are rather coarse textured and verge on schist, whereas others are finer textured, show no crenulations, and verge on siltstone (fig. 8) and slate (fig. 6). The slate fragments are commonly the most carbonaceous (fig. 9). Chert (fig. 10), quartz (fig. 8), and quartzite (fig. 9) form angular bladed to equant fragments, chiefly of fine sand size, and are typically associated with phyllite fragments. The quartz fragments commonly show strain shadows, or comprise an aggregate of elongated irregular grains characteristic of vein quartz. Some of the quartzite fragments, made up of finer quartz grains, are hard to distinguish from the chert fragments. Grains of quartz are included in or attached to fragments of coarser textured phyllite. Some quartzite fragments are sericitic (fig. 10), and their mineral composition is almost that of phyllite. Most of the fragments of volcanic rocks are as large as pebbles, in more rounded grains than many of the other fragments (fig. 11). They are commonly associated with fragments of plagioclase feldspar and chlorite. Some of the feldspar fragments are likewise more rounded (fig. 12) and appear to be formed chiefly from phenocrysts broken out of the trachitic to ophitic, less commonly glassy, groundmass of the volcanic fragments. The chlorite fragments are apparently pieces broken out of the altered groundmass of volcanic rocks. The chlorite forms an interstitial filling between fragments in some instances, but this feature is confined to graywacke that contains fragments of volcanic rocks. Limestone and shale fragments are rounded and form equant or tabular grains. They are commonly in the coarser sizes (fig. 9). Some of the rocks contain scattered flakes of muscovite, but biotite is rare. The fine-grained mica, sericite, is commonly seen. It is one of

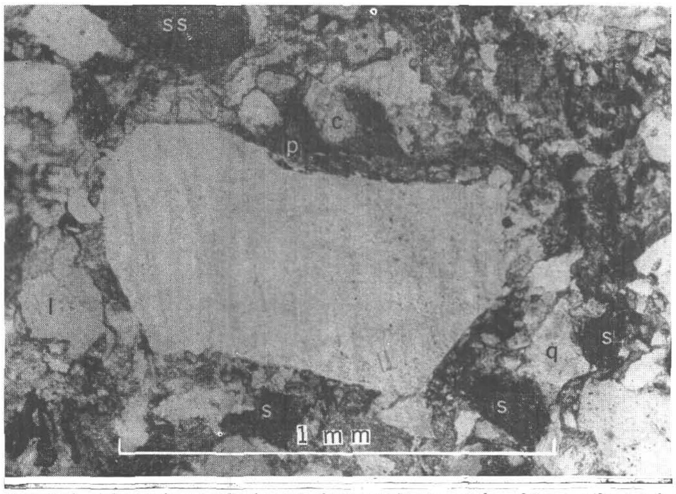


FIGURE 8.—Photomicrograph of quartz fragment in graywacke, about 4 miles southwest of mouth of Steamboat Creek. Shows planes of inclusions and phyllite (*p*) attached to one edge; smaller fragments are siltstone (*ss*), limestone (*l*), chlorite (*c*), shale (*s*), and quartz (*q*). Plain light.

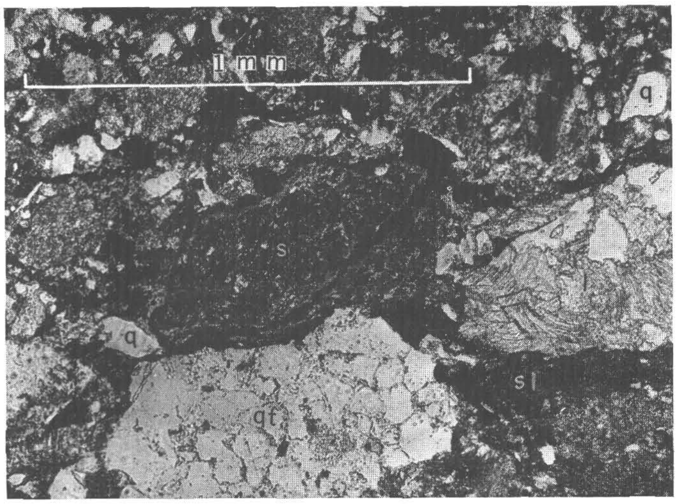


FIGURE 9.—Photomicrograph of quartzite (*qt*), shale (*s*), and limestone (*l*) fragments in graywacke, in hills northeast of Chuilnuk Mountains. Smaller fragments are quartz (*q*) and slate (*s'*). Plain light.

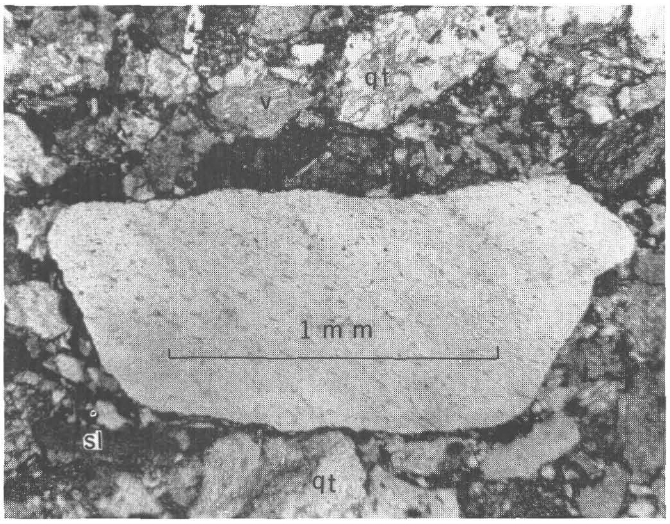


FIGURE 10.—Photomicrograph of chert fragments in graywacke, on south bank of Kuskokwim River about 4 miles southeast of Georgetown. Smaller fragments are slate (*sl*), mafic volcanic rocks (*v*), and sericitic quartzite (*qt*). Plain light.

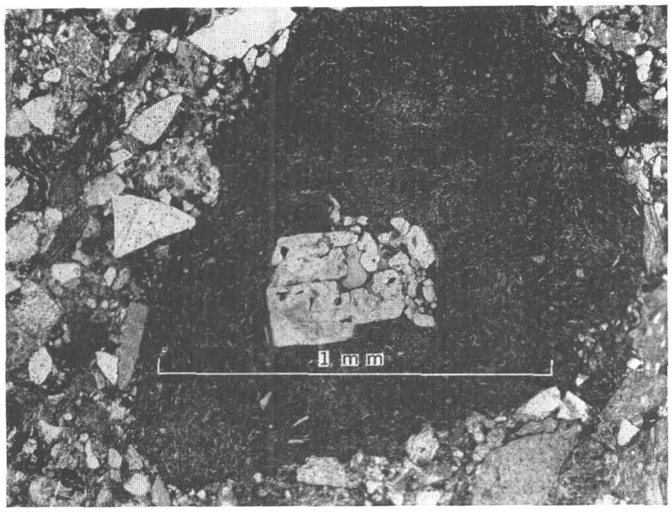


FIGURE 11.—Photomicrograph of fragment of porphyritic basalt in graywacke, on south bank of George River near mouth. Basalt fragment contains plagioclase phenocryst. Plain light.

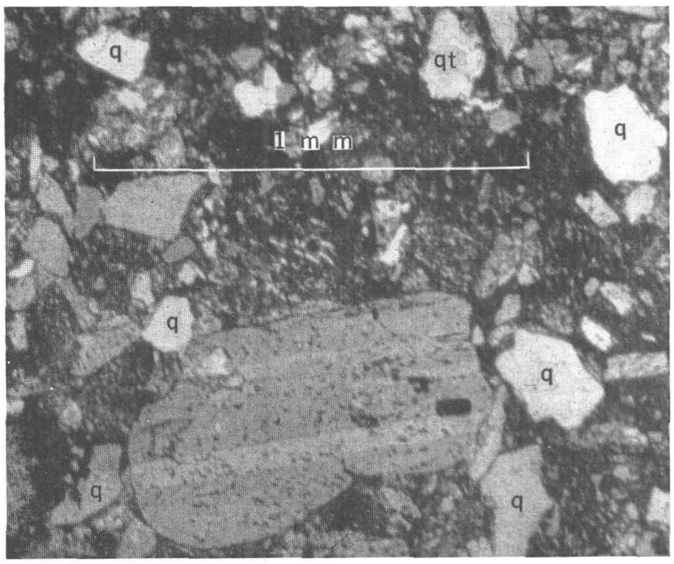


FIGURE 12.—Photomicrograph of plagioclase fragment in graywacke, on upper Little Creek. Other fragments are quartz (*q*) and quartzite (*qt*). Crossed nicols.

the minerals of the phyllite fragments and does not form discrete particles as might seem to be true at first glance. Less important constituents of the graywacke include magnetite, zircon, apatite, and titanite. Finely divided ferruginous material stains the smaller fragmental constituents and gives the false appearance of a limonite cement between the coarser fragments.

The graywacke is considerably altered at various localities. The most common type of alteration is silicification, in which the finer grained constituents are encroached upon by a mosaic of fine-grained quartz and chalcedony indistinguishable from and commonly merging with that of the chert fragments. Enlargement of the quartz fragments with the development of irregular sutured boundaries is a part of this process. The rocks that are silicified are commonly sericitized, and scattered fine-grained mica, which encroaches first upon the smaller phyllite and shale fragments, is formed. Where hydrothermal alteration has been most active, as near quicksilver deposits, the graywacke is carbonatized, as well as silicified and sericitized, to such an extent that the rock is pearl gray like the similarly altered biotite basalt sills and dikes.

SHALE

The shale that is interbedded with the graywacke, as has already been pointed out, is a fine-grained graywacke in which the fragments are too small to be distinguished with the naked eye. The more massive shales may be confused with basaltic volcanic rocks. Those near the base of the Kuskokwim group occur in such thick beds that it was impossible to find the bedding in some of the largest of outcrop exposures, and microscopic examination was necessary to prove their sedimentary origin. Most of the shale, however, is thinner bedded and less massive than associated graywacke, and its sedimentary character is readily decided in the field.

With few exceptions, the sale is very dark, almost black. A few bentonitic shales are lighter colored, cream to buff, or greenish buff. The shale weathers to somewhat lighter, characteristically gray-brown shades. Because it is commonly less massive than the graywacke, the shale has a greater tendency to part along the bedding. A subconchoidal fracture is characteristic of breaks in other directions. About the only mineral identifiable with the unaided eye is muscovite, which forms tiny flakes that lie parallel to the bedding and are exposed along the bedding partings. They are distinguishable only because they reflect points of light. Seams of coal a fraction of an inch thick, associated with the shale, have been observed in a few places. They are formed of a compressed mat of detrital terrestrial plant remains. Well-preserved fossil marine shells occur in thin zones in the shale, which can be traced for several hundred feet in good exposures.

The fragments in the shale are chiefly in the coarse silt sizes, which make up more than half the rock. They are about 25 microns in diameter, sharply angular, equant to tabular in shape, and, like the fragments in the graywacke, unsorted as to size. They are set in a poorly defined matrix composed of smaller silt- and clay-sized particles.

The coarse silt particles of the shale and intermixed fine sand particles are chiefly quartz fragments (fig. 13), accompanied by minor amount of feldspar, muscovite, and chert. The clay particles are too small to be

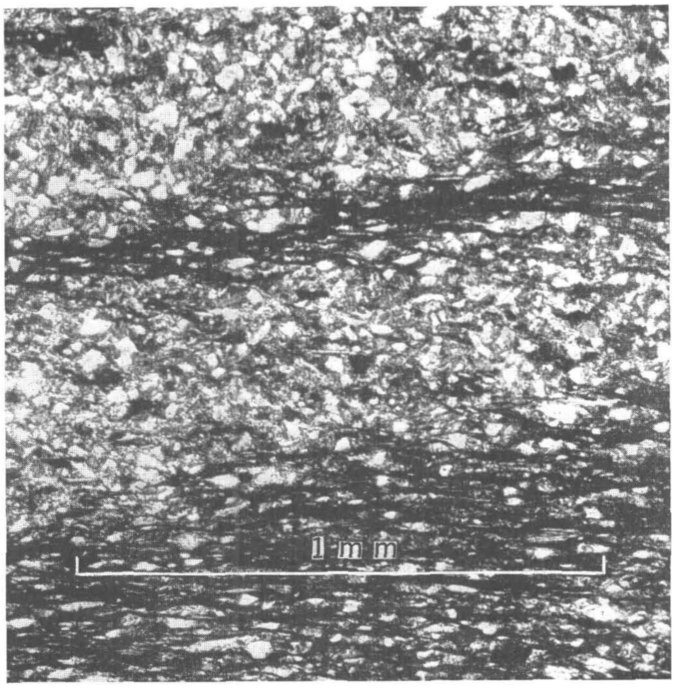


FIGURE 13.—Photomicrograph of graywacke siltstone or shale, near headwaters of Mukslulik Creek. Bedding is shown by alternate light and dark streaks; fracture cleavage, marked chiefly by thin, undulating, carbonaceous layers, trends across the bedding at a slight angle in this section. Constituents include abundant quartz (most of light-colored fragments) and thin plates of muscovite (center). Plain light.

resolved by the microscope, but they seem to contain finely divided carbonaceous and ferruginous material. Sericite and chlorite are recognizable constituents of the fine silt particles. The less numerous mineral constituents of the shales are biotite, magnetite, apatite, and titanite.

The chief petrographic difference between the shale and graywacke is in the relative proportions of mineral and rock fragments. The shale carries few recognizable rock fragments, since its material has been comminuted to individual mineral grains. The overall mineral composition of the two facies seems to be about the same, however. Quartz fragments are more abundant in shale than in graywacke, but may be accounted for by complete mechanical breakdown of phyllite and quartzite such as found in the graywacke. Chlorite and sericite are more abundant fine constituents of the shale than of the graywacke, derived as they are by mechanical breakdown of mafic to intermediate volcanic rocks and phyllites. The relatively large concentration of carbonaceous and ferruginous clay materials in the matrix of the shales may be similarly explained.

The shale is more affected by alteration, particularly silicification, than graywacke. Scattered quartz fragments are the only original constituents recognizable in some specimens examined. These fragments lie in a matrix of secondary silica, chiefly chalcedony. Hand specimens of such rocks are commonly gray instead of black and show less of the shaly parting. The shale is less commonly altered to a pearl-gray rock than is the graywacke or the biotite basalt.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Kuskokwim group is extremely thick and is estimated to contain between 40,000 and 65,000 feet of strata. The basal zones of the group, comprising 5,000 to 10,000 feet of massive graywacke and shale, flank the rocks of the Gemuk group found along the axis of the Gemuk anticlinorium. It is impossible to determine the thickness closely in this area because the strata are repeated by folding and faulting. One of the best places to observe the probable thickness of the massive basal strata is in the area northwest of the divide between the headwaters of Girl Creek and the upper main fork of the Holokuk River. Here the beds dip 3C°–75° SE. from the axis of an anticline that plunges northeastward in the valley of Girl Creek, and which is centered in a wide exposure of the Gemuk group southwest of the headwaters of the Buckstock River (pl. 1).

The thickest continuous, most readily observed, and essentially unrepeated sections of the Kuskokwim group are exposed in the transecting gorge of the lower course of the Holokuk River downstream (northwest) from the mouth of Chineekluk Creek. The strata of these sections are on the northwest limb of the Gemuk anticlinorium. From Chineekluk Creek downstream to the vicinity of Kaluvarawluk Mountain there is some repetition and the dips flatten out, but there are probably 10,000 to 15,000 feet of strata above the massive basal beds. The best section, 15,000 to 20,000 feet of interbedded graywacke and shale that dip 45° to 75° NW., is exposed in the lower part of the gorge downstream (northwest) from Kaluvarawluk Mountain nearly to the mouth of Kogoyuk Creek. Below (northwest of) the mouth of the latter creek, bedrock in the vicinity of the Holokuk River is covered with surficial deposits for about 2 miles, but strata that dip very steeply northwest are exposed for about 1 mile beyond the cover before the axis of a syncline is reached; thus, barring the possibility of repetition beneath the cover, the total thickness of the Holokuk River gorge section may be as much as 45,000 feet; although beds may be repeated the section is at least 25,000 feet thick.

The rocks are covered in the vicinity of the mouth of the Holokuk River, but they are well exposed opposite the mouth of the Holokuk on the north side of the Kuskokwim River. These exposures are near the east end of a nearly continuous series of cut-banks, with favorable exposures of the Kuskokwim group, that are downstream on the north side of the Kuskokwim River nearly to Russian Mission. The strata are repeated in major folds between the exposures opposite the mouth of the Holokuk River and the vicinity of Kolmakof, but from there on west they constitute a northwest-dipping section at least 10,000 feet thick. It is difficult to determine whether the strata of the section in the cut-banks between the mouth of the Holokuk River and Russian Mission are equivalent to part of the Holokuk River section, or lie stratigraphically above the Holokuk River section. The dip is to the northwest in more than half the exposure in the cut-banks, however, and it is likely that at least the 10,000-foot section between Kolmakof and Russian Mission includes higher strata than those on the lower Holokuk River. If so, these are the highest strata known in the Kuskokwim group of the central Kuskokwim region.

An apparently unrepeated section of part of the Kuskokwim group was found at one other locality. The rocks in the hills that border Downey Creek, south of the Kuskokwim River at Georgetown, dip about 60° S. for 7 miles south of the river, giving a thickness of roughly 35,000 feet.

The stratigraphic relations of the Kuskokwim group to underlying groups has been touched upon in the discussion of the Holitna and Gemuk groups. It was pointed out that minor faults are possibly characteristic features of the contact between the Holitna group and the Kuskokwim group over much of its length. The contact in the bluffs of the Holitna River 9 miles northeast of Nogamut is a reverse fault on which the Holitna group has moved up and over the Kuskokwim group; thus the uppermost beds of the Holitna group are not at the contact and the relation of the Holitna group to the Kuskokwim group can not be determined. Conversely, the lowermost beds of the Kuskokwim group are not exposed along the contact, but are presumably adjacent to the fault at depth; therefore their stratigraphic relation to the Holitna group is likewise inconclusive. The contact is covered by surficial deposits at other localities investigated. The unconformable relation of the Kuskokwim group to the Holitna group is implied by a limestone pebble conglomerate with shale matrix, reported by prospectors about 15 miles due east of the Taylor Mountains and about ¼ mile east of Titnuk Creek. This locality is within 1 mile south of exposures of the Holitna group, in the terrane of the Kuskokwim group. A somewhat comparably situated conglomerate, bearing limestone pebbles, is reported yet farther east and northeast, about 45 miles east of the border of the map, in the area south of the Lime Hills between the headwaters of the Hoholitna and Stony Rivers (Smith, 1917, p. 58–61). Conglomerates that contain limestone pebbles also occur near the base of the Kuskokwim group along the Kuskokwim River, 40 miles northeast (Spurr, 1900, p. 159) of the map area.

Little can be learned of the angularity of the unconformity between the Holitna and Kuskokwim groups at any one locality, because the contacts are covered or faulted as mentioned above. The contact is apparently not sufficiently discordant to produce contrasts in the gross structural pattern, as the major folds observed in the Kuskokwim group are parallel to those in the Holitna group and are presumably of the same fold system. On the other hand the absence of the Gemuk group in the eastern areas indicates that the contact between the Holitna and Kuskokwim groups is one of profoundest regional unconformity, though unconformable relationships can not be seen at any particular spot.

The regional unconformity just cited extends into areas where the Gemuk group does occur. There is no apparent angular unconformity between the Gemuk group and the Kuskokwim group, as was pointed out in the discussion of the Gemuk group. There is, however, good evidence for a strictly erosional break between the two. The lower zones of the Kuskokwim group, particularly in the area at the head of Timber Creek, Buckstock River, and Girl Creek, contain breccia with abundant large fragments derived from volcanic rocks in the uppermost zones of the Gemuk group.

The Kuskokwim group apparently terminates upward at a disconformity at least in the central Kuskokwim region. It was shown that the highest strata of the Kuskokwim group exposed in the Central Kuskokwim region are probably in the section that dips northwest east of Russian Mission. These strata strike northeastward into the area southeast of the Iditarod River. Here the overlying Iditarod basalt occurs in isolated synclinal belts and is apparently folded with the Kuskokwim group, from which it is separated by a basal breccia that marks as nearly as can be determined an otherwise conformable contact. Recent studies by Hoare indicate that the Kuskokwim group in the area southwest of the Aniak River may contain higher strata than it does within the central Kuskokwim region.

Hoare finds that the Kuskokwim group thins appreciably to the southwest of the central Kuskokwim region, despite the acquisition of possible higher stratigraphic zones referred to in the preceding paragraph, but knowledge of the amount, nature and areal extent of thinning must await further studies. The sections of the Kuskokwim group also thin northeastward in the Kuskokwim Mountain belt. The thinning is not detectable within the region, but becomes obvious in areas to the northeast where the Kuskokwim group disappears (Eakin, 1918, pl. 2; Mertie and Harrington, 1924, pl. 3) and volcanic rocks, not unlike those that overlie the Kuskokwim group in the central Kuskokwim region, lie directly on correlatives of the Holitna or Gemuk groups.

The Kuskokwim group probably thins appreciably toward the major structural axes southeast (Alaska-Yukon geanticline) and northwest (Aniak-Ruby geanticline) of the Kuskokwim Mountain belt, but because it is largely eroded from these positive tracts the amount and also the method of thinning is not directly determinable.

The group probably thins to the southeast, chiefly by transgressive overlap of the higher strata on the Alaska-Yukon geanticline. Some of the highest strata possibly lie near the lower contact (Mertie and Harrington, 1924, p. 27–28) on the northwest flank of the geanticline at the northeasternmost localities in which the group is exposed. There is also some indirect evidence that the Kuskokwim group thins by convergence of strata toward the principal source areas. Coarse clastic sediments are about as abundant at the top as at the bottom of the group. This feature probably implies continuous subsidence of the trough of deposition beneath the sea accompanied by continuous rise above sea level of the source areas. Contrasting movements such as this, upward in geanticlinal belts and downward in geosynclinal belts, would have caused a decrease in thickness or convergence of strata of a given age span from the center toward the margins of the geosyncline. Where these contrasting movements were extreme the effect of convergence would doubtless overshadow that of transgressive overlap in accounting for marginal thinning of the Kuskokwim group. Lateral gradation from graywacke on the northwest southeastward into shale, which was noted in the lowermost zones of the group, probably implies relatively greater initial activity of the Aniak-Ruby geanticline during deposition of the Kuskokwim group and suggests that convergence originally predominated in that direction. Studies of the relation of the Kuskokwim group to the Holitna group suggest that some presumably basal southeastern shale facies of the Kuskokwim group overlap the Alaska-Yukon geanticline.

Some of the apparent thinning of the Kuskokwim group may be due to erosion. The disconformity at the top of the Kuskokwim group already described and other more profound unconformities that transect it, such as those beneath the Holokuk and Waterboot basalts or at the surface of the bedrock beneath the surficial deposits, mark intervals in which relatively small to large volumes of the group have been eroded.

Possible correlatives of the Kuskokwim group are scarce and spottily distributed along the northeastern continuation of the Kuskokwim Mountain orogen in central Alaska (Mertie, 1937 b, p. 156–172). R. W. Imlay (written communication, 1952) states that strata in this region hitherto placed in the Late Cretaceous are of late Early Cretaceous age. In view of probable northeastward thinning by transgressive overlap in southwestern Alaska, the general scarcity in central Alaska may be attributed to nondeposition of correlatives of the Kuskokwim group rather than to erosion. As a corollary of this statement it seems likely that nearly the full original thickness of the Kuskokwim group is included in the sections in the central Kuskokwim region which lie beneath the least penetrating of the unconformities, the one at the base of the Iditarod basalt.

LOCAL DETAILS

The Kuskokwim group is so generally distributed and its lithology so uniform that there are few significant and strictly local conditions to describe. It seems worthwhile, however, to indicate several places in which the group is favorably exposed and to point out significant relations in these areas.

KUSKOKWIM RIVER CUT-BANKS

The best exposures of the Kuskokwim group are in the cut-banks of the Kuskokwim River downstream from Sleetmute as far as Russian Mission. These exposures were first examined by J. E. Spurr (1900, p. 127–128, 129–130, 159–160, 160–162) in the course of the first geological survey of southwestern Alaska, and subsequently by A. G. Maddren (Smith and Maddren, 1915, p. 281–282).

The cut-banks and river bluffs near Sleetmute extend along the west side of the Holitna and Kuskokwim Rivers from a point about five miles upstream from the mouth of the Holitna River to a point on the Kuskokwim River opposite Sleetmute village near the mouth of Vreeland Creek (pls. 1, 3). The strata in the Sleetmute cut-banks dip steeply and are sharply and complexly folded, hence continuous unrepeated sections are unavailable, but the prevailing dips are southerly. Clastic fragments of limestone quite like that of the Holitna group, and distinguishable with the unaided eye, were found in the graywacke here. These and also abundant microscopic fragments of limestone doubtless explain Spurr's description of the graywacke as a limestone (Spurr, 1900, p. 127). Thin coaly seams a fraction of an inch thick were found in the exposures above the mouth of the Holitna River. Fragments of the fossil shell, *Inoceramus*, occur in the cut-banks both above and below the mouth of the Holitna River.

Rather closely folded sections of the Kuskokwim group are well exposed in the cut-banks near Georgetown, Crooked Creek, Oskawalik, and Napaimiut, but the best exposures of unrepeated strata are in the cut-banks downstream from Kolmakof, on the north side of the river. The section below Kolmakof to Russian

Mission was examined in considerable detail at 53 points over a distance of about 10 miles, and the relative proportions of graywacke and shale were estimated at 23 of these stations. Their combined averages showed 65 percent of graywacke and 35 percent of shale. It is believed that this section is fairly representative of the Kuskokwim group, above the massive basal zones. Toward the west, or downriver, end of the section the rock is less than commonly indurated. This is probably largely because the strata dip gently here and have been under less pressure connected with folding. Fossils, including fragments of *Inoceramus* and plant remains are fairly common in this section. The plant remains, particularly leaf fragments, are most abundant in the upper and western part of the section. At least 10,000 feet of strata are exposed between Kolmakof and Russian Mission.

KOLMAKOF RIVER CUT-BANKS

Beds believed to be at about the same stratigraphic position as those in the Kuskokwim River cut-banks below Kolmakof are exposed in rather continuous cut-banks along the west side of the Kolmakof River. The Kolmakof River section is more repeated than that to the southwest, but the folds, the axes of which fan out westward across the course of the river, are relatively broad and open. Poorly indurated rocks have afforded some of the best fossil collecting in the Kuskokwim group, and remains of marine vertebrates and invertebrates and fragments of terrestrial plants are relatively abundant at several points along the river. Rarely has it been possible in other localities to trace the fossiliferous zones with the hope of collecting more fossils, but these sections seem to provide just such an opportunity. The graywacke along the Kolmakof River is commonly of a lighter gray than usual, apparently due to an admixture of a relatively large amount of chert fragments.

HOLOKUK RIVER GORGE

The strata of this section are more highly indurated than those of the other cut-bank sections of the Kuskokwim group. This may be due not only to folding, but also to the numerous sheets and sills of albite rhyolite that intrude the strata and are apparently responsible for conversion of the shales in particular to argillite. The original sedimentary features, particularly in the fine-grained facies, are not very clear, because of the alteration effects. The shales are a light gray, appear more massive, and have a blocky fracture. This massiveness leads to some confusion with rocks about to be discussed that lie stratigraphically beneath the Holokuk River gorge section, but which get their massiveness at least in part from sedimentary conditions rather than by secondary alteration.

UPPER HOLOKUK RIVER AREA

This area is located astride the northeast-plunging Gemuk anticlinorium and, in addition to showing the relations of the Kuskokwim group and the underlying Gemuk group, shows what appear to be some rather significant sedimentary facies relationships found within the basal zones of the Kuskokwim group.

The rock of the ridge between the upper Holokuk River and Girl Creek is predominantly thick-bedded shale, accompanied by smaller amounts of massive graywacke and breccia, which are in an apparently synclinal tract the axis of which roughly follows the ridge-top. Their structural and stratigraphic relation to an anticline along Girl Creek and to the underlying Gemuk group in areas to the southwest have already been indicated in the earlier discussion of thickness and stratigraphic relation of the Kuskokwim group. The graywacke lies lowest in the stratigraphic section; it occurs along the contact with the Gemuk group in the southeastward facing slopes southeast of the ridgetop and northwest of the upper Holokuk River. It apparently disappears in a northeastward direction along the contact with the Gemuk group, as massive graywacke does not occur at or northeast of the mouth of Girl Creek. Faulting may be locally responsible for this, but it is believed that much of the disappearance of the graywacke may be because it grades laterally into finer grained rock. This inference is borne out by the much greater extent and thickness of the basal graywacke that borders the Gemuk group in the anticlinal tract southwest of the headwaters of Girl Creek.

Southeast of the upper course of the Holokuk River the massive lower beds of the Kuskokwim group, as well as the upper strata of the underlying Gemuk group, are faulted off against the more thinly bedded strata higher in the Kuskokwim group; thus, lateral facies changes in the basal zones of the Kuskokwim group may not be directly observed here. Evidence for a general eastward or southeastward change in the basal zones from coarse to fine facies is available, however, in more distant southeastern localities. Toward the extreme headwaters of the Holokuk River, where there is no evidence of faulting, shales seem to predominate in the relatively few available exposures that adjoin the anticlinal area of the Gemuk group on Atsaksovluk Creek. Massive shales, accompanied by minor amounts of graywacke, also crop out in an anticlinal belt in a large upfaulted block along the headwater divide between Boss and Egozuk Creeks, tributaries of the Holokuk River, and Mukslulik and Bakbuk Creeks, northwestern tributaries of the Holitna River.

The rocks of the basal zones of the Kuskokwim group, such as are found in the upper Holokuk River area, are massive and weather brown. In this they differ from rocks of both higher zones and of apparent lateral equivalents of the basal zones in southeastern areas. The thick massive beds form prominent outcrops that stand out from the slopes much like the massive strata of the Gemuk group in the Cinnabar Creek area. The brown color gives the superficial appearance of weathered mafic volcanic rocks, and hand specimens of the finer textured facies are difficult to distinguish from basalt. Actually, these rocks of northwestern areas commonly contain such large quantities of fragmental debris, apparently derived from the basaltic volcanic formations in the Gemuk group, that they approach the composition of basalt or andesite and the brown-weathered surface is explained. The strata in some localities may be crossed for hundreds of feet without a sign of bedding. Lack of bedding may probably be explained by the rather rapid dumping of large quantities of detritus, eroded from a nearby source, onto bottoms deep enough to be unaffected by waves and currents. The apparent northwestward thickening of the coarser facies indicates that the source was probably to the northwest. That is also the direction in which the volcanic rocks of the Gemuk group appear to become more abundant.

UPPER HOLITNA RIVER AREA

The best and practically the only cut-bank exposures of the Kuskokwim group in the upper Holitna River area are in the gorge of the Chukowan River west of Kashegelok, and in the Holitna River cut-banks at the west foot of the hill that extends southward from Nogamut.

The rocks in the Chukowan River gorge dip steeply and are repeated in at least one major anticline and in several minor folds. Disregarding repetition, the regional dip in the gorge is to the east-northeast on the east limb of the Gemuk anticlinorium. The most westerly rocks exposed, a little below the mouth of the Gemuk River, are probably not far stratigraphically above the top of the Gemuk group, which apparently lies beneath the cover of surficial deposits in the lower Gemuk River valley. East of the east end of the gorge, where the Chukowan River emerges onto the broad bottomlands of the upper Holitna River, the strata exposed in cut-banks in two low hills that border the river are subhorizontal and much less indurated than the steeply folded rocks.

The rocks at "Nogamut Hill" also are nearly horizontal and show several interesting features. The Holitna River first strikes the latter hill at a steep, high cut-bank in which shale seems to predominate over graywacke. Thin zones with rather abundant fossils occur in this cut-bank, also several beds, one to two inches thick, of puttylike bentonitic clay. A clastic dike formed of graywacke extends vertically through the shale strata. Lenticular, buff-weathering nodules lie along the bedding. At first appearance the nodules look like boulders of dolomite, but extremely long lenses of similar material are evidently of other origin, and a microscopic study shows that they are probably clay-ironstone concretions.

The Kuskokwim group is exposed at one point farther downstream on the Holitna River, 9 miles northeast of Nogamut, where the fault contact with the Holitna group is crossed. The shale here contains structures related to the fault.

OTHER AREAS

Several rolling upland areas, where exposures are characteristically poor because of the widespread cover of surficial deposits produced by frost weathering, offer typical occurrences of the Kuskokwim group. One such area extends east-west south of the Kuskokwim River between Sleetmute and Oskawalik. Here the predominant dip is to the south, and in the vicinity of Downey Creek south of Georgetown there is a thick unrepeated section already referred to in the discussion of thickness of the Kuskokwim group. Another is northeast of the Kuskokwim River, between Sleetmute and Georgetown. The Kuskokwim group of this area and of the area along the Georgetown Trail, which follows the divide west of the George River and north of Georgetown, was also described by P. S. Smith in a report on an earlier survey (Smith, 1917, p. 77–84). The rocks northeast of the Sleetmute-Georgetown and Georgetown Trail areas have not been surveyed on the ground, but aerial photographs of the George River basin show the rolling upland topography characteristic of the Kuskokwim group.

A similar broad rolling upland, which touches the Holitna River at Kashegelok and Nogamut, extends southeastward from the vicinity of the Taylor Mountains through the Nushagak Hills at the headwaters of the Nushagak River. The southeastern part of this area was covered by P. A. Davison in an earlier survey of the Nushagak Hills and the Nushagak River (Mertie, 1938, p. 59–61).

AGE

Fossils of Late Cretaceous age have been collected from several localities in the terrane of the Kuskokwim group. Seven out of a total of thirty-eight localities yielded undoubted early Late Cretaceous fossils. Fossils of probable early Late Cretaceous age were found at three localities. The fossils from three other localities possibly indicate middle rather than early Late Cretaceous age. About twenty localities in all yielded collections diagnostic of the Late Cretaceous and none of the fossils in the remaining collections suggest other than Late Cretaceous age. Most of the collections, which consist chiefly of fossil marine animals, were examined and reported on by R. W. Imlay and J. B. Reeside, Jr. (see also Imlay and Reeside, 1954, annotation 35, p. 238). Some of the earlier collections were identified by T. W. Stanton. Plant remains were, with one exception, identified and reported on by R. W. Brown.

The fauna comprises chiefly pelecypod and cephalopod mollusks though it includes a few other categories such as annelid worms, brachiopods, and barnacles. Remains of fish occur locally in some abundance. The flora, which is all terrestrial, includes ferns and both monocotyledonous and dicotyledonous flowering plants. The best collecting is in rare exposures where the fossiliferous zones persist for considerable distance along the bedding. The marine fossils may be preserved as complete specimens in such zones. Most of the fossil material is fragmental, however, and identification is difficult. The remains of the marine animals as well as the terrestrial plants were apparently transported far enough to be broken into fragments before deposition.

Fossils from the Kuskokwim group

[Identification by: a, T. W. Stanton; b, R. W. Brown; c, J. B. Reeside, Jr.; d, R. W. Imlay]

	11	13	9087	9088	9222	9223, 9224	9225	9226	9227	9228	31AD75, 31AD75b	31AD75a	41ACa123	41ACa124	18646	18866	42ACa43	18926	19386	19387	19388	19389	19390	44AW90	19391	44AW95, 104	19392	19393	44AW110	44ACa23	19394	19395b	19396	19728	19729	45ACa79	19732	19734	19735	19733
Serpula sp.															c																									
Brachiopod? fragment of, undetermined																		c																						
Ostrea sp.								a		a						c						c															c			
Inoceramus dunveganensis McLearn			d												d	d							d														d			
athabaskensis McLearn																					d																			
cf. *I. athabaskensis* McLearn																							d				d													
nahwisi McLearn																					d																			
cf. *I. reachensis* Etheridge							d	d										d																						
cf. *I. altus* Meek					d																																		d	
sp.																																d			d					
sp.	a	a		a		a				a	c	c								c		c			c			c			c			c						
Scaphites cf. *S. puerculus* Jimbo and *S. inermis* Anderson																		c																						
aff. *S. condoni* Anderson																																					c			
Scaphites? imprints																			c																					
Pachydiscid? ammonite															c																									
Exiteloceras? sp.																							c																	
Helioceras cf. *H. phoenixensis* (Anderson)																																					c			
Ammonite fragments, undetermined																c																							c	
Lepadid? barnacle plates																c																								
Fish bones, undetermined																c																					c		c	
Fish scales, undetermined																c																					c	c	c	
Crustacean? trails																																								c
Plant fragment, cf. *Cladophlebis septentrionalis* Hollick																	b																							
Seed, probably *Prunus* sp.														b																										
Grass or sedge, undetermined													b																											
Dicotyledonous leaf fragments, undetermined									a																	b														
Wood and/or bark fragments and imprints, undetermined																								b					b	b						b				

Localities at which fossils from the Kuskokwim group were found

Collection No.	Field No.	Collector, year of collection, description of locality
11	--------------	J. E. Spurr, 1898. Cut-bank on southeast side of Kuskokwim River, about 9½ miles southwest of Oskawalik.
13	--------------	J. E. Spurr, 1898. Cut-bank on north side of Kuskokwim River, about 3 miles east of Kolmakof.
9087	--------------	A. G. Maddren, 1914. Cut-bank on north side of Kuskokwim River, about 1½ miles east of Kolmakof.
9088	--------------	A. G. Maddren, 1914. Cut-bank on north side of Kuskokwim River, about 3 miles west of Kolmakof.
9222	14AS134	P. S. Smith, 1914. Divide between Kuskokwim River and South Fork of George River, 7½ miles due north of village of Sleetmute.
9223	14AS135	Do.
9224	14AS136	Do.
9225	14AS136a	Do.
9226	14AS166	P. S. Smith, 1914. Georgetown Trail, 1½ miles southeast of Twin Buttes.
9227	14AS167	P. S. Smith, 1914. Georgetown Trail, southern summit of Twin Buttes.
9228	14AS170	P. S. Smith, 1914. Georgetown Trail, 1 mile northwest of Twin Buttes.
--------	31AD75, 31AD75b.	P. A. Davison, 1931. Nushagak Hills, 9 miles southeast of Finn Mountain and about 1¼ mile north of Nushagak River; slope of south-pointing spur.
--------	31AD75a	P. A. Davison, 1931. Nushagak Hills, 9½ miles southeast of Finn Mountain; gravels of Nushagak River, at base of spur where collections 31AD75 and 31AD75b were made.
--------	41ACa123	W. M. Cady, 1941. Cut-bank on north side of Kuskokwim River, 7½ miles northwest of Sleetmute.
--------	41ACa124	W. M. Cady, 1941. Willis quicksilver prospect, 10 miles northwest of Sleetmute and 1¼ miles north of Kuskokwim River; rock fragment from mine dump.
18646	41ACa125	W. M. Cady, 1941. Northeast side of spur between Cribby Creek and Kuskokwim River, 9½ miles northwest of Sleetmute and 2 miles northeast of Kuskokwim River; small quicksilver prospect.
18866	42ACa42	W. M. Cady, 1942. South bank of Kuskokwim River, 4 miles southeast of the mouth of George River; boulder in river gravels at foot of cut-bank.
--------	42ACa43	W. M. Cady, 1942. South bank of Kuskokwim River, 3 miles southeast of mouth of George River; river gravels at foot of cut-bank.
18926	43ACa99	W. M. Cady, 1943. Cut-bank on east side of Holitna River, 3 miles south of Nogamut; point where river first strikes "Nogamut Hill."
19386	44AW64–69	R. E. Wallace, 1944. Cut-bank on west side of Holokuk River, 10 miles airline southeast of mouth of river.
19387	44AW70	R. E. Wallace, 1944. Ridge top 2 miles east of Kogoyuk Creek and 5 miles south of junction of Kogoyuk Creek and Holokuk River.
19388	44AW71, –72, –74–78.	R. E. Wallace, 1944. Cut-banks north of Kuskokwim River, 2½ miles east of Napaimiut.
19389	44AW73	Do.
19390	44AW82–89	R. E. Wallace, 1944. Cut-banks north of Kuskokwim River, 4 to 6 miles west of Kolmakof.
--------	44AW90	R. E. Wallace, 1944. Cut-bank north of Kuskokwim River, about 6 miles west of Kolmakof.
19391	44AW91–94	Do.
--------	44AW95–104	R. E. Wallace, 1944. Cut-banks north of Kuskokwim River, 2 to 5 miles east of Russian Mission.
19392	44AW107–109	R. E. Wallace, 1944. Cut-banks north of Kuskokwim River, between Kolmakof and Russian Mission.
19393	44AW105, –106	R. E. Wallace, 1944. Cut-bank north of Kuskokwim River, about 3 miles east of Kolmakof.
--------	44AW110	R. E. Wallace, 1944. Cut-banks north of Kuskokwim River, between Kolmakof and Russian Mission.
--------	44ACa23	W. M. Cady, 1944. Lower northwestern slopes of Taylor Mountains, 6½ miles southeast of Nogamut and 12½ miles northeast of Kashegelok; outcrop near Creek.
19394	44ACa16	W. M. Cady, 1944. Lower northwest slopes of Taylor Mountains, 6½ miles southeast of Nogamut and 12½ miles northeast of Kashegelok; crest of spur.
19395B	44ACa22	W. M. Cady, 1944. Lower northwestern slopes of Taylor Mountains, 6½ miles southeast of Nogamut and 12½ miles northeast of Kashegelok; outcrop near creek (same locality as collection 44ACa23).
19396	44AHr4	J. M. Hoare, 1944. Hills between Nogamut and Taylor Mountains, 4½ miles southeast of Nogamut and 10½ miles northeast of Kashegelok; crest of ridge.
19728	45ACa30	W. M. Cady, 1945. Northeast slopes of Kiokluk Mountains, ½ mile northeast of north end of largest lake; fragment of rock in moraine.
19729	45ACa66	W. M. Cady, 1945. Cut-bank southeast of Holokuk River, 3½ miles southwest of mouth of Boss Creek.
--------	45ACa79	W. M. Cady, 1945. Old cut-bank west of Kolmakof River, 17 miles northwest of Napaimiut, 14 miles air line north of mouth of river.
19732	45ACa82, 45AHr21	W. M. Cady and J. M. Hoare, 1945. Cut-bank north of Kolmakof River, 13 miles northwest of Napaimiut and 10 miles airline north of mouth of river.
19734	45ACa81	W. M. Cady, 1945. Cut-bank north of Kolmakof River, 13 miles northwest of Napaimiut and 10 miles airline north of mouth of river (about ⅕ mile northeast of locality of collection 19732); talus fragment.
19735	45AHr22	J. M. Hoare, 1945. Cut-bank west of Kolmakof River, 8 miles northwest of Napaimiut and 3½ miles airline north of mouth of the river.
19733	45ACa84	W. M. Cady, 1945. DeCourcy Mountain mine, 17 miles northwest of Crooked Creek and ¼ mile north of Return Creek; loose fragment from road cut.

The most useful fossils in the more precise correlation of the Kuskokwim group are various species of the pelecypod, *Inoceramus*. *Inoceramus dunveganensis* McLearn, *I. athabaskensis* McLearn, and *I. nahwisi* McLearn are according to Imlay of Cenomanian age and are thus diagnostic of the early part of Late Cretaceous age. Imlay states that the *Inoceramus* cf. *I. reachensis* Etheridge is probably of Late Cenomanian age. Brown states that the plant fragment in collection 42ACa43 appears to belong to the species *Cladiophlebis septentrionalis* Hollick and indicates that, if so, the formation from which it was obtained is Cretaceous in age. The dicotyledonous leaf fragments in two of the collections indicate that their age is probably Cretaceous or younger.

Fossils apparently range vertically in the Kuskokwim group from the highest zone at least down to the top of the massive strata near the base. A false impression of their greater abundance in upper zones may be gained partly because they are collected more easily from the less indurated upper strata. There is no evidence that the various fossil forms are zoned and some of the forms recognized seem to range vertically through the greater part of the Kuskokwim group above the lower massive strata. It therefore seems likely that nearly all, if not all, of the beds above the massive zone are of early Late Cretaceous age.

The zone of massive strata near the base is possibly of late Early Cretaceous age. Rocks that contain fossils of this age lie unconformably on older formations and are succeeded conformably by Upper Cretaceous rocks in northern Alaska north of the Brooks Range (Payne and others, 1951), in the Mackenzie River region of northwestern Canada (Hume and Link, 1945, p. 40), and in the Anadir River region of northeastern Siberia (Kropotkin and Shatalov, 1936, p. 128; Gundlach, 1942, p. 98). Inasmuch as these regions lie in directions north, east, and west, respectively, of the central Kuskokwim region it seems very likely that the Kuskokwim group comprises a similar succession of upper Lower Cretaceous-Upper Cretaceous beds.

Fossils have been collected in several areas of the Kuskokwim group outside of the region. Several collections believed to be diagnostic of Upper Cretaceous rocks are reported from localities northeast of the region (Mertie and Harrington, 1924, p. 39, coll. 7823;

p. 40, coll. 9367; Brown, 1926, p. 109–110). One of these collections (Brown, 1926, p. 109, coll. 12561), which has recently been reexamined, may very likely be older than Late Cretaceous in age. Imlay states that this collection contains very poorly preserved fossils of either Jurassic or Cretaceous age. The collection is from a locality in the vicinity of the extreme northeastern end of the terrane of the Kuskokwim group, and may actually come from correlatives of the underlying Gemuk group.

A few of the collections from the northeastern region contain fossil shells that have been believed to be of either Cretaceous or Tertiary age (Mertie and Harrington, 1924, p. 39, coll. 7822; p. 40, colls. 9364–9366). Certain of these collections (9364–9366) have been reexamined and Tertiary affinities seem doubtful. Julia A. Gardner of the Geological Survey states that they contain unidentifiable molds of pelecypods and of gastropods that she does not recognize as resembling any Tertiary forms with which she is familiar. A collection of fossil plants from the same slab as that of the shells, and originally determined to contain species of early Tertiary (Eocene) age (Mertie and Harrington, 1924, p. 40, coll. 7007), has been reexamined by Brown and found indeterminable.

The rocks of the terrane of the Kuskokwim group southwest of the Central Kuskokwim region have, according to Hoare, yielded fossils diagnostic chiefly of the middle rather than the low Upper Cretaceous (see also Imlay and Reeside, 1954, annotation 35, p. 238–239).

Rocks of the same general age as those of the Kuskokwim group are reported in regions both to the northwest and southeast of the broad belt that passes northeastward through the central Kuskokwim region. Those to the northwest are separated from exposures of the Kuskokwim group by older formations exposed along the Aniak-Ruby geanticline, but those to the southeast are connected with the terrane of the Kuskokwim group across the southwest-plunging axis of the Alaska-Yukon geanticline. The latter relationship has been described in the discussion of the areal distribution of the Kuskokwim group.

The rocks northwest of the Aniak-Ruby geanticline are exposed along and west of the lower Yukon and Koyukuk Rivers, where several stratigraphic sections have been studied by various authorities, and fossils collected. The most recent paleontologic studies by Imlay indicate that the rocks of these sections are of late Early Cretaceous and possibly early Late Cretaceous age (see also Imlay and Reeside, 1954, annotation 31, p. 236–237).

The rocks immediately southeast of the Alaska-Yukon geanticline are believed to include Upper Cretaceous strata, because they are continuous with those in the terrane of the Kuskokwim group. Farther southeast, in the Alaska Range, and in general continuity with the rocks southeast of the Alaska-Yukon geanticline, S. R. Capps (1935, pls. 1, 2) mapped an "undifferentiated complex, mainly black argillite, slate, and graywacke with some sandstone and conglomerate, and minor amounts of lava and tuff" that he refers to as "probably in part Upper Cretaceous". This "complex" is largely underlain by another "undifferentiated complex" that Capps describes as "mainly medium basic lava and tuff, but locally containing considerable metamorphosed sediments and some intrusive rocks" and which he designates as "Lower Jurassic to Cretaceous". Capps (1935, p. 58) points out that good fossils have been hard to find in the southern Alaska Range and falls back on correlations based on other lines of evidence. The inferred sequence of a volcanic followed by an essentially nonvolcanic complex in the southern Alaska Range compares with that of the Gemuk group and Kuskokwim group in the Central Kuskokwim region. The rocks of the younger complex seem, as described, quite comparable to those of the Kuskokwim group and suggest that Upper Cretaceous strata, possibly as thick and identical, extend eastward through the Alaska Range southeast of the Alaska-Yukon geanticline.

Rather extensive exposures of rocks, of possible late Cretaceous age, are reported in the area of the Wood River Lakes in the Nushagak district (Mertie, 1938, p. 56–59).

IDITAROD BASALT

AREAL DISTRIBUTION

Basaltic volcanic rocks form a range of hills southeast of the Iditarod River and are here named the Iditarod basalt after this river. This range extends northeastward from the Russian Mountains for nearly 50 miles. The rocks occur in synclinal belts ½ mile to 5 miles wide. They are probably downfaulted along the Iditarod River, beyond which to the northwest older rocks crop out. Two of the synclinal belts are arranged in echelon south of Quinn Creek. The formation is best and typically exposed in a wide tract northeast of Montana Creek in the vicinity of DeCourcy Mountain. It is also well exposed on the eastern slopes of the Russian Mountains.

LITHOLOGIC CHARACTER

The Iditarod basalt comprises chiefly massive basalt lava flows underlain by a comparatively thin but widely distributed basal zone of sedimentary breccia. Similar breccia zones, irregularly distributed, are interbedded with the flows. The breccia is composed of rock and mineral fragments, eroded chiefly from the lava flows, but also from the underlying graywacke and shale of the Kuskokwim group.

BASALT

Dense, uniformly fine-grained and massive, dark-colored basalt predominates; flow structure occurs in a few places and scoria in others. Fresh specimens are commonly greenish black, though some that are blue-black and purplish-black have been noted. The rock weathers brown. It is locally porphyritic and amygdaloidal. The phenocrysts of the porphyritic basalt are laths of plagioclase feldspar or grains of pyroxene, or both. The amygdules are composed of quartz, carbonate, and chlorite.

Much of the rock contains very small euhedral to subhedral phenocrysts no more than 1 millimeter in diameter and barely visible in hand specimen. Phenocrysts of pyroxene, principally augite, are commonly of the pigeonite variety. Plagioclase phenocrysts are chiefly labradorite, but some are composed of bytownite, and some contain zones of both labradorite and bytownite. The texture of the groundmass is predominantly ophitic or subophitic. A second generation of pyroxene fills in the spaces between randomly oriented plagioclase laths that average about $\frac{1}{10}$ millimeter long. Trachitic textures are rather common and glassy textures occur locally. Magnetite is a common accessory mineral in the groundmass.

Biotite, as well as hornblende, may form rims upon or completely replace the pyroxenes, presumably as a result of primary reaction of the pyroxene with molten portions of the basalt before it cooled. Secondary alterations are a common feature of the Iditarod basalt. The pyroxenes, particularly in the groundmass, are widely altered to chlorite; and carbonate, quartz, and fine-grained mica are common alteration products of feldspars as well as of pyroxenes. It is difficult to tell what proportion of the quartz is secondary. Much of it obviously replaces other minerals, but some specimens contain clear interstitial quartz that is very likely primary. The quartz, chlorite, and feldspar of amygdules are probably of the same generation as the secondary alteration products. Iron oxides account for the brown weathered surface of the rock. Only three of the many specimens collected from the Iditarod basalt proved to be spilitic.

BRECCIA

The basal breccia in particular is commonly mottled with dark shades against a light background; hence it is readily distinguished from adjacent basalt whose shades are more uniform.

