Geology of the Eastern Part of the Alaska Range and Adjacent Area

By FRED H. MOFFIT

A CONTRIBUTION TO ALASKAN GEOLOGY

GEOLOGICAL SURVEY BULLETIN 989-D

A summation of geological knowledge of the region, gained in more than forty years of exploration and investigation

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FOREWORD

"Geology of the Eastern Part of the Alaska Range and Adjacent Areas," by Fred H. Moffit, presents a carefully considered summary of many years of geologic investigation in this part of Alaska by the geologist most eminently qualified to do so.

Mr. Moffit's first work in Alaska for the Federal Geological Survey was in 1903, and with the exception of two brief intervals (1917–18; 1933) field work in Alaska was continuous each season until 1944.

Compulsory retirement age was reached in April of 1944, but a special temporary appointment was granted to enable him to complete some important work on hand, and he did not retire from active service until January 1, 1945.

After retiring, Mr. Moffit continued work on this manuscript and herein presents an integrated and informative discussion of the geology of this interesting and important section of Alaska. Here he has pooled the information gleaned from many years of field investigations and drawn together his vast knowledge of this area, which heretofore appeared in many Survey bulletins and separate chapters in the bulletins on the mineral resources of Alaska.

One needs only a few minutes' study of the pamphlet "Publications of the Geological Survey" to appreciate the scope of the foundation for this report, and future students of this area will be ever grateful for the time and effort which Mr. Moffit put into the preparation of this important contribution to the knowledge of the geology of Alaska.

W. H. Bradley,
Chief Geologist.

A CONTRIBUTION TO ALASKAN GEOLOGY

GEOLOGY OF THE EASTERN PART OF THE ALASKA RANGE AND ADJACENT AREA

By Fred H. Moffit

ABSTRACT

This paper describes the geology of a part of the Alaska Range, extending from the Delta River to the international boundary between Alaska and Canada, and of an additional area that includes part of the Wrangell Mountains and the upper Copper River valley.

The Alaska Range is one of the youngest yet one of the most outstanding physiographic features of the Territory. It includes Mount McKinley, the highest peak of the North American continent, and many other peaks of exceptional height and is noteworthy for the ruggedness of its outlines, its many snow-capped summits, and its numerous glaciers, the sources of many glacial streams. Eastward from Mount McKinley the range becomes lower and less rugged and finally loses its identity as a structural feature or merges with the Coast Range mountains north of Mount St. Elias. The Alaska Range and the Wrangell Mountains are comparable in age, both developed largely in Tertiary time. The Alaska Range owes its height and length to folding, faulting, and elevation of the land; but the mountains of the Wrangell group are due to the piling up of lavas and tuff beds. The forms of both mountain systems were much modified by the erosion of streams and glacial ice.

The rocks are partly sedimentary and partly igneous in origin, ranging in age from pre-Cambrian to Recent and in degree of metamorphism from schist or gneiss to unaltered rock. The oldest and most highly altered rocks, derived chiefly from siliceous and argillaceous sedimentary beds intruded by granitic bodies, occur on the north side of the Alaska Range and are correlated tentatively with the Birch Creek schist (pre-Cambrian) of the Yukon and Tanana River valleys. The oldest Paleozoic rocks are the Middle and Upper Devonian sequence of the Tetlin and Chisana areas, which include conspicuous limestone units and locally are interbedded with lava flows. Rocks of early Carboniferous age are lava flows and sedimentary beds that are dominantly argillaceous but locally calcareous and contain one or more massive limestones. These rocks, which include the Chisna formation, have been referred to the early Carboniferous or possibly the Devonian, but the assignment is not certain. The Devonian rocks are restricted to the Nutzotin Mountains area, where they are associated with Permian rocks that consist dominantly of lava flows and calcareous tuffs but include a large amount of fossiliferous limestone and subordinate shale.

Upper Triassic limestone and shale were deposited unconformably on the older rocks and in turn were elevated above the sea, folded, and partly eroded in early

Jurassic(?) time. Then a great thickness of Upper Jurassic and Lower Cretaceous marine deposits, possibly separated from each other by an unconformity, was deposited on the remains of the Upper Triassic and older rocks. The volcanism that characterized the Permian apparently continued into early Mesozoic time. More important in many ways was the intrusion of great bodies of granitic and dioritic rock that accompanied the mountain-building disturbances of the Late Mesozoic time and continued into the Tertiary. The rocks deposited in Late Jurassic and Early Cretaceous time, consisting largely of thin-bedded shale and argillite or sandstone with important conglomerate members, were folded and eroded in Late Cretaceous time and overlaid locally by Upper Cretaceous terrigenous deposits.