The mottling of the breccia is produced by black fragments of shale or graywacke that are scattered among gray to buff fragments of basalt. The fragments, some partly rounded, are 1 to 2 feet in diameter at a few localities. The mottling is less apparent in breccia beds that are interlaminated with the basalt flows, inasmuch as they contain fewer graywacke and shale fragments than does the basal breccia. The breccia weathers to shades of brown and the mottling does not show on the weathered surface.

Various types of fine detrital mineral and rock grains, in addition to the basalt, shale, and graywacke fragments visible in the hand specimen, may be seen in thin sections of the breccia. They include quartz, quartzite, chert, plagioclase feldspar, and pyroxene, and also chlorite detached from the basalt, shale, and graywacke. The basalt fragments constitute 75 to 90 percent of the average specimen and are succeeded in abundance by shale and graywacke. The fine detrital grains are sparsely scattered between the larger fragments and comprise less than 1 percent of the rock. Finely divided ferruginous material stains the smaller fragmental constituents and, as in the graywacke of the Kuskokwim group, gives the false appearance of a limonite cement binding the coarser fragments. The smaller of the fragmental constituents actually form a poorly defined matrix in which the larger fragments are set, as in the graywacke.

The breccia is more highly altered than either the basalt or the underlying graywacke and shale of the Kuskokwim group. This is probably because it is more porous and thus has allowed mineralizing solutions to move more freely, and also because the included rock fragments underwent subaerial weathering before they entered the breccia. Fresh surfaces of the breccia are somewhat bleached and thin sections show abundant carbonate and secondary quartz.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Iditarod basalt is estimated to be between 2,000 and 3,000 feet thick. The original thickness before erosion cannot be determined because the upper contacts are apparently all eroded. The thickness was estimated southeast of DeCourcy Mountain, which lies near the axis of a rather poorly defined syncline in the southeastern limb of which the lower contacts of the basalt are exposed. Near the DeCourcy Mountain mine, and about $\frac{3}{4}$ mile southeast of the axis of the syncline, the lower contact of the basalt dips 50° to 75° northwest and, assuming the same dip throughout the section between DeCourcy Mountain and the mine, a maximum thickness of about 3,000 feet of lava beds is indicated.

The stratigraphic relation of the Iditarod basalt to the underlying Kuskokwim group has been dealt with in the discussion of the latter. It will suffice here to say that the base of the basalt is marked by breccia that lies disconformably on the uppermost strata of the Kuskokwim group. The relations between the Iditarod basalt, and the Getmuna rhyolite group and Holokuk and Waterboot basalts cannot be directly determined, because the latter three formations are exposed in areas separate from the Iditarod basalt. The greater alteration of the Iditarod basalt suggests its greater age.

The Iditarod basalt may have originally extended northeast and southwest along the synclinal tracts in the Kuskokwim Mountain belt, beyond the limits of the central Kuskokwim region, before it was faulted and eroded. Hoare has found volcanic rocks interbedded with strata believed to be equivalent to the Kuskokwim group, in the region to the southwest. Possibly the Iditarod basalt intertongues with the Kuskokwim group. Further field work is necessary to determine whether this is a fact, but if so the Iditarod basalt might more properly be referred to as a formation of the Kuskokwim group.

LOCAL DETAILS

The Iditarod basalt has been examined in some detail in several areas in its belt of exposure. Areas to the northeast will be discussed first.

HAYSTACK BUTTE AREA

Breccia like that at the base of the Iditarod basalt crops out in Haystack Butte, a sharp butte on the divide between the headwaters of Flat Creek, a tributary of Crooked Creek, and Glacier Creek, a tributary of the Iditarod River. The breccia there and in a group of buttes 1 mile to the west-southwest, called "Little Haystack Buttes," but not shown on plate 1, is isolated from the main body of basalt, 1½ miles to the northwest, probably through erosion of the southeast edge of the basalt. The attitude of the breccia is uncertain, since its structure is massive; but the north-northeast trend of the outcrops suggests the strike of dipping beds. Graywacke and shale fragments occur in the surficial deposits on both sides of the outcrops of breccia and, if it is assumed that the breccia is the basal breccia of the basalt, the outcrops probably lie at the axes of synclines in the limbs of which the underlying Kuskokwim group occurs. An alternate interpretation is that beds of breccia are interlaminated in the Kuskokwim group and are not closely related to the Iditarod basalt. If interbedded with the graywacke and shale their position is near the top of the Kuskokwim group.

The fragments in the breccia are large, many as much as 1½ feet in diameter. Some are well rounded, some subangular and others quite angular. The shale and graywacke fragments are more conspicuous than the basalt fragments. The lava fragments are abundant, however.

DECOURCY MOUNTAIN AREA

The basalt lavas in the vicinity of DeCourcy Mountain were examined as a part of the study of the DeCourcy Mountain mine and environs. The basal breccia zone, exposed along the southeastern border of the basalt, lies about ⅓ mile northwest of the mine workings. Here the basalt strikes approximately N. 50° E. and dips about 50° NW., but farther northwest, near DeCourcy Mountain, the dip flattens, and the northwest-dipping homocline gives way to folds, the structures of which are difficult to determine, because the lava is extremely massive and shows few bedding features upon which to observe dip and strike. North and east of DeCourcy Mountain, in the hills northeast of Smith Creek, flow structures in the basalt, presumably parallel to the bedding, dip rather consistently southward and the northeast-striking axis of a syncline apparently passes in the vicinity of DeCourcy Mountain.

The basalt in this area is rather varied in outward appearance; some is greenish and amygdaloidal, some dense blue-black; and much is porphyritic with prominent phenocrysts of plagioclase feldspar or pyroxene, or both. An attempt to differentiate flows on the basis of these features was abandoned after it was found that the lithology of the basalt varies over short distances along the strike. Specimens of lava from the summit of DeCourcy Mountain proved to be spilitic, upon microscopic examination. The basal breccia forms a well-defined zone, exposures of which are several hundred feet wide, that may be traced southwestward from the vicinity of the DeCourcy Mountain mine to Montana Creek. The breccia contains abundant fragments of dark shale that give it a characteristic mottled appearance. Breccia beds are also interlaminated in the lavas above the basal breccia.

LITTLE CREEK AREA

The basalt in the DeCourcy Mountain area continues to the southwest into the Little Creek area, where essentially the same rock types and relation prevail. The belt of basal breccia, and the southeastern border of the basalt, are parallel to, but about 2 miles to the northwest of, the projected trend of the breccia belt in the DeCourcy Mountain area. This is possibly due to northeastward plunge of the basalt in the synclinal belt near DeCourcy Mountain, and the basalt in the Little Creek area may have been eroded from the southwestern projection of this belt. An alternate interpretation is that the basalt is offset by a fault parallel to Montana Creek, though there is no evidence for such a fault.

There are on upper Little Creek, southeast of the border of the main belt of basalt, several isolated exposures of basalt, some of which may, as in the interpretation of the breccia of Haystack Butte, be erosional outliers of the main belt. The linear distribution of the outlying basalt on Little Creek, the southeastern border of the main belt of basalt near DeCourcy Mountain, and the outlying exposures of breccia in the vicinity of Haystack Butte suggests that the syncline that passes through DeCourcy Mountain may be extensive, and it strengthens to some extent an inference that the outlying exposures of basalt and breccia are part of the Iditarod basalt. The contacts of the isolated bodies of basalt on upper Little Creek are covered by surficial deposits that make it impossible to separate basalt flows that may be interbedded in the uppermost part of the Kuskokwim group from similar flows in the succeeding Iditarod basalt. Moreover, intrusive bodies of basalt that may be confused with flows occur in this area. However, many of the intrusive bodies, which are characteristically altered to silica-carbonate rock, can be identified.

RUSSIAN MOUNTAIN AREA

Basalt flows, believed to be a southwestern continuation of the Iditarod basalt, crop out on the lower eastern slopes of the Russian Mountains, where they are intruded by a quartz-monzonite stock. The extent of the basalt north and west of the Russian Mountain stock is uncertain, because ground surveys do not extend into the latter areas; nevertheless, a careful study of aerial photographs suggests that the basalt is absent there just as ground surveys have indicated on the south slopes.

The basalt dips west on the east slopes of the Russian Mountains, in conformity with dips in the underlying Kuskokwim group, east of Russian Mission and north of the Kuskokwim River. It is probably continuous with the southeastern border of a synclinal belt of basalt that extends northeastward toward the headwaters of Quinn Creek, a southern tributary of the upper Iditarod River. The northeastern end of the latter belt is southeast of the Little Creek synclinal belt described above. The belt apparently ends a little southwest of the headwaters of Quinn Creek, owing to northeastward rise of the synclinal axis from beneath the basalt, which has been eroded from the area farther northeast. The synclinal axis is probably a continuation of the one that plunges northeastward beneath the DeCourcy Mountain belt of basalt, at Montana Creek.

The lithologic features of the basalt of the Russian Mountain-Quinn Creek belt are comparable with those of the Little Creek and DeCourcy Mountain belts. Fresh exposures are more abundant on the east slope of the Russian Mountains, and such features as phenocrysts and flow structure are consequently more apparent than in the heavily frost-weathered terrain to the northeast. Breccia beds are common.

AGE

The Iditarod basalt is believed to be of middle or late Late Cretaceous age. Its age limits are in the time interval between the deposition of the lower Upper Cretaceous strata of the Kuskokwim group and strong folding in earliest Tertiary, folding apparently participated in by the basalt as well as the older formations. Hoare has found that the lithologic equivalents of the Kuskokwim group in the area west of the Aniak River include chiefly strata of middle Late Cretaceous age. The Iditarod basalt may be confined to the upper section of rocks of the Upper Cretaceous or may be in part a facies of the middle Upper Cretaceous west of the Aniak.

The date of the folds believed to mark the upper age limit of the Iditarod basalt is suggested by relations west of Bering Sea in the Anadir River region of northeast Asia. Here beds of Eocene age lie unconformably on folded and eroded Paleocene rocks (Kropotkin and Shatalov, 1936, p. 129, 133; Gundlach, 1942, p. 97, 98), and it is inferred that the folds in western Alaska were also formed in the earliest Tertiary. The date of the folds is indeterminate in the central Kuskokwim region, inasmuch as fossils have not been found in the formations that lie unconformably on the folded Upper Cretaceous strata. Relatively undeformed Eocene beds occur at scattered localities in Alaska but they either lie upon formations older than Late Cretaceous age, or their field relations are not clear.

GETMUNA RHYOLITE GROUP

AREAL DISTRIBUTION

Rhyolitic volcanic rocks, probably extrusive phases of the albite rhyolite sheets, sills, and dikes, occupy an elongate area of about 15 square miles north of the Horn Mountains that trends northeast across the middle course of Getmuna Creek, a southwestern tributary of Crooked Creek. These rocks are here named the Getmuna rhyolite group for Getmuna Creek. Tuff comprises the major part of this formation, though some lava crops out in a small tract of about 3 square miles at the southwest end of the area in which the Getmuna rhyolite group is exposed.

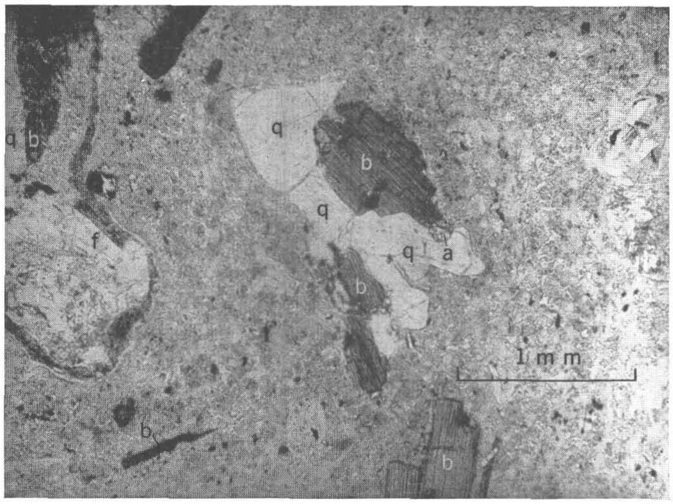
LITHOLOGIC CHARACTER

The tuff beds and the lava flows are rhyolitic. The lava is of albite rhyolite. The tuff contains accidental fragments of the lava that appear to have been blasted from the walls of the vents, through which it was extruded.

LAVA

The lava is light purplish brown, which serves to distinguish it from the light-gray to whitish rocks of the finer grained facies of the intrusive albite rhyolite.

The weathered surface is buff colored. A very few small subhedral to euhedral phenocrysts of feldspar, quartz, and biotite, most of whose longest dimensions are less than 1 millimeter, are recognizable in hand specimens. The feldspars are slightly corroded phenocrysts of plagioclase, commonly zoned from andesine in the center to oligoclase at the borders. Quartz phenocrysts are more deeply corroded. Biotite sheaves era euhedral. The groundmass contains grains that are about 40 microns in diameter and are partly obseured by a very fine wormy intergrowth of quartz and albite (fig. 14). Rhyolite glass occurs in the groundmass of some specimens. Microscopic accessory minerals other than biotite are rare. Neither the lava nor the tuff has been much altered.



F·GURE 14.—Photomicrograph of rhyolite lava, from locality between the forks o Getmuna Creek. Portion of a small isolated mass of lava, of much less than thin-section size but larger than the area of the picture, imbedded in the tuff. The groundmass of the lava consists of a fine intergrowth of quartz and feldspar, in which are imbedded grains of quartz (*q*), plagioclase feldspar (*f*), biotite (*b*), and apatite (*a*), some of them attached. The grains are probably fragments of tuff rather than phenocrysts. Plain light.

TUFF

The tuff is mottled with the contrasting light and dark shades of the fragmental materials and hence is readily distinguished in the field from the uniformly light colored lava. The weathered surface is of a more uniform buff color. The grains and fragments are angular, unsorted as to size, and set in a relatively sparse, gray, stony matrix. Pieces the size of one's fist lie next to fragments too fine to be seen with the naked eye. Most of the fragments are in contact with one another, and the corner of one commonly abuts against the side of its neighbor. Small tabular fragments that are included in the matrix, particularly biotite, are dimensionally oriented parallel to the borders of the spaces between fragments and to flowage layers of the matrix.

The fragmental constituents, particularly fragments of the lava, are most abundant near the contacts with the lava. Anhedral quartz grains, which are about 1 millimeter in diameter, make up more than half the volume of the tuff. The quartz grains are bounded by surfaces of conchoidal fracture and many of them are cracked through and completely shattered (fig. 15).

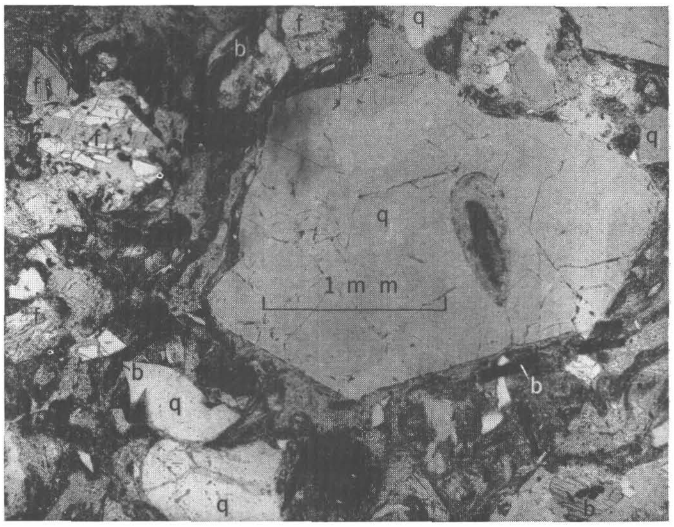


FIGURE 15.—Photomicrograph of fractured quartz fragment in rhyolite tuff, from locality between the forks of Getmuna Creek. The section of this fragment includes an embayment of the groundmass of the rhyolite, in which the quartz formed as a phenocryst; smaller fragments are quartz (*q*), plagioclase feldspar (*f*), and biotite (*b*). Note light and dark streaks of flowage layers. Crossed nicols.

Euhedral to subhedral books of biotite whose sections are mostly less than $\frac{1}{10}$ millimeter long, but some of which are more than 1 millimeter long and easily visible to the naked eye, are very common. The larger fragments of biotite may be bent around the corners of other fragmental material. Fragments of an apparently mafic rock with ophitic and trachitic textures (fig. 16) occur. Other minerals of the fragmental material are labradorite and andesine (fig. 15), apatite (fig. 14), zircon, and garnet. Apatite forms inclusions in the quartz fragments, and in one specimen collected biotite is partly included in a fragment of quartz (fig. 14). The fragments constitute 70 to 90 percent of the volume of the tuff.

The stony matrix of the tuff is made up of extremely fine crystalline material, too fine grained to be readily identified in thin section (fig. 16). The matrix has about the same index of refraction (between 1.53 and 1.54) as that of albite. This suggests the close relationship of the tuff and the lava. Some of the matrix material is microlitic and locally appears nearly isotropic between crossed nicols. The isotropism is probably produced chiefly by fine crystalline aggregates associated with minor amounts of glass. The matrix contains brownish flowage layers, thinly draped around the frag-

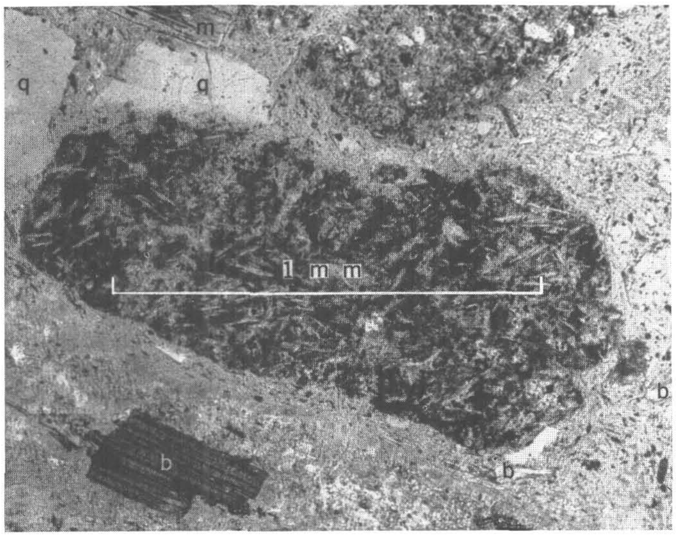


FIGURE 16.—Photomicrograph of fragment of basaltic rock in rhyolite tuff, from locality in hills south of Juninggulra Mountain. The fragment has been silicified but the ophitic texture is preserved; above it is the corner of a large fragment of rhyolite lava; smaller fragments are biotite (*b*), muscovite (*m*) formed from partly bleached biotite, and quartz (*q*). Flowage layers are formed close to the fragments. Plain light.

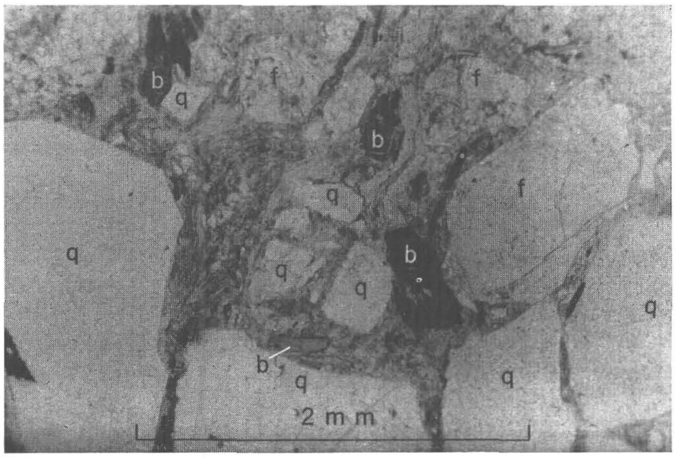


FIGURE 17.—Photomicrograph of rhyolite tuff, in hills south of Juninggulra Mountain. Fragments include quartz (*q*), plagioclase feldspar (*f*), and biotite (*b*). Note flowage layers in matrix, which are draped around fragments, and bent and broken fragment of biotite. Plain light.

ments (fig. 17). Elongated clear colorless areas that separate the brownish layers are believed to be the tubes of flattened shards of glass now almost completely devitrified. Spherulitic masses and perlitic cracks that occur near them indicate the original glassy character of the matrix.

ORIGIN OF THE TUFF

It is significant, in connection with the mode of emplacement of the tuff beds, that the fragments are joined together by a pyrogenic matrix rather than by cementing material. Seventy to ninety percent of the mixture extruded to form the tuff beds was solid enough, however, to make movement as a typical lava flow impossible. As an alternative, it is believed that the fragments, accompanied by the molten and highly viscous felsic lava, were blown out of the vent or vents and came to earth before the molten constituents had solidified. Somewhat similar tuffs have been widely recognized and several authorities (Iddings, 1899, p. 404–406; 1909, p. 331–333; Mansfield and Ross, 1935; Gilbert, 1938) have referred to them as welded. Most such tuffs are generally considered to have been deposited from burning or glowing clouds of extruded fragments and molten material, supported by rapidly expanding gases (Gilbert, 1938, p. 1852–1854).

There is little evidence concerning the location of the vent or vents from which the Getmuna rhyolite group was extruded. There are few good outcrops, and those available do not show significant features, although the volcanic rocks are dissected to a depth of 500 to 600 feet by Getmuna Creek and its tributaries. Probably the Getmuna group itself, or the mafic volcanic rocks (Holokuk basalt) that border it to the south and east, covers the site. The fragments of rhyolite lava in the tuff increase in a westward direction as the border of the lava is approached. This suggests that the contact with the lava is very near to the mouth of the vent through which the tuff was extruded, if it does not actually represent the walls of the vent. Unfortunately, this contact could not be seen except as a change in the type of rock fragments in overlying residual deposits.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Getmuna rhyolite group is at least 500 feet thick. This is the average elevation of the upland exposures above the bottomland of Getmuna Creek. The maximum thickness is estimated to be about 1,500 feet, with allowance for repetition by warping or possible faulting. Planar structures in the volcanic rocks, probably flow structures believed to have been nearly horizontal at the time of formation, now tilt rather steeply. Dips of as much as 75° NW. were observed, though these are probably quite extreme.

The stratigraphic relationships of the Getmuna group must be inferred from indirect evidence; it was not seen in contact with the other bedrock formations of the vicinity. The hypabyssal albite rhyolite, of which these volcanic rocks are probably extrusive phases, is believed to have been intruded near the close of the episode in which the Kuskokwim group, Iditarod basalt, and older rocks were folded. The Getmuna group is therefore believed to cover the eroded surface of the folded and dissected Kuskokwim group and to postdate the Iditarod basalt which is also folded. The Getmuna group probably is older and extends beneath the Holokuk basalt exposed nearby, since the basalt contains fragments of rhyolite that were apparently derived from the Getmuna flows. This sequence is further suggested by the apparent general failure of the hypabyssal albite rhyolite to intrude the Holokuk basalt. The Getmuna group dips more steeply than the Holokuk basalt in the vicinity, but contacts are covered and it was impossible to determine whether or not they are conformable.

AGE

The Getmuna rhyolite group is probably of early Tertiary age if it is the extrusive equivalent of the hypabyssal albite rhyolite, believed to have been intruded near the close of folding in the earliest Tertiary. Its upper age limit is probably Miocene, or about the same as that of the Holokuk basalt.

HOLOKUK BASALT

AREAL DISTRIBUTION

Basaltic volcanic rocks—chiefly flows, now disconnected but believed to have formed a widespread and rather continuous plateau before stream dissection—crop out in the mountainous area east of the Holokuk River, where thay are typically exposed in the Kaluvarawluk and Kiokluk Mountains. The Holokuk basalt also crops out in the flanks of the Horn Mountains, north of the Kuskokwim River. Dikes of similar composition, inferred to have been the feeders of the volcanic rocks, are particularly well exposed in and near the valleys of the Kolmakof River, upper Oskawalik River, and Vreeland Creek. The basaltic volcanic rocks are here named the Holokuk basalt for the Holokuk River.

LITHOLOGIC CHARACTER

The flows and less abundant water-deposited detritus of the flows are made up almost exclusively of basalt. These volcanic rocks are black where freshly exposed in glaciated mountain areas, but outside of the glaciated areas, where weathering has taken place over a long period of time, browns and buffs are characteristic.

The texture and composition of the Holokuk basalt are highly variable from place to place. The basalt is nearly everywhere porphyritic, however, and contains large lath-shaped phenocrysts of plagioclase, predominantly labradorite, many about ½ centimeter (0.2 inch) long. Pyroxene phenocrysts, chiefly of hypersthene, which are commonly too small to distinguish in the hand specimen, occur in the Holokuk basalt in the vicinity of the Horn Mountains. Phenocrysts of biotite and quartz characterize basalt flows on the summit of Kaluvarawluk Mountain. Ophitic, trachitic, and felsophyric textures are characteristic of the groundmass of the Holokuk basalt. The pyroxene of the groundmass of nearly all of these rocks is augite, regardless of the composition of the phenocrysts. Small laths of labradorite less than 0.1 millimeter long, and with only a few if any twin laminae, commonly occur in the groundmass. Some of these rocks seem to contain traces of interstitial primary quartz.

The Holokuk basalt is little altered. There is little if any interstitial chlorite replacing the pyroxenes of the groundmass, and carbonate is not common. Some specimens contain secondary quartz.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Holokuk basalt is at least 3,000 feet thick along the southeast slopes of the Horn Mountains. The thickness is not as great in the mountains east of the Holokuk River; the greatest thickness in the Kiokluk Mountains and in the area east of Holokuk Mountain is 1,500 feet, and on Kaluvarawluk Mountain less than 1,000 feet. Because the volcanic rocks at all of these localities are considered to be faulted and erosional remnants of an originally extensive volcanic plateau, much greater original thicknesses are inferred than the maximum of 3,000 feet observed in the Horn Mountains.

The stratigraphic relations of the Holokuk basalt are best shown in the Kiokluk Mountains, where an angular unconformity between the volcanic rock and the underlying Kuskokwim group can be observed.

The original extent of the Holokuk basalt before stream dissection is conjectural, particularly in areas to the northwest and southeast of the Kuskokwim Mountains; but volcanic rocks, probably residual remnants of a large extrusive sheet or sheets, are reported (Mertie and Harrington, 1924, p. 62–66) in regions of the Kuskokwim Mountains to the northeast of the central Kuskokwim region. The basaltic composition and unconformable relationship of the latter are similar to the composition and relations of the Holokuk basalt and suggest that they are stratigraphic equivalents of the Holokuk basalt. It is noteworthy that throughout the Kuskokwim Mountain belt the volcanic rocks are least dissected in the vicinity of the quartz-monzonite stocks. This is probably because the stocks, which are more resistant to erosion than the other formations, help maintain a higher local base level of erosion. Possibly volcanic rock is generally absent in areas to the northwest and southeast of the Kuskokwim Mountains, where the stocks are least common, because it has been eroded, rather than because its distribution was originally limited.

LOCAL DETAILS

Detailed examinations of the Holokuk basalt have been attempted in several areas.

HORN MOUNTAIN AREA

Basaltic volcanic rocks crop out in both the eastern and western slopes of the Horn Mountains and form 2 broadly arcuate belts of exposure, each 1 to 2 miles wide. These belts trend a little east of north into the area north of the middle course of Getmuna Creek, about 10 miles north of the Horn Mountains. The quartz monzonite of the Horn Mountain stock lies between the two belts of Holokuk basalt throughout much of the area south of Getmuna Creek, and the Getmuna rhyolite group crops out between them in the area north of Getmuna Creek.

The Holokuk basalt flows dip west on both eastern and western flanks of the Horn Mountains, but at the extreme western foot of the mountains and in the area northwest of upper Getmuna Creek they dip east. The north-northeast strike of the basalt contrasts markedly with the east-northeast strike of the strata of the Kuskokwim group east and west of the Horn Mountains. This relation is particularly well shown at the foot of the southeastern slopes, where exposures of interbedded graywacke and shale of the Kuskokwim group are close to exposures of basalt. Here folded graywacke and shale strike directly toward the basalt, which has apparently been downfaulted along an arcuate fault that possibly extends along the whole length of the eastern foot of the mountains. The relation of the basalt flows to the quartz monzonite core of the mountains is discussed in detail in connection with the description of the quartz monzonite. The contact between the Holokuk basalt and Getmuna rhyolite group is covered.

The Holokuk basalt in the Horn Mountain area is made up almost entirely of flows, commonly with columnar structure. The rock appears to be predominantly hypersthene basalt. A thin interbed of shale, a few feet thick, was noted in the northeastern foothills of the Horn Mountains a little north of Jungjuk Creek. Some of the basalt northwest of the head of Getmuna Creek is chocolate brown on the fresh surface. A succession of interbedded basalt, rhyolite, and breccia underlies the typical columnar basalt in the western foothills of the Horn Mountains. These beds possibly include correlatives of the Iditarod basalt and Getmuna rhyolite group. The breccia contains fragments of fine-grained graywacke, derived from the Kuskokwim group, which is also exposed in the vicinity.

West and northwest of the Horn Mountains, particularly in the Kolmakof River valley, are numerous basaltic dikes believed to occupy fissures through which the Holokuk basalt reached the surface.

KALUVARAWLUK MOUNTAIN

Several lava-capped mountains stand east of the lower and middle courses of the Holokuk River. Northernmost of these is Kaluvarawluk Mountain, whose summit ridge is at an altitude of about 3,000 feet above sea level. The Holokuk basalt extends down to altitudes that range from 2,000 to 2,500 feet. The stratification dips gently at angles of less than 25 degrees. Several steeply dipping albite rhyolite sheets that crop out in the vicinity of Kaluvarawluk Mountain are apparently overlain unconformably by the basalt which abruptly terminates the areas of exposure of the rhyolite.

The rock in Kaluvarawluk Mountain is chiefly columnar quartz basalt.

DIVIDE BETWEEN OSKAWALIK RIVER AND CHINEEKLUK CREEK

Basalt lava crops out in a large area east of the east end of Holokuk Mountain, toward the headwards of the main fork of the Oskawalik River (pls. 1, 7). The stratification, which is easily seen at a distance, dips rather gently, 5° to 10° in various directions. Basalt dikes, perhaps the sites of feeders for these flows, are a common feature of the upper main fork of the Oskawalik River and of the headwaters of Vreeland Creek. Olivine basalt was collected in the western part of this area, nearest Holokuk Mountain.

KIOKLUK MOUNTAINS

The structural and contact relationships of the Holokuk basalt to the subjacent Kuskokwim group were seen most clearly on the southern slopes of the Kiokluk Mountains. Here the volcanic rocks are exposed above an altitude of about 2,800 feet, and interbedded graywacke and shale crop out in the lower slopes. Fragments derived from the underlying shale-graywacke succession are mixed with basaltic detritus at the base of the volcanic rocks. The volcanic rocks strike N. 52° E. and dip 10° NW., and the shale and graywacke beneath are locally contorted. The shale and graywacke strike N. 85° W. and are vertical at one point in the exposure, and at another the strike is N. 15° W. and dip 34° E. This locality is in the area southwest of the Kiokluk Mountain stock. The volcanic rocks are widely distributed in the subsidiary ridges and spurs of the Kiokluk Mountains west of the stock but are not known in the eastern and southeastern slopes, where the granodiorite of the stock is in direct contact with the Kuskokwim group. They are found at relatively low altitudes in the northern slopes and foothills, where they are probably continuous with similar rocks, already described, in the area at the headwaters of the Oskawalik River. They are probably faulted in the northern foothill area.

The Holokuk basalt in the Kiokluk Mountains includes a great deal more interbedded water-deposited basaltic detritus than elsewhere and, in addition, some beds of vitric tuff.

AGE

The Holokuk basalt is of Tertiary age. It lies unconformably on folded and eroded strata of Late Cretaceous age. Folding and erosion probably took place by early Eocene, as already pointed out in the discussion of the age relationships of the Iditarod basalt. The Holokuk basalt is cut by faults that were possibly first formed in the late Pliocene in connection with differential regional uplift. To make a closer age determination it is necessary to seek additional information beyond the confines of the central Kuskokwim region. The evidence outlined below would probably place the extrusion of the Holokuk basalt in the middle Tertiary, sometime in the interval from late Eocene through early Miocene.

Comparable, predominantly basaltic volcanic rocks that show similar relations to principal episodes of folding and regional uplift are widely scattered in Alaska and adjacent regions, but there is little direct evidence of their age, since they are very rarely interbedded with fossiliferous strata. These volcanic rocks are for the most part younger than Eocene sedimentary rocks (Lord, Hage, and Stewart, 1947, p. 240), with which their basal zones are interbedded at at least one place (Cockfield, 1921, p. 32), and older than a widespread upland surface in old age that intersects them and was very likely formed in late Miocene or Pliocene time. This surface probably corresponds to the Georgetown summit level, which intersects the Holokuk basalt in the central Kuskokwim region. The commonly high lying Holokuk basalt has apparently been protected from erosion on the flanks of the quartz-monzonite stocks and albite-rhyolite sheets that project above the Georgetown summit level. The basalt is largely absent, however, from the intervening areas underlain by the Kuskokwim group, whence it is believed to have been removed, during baseleveling to the Georgetown summit level, probably sometime in the Miocene or Pliocene. The age of the Georgetown summit level and its probable correlatives is discussed in more detail under the heading of geomorphology.

WATERBOOT BASALT

AREAL DISTRIBUTION

Basalt flows form the nearly horizontal caprock of Flat Top Mountain, east of the upper-middle course of the Aniak River, and are the type exposure of rocks here named the Waterboot basalt for Waterboot Creek. This mountain lies between Atsaksovluk Creek, an easterly tributary of the Aniak River, and Waterboot Creek, which flows west at the south foot of the mountain, and then north into Atsaksovluk Creek. The total area of the basalt capping is about 7 square miles. The lavas probably covered many times this area before they were eroded.

LITHOLOGIC CHARACTER

The Waterboot basalt on Flat Top Mountain is a black porphyritic olivine basalt that is more noticeably scoriaceous and vesicular than the Iditarod basalt or the Holokuk basalt. This cellular structure is a recurrent feature that apparently marks the tops of several successive and nearly horizontal lava flows, each a few feet thick. The largest phenocrysts are of euhedral augite and are as much as 3 millimeters (more than ⅒ inch) in diameter. The augite grains are bunched together in some places and the texture is glomeroporphyritic. Much of the augite is zoned and twinned. The olivine phenocrysts are smaller, but visible in hand specimen. They are also euhedral. The feldspar phenocrysts are euhedral laths of labradorite, barely distinguishable with the naked eye, and are commonly less than 1 millimeter long. The groundmass of the basalt is predominantly ophitic, though locally trachitic. It is made up of mutually contacting labradorite laths, about ¼ millimeter long, in the interstices between which occur fine augite and olivine grains. The groundmass is sprinkled with abundant grains of magnetite, against which the other minerals abut.

This is the least altered rock in the central Kuskokwim region. Alteration effects are confined entirely to the olivine phenocrysts. The olivine is commonly rimmed with iddingsite and some grains are completely replaced by it.

THICKNESS AND STRATIGRAPHIC RELATIONS

The total thickness of the basalt flows is probably not much more than 100 feet. The basalt forms a rimrock escarpment that crops out intermittently around the summit of Flat Top Mountain. This escarpment is less than 50 feet high where it was observed on the southern and eastern sides of the mountain. Fragments of siltstone that were found in the surficial deposits at the base of the escarpment in the latter areas were apparently weathered from the bedrock of the Gemuk group, which probably forms the footing of the basalt, a few feet beneath the ground surface.

Although the contact of the basalt and the underlying formations was not seen, it is inferred that it is an angular unconformity because the dips observed in the Gemuk group in the vicinity range from 55° to 84°, whereas the dip of the basalt flows is less than 2° to the northwest. Hoare reports a similar volcanic caprock immediately west of the Aniak River, which, before stream dissection, was probably continuous with that of the Waterboot basalt on Flat Top Mountain. The altitude of the contact, which is probably as nearly horizontal as the flows, is about 2,000 feet, and, projected outward from Flat Top Mountain, it passes over all but the higher summits in the vicinity. These summits are at the Georgetown summit level, which is described on pages 94 to 96, in the discussion of geomorphology. This summit level intersects the Holokuk basalt, and it is inferred that the Waterboot basalt succeeds the Holokuk basalt in stratigraphic position, though they are not found in mutual contact.

AGE

The Waterboot basalt is probably of late Miocene or Pliocene age. It is younger than the folds formed in the earliest Tertiary, which it transects, and it lies upon a surface in old age, believed to correlate with the Georgetown summit level, whose baseleveling ceased and whose regional uplift and dissection were probably begun in late Miocene or Pliocene time.

SURFICIAL DEPOSITS

Surficial deposits cover most of the bedrock of the central Kuskokwim region and are most abundant in the larger stream valleys. They are accumulations of terrigenous sediments, few, if any, of which were marine deposited. The thickness of the surficial deposits may only be estimated, because depths to bedrock, except in river cut-banks and in a relatively few mining cuts, have not as yet been determined. Some of the surficial deposits are possibly more than 100 feet thick.

The succession of surficial deposits is generally as follows, in the order of appearance: (1) The residual deposits, which cover more than 90 percent of the bedrock to depths commonly less than 10 feet, are composed chiefly of rather coarse rocky soil and rubble produced by weathering of bedrock. (2) Gravel deposits, which are exposed chiefly on rock benches and in terraces and are buried beneath other surficial deposits in stream valleys, are made up of gravel and smaller amounts of sand and silt deposited by streams. (3) Glacial deposits, which occur chiefly in the vicinity of the higher mountains, include till and outwash gravel. (4) Silt deposits, which cover upland slopes as much as 500 feet above the present stream courses, particularly east of the Kuskokwim Mountains, are composed of massive buff-colored silt deposited largely by the wind. (5) Flood-plain deposits, which occur most abundantly along the larger streams, are made up of stratified silt and smaller amounts of sand and gravel.

All but the residual deposits are depicted on the geologic map (pl. 1). The residual deposits reflect the character of the bedrock formations beneath, from which they were derived, and have therefore been used in mapping the bedrock. The line of demarcation between the residual deposits and the other surficial deposits is rarely clear in the field, therefore the boundaries shown between bedrock units and the surficial deposits are necessarily approximate. The areal pattern of the surficial deposits is more clear when viewed from a distance than when studied close at hand, hence aerial photographs, supplemented by field studies in critical areas, have been used as a general guide in mapping the region.

The surficial deposits lie unconformably on the bedrock. Minor unconformities occur within them that are not so apparent, inasmuch as the beds, rarely tilted or folded, show few angular discordances. Most of the more recent surficial deposits lie upon earlier ones or fill valleys or channels eroded in them. The unconformities at the base of and within these deposits are in many places high above the present baselevel of erosion; all except the unconformities beneath residual deposits record repeated widespread differential uplift during the Quaternary period, and faults that intersect them are an expression of this movement.

The surficial deposits are probably mostly of Quaternary age. Their age is inferred from their stratigraphic and geomorphic relations to the Sleetmute upland surface, a rolling late mature surface which was probably formed in the Pliocene. Their age is also shown by their relationship to glacial deposits of probable Pleistocene age and to flood-plain deposits of Recent age.

RESIDUAL DEPOSITS

DISTRIBUTION AND CHARACTER

A rocky soil rarely more than 10 feet thick covers rolling upland areas that range from 1,000 to 2,000 feet above sea level. The most widespread occurrences of the residual deposits are in the basin of the George River, southeast of the Holitna River in the vicinity of the Nushagak Hills, and southeast of the headwaters of the Iditarod River.

The rocky soil of the lower upland slopes commonly gives way to a rubble of coarse rock fragments, some as much as five feet in diameter, where the rolling upland surface slopes up toward the higher mountains, which formed chiefly on the quartz monzonite stocks and albite-rhyolite sheets. The occurrence of the large fragments may be due both to the more massive structure of the bedrock from which they were derived and to the absence of soil-forming vegetation at higher altitudes, as well as to the greater activity of frost at these altitudes. The rubble commonly forms vast fields of fragments on slopes and summits above timberline, where stone nets and stone streams, features characteristic of frost action, are developed. The rubble fields cover the whole bedrock surface of the larger intrusive sheets; they cover very little of the bedrock of the stocks, which are all much larger and form higher mountains, so thoroughly carved by glacial ice that few unglaciated slopes remain except on the lower spurs.

The stone nets comprise contacting rings of larger fragments, in the central areas of which occur smaller fragments. According to one theory of the origin of the rings, the coarse fragments have been separated

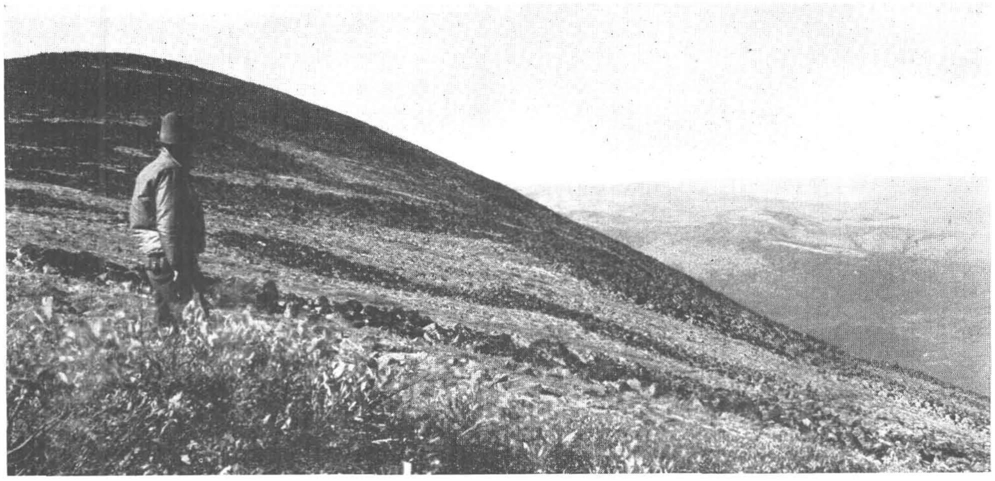


FIGURE 18.—Residual deposits on the upper northeast slope of Barometer Mountain. Rubble produced by frost weathering of bedrock moves in stone streams that trend down the slope; dark lichens cover the coarse rubble, and light-colored lichens grow on the finer soil.

from the finer by the upward heave and outward push of frost action, centered in the finer material whose moisture content is greater (Eakin, 1916, p. 76–82). The rings, some of which are as much as 15 feet in diameter, occur on flat-topped summits and mountainside terraces. Where the rubble of the flat areas spills onto the slopes, the rings of the stone nets are elongated downslope to form ovals, and farther down the ends of the ovals break to form parallel stone streams separated by the finer material (fig. 18). The stone streams commonly extend downslope at least to the border contacts of the massive blocky formation from which the fragments are derived, and in many places far beyond the contacts, on relatively gentle slopes. Large blocks of porphyritic albite rhyolite, derived from the Barometer Mountain intrusive, form stone streams that extend northward out over the shale and graywacke of the Kuskokwim group for more than half a mile beyond the northern contact of the intrusive, on a slope of as little as 5°. The lower ends of the streams are marked by terraces of soil and coarse fragments bound together by vegetation. The stone streams range from 5 to 10 feet in depth, as revealed by prospect pits cut through them to bedrock.

The larger blocks of rubble, which are commonly in the majority, are completely covered by lichens, which indicates that they have not been recently heaved and turned by the frost; but the smaller fragments, a few inches in diameter, which in some places form miniature stone nets and streams, are free of lichens and are therefore believed to reflect frost action going on under existing milder climatic conditions. It is inferred that the fields of coarse rubble, now inactive, comprise fragments pried out of the bedrock and moved downslope at the time of former glacial activity in the region, when the climate was colder throughout the year and alternate freezing and thawing was sustained over longer periods. The rubble fields are little disturbed by stream activity, the fragments are piled together loosely enough that water percolates downslope beneath them without forming surface streams. Furthermore, they formed generally on smaller mountains that have failed to support enough snow cover to produce the torrential stream flow necessary to undercut surficial deposits.

Talus slopes are formed at the sides of glacial troughs and near the foot of bluffs and cut-banks along the larger streams. The angle of repose of talus is 30° to 40°, which is much steeper than the slopes upon which stone streams commonly occur. The thickness of the talus depends upon the configuration of the concealed bedrock beneath; some deposits may be more than 100 feet thick. Quartz monzonite and related igneous rocks that form the cores of the higher mountain groups make very poor talus; the joints within the bedrock are spaced rather far apart, with the result that the available blocks are too large to be readily moved by frost action. The hornfels of the contact-metamorphic zones that surround the intrusive igneous bodies, or the interbedded graywacke and shale in cut-banks, are much less massive; when weathered they form large talus deposits.

STRATIGRAPHIC AND GEOMORPHIC RELATIONS

The stratigraphic and geomorphic relations of the residual deposits are fairly clear. The first-formed residual deposits are known to extend beneath silt and flood-plain deposits and are also intersected by the stream valleys that contain the latter deposits. These are the Boss valleys described (p. 97–100) in the discussion of geomorphology. Talus deposits and miniature stone nets and streams, on the other hand, lie on top of the other types of surficial deposits. Most of the residual deposits are at the Sleetmute upland surface (p. 96–97).

AGE

The earliest residual deposits probably date back to the Pliocene, when the Sleetmute surface began to form. The coarser residual deposits, notably the fields of rubble, very likely developed in the Pleistocene, at the time of greatest cold and related frost action. Rocky soil and the finer rubble have apparently continued to form through Recent time in the upland areas left undisturbed by erosion. Talus deposits have accumulated after erosion, in the Pleistocene, of the steep-walled glacial troughs and river gorges in which they occur.

GRAVEL DEPOSITS

DISTRIBUTION AND CHARACTER

Gravel and smaller quantities of interbedded sand and silt, and, rarely, light-colored volcanic ash, occur on rock benches and in terraces that overlook the flood plains of the streams. Gravel is also buried beneath flood-plain deposits. Some gravel and boulder beds lie on high benches on the divides between the streams.

The gravel deposits are best seen in the benches and terraces along the Kuskokwim River and in adjacent parts of the Holitna River and Aniak River valleys. Buried gravel is reported beneath flood-plain deposits in placer test pits in the northwestern part of the Holitna River basin. Gravel is probably buried beneath residual and flood-plain deposits in eastern areas of the George River basin and southeast of the headwaters of the Iditarod River, where the terrain is gently rolling and the dissection not deep enough to have cut and exposed the gravel in benches and terraces. Gravel deposits occur on high benches in the headwater region of the Oskawalik River, between Henderson Mountain and the Chuilnuk Mountains (pls. 1, 7), in the northwest foothills of the Kiokluk Mountains east of the Holokuk River, and at the divide between Oksotalik and Boss Creeks farther southwest (fig. 33).

Pebbles and boulders in the gravel deposits are well rounded. They are commonly coated with brown iron oxide in contrast to the well-washed appearance of the stream gravel in the flood-plain deposits. The gravel deposits contain tree trunks, peat, and other vegetal material. Economic concentrations of gold have been discovered in the gravel. In few places is the total thickness of the gravel deposits more than 100 feet, except possibly in the area near the confluence of the Holitna and Kuskokwim Rivers, east of the Kuskokwim Mountains.

STRATIGRAPHIC AND GEOMORPHIC RELATIONS

The gravel deposits lie on bedrock. Like the residual deposits they are intersected by the Boss valleys, which in turn contain younger surficial deposits, particularly flood-plain deposits. The gravel is widely covered by silt deposits, notably in the upper Holitna River valley. The upper surface of the gravel deposits is commonly continuous with the neighboring Sleetmute upland surface.

AGE

The gravel deposits are probably of pre-Wisconsin age, since they underlie the silts. Some of the gravel at grade with the Sleetmute upland surface is probably as old as the Pliocene.

GLACIAL DEPOSITS

DISTRIBUTION AND CHARACTER

Till and outwash gravel deposits are included under the heading of glacial deposits. The till forms ground, terminal, and lateral moraines deposited in glaciated valleys and on piedmont slopes of the higher mountains. The outwash deposits comprise short valley trains and outwash plains that extend out from the mountains. Few morainal deposits are more than 100 feet thick; though the thickness of outwash deposits could not be determined, it seems unlikely that they exceed 100 feet.

The glacial deposits occur chiefly in the glacial troughs and contiguous piedmont areas on the north and west sides of the Horn, Russian, Kiokluk, Chuilnuk, and Taylor Mountains. They commonly fail to transgress beyond the foot of the short glacial troughs on the southern and eastern slopes of these mountains.

Ground moraines in the piedmont areas on north slopes, particularly of the Horn, Russian, and Taylor Mountains, are the most widespread of the morainal deposits. The surfaces of the ground moraines are comparatively smooth, in conformity with the glacially eroded bedrock beneath. The ground moraines are spread over valley bottoms and intervening low ridges as much as three miles from the mountain borders. The morainal character of these otherwise streamlined deposits is shown by the scattering of erratic blocks of rock that project above their surfaces. The ground moraine extends down the valleys to altitudes of about 1,000 feet, where it is commonly covered at the lower margins by glacial outwash deposits. This probably marks about the downslope extent of the piedmont glaciers. Terminal and lateral moraines occur chiefly near the mouths of the glacial troughs and form loops of hummocky ground that extend downstream for short distances, commonly less than 1 mile, in the piedmont areas. They are best developed in the Chuilnuk and Kiokluk Mountains, where they occur at altitudes of about 1,200 feet above sea level.

Glacial outwash deposits are most abundant in the piedmont areas northwest of the Horn and Russian Mountains. Here they form broad, gently sloping outwash plains as much as 5 miles wide, that extend northwestward to the Kolmakof and Owhat Rivers respectively. The downstream margins of these outwash deposits are about 500 feet above sea level. Their comparatively great width is possibly due to lateral cutting of the Kolmakof and Owhat Rivers in a northwestward direction, in response to a slight downward tilt of the land surface toward the northwest that is associated with differential uplift and faulting along the Owhat and Iditarod Rivers. The outwash deposits of the Kiokluk and Chuilnuk Mountains are confined largely to narrow linear belts on the floors of the valleys in the piedmont areas, which extend downstream from the terminal moraines. Much the same is true of the outwash deposits of the Taylor Mountains, except that in the absence of terminal moraines their upstream limits appear to be at the downstream limits of the ground moraine.

Glacial deposits occur in a few other areas. Most noteworthy are those in the Gemuk and upper Aniak River valleys. They mark the most northerly advance of the margin of a large ice sheet that once extended from the Central Kuskokwim region south to Bristol Bay but that now is gone, except for some very small glaciers near the heads of valleys. Tongues of this sheet, which parted north of the low divide northeast of Gemuk Mountain, extended down both the Gemuk and Aniak Rivers. Meltwaters from the vicinity of the divide spilled outwash gravel over low passes into the headwaters of Beaver Creek and the western tributary of Waterboot Creek, between the two tongues of ice. The outwash gravels of both the Gemuk River and the Aniak River merge with those of the existing streams, and their downstream limits are indefinite. A study of aerial photographs suggests that glacial deposits, formed at the margin of the same ice sheet, probably occur in the headwaters of Enatalik Creek and the Kogrukluk River. Glacial deposits, largely outwash gravels from a small group of glaciated peaks known as the "Mukhailinguk Mountains", are believed to occur in the area between the Kogrukluk River and Shotgun Creek.

STRATIGRAPHIC AND GEOMORPHIC RELATIONS

The stratigraphic relations of the glacial deposits are not very clear. Outwash deposits appear to blend downstream with the gravel and some of the flood-plain deposits. Morainal deposits probably lie on the older residual deposits, but exposures that show this feature were not discovered. Geomorphic relationships, on the other hand, are helpful. The moraines are in glacial troughs incised deeply into bedrock through the rubble fields of the unglaciated uplands. Some moraines occur in the Boss valleys, particularly on Boss Creek, which shows that the glacial deposits were laid down after the formation of some of the typical Boss valleys. Flood-plain deposits that occur in small valleys cut in the moraines obviously succeed the glacial deposits.

AGE

The glacial deposits are considered to be of Wisconsin age, because the effects of glaciation during the Wisconsin stage of the Pleistocene are most conspicuous elsewhere in Alaska (Capps, 1931, p. 6–8), and it is assumed that the small glaciers of the central Kuskokwim region were probably active at that time.

SILT DEPOSITS

DISTRIBUTION AND CHARACTER

Massively bedded buff-colored silt blankets the slopes as much as 500 feet above the level of existing streams, chiefly in the area southeast of the Kuskokwim Mountains. The upper limit of distribution of the silt is everywhere about 800 feet above sea level. Mapping of the silt has been facilitated by the unique pattern of the vegetation that grows on it. In the vicinity of streams the tree cover gives way to open moss-covered terrain that is visible on aerial photographs (pl. 6) as lighter colored scars. The silt is commonly a few feet thick and the thickest section of the silt observed is about 100 feet.

Silt has been well exposed in opencuts at the Red Devil mine, in the gorge of the Kuskokwim River, northwest of Sleetmute. The cuts are about 100 feet above the river and 350 feet above sea level. The silt, which rests on a buried rocky soil formed by weathering of the bedrock, is exposed to a thickness of 25 feet in one of the larger cuts. The deposit shows faint bedding that dips gently in the direction of the slope of the surface of the ground nearby. A few bedding laminae consist of single layers of rounded pebbles less than 1 inch in diameter. The silt forms a veneer or facing on the sides of a small valley, now undergoing dissection by a small stream that enters the Kuskokwim River about 1,000 feet northeast of the mine.

Silt also blankets the upland surface on the southwest side of the Kuskokwim River near Sleetmute village. Here it is about 550 feet above river level and 800 feet above sea level, and about at the upper limits of silt deposition in the region. Similar silt lies on top of terrace-gravel deposits in several rather even-topped low ridges, which trend southwest from the neighborhood of Beaverhouse Hill on the lower Holitna River. The top of the terrace gravel is about 50 feet above river level and is succeeded by about 100 feet of silt; the top of the silt on the ridges is about 400 feet above sea level. The silt deposits probably extend up the Holitna River nearly to its headwaters. They were seen on the upland surfaces of the hills west of the mouth of the Chuilnuk River at an altitude of about 600 feet. They have also been described by prospectors as occurring at an altitude of about 800 feet in the area southwest of the Holitna River adjacent to the Kuskokwim Mountains, where they overlie gravel deposits and are in turn overlain by flood-plain deposits. Little silt occurs northwest of the fault that marks the boundary between the basin of the Holitna River and the Kuskokwim Mountains, and if at one time silt did extend into the area northwest of the fault, it has since been eroded away by streams that were rejuvenated with uplift of the mountains.

The basin of Chikululnuk Creek, a headwater tributary of the Chukowan River, also contains silt deposits. These occur in a rather broad belt that extends from the mouth of Chikululnuk Creek northeast into the valley of Oksotalik Creek, another tributary of the Chukowan. Their upper limit of distribution is also at about 800 feet above sea level. This area is isolated from the larger silt-covered areas in the Holitna River basin by an upland terrain through which the Chukowan River and Oksotalik Creek pass eastwerd toward the Holitna. The fault at the northwestern border of the Holitna River basin may be traced southwestward into this area on aerial photographs. The pictures show the fault passing through the silt deposits and on into the upland area south of the Gemuk River.

Rather thick accumulations of silt, less massive than in areas southeast of the Kuskokwim Mountains, are interbedded in the upper parts of gravel deposits that occur in terraces and on benches in the gorge cut by Kuskokwim River through the Kuskokwim Mountains.

ORIGIN

Most of the silt was probably deposited by the wind. A thorough explanation of the origin of the silt must await further study, which should be applied specifically to its areal distribution, sedimentary structures, and possibly its petrography, as well as to geomorphic and stratigraphic relations. Similar deposits are reported in regions to the north and northeast of the central Kuskokwim region, in central Alaska, and it has been suggested that they are both wind and water laid (Mertie, 1936, p. 138, 1937b, p. 188–189; Eardley, 1937, p. 327–329, 332–336).

There are two features of the silt deposits that have hitherto seemed to favor the conclusion that they were deposited from a body of water rather than by the wind. Thin beds of rounded pebbles included in the silts were undoubtedly deposited by water; and, further, rather uniform upper limits of silt occurrence at an altitude of about 800 feet in the Holitna and upper Kuskokwim River basins suggest the existence in the past of an extensive lake in these areas. The level upper limit of distribution may be explained, however, as the upper limit of wind deposition as opposed to wind transport. It is possible that, at the time of formation of the silt deposits, the upper limit of vegetation adequate to trap windblown silt and protect it from dissection by streams (Eardley, 1937, p. 335) was at a uniform altitude. This seems the more possible in that the altitude of timberline today ranges from 800 to 1,000 feet above sea level. Interbeds of water-rounded pebbles are compatible with wind deposition, because surfaces upon which wind deposits form are also exposed to rain and snowfall and the stream action of resultant runoff. Moreover, ponding of the water to form a lake is difficult to explain (see p. 98–99).

The fact that on most slopes the silt forms a veneer rather than terraces, such as would be produced by deltaic and beach deposition, further suggests wind deposit. The silt deposits have much the appearance of loess deposits, such as those of the Mississippi Valley, whose eolian origin is generally accepted. The nearby outwash plains of the extensive glaciers that descended from the slopes of the Alaska Range, and spread out on the lowlands to the west (Smith, 1917, p. 86, fig. 4), are the most likely source of windblown silt deposited in the upper Kuskokwim and Holitna River valleys. The outwash deposits are distributed widely in the valleys of the Hoholitna and Stony Rivers, a little east of the central Kuskokwim region. Water-deposited silt of the benches and terraces in the Kuskokwim River gorge is quite likely composed of sediments eroded from the windblown deposits in the Holitna and upper Kuskokwim River valleys.

STRATIGRAPHIC AND GEOMORPHIC RELATIONS

The silt deposits lie upon the gravel deposits over wide areas in the valleys, and upon the residual deposits of upland slopes. They are also contained in the Boss valleys, and small valleys are in turn cut in them. The relationship of the silt deposits to nearby glacial deposits, as in the Chuilnuk, Kiokluk, and Taylor Mountains, is uncertain; their upper limit of distribution, at an altitude of about 800 feet, is below the lower limit of recognizable glacial deposits.

AGE

The silt deposits are believed to be of Wisconsin age. The glacial outwash deposits, from which the silt was very likely derived, probably mark the farthest northwest advance of the glaciers of the Alaska Range, in the Wisconsin stage of the Pleistocene (Capps, 1931, p. 6–8). Vegetation encroached over most of the outwash deposits during subsequent retreat of the ice and prevented further removal and deposition of silt by the wind in Recent time.

FLOOD-PLAIN DEPOSITS

DISTRIBUTION AND CHARACTER

Various quantities of silt, sand, and gravel, with intermixed wood, peat, and other vegetal material, and, locally, placer concentrates, make up the flood-plain deposits of existing streams. Fresh gravel and sand, and some silt, form crescent-shaped bars on the concave sides of the bends of the streams. Silt and a little sand laid down on the surfaces of flood plains during intermittent stages of high water, especially in the spring, are the principal constituents of the deposits. Numerous ponds and lakes occur on the flood plains, chiefly in abandoned stream channels. The flood-plain deposits thus comprise widespread blankets of silt, with interlayered gravel and sand bars, laid down and redissected as the meanders of the streams sweep down the valleys. Channels of seasonally torrential streams are braided, such as those of the Aniak and Gemuk Rivers, which in the spring carry water of melting snows from extensive mountainous areas. The braided channels commonly intersect old glacial outwash deposits and they probably resemble, on a smaller scale, the braided streams that flowed on the outwash plains when the glaciers in these mountains melted. The flood-plain deposits are probably not more than 50 and are commonly less than 25 feet thick, except possibly along the Kuskokwim River west of the Kuskokwim Mountains.

STRATIGRAPHIC AND GEOMORPHIC RELATIONS

The flood-plain deposits are formed chiefly in the Boss valleys. In some areas where the Boss valleys are absent, the flood plain deposits lie stratigraphically above the gravel deposits and the two together probably form single unbroken sequences. This is inferred to be the case where the Boss valleys are less in evidence, as in the eastern part of the George River basin or southeast of the headwaters of the Iditarod River. It should also be pointed out that the flood plains of some of the sluggish smaller streams are completely buried by residual deposits contributed by the neighboring slopes, and where slope movement is extreme the watercourses may be choked and covered by the debris.

AGE

The flood-plain deposits now being laid down by the streams that flow over them are obviously of the Recent epoch. This can probably be said of most such deposits inlaid in Pleistocene glacial and silt deposits, though the stream that formed them may have disappeared. Those deposits on the other hand, that succeed the gravel deposits without a perceptible break are practically one with the gravel deposits, and possibly range in age from Pliocene to Recent. Some flood-plain deposits in the Boss valleys probably date back to early Pleistocene.

IGNEOUS ROCKS

Igneous rocks crop out in relatively small isolated areas rather evenly distributed throughout the central Kuskokwim region, particularly in the Kuskokwim Mountains. They seem less abundant southeast of the Kuskokwim Mountains in the basin of the Holitna River, but this is possibly because they are covered there by extensive surficial deposits.

Both intrusive and extrusive rocks are represented. Largest of the intrusive bodies are the stocks made up predominately of quartz monzonite and granite. They transect the structure of the bedded rocks. The sheets, large tabular bodies, some of which are nearly elliptical in ground plan, consist of albite rhyolite. They commonly trend parallel to the strike of the bedded rocks but may dip at an angle to the beds. The smallest intrusive bodies are sills and dikes, chiefly of basalt, diabase, and rhyolite. The distribution of intrusive igneous bodies large enough to be depicted at a scale of 4 miles to the inch is shown on the geologic map (pl. 1).

The extrusive rocks include lava flows of basalt, andesite, and rhyolite, and andesitic and rhyolitic tuffs. They are part of the sequence of bedded rocks and are discussed in that connection.

The succession of igneous rocks is tabulated below to show geologic age, the name of the unit, its character, and its structural relationships to other igneous rocks and to the bedded rocks.

The intrusive rocks were emplaced both during and after folding in earliest Tertiary time; they may be referred to as syntectonic and posttectonic. The biotite-basalt sills and dikes and the albite-rhyolite sheets, dikes, and sills are syntectonic and thus of earliest Tertiary age. The basalt dikes, quartz-monzonite stocks, and quartz-diabase dikes are posttectonic and were intruded later in the Tertiary. The quartz monzonite and quartz diabase intrude the Holokuk basalt of middle Tertiary age, and are intersected by an old-age surface that evolved in middle or late Tertiary. The extrusive rocks, except for marine basaltic and andesitic volcanic interbeds in the Gemuk group, are chiefly terrestrial basalt flows extruded in the Upper Cretaceous before folding, and in the Tertiary after folding.

Summary of igneous rock units in the central Kuskokwim region, Alaska

Geologic age	Unit	Character	Structural relationships
Pleistocene.	Silt deposits.	Volcanic ash, light-colored in unconsolidated beds.	Thin interbeds in silt.
Late Miocene or Pliocene.	Waterboot basalt.	Olivine basalt flows.	Lies on surface inferred to intersect Holokuk basalt.
Oligocene or Miocene.	Quartz diabase; and related Quartz monzonite.	Basalt, quartz diabase, norite, gabbro, andesite, granodiorite, quartz monzonite, granite, granite pegmatite, aplite and other rocks, in differentiated plutonic and hypabyssal suites.	Chiefly stocks and dikes that intrude both Holckuk basalt and folded bedded rocks beneath Holokuk basalt.
Late Eocene, Oligocene, or Early Miocene, or all three.	Holokuk basalt.	Basalt flows and interbedded basaltic detritus.	Lies unconformably on folded Kuskokwim group.
	Basalt.	Basalt, in hypabyssal bodies, some of which are columnar, and many of which are fresh and unaltered.	Mostly dikes that intrude folded rocks.
Eocene or possibly Oligocene or Early Miocene.	Getmuna rhyolite group.	Rhyolite lava and tuff.	Probably unconformable on folded Kuskokwim group.
	Albite rhyolite.	Albite rhyolite, in hypabyssal bodies; large bodies are porphyritic, small bodies nonporphyritic.	Sheets and dikes parallel strike of beds of folded rocks but commonly dip across bedding.
Early Eocene or possibly Paleocene.	Biotite basalt.	Small hypabyssal bodies that are commonly altered.	Commonly parallels bedding of folded Kuskokwim group but shows little evidence of folding; forms sills and dikes.
Late Cretaceous.	Iditarod basalt.	Basalt flows.	Lies disconformably on Kuskokwim group and partakes of its folding.
Early Cretaceous.	Gemuk group (upper).	Andesite flows and tuffs.	Forms interbeds in siltstone and chert.
Permian?.	Gemuk group? (lower?).	Greenstone (basalt) flows.	Undetermined; probably forms thick interbeds with siltstone, chert, and minor limestone.

BIOTITE BASALT

AREAL DISTRIBUTION

Biotite basalt sills and dikes, commonly less than five feet thick, are exposed to good advantage in mines, stream bluffs, and cut-banks in the Kuskokwim Mountains. In most places they are covered by surficial deposits, and if in evidence at all they are marked only by streaks of brown to yellow-brown weathered fragments thrown up by the frost. The sills and dikes of this rock discovered in the course of the geologic reconnaissance probably represent only a small percentage of those that actually exist; they are too small to show on plate 1.

Biotite basalt seems to be peculiar to the central Kuskokwim region, as no comparable rocks are reported in other parts of Alaska. Lack of exposures may have prevented discovery elsewhere, although this seems unlikely in view of the widespread activity of prospectors and geologists.

INTRUSIVE RELATIONS

The contacts of the biotite basalt are commonly parallel or subparallel to the strata of the bedded rocks, thus sills and dikes that resemble sills apparently predominate; steplike "offsets" of the dike bodies are common. Such features have been attributed by prospectors to cross faulting, but close examination shows that in most the plane of the "offset," at places where separation is not complete, is not a plane of discontinuity within the intrusive body; thus the "offsets" are not faults formed after intrusion. Neither do the majority of these "offsets" appear to mark fault planes formed before intrusion, as the adjoining strata are undisturbed except for cross jointing. Those joints that lie in the projected plane of the "offsets" formed before intrusion, and they bound the ends of the sill-like bodies much as bedding joints bound their tabular surfaces. At some places the contacts are very irregular, which seems to preclude joint control of the emplacement of the intrusive rocks. The irregular contacts were examined under the microscope and were nevertheless found to follow minute systems of joints that were invisible in the hand specimen. Some of the cross joints pass from the strata through the intrusive, hence they were formed after intrusion. These relations seem to indicate that the biotite basalt was intruded after most of the movement that affected the bedded rocks.

The features outlined above are of considerable significance in the localization of quicksilver ore and will be described in more detail in that connection.

PETROGRAPHIC CHARACTER

The biotite basalt is in general dense and nonporphyritic; it is commonly more altered than the other types of basalt found in the central Kuskokwim region. In some places biotite is absent, but other characteristic features assist in identification.

MEGASCOPIC FEATURES

Fresh biotite basalt is nearly all dark gray to black. It is locally vesicular or amygdaloidal, and the amygdules commonly contain light-colored minerals that give the rock a mottled appearance. Dark specks of subhedral to euhedral pyroxene and, more rarely, sheaves of biotite may be visible in hand specimens. Weathering is pronounced, and the biotite basalt is commonly coated with a yellow-brown iron-stained layer of decomposed rock.

MICROSCOPIC FEATURES

Biotite is distinguishable under the microscope as fine plates in the groundmass, whose sections are 0.1 or 0.2 millimeter long (fig. 19); locally it also forms

FIGURE 19.—Photomicrograph of biotite basalt, from locality 5½ miles northwest of Sleetmute, north of Kuskokwim River. Relict pyroxene phenocryst in center of picture is completely altered to carbonate (*c*) and antigorite (*a*); groundmass includes plagioclase feldspar (*f*), biotite (*b*), and quartz (*q*). Plain light.

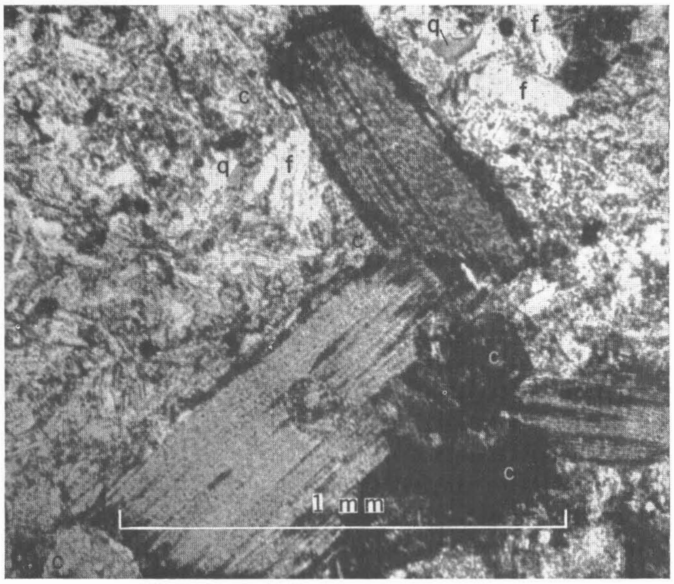


FIGURE 20.—Photomicrograph of biotite phenocrysts in biotite basalt, at Parks, northwest of Sleetmute. Groundmass includes plagioclase feldspar (*f*) and quartz (*q*), which make up most of the light-colored areas, as well as titanite, chlorite, and leucoxene, which are indistinguishable in this picture; carbonate (*c*) occurs adjacent to the biotite crystals. Plain light.

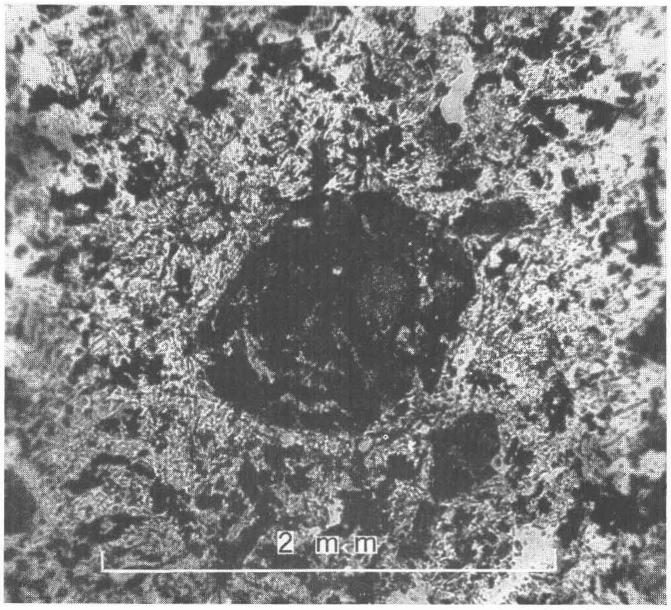


FIGURE 21.—Photomicragraph of altered pyroxene phenocryst in silica-carbonate rock, at the Willis prospects 10 miles northwest of Sleetmute. Pyroxene is completely altered, chiefly to carbonate, which appears as dark areas in the picture; plagioclase and its principal alteration products, chalcedony and quartz, appear as light areas. Plain light.

phenocrysts (fig. 20). Though they average less than 1 millimeter, the phenocrysts of biotite are as much as 3 millimeters in diameter in a few places where they are abundant. Pyroxene, chiefly augite, also forms microscopic phenocrysts that are commonly more abundant than those of biotite, and as much as 1 millimeter in diameter (fig. 21). The few feldspar phenocrysts that occur in the biotite basalt facilitate identification where biotite is absent. The texture of the groundmass is subophitic. Anhedral augite is distributed through the groundmass, chiefly in the interstices between abundant small and randomly oriented, euhedral plagioclase laths, almost exclusively labradorite, that average about 0.1 millimeter in length. The labradorite grains are so narrow that they may form only a simple twin pair if they are twinned at all. Less common minerals of the groundmass are magnetite, ilmenite, and titanite.

Biotite basalt is the most widely and complexly altered rock in the central Kuskokwim region. Alteration seems at some places to have included two general phases, an early phase, in which the original fresh appearance and primary texture of the rock was not changed, and a more recent phase, not necessarily preceded by the early one, in which the rock was bleached and the original texture was more or less obliterated. The most important alteration characteristic of the early phase was albitization, specifically replacement of labradorite by nearly pure albite. Although the mutual relations of albitized and unaltered rock were not determined, it is believed that the albite has replaced former labradorite; it was not formed directly by crystallization from a magma, since the albite is very nearly pure and contains little of the anorthite molecule. Such feldspar could probably not have formed by crystallization from a magma (Schaller, 1925, p. 279). At other places in the world where feldspars as sodic have been found (Credner, 1875, p. 179; Gilluly, 1933, p. 71–76), their occurrence is suggestive of replacement origin.

Replacement of the ferromagnesian minerals by chlorite or, more rarely, antigorite is the most universal and probably the earliest alteration that occurred in the later phase. Commonly the plagioclase as well as the pyroxene is altered to fine-grained mica. Locally, where hydrothermal alteration is more intense, the rock is successively and more or less completely carbonatized, silicified, and sericitized and is pearl gray, in contrast to the darker shades of the unaltered formation. The carbonate minerals include ankerite, calcite, and siderite, and the silica minerals chalcedony and quartz (fig. 21). The fine-grained mica, either sericite or paragonite, was not determined. Relicts and pseudomorphs of pyroxene phenocrysts form dark gray-green specks that contrast sharply against the bleached background of the groundmass.

Five specimens (thin sections) from the upper Oskawalik River illustrate a somewhat typical succession of alteration after completion of albitization. The estimated modes of these specimens are tabulated.

Specimen 1 is a dark gray-green nonporphyritic amygdaloidal rock in which the ferromagnesian minerals have altered completely to chlorite. The quartz is interstitial and the quartz of the amygdules is deposited on chlorite. In specimen 2 antigorite instead of chlorite replaces the primary ferromagnesian minerals; the rock is a little lighter colored than specimen 1, possibly because of the slightly greater amount of

Modes of altered basalts from upper Oskawalik River

	1	2	3	4	5
Albite	45	50	55	5	------
Antigorite	------	40	------	45	------
Chlorite	40	------	10	------	15
Quartz	Tr.	------	5	15	50
Carbonate	5+	10−	15+	35	30
Titanite	5	------	------	------	------
Fine-grained mica	------	------	15	------	------
Apatite	5	------	------	------	5

1. (44ACa61) ½ mile east of Henderson Mountain.
2. (44ACa78) 2 miles northeast of Henderson Mountain.
3. (44ACa81) 3 miles north-northeast of Henderson Mountain.
4. (44ACa87) 1½ miles southeast of the fork of the Oskawalik River.
5. (44ACa80) 2 miles northeast of Henderson Mountain.

carbonate. Specimen 3 is a mottled gray porphyritic rock, considerably more bleached than specimens 1 and 2, probably owing to the presence of fine-grained mica and a larger amount of carbonate. Specimen 4 contains greatly increased carbonate and more abundant quartz. It would seem that carbonate increases at the expense of albite. In specimen 5 the plagioclase is completely altered and some carbonate replaces chlorite; much of the carbonate is siderite. Small veins of chlorite cut across fractured albite laths in some of the altered rocks. Quartz is much increased. These specimens therefore suggest a possible succession of dominant minerals—chlorite and antigorite, sericite, carbonate, and quartz—as bleaching of the rock, owing to alteration, progressed.

The highly altered silica-carbonate rock, which weathers yellow-brown and forms the "yellow rock" of the quicksilver prospectors, is the principal country-rock formation associated with the quicksilver ore bodies.

LOCAL DETAILS

The biotite basalt sills and dikes were studied in considerable detail in several areas of the region.

DECOURCY MOUNTAIN AREA

Mafic intrusive rocks that are almost exclusively basalt are exposed at, and in the vicinity of, the quicksilver mine on upper Return Creek. The basalt in the mine forms irregular dikelike bodies whose strikes range from north to northeast, parallel to the strike of the enclosing bedded rocks. The latter dip to the northwest and the dikes at many places dip steeply southeast. The dikes are so completely altered that primary minerals are unrecognizable except as relicts. These rocks are more heavily silicified than altered biotite basalt from the other areas. A large body of little altered, nonporphyritic hypersthene basalt lies in close proximity to the altered basalt. Possibly it was intruded after alteration of the dikes. It may be one of the feeder dikes associated with basaltic volcanic rocks in the vicinity.

EAGLE CREEK AREA

Weathered fragments of medium fine grained norite were found near outcrops of biotite basalt on a small peak north of Juninggulra Mountain, near the head of Eagle Creek. The basalt appears to be enclosed in the sedimentary rocks, and its proximity to the norite suggests that they form parts of a connected intrusive body. Possibly the intrusive rocks near the head of Eagle Creek are related to hypersthene basalt, fragments of which occur locally in the surficial deposits near the border of the albite rhyolite sheet of Juninggulra Mountain.

SLEETMUTE AREA

The mafic rocks of the Sleetmute area are nearly all biotite basalt or its altered facies (pl. 3). P. S. Smith (1917, p. 120–121) has described them briefly. The structural relations of the biotite basalt sills and dikes are better shown in the mines near Sleetmute than at any other place in the central Kuskokwim region.

Underground development in several levels at the Red Devil mine has made possible a better understanding of the vertical and horizontal distribution of the biotite basalt. Echelon systems of sills and sill-like bodies, individual members of which are connected locally by dikes, extend downward at least to the present base of the workings. The bodies occur along faint southeastward-plunging flexures in the strata, which form the southwest limb of the Sleetmute anticline. They increase in size down the plunge of the flexures and probably continue down the flexures to depths much below the present workings, from which it is inferred that the flexures provided openings, actual or potential, that aided intrusion. At the Alice and Bessie mine is an extensive sill, located in the northeast limb of the Sleetmute anticline. A long and well-defined dike strikes across the strata on the northeast limb of the anticline at the Willis prospects; it is one of the few such cross-cutting dikes of biotite basalt known in the region.

It is commonly difficult to prove the original mineral composition of altered biotite basalt exposed at the quicksilver mines, because carbonatization, silicification, and sericitization have progressed so far in these rocks that primary minerals, with the possible exception of biotite, are almost completely obliterated. Enough of the subophitic texture remains, however, to indicate that the rock was originally a basalt, and nearby sills and dikes are sufficiently unaltered to show the plagioclase laths. Such a basalt crops out in the bluff northeast of the Kuskokwim River, about 1½ miles east of the Red Devil mine. A coarse amygdaloidal biotitic basaltic rock, which locally has the appearance of a lamprophyre, crops out along the river bank about half a mile downstream from the Alice and Bessie mine, near Parks. It is in places a diabase like the specimen described by P. S. Smith (1917, p. 121), but two other specimens collected since then from the same locality have proved to be finer grained and typical biotite basalt. An amygdaloidal biotite basalt dike crops out in the river bluff about one mile southwest of the Willis prospects. The calcic plagioclase of some of these rocks has possibly been altered to more sodic plagioclase, chiefly albite, but the feldspar grains are so small and altered that identification is difficult.

A highly altered biotite basalt sill that crops out in the cut-banks southwest of and nearly opposite Sleetmute village is underlain by a sill of albite rhyolite. This relation suggests that the alteration of the basalt may have been caused by hydrothermal solutions from the rhyolite.

Fragments of graphite occur in altered basalt at the Two Genevieves claims southwest of Cribby Creek. This is the one known occurrence of graphite in the biotite basalt and is probably of only local significance.

UPPER OSKAWALIK RIVER AREA

Altered basaltic sills and dikes, comparable to those in the Sleetmute area, except that they definitely contain albite, crop out in the banks of the Oskawalik River north and east of Henderson Mountain. The modes of specimens of these rocks were presented in the general discussion of the petrographic character of biotite basalt, to show varying degrees of more advanced alteration and obliteration of the feldspar.

HOLOKUK RIVER AREA

Numerous highly altered sill-like basaltic dikes were found in areas that border the middle course of the Holokuk River. A heavily albitized amygdaloidal basalt dike crops out in the western cut-bank of the Holokuk River below the mouth of Camp Creek. Similar dikes, highly altered but not all albitized, are exposed in the hills and mountains back from the river. Many of them, like the dikes at the river, are bleached a light greenish gray and, like the sedimentary rocks associated with the numerous albite rhyolite sheets found in the vicinity, they are altered and indurated. This suggests that the alteration of the basalt as well as of the sedimentary rocks was accomplished by hydrothermal solutions that arose from the albite rhyolite. Biotite was not found in the rocks examined and may have been completely altered.

Several small dikes exposed in the cut-banks near the mouth of Egozuk Creek are albitized as well as chloritized and carbonatized. The latter dikes are considerably bleached, one to the typical pearl-gray color of the altered biotite basalt associated with quicksilver ore.

OTHER AREAS

Biotite basalt sills and dikes occur in many areas not already mentioned. The quicksilver deposits in the Cinnabar Creek area are associated with altered biotite basalt like that at the quicksilver mines near Sleetmute. Altered rocks associated with the quicksilver occurrence near Kolmakof are probably related.

AGE

The biotite basalt is probably of earliest Tertiary age. It intrudes the sequence of folded rocks, the topmost of which are the Iditarod basalt flows of middle or late Late Cretaceous age. The biotite basalt has not been found to intrude various unconformable and comparatively flat-lying volcanic rocks that truncate the folds. The intrusive relations of the biotite basalt suggest that it was emplaced near the close of the episode of folding in earliest Tertiary time.

The biotite basalt and albite rhyolite are of similar age, but the basalt is thought to be somewhat younger. Basalt, exposed in the belt of albite rhyolite sheets that crosses the lower course of the Holokuk River, and the nearby bedded rocks are altered and indurated. The changes in both were possibly caused by emanations from the cooling albite rhyolite sheets; if so, the basalt was already in place when the rhyolite was intruded. More direct and positive evidence as to the relative ages of the two rocks is not available.

ALBITE RHYOLITE

AREAL DISTRIBUTION

Sheets, sills, and dikes of albite rhyolite form a pattern traceable intermittently from Little Eldorado Creek, on the north, southwest through the Donlin Creek area to Juninggulra Mountain, thence southeast through the California Creek area to Sleetmute, and from Sleetmute southwest into the area between the lower courses of the Holokuk and Aniak Rivers. They are most extensive in the belt between Sleetmute and the Aniak River, where large sheets, 6 to 8 miles in surface length and ½ to ¾ mile in average width, are common. The sheets in the northeastern half of the latter belt are distributed in echelon, but a few of them, such as those of Barometer Mountain and Holokuk Mountain, are elliptical in plan. Outlying sheets, comparable to those of the pattern just described, occur southeast of the Horn Mountains near the Kuskokwim River, at the head of Taylor Creek south and southeast of the Taylor Mountains, and at the head of Julian Creek on the upper George River. Most of the bodies of albite rhyolite form straight, treeless ridges recognizable from afar. Some of the higher, bare-rocked ridges appear black, because the rock, light colored itself, favors the growth of a black lichen.

Intrusive bodies of rhyolite are widely distributed through the Kuskokwim Mountain belt to the northeast of the central Kuskokwim region, though they are apparently not as large nor as abundant there (Mertie and Harrington, 1924, p. 71–74).

INTRUSIVE RELATIONS

Few contacts of the large sheets can be seen, and only exceptionally can the dip of the sheets be inferred from their topographic expression. The large sheets in the Sleetmute - Aniak River belt strike northeast, parallel to a thick homocline of bedded rocks that dips steeply northwest. Their dips are possibly steeper than that of the homocline. Some of the larger albite rhyolite bodies, which are elliptical or partly elliptical in plan, such as those of Juninggulra Mountain, Barometer Mountain, and Holokuk Mountain, are probably of this type.

The areal occurrence pattern of the sheets, sills, and dikes is like that of the major folds of the bedded rocks. Barometer Mountain, near Sleetmute, is in the vicinity of a major synclinal axis that plunges southwestward. The homocline of the Sleetmute - Aniak River belt forms the south limb of the syncline. The north limb is also paralleled by rhyolite sheets and sills that may be traced intermittently northwestward to Juninggulra Mountain. Though the strike of the sheets on California Creek is parallel to the strike of bedding in the north limb of the syncline, the dip of the sheets is across the bedding, as inferred for some of the elliptical albite rhyolite bodies. At Juninggulra Mountain, where the pattern of the rhyolite bodies veers from a northwesterly to a northeasterly trend, the strikes of bedding and minor fold axes do likewise.

Small sills and a few dikes are well exposed in cutbanks, particularly along the Kuskokwim River near Sleetmute and Georgetown, and in the gorge of the Holokuk River. Those near Sleetmute and Georgetown are predominantly sills, but the rhyolite bodies seen in the Holokuk River gorge, particularly in the vicinity of Holokuk Mountain, include a large number of dikes.

The internal structures of the rhyolite sheets and sills are almost impossible to determine, except in cut-bank exposures where the bedrock is free of frost-weathered mantle. The sills and dikes mentioned in the preceding paragraph are irregularly jointed and faulted.

The general concordance of the rhyolite sheets with the strike of the bedded rocks and with the major fold patterns indicates that they were probably emplaced before or during the time of folding. Sheets that strike parallel to the bedding, but dip across it, suggest intrusion in tension fractures at the time of folding.

PETROGRAPHIC CHARACTER

The larger sheets are of porphyritic albite rhyolite. At places, particularly in the smaller bodies, the rock is apparently a very felsic differentiate of the porphyritic type.

MEGASCOPIC FEATURES

These rocks, with few exceptions, are light colored. The fresh nonporphyritic rhyolite is light gray to whitish, and the porphyritic rhyolite is mottled in proportion with the number of phenocrysts. The weathered surfaces are buff colored. Short euhedral to subhedral feldspar phenocrysts, commonly flesh colored, predominate. Quartz phenocrysts are in general smaller, less well formed, and less abundant than the feldspar phenocrysts. Mica, also less abundant than feldspar, occurs in tabular phenocrysts that are rather prominent, particularly if of the dark variety, biotite. Muscovite is common but not as apparent. Rarely do both varieties of mica occur together in abundance. In much of the rhyolite the only phenocrysts recognizable are of feldspar; but the feldspar is commonly altered to a fine micaceous powder composed of sericite and kaolinite, which may be removed from the phenocrysts with the point of a knife blade.

MICROSCOPIC FEATURES

The phenocrysts are about 2 millimeters in diameter, though some are more than 3 millimeters (about ⅛ inch). The larger ones are of feldspar; quartz and biotite phenocrysts are commonly less than 1 millimeter in diameter. Quartz and, less commonly, feldspar phenocrysts are corroded and deeply embayed by the groundmass, many to such an extent that their originally euhedral outline is completely obliterated. Plagioclase feldspar commonly shows normal zoning, indicating continuous reaction with the melt during crystallization of the more alkalic groundmass.

Plagioclase, particularly of the sodic varieties, is much more common than orthoclase in the phenocrysts. Albite is a common phenocryst-forming plagioclase. Where phenocrysts are abundant, zoned oligoclase and minor amounts of andesine are characteristic. Some phenocrysts are zoned from andesine in the center to albite in the outermost zone. Sanidine, a variety of orthoclase formed at relatively high temperatures, forms euhedral phenocrysts in some of these rocks.

The groundmass is microgranitoid; the grains are about a tenth of a millimeter in diameter. Anhedral quartz and albite are the most abundant minerals of the groundmass. Oligoclase occurs in subhedral to euhedral grains, somewhat larger than the other minerals of the groundmass generation; some thin sections show gradation in size from groundmass to phenocryst proportions. Andesine rarely occurs in the groundmass. The groundmass feldspars, particularly orthoclase and albite, are in general not readily distinguishable in thin section. If the grains are big enough the twinning bands and euhedral to subhedral outlines of the plagioclase may be distinguished, but in most thin sections small anhedral grains predominate in the groundmass. The latter were examined in index oils and found to be chiefly albite.

In addition to biotite and muscovite there are several microscopic accessory minerals that include, in decreasing order of their abundance: zircon, apatite, magnetite, titanite, tourmaline, garnet, and ilemenite. The porphyritic rhyolite contains these minerals in greatest abundance.

Fine-grained mica, probably sericite, is the most common secondary mineral of hydrothermal origin, formed chiefly by the alteration of feldspar. No trace of the original feldspar remains in many specimens although relicts of phenocrysts and sericitic patches in the groundmass show its former presence. Carbonate, which is mostly calcite and is present nearly throughout the altered rock, replaces feldspar phenocrysts and areas of the groundmass. Chloritized biotite is a common feature. Pyrite occurs locally as a secondary mineral. Several of the rhyolite bodies contain a much greater amount of quartz than would be expected in a normal igneous rock of primary origin, and it is believed that part of this quartz is secondary. Sutured mosaics of spherulitic and graphically intergrown quartz and feldspar occur in a few places. Some of the rhyolite is replaced by tourmaline, probably by pneumatolytic alteration.

The effects of alteration do not stop at the contacts of the rhyolite bodies; they extend into the adjacent sedimentary rocks (pp. 86–87). Lode gold mineralization is believed to have accompanied this hydrothermal activity.

CHEMICAL CHARACTER

Two specimens of the porphyritic albite rhyolite were analyzed chemically and the analyses were computed into normative mineral molecules (Cross, Iddings, Pirsson, and Washington, 1903; Washington, 1918, p. 1151–1180) to assist in determination of mineral composition and in identification of the rock, and for comparison with analyses and norms of the quartz monzonite

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and related rocks. The analyses and norms are tabulated below:

Chemical composition and parameters of porphyritic albite rhyolite

Analyses[1]			Norms[2]		
	1	2		1	2
SiO_2	72.61	72.96	Quartz	31.25	26.22
Al_2O_3	15.08	14.10	Corundum	2.36	.14
Fe_2O_3	.77	.68	Orthoclase	18.90	22.13
FeO	1.18	.86	Albite	38.20	44.12
MgO	.08	.13	Anorthite	4.95	3.56
CaO	1.31	.78	Hypersthene	1.57	1.14
Na_2O	4.52	5.22	Magnetite	1.11	1.00
K_2O	3.20	3.74	Ilmenite	.35	.27
H_2O+	.20	.08	Apatite	.67	.24
H_2O-	.25	.50			
CO_2	.05	.13	Semitotal	99.36	98.82
TiO_2	.18	.14	Water and CO_2	.50	.71
P_2O_5	.29	.10			
MnO	.08	.02	Total	99.86	99.53
BaO	.17	.19			
SrO	Tr.	--------	Classification:		
			Class, order	I, ″4	I, 4
Total	99.97	99.63	Rang, subrang	(1)2, ″4	1″, ″4
			Name	Lassenose	Kallerudose

[1] J. E. Husted, analyst.
[2] Norms calculated, and symbols and norms determined by W. M. Cady.

1. Porphyritic albite rhyolite, summit of Barometer Mountain, 7 miles N. 77° W. of Sleetmute.
2. Porphyritic albite rhyolite, east slope of Barometer Mountain, 5 miles N. 83° W. of Sleetmute.

The chemical analyses and norms calculated from them have been particularly helpful in indicating the feldspar content of the groundmass of these rocks. The analyses show predominance of soda (Na_2O) over potash (K_2O) sufficient to produce a 2:1 ratio of normative albite over normative orthoclase. The ratio of modal albite to modal orthoclase would be even greater, because the potash of mica is included in the normative orthoclase molecule; moreover the percent of modal albite is reinforced by anorthite to values of An_{10}. The normative albite and anorthite, which are in about the proportions of modal calcic albite and sodic oligoclase, are between two-fifths and one-half of the total norm, which is more than double the 1:5 ratio of plagioclase phenocrysts to groundmass in the modes of the specimens of porphyritic albite rhyolite analyzed. Thus the groundmass would be expected to contain albite also, probably in greater proportions than orthoclase, which constitutes about one-fifth of the total norm and thus less than one-fifth of the mode. This is in agreement with the studies of indices of refraction of the groundmass feldspars already described, wherein albite was found to be more abundant than orthoclase.

The 9:1 albite-anorthite ratio of the norms clearly indicates that the rocks analyzed are of the chemical composition of granites. The greater than 2:1 ratio of albite to orthoclase in both norm and calculated mode places them with the sodic granites. The normative feldspars calculated from the two analyses are plotted on the classification diagram of the quartz monzonite and associated rocks (fig. 23), described on page 75 and shown on page 77. The values of the normative feldspars are subject to modification for direct comparison with modal feldspars used in classification, but this is not critical here inasmuch as the correction merely moves the points plotted deeper into the sodic granite field.

If a line is drawn through the two plotted points, a trend of variation is suggested which parallels that of the quartz monzonite; but it is in a distinctly more sodic field, and thus it is believed that the albite rhyolite is not closely related to the quartz monzonite. The most felsic types are widely distributed in the smaller sills; the nonporphyritic rhyolite is apparently the most felsic and also the least sodic, as it contains less plagioclase. More mafic types than those of the analyzed samples were not found, although they doubtless occur at lower levels in the larger sheets and sills, at which calcic plagioclase phenocrysts are most abundant. They possibly include dacite and granodiorite. Mertie reports similar rocks, namely oligoclase-quartz diorite and oligoclase dacite, in association with soda granite and soda rhyolite in areas to the northeast of the central Kuskokwim region (Mertie and Harrington, 1924, p. 71–74).

The common association of quartz phenocrysts and normally zoned plagioclase phenocrysts that have andesine at their cores, suggests that the first crystal generation started to form from a melt with the composition of granodiorite. The occurrence of biotite almost exclusively as a first-generation mineral, commonly found both as inclusions in plagioclase phenocrysts and in separate phenocrysts, probably has accounted for the low orthoclase content of the groundmass, through early withdrawal of potash from the melt. Occurrence of this early biotite also suggests a relationship to the biotite basalt. Perhaps the albite rhyolite and the biotite basalt are derived from a common parent magma, which very early in its differentiation contained water sufficient for the formation of biotite.

LOCAL DETAILS

There are several areas, in which albite rhyolite crops out, that warrant more detailed consideration.

DONLIN CREEK AREA

Silicified rhyolite is the principal igneous rock in this area. The rhyolite, whose contacts are almost completely covered chiefly by thick residual deposits, is exposed in 6 elliptical areas southeast of Donlin Creek. The rock is characterized by an abundance of quartz, as much as 75 percent in some specimens and more than normal for an unaltered rhyolite. Aggregates of fine-grained mica, probably sericite, replace feldspar; biotite is altered to fine-grained mica and muscovite. Albite and oligoclase are the most abundant feldspars. Graphite formed from included shale fragments occurs in the rhyolite. The gold placer deposits on Donlin Creek lie a little to the north, which suggests a common hydrothermal origin of alteration products of the rhyolite and of gold lodes.

JUNINGGULRA MOUNTAIN AND VICINITY

Several large bodies of porphyritic rhyolite are grouped in the vicinity of Juninggulra Mountain. Float fragments of hypersthene basalt and dacite were found near the borders of the rhyolite, on the north slope of the mountain that lies next west of Juninggulra Mountain. They may derive from border facies of the rhyolite or they may come from other, more mafic extrusive and intrusive rocks that occur in the vicinity. It is believed that the knobs that rise above the general level of the ridge of Juninggulra Mountain are a subdued reflection of the original shape of the roof of the rhyolite body, for graywacke and shale float occurs in many of the saddles between the knobs.

RIDGE BETWEEN BELL CREEK AND CREVICE CREEK

A thin sheet of porphyritic rhyolite extends for about four miles through the western summits, and eastward down the southeastern slopes of the ridge between Bell and Crevice Creeks. Adjacent bedded rocks dip south and form the southern limb of an anticline centered roughly along the ridge. The trace of the sheet seems to swing southeastward on the southeastern slopes, which suggests that it dips south with the strata and is possibly a sill. The specimen collected from this sheet is rather thoroughly silicified, hence feldspars are not identifiable. A sill-like body of basaltic rock was found north of the east end of the rhyolite body, apparently north of the anticlinal axis above mentioned. Its relation to the rhyolite is undetermined.

CALIFORNIA CREEK AND VICINITY

An extensive sheet of porphyritic rhyolite crops out in the cut-bank north of the Kuskokwim River between California Creek and the mouth of the George River. It probably strikes east-northeast, across the headwaters of California Creek and into the basin of the South Fork of the George River, and it is paralleled by at least two other sheets of similar composition that cross the divide farther to the southeast.

Structural relations are best shown in the cut-bank previously mentioned. Here the strata, though repeated in minor folds, in general dip steeply to the south-southeast. The strata strike parallel to the sheet northeast of the cut-bank. Contacts of the sheet in the cut-bank are irregular, probably to some extent owing to deformation after intrusion; but they doubtless also reflect the original irregularities of the body. The sheet appears to dip more steeply than the bedded rocks, and its downward direction seems to be controlled by the orientation of joints and zones of weakness that cut across the beds. The topographic expression of this, and of a similar sheet in the headwater tributaries of California Creek, suggests that it dips steeply to the north-northwest across the bedding.

The rhyolite bodies on California Creek are comparable in many respects to those in the Donlin Creek area. A little placer gold has been found on California Creek where, as on Donlin Creek, it suggests a common hydrothermal origin of gold and alteration effects.

Basaltic and dioritic intrusive bodies occur in close proximity to the rhyolite sheets near the head of California Creek, but their structural and petrologic relations to the rhyolite could not be determined.

BAROMETER MOUNTAIN - SLEETMUTE AREA

A great variety of rhyolitic intrusive rocks is found in this area (pls. 1, 3). Extremely thick bodies of porphyritic rhyolite predominate. Barometer Mountain is formed on the largest body. Smaller sheets and sills are exposed in the cut-banks and hills south and west of Sleetmute, as described by J. E. Spurr (1900, p. 160) and P. S. Smith (1917, p. 119–120) in the course of earlier surveys.

Small rhyolite intrusives bodies, which crop out in the cut-banks along the Kuskokwim River near Sleetmute, strike northwest and dip steeply southwest, parallel to the strata of the bedded rocks. Comparably oriented sills occur in the hills west of Sleetmute and north of Barometer Mountain. Bedded rocks are so poorly exposed in the immediate vicinity and southwest of Barometer Mountain that the intrusive relationships of the Barometer Mountain rocks as well as of rhyolite bodies to the southwest are uncertain. The ridge of Barometer Mountain trends northwest parallel to the strike of the bedded rocks at and west of Sleetmute. The rhyolite sheets southwest of Barometer Mountain trend in about the same direction and some appear from their topographic expression to dip to the south. The bedded rocks, at a single exposure found in the vicinity of the latter sheets, strike northwest and dip steeply northeast. Barometer Mountain is in the vicinity of a major southwestward plunging synclinal axis. Probably the Barometer Mountain intrusive and sheets to the southwest of Barometer Mountain dip steeply across the bedding and strike parallel to it.

The rhyolite of the Barometer Mountain-Sleetmute area seems to be representative of the less altered types, and the general descriptions under the headings of petrographic and chemical character apply very well. Specimens of rhyolite with a dark-gray instead of a light-colored groundmass were found at a few places. One taken from the Vreeland Creek-Fuller Creek divide, south of Barometer Mountain, contains small disseminated particles of graphite, which is responsible for the color of the groundmass. Mineral veins are locally associated with the rhyolite. Tourmaline veins cut the porphyritic rhyolite of Barometer Mountain. Quartz-stibnite-cinnabar veins cut the rhyolite at the Fairview and Ammiline prospects.

Prospectors report very little placer gold in the Barometer Mountain-Sleetmute area; perhaps this is related to the smaller amount of hydrothermal alteration of the rhyolite.

The rhyolite has been found in actual contact with other igneous rocks of the Central Kuskokwim region at one point in the Barometer Mountain-Sleetmute area. A rhyolite sill about 8 feet thick underlies a sill of carbonatized basalt, 5 to 6 feet thick, in the cutbanks south of the Kuskokwim River between the mouth of the Holitna River and Sleetmute. A thin shaly layer not more than 1 inch thick separates the two sills for a distance of about 25 feet, but for a few feet, near the northwest end of the exposure, the two sills are separated only by a joint plane that is continuous with the contact between the shaly layer and the overlying carbonatized basalt. Thicker zones of brecciated shale occur at other places along the contact, and the contact of these zones with the underlying rhyolite is very irregular. Silicified graywacke several inches thick is associated with the shale and shale breccia at one point near the southeast end of the exposure. A thin section of the breccia shows shale fragments enclosed by rhyolite, therefore the breccia formed when the rhyolite sill was emplaced. Carbonate, mostly calcite, is distributed uniformly through the shale zones and adjoining rhyolite. Carbonate veins cut across the contacts between rhyolite and shale. The main body of the rhyolite sill is not as altered as the zones near the contacts. It has already been suggested, in connection with the discussion of the biotite basalt, that the sill of carbonatized basalt that overlies the rhyolite at this exposure may have been altered by hydrothermal solutions from the cooling rhyolite. The brecciated contacts of the rhyolite could have been altered by the same solutions.

UPPER OSKAWALIK RIVER AND VICINITY

Two large sheets of porphyritic rhyolite crop out west of the upper Oskawalik River north of Henderson Mountain (pl. 1). They form two parallel ridges, each at least one-half mile across, that trend a little north of east and appear to extend at least as far west as the west fork of the Oskawalik River. They lie in the belt of sheets that extends southwestward from Sleetmute nto the area between the Holokuk and Aniak rivers. The borders of the two sheets are poorly exposed and their structural relation to the enclosing bedded rocks is uncertain. The strata in the vicinity dip fairly consistently to the north, much as they do farther southwest on the Holokuk River. The sheets may, on the other hand, dip south in agreement with the dip of the sheets exposed south of Barometer Mountain. Several sill-like bodies of porphyritic rhyolite crop out south and east of Henderson Mountain, a little west of the upper Oskawalik River.

The rhyolite on the upper Oskawalik River is in rather close association with other types of intrusive rocks, particularly in the vicinity of the Henderson Mountain stock. The smaller rhyolite bodies found near Henderson Mountain may be offshoots of deeper portions of that igneous body, rather than associates of the sheets farther north. Mafic sills and dikes are at least as abundant as the felsic intrusives in the immediate neighborhood of Henderson Mountain. Together, these divergent rock types may form a complementary suite consanguineous with the stock.

AGHALUK MOUNTAIN AREA

The Aghaluk Mountain sheet is centrally located in the extensive belt of porphyritic albite rhyolite sheets that trends southwest from Barometer Mountain across the Holokuk River. Several smaller, sill-like sheets crop out north of Aghaluk Mountain. A sheet that appears to be the largest in the belt lies southeast of the mountain, and extends northeastward from Veahna Creek nearly to the west fork of the Oskawalik River. The bedded rocks north of Aghaluk Mountain dip northwest. The strata at one outcrop southeast of the mountain dip southeast. Viewed from a distance the rhyolite that forms the summit of Aghaluk Mountain seems to dip northwest, but poor exposure made it impossible to measure the amount or direction of dip in outcrops. If the structure is comparable to that of sheets in the Barometer Mountain and Holokuk River areas the dip is steeper than that of the bedded rocks.

The rhyolite sheet of Aghaluk Mountain partly surrounds a body of fairly coarse-grained andesite southeast of the summit ridge. The andesite is comparable to some of the mafic and intermediate dike rocks discussed later, although it perhaps approaches a mafic type from which the rhyolite of Aghaluk Mountain differentiated.