Throughout Cenozoic time most of Alaska, with the exception of some coastal areas, has stood above the level of the sea and has been subjected to continuous subaerial erosion. In the late Eocene, mountain-building forces elevated the Alaska Range. At about the same time were laid down fresh-water gravels, sands, and peat beds, which became the coal measures, and shortly thereafter, still in the Tertiary, a renewed uplift of the range brought about the deposition of other thick fresh-water sediments—the Nenana gravel. Concurrently with the laying down of the coal measures, the outpouring of the Wrangell lava began. Tertiary history was ended with climatic changes that resulted in the development of Pleistocene glaciers, which left deposits of morainal material and outwash gravels and played an important part in shaping the topography of the Alaska Range and the Wrangell Mountains as they are today. At the height of glaciation the entire Copper River basin was filled with ice to a depth of many hundreds of feet. The north side of the Alaska Range, however, was less favorably situated for the accumulation of ice and shows relatively little glaciation. The glaciers of the present day seem to be in retreat.

Metallic minerals associated with the late Mesozoic and early Tertiary granitic intrusions are those of gold, copper, antimony, and molybdenum. Most of the gold production has come from the placer mines of the Chistochina district, where gold valued at nearly $3,000,000 has been derived largely from the gravels of Slate Creek and Miller Gulch, and from a lode deposit exploited as the Nabesna Gold mine, from which gold valued by the management at $1,869,376 had been produced when the mine was closed in 1940. No metals other than gold have been produced in the eastern Alaska Range, though known low-grade prospects may be of future commercial value.

INTRODUCTION

This paper describes the geology of the Alaska Range from the Delta River to the international boundary, which separates the Territory of Alaska from the Yukon Territory of Canada. It also describes some adjacent area, most of which is in the northern part of the valley of the Copper River (fig. 18).

The Alaska Range is a major physiographic feature of the Territory of Alaska. It is noteworthy because of its great relief, as it includes many lofty mountains, among them Mount McKinley, the highest peak of the North American Continent. The Range is also important geologically, as it includes many geologic formations of widely differing ages and presents interesting problems in stratigraphy, structure, and geologic history, many of which are not yet solved.

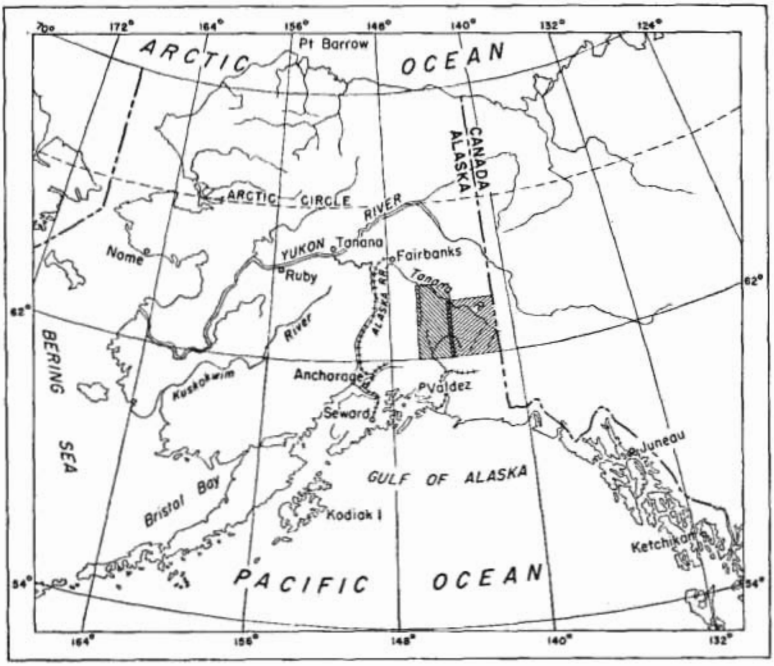

FIGURE 18.—Index map of Alaska showing location of the eastern Alaska Range and adjacent area described in this paper.

GEOLOGIC AND TOPOGRAPHIC SURVEYS

The men who made the early explorations in the eastern part of the Alaska Range contributed more to knowledge of the geography of the region than to its geology. They were of necessity occupied with the difficulties of travel, which left little time in the short mild season for geologic observation of more than the obvious features. Their contribution was essentially geographic, yet they laid a foundation for the work of later geologists.

The first known white man to cross the eastern Alaska Range was Lieut. H. T. Allen, who traversed the mountains from Suslota Lake to Tetlin Lake and the Tanana River in 1885. This was a journey, undertaken for the War Department, from Prince William Sound to St. Michael by way of the Copper, Tanana, Yukon, and Koyukuk Rivers—a journey that is outstanding in the history of Alaskan travel. Six years later (1891) Lieut. Frederick Schwatka and C. W. Hayes ascended the White River and crossed Skolai Pass to the Copper River drainage basin, taking a route around or across the southeast end of the range. In 1898, and again in 1899, W. J. Peters and A. H. Brooks visited the eastern part of the Alaska Range. Both expeditions were sponsored wholly by the U. S. Geological Survey. In the first year they descended the Tanana River, thus skirting the northeast side of the range, and in the second they crossed the passes at the head of the White and Nabesna Rivers and descended the latter stream, thus crossing the range by a route to the southeast of that used by Allen. Only a few weeks later Oscar Rohn made his way from the Chitina valley by the Nizina and Chisana Glaciers to the head of the Chisana River, and thence across Cooper Pass and up the valley of either Jack or Platinum Creek to the Copper River side of the Wrangell Mountains. In the same year that Peters and Brooks made their first expedition (1898), W. C. Mendenhall, who was attached as geologist to the military expedition under the command of Capt. E. F. Glenn, went from the head of Cook Inlet by way of the Matanuska valley, the Copper River basin, and the pass of the Delta River, to a point between 15 and 20 miles south of the Tanana River. This point, on the north side of the Alaska Range and north of Donnelly Dome on the Richardson highway, is the place where the main body of the expedition turned back because of the lateness of the season and the shortage of supplies. Thus Mendenhall had crossed the range although he did not reach the river.

A more thorough and systemic study of the geology of the region was begun by the U. S. Geological Survey in 1902. In that year Mendenhall and F. C. Schrader made reconnaissance geologic surveys on the south side of the range between the Gulkana and Chisana Rivers. This was followed in 1908 by a similar survey between the Nabesna and White Rivers, made by Adolph Knopf, S. R. Capps, and the writer. The area between the Chistochina and Delta Rivers was visited by the writer and B. L. Johnson in 1910, and at the same time the geology of the north side of the range west of the Delta River was mapped by Capps. In 1914 the stampede of miners to the newly discovered gold placers of Bonanza Creek in the Chisana (Shushanna) district made it desirable to study the area between the Chisana and White Rivers more thoroughly. This work was done by Capps and furnishes much important material that has been used in this report. Beginning in 1929 the writer, assisted by H. R. Joesting (1934), R. G. Wayland (1940), and R. E. Van Alstine (1942), spent some portion of 12 field seasons in geologic investigations in the part of the Alaska Range between the Delta River and the international boundary between Alaska and Canada. In 1943 and 1944, Van Alstine and R. F. Black made additional observations along the Alaska Highway.

The titles of the principal papers resulting from these investigations are starred in the bibliography given at the end of this report. Most of the geologic information collected in the course of the later field work is told in these papers in greater detail than is possible here, especially that relating to mining operations. Additional material containing references to the region is also listed there, and credit is given their authors where they are cited.

Most of the men so far mentioned were geologists whose primary purpose was to collect information relating to the geology of the areas they visited. The representation of this information required the use of topographic maps which were provided by the topographers with whom the geologists were associated in most of the earlier field work or who made independent surveys in later years. These maps serve two purposes—to meet the needs of the general public for geographic information and to enable the geologist to present to the public the geologic facts which he assembles.

The maps made by Allen were route maps rather than topographic maps and were for some years the chief source of information regarding the Copper and Tanana Rivers. The map of the Tanana River, made by Peters in 1898, and the map showing the Delta River, made by Mendenhall the same year, are also route maps which served a temporary need till they were replaced by later, more comprehensive topographic maps.

The first of the reconnaissance surveys yielding topographic maps of the kind appearing in this report were made by T. G. Gerdine and D. C. Witherspoon in 1902. The maps covered much of the south side and east end of the Alaska Range between the Delta and Chisana Rivers. This survey was extended to the White River by Capps in 1908. In 1910 J. W. Bagley mapped the north side of the range west of the Delta River, and at the same time Witherspoon and C. E. Giffin mapped the adjacent area on the south side. The map of the Chisana-White River area was revised and extended by Giffin in 1914, after the survey of the international boundary and the 141st meridian had been completed by the International Boundary Commission, thus providing more accurate determinations of geographic position and altitudes than had been available before. In 1914, also, Bagley surveyed an area north of the Tazlina River.