HOLOKUK RIVER AND VICINITY

Rhyolite sheets, sills, and dikes crop out abundantly in the vicinity of Holokuk Mountain and the gorge of the Holokuk River downstream from the mouth of Chineekluk Creek. The largest of these bodies forms Holokuk Mountain. The smaller sheets, exposed in the gorge, extend southwestward for many miles toward the Buckstock and Aniak Rivers. Most of the sheets are nearly vertical and cut bedded rocks that dip northwest.

The fresh surfaces of many of the specimens collected from this area have a peculiar pitted or porous to granular appearance that makes them seem weathered. A large portion of the groundmass of porphyritic rhyolite consists of a somewhat sutured aggregate of spherules of quartz and feldspar, which are responsible for the granular appearance. Tourmaline occurs in and associated with these rocks. Specimens of porphyritic rhyolite from Holokuk Mountain show bleached biotite phenocrysts that are rimmed with blue-green tourmaline. The tourmaline also occurs as dark patches in the groundmass, which are noticeable in the hand specimen. The tourmaline associated with the rhyolite sheets and sills was probably formed by the pneumatolytic action of emanations from the cooling rhyolite. Metamorphic effects extend far beyond the borders of the sheets and sills in the Holokuk River area and will be discussed further under the heading of metamorphism.

Mafic sills, dikes, and lava flows crop out in the vicinity of rhyolite bodies, but were not found in contact. Some of the mafic intrusive rocks, particularly biotite basalt, as well as nearby bedded rocks, are altered in the vicinity of the rhyolite and are therefore believed to have formed before the rhyolite. Flows of the Holokuk basalt cap the upturned and eroded rhyolite sheets, and the strata that enclose them, in the mountainous area east and north of Holokuk Mountain. This is best seen at the east end of Kaluvarawluk Mountain, where sheets that crop out east of the mountain form linear exposures that strike southwest and apparently pass beneath the lava of the mountain top.

AREA THAT BORDERS THE KUSKOKWIM RIVER SOUTH AND SOUTHEAST OF THE HORN MOUNTAINS

The Kuskokwim River bottomlands divide this area of rhyolite outcrops into eastern and western exposures, probably portions of a somewhat continuous belt of sheets that extends beneath the flood plain deposits. The sheets strike northeast, parallel to the axis of a rather extensive anticlinal tract in the bedded rocks of the vicinity. Those east of the Kuskokwim river intrude strata that dip southeast on the southern limb of the structure and many appear to be sills. Platy partings, believed to be parallel to the tabular surfaces of the rhyolite, dip northwest in the area west and north of the river. Bedded rocks that crop out in the general vicinity of the latter exposures are similarly oriented, and it is therefore inferred that the rhyolite probably forms sills on the northern limb of the anticline also.

LITTLE TAYLOR MOUNTAINS AND VICINITY

Several rhyolite sheets crop out in the vicinity of the Little Taylor Mountains, and south of the Taylor Mountains (pl. 6). Their relation to the other albite rhyolite sheets and sills in the central Kuskokwim region is somewhat uncertain, as they lie well to the southeast of the areas in which most of the rhyolite occurs.

The average strike of the sheets is east. The enclosing bedded rocks strike northwest, and their general dip is to the southwest, though they are commonly repeated on tight minor folds. The sheets strike northwest and dip southwest parallel to the strata, at a locality a little northwest of the summit of the Little Taylor Mountains.

The rhyolite of the Little Taylor Mountains is closely associated with heavily silicified and pyritized sedimentary rocks that form the summit peaks. The rhyolite in the vicinity of the summit is sericitized and pyritized. Gold concentrates from the neighboring Taylor Creek placers are said to contain large amounts of pyrite, possibly from this or similar source rocks.

OTHER AREAS

Rhyolitic intrusive bodies occur in scattered localities along the Kuskokwim River cut-banks downstream from Georgetown, near the head of Downey Creek south of Georgetown, on the lower Oskawalik River, and along the Georgetown Trail, particularly near Little Eldorado Creek. The sheets are large enough to be seen readily on aerial photographs. Numerous sheets were discovered on the photographs of areas not covered by ground surveys, particularly in the vicinity of the Buckstock River. The photographs show several patches of rhyolite along the divide between Michigan Creek and the head of Julian Creek on the upper George River. These bodies of rhyolite seem comparable to those on Donlin Creek and are probably related to the gold placers on Julian Creek. A rather large tabular mass of columnar rhyolite, examined in the course of the ground survey, forms one of the eastern ridges of the Kiokluk Mountains. It is the only columnar rhyolite known in the region.

AGE

The albite rhyolite, like the biotite basalt, is inferred to be of earliest Tertiary age. It intrudes folded bedded rocks whose uppermost beds are of middle or late Late Cretaceous age, but it is not known to intrude unconformable cappings of Tertiary volcanic rocks. The intrusive relationships of the rhyolite suggest that it was emplaced during folding. The date of the folds is believed to be earliest Tertiary. The rhyolite is possibly younger than the biotite basalt, because in some places the latter seems to have been altered by emanations from the cooling rhyolite. Though the rhyolite sheets, sills, and dikes are probably hypabyssal phases of the Getmuna rhyolite group, the volcanic rocks of the latter group are of little use in dating the intrusive rhyolite, because, as has already been pointed out, their contacts are covered and stratigraphic relations are not clear.

BASALT

AREAL DISTRIBUTION

Basalt dikes, some more than 100 feet thick, crop out in the upper Kolmakof River valley, and in a linear zone that trends northeast across the upper main fork of the Oskawalik River into the headwaters of Vreeland Creek. The dikes form prominent cliffed exposures, particularly where they protrude from the bluffs northwest of the Kolmakof River. One prominent hill in the upper Oskawalik River area is at the intersection of basalt dikes. Basaltic dikes that are not as well exposed and are more altered occur in the Little Creek, Montana Creek, and DeCourcy Mountain areas. The field relationships are commonly not clear in the latter areas, and the dikes are difficult to distinguish from outlying exposures of the Iditarod basalt, or from basalt flows possibly interbedded in the Kuskokwim group.

INTRUSIVE RELATIONS

All of the dikes are vertical, or nearly so, and commonly intersect the structure of the bedded rocks. The crosscutting relation of the dikes and their vertical orientation imply that they were intruded after the bedded rocks were folded. The proximity of the basalt dikes to the extrusive Holokuk basalt, in both the Kolmakof River and Oskawalik River areas, suggests that the dikes occupy fissures through which the Holokuk basalt was extruded, and that the basalt of the dikes is a hypabyssal phase of the Holokuk basalt flows. The presence of detrital basaltic rock, associated with the dikes in the Oskawalik River-Vreeland Creek area, implies that outliers of the Holokuk basalt flows and their interbedded detrital rocks may also be represented there.

PETROGRAPHIC CHARACTER

The basalt is a dense, gray-to-black, commonly nonporphyritic rock. The texture of much of the rock is trachitic, though it is subophitic in some places. Feldspar laths are mostly less than 0.1 millimeter long. The feldspar is labradorite and the pyroxene predominantly augite, although hypersthene is rather common. These rocks contain little if any quartz and are not much altered. In the Oskawalik River-Vreeland Creek area, breccias, some of which are contact breccias, contain fragments of basalt, fine-grained graywacke, and shale. At two places in the latter area the breccia fragments are somewhat rounded, and the matrix is also fragmental; instead of contact breccia, this suggests the water-deposited detritus briefly mentioned in the preceding paragraph. The basalt is columnar in places.

AGE

The basalt dikes are probably of middle Tertiary age. Their relation to the bedded rocks shows that they were intruded after the folding in earliest Tertiary time. If they are hypabyssal equivalents of the Holokuk basalt they were very likely emplaced at about the time the Holokuk basalt was extruded, probably some time in the interval from late Eocene through early Miocene.

QUARTZ MONZONITE

AREAL DISTRIBUTION

The quartz monzonite stocks and other stocks of related composition are the largest intrusive bodies of igneous rock. Their circular to elliptical groundplan is reflected by the patterns of the several higher mountain groups of which they form the resistant core rocks. These are the Horn, the Russian, the Kiokluk, the Chuilnuk, and the Taylor Mountains, and some others. Dikes and sills, and small stocklike bodies believed to be genetically related to the larger stocks, are described in a subsequent discussion of quartz diabase and related rocks.

Granular intrusive rocks, generally referred to as granitic rocks, are widely reported throughout the Kuskokwim Mountains and adjacent areas, to both the northeast (Mertie and Harrington, 1924, p. 69–71; Brown, 1926, p. 115–118, 124; Mertie, 1938, p. 75–82) and southwest (Hoare, J. M., Maddren, A. G., and Wallace, R. E., unpublished notes and maps) of the central Kuskokwim region. The granite rocks have been variously classified as granite, monzonite, quartz monzonite, granodiorite, and quartz diorite, and certain more mafic facies nearby have been described (Mertie and Harrington, 1924, p. 67). Their areal patterns suggest that they are stocks comparable to those in the central Kuskokwim region, though their structure is not specifically mentioned in the literature. The stocks in the central Kuskokwim region, therefore, are probably only a part of a much more extensive belt. Comparable stocks are known far to the northeast in the Yukon-Tanana region (Mertie, 1937b, p. 219–226) where, though northeast of the Kuskokwim Mountains proper, they lie within the Kuskokwim Mountain orogen.

INTRUSIVE RELATIONS

The stocks are much better exposed than are the other igneous bodies. The steep walls of the glacial troughs, that radiate outward from the centers of the mountain groups, commonly afford ideal exposures of contacts in only slightly weathered rock.

The borders of the stocks cut across the strata of enclosing bedded formations. The stocks intrude folded, steeply dipping bedded rocks as well as the more gently dipping Holokuk basalt, which lies unconformably on the folded rocks. The discordant relation of the stocks to the folded bedded rocks is particularly clear at the scale of the areal geologic map (pl. 1); the stock in the Horn Mountains is rather widely distributed across the folds and apparently was intruded after folding. Discordant relationships with the Holokuk basalt are not as clear on the map, because the basalt dips rather gently and lacks the pronounced linear strike elements of the underlying folded beds. Details of the contacts of the stocks are best exposed in the Taylor and Chuilnuk Mountains.

The bedded rocks that border the stocks seem little disturbed, in the sense that they have been pushed aside as the stocks were intruded. There is, on the other hand, rather good evidence that parts of the adjacent bedded rocks foundered into the magma from which the stocks consolidated and thus made way for intrusion. This evidence is presented, and the probable mode of intrusion described more fully, in the discussion of local details.

The stocks are much more extensive at depth, and unroofing by erosional processes is apparently in the early stages. The contacts of the stocks commonly dip outward, away from the mountain centers, and, if projected over the central summits, might barely clear the peaks. Isolated patches of the sedimentary and volcanic formations that roof the stocks do crop out in the summits of peaks and ridges near the stock borders.

Several different types of structures were found within the borders of the stocks. Certain general features, not yet studied in detail, may be mentioned. The felsic rocks tend to be massive. The less felsic rocks are not generally as massive, probably because of local variation in lithologic features. Primary flow structures, shown chiefly by the dimensional orientation of feldspar phenocrysts, are common locally, although not widespread. Joints occur throughout, most abundantly in the less felsic facies. Some of the joints are occupied by dikes and apparently were formed during the later stages of emplacement of the stocks, but most of the joints are barren and cut the dike rocks. Rectangular systems of barren joints are fairly common, particularly in the felsic facies. Joints parallel to the walls of glacial troughs are probably sheeting, produced by release of load on rocks breached by erosion.

PETROGRAPHIC CHARACTER

The average composition of the stocks is about that of quartz monzonite. Most of the stocks are made up of more than 95 percent of quartz monzonite and granodiorite, though one stock is made up almost entirely of granite. These three rock types grade into each other; if minor facies that occur in some of the stocks are considered, an unbroken series of igneous rock types from basalt through quartz diabase, granophyre gabbro, granodiorite, quartz monzonite, and granite to granite pegmatite are recognizable. The minor facies grade into the granodiorite, quartz monzonite, and granite.

The rocks are in general coarse grained enough that nearly all the mineral grains are distinguishable with the unaided eye, but locally, particularly near the borders of the stocks and in associated dikes and sills, finer grained facies are characteristic. The border facies at the walls of some of the stocks are more mafic than the cores of the stocks and are commonly basaltic. The border facies at the roofs of the stocks differ little from the rocks of the cores of the stocks.

Petrographic features peculiar to the various stocks are discussed under the heading of local details.

MEGASCOPIC FEATURES

Quartz monzonite, granodiorite, and granite are characteristically mottled in appearance, an effect produced by sporadic grains of dark minerals, large enough to be distinguished, among grains of light-colored minerals. Seen from a distance, the overall color of the rock is gray, of a shade proportionate to the quantity of dark mineral. These rocks are only slightly discolored by weathering. The mafic border facies of the stocks and the rocks of associated mafic dikes and sills, composed chiefly of basalt and quartz diabase, are commonly so fine-grained that, phenocrysts excepted, the minerals are indistinguishable. They are dark gray to black, an effect of both the finer grain and larger quantities of indistinguishable dark minerals. The felsic dike facies, composed of aplite and pegmatite, are lighter colored than the quartz monzonite, granodiorite, and granite and contain very few dark minerals. Both mafic facies and felsic dike rocks are commonly sugary textured and reflect the fine granitoid fabric of the rock.

The feldspar grains are in general opaque, and white or slightly pink to light gray. Pink color may indicate the presence of orthoclase feldspars whereas light gray betokens the plagioclase feldspars. The feldspar grains in granite are irregularly shaped, but in quartz monzonite and granodiorite some of them form tabu-

FIGURE 22.—Orthoclase phenocrysts in the granite of the Taylor Mountains, near head of Whitewater Creek. Picture shows tendency to parallel orientation of phenocrysts; carlsbad twinning is noticeable in the phenocryst at the extreme right.

lar lath-shaped grains in which the crystal outline is well preserved. The latter feature is characteristic of plagioclase. Locally orthoclase forms euhedral phenocrysts that are also lath shaped, but they are much larger than the grains of anhedral orthoclase characteristic of the granitoid groundmass (fig. 22).

Quartz grains, which are commonly anhedral and characteristically transparent and glassy in appearance, are easily distinguished in quartz monzonite, granodiorite, and granite. The quartz grains may appear dark, owing to shadows cast into them by neighboring opaque grains.

Biotite, the cleavage of which is distinctive, is the most readily recognizable dark mineral in the granitic rocks. Amphibole and pyroxene are not readily distinguishable but occur as dark patches that, like the biotite, contribute to the mottled appearance of the rock.

MICROSCOPIC FEATURES

The texture of these rocks is predominantly granitic. They are fine grained; the average diameter of grains is about 1 millimeter. The texture of the groundmass of basaltic facies is commonly microgranitoid, rather than ophitic or subophitic like the basalt dikes and sills already discussed. Phenocrysts in the basalt average about 1 millimeter in diameter and grains in the groundmass less than $\frac{1}{10}$ millimeter.

Plagioclase as well as orthoclase is anhedral in the granite, but in the quartz monzonite and granodiorite, as well as in the mafic facies, plagioclase is subhedral to euhedral. Anhedral orthoclase occurs in interstices between laths of plagioclase, in the intermediate and mafic rocks. The plagioclase grains are commonly zoned and are more calcic at the centers than at the borders.

One-half or more of the feldspar in the granites is orthoclase and the remaining feldspar is chiefly sodic oligoclase and albite. One-half to nearly all of the feldspar in the other facies is plagioclase, and the remainder is orthoclase. The quartz monzonite contains andesine and calcic oligoclase in equal or slightly greater quantities than orthoclase. Medium plagioclase, chiefly andesine, comprises a little more than two-thirds of the total feldspar in the granodiorite. The granophyre gabbro contains plagioclase, almost exclusively labradorite, and less than a quarter of the total feldspar is orthoclase. The quartz diabase and basalt contain minor amounts of interstitial orthoclase.

Quartz is characteristic of the granite and occurs in decreasing abundance in the less felsic facies. Like orthoclase the quartz is anhedral and is formed in interstices between other mineral grains, particularly in the intermediate and mafic rocks. Quartz commonly forms myrmekitic intergrowths with feldspar in the felsic and intermediate rocks. Intergrowths of interstitial quartz and orthoclase are characteristic of granophyre gabbro and related norite and quartz diabase.

Biotite is the most widely distributed ferromagnesian mineral and occurs to some extent in all facies of the stocks. It is practically the only ferromagnesian mineral that occurs in any quantity in the quartz monzonite, granodiorite, and granite. It is most abundant in the granodiorite and constitutes 10 to 20 percent of its volume. Augite is the most abundant ferromagnesian mineral of the mafic facies and commonly makes up 30 to 50 percent of their volume. Hypersthene is less common than augite. It is the essential ferromagnesian mineral of the noritic phases of the granophyre gabbro. Hornblende is not very abundant. Rims of hornblende and biotite commonly occur on augite, and biotite on hornblende, showing the paragenetic sequence, augite—hornblende—biotite.

Apatite, zircon, and magnetite are the principal microscopic accessory minerals, and smaller quantities of ilmenite, titanite, and garnet also occur. Tourmaline occurs in some pegmatites. Pleochroic haloes are commonly formed around small grains of zircon included in biotite and tourmaline.

The quartz monzonite and related rocks are on the whole less altered than most of the other igneous rocks in the region. The feldspars are locally altered to fine-grained mica and calcite, but almost never to the point that they are unrecognizable. The ferromagnesian minerals may be chloritized. Leucoxene is commonly formed on ilmenite. Other alterations are negligible.

CHEMICAL CHARACTER

Specimens of the quartz monzonite and related rocks were analyzed chemically and the analyses computed into normative mineral molecules (Cross, Iddings, Pirsson, and Washington, 1903; Washington, 1918, p. 1151–1180) to assist in classification of the stock formations and for the purpose of comparison with previously published analyses and norms of comparable intrusive rocks collected elsewhere in Alaska.

The analyses and norms of five samples from the central Kuskokwim region are tabulated on page 76 (columns 1–5) with thirteen analyses and norms (columns 6–18) of rocks from adjacent and also more distant regions of the Kuskokwim Mountain orogen. Samples 6–8 are from the Nushagak district, sample 9 is from the Iditarod district, sample 10 is from the Ruby district, sample 11 is from the Nixon Fork district, samples 12–17 are from the western Yukon-Tanana region, and sample 18 is from the Circle district (Mertie and Harrington, 1924, p. 59–60, 70; Brown, 1926, p. 124; Mertie, 1936, p. 231–232, 1937b, p. 219–225; 1938, p. 76–82).

The normative feldspars are plotted on the classification diagram (fig. 23) to assist in classification of the quartz monzonite and related rocks of the stocks. This diagram is based on a scheme presented by F. F. Grout (1932, p. 48) to show methods of using feldspars in the classification of igneous rocks. The norms are assigned more orthoclase and more of the anorthite molecule than are found in the corresponding modes, inasmuch as the ferromagnesian minerals of the modes of these rocks contain potash (K_2O) and lime (CaO) that are computed into the normative feldspars. This divergence of normative and modal feldspars is critical in the classification of borderline rocks, such as are represented by samples 8 and 11, which lie near the sodic-felsic borders of the quartz monzonite-monzonite field of the classification diagram. It is estimated, after consideration of probable volume percent of biotite in the mode, and the possible potash (K_2O) range in biotite, that a difference of 5 to 10 percent orthoclase content is likely between the norm and the mode of these samples. Thus it seems quite possible that the mode of sample 8 falls in the granodiorite field rather than in the quartz monzonite-monzonite field.

Mertie (1938, p. 81) has pointed out that neither sample 8 nor sample 11, "if classified on the basis of normative feldspar * * *, is a true monzonitic rock, because their ratios of potash to lime-soda feldspar are, respectively, 1:1.6 and 1:1.7, as compared with the theoretical limits of 1:1.5." It will be noted that the latter limits, if superimposed on the classification diagram, effectively separate samples 8 and 11 from the other samples that fall in the quartz monzonite-monzonite field. Mertie further states (1938, p. 81) that samples 8 and 11 are more closely related to the monzonitic rocks, as exemplified by sample 9, than to the granitic rocks, as exemplified by samples 10 and 18, but that "they might more accurately be designated grano-monzonites." The distribution of samples 8 and 11 on the classification diagram shows their close relationship to granodiorites, such as those of samples 2 and 4, collected in the central Kuskokwim region. It is therefore believed, after all these points have been considered, that samples 8 and 11 may properly be referred to as granodiorites.

On the classification diagram (fig. 23), the five samples (1–5) from the central Kuskokwim region fall in a nearly linear tract that extends from the granodiorite field diagonally across the quartz monzonite-monzonite field into the granite field. This pattern suggests a part of the genetic sequence of a petrographic series from basalt to granite pegmatite, although the purpose of the diagram is classificatory. The other samples from the Kuskokwim Mountain orogen are distributed more or less at random, though they fall in essentially the same fields as the central Kuskokwim samples. Samples 8–11, 14, 17, and 18 reinforce the pattern of the linear tract noted above, but samples 6, 7, 12, 13, 15, and 16 diverge from this pattern. The two samples of the hypabyssal porphyritic albite rhyolite have also been plotted (1 and 2, circled) on the classification diagram, and their aberrant distribution with respect to the samples of the quartz monzonite and related rocks, particularly from the stocks of the central Kuskokwim region, is quite apparent.

As a further aid to the description of the quartz monzonite and related igneous rocks of the Kuskokwim Mountain orogen a variation diagram (fig. 24) has been constructed to show the percentage of oxide equivalents (from the analyses), which varies with the percentage of salic minerals (from the norms). This diagram

Chemical composition and parameters of quartz monzonite and related rocks from stocks intruded in the Kuskokwim Mountain orogen

A. Analyses

[Samples 1-5 analyzed by J. G. Fairchild, 6-8 by George Steiger, 9-11 by E. T. Erickson, 12 by Charles Milton, 13-17 by J. G. Fairchild, and 18 by E. T. Erickson]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SiO_2	66.17	64.11	68.51	63.59	70.48	76.32	75.71	66.67	57.16	74.02	64.84	54.20	56.89	67.44	64.52	53.11	73.92	75.98
Al_2O_3	15.60	15.64	14.67	16.08	13.97	12.27	12.72	14.95	16.88	12.02	15.20	18.43	14.59	15.45	14.90	16.45	13.46	11.70
Fe_2O_3	.74	.73	.92	.58	.43	.54	.14	.71	.26	.92	.73	.55	.45	.65	.42	.76	.94	.39
FeO	2.54	4.31	3.26	4.11	3.21	1.38	1.50	3.80	5.36	2.72	4.18	6.38	6.13	2.68	3.72	8.29	1.26	2.24
MgO	.94	2.13	.53	2.28	.29	.25	.08	1.38	4.78	.69	2.02	3.08	4.23	.88	1.85	3.28	.53	.30
CaO	2.48	3.95	2.25	3.95	1.18	.81	.90	3.03	4.08	1.46	3.04	7.20	6.10	2.38	3.52	5.65	1.11	.58
Na_2O	3.85	3.70	3.12	3.46	2.77	3.54	4.15	3.55	4.67	3.22	4.03	2.64	2.10	3.26	2.62	2.02	2.42	2.73
K_2O	6.07	3.03	4.52	3.63	5.48	4.50	4.52	4.07	5.32	4.28	4.55	5.31	6.32	5.97	5.98	6.38	5.18	5.46
H_2O+	.59	.78	.70	.66	.62	.39	.43	.78	.69	.28	.41	.28	.74	.51	.76	1.15	.36	.42
H_2O-	.10	.20	.15	.24	.18	.08	.10	.11	.04	.09	.04	.05	.14	.06	.09	.20	.20	.05
CO_2	.45	.38	.40	.45	.46	None	None	None	.11	.04	.48	.23	.55	.32	.71	.95	.15	Trace
TiO_2	.45	.78	.62	.62	.45	.18	.15	.75	.30	.26	.30	.81	1.00	.41	.45	1.40	.35	.22
P_2O_5	.08	.15	.15	.15	.22	.04	None	.16				.60	.40	.16	.20	.55	.10	
MnO	.03	.05	.03	.07	.04	.05	.03	.07	.08	.05	.06	.12	.11	.03	.09	.08	.04	None
BaO	.03	.05	.05	.05	.07	None	None	None										
SrO	Tr.	Tr.	Tr.	Tr.	Tr.	None	None	None										
Total	100.12	99.99	99.88	99.92	99.85	100.35	100.43	100.03	99.73	100.05	99.88	99.88	99.75	100.20	99.83	100.27	100.02	100.07

B. Norms

[Samples 1-5 calculated by W. M. Cady, 6-11 by J. B. Mertie, 12-16 by W. M. Cady, 17-18 by J. B. Mertie; all symbols and normative names determined by W. M. Cady]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Quartz	13.49	17.35	25.94	15.56	28.76	35.67	31.54	20.21		33.36	12.56		1.38	18.17	15.02		36.68	35.96
Corundum			.88		1.77	.18											2.08	.22
Orthoclase	35.92	17.90	26.74	21.46	32.41	26.63	26.74	24.07	31.47	25.30	26.91	31.41	37.36	35.31	35.36	37.75	30.64	32.30
Albite	32.54	31.28	26.36	29.24	23.42	29.92	35.05	30.03	31.64	27.20	34.06	22.32	17.76	27.56	22.17	17.08	20.44	23.06
Anorthite	7.28	17.07	10.23	17.57	4.61	3.75	2.70	12.79	9.34	5.67	9.90	22.68	11.65	9.84	11.18	16.90	4.86	2.89
Nepheline									4.24									
Diopside	3.79	1.31		.90			1.57	1.03	8.95	1.35	4.34	7.66	13.21	.80	4.17	6.32		
Hypersthene	3.81	10.78	5.57	11.42	5.60	2.51	1.80	8.20		4.94	9.56	4.43	13.48	5.55	8.46	7.49	2.35	4.19
Olivine									12.31			7.10				7.39		
Magnetite	1.07	1.07	1.35	.84	.63	.79	.21	1.02	.37	1.32	1.07	.79	.65	.95	.60	1.11	1.37	.56
Ilmenite	.85	1.49	1.19	1.19	.85	.33	.29	1.44	.56	.49	.56	1.54	1.90	.78	.85	2.66	.67	.41
Apatite	.20	.37	.37	.37	.50	.10		.37				1.41	.94	.37	.47	1.31	.22	
Semitotal	98.95	98.62	98.63	98.55	98.55	99.88	99.90	99.16	98.88	99.63	98.96	99.34	98.33	99.33	98.28	98.01	99.31	99.59
Water and CO^2	1.14	1.36	1.25	1.35	1.26	.47	.53	.89	.84	.41	.93	.56	1.43	.89	1.56	2.30	.71	.47
Total	100.09	99.98	99.88	99.90	99.81	100.35	100.43	100.05	99.72	100.04	99.89	99.90	99.76	100.22	99.84	100.31	100.02	100.06
Classification:																		
Class, order	I(II), 4(5)	(I)II, 4	I'', 4	(I)II, 4''	I'', ''4	I, (3)4	I, ''4	I(II), 4	II, 5	I'', (3)4	''II, 4(5)	II, 5	II, 5	I'', 4	(I)II, 4''	II, 5	I, 3(4)	I, 3(4)
Rang, subrang	''2, 3	(2)3, (3)4	2, 3	(2)3, 3''	(1)2, ''3	1(2), 3	1'', 3''	2'', 3''	2, 3''	''2, 3	2, 3''	3, ''3	2, 2''	2, 3	2, (2)3	(2)3, 2''	''2, ''3	1'', ''3
Name	Toscanose	Tonalose	Toscanose	Harzose	Toscanose	Liparose	Liparose	Toscanose	Monzonose	Toscanose	Adamellose	Shoshonose	Ciminose	Toscanose	Adamellose	Auruncose	Tehamose	Alaskose

Localities at which samples were collected

1. Biotite granite, Russian Mountains, 14½ miles N. 71° E. of Aniak.
2. Granodiorite, western Chuilnuk Mountains, 34½ miles S. 42° W. of Sleetmute.
3. Quartz monzonite, eastern Chuilnuk Mountain, 32 miles S. 36° W. of Sleetmute.
4. Granodiorite, Henderson Mountain, 22 miles S. 55° W. of Sleetmute.
5. Biotite granite, Taylor Mountain, 10½ miles S. 57° E. of Nogamut.
6. Biotite granite, Tikchik and Agenuk Mountains, 45-60 miles N. 14° E. of Aleknagik (Mosquito Point).
7. Biotite granite, Akuluktok Mountain, 28 miles N. 28° W. of Aleknagik (Mosquito Point).
8. Granodiorite, ridge between Lakes Kulik and Beverly, 32 miles N. 6° W. of Aleknagik (Mosquito Point).
9. Monzonite, head of Flat Creek, 3½ miles due south of Flat.
10. Granite, head of Flint Creek, 7 miles S. 20° E. of Long.
11. Granodiorite, head of Hidden Creek, 32 miles N. 53° E. of McGrath.
12. Monzonite, Roughtop Mountain, 14 miles N. 20° W. of Hot Springs.
13. Monzonite, Elephant Mountain, 26 miles N. 41° E. of Hot Springs.
14. Quartz monzonite, Wolverine Mountain, 15 miles S. 35° E. of Rampart.
15. Quartz monzonite, summit southeast of Wolverine Mountain, 17 miles S. 41° E. of Rampart.
16. Monzonite, Sawtooth Mountains, 21 miles S. 68° E. of Rampart.
17. Granite, Hot Springs Dome, 3 miles NW. of Hot Springs.
18. Granite, southeast side of Mammoth Creek, 38 miles S. 58° W. of Circle.

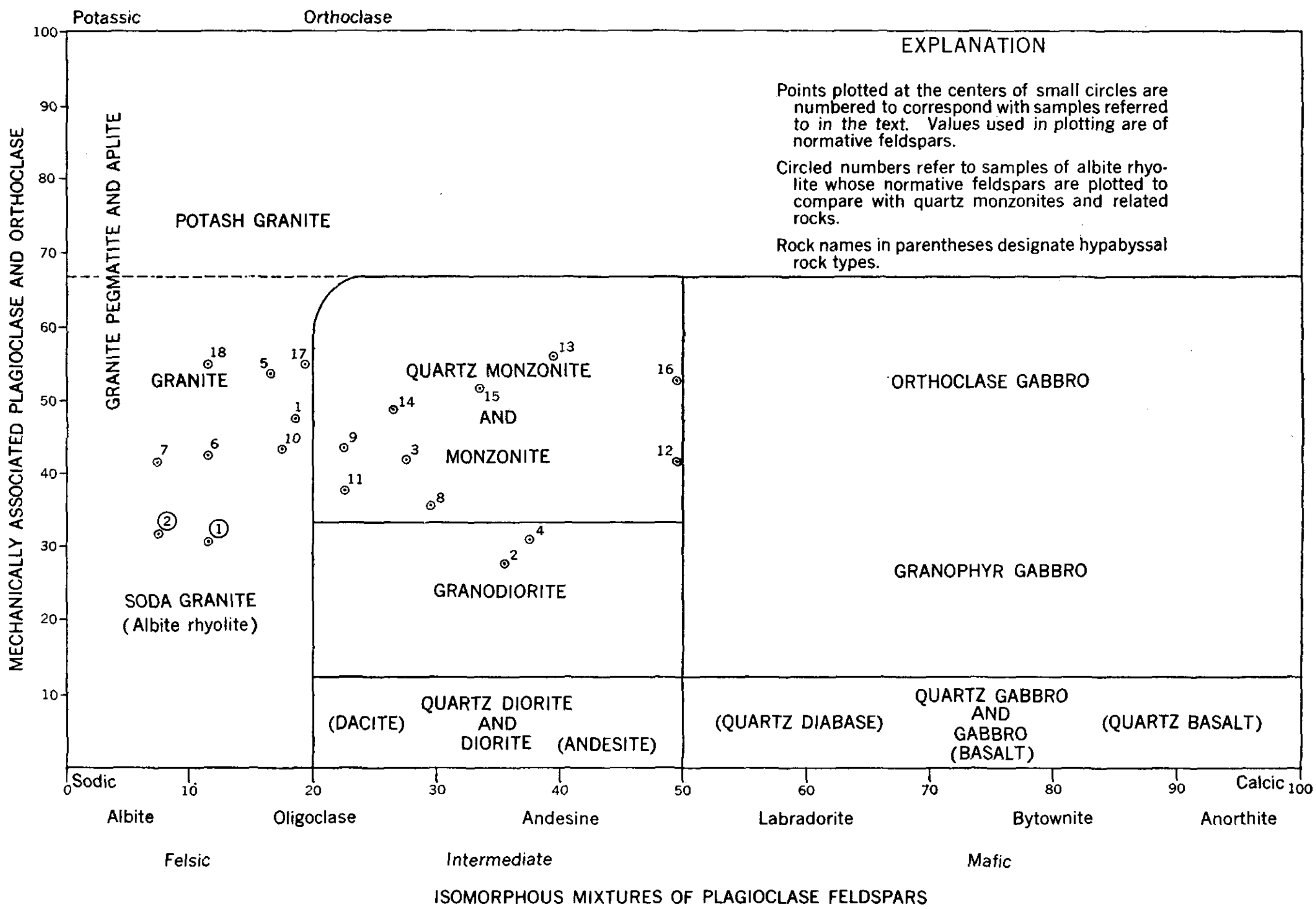


FIGURE 23.—Diagram to illustrate the classification of the quartz monzonite and related igneous rocks intruded in the Kuskokwim Mountain orogen, on the basis of feldspar content. (Based on diagram by F. F. Grout.)

follows one presented by G. W. Tyrrell (1929, p. 134–135). The curves on the diagram illustrate the variation in oxides and are smoothed so that they represent the mean of more or less divergent data. They show relations common in igneous rocks—decrease of alumina (Al_2O_3), ferrous oxide (FeO), magnesia (MgO) and lime (CaO), and increase of silica (SiO_2) and soda (Na_2O) with increase in percentage of salic minerals. The magnesia content most faithfully reflects the trend of variation of these rocks; 14 of the 18 analyses show percentages of magnesia that fall in a regular curve that does not require appreciable smoothing, and all but one of the other four are aberrant to values of less than 1 percent.

The variation diagram for these rocks also shows significant points of departure from the average granite-gabbro series (Tyrrell, 1929, p. 135, fig. 45). The potash (K_2O) content is greater than soda (Na_2O) content and decreases with increases of salic minerals. Alkali (K_2O and Na_2O) content is consistently greater than lime (CaO) content and essentially unvarying. Silica (SiO_2) saturation is reached at a higher percentage of salic minerals, and the curve of the silica number shows that although as a whole these rocks contain excess molecular silica over that required for saturation, they do not have as much in excess as do the rocks of the average granite-gabbro series.

These features indicate that the quartz monzonite and related rocks have persistent alkalic affinities which, however, may not be apparent in the minerals of the mode. Mertie (1937b, p. 224) states with regard to samples 12, 13, and 16, which show a normative silica deficiency, that, "In other words, the monzonitic rocks * * * are as alkalic as rocks elsewhere that carry feldspathoids, but the percentage of silica is just high enough to prevent the mineral expression."

Certain other relations are noteworthy: The high potash-soda ratio contrasts strongly with that of the porphyritic albite rhyolite, which contains more soda. The decrease in potash with increase in salic minerals is consistent with the occurrence of considerable amounts of interstitial orthoclase in granophyre gabbro and basalt facies, and with the occurrence of biotite in the granodiorite, quartz monzonite, and granite facies

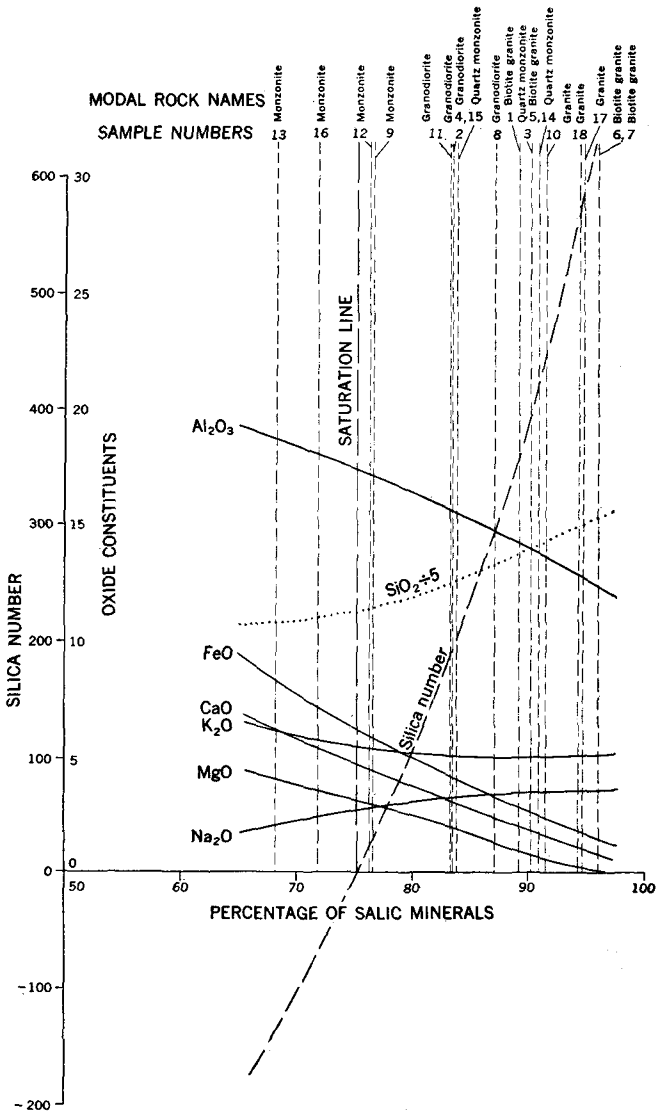


FIGURE 24.—Diagram to illustrate the variation in chemical composition of the quartz monzonite and related igneous rocks intruded in the Kuskokwim Mountain orogen, in terms of the content of equivalent oxide constituents variable with percentage of salic minerals. (Based on diagram by G. W. Tyrrell)

of the stocks in the central Kuskokwim region. The higher ratio of ferrous oxide (FeO) to magnesia (MgO) at the lower percentages of salic minerals is also related to the occurrence of biotite in the more mafic as well as felsic facies.

The sample numbers and corresponding modal rock names are shown across the top of the variation diagram, where their positions depend upon the percentage of salic minerals in their norms (fig. 24). The names are somewhat mixed in sequence, and instead of being referable to a single petrographic series they probably represent rocks of several petrographic series, each series developed within one or a group of closely spaced stocks. Samples 2 and 3, both from the stock in the Chuilnuk Mountains in the central Kuskokwim region, probably fall in such a series. Samples 12 to 17 from the western Yukon-Tanana region form an unmixed sequence: monzonite—quartz monzonite—granite; possibly they also represent a petrographic series.

The mafic rocks whose modes contain quartz do not seem to be provided for in the variation diagram inasmuch as undersaturation with silica is indicated at relatively high percentages of salic minerals. The probable explanation is that such rocks as granophyre gabbro, typical of the quartz-bearing mafic intrusive rocks, form relatively small differentiated bodies, chiefly border facies of the stocks and related dikes, that may not be representative of the average mafic rock concealed at depth. Mertie describes mafic rocks without quartz, associated with the quartz monzonite in areas to the northeast of this region (Mertie and Harrington, 1924, p. 68–69).

The chemical character of the individual stocks in the central Kuskokwim region warrants a little discussion. The chemical analyses and norms are used as a guide to the quantitative aspects of the modes. Specimens collected from the stocks in the Horn Mountains and Kiokluk Mountains proved unsuitable for chemical analysis, but their modes are believed to be sufficiently comparable to the modes of stocks whose rocks have been analysed to permit valid extrapolation of chemical characters.

The norm of sample 1, from the stock in the Russian Mountains, falls in the granite field of the classification diagram (fig. 23), very close to the quartz monzonite-monzonite field—so close that there seems full justification for use of either term. The modes indicate the classification of much of the stock, particularly the border facies, as quartz monzonite; mafic minerals are more abundant than in granites. The norms of samples 2 and 3, from the stock in the Chuilnuk Mountains, are in the granodiorite and quartz monzonite–monzonite fields respectively. Border facies of the latter stock, particularly those on the east side, are of granite and appear to grade into quartz monzonite and granodiorite from which the samples were taken. Considerable labradorite is found in the mode of the sample of granodiorite, but not enough of the anorthite molecule appears in the norm to justify its classification as granophyre gabbro. The modes of specimens from the stock in the Kiokluk Mountains are closely comparable to the mode of the granodiorite (sample 2) of the Chuilnuk Mountains. The modes of samples 4 and 5, from the stocks of Henderson Mountain and the Taylor Mountains, fall into the granodiorite and granite fields respectively, in conformity with the norms. The modes of the stock in the Horn Mountains are highly variable due to multiplicity of facies. They are somewhat different from the modes of the other stocks in the central Kuskokwim region. Proportionately large quantities of orthoclase associated with andesine in the modes suggest chemical compositions similar to those of samples 12, 13, 15, and 16, from the stocks in the western Yukon-Tanana region. The latter samples are in the quartz monzonite–monzonite field, but in a different portion of it that represents higher lime content, and at the same time higher potash content, than does the portion in which the other samples fall.

LOCAL DETAILS

The various stocks may now be described in detail beginning with those to the north (pl. 1).

HORN MOUNTAINS

The rocks of the Horn Mountains are an igneous complex made up of mafic and possibly felsic volcanic rocks as well as intrusive igneous rocks, chiefly quartz monzonite (see fig. 25). The core of the complex is a stock that is believed to intrude both the folded gray-

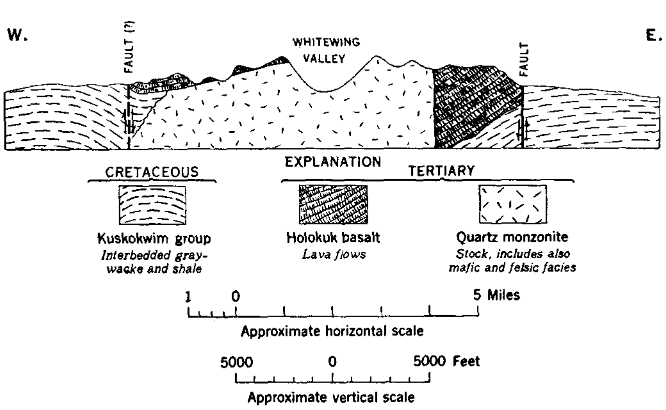


FIGURE 25.—Diagrammatic structure section of the Horn Mountains near latitude 61° 45′ N.

wacke and shale of the Kuskokwim group, and the Holokuk basalt flows which lie unconformably on the Kuskokwim group. The contact between the stock and the sedimentary rocks is covered by the Holokuk basalt and surficial deposits, and the contact of the stock with the basalt is not clear because the basalt and certain border facies of the stock look much alike. Time did not permit as detailed an investigation of these contacts as their obscurity seems to require.

The stock is about 10 miles long in a north-northeasterly direction and about 4 miles wide. The western contact, traced among the mountain summits along the west side of the stock, dips gently west and forms the roof of the stock. The trace of the contact exposed along the east side of the stock is arcuate, and the contact, which is probably nearly vertical, forms a wall of the stock. A western wall is not exposed and the eastern part of the roof is eroded. A narrow, intermittent zone of felsic igneous rocks, that may include both differentiated facies of the stock and lava flows like those of the Getmuna rhyolite group, borders the roof contact and is a good guide to its general position. Mafic igneous rocks, most of which are believed to be the lava flows of the Holokuk basalt, and which lie above the felsic rocks of the roof and border the eastern wall of the stock, are exposed in belts one to three miles wide around the eastern, southern, and western borders of the stock. The basalt flows that border the stock on the east are difficult to distinguish from mafic differentiates of adjacent portions of the stock, except where columnar structures characteristic of the lava occur. Consequently the position of the east wall of the stock is not as closely determined as the western roof contact. Fragments of contact breccia, found in surficial deposits in the vicinity of the east wall of the stock appear to have weathered from mafic facies of the stock.

The lava flows dip toward the west-northwest throughout most of the Horn Mountains proper. Those to the west dip gently subparallel to the roof contact of the stock, whereas the flows to the east dip more steeply and abut against the steep eastern wall. The outer boundaries of the volcanic rocks, like the eastern border of the stock, are arcuate. The volcanic rocks near the foot of the eastern slopes of the Horn Mountains are apparently downfaulted to the west, along their curved eastern boundary, against the sedimentary rocks to the east of them (fig. 25). Those along the west foot of the Horn Mountains dip east for a short distance, east of the sedimentary rocks that underlie them along their western boundary. The western belt of volcanic rocks may be locally downfaulted against the sedimentary rocks. Folds in the sedimentary formations exposed outside the belts of volcanic rocks strike east-northeast across the north-northeast trend of the stock.

It is believed that the steeply inclined, broadly arcuate, eastern border of the stock is emplaced against a fault plane, comparable in origin as well as in pattern to the faults and monoclinal flexures that mark the outer boundaries of the belts of volcanic rocks. The latter structures reflect a general downward movement of the volcanic rocks, and presumably any underlying sedimentary rocks, in the Horn Mountain area, and they produce the elongate north-northeasterly trend of the mountain group brought out by erosion. The sharp angularity between the bedding of the volcanic rocks and the eastern contact of the stock suggests either a fault contact or a discordant intrusive contact. Fragments of contact breccia found in surficial deposits in the vicinity suggest the latter, in which case a fault surface, formed before or during intrusion, may have determined the pattern of the contact. Such a fault possibly marked the eastern edge of a large underground block that subsided, and displaced the magma, which subsequently crystallized to form the stock, upward into the opening that remained. The structure postulated is in harmony with the general structure of the Horn Mountain complex and is comparable to similar phenomena reported from other regions of the world (Billings, 1942, pp. 284–288, 294–295; 1945, p. 44–57).

The internal structures of the stock in the Horn Mountains vary widely depending upon their location in the stock and the types of igneous rocks in which they occur. Well-defined dikes are scattered through the stock. Irregular dikelike structures, which bear numerous autoliths and a few xenoliths, merge imperceptibly with more massive rocks. Local bending and microfaulting of mineral grains are probably effects of movements that took place late in the consolidation of the magma. Primary flow structures are rather common in the border facies of the stock.

The stock in the Horn Mountains comprises the widest range of igneous rock types known in the stocks of the central Kuskokwim region. The central and greater portions of the stock are composed of quartz monzonite accompanied by smaller amounts of quartz latite. A thin zone of rhyolite, probably a felsic facies, lies at the roof of the stock. The eastern border facies, located along the eastern wall of the stock, is chiefly granophyre basalt, but textural and compositional gradation of rock types through granophyre gabbro and granodiorite into the typical quartz monzonite have been recognized here. Similar mafic to intermediate rocks extend across the relatively narrow northern extremity of the stock, from which it is inferred that they lie at depth on the western side, down the dip of the contact from the exposures of the roof facies. The border facies are poorly exposed at the southern extremity of the stock, but related igneous rocks, including latite and granophyre basalt, which are believed to form cupolas connected with the stock at depth, crop out in isolated patches in the foothills south of the Horn Mountains. Rhyolitic and basaltic dikes are probably late magmatic differentiates of the stock.

The relationship of the stock in the Horn Mountains to neighboring intrusive rocks is not directly determinable. Porphyritic rhyolite sheets crop out both to the north and south of the area of the Horn Mountains, but they were not found in contact with any of the rocks of the igneous complex. A tabular rhyolitic body beneath the basalt flows near the west foot of the Horn Mountains is possibly related to the volcanic Getmuna rhyolite group.

RUSSIAN MOUNTAINS

The Russian Mountains, like the Horn Mountains, are formed on an igneous complex that comprises a differentiated stock bordered by mafic volcanic rocks. The stock is smoothly oval in plan with a mean diameter of about eight miles. The border contacts of the stock dip steeply outward, approaching the vertical. Mafic border facies are common and may be confused with the adjoining Iditarod basalt lava. The lava flows are less extensive than those that border the Horn Mountains, and a contact-metamorphic zone, developed in adjacent graywacke and shale of the Kuskokwim group, takes their place on the southern slopes of the mountains. The outer boundary of the volcanic rocks along the eastern side of the stock is curved in plan and conforms to the oval pattern of the border of the stock. The actual contact of the volcanic rocks with adjoining sedimentary rocks is covered by surficial deposits. The volcanic rocks on the east slopes of the mountains dip toward the stock and the metamorphosed sedimentary rocks on the southern slopes dip southward. The northern and western borders of the stock are mapped on the basis of information gained from the study of aerial photographs, inasmuch as ground parties have not yet examined them.

The smooth oval pattern and steep walls of the stock, and concentric arrangement of the volcanic rocks, suggest ring fracture (Billings, 1945, p. 52) control of contacts, within and bordering the complex, comparable to the formation of arcuate faults believed to be related to central subsidence in the Horn Mountains.

Joints are the most prominent internal structures of the stock in the Russian Mountains. The majority of the through-running joints strike northwestward and dip steeply to the southwest. They are asymmetrically disposed with respect to the borders of the stock and presumably are related to regional movements considerably later than intrusion. Many of the joints contain dikes and veins. Similarly oriented dikes and mineralized shear zones extend out into the contact-metamorphic zone in the sedimentary rocks that border the stock.

The stock in the Russian Mountains is composed largely of porphyritic quartz monzonite and granite. Mafic border facies are comparable to those in the Horn Mountains, but not as common. Mafic dikes, which are very common, and felsic dikes, which are less so, are widely distributed throughout the stock and immediately adjacent formations. In the vicinity of sulfide minerals, the rocks are hydrothermally altered to some extent. Sulfide minerals are common within the confines of the stock and are believed to be genetically related to its formation. The sulfides and associated minerals will be discussed further under the heading of mineral resources.

KIOKLUK MOUNTAINS

The igneous complex in the Kiokluk Mountains is in many ways comparable to those of the Horn Mountains and Russian Mountains. The core of the complex is a stock that forms the eastern summits of the mountains. The stock is elliptical to oval in plan and 3 to 4 miles across. The borders of the stock are nearly vertical on the west and dip steeply outward on the east. Closely folded and contact-metamorphosed sedimentary rocks border the stock on the east and south. The Holokuk basalt, which overlies the sedimentary rocks unconformably and dips gently to the north, borders the stock on the west and north and forms most of the western peaks. A swarm of dikes and sills extends northeastward and southward from the latter peaks.

The stock in the Kiokluk Mountains is composed of granodiorite. The associated sills and dikes are composed predominantly of porphyritic andesite. A large sill-like body of columnar rhyolite, possibly connected with the stock, forms one of the eastern spurs of the Kiokluk Mountains. Certain of the dike and sill rocks, composed chiefly of porphyritic andesite, are rather heavily carbonatized, sericitized, and chloritized, though granodiorite of the stock is only slightly altered by hydrothermal solutions. A poikiloblastic texture is well developed in the granodiorite near the borders of the stock.

CHUILNUK MOUNTAINS

The Chuilnuk Mountains are centered on a semi-elliptical stock exposed over an area 7 miles long from east to west and 4 miles wide. The exposed contacts of the stock dip gently, as little as 25°, outward, and they appear deeply scalloped on the map (pl. 1), if the glacial deposits are ignored, due to the deep incision of glacial troughs, particularly on the north side of the mountains. The contacts are well exposed; they may be observed in detail and without a break for several hundred feet. They alternately parallel and cut across the stratification of inclosing formations; although the the stock may be locally concordant with inclosing strata, the general effect is one of large scale discordance. The stock is completely surrounded by a contact-metamorphic zone in adjacent sedimentary rocks; the outcrop of this zone averages about two miles wide. The broad surface exposure of the contact metamorphic zone is an effect of its relatively gentle dip, parallel to the contacts of the stock and subparallel to the outer slopes of the mountains, as the zone is actually only about 4,000 to 5,000 feet thick. A well-defined fault trace is recognizable at the north foot of the mountains, about at the outer margin of the contact metamorphic zone (see pl. 7). The position of the contact zone along the southern border of the mountains was extrapolated from observations made on the northern slopes, assisted by study of the aerial photographs. The contact zone produces a distinctly greater amount of talus than the stock, and the talus is distinguishable in aerial photographs. A sill-like cupola of the stock crops out in the contact-metamorphic zone at the eastern end of the mountains. Dikes and sills are scattered through the contact-metamorphic zone and the outer portions of the stock. There are few, if any, volcanic rocks in the Chuilnuk Mountains. The western summit peak appeared from a distance to be capped with volcanic rocks like the Holokuk basalt in the Kiokluk Mountains.

The stock in the Chuilnuk Mountains ranges from granodiorite on the west, comparable to that of the Kiokluk Mountains, through quartz monzonite, to granite on the east. The presence of the granodiorite on the west side of the stock, nearest to the Kiokluk Mountains, suggests that the rocks of the two stocks derived from a common magmatic source, connected at depth. Dikes and sills are commonly finer grained and more felsic than the stock proper, and many are typical sugary-textured aplites. The igneous rocks of the Chuilnuk Mountains are unaltered. Hot springs occur along the northeastern contacts of the stock near the largest of several lakes (pl. 7).

HENDERSON MOUNTAIN

Henderson Mountain is formed on a small circular to oval stock about one mile in diameter (pls. 1, 7). It is inferred from the comparatively wide outcrop of the contact-metamorphic zone that the contacts on all but possibly the south side of the stock dip rather gently outward. The bedded rocks in the vicinity of the stock strike east-northeast, dip steeply northwest, and are exposed at points close enough to the borders of the stock to show that the contact is discordant. A swarm of dikes strikes southeastward, out of the steep southeast slopes of Henderson Mountain, and is particularly well exposed in the low spur between the upper forks of the Oskawalik River.

The Henderson Mountain stock is composed of fine-grained granodiorite. Diabasic, dacitic, and rhyolitic dikes and sills, at the borders and in the vicinity of the stock, are probably late differentiates of the same magma as that of the granodiorite. The granodiorite is only slightly altered: ferromagnesian minerals are a little chloritized. Some of the dikes and sills are considerably chloritized and carbonatized. A small amount of gold, reported from surficial deposits on the northeast slopes of Henderson Mountain near the border of the granodiorite, may be related to hydrothermal activity associated with the stock.

Types of igneous rocks already described occur widely in the neighborhood of Henderson Mountain. Most of these have distinctive features and can be recognized, but a few are indistinguishable from the intrusive rocks in the immediate vicinity of Henderson Mountain; thus their portrayal on the map (pl. 1) as quartz diabase, albite rhyolite, and basalt is in part arbitrary.

TAYLOR MOUNTAINS

The Taylor Mountains (pl. 6) are formed on a semi-elliptical stock that crops out in an area that extends east-west 4 miles and north-south about 3 miles. The contacts of the stock are well exposed and field conditions were such that a fairly thorough examination of the contacts was possible.

The structure and geomorphic setting of this stock is comparable to that of the stock in the Chuilnuk Mountains already discussed. The northern border at the stock dips outward at an angle of about 45°, and the southern border, more steeply. At more centrally located points the dip of the contact is less than 45° outward. These observations reflect the broadly arched cross section of the stock. Cupolas of the stock, and roof pendants made up of the bedded rocks intruded by the stock, are common features in the general vicinity of the borders of the stock, thus the contact is quite irregular in detail although this is not apparent at map scale (pl. 1). The highest summit in the Taylor Mountains, located near the southern border of the stock, is a sharp peak crowned with the lower portion of a roof pendant that was isolated when the roof of the stock was eroded. Detailed study of the contact at numerous places shows that it is made up of steplike subplanar segments that alternately follow bedding joints and cross joints in the adjacent folded strata, relations that satisfactorily prove the discordant structure of the stock. A contact-metamorphic zone, which has an average surface width of about 1½ miles and thickness of 3,000 to 4,000 feet, surrounds the stock. The strata into which the stock is intruded form a major anticline, the axis of which strikes west-northwest across the southern portion of the stock. The strike of the anticlinal axis is in conformity with the regional structural trends, but the size of the anticline is possibly accentuated in the vicinity of the stock.

Feldspar phenocrysts are locally oriented in a planar flow pattern (fig. 22), but too little of this structure is apparent to show a systematic distribution. Dikes are scattered throughout the stock, and are most abundant, near its borders and in adjacent portions of the contact-metamorphic zone. They are not sufficiently abundant however, to be regularly encountered at traverse stations, hence no attempt was made to record systematically their orientation and distribution. Many of the dikes, related sills, and veins extend beyond the borders of the stock along outward projections of subplanar segments of the contact of the stock described in a previous paragraph. Dikes within the stock either pinch out or merge imperceptibly, at their extremities, with the general fabric of the stock formation. One such dike is systematically offset by several small faults that form well-defined fractures in the dike, but are barely perceptible or absent in the adjacent rock.

Several systems of joints cut the stock. The most pronounced joints strike west-northwest and dip steeply northeast (fig. 26). The mean strikes and dips of the joints, stated in decreasing order of prominence and abundance, are: N. 15° W., 85° NE.; N. 65° W., 75° SW.; N. 53° W., 54° NE.; N. 61° E., horizontal to 60° SE., and N. 85° E., 75° NW. or vertical. The last two joint systems indicated are much less common, but they are included because their strikes range less than 5° from the mean as compared with a 40° range in the other three joint systems. Some gently dipping joints are shown in the view in figure 27. Casual observations between traverse stations verified the continuous character of the joints. The joints cut the dikes within the stock, and the first three systems of joints indicated above pass from one side of the stock to the other. Joints that parallel the walls of glacial troughs and do not fit into any of the above indicated joint systems are believed to be good examples of sheeting (fig. 26).

FIGURE 26.—Granite spires formed by intersecting joints, as seen from a point near western border of stock in the Taylor Mountains. Joints that dip nearly parallel to the slope are probably sheeting; those at the backs of the spires are nearly vertical and strike west-northwest.

The mode of emplacement of this stock, and of the

FIGURE 27.—Residual pillars of granite transected by gently dipping joints, near the south border of the stock in the Taylor Mountains.

similar ones in the Chuilnuk Mountains and Henderson Mountain, probably differs from that of the stocks in the Horn and Russian, and probably also the Kiokluk Mountains, which latter are interpreted as related to arcuate fractures. The stock in the Taylor Mountains rose near the crest of a long anticline, and perhaps enlarged that anticline locally, although there is little proof that it did.

The details of the contacts commonly show that the granite of the stock has individually displaced small subrectangular blocks of the sedimentary rocks of the roof, which had been bounded by the surfaces of bedding and cross joints. "Piecemeal stoping" as described by Daly (1903, p. 93–100) was probably responsible for the formation of such contacts and may have been the principal method of emplacement of the stock. Xenoliths are not found and appear to have sunk out of sight. Dikes now occupy joints that extend beyond the borders of the stock, which indicates disturbance of the adjacent sedimentary rocks, probably late in the episode of intrusion, possibly due to pressure of the magma. The barren joints that cross the stock probably were not caused by the pressure of intrusion, inasmuch as they cut the late-magmatic dikes and are distributed asymmetrically with respect to the borders of the stock. The corrugated structure and lower density of the folded sedimentary rocks that adjoin the stocks in the Taylor Mountains, Chuilnuk Mountains, and Henderson Mountain favor piecemeal stoping; on the other hand, the structurally weaker, heavier, and nearly flat lying mafic volcanic rocks of the Horn Mountains, Russian Mountains, and Kiokluk Mountains favor formation of extensive ring and arcuate fractures, followed by magmatic stoping on a scale much larger than that of piecemeal stoping.

The granite in the Taylor Mountains is marked by several distinctive features that are not characteristic of the other stocks in the region. Large phenocrysts of orthoclase, as much as 4 inches long (fig. 22), occur widely through the stock. Aplite and pegmatite are common, occurring in irregular zones that merge imperceptibly with the typical granite, and also as dikes. The aplite and pegmatite, particularly the dike rocks, contain much more primary tourmaline than do the rocks of the other stocks. Milky quartz veins are common near the borders of the stock and extend out into the contact-metamorphic zone. A little of the tungsten mineral, wolframite, was found in a loose fragment from one such vein.

OTHER AREAS

Two large intrusive bodies, probably stocks, have been reported by prospectors and were identified on aerial photographs. One of these, located at the southern border of the area of the map (pl. 1), between Shotgun Creek and the head of the Kogrukluk River, is at the center of a mountain group known by natives on the Holitna River as "Mukhailinguk" or "south mountain," and is probably comparable to the Taylor Mountain stock. Prospectors who have worked in these mountains report a core of "granite." It is believed that the contact metamorphic zone can be distinguished from the "granite" on the aerial photographs and the two have been differentiated on the map. The other stock forms a ridge, commonly referred to as "Black Mountain," at the headwaters of the East Fork of the George River, near the northeastern corner of the area of the map. The stock and also the contact-metamorphic zone are recognizable on the aerial photographs. Two intrusive bodies, possibly made up of albite rhyolite, are exposed a short distance southwest of the mountain proper.

AGE

The quartz monzonite and related granite, granite pegmatite, granodiorite, granophyre gabbro, and quartz diabase are probably of middle or late Tertiary age. The intrusive relationships of the stocks show that they were formed after cessation of folding that took place in the earliest Tertiary. The youngest bedded rock formation intruded by the stocks is the Holokuk basalt formed in the interval between the late Eocene and late Miocene. The stocks form monadnocks that stand above the Georgetown summit level, which appears to be made up of remnants of a surface in old age that was developed sometime in the Miocene or Pliocene. It is inferred, therefore, that the stocks are of Oligocene or Miocene age.

QUARTZ DIABASE

AREAL DISTRIBUTION

Numerous dikes, and a few sills and small stocklike bodies of quartz diabase and related mafic and intermediate igneous rocks, crop out in a belt that extends from the vicinity of Sleetmute southwestward through the Kuskokwin Mountains at least to the Gemuk River. The larger of these bodies are fairly prominent features of the landscape, commonly distinguishable at a distance and traceable on aerial photographs. They are closely associated geographically with the stocks in Henderson Mountain and the Kiokluk Mountains. Similar intrusive bodies occur at several other points, chiefly to the northwest of the belt mentioned above, where they are dwarfed by the larger sills, dikes, and sheets of albite rhyolite.

INTRUSIVE RELATIONS

The relations of these intrusives to adjacent bedded rocks is rather clear, although their contacts are rarely visible. The exposures commonly trend across the strike of the bedded rocks in the vicinity, and it is inferred that they intrude strata that were already folded. This is particularly clear in the area southeast of the upper Holokuk River where the dikes strike nearly at right angles to fold axes. Dikes may intrude the Holokuk basalt on the north slopes of the Kiokluk Mountains. Faulting in this area is complex; proof of the intrusive relationships of the dikes could not be obtained, inasmuch as intrusive contacts are indistinguishable from fault contacts at critical localities. Mafic dikes cut nearly all of the stocks. The quartz diabase and related rocks appear to be continuous with the dike facies, particularly of the stocks in Henderson Mountain and the Kiokluk Mountains; a close genetic relationship is inferred between the quartz monzonite and related rocks of the stocks, and the hypabyssal quartz diabase and its related rock types. At a few places the quartz diabase may be more closely related genetically to albite rhyolite sheets and sills that are exposed nearby.

PETROGRAPHIC CHARACTER

Though quartz diabase predominates, these rocks range from basalt through quartz diabase, gabbro, and norite to andesite and, in some places, granodiorite.

MEGASCOPIC FEATURES

The fresh basalt is nearly all dark and in some places porphyritic. Andesite is lighter and commonly porphyritic. Diabase, gabbro, and norite are increasingly mottled with increase of granularity, and in general aspect they are lighter than the basalt. The basalt weathers brown, and the andesite, buff, but the color of the coarser grained rocks is little changed by weathering.

Several minerals are recognizable in hand specimens of the coarser grained rocks. Feldspar and pyroxene are distinguishable in norite and gabbro. Feldspar, quartz, and, more rarely, some of the ferromagnesian minerals may be recognized in the diabase with the aid of a hand lens. Several minerals that form phenocrysts are recognizable in the porphyritic rocks. Chief among these are light-colored oblong euhedral grains of plagioclase feldspar and dark specks of subhedral to euhedral pyroxene.

MICROSCOPIC FEATURES

Quartz diabase is for the most part nonporphyritic and is ophitic to fine-granitoid in texture. The grains are about half a millimeter in diameter. The finer grained, more ophitic types, grade imperceptibly into basalt, the coarser, more granitoid facies, have much in common with norite and gabbro. Interstitial quartz is relatively abundant and commonly occurs in intergrowths with alkali feldspar. Such rocks might be more correctly referred to as granophyre diabase.

Plagioclase laths in the diabase are large enough to show polysynthetic twinning. Augite is commonly rimmed with hornblende. Simple grains of hornblende are also common. Biotite frequently rims augite and hornblende. The pyroxene grains form clusters in some of the diabase. These clusters appear as a rather coarse mottling in the hand specimen and make the rock look coarser grained than it actually is. This glomero-porphyritic texture may be easily confused with the coarser granitoid textures that are particularly characteristic of granodiorite.

The pyroxene of the norite is hypersthene, but some of the noritic rocks contain augite also; thus their composition may locally approach that of gabbro. The norite is a little coarser grained than the diabase, and its texture is predominantly granitoid. The norite contains a much larger quantity of interstitial granophyre than does the diabase and could be more specifically described as quartz norite. As in the case of diabase the pyroxene grains are commonly rimmed by hornblende and biotite, indicating reaction of the pyroxene with the melt after formation. Also, as was found in the diabases, biotite is a common accessory mineral. The other accessory minerals of the norite include chiefly apatite and magnetite.

Typical basalt commonly contains euhedral to subhedral phenocrysts of pyroxene, chiefly augite, about half a millimeter in diameter. Plagioclase feldspar phenocrysts are rather uncommon in the basalt. The groundmass of the typical basalt is subophitic in texture. Anhedral augite is distributed through the groundmass, chiefly in the interstices between euhedral plagioclase grains, oriented at random, that range from a tenth to half a millimeter long. The plagioclase is almost exclusively labradorite. Interstitial quartz is associated with the anhedral augite. Other less abundant minerals include magnetite, biotite, and ilmenite.

The basaltic facies of these dike rocks differ from the biotite basalt of the dikes and sills associated with the quicksilver deposits, in that they lack microscopic biotite phenocrysts and form much larger intrusive bodies, which have pronounced topographic expression. Unlike the basaltic dikes, which are believed to be the feeders of the Holokuk basalt, the quartz diabase and related rocks almost invariably contain interstitial quartz.

The andesite, which is comparatively rare, grades into granodiorite much like that of the stock in the Kiokluk Mountains.

LOCAL DETAILS

Quartz diabase and its associated rock types were examined in detail in several areas. They are as follows, beginning at the northeast in the vicinity of Sleetmute:

RED MOUNTAIN

A small intrusive complex occurs in Red Mountain 9 miles south-southwest of Sleetmute. It comprises several poorly-defined and somewhat disconnected bodies of igneous rock within a narrow zone of altered graywacke and shale at the ridge of the mountain. The altered sedimentary rocks are included with the igneous rocks on plate 1, as no attempt was made to work out their detailed relationships. The texture of the igneous rock is microgranitoid. It contains abundant quartz and orthoclase as well as labradorite, but ferromagnesian minerals, particularly hypersthene and biotite, are abundant enough to produce a rock that is black and looks outwardly like the mafic dike rocks. Fine-grained dikes cut coarser facies that have the general appearance of granodiorite approaching granophyre gabbro. Finer facies display the sugary texture characteristic of lamprophyrs.

UPPER OSKAWALIK RIVER AREA

Various mafic rocks, including norite, diabase, and basalt, crop out in the upper Oskawalik River area east and south of Henderson Mountain. They form numerous sills and dikes, some of which are indistinguishable from dike rocks that appear to issue from, and are probably closely related to the stock in Henderson Mountain. Norite that crops out about 2½ miles southeast of Henderson Mountain has a semielliptical groundplan; its structure is perhaps more nearly comparable to that of a stock. Peculiar to this area, as well as to Red Mountain, is a sugary-textured basaltic rock with biotite phenocrysts, features that suggest the lamprophyr retinue. The more unusual types are possibly differentiated facies of the quartz monzonites and related rocks already described.

Dikes and sills of trachitic-textured columnar basalt that occur in this area are probably intrusive facies of Holokuk basalt.

HOLOKUK RIVER AREA

Dioritic and basaltic dike rocks are exposed southwest of the middle course of the Holokuk River in the vicinity of Camp Creek, and in the upper Holokuk River area southwest of the mouth of Girl Creek. Those near Camp Creek are rather closely associated with albite rhyolite dikes and sills and may be intermediate and mafic relatives of the rhyolite. The basalt dikes in the upper Holokuk River area are associated with dikes of granodiorite and andesite that extend outward from the Kiokluk Mountains, which suggests their consanguinity with the granodiorite of the stock in the Kiokluk Mountains.

These rather large and extensive mafic and intermediate dikes are not to be confused with small dikes and sills of altered biotite basalt that also crop out in the middle and upper Holokuk River areas.

ATSAKSOVLUK CREEK - CINNABAR CREEK AREA

This large area extends northeastward about 25 miles from the vicinity of Cinnabar Creek to the headwaters of Atsaksovluk Creek, in a belt about 10 miles wide that extends to the headwaters of Timber Creek on the northwest and includes the headwaters of Chikululnuk Creek on the southeast. The igneous rocks discovered in this area are exclusively mafic and nearly all form sills or sill-like dikes. Some of these intrusive bodies are extremely large by comparison and appear to be much coarser grained than others. They are composed chiefly of quartz diabase or, more specifically, granophyre diabase, which is commonly glomeroporphyritic. One of the diabase bodies, which forms a peak sometimes referred to as "Black Mountain," near the head of the middle fork of Chikululnuk Creek, is albitic and contains myrmekite. Augite in this rock is rimmed with hornblende. Coarse basalt that crops out in two places a few miles northeast of Cinnabar Creek is also albitic. A specimen of the coarse basalt contains zoned plagioclase that passes from labradorite at the center of the grains through andesine and oligoclase to albite at the borders.

OTHER AREAS

Dikes, sills, and small stocklike bodies of basalt, diorite, and andesite were found in several other widely scattered localities, particularly near Aghaluk Mountain, at the head of California Creek, and on the ridge between Bell Creek and Crevice Creek.

AGE

The quartz diabase and related dike rocks are, like the quartz monzonite, probably of middle or late Tertiary age. The dikes cut discordantly across folds formed in the earliest Tertiary, but their relationship to the Holokuk basalt is uncertain. Their petrographic character and field relationships indicate, however, that they are probably consanguineous with the quartz monzonite and other stock formations and are of Oligocene or Miocene age.

METAMORPHIC ROCKS

Metamorphic rocks underlie a relatively small part of the central Kuskokwim region, and at only a few places are the effects of metamorphism pronounced. The principal types of metamorphic rocks are argillite and hornfels. The interbedded graywackes and shales of the Kuskokwim group are the chief rocks affected, and these only locally in the vicinity of intrusive igneous rocks. Some igneous bodies, also, show metamorphic effects. Two major episodes of metamorphism are apparently represented. Argillite, formed in the first episode, is associated with the albite rhyolite dikes, sheets, and sills; and alteration probably took place in the earliest Tertiary. Hornfels, produced in the second episode, is associated with the stocks of quartz monzonite and related rocks, and probably formed in the middle Tertiary.

The distribution of hornfels in the vicinity of the stocks is shown on plate 1.

ARGILLITE

AREAL DISTRIBUTION

The largest area, which is about 10 miles wide and perhaps 25 miles long, trends southwest from the Holokuk River, southeast of Kay Creek and northwest of Girl Creek, probably to the Aniak River. A swarm of rhyolite sills, dikes, and sheets occurs in this area. These bodies are so numerous over at least a part of the area that they constitute more than 10 percent of the total rock mass; with the argillite that intervenes, they support a ridge whose summits are more than 3,000 feet above sea level.

A few miles to the northwest is a parallel belt of rhyolite intrusive rocks that extends from the Aniak River to Barometer Mountain. In this belt the argillite is discontinuous and occurs near individual bodies of rhyolite. Similar relationships occur in a discontinuous belt that extends from Barometer Mountain northwest to Juninggulra Mountain and thence northeastward again along the southeast side of Donlin Creek, and also in the vicinity of the Little Taylor Mountains. Numerous other isolated bodies of the rhyolite are locally bordered by argillite.

As the borders of the argillite are poorly defined and no attempt was made to trace them, the argillite is not differentiated from the Kuskokwim group on the geologic map.

PETROGRAPHIC CHARACTER

MEGASCOPIC FEATURES

Argillite is by far the most common rock. It ranges from light gray to dark gray and brown and is mottled in many places, owing to differential alteration effects along joint planes. It is sufficiently indurated that parting commonly fails to follow bedding planes. The typical rock breaks into subrectangular fragments along joint planes. Bedding is identifiable in some places but is commonly obliterated. Metamorphic effects are not sufficient in most places to change the original texture of the rocks appreciably; thus fine-grained shale becomes fine-grained massive argillite. Pyrite and carbonates are the secondary products most readily identified in hand specimens, though they are not the most characteristic. The hard, flinty character of the metamorphosed rock reflects the widespread occurrence of secondary quartz. Pyritization is commonly indicated by abundant iron stain.

MICROSCOPIC FEATURES

Secondary quartz is the most characteristic mineral of the argillite. At some localities carbonate is abundant; elsewhere sericite, pyrite, and chlorite are the predominant alteration products.

The original clastic texture of the sedimentary rocks is in most places still plainly visible; secondary quartz merely fills in as extremely fine grains in the interstices between the sedimentary grains. Only in extremely fine-textured rocks are the original structures obliterated. Original grains of feldspar and quartz and fragments of chert and shale are only slightly altered. Sericite has commonly formed from the argillaceous constituents. Metamorphism, therefore, can be considered as incipient, and at only a few places in this region have the rocks been so thoroughly altered as to obliterate the original constituents.

The argillite is apparently on outward continuation of alteration effects within the intrusive bodies of albite rhyolite. These effects have been discussed in the section of this paper that deals with igneous rocks.

LOCAL PETROGRAPHIC DETAILS

Fine-grained, light-gray, well-indurated argillite from the high ridge at the head of Kogoyuk Creek is rather typical. It is made up principally of fine-grained micaceous material alined subparallel to the bedding. A pattern of small circular spots, one-tenth to one-half millimeter in diameter, is formed in this material. The centers of the spots are extremely fine-grained and grade outward into coarser grained sericite. Leucoxene grains are concentrated in the centers of the spots, in bands that parallel the original bedding. Patches of carbonate are distributed throughout a thin section and replace the micaceous material, and biotite fills joints that cross the section. A specimen from the ridge south of Kogoyuk Creek is composed entirely of sericite and chlorite. Although this is one of the most highly altered specimens found in the area, the clastic character is still apparent.

Argillitic graywacke from the ridge south of Camp Creek, near Holokuk Mountain, is silicified, but quartz and feldspar, which make up the greater part of the fragmental material, are practically unaltered. Specimens of pyritized argillite were found about half a mile down the Holokuk River from the mouth of Camp Creek. The pyrite is evenly disseminated throughout the argillaceous material and probably has been introduced hydrothermally.

Altered graywacke from the Little Taylor Mountains shows considerable amounts of very fine grained quartz and rather coarse grained sericite, between fragments of quartz, feldspar, chert, and shale.

A fine, silty shale from the Donlin Creek area is highly indurated. A myriad of minute crystals of biotite form a groundmass in which are spherical bodies composed of extremely fine-grained aggregates of quartz. The coarsest quartz grains are near the centers of the spots. The biotite is probably an effect of recrystallization of the argillaceous constituents of the shale, and quartz aggregates may have formed either by recrystallization of quartz present in the original sedimentary rocks, or by introduction of silica, or both. Biotite has formed spherules in another specimen of altered silty shale; these aggregates of biotite are in turn partly replaced by coarse-grained quartz.

HORNFELS

AREAL DISTRIBUTION

Aureoles of metamorphic rocks, chiefly hornfels, occur adjacent to the contacts of the stocks in the Taylor, Chuilnuk, Kiokluk, Henderson, Horn, and Russian Mountains. Exposures of these zones range from less than 1,000 feet to a little more than 3 miles in width, but their maximum true thicknesses at right angles to the contacts of the stocks are about 5,000 feet. The greater apparent widths are produced by the relatively gentle dips of the contacts. This is particularly true of the contact-metamorphic aureoles adjacent to the stocks in the Taylor, Chuilnuk, and Kiokluk Mountains.

The latter contact aureoles are also more prominent than those adjacent to the stocks in the Russian and Horn Mountains. The effects of metamorphism appear more common around the Taylor, Kiokluk, and Chuilnuk stocks, but the difference is partly due to the greater difficulty of recognizing them in the basalt flows that border the Horn and Russian Mountains. It is possible that rocks exposed at the borders of the stocks in the Taylor, Chuilnuk and Kiokluk Mountain are more highly metamorphosed because they lie on the tops of the stocks rather than at their sides.

The hornfels is better indurated than unmetamorphosed graywacke and shale and resists erosion as well as, or in places better than the igneous rocks. It is thus contained within the outer borders of the mountains.

PETROGRAPHIC CHARACTER

MEGASCOPIC FEATURES

The hornfels, some of which is dense, massive, highly indurated, and completely recrystallized rock, grades into slightly altered bedded graywacke and shale. It is typically gray, dark gray, black, or dark brown.

The texture is largely dependent upon the amount of alteration and whether the original rock was fine- or coarse-grained. The fine-grained graywacke and shale become flinty- and the coarser graywacke sugary-textured. Bedding can be traced in the less metamorphosed rocks, but those that are more altered are commonly enough indurated to favor parting or fracturing along a network of joint planes (fig. 28) rather than

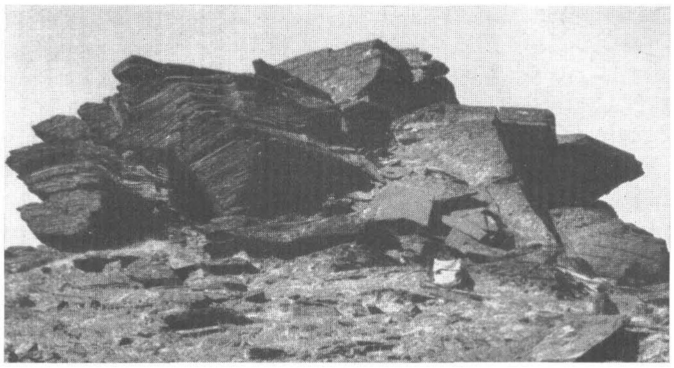


FIGURE 28.—Outcrop of hornfels in contact-metamorphic zone north of Taylor Mountain stock, showing strong jointing transverse to bedding of the metamorphosed shale and graywacke of the Kuskokwim group.

along bedding planes, and thus the bedding is not as clear. The bedding is completely obliterated and the rock is massive and dense, commonly dark-gray to black where metamorphism is most intense. Such hornfels was mistaken for basalt at several places, and its true identity was discovered only by microscopic examination.

Metacrysts approximately one millimeter in diameter are formed in some of the hornfels and give it a porphyroblastic texture. The metacrysts are best formed near the stocks and apparently mark the most intense metamorphism in the region.

Igneous rocks, chiefly basalt flows that border some of the stocks, have been altered, but it is difficult to distinguish them in the field from unaltered basalt.

MICROSCOPIC FEATURES

The minerals of the hornfels and the finer details of texture are commonly indistinguishable except under the microscope. Quartz and biotite are the most common minerals. Less abundant are cordierite, chlorite, amphibole, sericite, pyroxene, clinozoisite, tourmaline, orthoclase, plagioclase, graphite, carbonates, limonite, apatite, magnetite, and titanite. The latter three are unaltered survivors of the mineral assemblages of the original sedimentary rocks, but all the others are to a varying degree products of metamorphism.

The hornfels was originally graywacke and shale composed of angular fragments of quartz, feldspars, chert, carbonaceous shale, biotite, muscovite, magnetite, and fine argillaceous material. The first change in incipient stages of metamorphism was evidently the development of fine-grained biotite, which enlarged under more intense metamorphism. The fine-grained, opaque, carbonaceous material probably recrystallized to graphite in the early stages of metamorphism, but in only a few localities is the material coarse enough to identify as such. Quartz began to recrystallize in later stages, and the clastic grains were obliterated by formation of sutured and interlocking grain borders. A few specimens suggest that even before the clastic character of the rock was completely disguised, a porphyroblastic texture was formed by extensively developed metacrysts of cordierite. The cordierite metacrysts have most commonly engulfed minute biotite and quartz crystals as they developed, but in some places the metacrysts appear to have pushed the other crystals aside. The greatest development of the cordierite metacrysts was accompanied by complete disappearance of the original clastic texture. In some places this marks the highest grade of metamorphism reached. Presumably the rocks in which cordierite has developed originally contained abundant kaolin or other alumina-rich minerals. They have been found only in the contact metamorphic aureole of the Taylor Mountains.

Cordierite is absent, however, in some of the rocks that have undergone metamorphism sufficiently intense to obliterate all vestiges of the clastic texture; the principal changes in these rocks were the further development of biotite and recrystallization of the quartz into a fine mosaic of interlocking grains. A poikiloblastic texture, characterized by many small pyroxene, sericite, biotite, and other indeterminable mineral grains that are enclosed in quartz, occurs in some rocks. This feature possibly marks the highest grade of metamorphism of alumina-poor rocks. The overall textures are typically hornfelsic.

A small amount of material may have been introduced by the intruding magma that later crystallized to form the stocks. Traces of chlorite, tourmaline, feldspars, and carbonate, principally calcite, but possibly also ankerite, may contain introduced material. That is probably about the extent of metasomatism attributable to the intrusion of the stocks.

The most intense metamorphism corresponds to the low-medium grade as described by Harker (1939, p. 51–57). The intensity of metamorphism, as might be expected, decreases outward from the contacts of the stocks toward unaltered graywacke and shale.

LOCAL PETROGRAPHIC DETAILS

The metacrysts of cordierite in the hornfels of the Taylor Mountains are circular to elliptical in cross section and, where elliptical, trend parallel to the bedding planes. Multiple twinning is common in the circular metacrysts and forms a cross pattern within them. Foreign material in the cordierite may be concentrated in the centers of the metacrysts whereas the borders remain relatively clear. Biotite that borders the cordierite has in some specimens been altered to relatively large plates of secondary muscovite. In rocks that appear to be the most highly metamorphosed the groundmass between relatively clear cordierite metacrysts is spotted with numerous small incipient cordierite crystals that suggest a second generation of metacrysts. Some secondary quartz occurs, but it is relatively scarce.

Specimens from the contact zone at the border of the Chuilnuk Mountain stock show only incipient metamorphism, with the formation of biotite and slight recrystallization of quartz. Sedimentary rocks composed predominantly of quartz have recrystallized to impure quartzite with interlocking grains of quartz, biotite, and magnetite.

Several specimens that were taken at and immediately adjacent to the contact of the Kiokluk Mountain stock show alteration of both the sedimentary rock and the igneous rock of the stock. Relict structures and some original minerals remain in both, but the rocks are made up predominantly of a very fine grained mosaic of biotite, quartz, feldspar, and clinozoisite. The identification of the clinozoisite is questionable because of the small size of the grains present. Chlorite and abundant opaque minerals occur in the metamorphosed sedimentary rock. The texture of the igneous rock a few feet from the contact is poikiloblastic, with a myriad of small euhedral and subhedral grains of biotite, quartz, feldspar, and pyroxene superimposed on a background of larger crystals.

STRUCTURAL GEOLOGY

The large structures of the central Kuskokwim region (see pl. 1) are chiefly to be described here. Many structural details, as well as the age relationships of structures, are necessarily described in sections where thickness and stratigraphic relationships, and local details of the bedded rocks are discussed. The structural relationships of the intrusive rocks to the formations that enclose them have also been discussed in foregoing sections.

Interpretations of interregional structural relationships presented here are based on studies by Cady of the geologic literature and aerial photographs of several regions adjacent to the central Kuskokwim region, and on field work by Hoare in the lower Kuskokwim-Togiak-Goodnews region to the southwest, as well as on the results of work within the central Kuskokwim region.

GEANTICLINES AND GEOSYNCLINES

The major geanticlinal elements of the structural framework of Alaska, and the intervening geosynclines, plunge southwest in the vicinity of the central Kuskokwim region (pl. 2). They are chiefly of middle to late Mesozoic age in this part of Alaska. The axis of the Kuskokwim geosyncline coincides approximately with the northeast trend of the Kuskokwim Mountains. The Aniak-Ruby geanticline lies northwest of the Kuskokwim geosyncline and the Alaska-Yukon geanticline to the southeast. The Kuskokwim geosyncline widens in the southern part of the central Kuskokwim region and merges with the Yukon-Koyukuk and Alaska Range geosynclines, respectively, across the southwestward plunging ends of the Aniak-Ruby and Alaska-Yukon geanticlines.

Evidence presented in the discussion of bedded rocks places the first appearance of the Aniak-Ruby and Alaska-Yukon geanticlines in late Early Cretaceous time. Their appearance was followed by continued geanticlinal uplift and geosynclinal subsidence through at least the middle of the Late Cretaceous epoch. The rocks of the geanticlinal tracts are commonly of Early Cretaceous age or older. They are overlapped marginally by unconformable Upper Cretaceous strata, that in the direction of the axes of the geosynclinal tracts are progressively more conformable with the older rocks beneath. An angular unconformity is rarely found beneath the Upper Cretaceous strata. Instead it is commonly a regional unconformity, with no appreciable local structural discordance. Vertical movements that produced the broad geanticlinal uplifts and geosynclinal downwarps were probably responsible for this unconformity.

FOLDS

The folds occur most profusely in the late Mesozoic geosynclinal deposits. The Kuskokwim Mountain orogen is a typical system of these folds; it affects chiefly the Upper Cretaceous strata of the Kuskokwim group deposited in the Kuskokwim geosyncline, and is believed to have formed in earliest Tertiary time. The orogen, like the geosyncline in which it formed, trends northeast coincident with the Kuskokwim Mountains. Chevron folds, whose opposite limbs meet at an angle at the fold axes instead of in a smooth curve, are most typical of the Kuskokwim group. The axial zones of these folds are commonly complicated by numerous small faults and intricate smaller and commonly disharmonic folds, but the limbs of the larger folds are homoclines that dip rather uniformly. The folds in the lower part of the Kuskokwim group and in the Gemuk and Holitna groups are more smoothly flexured. This is probably because of the greater confining load under which they formed. The folds have been identified on the ground by observation of the dip and strike of the strata, and on aerial photographs by the patterns of characteristic lineaments.

The folds tend to parallel the margins of the geanticlines. This is particularly true of the folds near the borders of the orogens. Although the axes of the geanticlines and geosynclines are all nearly parallel, the margins of each of the geanticlines converge southwestward in the direction of plunge, with the result that the folds in the geosynclinal tracts diverge in the same direction. Those near the Alaska-Yukon geanticline actually trend southeast across the southwest end of this geanticline at right angles to the trend of the structural framework, as in the vicinity of the Taylor Mountains.

Between the divergent sheaves of folds described above, and a little southeast of the center line of the Kuskokwim Mountain orogen in the southern half of the central Kuskokwim region, is the Gemuk anticlinorium. Lower Cretaceous and earlier rocks of the Gemuk group are exposed along the axis of this anticlinorium, from the vicinity of the Kiokluk Mountains southwest to the Gemuk River and beyond. The succession of strata in the Gemuk anticlinorium differs from that in the geanticlines in that it is unbroken, and the Kuskokwim group probably lies altogether on Lower Cretaceous formations of the Gemuk group, rather than upon a variety of formations whose age may range from Ordovician to Early Cretaceous. This is believed to be largely because the anticlinorium was folded in the geosynclinal belt of subsidence after the Upper Cretaceous geosynclinal rocks were laid down, whereas the geanticlines were uplifted and erosionally dissected before and during deposition of the geosynclinal rocks. The Gemuk anticlinorium plunges northeastward in the area southwest of Sleetmute, where the folds on the flanks of the anticlinorium converge to the northeast. It continues southward into the area of the Tikchik Lakes south of the central Kuskokwim region, where, like the smaller folds to the east, it wraps around the southwestward-plunging end of the Alaska-Yukon geanticline.

The northwest limb of the Gemuk anticlinorium includes a thick section of the strata of the Kuskokwim group transected by the Holokuk River. Northwest of this section are about half a dozen parallel synclines and anticlines that strike northeast. To the northeast, on the other hand, in the area between the headwaters of Crooked Creek and Sleetmute, the fold axes strike northwest instead of northeast, and thus trend at right angles to the regional fold pattern for a distance of about 40 miles. These anomalously oriented folds may possibly be attributed to a geanticlinial spur, buried beneath the Kuskokwim group in the George River area, which has produced, on a smaller scale, a radical change in the orientation of folds comparable with that at the plunging nose of the Alaska-Yukon geanticline in the area southeast of the Holitna River.

The folds are believed to have been produced in earliest Tertiary time by horizontal compression of the structurally weak geosynclinal accumulations between the more competent geanticlinal elements of the structural framework. The geanticlines seem to have been simply crowded closer together from all directions, so that their ends have plowed into the geosynclinal accumulations to produce a fold pattern resembling that of the bow wave in front of a barge.

FAULTS

GENERAL RELATIONS

The faults, which are chiefly of Quaternary age and apparently still active, strike east-northeast and transect the folds of the Kuskokwim Mountain orogen. The principal faults are probably continuous to the northeast, at the northern foot of the Alaska Range and in the upper Kuskokwim River region, with faults that intersect the Alaska-Yukon geanticline. They are deflected into parallelism with the pattern of folds in the Kuskokwim Mountain orogen, toward their southwest ends. They are possibly also continuous to the southwest with faults in the Tikchik and Togiak regions.

Their straight linear traces seem to indicate that most of the faults are either normal faults or high-angle reverse faults, although thrust faults with fairly straight linear traces have been recognized. The Sleetmute surface is commonly well preserved, except near streams, in areas on the downthrown sides of the faults, and is more or less completely dissected from areas on the upthrown sides. Evidently the movement has been up relative to base level on both sides of the faults, but at a greater rate on the side that is most thoroughly dissected. The faults are best seen from the air and most of them are well shown on aerial photographs, either by the streams that follow them or by traces in the surficial deposits accentuated by vegetation. The surficial deposits show the fault traces quite effectively, because small fault scarps are formed in the deposits as a result of recent movement. Most of the faults in the central Kuskokwim region are upthrown to the northwest. This seems to be accentuated in the mountains of the Tikchik and Togiak regions, southwest of the central Kuskokwim region. These mountains, which lie chiefly to the northwest and west of the probable southern extension of the southeasternmost major fault zone, are higher than those northwest of the faults in the central Kuskokwim region.

DETAILED DESCRIPTIONS

Several major faults are designated by name on plate 1. These faults and some minor faults are described below. Those to the north are discussed first.

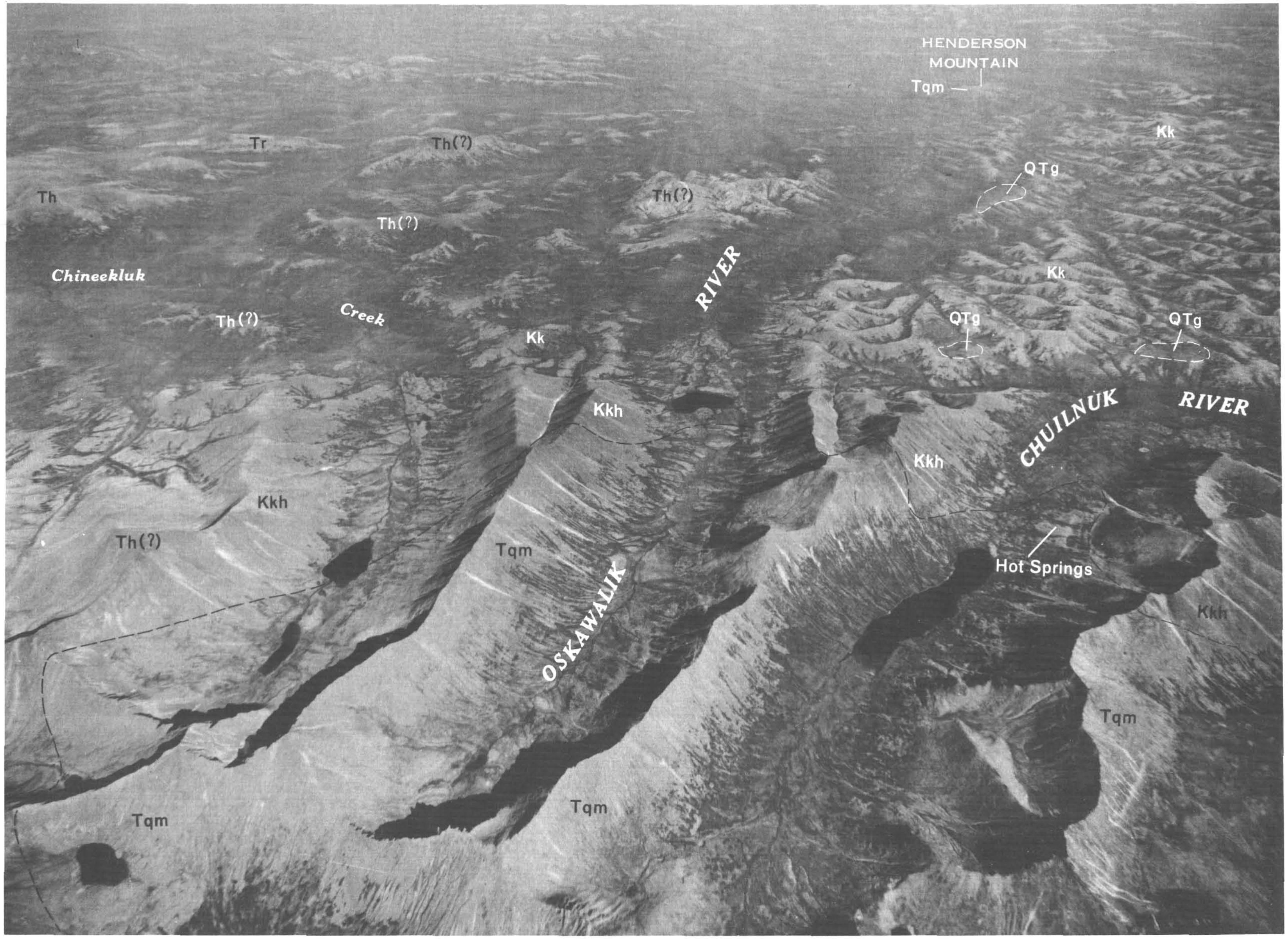
IDITAROD FAULT

The course of the Iditarod River in the central Kuskokwim region is believed to follow a fault zone that extends northeastward far beyond the confines of the region, and to the southwest along the Owhat River at least to its junction with the Kuskokwim River, a little east of Aniak. The Owhat and Iditarod Rivers are part of a great lineament noted by Mertie (Mertie and Harrington, 1924, p. 7, 76–77) that follows Bonanza Creek, the headwaters of Moore Creek and Fourth of July Creek, and segments of the Takotna River and Nixon Fork of the Takotna River in areas northeast of the central Kuskokwim region. Along the Nixon Fork, near the northeast end of the fault zone, Upper Cretaceous rocks equivalent to the Kuskokwim group lie to the northwest of the fault, and Ordovician, Silurian, and Devonian strata equivalent to the Holitna group lie to the southeast; thus the upthrown side is to the southeast (Brown, 1926, p. 120–123). At the southwest end of the fault zone on the other hand, along the Owhat River, the upthrown side is to the northwest, inasmuch as greenstones, probably of Carboniferous age and equivalent to part of the Gemuk group, lie to the northwest, and the Upper Cretaceous rocks of the Kuskokwim group lie to the southeast.

This extensive fault zone might therefore be described as a great scissors fault. The point where the up-

AERIAL VIEW OF THE TAYLOR MOUNTAINS, LOOKING SOUTH TOWARD THE NUSHAGAK HILLS, CENTRAL KUSKOKWIM REGION, ALASKA

The granite stock (*Tqm*) in the Taylor Mountains is near the center of the picture; it is bordered by a contact-metamorphic zone of hornfels (*Kkh*) in adjacent portions of the interbedded graywacke and shale of the Kuskokwim group (*Kk*); a roof pendant of the metamorphic rocks forms the summit peak of the Taylor Mountains. Glacial moraines and outwash gravels (*Qg*) almost surround the mountains. Sheets, sills, and dikes of albite rhyolite (*Tr*) probably lie in the middle distance, south of the Taylor Mountains. Silts (*Qs*) appear to be extensive in the valley of lower Kiknik Creek. (Photograph by U. S. Air Force.)

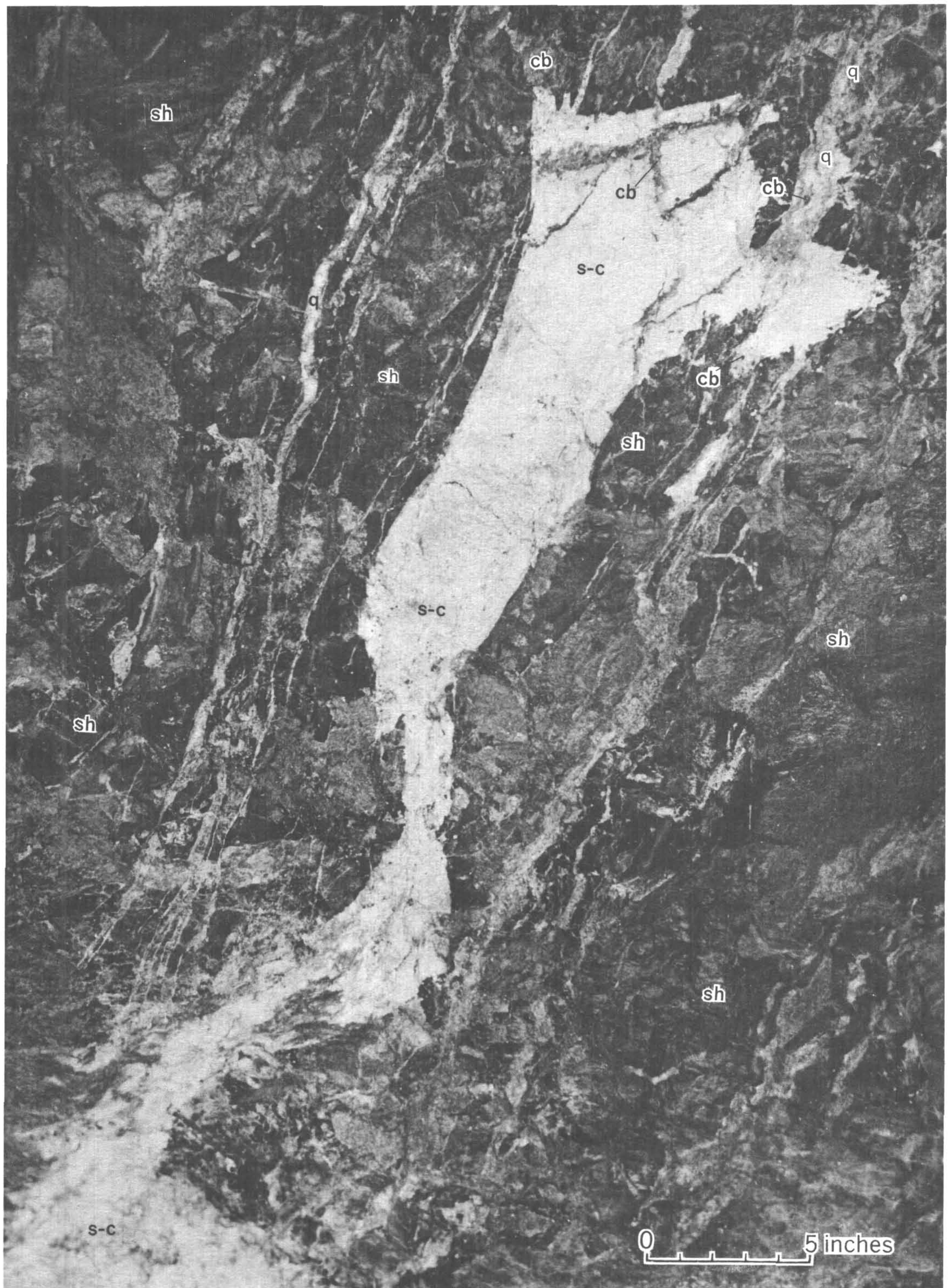


AERIAL VIEW OF THE NORTH SLOPE OF THE CHUILNUK MOUNTAINS, LOOKING NORTH OVER THE OSKAWALIK VALLEY, CENTRAL KUSKOKWIM REGION, ALASKA

The Chuilnuk Mountain fault forms a sharp line of demarkation, at the north foot of the mountain and a little above the center of the picture, between mature glacial topography in the mountains and the late-mature topography of the Sleetmute upland surface in the hills to the north. Dashed line shows approximate position of the borders of the stock (*Tqm*) in the Chuilnuk Mountains. Upland benches, covered by gravel (*QTg*) that contains boulders and pebbles of granitic rock eroded from the Chuilnuk Mountain stock, are enclosed by a dotted line. Contact metamorphic rocks (*Kkh*) occur in much of the area between the stock and the Chuilnuk Mountain fault. An albite rhyolite sheet (*Tr*) and the Holokuk basalt (*Th*) are also pointed out. The Kuskokwim group (*Kk*) constitutes the sedimentary bedrock in the area of the picture. (Photograph by U. S. Air Force.)

AERIAL VIEW OF THE HOLITNA FAULT, LOOKING NORTH FROM MUKSLULIK CREEK TOWARD THE HOLOKUK RIVER, CENTRAL KUSKOKWIM REGION, ALASKA

The rolling late-mature Sleetmute surface is in the foreground, southeast of the fault, and a fault block, uplifted and maturely dissected by the Boss valleys, occupies the central part of the view; the Boss Creek fault forms the northwestern boundary of the fault block. Circle at lower left is centered on lobe in the scarp of the Holitna fault, pictured in left foreground of figure 29. (Photograph by U. S. Air Force.)



SILICA-CARBONATE ROCK EXPOSED AT THE RED DEVIL MINE, SLEETMUTE AREA, CENTRAL KUSKOKWIM REGION, ALASKA

The silica-carbonate rock (*s-c*) trends roughly parallel to the bedding of the shale (*sh*), which is heavily fractured and locally brecciated; vein quartz (*q*) fills the openings in the shale, and cinnabar (*cb*) occurs in veins and irregular openings within and at the contacts of the silica-carbonate rock.

thrown block shifts from the southeast to the northwest side is probably about at the divide from which the headwaters of Moore Creek flow northeast, and of Bonanza Creek flow southwest (Mertie and Harrington, 1924, pl. 2. Fourth of July Creek flows on the southeast side of its valley (Mertie and Harrington, 1924, pl. 9, *B*), as might be expected on a surface tilted southeastward against an upthrown block. Bonanza Creek and the Iditarod and Owhat Rivers, on the other hand, show exactly the opposite relations and now appear to be cutting laterally northwestward. Moreover, the amount of erosional destruction of adjacent portions of the Sleetmute surface reflects the scissors movement. This surface appears to be fairly well preserved in the area of the divide between the headwaters of Moore and Bonanza Creeks, where differential movement has presumably been least, but it is much more deeply redissected west and northwest of the fault in the upper Iditarod-Owhat River area. The opposite may be said of the area along the Nixon Fork of the Takotna River, where the most rugged terrain is southeast of the fault zone, which is marked by a well-defined northwestward-facing escarpment. (U. S. Geol. Survey, Medfra sheet, 1950).