In 1932 the desirability of correcting and extending parts of the older maps was recognized. For that purpose C. F. Fuechsel carried a line of primary horizontal and vertical control from the United States Land Office meridian at Copper Center to Slana and made some revision of earlier surveys near Slana. In 1934 and 1935, Gerald Fitz-Gerald continued the revision and extended the mapped area to include the north slope of the range from Tetlin Lake to the Robertson River. The north slope of the range from the Robertson River to the Delta River was added by FitzGerald in the following year. Finally, an area that lies between the Tetlin and Chisana Rivers was revised by T. W. Ranta in 1937, 1938, and 1939. This was facilitated by the use of air photographs in some areas that were not covered by the usual ground methods. Air photographs taken under the direction of FitzGerald for the Geological Survey were also used in mapping the Tanana River and some of the adjacent area, especially the lake-dotted valley of the upper Tanana. Further revision and extension of some of the maps has been made possible through use of trimetrogon air photographs taken by the U. S. Army during World War II.[1] These topographic maps, issued by the Geological Survey since 1902, are included with the publications listed in the bibliography at the end of this report.

GEOGRAPHY

The three great mountain ranges of the main body of Alaska are the St. Elias and the Coast Ranges bordering the Pacific shore line, the Brooks Range between the Yukon Valley and the Arctic coastal plain, and the intermediate Alaska Range. The Alaska Range, almost concentric with the Coast Ranges but with a slightly shorter radius, extends in a great bow for 600 miles from the White River to the Alaska Peninsula, separating the valleys of the Copper and Susitna Rivers and the tributaries of Cook Inlet from the great interior valleys of the Yukon and the Kuskokwim. Seemingly the Alaska Range dies out as a structural unit in the vicinity of the international boundary, north of the White River, or merges with the Coast Ranges, but information on the geologic structure of that area is not sufficient to warrant a final statement regarding the relation of the ranges. On the west, however, it appears to continue uninterruptedly into the Alaska Peninsula. Only the eastern part of the range, roughly 200 miles in length and nearly 50 miles in greatest width, is considered in this report. Alaska Range is the inclusive name for this chain of mountains. The names Mentasta Mountains and Nutzotin Mountains, however, have been used to designate parts of the range in the vicinity of Mentasta Pass and to the southeast.

The Wrangell Mountains, because of their isolated position, their height, and their rugged peaks, snow fields and glaciers, must be classed among the impressive mountains of Alaska. They form an independent group and are not properly a part of the Alaska Range. They originated in a different manner and occupy a place in the forks between the Alaska Range and the Coast Ranges, and they include the highest mountains shown on plates 6 and 7. Mount Sanford (16,208 feet) is the highest and dominates the group from most places in the Copper River valley; at some points (figs. 19–21) it is hidden

[1] The most recent topographic maps of the area, published after completion of this report by Mr. Moffit, have been utilized in the preparation of plates 6 and 7. They are the Tanacross (1950), Mount Hayes (1951), Gulkana (1951), and Nabesna (1951) sheets of the Alaska Reconnaissance Series, published at a scale of 1 : 250,000 from data furnished by the U. S. Geological Survey, the U. S. Coast and Geodetic Survey, and the International Boundary Commission, and edited and published by the Geological Survey. Culture and drainage have been compiled from trimetrogon photographs, and the topography from the original surveys mentioned by Mr. Moffit and from other original sources, 1898–1949, supplemented by stereophotogrammetric compilation.