ATSAKSOVLUK FAULT

A fault may be traced northeastward, along the northwest side of the valley of Atsaksovluk Creek, from the vicinity of Flat Top Mountain to the headwaters of the Buckstock River. The fault trace is in surficial deposits, at the foot of the steep southeastern slope of the mountains along the divide between Atsaksovluk Creek and the headwaters of Timber Creek. A northeastern continuation of this fault possibly occurs a little northwest of the divide between the headwaters of Girl Creek and the Holokuk River. The trace of the fault is very straight, even in areas of considerable relief, and the dip of the fault plane is probably almost vertical. The northwest side of the fault is upthrown relative to the southeast side. The principal evidence for this is the fact that the Sleetmute surface has been completely eroded from much of the mountain area immediately northwest of the fault, whereas this surface is comparatively undissected in the low area less exposed to erosion southeast of the fault in the basin of Atsaksovluk Creek.

The altitude of the Sleetmute surface southeast of the fault is about 1,500 feet, and the higher summits of the mountains northwest of the fault are at altitudes of about 3,500 feet. The difference in elevation of about 2,000 feet is a fair measure of the minimum displacement. The actual displacement on the fault is probably not a great deal more, inasmuch as remnants of the Sleetmute surface are preserved within 5 miles to the northwest of the fault and, moreover, fault movement has failed to produce appreciable stratigraphic displacement, such as might show up as offsets in the pattern of the areal geologic map. Remnants of the Sleetmute surface show up in areas immediately northwest of the fault, both to the southwest, in the direction of Flat Top Mountain, and to the northeast, toward the Buckstock River. It is therefore inferred that displacement decreases both to the southwest and northeast, along the fault, from a central point about coincident with the highest summits. The uplift across the head of the Buckstock River is shown by the modifications of the drainage pattern in that area indicated in the discussion of geomorphology. Although insufficient to cause destruction of the Sleetmute surface, the uplift was enough to cause defeat of the headwaters of the Buckstock River and their capture by Atsaksovluk Creek and the Holokuk River.

HOLOKUK FAULT

The mountainous belt northwest of the headwaters of the Holokuk River was probably uplifted on a fault that follows the headwaters of the river. A fault trace continues eastward into the northwestern foothills of the Kiokluk Mountains, where there are several small faults. As in the Atsaksovluk Creek area, the Sleetmute surface is fairly well preserved southeast of the fault, but destroyed to the northwest. The difference in elevation between the Sleetmute surface on the downthrown block to the southeast, and the highest summits on the upthrown block to the northwest, is somewhat less than in the case of the Atsaksovluk fault; thus the minimum displacement on the Holokuk fault is probably in the neighborhood of 1,500 feet.

CHUILNUK MOUNTAIN FAULT

A fault trace at the north foot of the Chuilnuk Mountains (pl. 7) perhaps marks the northeastern continuation of the fault zone in the northwestern foothills of the Kiokluk Mountains. The north side of the fault is possibly the upthrown side. Part of the headwaters of the Oskawalik River have been captured by the Chuilnuk River, which has eroded headward along the northeastern foot of the Chuilnuk Mountains (see p. 98). It seems rather likely that the capture might have been assisted by uplift of the area north of the fault to cause defeat of the headwaters of the ancestral Oskawalik River.

BOSS CREEK FAULT

This fault extends east-northeast from the vicinity of Flat Top Mountain, parallel to Atsaksovluk Creek and across the head of Boss Creek, and may continue along the lower southeast slopes of the Chuilnuk

Mountains out into the lowlands of the Holitna and Kuskokwim Rivers. Between the Boss Creek fault and the Atsaksovluk and Holokuk faults to the northwest is a graben left between the two fault zones when the areas beyond the fault zones, both to the southeast and the northwest, were uplifted. Because of failure of strong uplift in this intervening belt, rejuvenation of drainage has caused only partial redissection, and the Sleetmute surface is preserved in areas along the stream divides. A horst from which the Sleetmute surface has been eroded is southeast of the Boss Creek fault. It has been produced by uplift of the belt between the Boss Creek fault and the Holitna fault next southeast (see fig. 30).

The trace of the Boss Creek fault is very straight and the fault plane is probably nearly vertical. The altitude of the summits of the peaks southeast of the fault at the eastern headwaters of Boss Creek is about 3,000 feet, and that of the Sleetmute surface northwest of the fault in the graben is about 1,500 feet; thus the minimum displacement in this vicinity is about 1,500 feet. Farther southwest on Oksotalik Creek the summits are at altitudes of less than 2,500 feet and displacement less than 1,000 feet. The actual uplift of the horst in the area where the Sleetmute surface has been completely eroded from it has been greater than the difference in altitude between its highest peaks and that of the Sleetmute surface in the graben. This area extends 10 miles both to the northeast and southwest of the zone of greatest movement in the vicinity of Boss Creek.

The Boss Creek fault is almost directly in line with a fault that extends southwestward from the northwest foot of the Alaska Range near Farewell (pl. 2). The Farewell fault may be traced southwestward on the aerial photographs to within 25 miles of the Stony River or about 80 miles from Farewell. The distance from the Stony River to unquestionable fault traces southeast of the Chuilnuk Mountains is about 60 miles. The gap between recognizable fault traces is covered almost continuously by surficial deposits. It is believed that in this gap the fault probably accounts for an apparent southwestward offset in the contact between the limestones of the Holitna group along the axis of the Alaska-Yukon geanticline on the east, and the graywackes and shales of the Kuskokwim group that overlap the western flank of the geanticline. The offset is believed to be produced in that area, on the western flank of the geanticline, by westward "down-dip" shift of the contact between the Holitna group and the overlying Kuskokwim group with progress of erosion, in response to uplift southeast of the fault. Such uplift of the southeast side of the fault in the Stony River—Chuilnuk Mountain interval is compatible with uplift of the horst southeast of the Boss Creek fault in the Kuskokwim Mountains.

HOLITNA FAULT

The Holitna fault (pl. 8) is the most spectacular in the region. It is at least 45 miles long, it marks the boundary between the Kuskokwim Mountains uplifted on the northwest and the lowlands of the Holitna River basin on the southeast, its trace is readily recognized on the ground as well as from the air, and it shows the best evidence of recent movement.

The trace may be followed northeastward from the Gemuk River nearly to Portage Creek without a break. The fault possibly continues south into the Tikchik Lakes area, south of the central Kuskokwim region, where Hoare has recognized a major fault in the course of recent ground surveys. To the northeast the fault seems to end abruptly against a group of hills southwest of the course of Portage Creek. The Holitna fault bounds the southeast side of the horst described above in the discussion of the Boss Creek fault, and the rugged topography of the Boss valley terrain on the horst contrasts clearly with the smoothly rounded contours of the Sleetmute surface in the Holitna River basin (pl. 8, fig. 30).

The fault trace was examined to good advantage on the ground near the head of Mukslulik Creek (fig. 29.) Here it is not actually as straight as it appears on first glance at the aerial photographs, and there is enough relief to show that it is the trace of a reverse fault that dips northwest beneath the horst. The trace curves southeastward and upward at the foot of the mountain spurs and northwestward down into the intervening valleys. By standing on the trace at the crest of one spur and looking across to the trace on the next spur, and also noting its position in the intervening valley, the field party was able to estimate the approximate dip of the fault plane. The fault was thus found to dip at an angle of between 20° and 30° to the northwest on Mukslulik Creek. The trace is marked by a southeastward-facing scarp in the surficial deposits that is as much as 20 feet high. Winter snows accumulate to greater depths at the southeastern foot of the scarp, and linger in summer, forming wet strips that are marked locally by growths of alder bushes. The scarp is commonly irregular in detail and characterized by lobes that protrude southeastward downslope. These lobes are believed to have been produced by the creep, assisted downhill by frost action, of surficial deposits that had been raised into an unstable position by upthrow on the northwest side of the fault.

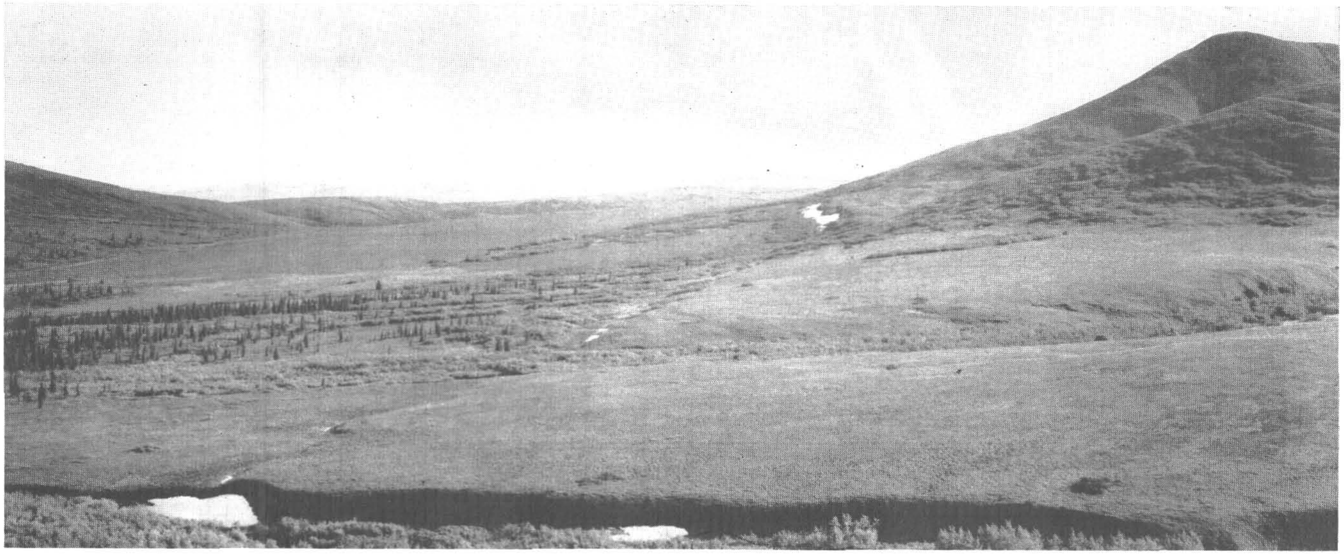


FIGURE 29.—Holitna fault at the southeastern front of the Kuskokwim Mountains. The fault scarp faces southeast and trends southwestward in this view, across the headwater tributaries of Mukslulik Creek. Lobe of scarp in left foreground produced by creep of surficial deposits lifted to unstable position by fault movement. The lobe shows within the circle at lower left of plate 8.

OTHER FAULTS

Small faults were seen in the bedrock in many areas, particularly in cut-bank exposures along the rivers, and in mine openings. One of the best exposed faults is in the bluffs north of the Holitna River, 9 miles northeast of Nogamut. Here the limestone of the Holitna group is thrust southwestward up over the shale and graywacke of the Kuskokwim group. The fault is marked by a shear zone about 5 feet thick comprising ground-up fragments of the graywacke and shale. The bedding of the Kuskokwim group beneath the shear zone dips gently northeast. The limestone above the shear zone is intricately folded to form sharply crenulated drag folds that plunge gently northeast in the direction of dip of the fault. This fault is possibly an effect of local adjustment, at the contact between the competent limestones and less competent graywacke and shale that accompanied folding in earliest Tertiary time, rather than an effect of movement in the Quaternary, when the major faults already described were formed. Many of the smaller faults were probably formed in connection with folding. The faults that border the Horn Mountains have already been described in the discussion of the Holokuk basalt. They are possibly older than the major faults and formed in middle or late Tertiary at the time of emplacement of the stock in the Horn Mountains.

GEOMORPHOLOGY

The landscape of the central Kuskokwim region has been carved by several processes of weathering and erosion. Depositional features of the landscape, such as glacial and flood-plain deposits, are described on pages 56–61.

The processes of denudation most active in the region are frost action and stream erosion; glacial erosion has taken place locally.

Frost action predominates in the central Kuskokwim region, probably because of two significant factors: (1) freezing and thawing recur frequently during a large part of the year and (2) lightness of precipitation forestalls glacial action and checks growth of a protective covering of vegetation. There are large areas in which stream erosion and deposition are at a minimum, where the residual deposits formed by frost action are neither eroded away nor buried, but accumulated, and freezing and thawing alone may remain in full play.

The subarctic climate of high latitudes favors frequent freezing and thawing, particularly during spring and fall when the ground is not overlain by a protective covering of snow. Precipitation is relatively light, owing to the position of the region in the climatic lee of the large dry continental land mass of Asia, source of the prevailing winds which blow over interior Alaska. In this relation the Asian land mass, is effectively continuous with North America during winter, when the Bering Sea is frozen over. Stream erosion and deposition are subordinate to frost weathering in large areas, probably because the region as a whole is comparatively stable and has undergone relatively small amounts of uplift leading to rejuvenation of streams, and subsidence resulting in aggradation by streams.

Locally, however, frost action is, overshadowed by the other processes. Differential uplift, still going on, has promoted complete stream dissection of much of

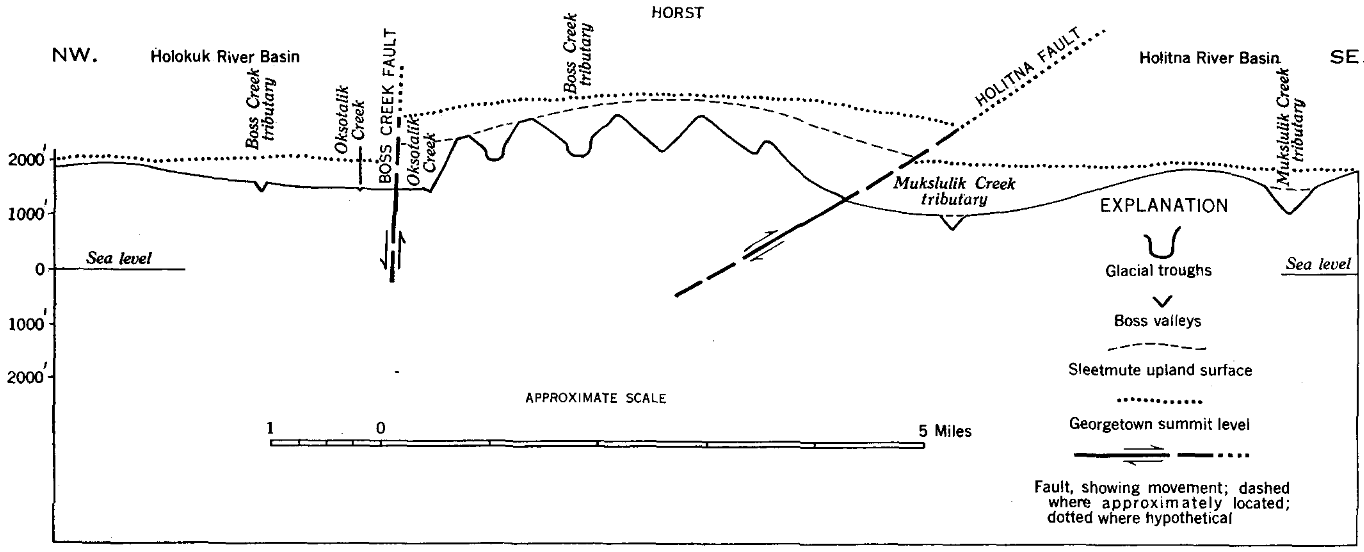


FIGURE 30.—Diagrammatic profile from the Holokuk River basin to the Holitna River basin to illustrate the succession of denudational surfaces and their relation to differential uplift in the central Kuskokwim region.

the area of the Kuskokwim Mountains northwest of the upper Holitna River. Glacial erosion took the place of frost action for a time in the various isolated higher mountain groups that supported perennial snows. Frost weathering has begun to reassert itself however in the glaciated mountain areas, and has also taken over on slopes where stream action has lagged with cessation of differential uplift.

The geomorphic features produced by denudation include a general upland summit level, a late-mature upland surface whose highest points are at the summit level, and valleys of rejuvenated streams incised below the upland surface. These are referred to respectively as the Georgetown summit level, the Sleetmute upland surface, and the Boss valleys. Glacial troughs occur in isolated groups of higher mountains that rise above the Georgetown summit level. The succession of these denudational surfaces is illustrated in figure 30.

GEORGETOWN SUMMIT LEVEL

DISTRIBUTION

The general summit level in extensive areas of the Kuskokwim Mountains, chiefly north of the Kuskokwim River and southeast of the Holitna River in the Nushagak Hills, is at altitudes of 2,000 to 2,200 feet above sea level. The best examples are Twin Buttes, Lookout Mountain, and several other summits along the Georgetown Trail, which takes a course north from Georgetown, on the divide between the George River and Crooked, Donlin, and Little Eldorado Creeks. Summits between the forks of the George River, and in areas a little south of the Kuskokwim River between Sleetmute and Oskawalik, are mostly in this range of altitudes. So also are most of the summits in the Nushagak Hills, as well as those along the Chukowan River in the southwestern part of the Holitna River basin.

The summit level may be traced far beyond the limits of the central Kuskokwim region. Topographic maps (Mertie and Harrington, 1924, pls. 1, 2) show that it extends for more than 125 miles northeast from the headwaters of the George River, between isolated higher mountain groups in the area between the Innoko and Kuskokwim Rivers. Accordant summits are also traceable from the Nushagak Hills eastward to the western foot of the Alaska Range. Although they become higher in that direction and reach altitudes of more than 3,000 feet (U. S. Geol. Survey, Taylor Mountains and Lake Clarke sheets, 1951) the change of level is gradual and imperceptible to the casual observer.

CHARACTER AND ORIGIN

The Georgetown summit level refers simply to the closely accordant altitudes of the summit peaks and ridges. The summits are probably all that is left of a widespread, broadly undulating surface in old age, with perhaps 200 feet of relief. Some of the summits are flat on top, and, though a few of the flat tops may be remnants of the old-age surface, it seems doubtful that flatness alone is significant, as flat-crested peaks and ridges, shaped by frost action and slope movement of residual deposits, occur at a wide range of altitudes.

The summit level is characteristic of the terrain underlain by the Kuskokwim group and by the smaller albite rhyolite sheets, as well as by most sills and dikes of various compositions. Isolated groups of higher mountains that stand above the summit level are formed on bodies of rock more resistant to weathering and erosion, chiefly quartz monzonite stocks and some of the larger albite rhyolite sheets. These mountains are probably monadnocks left projecting above the old-age surface.

The Georgetown summits are not everywhere at an altitude of about 2,000 to 2,200 feet. It was pointed out in the discussion of their distribution that they become gradually higher east of the Nushagak Hills toward the foot of the Alaska Range. They are lower than 2,000 to 2,200 feet on the east side of the Kuskokwim Mountains along the upper Kuskokwim River, southeast of the Kuskokwim Mountains in the Holitna River basin, and to the west of the mountains along the Aniak, Owhat, and Iditarod Rivers. These variations in the summit level are probably due largely to differential vertical movements that warped the old-age surface after it was formed. Summit altitudes are extremely variable in the uplifted and block-faulted terrain of the Kuskokwim Mountains south of the Kuskokwim River. Here it seems likely that the old-age surface has been dislocated by differential uplift, and completely eroded away from areas that have undergone the most uplift (see fig. 30).

The old-age surface is probably the surface upon which the major streams such as the Kuskokwim and Yukon Rivers originally flowed. These rivers transect the geanticlines and fold systems of western Alaska and were perhaps superposed upon these structures from a covering of sedimentary deposits on the old-age surface.

GEOMORPHIC AND STRATIGRAPHIC RELATIONS

The Georgetown summit level corresponds approximately with the summits of the rolling late-mature Sleetmute surface (fig. 31). The Georgetown level, or related monadnocks, intersects the bedded rocks up to and including the Holokuk basalt, and all of the intrusive igneous rocks, notably the quartz monzonite stocks. The Georgetown level is about at the altitude of the horizontal capping of Waterboot basalt on Flat Top Mountain and it is inferred that the basalt flows lie upon a flat remanant of the old-age surface represented by the Georgetown level.

AGE

The Georgetown level is probably of late Tertiary age. It is most nearly analogous to the summit level of the Yukon Plateau in east-central Alaska (Mertie, 1937b, p. 31–32) and in Yukon Territory (Cockfield, 1921, p. 6), and it seems a fairly safe assumption that the two are equivalent, barring an abrupt change in geomorphic relationships between southwestern and central Alaska. The date of origin of the summit level of the Yukon Plateau has not been determined. Several geologists have assigned ages (Dawson, 1891, p. 10–17; Spurr, 1898, p. 260; Spencer, 1903, p. 131; Brooks, 1906, p. 279, 290, 292, 293; Cockfield, 1921, p. 6–7, 32) that range from Eocene to early Pleistocene. Some of the ages that have been assigned to the summit of the Yukon plateau are subject to revision, and the evidence for most of the age assignments is not clearly presented. Dawson (p. 16) refers to folded Miocene beds that have been reduced "nearly to the base level of erosion" and Cockfield (p. 32) states, though without explanation, that "it is believed that the planation of the Yukon plateau was complete towards the close of the Miocene." The consensus of these references is that late Miocene is probably the earliest date assignable. The surface of the plateau is probably no younger than Pliocene, if

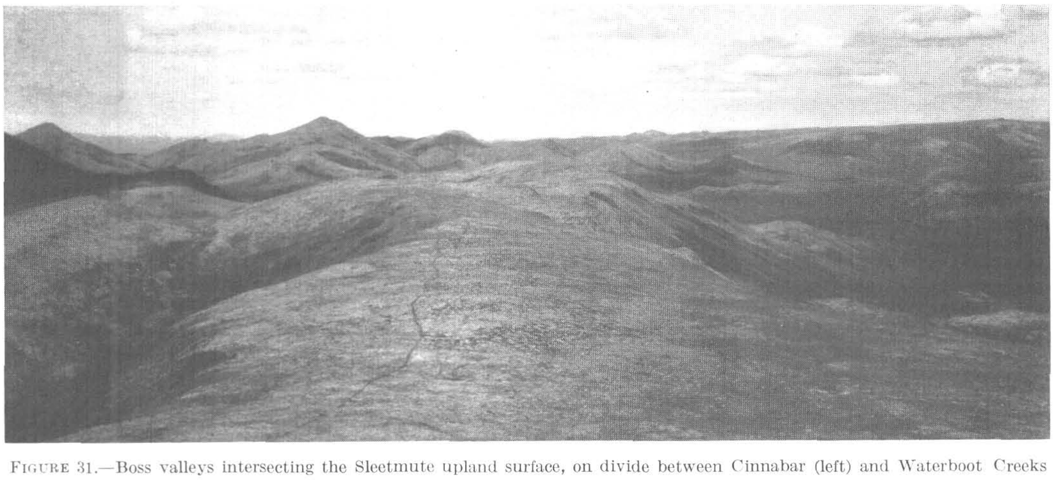


FIGURE 31.—Boss valleys intersecting the Sleetmute upland surface, on divide between Cinnabar (left) and Waterboot Creeks (right). These youthful stream valleys, undergoing erosion through the Sleetmute surface beginning in Pleistocene time, characterize mountainous areas sharply uplifted in late Pliocene–early Pleistocene time. A remnant of the late-mature Sleetmute surface is in middle foreground, bordered by valleys of the Boss valley terrain. The nearly horizontal summit of Flat Top Mountain, about at the Georgetown summit level, appears on horizon at right. The Georgetown level marks an erosion surface in old age, formed in the late Tertiary, that can be approximately projected across the summits of the Sleetmute surface.

strong uplifts and rejuvenation of drainage that took place along the coast of Alaska in the late Pliocene or early Pleistocene (Tarr and Butler, 1909, p. 160–164; Maddren, 1914, p. 131; Mertie, 1931, p. 127–131) had their counterparts inland.

SLEETMUTE UPLAND SURFACE

DISTRIBUTION

This rolling upland surface, shown in figure 32, is the most characteristic geomorphic feature in the central Kuskokwim region. It commonly ranges in altitude from 1,000 to 2,000 feet above sea level, though it descends to much lower altitudes in some valleys where it has been undisturbed by excessive uplift and rejuvenation of streams. It is typical of the terrain north of the village of Sleetmute and is best developed where nearly all of the bedrock is composed of graywacke and shale of the Kuskokwim group. This is most true north of the Kuskokwim River in the basin of the George River, and southeast of the Holitna River in the vicinity of the Nushagak Hills.

The Sleetmute surface is preserved on the tops of some of the benches and terraces along the Kuskokwim River between Sleetmute and Napaimiut and in adjacent portions of the Holitna and Aniak River valleys. It is well preserved on a bench top in the valley of upper Crooked and Donlin Creeks. The surfaces of many of the benches and terraces commonly slope upward and merge imperceptibly with the typical Sleetmute upland surface.

The Sleetmute surface is fully as extensive as the Georgetown summit level and likewise may be traced far beyond the confines of the central Kuskokwim region. The terrain can be recognized at a distance on the ground as well as in the air. It is traceable northeastward into the upland area between the Innoko and upper Kuskokwim Rivers and far into the headwaters of the Nowitna River. It also may be traced eastward from the Nushagak Hills to the west foot of the Alaska Range.

CHARACTER AND ORIGIN

The Sleetmute surface is predominantly a late-mature upland formed chiefly by frost action. Where best preserved from downcutting by streams the Sleetmute surface slopes in smooth open S-curves from the upland summits to the stream bottoms. The slopes are comparatively free of streams, but long curvilinear stripes, produced by the vegetation as well as by the soil pattern, radiate from the upland areas into the valleys and show the downslope path of soil creep. Creep of the residual deposits, directed by the force of gravity and urged on by frost heaving, has been chiefly responsible for shaping of the Sleetmute surface. The principal function of the streams at the foot of the slopes, especially in areas where the Sleetmute surface is best preserved and is at grade with the streams, is to carry away the debris as it arrives and thus to allow for continued slope movement and lowering of the divides.

The streams that originally flowed at grade with the Sleetmute surface, in the bottoms of its broad open valleys, have nearly all been rejuvenated and constitute the existing drainage (fig. 30); thus most of the present drainage pattern evolved on the Sleetmute surface. In a few places, nevertheless, the valleys in the Sleetmute surface have been completely abandoned and left high and dry on the divides, as in the headwater region of the Oskawalik River between Henderson Mountain and the Chuilnuk Mountains, and at the divide between the heads of the Buckstock River, the Holokuk River, and Atsaksovluk Creek.

FIGURE 32.—The Sleetmute upland surface, near the headwaters of Cribby Creek and about 10 miles northwest of Sleetmute. *This is a late-mature denudation surface, formed chiefly by frost action beginning in the late Tertiary; where preserved, it* marks areas little disturbed by uplift and subsequent erosion in late Pliocene–early Pleistocene time. Upper slopes in this view, covered with light-colored lichens, are undissected parts of the Sleetmute surface.

In the upper Oskawalik River area benches covered with stream gravel (pls. 1, 7) stand as much as 400 feet above river level. Their surfaces are a part of the Sleetmute surface, which slopes gently upward to the south in the direction of the Chuilnuk Mountains. The gravel on the benches includes waterworn pebbles and boulders of granitic rock, derived from the stock in the Chuilnuk Mountains, and basalt, probably from the Holokuk basalt in the vicinity. At least one of these abandoned valleys is separated from its former headwaters in the Chuilnuk Mountains by the present headwaters of the Chuilnuk River, which flow to the east several hundred feet below. One particular gravel-covered bench is in a gap, through which a fork of the Oskawalik River evidently flowed north from the Chuilnuk Mountains before it was captured by the Chuilnuk River. In this area the Sleetmute surface may be traced upward on to the spurs between the glacial troughs of the Chuilnuk Mountains.

The divide at the head of the Buckstock River is apparently the abandoned valley floor upon which that river flowed when its headwaters were yet farther to the south, before capture by the Holokuk River and probably also by Atsaksovluk Creek.

GEOMORPHIC AND STRATIGRAPHIC RELATIONS

The high points of the Sleetmute surface are about at the Georgetown summit level. The Sleetmute surface is at the top of the residual and gravel deposits and is intersected by the youthful Boss valleys (figs. 31, 33). It is overlain locally by a veneer of silt. Where the broad open valleys of the Sleetmute surface are better preserved, the youthful valleys are confined to their bottoms. In such areas remnants of the lower slopes of the Sleetmute surface remain on the tops of benches and terraces that are commonly less than 100 feet above the streams in the youthful valleys. On the other hand where the youthful Boss valleys are much deeper and wider only the upper slopes and summits of the Sleetmute surface have escaped erosion, and the uplands that remain may stand as much as 1,000 feet above the bottoms of the youthful valleys incised in them (see fig. 30).

AGE

The Sleetmute surface probably began to form in late Tertiary time, and has continued to evolve up to the present where streams have not been rejuvenated and remain at grade with this surface. The evolution of the Sleetmute surface very likely began in the Pliocene inasmuch as the Georgetown summit level, which is intersected by the Sleetmute surface, is of late Miocene or Pliocene age and some of the Boss valleys, which in turn intersect the Sleetmute surface, probably date from earliest Pleistocene time.

BOSS VALLEYS

DISTRIBUTION

The Boss valleys contain most of the existing drainage. They are best developed near the southeastern escarpment of the Kuskokwim Mountains, along the divide between the headwaters of Boss Creek and Mukslulik Creek (pl. 8, fig. 30). Here the sides of the Boss valleys extend all the way from the streams, at altitudes between 1,000 and 1,500 feet, to the summit ridges at about 3,000 feet. The Boss valleys are nearly as well developed in the mountains along the divide between Atsaksovluk Creek and Timber Creek. Both of these areas are in uplifted fault blocks. Elsewhere, as exemplified by the area of the Kuskokwim Mountains north of the Kuskokwim River, and by the Nushagak Hills, the valleys are confined to lower altitudes, commonly of less than 1,000 feet, and are more or less widely separated by expanses of the Sleetmute upland surface as shown in figure 31. In some places, as along parts of the Kuskokwim River, and in adjacent portions of the Holitna and Aniak River valleys, the Boss valleys are represented only by inner valleys at altitudes of less than 500 feet, within the broad valleys of the Sleetmute surface. The Boss valleys are locally absent, as in areas southeast of the headwaters of the Iditarod River and in the eastern part of the George River basin.

CHARACTER AND ORIGIN

The Boss valleys are steep-sided youthful valleys (figs. 31, 33) whose slopes are nearly straight from summit ridge or upland surface to the flood plain of the stream. Where the Boss valleys are best and most extensively developed the flood plains are narrow and cross sections are V-shaped, and their sides extend up to the tops of the summit ridges; thus they make up a mature land surface that contrasts with the late-mature Sleetmute surface. In such areas the Boss valleys are 1,500 to 2,000 feet deep, but where the Sleetmute surface is more extensive, and the Boss valleys are merely the inner valleys closer to the streams, they are commonly less than 500 feet deep, and along the main streams these valleys are mostly less than 100 feet deep.

The Boss valleys are primarily stream dissected though the streams are assisted by frost action and the downslope creep of residual deposits. The streams undercut the residual deposits faster, however, than they can move down the valley sides, and the only features attributable solely to frost action are nivation cirques, formed on the higher slopes where snowbanks remain late in summer.

Most of the streams are rejuvenated and have inherited all but the details of their patterns from the streams that flowed in the broad, open valleys of the Sleetmute surface. They are incised deepest in the Kuskokwim Mountains area where they have eroded bedrock and left benches. Elsewhere, particularly east of the mountains, the rejuventated streams rarely reach bedrock, and terraces are formed in the surficial deposits. The Boss valleys are absent in some places simply because the streams have not been rejuvenated. The presence or absence of the Boss valleys and their great range in depth depend, eventually, on differential uplift, which has caused varied lowering of the base level of the streams.

SPECIAL DRAINAGE FEATURES

STREAM CAPTURE

Although most of the Boss valleys have inherited their patterns from the drainage on the Sleetmute surface, the drainage pattern has undergone a few modifications by stream capture. The Chuilnuk River, which flows eastward and southeastward at the northeast foot of the Chuilnuk Mountains, has captured former headwaters of the Oskawalik River that flowed north from the Chuilnuk Mountains (pls. 1, 7). This part of the Chuilnuk River occupies a valley several hundred feet deep, which the river eroded headward into the Sleetmute surface, and into which at least one tributary of the Oskawalik River was diverted. Similarly, parts of the head of the Buckstock River have been captured by the Holokuk River and possibly also by Atsaksovluk Creek. The largest tributary of the head of the Holokuk River flows northward in the direction of the present head of the Buckstock, and then turns abruptly northeast at an elbow of capture, producing the present drainage pattern. Part of the headwaters of Atsaksovluk Creek flow south toward the head of Chikululnuk Creek before they turn southwest along the Boss Creek fault zone, which suggests that Atsaksovluk Creek has captured the former headwaters of Chikululnuk Creek.

ANTECEDENT STREAMS

Several streams, such as the Kuskokwim River, Oksotalik Creek, and possibly the Chukowan River, make their way through mountainous areas in which the Sleetmute surface has been arched up or lifted up on fault blocks. They have cut youthful valleys in the Sleetmute surface, and it is inferred that they flowed on the Sleetmute surface, in about their present courses, before uplift, and have been able to maintain these courses despite the uplift. Thus they are probably antecedent streams.

The Kuskokwim River enters a gorge near Sleetmute, through which it flows westward through the Kuskokwim Mountains. The river is several hundred feet lower than the Sleetmute upland surface at some intermediate points in the mountains, though at either end of the gorge it is less than 100 feet lower than the Sleetmute surface. The greatest difference in altitude between the bottom of the gorge and the Sleetmute surface appears to be a little downstream from the mouth of Eightmile Creek, where the gorge is possibly 400 feet deep and narrowly constricted. These relations imply that the Kuskokwim Mountains have been arched up along an axis which crosses the Kuskokwim River somewhere in the vicinity of Eightmile Creek, that downcutting by the river has kept pace with the uplift, and that the course followed by the river on the Sleetmute surface has been maintained.

Two alternates are postulated to this interpretation of the Kuskokwim gorge, both of which might seem to explain a lacustrine origin of thick deposits of silt east of the Kuskokwim Mountains in the basin of the Holitna and upper Kuskokwim Rivers. Both alternatives assume that a lake, presumably ponded before the gorge was cut through the Sleetmute surface, stood at an altitude of about 800 feet above sea level east of the Kuskokwim Mountains. The ponding might be considered to be due, either to uplift of the Kuskokwim Mountains across the course of the Kuskokwim River, causing its temporary defeat, or to uplift of the existing divide between the headwaters of the Holitna and Nushagak Rivers, defeating an ancestral Kuskokwim River that flowed south into Bristol Bay rather than west to Bering Sea. According to either postulate ponding would have been followed by overflow at a low point in the mountains northwest of Sleetmute followed by rapid downcutting of the gorge in that area.

Defeat of the Kuskokwim River by uplift of the Kuskokwim Mountains seems an unlikely explanation inasmuch as the silt, as explained in the discussion of the surficial deposits, is inlaid in the valleys of existing streams, such as that at the Red Devil mine, which enter the Kuskokwim River at grade within its gorge. In other words, the grade of the main river, which controls that of the tributaries in the gorge, was at or below the existing grade before silt deposition in the valleys of the tributaries. This places formation of the gorge before the silt was deposited.

It also seems unlikely that defeat of an ancestral Kuskokwim River, which flowed out to the south through the area of the Holitna-Nushagak divide, is a satisfactory explanation. The altitude of the lowest point in the present divide, at the head of the Kogrukluk River, is approximately 1,000 feet above sea level (U. S. Geol. Survey, Taylor Mountains sheet, 1951), or about 750 feet above that of the Kuskokwim River in the vicinity of Sleetmute. This would mean that uplift in the divide area would of necessity have totaled at least 750 feet. Such uplift would have placed the

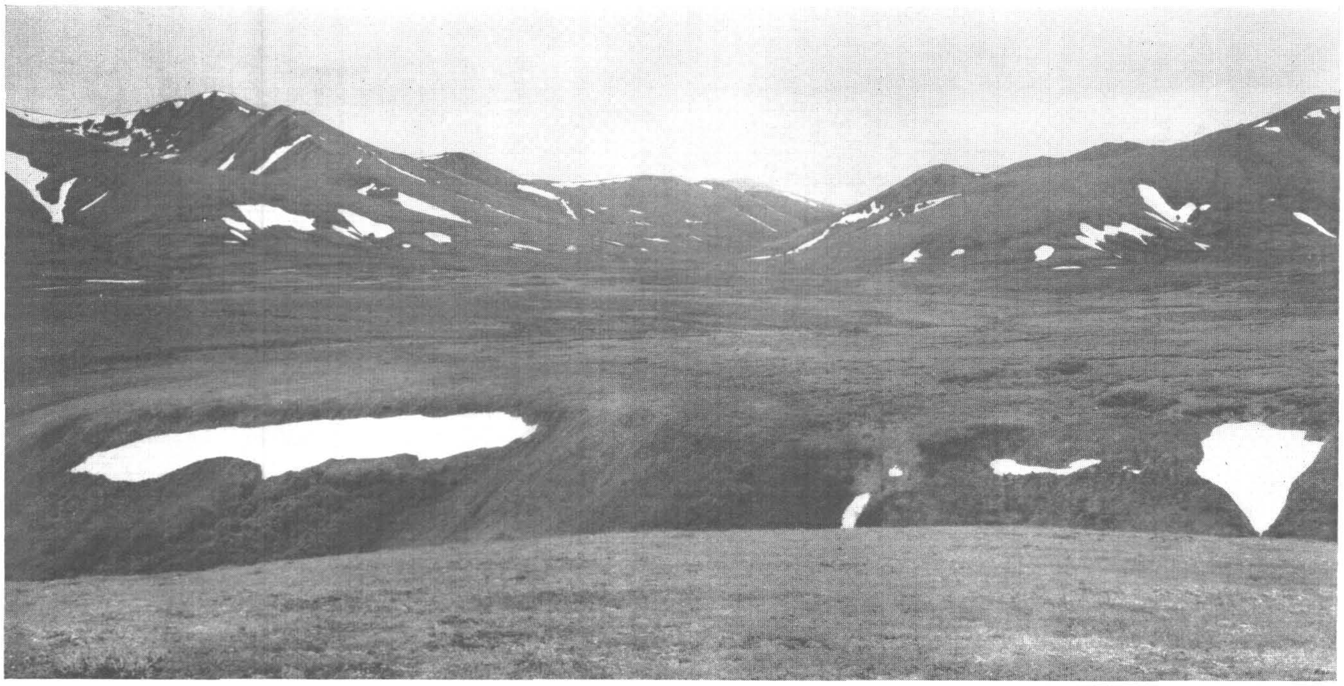


FIGURE 33.—Bench at divide between Oksotalik and Boss Creeks. Oksotalik Creek flows south (away from viewer) across the surface of the bench, which is a part of the late-mature Sleetmute surface, and through the youthful valley in a Boss-valley terrain in the middle distance. Boss Creek flows north; gulch in foreground formed where a headwater tributary intersects gravel on the bench. The trace of Boss Creek fault (not distinguishable) lies at the southeast edge of the bench, near foot of hills in middle distance.

summit ridges of the Sleetmute surface in this area at an altitude of about 2,800 feet and exposed this surface to considerable dissection. Instead, the summits in the vicinity have an average altitude of about 2,000 feet above sea level, which conforms with summit altitudes in many other areas near the headwaters of streams, and they are apparently no more dissected.

Oksotalik Creek is also in part an antecedent stream. This stream, whose headwaters are at grade with the Sleetmute surface in the graben north of the Boss Creek fault (fig. 33), flows directly south, into and through the horst south of the fault (fig. 30), and emerges in the Holitna River basin, where it has cut a relatively shallow valley through the Sleetmute surface. These relations show very satisfactorily how the downcutting by Oksotalik Creek has kept pace with uplift of the horst. The headwaters of Oksotalik Creek immediately north of the Boss Creek fault flow on a gravel-covered bench whose surface is continuous with the Sleetmute surface on the nearby hills in the graben. The bench has formed as the headwaters of Boss Creek cut below the grade of Oksotalik Creek, and this headward encroachment of Boss Creek on the headwaters of Oksotalik Creek continues at the present time. This is probably because uplift of the horst across the course of Oksotalik Creek has fostered a higher local baselevel in the headwaters of Oksotalik Creek.

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GEOMORPHIC AND STRATIGRAPHIC RELATIONS

The Boss valleys intersect the Sleetmute surface and the residual and gravel deposits that lie immediately beneath it. Terraces are formed where the valleys intersect the residual or gravel deposits or both, and benches where they intersect the bedrock as well. A few of the Boss valleys are partly modified to U-shaped glacial troughs. The Boss valleys contain the flood plain deposits of existing streams, glacial deposits, and silt deposits. Though in many places there is a rather sharp change in slope between the walls of the Boss valleys and the Sleetmute surface, as at the rims of benches and terraces, there are commonly other places where it is difficult to separate the two. In these places the Sleetmute surface simply becomes steeper and steeper in the downslope direction and rounds over into the steep walls of the Boss valleys (fig. 32). This is probably because downcutting by the rejuvenated streams that flow in the Boss valleys has not been fast enough to exceed the rate of denudation by frost weathering on the Sleetmute surface and to undercut the residual deposits formed at that surface.

AGE

The Boss valleys date back at least to pre-Wisconsin time, because some of them have been re-eroded by small glaciers and contain glacial deposits, as well as silt deposits related to glaciation. They are probably not older than the Pleistocene; the most likely time of the beginning of differential uplift of the Sleetmute surface, to cause rejuvenation of streams to form the Boss valleys, was at the end of the Pliocene or beginning of the Pleistocene. The uplift is probably synchronous with late Pliocene–early Pleistocene uplifts indicated by elevated, tilted, folded, faulted, and glacier eroded Pliocene strata, some of which are marine, found along the coast of the Gulf of Alaska southwest of the St. Elias Mountains (Tarr and Butler, 1909, p. 160–164; Maddren, 1914, p. 131; Mertie, 1931, p. 127–131). This is the best available clue to the date of major faulting and uplift that was widespread in the central Kuskokwim region, other parts of Alaska, and neighboring regions.

GLACIAL TROUGHS

DISTRIBUTION

Glacial troughs are confined chiefly to isolated groups of mountains whose summit areas have altitudes over 3,000 feet. These mountains include the Horn Mountains, Russian Mountains, Kiokluk Mountains, Chuilnuk Mountains, Taylor Mountains, and a small group of peaks in the area between the Kogrukluk River and Shotgun Creek. The heads of the Gemuk and Aniak Rivers are also in glacial troughs, that open northward from an extensively glaciated area that spreads south of the central Kuskokwim region to Bristol Bay. Small glacial troughs and cirques occur in a few other areas, notably in mountains between the Holokuk River and Timber Creek and between the headwaters of Mukslulik Creek and Boss Creek. The bottoms of the glacial troughs are commonly at altitudes of 1,000 to 1,500 feet.

CHARACTER AND ORIGIN

The glacial troughs are typically U-shaped, and their sides extend up to the tops of the summit ridges to form knife-edge arêtes and horn peaks (pl. 6); thus they comprise a glaciated terrain that contrasts strongly with terrains of both the Sleetmute surface and the Boss valleys. Most of the glacial troughs are 1,500 to 2,000 feet deep.

The glacial dissection is more youthful in a few of the mountainous areas. The mountains between the Holokuk River and Timber Creek barely reach an altitude of 3,000 feet, and glaciation has been confined to islolated small troughs and cirques separated by unglaciated surfaces. The mountains on the divide between the headwaters of Boss Creek and Mukslulik Creek show little more than the initial effects of glaciation. Some of the Boss valleys in the latter area are partly changed to a U-shape and small cirques are formed (fig. 30), particularly on the northwestern slopes. None of these troughs now contain glaciers.

The glacial troughs are little modified by subsequent erosion and weathering. Talus deposits occur on the slopes and modify the U-shaped profiles of the troughs slightly. The rocks are comparatively clean and fresh and residual deposits have not yet accumulated.

Glacial troughs occur chiefly on the north and west sides of the Horn, Russian, Kiokluk, Chuilnuk, and Taylor Mountains. They are very short on the southern and eastern slopes, which supported less extensive glaciers. This asymmetrical distribution of the glacial troughs was probably caused by greater accumulation of snow, on northern slopes protected from the direct rays of the sun, and on western slopes exposed to the moisture-bearing prevailing winds. The effect of less direct exposure to the sun is particularly clear in the Taylor Mountains, where, as a result of glacial action, the troughs on the northern slope are eroded headward almost to the southern contact of the more resistant rocks of the granite stock. This asymmetry seems clearly related to differential snow accumulation rather than to differences in the resistance of bedrock to glacial erosion. Comparable, though less extreme, southward shifts of divides are noted in all others but the Horn Mountains.

GEOMORPHIC AND STRATIGRAPHIC RELATIONS

The glacial troughs are at grade with the Boss valleys in the vicinity of the higher mountains, and, as has been pointed out already, some of the Boss valleys have been slightly modified by glaciation. The headwaters of the Chuilnuk River in the Chuilnuk Mountains flow in a glacial trough that extends northeastward beyond the foot of the mountains and becomes a youthful stream valley. Here the bottom of the glacial trough is cut below the Sleetmute surface and follows a part of the Chuilnuk River that had, before glaciation, captured part of the headwaters of the Oskawalik River.

AGE

The glacial troughs were probably eroded in Wisconsin time. The effects of glaciation that took place during the Wisconsin stage of the Pleistocene elsewhere in Alaska (Capps, 1931, p. 6–8) are the most conspicuous; it is inferred that the small glaciers that were characteristic of the central Kuskokwim region were active at that time. This helps date faulting in the region: the mountains of the horst at the heads of Boss and Mukslulik Creeks must have been raised high enough, and amply before Wisconsin time, to permit complete dissection of the Sleetmute surface by the drainage in the Boss valleys before these valleys were glaciated.

OTHER DENUDATIONAL FEATURES

Postglacial notches intersect the bedrock of glacial troughs in a few places, and small gulches are cut in the constructional surfaces of glacial, silt, and flood-plain deposits. The drainage of the glacial troughs passes through gulches cut in the terminal moraines. The silt deposits are also dissected by surface run-off. Similar valleys are formed locally in flood-plain deposits; some of the latter may reflect lowering of base level going on at the present time.

GEOLOGIC HISTORY

Gneiss, quartzite, schist, amphibolite, and granite exposed in several areas beyond the confines of the central Kuskokwim region, particularly in the region between the Yukon and Tanana Rivers (Mertie, 1937b, p. 47–59), are the oldest rocks known in Alaska. They record the deposition, probably in the sea, of sand, mud, and basaltic lava, their subsequent folding and metamorphism, and the intrusion of granitic magma. This probably all took place in early pre-Cambrian time. The formation of these rocks was followed in later pre-Cambrian time by general uplift of broad areas above sea level, constituting the platform of the continent of North America.

A mobile belt developed in the earth's crust between the continental platform and the adjacent floor of the Pacific Ocean as late pre-Cambrian time progressed. Portions of the mobile belt started to subside beneath the sea about as soon as mobility was established; sand and mud, eroded from the adjacent platform, were transported southward by streams and dumped in submerged basins of subsidence, where they formed the material of many thousands of feet of shale and quartzite of later pre-Cambrian age (Mertie, 1937b, p. 59–65). This was also a time of volcanic activity, as attested by the greenstone that is interbedded with the shale and quartzite. The greenstone is formed from basaltic lava that was probably poured out on the seabottom, near the oceanic margin of the mobile belt, and became interbedded with the sand and mud.

As time progressed, erosion reduced the platform to lower relief and the supply of sediments derived from it was diminished. Meanwhile subsidence continued in the mobile belt, and marine waters spread over greater and greater areas of the mobile belt and adjacent margins of the platform. Under these conditions marine limestone was widely precipitated, near or on the platform, in areas beyond the range of distribution of the sand, mud, and submarine lava. Areas of marine submergence continued to expand from the late pre-Cambrian on up through the Cambrian and Ordovician periods, until in late Ordovician time the continental platform was widely flooded.

Subsidence and submergence continued during the Silurian and Devonian, except for one or two notable episodes of uplift, and so also did deposition of limestone, both as strata and as small reefs. The limestone, which is included in the Holitna group, is the oldest rock exposed in the central Kuskokwim region. An episode of temporary uplift during the Early Devonian probably accounts for a break in the record at that time; this break appears to be universal in Alaska. During the time of deposition of the Holitna group the "hinge line" that marks the transition from the mobile belt to the platform extended through or very close to the central Kuskokwim region, which lay either in a comparatively stable part of the mobile belt or on a more mobile part of the platform, depending on where the line or zone of transition is drawn.

The mobile belt perhaps encroached upon the platform during the deposition of the Gemuk group, which placed the central Kuskokwim region in a zone of greater mobility. Subsidence increased, beginning in the Carboniferous and continuing through the Early Cretaceous. Hand in hand with increased subsidence went a revival of submarine volcanism, and a change of the sedimentary regime from limestone deposition to the deposition chiefly of thick successions of mixed silt and chert. The latter are believed to be largely clastic and chemical products, respectively, of the exposure of the volcanic rocks to the action of seawater and atmospheric weathering. The first marine lava flows extruded were probably of basaltic composition, but as time progressed marine lavas of andesitic composition appeared. Although subsidence was predominant during the time of formation of the Gemuk group there were evidently episodes of uplift and emergence above sea level. Upper Carboniferous (Pennsylvania) and Lower and Middle-Triassic rocks have not been found in the central Kuskokwim region and vicinity and are unreported elsewhere from interior Alaska; thus it is quite likely that these were times of emergence.

By late Early Cretaceous time, northeastward-trending belts, at both the eastern and western borders of the central Kuskokwim region were uplifted vertically, forming the Alaska-Yukon and Aniak-Ruby geanticlines, respectively. Sediments were eroded from emerged areas of the geanticlines and were carried by streams to the trough of the intervening Kuskokwim geosyncline, where scores of thousands of feet of sediments were deposited while subsidence continued, during latest Early Cretaceous and early and possibly middle Late Cretaceous time. The sediments were drawn from older rocks exposed in the geanticlines—phyllite, slate, quartzite, limestone, siltstone, chert, basalt, and andesite.

The geanticlines, particularly the Aniak-Ruby geanticline, continued to be uplifted rapidly during at least the early part of Late Cretaceous time, and areas of sharp relief evidently appeared from which the older rocks were violently eroded and subjected to disintegration almost entirely mechanical. The disintegration products, chiefly angular silt- and sand-size fragments, were transported fairly short distances to the Kuskokwim geosyncline. The submarine relief of the belt of the Kuskokwim geosyncline, like the subaerial relief of the geanticlines, was continually steepened in the early Late Cretaceous epoch, particularly along the borders of the trough. Sediments left by the streams in this marginal area formed loose, unconsolidated deposits that were continually and repeatedly upset by the steepening of the trough borders, and slid down the submarine slopes of the trough. Part of the silt and sand involved in the slides became incorporated in turbidity currents of high density and were distributed in the otherwise unagitated water below wavebase. The sediments of the slides and of the turbidity currents came to rest to form the interbedded graywacke and shale of the Kuskokwim group. The graywacke beds formed at the time of sliding, and of possibly related generation of turbidity currents capable of transporting the sand-size particles. The latter settled at depths at which the currents were checked by seawater of equal density. Shale beds were laid down in more quiet intervals of settling. Beds of graywacke, many of which are as much as two feet thick, were probably formed in a very short time by this process, an instant of time in the geologic sense.