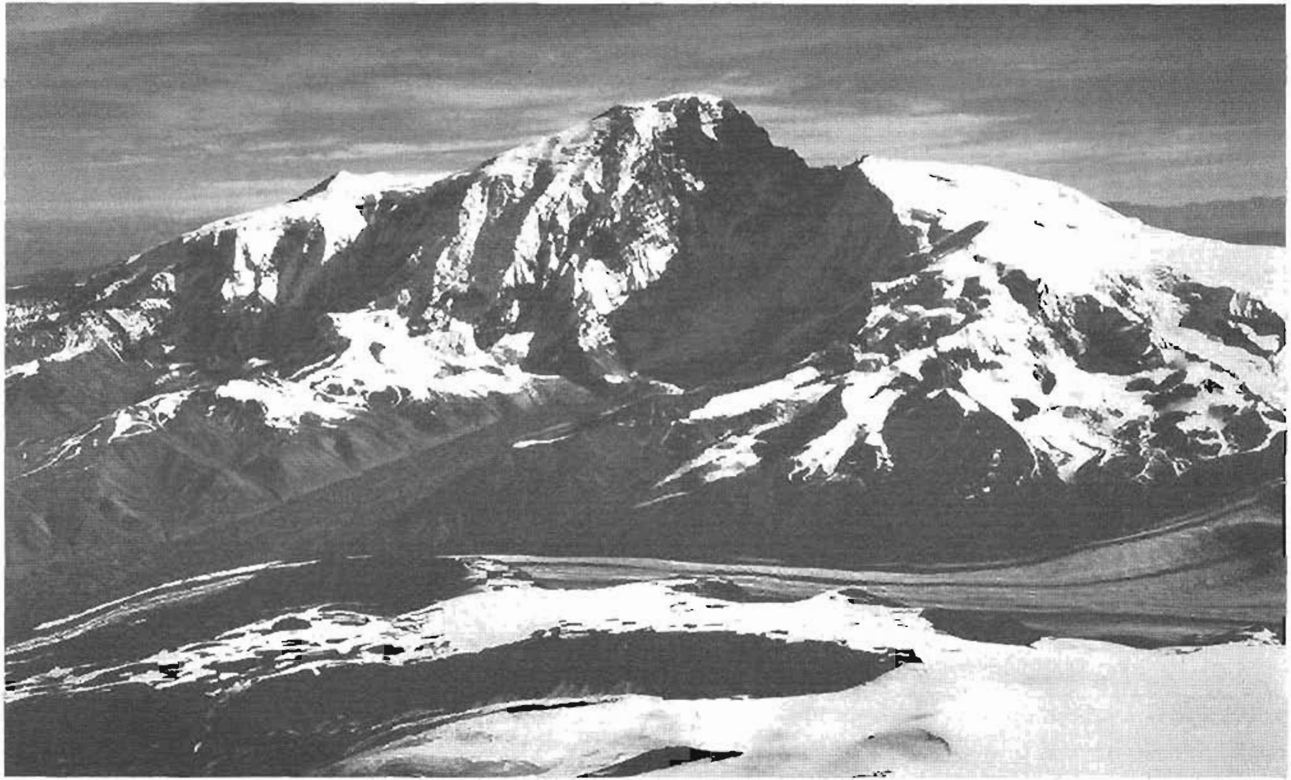

FIGURE 19.—The West face of Mount Sanford (16,208 feet) and Sanford Glacier. (Air photograph by Bradford Washburn.)

FIGURE 20.—Mount Drum (12,002 feet) from the north. The snow-covered, west slope of Mount Wrangell shows on the left. Between Mount Drum and Mount Wrangell are the distant Chugach Mountains. (Air photograph by Bradford Washburn.)

FIGURE 21.—Mount Wrangell (14,006 feet) from the northwest. Shows the broad, domelike form of the mountain but does not give an adequate impression of its height. (Air photograph by Bradford Washburn.)

by Mount Drum (12,002 feet) and Mount Wrangell (14,006 feet). Although these three peaks are built up of lava flows and tuff beds erupted from volcanic vents, Mounts Sanford and Drum, and also Mount Jarvis, became extinct long ago; only Mount Wrangell shows signs of activity in steam clouds and occasional puffs of volcanic ash. The Wrangell group includes two other high peaks—Mount Blackburn (16,140 feet) and Regal Mountain (13,400 feet)—which are not within the map area and are best seen from the Chitina valley.

The valley of the Tanana River and its larger headwater branches, including the lower courses of the Chisana and Nabesna Rivers, adjoins the eastern Alaska Range on the northeast. Most of the valley is a broad lowland area, but at the middle course of the river at Cathedral Rapids it is little more than a mile wide, and relatively narrow below that as far as the Johnson River.

South of the Alaska Range lies the valley of the Copper River and its upper tributaries. Most of the area belongs to the Copper River drainage basin, but a part of it on the west and north is drained into the Susitna and Tanana Rivers. This area has been called the "Copper River plateau" (Mendenhall, 1900, p. 282), but the term "basin," also used by Mendenhall (1905, p. 16, 19), seems to describe the form of the feature as well as to designate the drainage area of the river; for on clear days the broad valley floor seems to be inclosed on all sides by high mountains. The eastern extension of the basin separates the Wrangell Mountains from the Alaska Range at the north, but no prominent physiographic feature appears to set them off from the range on the east.