Uplift of the geanticlines and steepening of the sides of the submarine geosynclinal trough slackened as Late Cretaceous time progressed. This resulted in reduction of both subaerial and submarine relief, and in increase of the distance sediments were transported from source areas. The sediments contributed by the geanticlinal uplifts under these conditions were subjected to chemical decomposition as well as to mechanical disintegration; thus chemically resistant quartz was the chief detrital mineral to arrive at the shores of the geosynclinal trough, commonly in the form of sand grains well rounded in their longer downstream journeys. Once arrived at the shores these sands came to rest on relatively stable ground, unaffected by slides such as characterized the earlier stages of formation of the geosynclinal deposits. Instead they were reworked and resorted by waves and normal shallow-water currents to produce some of the cleaner sandstones found in the upper part of the Kuskokwim group.

During the final stages of deposition of the Kuskokwim group, subsidence of the geosynclinal trough probably did not always keep pace with deposition, and some of the deposits were possibly laid down in fresh water rather than sea water. Late in Late Cretaceous time the deposits in the geosyncline were uplifted slightly above sea level, and the lava flows of the Iditarod basalt spread out over the uppermost strata of the Kuskokwim group.

The geanticlinal tracts moved closer together in earliest Tertiary time, probably because the more rigid continental platform and Pacific Ocean floor approached one another and decreased the width of the mobile belt. The geosynclinal accumulations of the Kuskokwim group, which were structurally less competent than the geanticlines, were as a result thrown into folds that were draped around the margins of the geanticlines, and were also grouped into rather extensive anticlinorial uplifts, such as the Gemuk anticlinorium, which includes an upbuckled portion of the floor of the Kuskokwim geosyncline. Biotite basalt sills and dikes and albite rhyolite sheets, sills, and dikes, partly concordant with the enclosing formations, were intruded in the geosynclinal rocks and underlying strata near the close of folding. Gold-quartz-tungsten veins were formed at the borders of the rhyolite bodies during late stages of their emplacement. Hydrothermal alteration of the rhyolite, metamorphism of the adjacent country rock to argillite, and possibly also the hydrothermal alteration of the biotite basalt took place at this time. After folding, the rocks were uplifted and eroded probably almost to base level. This was achieved some time in the early Tertiary, probably by the beginning of the Eocene epoch.

At some time between the Eocene and the late Miocene volcanic rocks were extruded and spread widely over the uplifted and eroded folds, and all were intruded by stocks of quartz monzonite and related hypabyssal rocks. First to appear were rhyolite lava and tuff that were extruded locally to form the Getmuna rhyolite group. The tuff is believed to have been blasted explosively through vents that first allowed the relatively quiet passage of the lava. The Holokuk basalt later rose through fissures and flowed over large areas of the central Kuskokwim region. Detritus, weathered and eroded from the basalt flows, was deposited with them as interbeds. The stocks had probably been intruded by early Miocene time; with them was formed the hornfels of the contact metamorphic zones in the bedded rocks at their borders. Copper sulfide-gold-silver mineralization took place in the late stages of, or a little after, emplacement of the stocks.

After the time of intrusion of the stocks the region was differentially uplifted, with tilting of strata, and reduced by weathering and erosion to a surface in old age. The Georgetown summit level now shows the position of this surface. The stocks and some of the larger albite rhyolite sheets, as well as related metamorphic zones in adjacent bedded rocks, were less completely dissected because of their greater resistance to the destructive processes. They remained as monadnocks that projected above the old-age surface. The Waterboot basalt poured out locally on this surface. Probably at about the same time ore-forming fluids, bearing quicksilver and antimony, arose along fractures in the long since solidified biotite basalt sills and dikes to form the quicksilver-antimony lodes. The old surface was then uniformly uplifted in late Miocene or Pliocene time.

The uplifted old-age surface was destroyed by processes of weathering and erosion that reasserted themselves throughout most, or the remainder of Pliocene time, with the result that late in the Pliocene the Sleetmute surface, a rolling late-mature surface, whose summit level was probably at or not far beneath that of the former old-age surface, was established throughout the region. Scattered over the region, however, were the monadnocks whose summits still stood at relatively high altitudes near the headwaters of the streams. The major stream courses had probably by this time established approximately their present pattern. The large streams that transect the geologic structures, such as the Kuskokwim and the Yukon, were perhaps superposed from a cover of upper Tertiary sedimentary deposits that lay upon the old-age surface.

Residual deposits accumulated at the Sleetmute surface and gravel was deposited in the stream valleys as the Pliocene denudation continued. Remnants of these ancient unconsolidated materials probably persist to this day, particularly on the benches high above the present stream courses. The placer deposits started to form in the gravel laid down by the streams that flowed on the Sleetmute surface in the Pliocene.

In latest Pliocene or earliest Pleistocene time the region began to be differentially uplifted. The Kuskokwim Mountains, in the area northwest of the upper Holitna River basin, were broken into several fault blocks that have been raised at different rates with the result that some blocks now stand higher than others. The uplifted blocks were immediately attacked by stream erosion, and the late-mature Sleetmute surface was removed from the higher ones before the Wisconsin stage of the Pleistocene, and the V-shaped Boss valleys took its place. Much of the rest of the mountain belt was likewise uplifted beginning in late Pliocene-early Pleistocene time, or later, but the uplift has been more uniform and faults much less common. In these areas the Sleetmute surface has been only partly destroyed by later erosion; benches and terraces as well as the rolling upland remain.

In the few areas in which the streams are almost at grade with the Sleetmute surface, as in the eastern George River basin and southeast of the headwaters of the Iditarod River, there appears to have been little appreciable uplift, at least above local base levels. Thus formation of the Sleetmute surface has continued in these areas, and it may probably be said that in some places the gravel and residual deposits, first formed possibly as early as the Pliocene, have formed continuously since, and existing flood-plain and residual deposits have followed without cessation of deposition.

The deep gorges, such as those of the Kuskokwim River, the Holokuk River, and Oksotalik Creek, have been cut in response to differential uplift during the Pleistocene. Most of the streams have maintained their original courses by the cutting of such gorges, but in a few places streams were defeated by uplift across their courses, and captured by streams whose headward erosion was not compensated for by uplift.

A colder and possibly drier climate came to the region in the Wisconsin stage of the Pleistocene epoch; the valleys at higher altitudes, particularly of the uplifted fault blocks and of the old monadnocks, were soon filled with glacial ice, and rubble fields, stone nets, and stone streams formed at lower altitudes. The glaciers changed the V-shaped stream valleys of the higher mountains into U-shaped troughs and deposited derived debris as moraines and glacial outwash deposits. During glacial times large volumes of silt were blown by the wind from outwash plains west of the Alaska Range and deposited on upland surfaces and in the valleys southeast of the Kuskokwim Mountains. Some of this material was transferred downstream by the Kuskokwim River and deposited above the gravel deposits in and west of the Kuskokwim Mountains.

Existing streams have formed flood-plain deposits, beginning before glacial times, in the valleys and gorges that they had cut below the Sleetmute surface. Since glacial times flood-plain deposits have also been laid down by the streams that flow through glacial moraines and outwash, and through silt deposits. Some placer gold, scheelite, and cinnabar were laid down with the flood-plain deposits.

Faulting and related differential uplift are still going on at the present time.

MINERAL RESOURCES

GENERAL STATEMENT

The central Kuskokwim region might well be referred to as a quicksilver-mining province, since quicksilver is the principal mineral resource. Gold is second in importance and tungsten third. Copper, antimony, silver, tin, and molybdenum are known, but none has been developed commercially. Several types of nonmetallic mineral deposits, particularly sand, gravel, clay, building stone, lime, and water for hydroelectric power, might become of value if an increase in population resulted in local demands. Fuels such as coal and oil seem to be almost entirely lacking.

The mode of formation and distribution of the nonmetallic deposits has already been covered, although not specifically, under the general heading of descriptive geology, and the following discussion is devoted exclusively to the metallic minerals.

The various ore-mineral occurrences show a fairly close structural relationship to igneous rocks, in that they are formed in fractures within the igneous rocks or are limited to their vicinity. Inasmuch as the igneous rocks so fractured and mineralized evidently solidified in advance of ore deposition they may not be called upon as an ultimate magmatic source of ore-bearing fluids. The compositional relationship, if any, of these ore deposits to the igneous rocks must, for this reason, be traced through invisible lines of ascent beneath the ground surface. It is commonly accepted that cooled and fractured igneous rocks may serve as conduits for the ascent of metalliferous fluids from yet molten magma bodies connected below (Hulin, 1945). In further support of this concept it should be pointed out that there is little evidence in the central Kuskokwim region of the occurrence of ore minerals in areas distant from igneous rocks, although such areas do include some relatively large fractures and faults.

The structural relationship of quicksilver-antimony ore to biotite basalt sills, dikes, and immediately adjacent sedimentary rocks is rather clear. At only one or two places was quicksilver found associated with other types of igneous rock. The lode relationships of gold are not clear because the lodes have not been exposed by mining operations. However, most of the gold placer deposits are formed on bedrock that includes intrusive bodies of albite rhyolite, and at one locality a small amount of lode gold is reported in the vicinity of the rhyolite. Small amounts of copper, tin, tungsten, silver, and gold occur in fractures that lie within or border the quartz monzonite stocks.

The associations of quicksilver with biotite basalt and of gold with albite rhyolite are apparently peculiar to the central Kuskokwim region. Biotite basalt, such as occurs at the quicksilver deposits, is probably not present in other Alaskan regions. The rhyolite occurs in a few areas to the northeast and southwest, but it has not been shown to be associated with gold. The ore minerals associated with the quartz monzonite stocks, however, are similar to those associated with stocks in the Kuskokwim Mountain belt both northeast and southwest of the central Kuskokwim region, although not in the workable quantities found in the latter areas. The unusual association of quicksilver with biotite basalt and of gold with albite rhyolite may perhaps be explained by the wide occurrence of these two igneous rock types as intrusive bodies in the Kuskokwim group, which is possibly thicker and certainly more widely distributed in the central Kuskokwim region than elsewhere.

Mertie (1937b, p. 241–250) has referred to two episodes of mineralization in central and southwestern Alaska, Mesozoic and Tertiary, but he points out that they are not everywhere distinguishable or clearly representative of two distinct parts of geologic time. He refers the gold lodes of central Alaska to the first period. These lodes are associated with large granitic batholiths, and are presumably the bedrock source of most of the gold in the great Alaskan placers. Mertie connects the second, or Tertiary, period of mineralization with the intrusion of the alkalic stocks of central and southwestern Alaska. Few lodes representative of the Tertiary, other than those of quicksilver, have been found or explored; but most of them in southwestern Alaska are probably assemblages of gold and silver and base-metal sulfide minerals, indicated by the content of placer deposits derived from them.

The ore minerals of the central Kuskokwim region were probably all deposited in the Tertiary period, inasmuch as they occur in veins that intersect igneous rocks all of which are intruded in the folded strata of the Upper Cretaceous Kuskokwim group. Three successive epochs of lode mineralization are implied in the following discussion: (1) gold-quartz-tungsten, (2) copper sulfide-gold-silver, and (3) quicksilver-antimony. The ore deposits are described below, however, in descending order of economic importance.

QUICKSILVER DEPOSITS

Quicksilver has been mined profitably only in the central Kuskokwim region, although small quantities of the ore mineral have been found rather widely in Alaska, particularly in gold placer concentrates. The principal deposits are near the Kuskokwim River, in the vicinity of Sleetmute, and near DeCourcy Mountain, southeast of the Iditarod River. Quicksilver has been prospected, however, at several other localities.

The geologic relationships of the quicksilver deposits are remarkably similar throughout the region. The deposits consist of irregular bodies of cinnabar, commonly associated with the antimony mineral stibnite, in host rocks that comprise chiefly biotite basalt and adjacent graywacke and shale strata of the Kuskokwim group. The host rocks, particularly the basalt, are commonly bleached in the vicinity of the deposits and form a wall rock which is pearl-gray on the fresh surface, but which weathers yellow-brown, forming the "yellow rock" that prospectors use as a guide in the search for quicksilver. The "yellow rock" is referred to here as silica-carbonate rock. Most of the deposits are in limbs of large folds in the sedimentary rock, which form comparatively simple homoclines in which sills and, less commonly, dikes of the biotite basalt are intruded.

The known quicksilver lodes are intersected by, or occur within a few hundred feet beneath the Sleetmute surface, a rolling late-mature upland terrain that is characteristic of the region. (See p. 96–97.) The lodes have not been found, however, in areas of more sharply dissected topography such as the Kuskokwim Mountains northwest of the upper Holitna River. The latter areas include the Boss valley terrain which is formed by deep erosion of portions of the Sleetmute surface uplifted on fault blocks. They also include the higher mountain groups that are deeply cut through by glacial troughs. It appears likely that quicksilver lodes have been completely eroded from these areas of deep dissection, in view of the generally shallow occurrence of quicksilver as compared with other kinds of ores. Lindgren (1933, p. 464, 465) has stated that "quicksilver deposits generally become impoverished at a depth of less than 1,000 feet" and that "the irregularity and brecciated character of [quicksilver] deposits suggest their development near the surface." The quicksilver deposits in the central Kuskokwim region appear to be impoverished at depths of much less than 1,000 feet.

Quicksilver also occurs in placer deposits composed of nuggets of cinnabar. The nuggets are commonly rounded and form short pay streaks, less than half a mile long.

CHARACTER

The location and form of the quicksilver lodes are controlled chiefly by zones of fracture that have developed at the contacts between formations of contrasting competency. These are principally contacts between the biotite basalt sills, which have been altered to silica-carbonate rock, and adjoining less competent graywacke and shale (pl. 9). The location and form of the deposits is also controlled by bedding joints. The silica-carbonate rock and shale are commonly brecciated (fig. 34) to a width of several inches parallel to and in the vicinity of contacts; ore fills the openings. Where movement has apparently not been so extreme, simple fractures containing ore cross the contacts and are widest in the silica-carbonate rock (fig. 35, pl. 9). The ore extends out from the silica-carbonate rock chiefly as fillings in bedding joints in the shale and graywacke. Ore is most abundant in openings at, or in the vicinity of, the upper surfaces of the bodies of silica-carbonate rock. Faults and other major cross-cutting features are of less significance in the localization of ore.

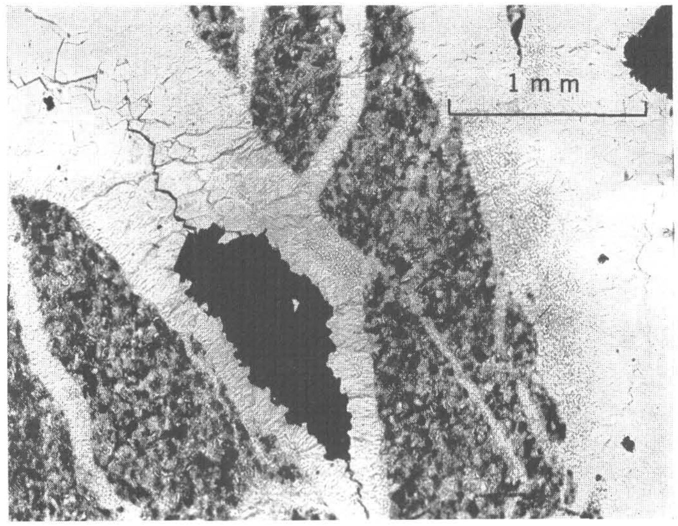

FIGURE 34.—Photomicrograph of cinnabar in veins in brecciated shale, at the De Courcy Mountain mine 17 miles northwest of Crooked Creek. Solid black areas are cinnabar, light colored areas, vein quartz, and mottled areas, shale; light-colored constituents of the shale are chiefly quartz and sericite; dark constituents are chiefly aggregates of finely divided ferruginous and carbonaceous material. Plain light.

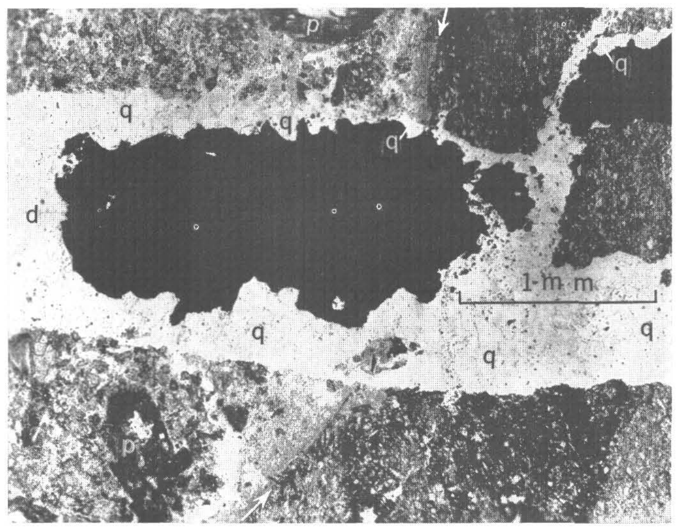

FIGURE 35.—Photomicrograph of cinnabar vein cutting contact between silica-carbonate rock and shale, at Alice and Bessie mine near Parks. Arrow points to contact and indicates its trend; silica-carbonate rock is to left and shale to right. Solid black areas are cinnabar and light areas include vein quartz (*q*) and dickite (*d*). Relicts of pyroxene phenocrysts (*p*) are distinguishable in the silica-carbonate rock. The dark material in the shale is chiefly carbon and the light fragments chiefly quartz. Plain light.

The ore commonly forms fissure fillings and incrustations; to a smaller extent it is disseminated in the altered wall rock of the fissures. In the typical ore vein or cavity filling a thin band of quartz borders the wall rock; the remaining space is filled either with a solid mass of cinnabar or with stibnite sprinkled with crystalline cinnabar or cut by cinnabar veinlets.

MINERALOGY

The principal metallic mineral in each of the quicksilver lodes, in terms of economic value, is cinnabar, the red mercuric sulfide (HgS). Stibnite, the lead-gray antimony trisulfide (Sb_2S_3), is locally more abundant than cinnabar, but because of its comparatively low value it has not been exploited commercially. Quartz (SiO_2) is the chief gangue mineral. Comparatively small amounts of calcite ($CaCO_3$) and other carbonate minerals are associated with the quartz. Clay minerals, including dickite ($H_4Al_2Si_2O_9$), form a frosty white powder closely associated with the ore minerals. The order of crystallization or paragenesis of the minerals is first carbonate, followed successively by quartz, stibnite, cinnabar, and dickite.

The quartz and carbonate commonly form comb structures along the vein borders (fig. 36). Stibnite needles (none appear in fig. 36) are supported by the quartz; and crystals of cinnabar, commonly twinned, may be perched on the quartz or on the stibnite needles. Dickite fills space that may remain in the centers of the openings and in some instances completely surrounds the cinnabar crystals. The cinnabar is less commonly disseminated in microscopic cracks in the wall rock; cracks in the silicified ferromagnesian phenocrysts of the altered basalts are most favored. Stibnite forms microscopic rosettes in the altered wall rock (fig. 37) and appears to have replaced the wall rock. Such replacement has apparently progressed in some places to the extent that the full width of thin sills of altered basalt, as much as a foot thick, have been replaced by stibnite. Such stibnite bodies are commonly cut by veinlets of cinnabar.

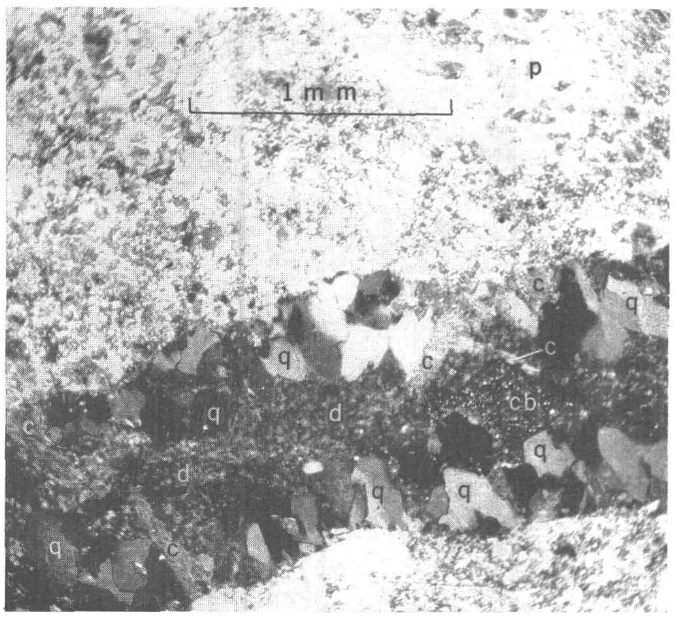

FIGURE 36.—Photomicrograph of cinnabar-bearing vein in silica-carbonate rock at Alice and Bessie mine a little east of Parks. A rhombohedron of cinnabar (*cb*) lies at the center of the vein, perched on quartz (*q*) and calcite (*c*) that form the comb structure of the vein border; dickite (*d*) fills the center of the vein. A relict pyroxene phenocryst (*p*) shows in the wall rock, which comprises carbonate and sericite, responsible for the lighter shades, and dickite, chalcedony, and quartz, responsible for the darker shades. Crossed nicols and also ordinary reflected light, scale shown approximate.

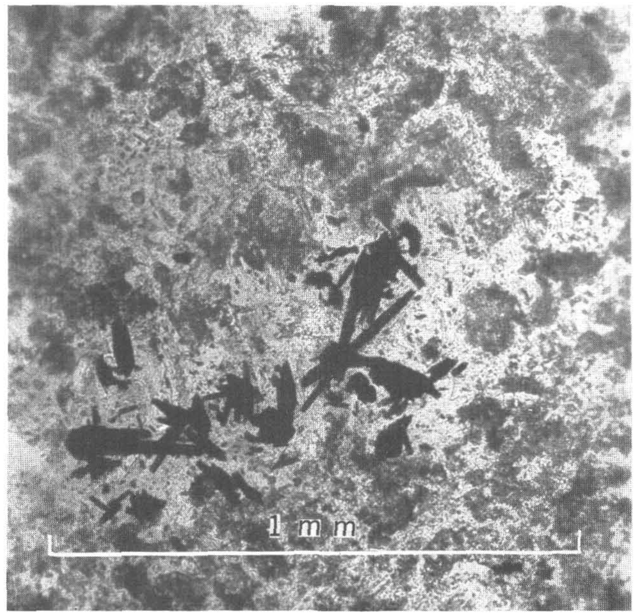

FIGURE 37.—Photomicrograph of stibnite needles in silica-carbonate rock, at Red Devil mine, 6 miles northwest of Sleetmute. Light areas include sericitic mica, chalcedony, and quartz and darker areas, other than the black of the stibnite needles, include chiefly carbonate. Plain light.

Less abundant minerals, associated locally with the quicksilver deposits, are the orange-red arsenic sulfide, realgar (AsS), pyrite (FeS_2), and native mercury (Hg). In the weathered zone light yellow and brown antimony oxides coat the stibnite-bearing veins; orpiment (As_2S_3), the yellow sulfide of arsenic, forms on realgar; and the surfaces of cinnabar crystals may be somewhat darkened. A pulverulent, earthy form of cinnabar, referred to by the miners as "paint," coats joint surfaces and is commonly slickensided.

Like quicksilver deposits elsewhere the Alaskan deposits are characterized by a relatively simple suite of ore and gangue minerals. Most of the minerals described above, as well as their mutual relationships, may be observed with the naked eye.

ROCK ALTERATION

The quicksilver deposits are, with few exceptions, in zones of altered rock conveniently referred to as silica-carbonate rocks. These zones include biotite basalt sills and dikes, as well as graywacke or shale strata immediately adjacent, that have been carbonatized, silicified, sericitized and kaolinized. It seems worthwhile to summarize here salient features of the silica-carbonate rock related to quicksilver and origin of the ore deposits, although the alteration of the basalt and sedimentary rocks has been discussed at considerable length in earlier pages.

Locally, where the rock is definitely bleached to a pearl gray (pl. 9), an indication of the most advanced alteration, it is made up almost entirely of carbonate, chalcedony, quartz, fine-grained mica of sericitic habit, and clay minerals. Chalcedony is one of the more abundant of these in the vicinity of quicksilver deposits, as is readily shown by the extreme toughness, under the hammer, of the altered rock before it weathers. The abundance of carbonate, chalcedony, quartz, and sericite is shown by photomicrographs of thin sections (figs. 36, 37). In old prospects and mine openings, where weathering under wet conditions has progressed for a considerable time, the carbonate is dissolved from the altered rock, which loses its cohesiveness. Where this happens a white puttylike mass, in which characteristics of the clay minerals are most pronounced, may result. Under relatively dry conditions, such as in outcrop exposures, the rock weathers a rusty brown and becomes somewhat porous. Where this takes place the clay mineral content is not as apparent, but iron stain, absorbed from weathered pyrite, is distinctive. The altered sedimentary rocks are commonly difficult to distinguish from altered basalt unless sufficient rock is exposed for the identification of bedding. The altered sedimentary rocks appear more blocky, have a more granular fracture, and lack the dark-specked appearance of the altered basalts that is produced by dark relict phenocrysts of ferromagnesian minerals.

The features of the silica-carbonate rock are a valuable guide in the search for quicksilver deposits and are apparently related to the origin of the ore.

ORIGIN

The close association of all the quicksilver deposits with fractures is in agreement with the generally accepted conclusion that quicksilver and associated ores were formed by hydrothermal solutions that rose through such openings. The solutions are believed to have risen chiefly through fractures, which were best developed in silica-carbonate rock and in the vicinity of contacts between rocks of contrasting competency. The cross-cutting relationship of the ore veins in the silica-carbonate rock (figs. 35, 36) indicates that a preliminary wave of hydrothermal solutions, in advance of ore mineralization, was responsible for wall-rock alteration. The effect of the advance formation of silica-carbonate rock, particularly the introduction of silica, has been to increase the brittleness (Ross, 1942, p. 447) of the enclosing rocks and thereby further prepare them for the formation of open fractures favorable for deposition of ore.

Both wall-rock alteration and vein mineralization took place some time after the start, in Late Cretaceous—early Tertiary time, of mountain-building movements that have continued up to the present, and are responsible for fractures in the wall rock. The youngest rocks that the quicksilver-antimony veins are known to cut are the quartz monzonites and related igneous rocks of the stocks. Although the ore veins have not been found in the stocks of the central Kuskokwim region, they have been noted by Mertie (1937b, p. 248) in central Alaska, where the quicksilver veins cut the stocks. Quicksilver-antimony veins intersect a monzonite stock at the head of Chicken Creek (Brooks, 1916, p. 49), near Flat, 10 miles north of the area of plate 1. The stocks were probably intruded in the Oligocene or Miocene, in which case the quicksilver deposits are of Miocene age or later. A late Miocene or early Pliocene episode of mineralization is inferred, since the quicksilver deposits are intersected by the Sleetmute upland surface, which probably began to evolve in the Pliocene. Wall-rock alteration possibly took place in a considerably earlier episode, very likely that of gold mineralization connected with the intrusion of the albite rhyolite sheets and dikes.

A possible history of mineralization related to the quicksilver deposits is as follows:

1. Acid carbon dioxide ground waters, probably heated by cooling igneous masses at greater depth, reacted with the plagioclase of the biotite basalt, and hot alkaline calcium and sodium bicarbonate solutions were formed. Ferromagnesian minerals were replaced by calcite in the presence of these solutions, and at the same time the displaced iron and magnesium entered their carbonates, namely siderite, ankerite, and dolomite; carbonization was thus completed. The silica freed in these reactions dissolved.

2. The silica-bearing hot sodium bicarbonate solutions first attacked any ferromagnesian minerals not reached by carbonatization. Later they attacked the carbonates and, locally, the feldspar, replacing all with chalcedony and quartz. These alkaline waters altered the plagioclase of the wall rock to fine-grained mica, loosely referred to as sericite. Late in the episode of silicification and sericitization, after formation of the silica-carbonate rock, the wall rock, cracked and thus was prepared for vein formation. Alkaline waters continued to carry silica in solution, much of it possibly dissolved from lower zones of the wall rock newly opened. Quartz was deposited from this solution at least at the borders of the veins. Uncommon appearance of carbonate before quartz in the veins may be due to the opening of fractures before the stage of carbonatization was completed.

3. The constituents of the ore minerals, cinnabar, and stibnite, are believed to have ascended from much greater depths in the earth than the mineralizing fluids responsible for wall rock alteration, through fractures

that became much deeper and more extensive late in the tectonic cycle, when tensional stresses became more effective. Quicksilver, at least, may have arisen from depth as the vapor of the native element (Krauskopf, 1951).

Hydrogen sulfide, which came up with the mercury and antimony, reacted with the sodium bicarbonate waters to produce alkaline sulfide solutions, in which the vapors of the metals or their sulfides condensed and dissolved. Stibnite, less soluble than cinnabar, was precipitated first from the alkaline sulfide solutions. Precipitation of these ore minerals was prompted by a decrease in the alkalinity, as well as by cooling of the alkaline sulfide solutions upon mingling with ground waters of surface origin (Ross, 1941, p. 137–141, 1942, p. 460–464).

4. The appearance of the hydrothermal clay mineral, dickite, in the centers of many veins, and apparently also in the wall rock, may indicate the final ascent of acid mineralizing solutions. These were comparable in their effect to the acid solutions, of surface origin, that are responsible for the formation of kaolin in common weathering processes. Native mercury, which is rare in the region, may have been formed by the oxidizing action of ground-water solutions on cinnabar.

The origin, at depth, of the ore metals quicksilver and antimony can only be inferred. An ultimate source in deep-seated magmas, possibly still unconsolidated connections of the biotite basalt sills and dikes, is suggested by the surface association of the latter with the ore minerals. However, this surface association may exist only because the igneous rocks furnish favorable receiving structures. Recent studies (Guimaraes, 1947, p. 731) have suggested that mercury is much more abundant as a trace element in sandy argillaceous sedimentary rocks than in igneous rocks. If so, the exclusively magmatic origin of mercury bearing ore fluids is in doubt.

RESERVES

The authors' original unpublished estimates of quicksilver reserves in the central Kuskokwim region were based on data obtained by sampling in surface trenches before mining operations began. Production from the operating mines over the ten-year period 1940 to 1950, amounting to about 5,000 flasks of quicksilver, has provided a basis for correction of the original estimates and has indicated operating difficulties that may influence future recovery of ore and extraction of quicksilver.

Production figures have indicated a downward revision of estimates to about one-quarter to two-thirds of estimates based on results of original exploratory sampling. The original estimates showed a reserve of about 15,000 to 50,000 flasks of quicksilver from all grades or ore, but the revised estimate, before mining, ranges from 10,000 to 15,000 flasks, or, after mining to date, from 5,000 to 10,000 flasks. The revision has apparently been necessary because the ore decreases rapidly with depth in most of the mines. Thus it has been found that the deposits in the Cinnabar Creek area, though rich, did not persist far below the surface and yielded less ore than was anticipated. Certain ore bodies at the DeCourcy Mountain mine have a similar history. There is less evidence in the Sleetmute area that values decrease with depth. Both increase and decrease of values with depth have been noted at the Red Devil mine, but it is believed that as greater depths are reached in the Sleetmute area a general decrease in values will be encountered. Thus, it is evident that future reserves must come through the discovery of new deposits. As traces of cinnabar have been found in placer concentrates from most of the areas in which the altered biotite basalt occurs, in the large part of the Kuskokwim Mountain belt from which the Sleetmute surface has not been completely eroded, it appears likely that future prospecting for quicksilver lodes will add appreciably to the known reserves.

The decade of production experience during the war and postwar years, 1940 to 1950, has shown what proportion of the quicksilver reserve may actually reach the market during periods both of high and of low prices. It has demonstrated also the effect of various technical obstacles, related chiefly to accessibility of the mines but also to metallurgy. Practice indicates that when prices are as high as \$2.50 a pound, ore bodies are mined whose width is 3 feet or more and whose original assay was greater than 30 pounds of quicksilver a ton, or 1.5 percent. When prices are about \$1.00 a pound, only that ore is mined whose original assay was greater than 50 pounds a ton. Thus, about 2,000 flasks (net weight each 76 pounds) of a total reserve of 5,000 to 10,000 flasks could be marketed at \$1.00 a pound, and 5,000 flasks at \$2.50 a pound. This situation is produced by high costs of mining and extraction, commonly greater than \$30.00 a ton of ore mined, including royalties and amortization of investment. The high costs are due to the inaccessibility of the mines in the central Kuskokwim region to supplies of labor and capital goods. Improvement of transportation facilities, particularly the construction of roads, is the most urgent remedy.

Other factors have also slowed production. At the Red Devil mine, near Sleetmute, the yield of the metallurgical plant is low because of the high antimony content of the ore. Owing to the condensation of antimony oxides with quicksilver in the plant, a mixture is formed from which the quicksilver can be separated only by repeated and costly processing. This situation contributed to the shutting down of operations at the Red Devil mine in 1946, when prices returned to peacetime levels. The difficulty has been partly met by plant adjustment, and further improvements can doubtless be made if need for quicksilver becomes urgent enough to justify more complete exploitation of the reserves in the Sleetmute area. Arsenic occurs in abundance only at one small mine and has not been found elsewhere in sufficient quantities to contaminate the quicksilver.

Potential reserves of antimony are restricted chiefly to the Red Devil mine. Here the antimony content of the ore is as great as that of the quicksilver, though its value is much less.

MINES AND PROSPECTS

Quicksilver mines and prospects have been opened in the Sleetmute, DeCourcy Mountain, Cinnabar Creek, and Kolmakof areas. The quicksilver deposits of all four of these areas were investigated by the Geological Survey, and they were sampled by Mr. B. S. Webber and his associates of the U. S. Bureau of Mines, at the time the Geological Survey parties were in the field or soon after. The analytical data provided by the samples was incorporated in a report of investigations published by the Bureau of Mines (Webber, and others, 1947, p. 8–50). The reader should refer to this report for details of sampling operations, analytical data, costs of recovery, and the history of ownership, production, development, mining, furnacing, and retorting.

The Geological Survey investigations of the four quicksilver-bearing areas are reported here. The areas are discussed in the order of their productivity.

SLEETMUTE AREA

The village of Sleetmute, near the confluence of the Holitna and Kuskokwim Rivers, is the trading center for mines and prospects situated 6 to 10 miles farther downstream, and a mile or less from the Kuskokwim River (pls. 1, 3). Quicksilver was discovered first at the Alice and Bessie claims, in 1906, by E. W. Parks, and the first Geological Survey investigation of quicksilver in the Sleetmute area was made here by P. S. Smith, in 1914 (Smith and Maddren, 1915, p. 274–280). Almost all the production of more than 3,000 flasks of quicksilver has come from the Red Devil mine, staked by Hans Halverson in 1933 and operated seasonally from 1939 to 1946.

Interbedded graywacke and shale of the Kuskokwim group form the bedrock of the area, except where they enclose sills, sheets, and dikes of silica-carbonate rock and albite rhyolite. Unconsolidated surficial deposits, including thick silt beds (not shown on pl. 3), are common. The latter cover the bedrock deeply and conceal some of the quicksilver deposits. The Sleetmute anticline (pl. 3) is a major structure in the sedimentary rocks of the vicinity of the quicksilver deposits. The Kuskokwim River flows northwestward about at the axis of this anticline, and the strata of the Kuskokwim group dip to the northeast, north of the river, and to the southwest, south of the river. The rolling late mature Sleetmute upland surface is well preserved in this area, and is only partly dissected by the Kuskokwim River and its tributaries. Quicksilver ore mineral has been found at altitudes that range from 240 feet, the approximate level of the Kuskokwim River, to 1,000 feet, at the surface of the upland in the vicinity.

RED DEVIL MINE

The Red Devil mine is located near the southwest bank of the Kuskokwim River 6 miles in an air line northwest of Sleetmute. When operations were shut down in 1946 the mine had two adit levels at altitudes of 325 feet and 311 feet, and two shaft levels at altitudes of 275 feet and 235 feet, connecting about 2,000 feet of drifts and crosscuts and 20 stopes of various dimensions (see pl. 4). The ore was being processed in a 40-ton oil-burning Gould rotary furnace supplemented by an oil-burning 2-tube Gould D-retort furnace.[1]

The graywacke and shale beds in the vicinity of the mine strike N. 45° W. and dip 55° to the southwest, on the southwest limb of the Sleetmute anticline. The major mine workings are in a zone about 250 feet thick, chiefly of shale interbeds in which, over a distance of at least 300 feet parallel to the trend of the formation, the strike veers to N. 35° W. Within this flexure silica-carbonate rock forms massive sill-like plugs that plunge 30°–40°, S. 10°–15° E. in the lower levels of the mine; the plugs diminish to thin sills in the upper levels. Both sills and plugs are arranged in echelon within the flexure so that a horizontal line projected through their centers strikes N. 60° W. Before mining development started the bedrock was completely covered by a mantle of silt as much as 25 feet thick.

The ore commonly extends up the hanging-wall borders of the sills, some of the thinner of which are completely replaced by stibnite, and on beyond the upper ends of the sills along the bedding of the sedimentary rocks, nearly parallel to the plunge of the plugs. The plunge of the ore bodies is thus 30°–40° south-southeast, and locally may be as low as 20°. Six mineralized zones, arranged in echelon and designated A, B, C, D, E, and F, are recognized.

Zone B, 40 to 50 feet thick, has produced the most quicksilver, about 2,000 flasks, and has been the best

[1] The Red Devil mine, previously operated by the Kuskokwim Mining Company. was reopened in the fall of 1952 by the Decoursey Mt. Mining Co., Inc., and since then the inclined shaft has been extended downward about 100 feet to a new working level, and furnacing facilities have been improved.

exposed for study during the progress of mining operations. It contains five ore bodies, designated B1, B2, B3, B4, and B5, that have an average thickness of about 3 feet and a length, exposed down the rake from the 311-foot level to the 235-foot level, of about 150 feet; their strike length is about 40 feet.[2] Zone C, 30 to 40 feet thick, has produced about 700 flasks. It contains three ore bodies that have an average thickness of 3½ feet and a length, exposed down the rake, of about 100 feet, chiefly above the 325-foot level; their strike lengths range from 20 to 40 feet. Zone F, which has yielded about 200 flasks, differs from the others in that the productive ore body (not shown on pl. 4) follows a dike (not shown) rather than a sill of silica-carbonate rock. This zone, which has apparently one ore body, is about 4 feet thick, measures 30 feet along the strike, and has been mined from the surface, at an altitude of 465 feet, to a depth of about 40 feet. The 325-foot adit was extended beneath this ore body, but no workable ore was discovered at the adit level. Zone A, which contains one ore body that has yielded possibly 160 flasks of quicksilver, is poorly represented at the surface, whose approximate altitude is 310 feet, but has been mined successfully over a 30-foot strike length at the 235-foot level. Zones D and E have been nonproductive and seem to carry more antimony than quicksilver. The 325-foot adit level and also surface trenches at elevations 430 feet to 450 feet intersect these zones.

The future of this mine would seem to depend on the downward extent chiefly of ore zone B, and also of zones A and C, though there is some ore remaining at upper levels that was either not as accessible as the ore that has been stoped, or contains so much antimony that metallurgical treatment was not successful. None of these zones have been exposed to a sufficient depth in the downward expanding silica-carbonate rock to determine to what amount, if any, the increase of the latter with depth has prevented quicksilver mineralization. It is inferred that formation of ore would have been restrained to some extent at depth inasmuch as the larger bodies of silica-carbonate rock are not as readily shattered, and therefore do not contain abundant openings for passage of ore fluids and to receive the ore minerals.

ALICE AND BESSIE MINE

The Alice and Bessie mine, which has not been in production since 1923, is located north of and adjacent to the Kuskokwim River near the former post office of Parks, about 9 miles in an airline northwest of Sleetmute. The mine workings include numerous surface trenches and pits at altitudes of 340 to 420 feet, as well as a crosscut adit 525 feet long, and a connected drift 240 feet long, at the 240-foot level. Total production of about 100 flasks of quicksilver has come largely from surface pits. In addition to a makeshift steel drum, in which most of the ore was processed, a 12-tube Johnson-McKay retort furnace and a small Scott furnace have been used.

The mine openings intersect the graywacke and shale strata of the northeast limb of the Sleetmute anticline, where the formations strike N. 40° W. and dip 55° NE. The strata are intruded by sills and dikes of silica-carbonate rock. Bedrock is covered in most places by 3 to 6 feet of frost-broken fragments derived from the bedrock. Zones known to contain cinnabar, and from which most of the production came, lie principally in and adjacent to a rather extensive sill, 5 to 20 feet thick and at least 700 feet long, that is exposed at the lowest underground levels at an altitude of 240 feet, as well as at the surface at altitudes of 340 feet to 420 feet. The ore, including a little stibnite, occupies fractures formed nearly at right angles to the sill and adjoining beds of graywacke (fig. 35), and is also disseminated in the silica-carbonate rock of the sill. The early miners obtained some ore near faulted contacts between the silica-carbonate rock and graywacke, in small openings that now lie off the main adit, 100 to 150 feet in from the portal. A little ore is associated with a dike in an opencut northwest of the adit, and some is reported in the bed of the Kuskokwim River on the southeasterly projection of the main sill.

BAROMETER MINE

The Barometer mine is about ½ mile southwest of the Kuskokwim River and 7 miles air line northwest of Sleetmute, at an altitude of about 350 to 450 feet. The workings include a branching adit, whose total footage is about 175 feet, and several surface trenches and pits. The mine, which was discovered in 1921 by Hans Halverson, produced 10 flasks of quicksilver in 1938 and 6 flasks in 1940. Single-tube Gould D- and Johnson-McKay retort furnaces were used successively here.

This mine, like the Red Devil mine, is opened in a shaly zone of the interbedded graywacke and shale that strikes N. 45° W. and dips about 55° SW., on the southwest limb of the Sleetmute anticline. Cinnabar occurs along bedding joints and in openings along fault and fracture zones, particularly in the vicinity of silica-carbonate rock. Its distribution is irregular and quite unpredictable. Realgar, in addition to cinnabar and stibnite, is rather abundant in this deposit.

[2] Paul Sorenson and Robert Lyman of the Decoursey Mt. Mining Company report that ore body B4 was opened in 1953 to about the 155-foot level by a crosscut and drift connected with the inclined shaft, and that a small raise, since extended up the rake of ore body B4 to the 235-foot level, yielded ore from which about 200 flasks of quicksilver have been produced.

WILLIS PROSPECTS

The Willis prospects lie about 1 mile north of the Kuskokwim River and 10 miles airline northwest of Sleetmute. The openings, which are at an altitude of 600 to 750 feet, consist of numerous pits, trenches, and short adits. These prospects were discovered in 1909 by Oswald Willis and Jack Fuller, and Willis has explored them almost continually since that time. A little more than two flasks of quicksilver were produced here during World War I, in a retort constructed from galvanized sheet iron and oil drums.

The openings expose dikes of silica-carbonate rock that strike roughly north-northeast, across interbedded graywacke and shale, on the northeast limb of the Sleetmute anticline. The sedimentary rocks strike N. 60° W. and, although they dip steeply southwest 45°–80°, original bedding features indicate that the tops of the beds are to the northeast and the formation overturned. The most extensive exploration has been in a zone immediately southeast and above a dike about 40 feet thick, that dips about 65° southeast. The graywacke and shale above the contact are fractured and brecciated and the dike itself is broken by joints that penetrate into it at right angles to the contact; the cinnabar and associated stibnite form veins and incrustations in the openings.

FAIRVIEW PROSPECT

The Fairview prospect is approximately 1¼ miles west of the point where McCally Creek enters the Kuskokwim River. The workings consist of a few surface pits and trenches opened at altitudes of 860 to 900 feet.

Cinnabar-stibnite veinlets occupy fractures in the central portion of a sill of porphyritic albite rhyolite, about 120 feet thick, that strikes N. 60° W. and appears to dip steeply to the southwest. The sill intrudes interbedded graywacke and shale on the southwest limb of the Sleetmute anticline. This occurrence is unique in that quicksilver is rarely found in association with the albite rhyolite.

OTHER CLAIMS AND PROSPECTS

Several other quicksilver claims have been staked in the vicinity of Sleetmute. Considerable prospecting with trenches and pits has been done at places other than where claims have been staked. The Vermillion and Mercury claims, which cover the area near the mouth of McCally Creek between the Red Devil and Barometer mines, have been rather systematically trenched and small amounts of ore mineral found, chiefly as bedding stringers in a a shaly zone of the interbedded graywackes and shales. At the Two Genevieves claims, southwest of Cribby Creek, cinnabar is localized in vugs and a breccia zone at the upper border of a sill of silica-carbonate rock. At the Ammiline prospect on the east slope of the valley of Parks Creek the cinnabar occurs in fractures in albite rhyolite like that at the Fairview claims. Another prospect, reported to show cinnabar and stibnite, is southwest of the head of the small creek that flows past the Barometer mine. Traces of cinnabar have been found at an altitude of about 1,000 feet on the northeast slope of Barometer Mountain, in graywacke and shale near the contact with the porphyritic albite rhyolite at the head of McCally Creek. A small amount of cinnabar occurs in the bedrock back of Mellick's trading post at Sleetmute. Numerous claims have been staked on discoveries of float quicksilver ore. Some of the principal lode deposits operated as mines, notable the Red Devil mine, were originally located on float discoveries.

DECOURCY MOUNTAIN AREA

This comparatively small but productive area lies a little northwest of the divide between Crooked Creek and the Iditarod River, about 17 miles airline northwest of the village of Crooked Creek on the Kuskokwim River (see pl. 1). DeCourcy Mountain, the highest point in the vicinity, stands among the rolling hills southeast of the Iditarod River. The quicksilver lodes lie south of DeCourcy Mountain on the north side of Return Creek, which flows into Montana Creek, a southeastern tributary of the Iditarod River. The area is accessible by trails from Crooked Creek and Flat and, during times of high water, by power boat via either Crooked Creek or the Iditarod River. A landing strip for small airplanes serves the area.

The quicksilver deposits, which have become known as the DeCourcy Mountain mine, were discovered in the winter of 1910–11 by Matt DeCourcy and first staked by him in 1919. Mining and treatment of the ore continued intermittently from 1920 to 1932, with a total production of about 150 flasks of quicksilver. Operations were resumed in 1942 by Robert Lyman and continued through 1949, raising the total production to more than 1,200 flasks. The ore was treated in a wood-burning 2-tube Gould D-retort furnace.

Interbedded graywacke and shale of the Kuskokwim group, intruded by sill-like bodies of basalt and diabase, form the bedrock in the vicinity of the deposits. Both igneous and sedimentary rocks have been extensively, although not completely altered to silica-carbonate rock. These rocks are overlain to the northwest by the Iditarod basalt. The bedrock is almost everywhere concealed by a mantle of unconsolidated frost-broken fragments of bedrock. The structure of the area in the vicinity of the deposits, insofar as it could be determined, suggests a homocline that strikes northeast and dips northwestward. The quicksilver deposits have been opened chiefly in the side of a gulch that is developing in the present cycle of erosion and which intersects the gently rolling Sleetmute upland surface formed during an earlier cycle.

Quicksilver ore is restricted to the silica-carbonate rock and to unaltered formations immediately adjacent. Silica-carbonate rock is more highly silicified here and includes more altered sedimentary rocks than in other quicksilver mining areas of the central Kuskokwim region. The resulting extreme brittleness of relatively large masses of wall rock doubtless explains the predominance of ore bodies that occur in comparatively wide breccia zones that may dip across the strata, although they generally parallel the strike. Apparent offsets of the large veins reflect an irregular fracture pattern rather than post-ore faulting. Zones of impregnation and filling along bedding-plane joints, such as occur where wall-rock alteration is confined largely to sills and dikes, are less common. The DeCourcy Mountain deposits contain very little stibnite.

The ore bodies are exposed for short distances over a slightly curved belt about 2,000 feet long, 250 feet wide and through a vertical range of 360 feet (pl. 5). Occurrences of cinnabar, not necessarily of ore value, are known over an area 2,600 feet long, as much as 2,000 feet wide, and through a vertical range of about 420 feet. An upper vein system exposed between altitudes of 760 and 1,020 feet comprises the Tunnel vein, the Retort veins, the Top vein, and the DeCourcy vein. A lower vein system, exposed between altitudes of 640 and 740 feet, includes the *A*-vein and some associated veinlets.

The Tunnel vein has proved to be the most productive. It has been mined from three adit levels at altitudes of 820, 871, and 910 feet, which connect about 750 feet of drifts and crosscuts that enter the ore zone. The ore body has been mined and completely exposed at the surface by trenching between altitudes of 910 and 950 feet. The graywacke and shale in the vicinity of the vein enclose sill-like bodies of silica-carbonate rock commonly less than 10 feet wide. The strata strike N. 5° E. and dip 65° W. The vein strikes N. 10°–15° E. and in general dips 65° E. across the strata. It seems to be formed in a rather thick shaly zone. The continuity of the vein is broken by barren fractures, but postmineral fault movements seem to be limited to displacements of less than 1 inch. The Tunnel vein, and adjacent mineralized zone comprised in the ore body, are 200 feet long at the surface, average 3.2 feet wide and are known through a vertical range of 130 feet. About 800 flasks of quicksilver had been produced from this vein up to the time mining operations were shifted to new sites in 1947.

The Retort and Top veins, from which most of the early production came, and from which a large proportion of the ore found in the mantle of frost-broken bedrock fragments has been weathered, have been mined from surface trenches and pits at altitudes between 960 and 1,020 feet. The adit level at 820 feet was extended 400 feet northeastward from the Tunnel vein to explore beneath the Retort and Top veins, but no mercury has been produced from this lower level. This level was mapped with a compass and its position as shown is approximate. The Retort and Top veins have been exposed at the surface by stripping to bedrock over a horizontal distance of 300 feet. Irregular bodies of silica-carbonate rock, which comprises both altered basalt or diabase and altered graywacke and shale, enclosed in an equal amount of unaltered graywacke and shale, are exposed in the stripping. The igneous rocks are sill-like, strike about N. 30° E., and dip from 50° to 75° W. parallel to the strata of the sedimentary rocks. Cinnabar is localized in discontinuous bedding-plane joints, chiefly in shale, and in a fracture (Top vein). This fracture strikes N. 20° E. from a body of intrusive silica-carbonate rock into adjacent unaltered sedimentary rocks, and dips about 80° W. at a slightly steeper angle than the bedding. The continuity of the fracture is broken at a barren cross fracture with apparent offset. An extensive fracture that strikes approximately N. 54° E. and dips 79° NW. has been exposed on the 820-foot level, but it has not been recognized at the surface. This fracture, and other fractures and bedding joints encountered on the 820-foot level, are either barren or show only weak cinnabar mineralization. It should be possible to test the downward extent of the Retort and Top veins with comparatively short crosscuts, or by drilling, from the northeastern extension of the 820-foot adit. About 300 flasks of quicksilver have been derived, chiefly from the float ore weathered from these veins.

The DeCourcy vein and some associated veinlets make up a mineralized zone, about 300 feet long, that has been exposed at the surface by trenching and stripping between altitudes 770 feet and 840 feet. The graywacke and shale in the vicinity of the veins strike roughly N. 30° E. and dip about 55° W. A large body of silica-carbonate rock contains most of the DeCourcy vein. The vein, which lies in a brecciated zone in the silica-carbonate rock, strikes northeastward and dips east in some places and west in others, and extends into sedimentary rocks beyond the silica-carbonate rock in a fracture that dips across the bedding. North of the silica-carbonate rock the mineralized fracture dips very steeply east, and to the south it dips steeply west. Abrupt irregularities in width and shape of the vein are common in the silica-carbonate rock; they reflect its blocky fracture where brecciated and give the appearance of post-mineral offsets although neither mineral gouge nor brecciated ore were found to substantiate faulting. One cross fracture contained an unbroken contination of the ore. A few flasks of quicksilver have been derived from this ore body and from float ore weathered from it.