All the mountainous area was invaded by ice in Pleistocene time and bears the marks of glacial erosion in truncated spurs, valleys with staightened walls and U-shaped cross sections; roches moutonnées, low rounded knobs smoothed off by the ice; and heaps of unconsolidated rock waste left by the ice when it melted. Topographic forms produced by normal stream erosion after the ice disappeared are less conspicuous and for the most part are restricted to the softer rocks.

The ice, however, was not confined to the mountains. It also left characteristic evidences of its presence in the lowland areas, where it built up deposits of waste.

Although the glacial forces had secondary part in producing the relief of the area, they affect strongly its general aspect.

RELIEF

The Alaska Range, as seen from any favorable viewpoint, is a wilderness of rugged mountains, many of which bear loads of perpetual snow. These are the gathering ground for glacial ice, which covers the higher slopes and fills the valleys between. The range has its greatest altitude in Mount McKinley (20,300 feet), 160 miles west of Isabel Pass at the head of the Delta River; it decreases in average height eastward and southward from that point. Mount Hayes (13,700 feet), 25 miles west of the Delta River pass, is the highest point of the Alaska Range in the area under consideration (fig. 22). Mount Kimball (10,000 feet), 35 miles east of the Delta River pass, is next in height, yet is less than 600 feet higher than Mount Allen, just north of the Chisana River.

The altitude of the Tanana River at the mouth of the Delta River is 995 feet. The altitude of the valley floor increases to 2,000 feet at the point where the Nabesna River emerges from the mountains and to 2,500 feet at a corresponding point on the Chisana River. The Tanana River has an altitude of about 1,700 feet at the mouth of the Nabesna River.

On the south side of the range the low points along the break between the lowland area and the mountain front are somewhat higher, from 2,000 to 3,000 feet in altitude. This difference finds expression in the vegetation of the two sides of the range, for plant growth begins somewhat earlier on the north side, more strongly influenced by the lower altitude than by the southern exposure.

From the figures that have been given it is evident that the greatest relief of this part of the Alaska Range is about 8,000 feet, but as measured from local bases of reference in nearby valleys, most of the mountaintops have a relative relief of less than 5,000 feet.

The relief of the Wrangell Mountains is greater. Mount Sanford (16,208 feet), Mount Wrangell (14,006 feet), Mount Jarvis (12,600 feet), and Mount Drum (12,002 feet) are the highest mountains within the area covered by the topographic map. Their altitudes may be compared with the altitude of the Copper River, which is 1,000 feet at Copper Center and 2,100 feet at Slana, and of the Nabesna River, which is 2,200 feet at Reeve Field, near the mouth of Jack Creek. The west slope of Mount Sanford rises over 13,000 feet in 12 miles, as shown on figure 19. Mounts Sanford and Drum (fig. 20) have been deeply undercut by glacial ice and are evidently older than Mount Wrangell. Their profiles are jagged and their slopes precipitous, except the north slope of Mount Sanford which is gentle and gives a favorable approach to the summit.

Mount Wrangell, on the other hand, was built up in such recent geologic time that the original form of the lava flows and tuff beds has not yet been greatly modified by ice, water, and the breaking down of the bedrock through freezing and thawing (fig. 21). Its surface is smooth, its slopes are low, and it shows little bare rock above the snow line. In contrast with its lofty neighbors and in spite of its height it has the appearance of a great overturned saucer covered with snow.

FIGURE 22.—Mount Hayes (13,700 feet) and surrounding mountains from the north. Shows the rugged nature of the Alaska Range between the Delta and Nenana Rivers. (Air photograph by Bradford Washburn.)

The mountains of the Alaska Range and the Wrangell group show differences of topographic form that depend on various factors, among the most important of which are the character of the rocks themselves, the time they have been exposed to erosion, and the extent and intensity of the glaciation. In general the older, generally metamorphosed rocks of the Alaska Range have been carved by the glacial ice into jagged forms, with sharp peaks and narrow ridges. The rocks of the Nutzotin Mountains are softer and more easily eroded. The mountain valleys are distinctly glaciated; and the mountain slopes are seamed with parallel, V-shaped gulches separated by steep, sharp ridges (fig. 23). The volcanic mountains of the Wrangell group show considerable diversity of form depending in large part on their individual ages and the degree of erosion brought about by glaciation and weathering. The basis for such generalization, however, is not everywhere evident.

DRAINAGE

A characteristic of the drainage system in the area considered in this report (pls. 6, 7) is the effectiveness with which the steeply graded tributaries of the Tanana River, such as the Delta, Tok, Nabesna, and Chisana, have cut into the Alaska Range, capturing streams that originate south of the range, on its south slopes, or in the Wrangell Mountains. These streams, with Jarvis Creek and the Gerstle, Johnson, Robertson, and Tetlin Rivers, are the large tributaries of the Tanana River that drain the north side of the range.

The Copper River receives its water from many widely separated sources. It originates on the northeast slope of Mount Wrangell and the east slope of Mount Sanford, whence it flows in a great bow around the west side of the Wrangell Mountains and through the Chugach Mountains to the Gulf of Alaska. Within the area under discussion it receives numerous tributaries from the Wrangell Mountains, and from the Alaska Range on the north, where the Slana, Chistochina, Gakona, and Gulkana Rivers have their sources in the ice field between Mount Kimball and Little Delta River. Thirteen miles below the Gulkana River is the mouth of the Tazlina River, the only river that enters this part of the Copper River from the west. It drains Tazlina Lake, fed by the glaciers in the Chugach Mountains at the south.

The drainage pattern—the location and relation of the streams with reference to one another and to the mountains of the eastern Alaska Range, and their origin in the meltwater of its glaciers—is best visualized by a study of plates 6 and 7. Some characteristics of the drainage system, however, are not represented and require description. Only the small streams are clear-water streams. All the larger

FIGURE 23.—Characteristic topography of the Nutzotin Mountains, the result of glaciation and the rapid erosion of soft shale and sandstone beds.

streams are fed in part by milky water from glacial sources and occupy glaciated valleys within the mountain areas.

The glacial streams are swift, especially in their upper courses, and flow in braided channels, shifting from place to place over wide flood plains. Unlike the larger streams of the Chitina River valley, their lower courses are not intrenched in rock-walled canyons, although some, like the Delta River and Jarvis Creek, have incised their channels in unconsolidated deposits. Many of the streams have slower currents and follow meandering channels through open valleys in their lower courses. Slana River is an excellent example and it derives its Indian name from this characteristic. Such, also, is the upper Tanana, which flows many extra miles in its complicated course to reach its destination.

Most of the lowland area on both sides of the Alaska Range lacks a well-developed drainage system and is dotted with lakes and ponds. The upper Tanana Valley is a notable example of this feature (pl. 6). This part of the valley appears to have been buried in unconsolidated deposits poured in from the surrounding mountains, especially the Wrangell Mountains, and to have been occupied by a large lake (R. E. Van Alstine, personal communication, 1943) that left its traces in terrace gravel deposits on its border.

Tetlin Lake and some of the many smaller lakes and ponds of the upper Tanana Valley probably are remnants of this former lake whose limits have not yet been determined but which may have been 20 miles wide in places and several times as long. No lake of comparable size is known to have existed in the Copper River basin in Pleistocene time, but several lakes, all of which are smaller than Tetlin Lake, occur there now. The three largest are Paxson (Gulkana), Louise, and Ewan Lakes.

The larger streams that cross the Copper River lowland have incised their canyonlike channels in the unconsolidated gravel, sand, and morainal materials that cover the valley floor. In consequence the general drainage, although immature, is better established than that of the upper Tanana River lowland. It was possible to construct the Richardson Highway across the Copper River lowland from south to north without serious obstacles by taking advantage of higher ground and the terraces bordering the streams, wherever they were available. The highway passes through a country of slightly rolling surface with long easy slopes and no steep grades except where it crosses the stream valleys. Much of the area is covered with scrubby spruce. The lower ground is swampy or dotted with small lakes and ponds, and it furnished routes favorable for winter travel in earlier years when roads were few. Thus winter was the best time for transporting supplies and equipment to the placer-mining camps.

As the larger streams get much of their water from melting ice in the high mountain areas they are subject to rapid fluctuations in volume of runoff. In addition to the annual fluctuations dependent on the seasons, they show daily flow maxima following rapid melting as the sun warms the air. These high-water and low-water stages of glacial streams are observed with care by the experienced traveler. Some glacial streams are also treacherous because of quicksands, and some because of boulders and swift water. The crossing of Chisana River for several miles above the mouth of Cross Creek is dangerous owing to quicksand, as would be suggested by the dunes on the flood plain.

Although daily fluctuations in the volume of water in the glacial streams are of importance, great floods take place at times of exceptionally heavy or prolonged rainfall, or after snowfalls followed by warm rains.