The *A*-vein is a part of a mineralized zone more than 500 feet long that has been exposed in pits and trenches at the surface at altitudes between 660 and 740 feet. An abandoned adit about 100 feet long, opened at an altitude of 660 feet southeast of the *A*-vein, failed to reach the mineralized zone. The sedimentary strata strike roughly north and dip 30° to 70° west at the *A*-vein. A large body of hypersthene diabase porphyry, locally altered to silica-carbonate rock, appears to cut the bedding of the sedimentary rock at least locally east of the *A*-vein. The otherwise straight border of the silica-carbonate rock curves sharply for a short distance around the south end of the *A*-vein. The *A*-vein occupies principally a continuous fissure that is roughly parallel to the strike, but that dips 75° E. across shaly graywacke at or near the contact with the silica-carbonate rock. The fissure enters the silica-carbonate rock at the sharp curve in the contact south of the main vein and pinches out. There is evidence of some post-mineral movement here, as the fissure walls, which are slickensided horizontally or nearly so, are smeared with fine cinnabar apparently ground into paper-thin coatings of polished, greasy appearing gouge. Small but distinct crystals of cinnabar, on the other hand, coat the slickensided surfaces. A few flasks of mercury have been retorted from loose weathered fragments of this vein.

A tributary of Return Creek, a little south of the lode workings, was prospected for placer cinnabar and the operator believes that worthwhile quantities of quicksilver could be recovered from this source with proper placer mining equipment.

The future of the lode deposits in the DeCourcy Mountain area is apparently dependent upon the downward extent of the veins that have been exposed. The Tunnel vein has been rather thoroughly tested at depth, but the others have not. The tenor of the ore diminishes with depth in the Tunnel vein, which experience possibly indicates the condition of the other veins. The cinnabar placers have not been thoroughly enough prospected to make possible a reliable estimate of the quicksilver reserve they may contain. Much of the cinnabar that has been weathered and eroded from the lodes has doubtless entered the tributary of Return Creek south of the mine, and therefore a large reserve of quicksilver, possibly as great as that in the lodes, might be expectable in the stream deposits and on adjacent hill slopes.

CINNABAR CREEK AREA

The Cinnabar Creek area, which lies on the Aniak-Holitna divide south of Flat Top Mountain, includes a mineralized belt that extends northward for about 6 miles from upper Beaver Creek across the middle course of Cinnabar Creek (pl. 1, fig. 38). The deposits have been reached chiefly by poling boat with outboard motor in the Holitna, Chukowan, and Gemuk Rivers. A winter tractor trail has been cleared from the Aniak River by way of the west fork of Timber Creek.

The quicksilver claims in the Cinnabar Creek area were located in 1941 by Russell Schaefer and Harvey Winchell. In 1942, 2,320 pounds of high-grade ore were selected from residual material weathered from the lode at the Lucky Day prospect and were brought to Sleetmute for treatment, where 15 flasks of mercury were produced. In 1943 similar material from the same lode yielded 1,200 pounds of ore from which 11 flasks were obtained.

Both the Gemuk and Kuskokwim groups are included in the bedrock of the Cinnabar Creek area. Most of the Gemuk group in the area is composed of massive siltstone, but a narrow zone of chert and limestone strikes northward near the center of the mineralized belt, and andesitic lava flows make up the upper part of the Gemuk group southwest of Cinnabar Creek. Typical interbedded graywacke and shale occur in the Kuskokwim group exposed southwest of the lava flows. The sedimentary rocks are intruded by large sills of coarse basalt and quartz diabase, and small sills of biotite basalt, some of which are altered to silica-carbonate rock; the sedimentary rocks in the vicinity of the sills may partake of this alteration. The formations are all in a homocline that dips southwest. The topography of the hills was developed during at least two cycles of erosion. The two most recent are first, formation of the late mature somewhat rolling Sleetmute surface and second, incision to form steep-walled gulches that left only remnants of the earlier surface in the upland areas (fig. 31).

The quicksilver deposits include both lodes and placers. The lodes contain higher grade ore near the Sleetmute upland surface.

LUCKY DAY PROSPECT

The Lucky Day lode prospect is located near the head of Canary Gulch, a southward flowing tributary of Beaver Creek, about 2¼ miles air line southwest of the mouth of Cinnabar Creek. Development work on and near the lode included about 12 pits and trenches and 7 short adits, none of the latter of which were accessible when visited by the Geological Survey party in 1943. Nearly all the production, about 26 flasks of quicksilver has come from surface trenches and pits,

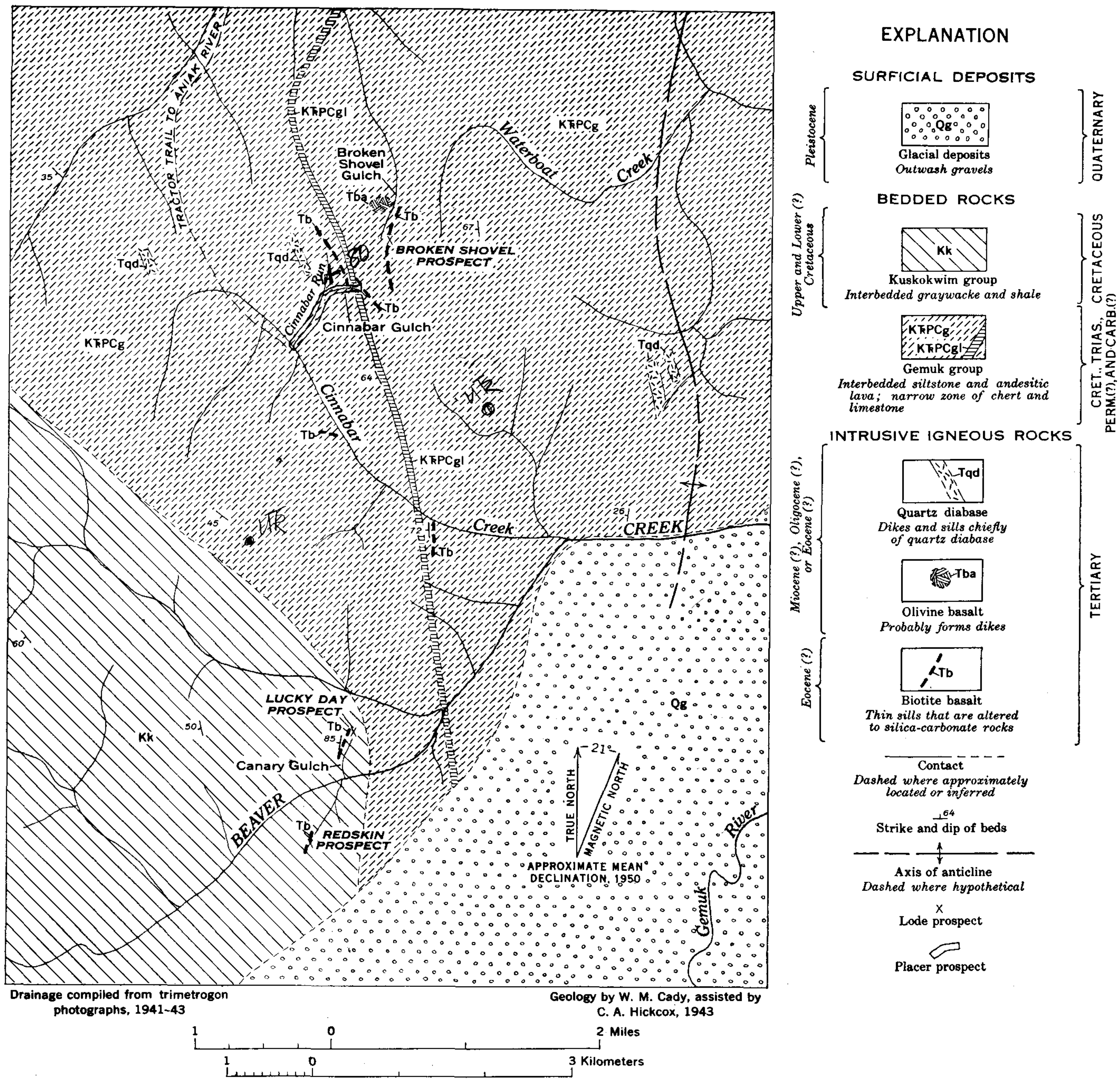

FIGURE 38.—Geologic sketch map of the Cinnabar Creek area, showing location of the quicksilver deposits.

chiefly in slightly displaced residual deposits 6 to 10 feet deep near the extreme head of Canary Gulch. The ore was transported to Sleetmute by back packing and poling boat and processed in retort furnaces at the Red Devil mine.

The ore is in a shaly zone of the Kuskokwim group within a few hundred feet west of exposures of the uppermost strata of the Gemuk group. Very irregularly distributed biotite basalt sills, some of which are altered to silica-carbonate rock, intrude the shaly strata. The formations in the vicinity of the lode strike a little east of north and dip steeply west or are vertical. The lode, exposed over a vertical extent of about 130 feet, consists of a low-grade mineralized zone at least 900 feet long and 50 feet or more wide, which dips parallel to the formations. This zone includes several narrow high-grade veins that average about one inch thick. The lode contains cinnabar, stibnite, native quicksilver, and dickite localized along and near the hanging walls of the sills. The cinnabar in the upper parts of the lode lies principally in bedding-plane fractures and is fine grained and dense, whereas in the lower parts of the lode there are more cross joints and breccia openings and the mixed cinnabar and quartz gangue is coarsely crystalline. The higher-grade veins within the lode are wider but leaner, where exposed in the lower prospect openings, than they are in several of the upper pits. A field party of the Bureau of Mines trenched and sampled the prospect after the Geological Survey party was in the field, and reported that a system of fractures that trends N. 50° E. is also mineralized (Rutledge, 1950, fig 5).

The operator, Russell Schaefer, believes that all the high-grade ore in the Lucky Day lode has already been mined and that all that remains is too low grade to be of commercial value at present. The low-grade material is at lower altitudes than that mined. Hand-selected high-grade ore from near the head of Canary Gulch contained about 1,100 pounds of quicksilver a ton (55 percent). Similarly selected ore from elevations 100 feet lower than that of the head of the gulch would probably contain less than 100 pounds a ton (5 percent). This seems comparable to the condition of the other quicksilver deposits thus far discovered in the Cinnabar Creek area, and suggests that the future of lode production in the area is dependent chiefly on discoveries of new and possibly short-lived deposits.

BROKEN SHOVEL PROSPECT

The Broken Shovel lode prospect lies a little east of Broken Shovel Gulch, a northward flowing tributary of Waterboot Creek, and about 2½ miles north-northwest of the mouth of Cinnabar Creek. A few shallow prospect pits have been dug in the steep head of the gulch, and at somewhat higher elevations on the upland southeast of the head of the gulch.

Siltstone of the Gemuk group strikes north and dips steeply west in the vicinity of the Broken Shovel lode. Sills of silica-carbonate rock exposed in the gulch may be traced southward onto the upland by following the yellow-weathered float rock fragments. A little below the head of the gulch, where sills of silica-carbonate rock happen to be most abundant, the strike of the sedimentary rocks swings to the northwest for several hundred feet and possibly, as at the Red Devil mine in the Sleetmute area, the sills were intruded in a flexure. The lode, as inferred from the distribution of float fragments of ore mineral on the upland surface east of the gulch, strikes north-northwest parallel to the strike of the inclosing rocks and presumably dips steeply to the west with the formations. As nearly as can be determined from the character of the fragments the minerals are coarsely crystalline and fill small cross joints and breccia openings, and cinnabar gives way to stibnite and quartz at lower elevations. Native quicksilver is reported. Fine particles of cinnabar, that fill cracks in altered olivine phenocrysts, are disseminated through partly altered basaltic sills northwest of the lower reaches of the gulch, in a zone that is apparently a continuation of the lode and associated sills already described.

The mineral occurrence at this prospect is comparable to that at lower elevations in the Lucky Day lode.

REDSKIN PROSPECT

The Redskin lode is near the head of Alder Gulch, a southern tributary of Beaver Creek opposite Canary Gulch, and about one mile south-southwest of the Lucky Day prospect. According to Schaefer only a few openings have been made, but the lode was exposed and appeared to be comparable with, although probably less extensive than, the Lucky Day lode. This claim was not examined by the Geological Survey party.

CINNABAR CREEK PLACERS

Placer quicksilver claims have been staked on Cinnabar Creek, Cinnabar Run and in Cinnabar Gulch. The tested ground extends from a point about 1,000 feet up Cinnabar Gulch from the junction with Cinnabar Run down to the confluence of Cinnabar Run and Cinnabar Creek, and totals about 3,100 feet. About 35 test holes have been sunk to bedrock by various prospectors.

The flood plain formed on the placer gravels is 100 to 150 feet wide. The average depth of gravels to bedrock is about 7 feet; they are deepest in Cinnabar Gulch. The meandering stream channel is about 4 feet deep in the gravel deposits. The pay streak, which contains cinnabar nuggets up to the size of one's fist, is said to be 2 to 6 inches thick and 25 feet wide. A few nuggets were obtained from the apparent remnants of a bench placer deposit, about 40 feet above the flood plain and south of the junction of Cinnabar Gulch with Cinnabar Run. Nuggets from Cinnabar Gulch are very angular, but at a distance of about 2,000 feet downstream, on Cinnabar Run, well-rounded nuggets occur. Some of the nuggets are large enough and contain enough attached country rock to show the type of lode occurrence. The cinnabar is finely crystalline, like the better ore of the Lucky day lode, and forms a dense, closely-knit mass in each nugget; breccia fragments of siltstone as well as quartz and stibnite are attached to the cinnabar in some of the nuggets. The lode source of the cinnabar nuggets has not been discovered, but, unless completely eroded away, it is probably near the head of Cinnabar Gulch. This gulch crosses at least one sill of silica-carbonate rock like that associated with the quicksilver lode at Broken Shovel Gulch, less than 1 mile to the northeast.

KOLMAKOF AREA

Cinnabar has been found in the bluffs on the north bank of the Kuskokwim River, about 3 miles downstream from the mouth of the Kolmakof River and the site of the old Russian fort at Kolmakof (pl. 1). The Russians from "Redoute Kolmakoffski" are said to have known of cinnabar at this locality as early as 1838, but there is no record of their having produced any quicksilver. The first and only reported production was in 1909 or 1910 when about two flasks were recovered. The first Geological Survey investigation of the locality was by A. G. Maddren in 1914 (Smith and Maddren, 1915, p. 280–286). A field party of the U. S. Bureau of Mines, under the direction of Mr. B. S. Webber, explored the area at the time of the Geological Survey investigations in 1944. This party opened 29 trenches and test pits in an area 600 feet long and 200 feet wide.

Interbedded graywacke and shale of the Kuskokwim group, which constitute most of the bedrock of the Kolmakof area, strike on the average N. 30° E. and dip 35° to 60° NW. A sill of silica-carbonate rock 25 to 30 feet thick, and exposed over a horizontal distance of 400 feet, can be followed eastward up the cliffed face of the bluff. This sill strikes N. 45° E. and apparently dips north with the sedimentary rocks. A few small bodies of silica-carbonate rock are exposed to the southeast at lower points on the face of the bluff. A loose mantle of surficial deposits covers the bedrock on top of the bluff. Shear zones parallel the bedding and are developed as irregular fractures and breccia zones at or near the upper contact of the sill.

Cinnabar is associated with silica-carbonate rock, as in other areas of the central Kuskokwim region. Stibnite is absent. Quartz is the principal gangue mineral. The ore occurs as facture fillings in brecciated zones, particularly at the upper border of the large sill, and is disseminated in both the silca-carbonate rock and adjacent graywacke.

GOLD DEPOSITS

The principal gold deposits in the central Kuskokwim region are in the Donlin Creek area at the head of Crooked Creek, near the head of Taylor Creek a little southeast of the Taylor Mountains, and on Julian Creek a tributary of the main fork of the George River. The gold commonly occurs in the vicinity of albite rhyolite dikes and sheets.

CHARACTER

The producing deposits are the familiar placer concentrations of native gold. The lodes appear to be chiefly quartz fracture fillings in breccia zones, at or near the contacts of silicified and sericitized rhyolite and adjacent graywackes and shales of the Kuskokwim group. The placer concentrations occur in the deposits of existing streams, in bench gravel, and in buried gravel beneath silts and modern flood-plain deposits. The largest concentrations of gold are in paystreaks immediately above the bedrock. Smaller concentrations may occur above a "false bedrock", commonly produced by a "hardpan" of interlayered clayey silt that lies immediately beneath the flood-plain deposits of existing streams, and above buried gravel. The most productive placers are in areas of the rolling late mature Sleetmute surface in conjunction with the lode associations outlined above. The streams in such terrains have gentle gradients and are fairly well adjusted to the topography, hence the stream bottomlands merge with the slopes in comparatively smooth curves. The benches are erosional remnants of such stream bottoms dissected by rejuvenated streams.

MINERALOGY

Gold (Au) is associated with the antimony mineral, stibnite (Sb_2S_3—antimony trisulfide) in the quartz lodes that adjoin exposures of albite rhyolite. The placer concentrates contain, in addition to gold and stibnite, the tungsten mineral, scheelite ($CaWO_4$—calcium tungstate); the tin mineral, cassiterite (SnO_2—tin dioxide); and the quicksilver mineral, cinnabar (HgS—mercuric sulfide). Presumably most of these occur in the lodes from which the gold and stibnite were derived. Magnetite (Fe_3O_4), the chief constituent of "black sand"; garnet, which forms "ruby sand"; pyrite (FeS_2), or "fools gold"; and zircon ($ZrSiO_4$) occur rather abundantly in the placer concentrates. The wall rock of the lodes, including both the rhyolite and interbedded graywacke and shale, is rather strongly silicified, sericitized, and pyritized. The effects of carbonatization seems to be more generally distributed, irrespective of the occurrence of gold.

ORIGIN

The close association of the gold deposits with intrusive bodies of albite rhyolite is consistent with a worldwide, apparently genetic relationship between gold-quartz deposits and albitic igneous rocks (Gallagher, 1940, p. 698–736). Such an association suggests a source of ore-forming fluids relatively close to the site of deposition as compared with that of quicksilver and antimony, whose localization as has already been pointed out is more directly dependent upon structure of the enclosing rock than upon the composition of associated intrusives. The gold, although obviously not derived from the magma from which the rhyolite that encloses the gold veins crystallized, may have been derived from yet molten deeper or interior zones that later solidified to form the core and lower parts of the intrusion.

A mechanism for this process has recently been suggested by C. J. Sullivan (1948, p. 486) and discussed critically by A. B. Edwards and A. J. Gaskin (1949, p. 237). Sullivan suggests that the gold is preferentially concentrated peripheral to and in the vicinity of "soda-rich albite porphyries" inasmuch as the gold atoms dispersed within the magma may not substitute because of disparate size, for the atoms of the element sodium in albite; conversely potassium atoms which are very nearly the size of atoms of gold are readily displaced by gold, and gold thus remains a trace element in normal potash granite and quartz porphyry. Edwards and Gaskin object that the process suggested by Sullivan does not provide a "collector mechanism" for removing the unwanted gold to the borders of the albite porphyry, and suggest volatile fluids immiscible with the albite porphyry melt as collecting media.

Lode gold mineralization probably took place late in the epoch of intrusion of the albite rhyolite, which, as indicated in a previous section, is syntectonic with folds formed in the bedded rock in earliest Tertiary time. Tungsten and tin mineralization, commonly associated with felsic igneous rocks such as the rhyolite, may probably be dated in the same manner. Quicksilver-antimony mineralization possibly took place later, in the late Tertiary, at the time when the quicksilver ores already described were introduced. Direct evidence for such a chronological relationship has not been obtained in the central Kuskokwim region, but Brooks (1916, p. 11, 16, 23, 27, 48, 52) indicates that in other regions of Alaska antimony mineralization, and presumably the associated quicksilver mineralization, follow partial deformation and reopening of older quartz veins, some of which are gold bearing.

The placer deposits contain gold believed to have been weathered and eroded from the lodes beginning with the development of the late mature Sleetmute surface in Pliocene time. Gold deposited in the gravels of streams that flowed on this surface during the Pliocene formed stream placers that have either been covered by deposits of Pleistocene silt of various origins, and by the deposits of existing streams forming buried placers, or have been redissected by streams rejuvenated during differential uplift in the late Pliocene to Recent times, leaving bench placers. Placer minerals, reworked from the bench placers or derived from the lodes, entered the deposits of existing streams, forming modern stream placers. Any ancient stream placers that may have existed in glaciated areas have probably been eroded by the ice, during the Pleistocene, and not enough time has elapsed since the Pleistocene for renewed stream erosion of bedrock sources and concentration of workable placer deposits (Mertie, 1940, p. 106). The general tendency of glacial action is to dissipate rather than to concentrate the placer minerals; hence it is unlikely that glacial deposits will contain placer concentrations (Mertie, 1940, p. 111). Nevertheless there is a possibility of concentration in glacial outwash deposits, or where existing streams cross glacial moraines. Glacial morainal deposits and outwash gravels may bury ancient placers peripheral to areas of glacial erosion and, although it has not been proven, it is rather likely that some placer deposits are thus hidden in the central Kuskokwim Region.

The relative unimportance of placer gold mining in the region may possibly be attributed to glacial interference, or to both complete removal by streams with downstream dissipation of the gold and burial of the ancient placers by deposits of existing streams. Stream dissipation of the gold seems a likely explanation in the more elevated parts of the Kuskokwim Mountains, where Pleistocene and Recent uplift has kept the streams almost continuously rejuvenated. Burial may explain the lack of discoveries in the lower areas particularly northeast of the Kuskokwim River and in the Holitna River basin.

RESERVES

It is commonly observed that the central Kuskokwim region is apparently poorer in gold than other regions of Alaska to the west, north, and northeast. Production to date (from all but Julian Creek, for which no figures are available), valued at less than $300,000, seems to bear out this observation, and suggests recovery to be expected in the future. The region has been rather thoroughly prospected and it seems unlikely that any major discoveries commensurate with those of the Klondike, Nome, Fairbanks, and Iditarod will result.

That appreciable placer gold reserves seem unlikely in at least a part of the region is further suggested by the forerunning remarks on the origin of the placer deposits. Streams in the region, those southwest of the Kuskokwim River in particular, have been continuously rejuvenated during the Quaternary period and pay streaks presumably dispersed. Northeast of the Kuskokwim River, however, and possibly in the Holitna River basin, where the streams show less evidence of rejuvenation, and the ancient gravels are not entirely eroded, placer gold possibilities seem more favorable. Some of the streams in the latter areas, particularly in the George River basin, show little or no indication of rejuvenation, and buried placers may lie at depth beneath a long accumulated mixture of stream gravel and residual deposits migrated from adjacent slopes.

MINES AND PROSPECTS

Placer gold has been mined successfully on four creeks and has been widely prospected in several other areas in the central Kuskokwim region.

DONLIN CREEK

Donlin Creek and Flat Creek join to form Crooked Creek about 17 miles by trail north-northwest of the village of Crooked Creek. Placer gold mines and prospects, referred to by local prospectors as "Donlin Creek", extend upstream from Omega Gulch, an eastern tributary of Crooked Creek, nearly to the head of Donlin Creek, and include most of the side gulches that enter from the east and southeast.

Gold was first discovered in Snow Gulch in 1909. Mining started in Quartz Gulch in 1910, later spread to Snow, Ruby, Queen and Lewis Gulches, and has continued intermittently to the present time. Hydraulic methods have been used chiefly, but scarcity of water has often hampered operations. The Donlin Creek placers were examined by A. G. Maddren (1915, p. 351–353) of the Geological Survey in 1914. Gold production to date is valued at at least $125,000.

The bedrock comprises interbedded graywacke and shale that dip southwest and are intruded by bodies of albite rhyolite. The rhyolite forms "domes" that trend northwest between the gulches southeast of Donlin and Crooked Creeks; a number of small bodies, their dimensions measureable in only a few tens of feet, are exposed in the placer cuts near the mouths of the gulches. Within 25 to 50 feet of the latter the sedimentary rocks are locally indurated through silicification, but this is not a common or general feature. Numerous small veinlets of calcite and quartz occur in the sedimentary rocks adjacent to the rhyolite. Pyrite is abundant near some of the rhyolite bodies.

The placer deposits mined profitably to date are well to the east and southeast of Crooked and Donlin Creeks on benches about 1 mile wide; only a few short, narrow pay streaks, that alternate with low-grade or almost barren gravel, have been discovered in or near these streams. Gold-bearing bench gravel, that lies about 20 feet above and southeast of the present stream channels, has been reworked by small tributary streams in the gulches to the east and southeast. Reconcentration of the gold has taken place along these side streams, and in small areas where they flow from the bench gravel out into the present main stream bottoms, with consequent reduction of gradient. Bedrock is reported at a depth of 10 to 12 feet. These concentrations are said to have been of extremely high grade but are limited to areas a few hundred feet in diameter. The gravel on the bench ranges in thickness from about 15 feet at the margin of the stream bottom to about 65 feet in placer cuts ¼ mile back on the bench, and is probably not more than 100 feet thick at points farther east and southeast. Gold concentrates are very irregularly distributed on the bedrock of the bench and some areas are entirely barren Only in the deposits of the stream that emerges from Snow Gulch do they show any continuity (Maddren, 1915, p. 352).

The gold recovered is all rough and coarse gold. Fine gold and dust have not been encountered. The gold ranges from pinhead to pea size. A number of nuggets weighing 2 to 5 ounces are reported recovered from each clean-up. Seven assays of gold mined from Ruby Gulch are reported to range from 902 to 910 fine. Sample pan and sluice box concentrates were examined and found to contain magnetite, scheelite, cassiterite, garnet, cinnabar, stibnite and pyrite, in addition to gold. Several nuggets found contain both cinnabar and gold, apparently as they occurred in the lode.

At least two lodes are known in the Donlin Creek area, though none have been mined. One is located near the western edge of the top of a hill between Queen and Snow Gulches, where float rock that contains stibnite with a quartz gangue was found over an area of about 20 by 40 feet, near the apparent contact of rhyolite and interbedded graywacke and shale. Specimens contain quartz and blades of stibnite that fill openings in brecciated rhyolite. A lode gold deposit is reported on the southern side of a high hill between Dome Creek and Quartz Gulch. Assays are said to have shown gold values of about $10 a ton and a small amount of silver, although investigation of the locality disclosed only vein quartz float. Such lodes as these are evidently the source of the placer gold in the Donlin Creek area.

A valid estimate of gold reserves in the Donlin Creek area must await systematic sampling. Operations to date, however, suggest something of what may be expected. Gold values in the gravel near the mouth of Ruby Gulch are said to have ranged from 5 cents to $3 a square foot and the average tenor of gravels from all the places where gold has been reconcentrated from the bench deposits is reported to be $1 to $2 a square foot of bedrock. On the other hand, values of only a few cents to 10 cents a square foot are reported in most of the bench gravel, though they may be as much as $2 locally, and the values contained in the gravel of the bottoms along Donlin and Crooked Creek may range from a few cents to a dollar a square foot. In 191C, when operations started, only values of $1 or more a square foot could be extracted economically, but since 1920 placer ground that averages about 50 cents a square foot has been mined at a profit.

TAYLOR CREEK

Taylor Creek enters the Holitna River from the south about 15 miles north-northeast of the Taylor Mountains. Placer gold has been mined along the fork of Taylor Creek that flows between the Taylor Mountains and the Little Taylor Mountains. The total production to date is said to be about $90,000, most of which was recovered in 1950 and 1951. The bedrock of the vicinity is made up of interbedded graywacke and shale that strike a little north of west and are intruded by numerous rather large albite rhyolite sheets. The gold is concentrated in the stream gravel. Depth to bedrock is reported to average about 10 feet. The head of the pay streak is reported to be about 3 miles upstream and west of the junction of Fork Creek (see pls. 1, 6), but the latter area was not investigated in sufficient detail to determine possible relations to the rhyolite. The pay streak averages about 250 feet wide. Cinnabar and cassiterite are reported in association with the placer gold. Below the mouth of Fork Creek the concentrates are reported to contain large quantities of pyrite. The latter mineral is probably derived from a heavily pyritized and silicified zone in the graywacke and shale adjacent to rhyolite dikes at the summit of the Little Taylor Mountains. Gold values are said to average about 10 cents a square foot.

NEW YORK CREEK

New York Creek enters the Kuskokwim River from the north about 3½ miles east of the village of Napaimiut. Gold placer mines and prospects are located chiefly in Murray Gulch, a tributary that enters New York Creek from the southwest. Gold was first discovered in Murray Gulch in 1910 and production since that time, said to be valued at only a few thousand dollars, has been sporadic and relatively insignificant. The gold has been exploited chiefly by trenches and short shafts and drifts reportedly in frozen ground. These deposits were examined by A. G. Maddren (1915, p. 353–355) of the Geological Survey in 1914.

The bedrock formations are chiefly interbedded graywacke and shale that dip northwest, and are intruded by rhyolite dikes that strike northwest across the upper part of Murray Gulch. The placer gold is distributed downstream from these dikes. The productive gravel along the present course of the stream is buried beneath silt and muck. The bedrock is reported at a depth of about 35 feet at the confluence of Murray Gulch and New York Creek and becomes shallower toward the head of the gulch. When Maddren (1915, p. 355) visited the area bench gravel northwest of Murray Gulch was being prospected "at two levels—a lower one about 15 feet above and 50 feet back from the present flood plain of the creek, and a higher one about 70 feet above and 260 feet back from the creek". Maddren states that the gold from the bench gravel is rough and does not show appreciable wear by stream washing such as characterizes the gold in the bed of the present stream.

JULIAN CREEK

Julian Creek flows southeastward into the main fork of the George River about 25 miles air line north-northeast of Georgetown on the Kuskokwim River. Supplies have been freighted up the George River from Georgetown by poling boats powered with outboard motors. Placer mines are reported to have been in operation on Julian Creek intermittently for 20 to 30 years. Cinnabar as well as gold is reported. Traces of the thorium-bearing mineral monazite have also been found (Bates and Wedow, 1953, p. 11). This area was not visited by the Geological Survey party, thus little more can be said about the geology and placer deposits at this time. Operations here are reported to have been more extensive than those on Donlin Creek.

FORTYSEVEN CREEK

This creek heads in the Kuskokwim Mountains about 17 miles west-northwest of Nogamut, flows for a little more than a mile southeast in the mountains and then out into the basin of the Holitna River, where, about 2 miles from the mountain foot, it joins Mukslulik Creek. Placer gold has recently been taken from near the head of Fortyseven Creek. The deposit was discovered in 1947 by Russell Schaefer of Crooked Creek, after the Geological Survey party was in the area. This party followed the ridge at the head of Fortyseven Creek, where mineralized bedrock was noted, and reached the foot of the mountains about 2 miles southwest of the gold placer. Schaefer has tested placer gravel on Fortyseven Creek rather extensively and marketed gold recovered.

Interbedded graywacke and shale form the bedrock of the area. The strata strike about north and dip steeply both to the east and west. An extensive fault (pl. 8), strikes northeast coincident with the foot of the mountains. The lode from which the gold and associated minerals, particularly scheelite, are derived is very near the top of the ridge at the head of Fortyseven Creek. It is in an extensive shear zone in the graywacke and shale, that is heavily silicified and impregnated with vein quartz (p. 121).

Placer gold and scheelite were recovered in a gulch at the head of Fortyseven Creek near the lode, and gold also occurs downstream from the fault at the front of the mountains, but significant placer concentrations do not occur in the stream gravel between the gulch and the fault. Schaefer reports (written communication) that the bedrock gradient is about the same upstream and downstream from the fault, but the surface gradient flattens downstream so that the depth of bedrock increases from 5 feet near the fault to 35 feet half a mile downstream.

Although only the gravel of the existing stream is on the bedrock upstream from the fault different types of deposits lie successively above the bedrock southeast of the front of the mountains. Schaefer states that the bedrock carries 80 percent of the total placer gold. Above the bedrock is a coarse, compact gravel that contains some gold. This gravel is overlain by a "yellow-clay hardpan." Quartz boulders, gold and some scheelite are concentrated on the hardpan. These are overlain on top by about 10 feet of fine "wash gravel."

The relations described above seem to indicate that first an ancient stream placer was deposited on the bedrock and buried by silt from which the "clay hardpan" was formed. Then the mountains were uplifted northwest of the fault and the buried placer and overlying silt were eroded from the mountain area and dissipated downstream, and minor amounts of the heavier and coarser materials were concentrated on the hardpan downstream from the fault. Downcutting by the stream in the mountains has not quite kept pace with uplift, so the surface gradient is greater upstream from the fault.

The deposit is sufficiently unique both as regards the fault relationships and the character of the lode that an estimate of its future possibilities should doubtless wait until both the lode and placer occurrences have been more thoroughly exploited, and more detailed geologic studies undertaken. The occurrence of a buried placer such as this, in the Holitna River basin, strongly suggests, however, that others like it may be found beneath the silt, and the flood plains of existing streams, if lode conditions in the basin are favorable.

LITTLE CREEK

Little Creek flows northward into the Iditarod River 7 miles east of Mosquito Mountain. Placer gold and cinnabar are reported on the middle course of the creek about 8 miles air line S. 70° W. of the DeCourcy Mountain quicksilver mine on Return Creek. Little Creek has been prospected at intervals over a distance of about 2 miles midway between the mouth and the head of the creek. A number of test shafts have been sunk about 12 feet to bedrock, and crosscuts have been opened in the valley bottom at intervals of about half a mile.

The geologic setting is closely comparable to that of the DeCourcy Mountain area. Interbedded graywacke and shale strike N. 40° E. and dip about 70° NE. beneath lava flows of the Iditarod basalt. The sedimentary rocks are intruded by sill-like bodies of basalt altered to silica-carbonate rock, but rhyolite, like that associated with placer gold elsewhere, was not found. The gold is reported to be evenly distributed in a continuous pay streak. Pebbles of vein quartz are abundant in the placer gravel and suggest the immediate bedrock source of gold and cinnabar. It is possibly significant that intrusive igneous rocks were not found upstream from the reported head of the pay streak.

Pans that assayed from a few cents to \$1.00 a square foot of bedrock are said to have been taken.

OTHER GOLD PROSPECTS

Practically all the main streams and many of the side streams in the central Kuskokwim region have been prospected for gold, hence there are none that are particularly unique in this respect. Reports or physical evidence of past operations, encountered in the course of Geological Survey investigations, have indicated gold prospecting, in addition to that already described, on Fuller, Eightmile, California, and Central Creeks—all tributaries of the Kuskokwim River; on the Oskawalik River, near Henderson Mountain; on Gold Run and Girl Creek, tributaries of the Holokuk River, and on Timber Creek, a tributary of the Aniak River. Gold of some account is reported from all of these streams and it seems significant that they flow through areas in which albite rhyolite intrusions are abundant.

TUNGSTEN DEPOSITS

Tungsten apparently occurs in various associations and at several different localities in the central Kuskokwim region.

Marketable tungsten ore has recently been recovered from a placer deposit, which also contains gold, a little southeast of the divide between Boss Creek and the Holitna River. This locality is at the head of Fortyseven Creek (see pl. 8), a small headwater tributary of Mukslulik Creek which flows southeastward into the Holitna River about 3 miles north-northeast of Kashegelok. The ridge at the head of Fortyseven Creek was traversed by the Geological Survey field party before the deposit was discovered and an extensive area of silicified graywacke and shale, and large white quartz veins, was noted. Russell Schaefer of Crooked Creek, who discovered the tungsten and gold, reports (written communication) that the lode, which is on the east slope of the ridge at the head of the creek, occurs in close association with the vein quartz. He has kindly furnished detailed data that cover geologic occurrence and mineralogy, and that make a rather full description possible. The lode will be described first.

Scheelite, the principal tungsten mineral, and gold are associated with vein quartz in a shear zone roughly 1,000 feet wide and 1½ miles long. The zone strikes approximately north and dips very steeply, about parallel to the shale and graywacke in the vicinity. More than three-fourths of the material in the shear zone is silicified shale and graywacke and the greater part of the remainder is vein quartz. The veins seem to be dislocated so that the quartz occurs in odd-shaped disconnected masses bounded by slickensides. The amount of shearing and dislocation, and of mineralization, decreases outward from the center of the shear zone.

The metallic minerals in the shear zone include native gold (Au); the tungsten minerals, scheelite ($CaWO_4$—calcium tungstate) and wolframite ($(Fe, Mn) WO_4$—iron and manganese tungstate); the arsenic mineral, arsenopyrite (FeAsS—iron sulfarsenide); the lead-antimony mineral, jamesonite ($2PbS.Sb_2 S_3$); the antimony mineral, stibnite (Sb_2S_3—antimony trisulfide); the silver mineral, argentite (Ag_2S—silver sulfide); and traces of gold-silver tellurides. Most of these occur only in small amounts. Quartz is the chief nonmetallic gangue mineral. Tourmaline and sericite are other significant gangue minerals although not nearly as abundant as quartz. The scheelite occurs as coarse particles enclosed in quartz and associated with tourmaline and sericite. The scheelite and tourmaline are only in the center of the mineralized shear zone and sericite is very common there.

The ore-forming fluids responsible for mineralization of this deposit apparently arose from depth by way of the shear zone in which the minerals are formed. The shear zone is probably connected at depth with an intrusive igneous body that during its cooling stage gave rise to the fluids. No such body is known to crop out at the surface anywhere in the vicinity, but Schaefer reports rhyolite a few miles to the north, near the head of Boss Creek. The presence of sericite, and particularly tourmaline, in close association with the scheelite, seems to suggest that the tungsten, as well as the other metals in the deposit, were derived from a cooling body of the albite rhyolite.

The genetic relationship of this tungsten deposit to the albite rhyolite is further suggested by the occurrence of scheelite in the placer gold deposits of the Donlin Creek area, near rhyolite bodies. If this interpretation is correct the tungsten lode at the head of Fortyseven Creek was formed at the time of gold-quartz mineralization elsewhere, which, as already indicated, was probably in earliest Tertiary time, toward the close of folding of the Kuskokwim group. Further evidence for this date is suggested by the nearly parallel orientation of the mineralized shear zone and the steeply dipping strata. The Kuskokwim group has been thrown into large folds overturned to the east in this area, and it seems likely that the shear zone was formed as a subsidiary feature of folding.

The placer and the lode at the head of Fortyseven Creek were discovered by Schaefer in 1947 and have been prospected by him since then, in addition to the placer gold already described. Since the summer of 1950 coarse fragmental scheelite has been recovered from the placer accumulation in the bottom of a gulch at the head of Fortyseven Creek, about 1,500 feet east of and downslope from the outcrop of the lode. The ore has been sluiced from a cut 400 feet long, 30 feet wide, and 5 feet deep. Schaefer also reports scheelite with the placer gold southeast of the mountains, but the fragments are much smaller, owing to the greater stream wear to which they have been subjected in the longer distance traveled from the lode.

Tungsten minerals have been discovered in other areas of the central Kuskokwim region. A loose specimen of wolframite, associated with vein quartz, was collected by the Geological Survey party from the ridge west of Stevens Creek in the Taylor Mountains. This specimen had apparently weathered from the bedrock of the contact-metamorphic zone north of the Taylor Mountain granite stock. Placer scheelite is reported near the west foot of the Horn Mountains by Harry Brink of Aniak.

The reserves of tungsten in the region have been so little tested that an estimate is not possible at the present time. The geologic associations indicate, however, that additional discoveries can be expected, particularly in the vicinity of the stocks and albite rhyolite sheets, sills, and dikes.

COPPER DEPOSITS

Copper-bearing metallic sulfide and associated gold, silver and tin occur in fissure veins and breccia fillings deeply within, as well as near the borders of the quartz monzonite stock that forms the core of the Russian Mountains. The ore is localized along major joints and shear zones that strike north-northwest across the stock and dip steeply southwest. Basaltic dikes, most of which are barren, are intruded into some of the joints.

The ore minerals are chiefly arsenopyrite (FeAsS—iron sulfarsenide), chalcopyrite ($CuFeS_2$—sulfide of copper and iron), pyrite (FeS_2—iron disulfide), pyrrhotite (also a sulfide of iron), and hematite (Fe_2O_3—iron sesquioxide). Assays are reported to have indicated small amounts of gold (Au), silver (Ag), and tin (Sn) whose occurrences are not commonly apparent from field examination alone. Quartz (SiO_2) is the principal gangue mineral. Small amounts of galena

(PbS—lead sulfide), sphalerite (ZnS—zinc sulfide), chalcocite (Cu_2S—cuprous sulfide), native copper (Cu), and scheelite ($CaWO_4$—calcium tungstate) are also present at some localities. Traces of metazeunerite, a rare copper-uranium-arsenic mineral, occur. Ore exposed to surface weathering is altered to limonite ($2Fe_2O_3.3H_2O$), goethite ($Fe_2O_3.H_2O$), azurite ($2CuCO_3.Cu(OH)_2$), malachite ($CuCO_3.Cu(OH)_2$), cuprite (Cu_2O), chrysocolla ($CuO.SiO_2.2H_2O$), and to various arsenic compounds, particularly scorodite ($FeAsO_4.2H_2O$), which may be confused with the green copper stain formed by malachite. The wall rock is little altered. Many of these minerals were identified during recent investigations of radioactivity in the Russian Mountains (Wedow and others, 1953, p. 2, 4; West, 1954, p. 5–7).

The ore-forming fluids arose from considerable depth in the Russian Mountain stock by way of the joints and shear zones. The fluids were evidently introduced from below very late in, or after, the time of consolidation of the stock, because at least all of that portion of the intrusive now exposed had been crystallized, and the joints intruded by dikes, in advance of ore mineralization. The deeply fractured stock probably served merely as a conduit for ore fluids that came from depths much greater than those of the rocks now exposed at the surface.

It is inferred that the ore veins were formed in Miocene time. The stocks are believed to have been intruded in the late Oligocene or early Miocene. The stocks, and the ore veins, were eroded to about their present general contours by late Miocene or Pliocene time, when the stocks formed monadnocks that stood above an old-age surface now preserved as the Georgetown summit level.

There are two prospects and several other indications of mineralization in the Russian mountains.

The Konechney prospect is located at the extreme head of Mission Creek in the southeastern part of the Russian Mountains, at an altitude of about 2,000 to 2,350 feet above sea level, and seven miles northeast of the village of Russian Mission, on the Kuskokwim River. The openings consist of two adits that total about 900 feet, and several surface pits and trenches. The prospect was discovered in 1920 by Joe Konechney and he has explored it almost continuously since that time. The country rock is quartz monzonite intruded by nearly vertical basaltic dikes that strike N. 25° W. Quartz veins and thin zones of breccia and gouge occur in both the dikes and quartz monzonite over a width of about 200 feet, and their orientation is like that of the dikes. The mineralized zone has been explored for about 1,000 feet along the surface trace. Assays are said to indicate an average of 1.0 percent copper, 0.1 ounce of gold a ton, and 1.0 ounce of silver a ton. A trace of metazeunerite was identified in pannings from the dump of the upper of the two adits.

A prospect is also located near the head of Cobalt Creek between altitudes of 1,550 and 1,750 feet, and a little more than a mile north-northeast of the Konechney prospect. The openings consist of several surface trenches and pits and three shallow shafts. This prospect was discovered before 1900 by Gordon Bettles, and was examined by A. G. Maddren (1915, p. 359–360) of the Geological Survey in 1914. The country rock is a porphyritic phase of the quartz monzonite. A fissure vein about 3 feet wide and associated breccia zones, located chiefly in the hanging wall of the vein, strike N. 25° W. and dip 80° SW. The mineralized zone has been explored for about 800 feet along the strike. A specimen selected from the dump of one of the shafts is reported to have assayed 11 percent copper, less than 0.25 ounces a ton of gold, and traces of silver. Two samples from a short shaft about 1,000 feet west of the vein described above are reported to have assayed 1.40 and 1.22 percent tin.

Another mineralized zone trends northwest across the ridge top about half way between the Konechney and Cobalt Creek prospects.

MISCELLANEOUS MINERAL LOCALITIES

Several other ore minerals and ore mineral localities not already mentioned have been observed by or reported to field parties of the Geological Survey in the central Kuskokwim region. Traces of copper were noted in the Little Taylor Mountains. Natives report antimony localities on Kay Creek, a tributary of the Buckstock River. Antimony claims on the upper Owhat River are recorded at the office of the U. S. Commissioner at Aniak. Molybdenite is reported from a locality on the upper Owhat River by Harry Brink of Aniak.

SUGGESTIONS FOR PROSPECTING

Most of the prospecting in the central Kuskokwim region has been for placer gold although quicksilver lodes have proved the most productive. Placer gold is the most desirable from the point of view of the prospector. He probably already has a greater background of experience with placer gold, and is able to recover it on a small scale with less of a capital outlay than is required for mining and retort extraction of quicksilver. Moreover the price of gold has been more dependable through the years, whereas that of quicksilver has fluctuated with the times. In recent years the gold pan has been supplemented by the ultraviolet mineral lamp. At least one prospector in the region has been led to the discovery of tungsten deposits through determination of the tungsten mineral, scheelite, with such a lamp.

Previously the scheelite had been discarded unnoticed among the lighter of the heavy mineral placer concentrates. Scheelite had also been overlooked in lode deposits because it lacks a metallic luster and looks much like barren rock.

The information now available concerning the geologic relations of the various types of mineral deposits in the region should make systematic prospecting possible. Some areas deserve more search than others simply because their geologic setting is more favorable. Discovery of quicksilver deposits, for example, requires different methods of exploration than discovery of gold, and tungsten possibly requires yet another approach, all dependent upon their geologic relations. Common to all three, however, are the probable association of their lodes with intrusive igneous rocks and their tendency to form placer concentrations. Both of these features are of obvious use as guides to prospecting.

Quicksilver lodes occur, with very few exceptions, within or close to bodies of silica-carbonate rock that were formed by the alteration of intrusive igneous rocks, chiefly sills and dikes of biotite basalt. The silica-carbonate rock is pearl gray on the fresh surface and weathers a yellow-brown forming the "yellow rock" of the quicksilver prospectors. It rarely crops out; hence there is little hint of the exact location of silica-carbonate bodies to be gained from a study of the "lay of the land." Instead they are located by search for fragments of "yellow rock" in the surficial deposits. These fragments, weathered from the bedrock, are a part of the residual deposits that, influenced by gravity and frost action, creep downslope toward nearby streams. Prospectors usually first test the stream deposits for cinnabar with a pan, but watch for boulders and pebbles of the "yellow rock." Should it be found that the cinnabar concentrates and the fragments of "yellow rock" both extend upstream to about the same point it is quite possible that a body of silica-carbonate rock, with a lode occurrence of quicksilver associated, may be found opposite this point on the neighboring slopes, after removal of the moss and soil.

The albite rhyolite, with which gold is commonly associated, is more resistant to weathering and also forms larger intrusive bodies than does the altered biotite basalt with which quicksilver occurs. Exposures of the rhyolite or its weathered debris are therefore more prominent features of the landscape, visible from a distance. The weathered surfaces of the larger bodies of rhyolite form rounded "domes" whose bedrock is covered by large blocks of rock pried up by frost and now covered with a growth of brittle black lichen. The "domes", therefore, appear black at a distance although the rhyolite of which they are formed is light colored, commonly buff on the weathered surface and gray to white on the fresh surface. Smaller bodies of the rhyolite are less apparent at a distance, but the frost-broken fragments are frequently exposed at the surface without covering of finer soil and moss.

The productive gold deposits are all placers. The placer deposits commonly occur in creeks that flow through areas in which the rhyolite crops out. The placers have all been discovered through the usual panning methods. The one or two known occurrences of lode gold in the region have been discovered where fragments of quartz-bearing gold veins are weathered out on slopes near the contacts between the rhyolite and the sedimentary country rock. The contacts are commonly covered by weathered rock fragments, and trenching is necessary to expose them in most places.

Both the rhyolite and the granitic rocks from which the stocks are formed appear to be guides to the discovery of tungsten. Awareness of this should encourage systematic testing of placer concentrates in the vicinity of these intrusive igneous rocks with the ultraviolet mineral lamp. Placer concentrations of tungsten ore may point to lode occurrences in the vicinity of the intrusive rocks.

Copper lodes are commonly capped by a rusty weathered zone that serves as a guide to discovery. Close examination of such cappings at one or two places in the region has led to the discovery of distinctive blue and green copper minerals with the rusty iron oxides. The association of copper with the granitic igneous rocks of the stock in the Russian mountains suggests the type of country rock to expect.

The form of land surface is probably one of the most useful guides to the selection of large areas in which to prospect in the central Kuskokwim region. The most productive quicksilver deposits are in the area of the rolling upland terrain that extends northeast from the vicinity of the Kuskokwim River. Quicksilver deposits are not known, on the other hand, in the rugged terrain of the Kuskokwim Mountains southwest of the Kuskokwim River. This terrain has been uplifted as much as 1,500 feet and streams have been able to cut deep enough to remove the rolling upland surface and probably also the shallow quicksilver lodes.

Quicksilver deposits are not known in the rolling terrain southeast of the Kuskokwim Mountains and are perhaps absent because silica-carbonate rock, apparently also necessary for their formation, possibly does not occur. The most likely area, therefore, in which to look for quicksilver extends from the vicinity of the Kuskokwim River north, where the rolling surface and silica-carbonate rock have already been found together. The Cinnabar Creek area in the south-

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western part of the central Kuskokwim region seems to be an exception. There the terrain is not as rolling, however, and the bottoms of the known quicksilver deposits have been reached at relatively shallow depths.

The distribution of gold placers is probably directly related to the shape of the land surface. The few placers that have been exploited in the region occur in the areas in which the rolling land surface is widespread. These areas of rolling land suraces are in the vicinity and north of the Kuskokwim River, and southeast of the Kuskokwim Mountains, as stated in the preceding paragraphs. The terrain is like that of areas in which quicksilver has been discovered, although the underlying reason for the association of the placers with this type of land surface is somewhat different. The rolling terrain is one on which stream dissection is relatively mild so that placer deposits have had an opportunity to accumulate instead of being carried away and dissipated downstream. It seems, therefore, that the least likely place to look for large deposits of placer gold is in the strongly uplifted and consequently deeply eroded terrain of the Kuskokwim Mountains southwest of the Kuskokwim River.

Glacial disruption of placer deposits is of only local concern, because there has been relatively little glacial activity in the central Kuskokwim region. The glaciated areas are readily recognized by the U-shaped valleys and intervening knife ridges in the higher mountains and by the characteristic hummocky moraines in the valleys at lower altitudes. These areas may be readily avoided and time devoted to the much more extensive unglaciated areas.

Something should be said, before closing, about prospecting for possible buried placer deposits hidden beneath either the deposits of existing streams, or beneath the rather widespread silt deposits, or both. The upper surfaces of the buried placers, as well as the bench placers, conform with the rolling land surface already suggested as a guide to discovery. The bench placers have been more readily discovered because the rolling surface has been enough redissected by streams, in areas in which the benches are formed, to expose the lower part of the bench gravels near bedrock, where most of the gold is commonly concentrated. The existence of the bench placers suggests, however, that buried placers occur in large areas that are little redissected, and where surface prospecting has consequently failed to reveal any gold. In such areas the transverse profiles of valleys are suggestive. Those that form a smooth, open S-curve from the stream bank to the rolling upland surface may very well contain buried placers. Valleys that on the other hand form sharp, V-shaped incisions in the rolling surface may have had all their once-burried gravel and associated pay streaks eroded away. Prospectors have already begun to test the deep buried gravel in the region and, as elsewhere in Alaska, these gravels may prove to be a very reliable source of gold.

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