ROADS AND TRAILS

The region of the upper Copper River valley and the eastern part of the Alaska Range has been served in past years by the Richardson Highway (pl. 7), which connects Valdez with Fairbanks, and by the Abercrombie trail or Nabesna road between Gakona and the Nabesna River. In 1942 the Corps of Engineers of the United States Army opened for use the Alaska Highway, a pioneer road along the north side of the range, thus giving more ready access to that area. This road is the fulfillment of a plan for an international highway from the United States to Alaska through Canada. Although it had been under consideration for several years, construction was not begun until it became evident that such a road was necessary for the military defense of Alaska. Its course is at the base of the Alaska Range on the south side of the Tanana River from the Delta River to the Tok, but a few miles east of the mouth of the Tok it crosses to the north side of the Tanana River and continues on that side of the valley across the international boundary. East of the Tanana crossing the Fortymile [2] highway provides an all-weather road northeastward to Dawson and the upper Yukon region. East of the international boundary a branch road turns south from the main highway and follows the route of the old Dalton trail leading to Haines on Lynn Canal. Until the Alaska Highway was constructed the little travel along the north side of the range was wholly by small power boats used by the traders and Indians on the Tanana River.

Another highway of great importance to those living in the Copper River valley, as it gives access to the coast throughout the year, is the

[2] Officially designated the Taylor Highway, June 12, 1951.

Glenn Highway connecting the Richardson Highway at mile 116, between Copper Center and Gulkana, with Palmer and Anchorage in the Cook Inlet region. It was constructed by the Alaska Road Commission and was opened for use in 1943.

The roads that have been constructed within the area of the Alaska Range are the Richardson Highway and the Slana-Tok highway.

The Richardson Highway, named for the late Gen. Wells P. Richardson, at one time President of the Alaska Road Commission, who was in charge of the construction and operation of the road for many years, was established as a military trail and telegraph line in early days but was converted to a stage road and later to an automobile road. It affords a summer route from Valdez northward across the Chugach Mountains and the wide Copper River basin, and along the east bank of the Delta River through the Alaska Range. In places it is confined within a narrow canyon with steep rock walls where construction and maintenance are difficult. Much trouble has been caused by the streams of the Castner and Canwell Glaciers and by rockslides elsewhere, but some of the difficulty has been met by relocation and improved construction. The highway through the Delta River [Isabel] Pass is closed to automobile travel in winter.

From the Richardson Highway near Gakona a road extends to Tok Junction on the Alaska Highway, via Slana, Mentasta Pass, and the Little Tok and Tok Rivers. The road follows the old Nabesna road or Abercrombie trail between the Richardson Highway and Slana, a route that was part of the old military trail and telegraph line from Valdez on the coast to Eagle on the Yukon River. It was built by the Corps of Engineers to facilitate construction of the Alaska Highway and to provide a connection between the Tanana and Copper river valleys. Its highest point is about 2,500 feet above sea level and its course is nowhere above timberline; although longer, it furnishes a route through the Alaska Range more favorable for winter travel than the Richardson Highway. Together with the Glenn and Fortymile [Taylor] Highways, it [3] affords an all-weather road from Anchorage and Palmer on the coast to Dawson on the Yukon.

Many trails leading to mining camps or hunting grounds have been laid out and used since the days of the first prospectors in 1898, but highways and the airplane have made most of them obsolete. Few of the old trails are travelled now and some that were well established are grown over with brush and young trees and are almost hidden from view. Formerly there were pack trails to the placer mines of Valdez Creek and the Chistochina River; from the Nabesna River through Cooper Pass to Chisana; down the Nabesna River and the Chisana

[3] On June 21, 1951 this road was officially designated the eastern extension of the Glenn Highway, but it is referred to throughout this report and shown on plates 6 and 7 as the Slana-Tok highway.

River; from Chisana to Horsfeld; from Chisana to the White River; and many others on the south side of the range that were in frequent use though they are rarely trod by horses now. In the early days trails led from the Tanana River to prospects near the head of Jarvis Creek and the hunting grounds at the head of Johnson River, and the Robertson River was reached by a trail from the upper Tok valley; but few trails were established on the north side of the range, as the search for valuable mineral deposits was not successful there.

POPULATION

The total population of the area shown on the two maps accompanying this paper was approximately 400 persons in 1940. This number includes whites and Indians and indicates a population density of about one person to 40 square miles of area. The whites, who are a minority, are gathered for the most part in small settlements near the roadhouses on the highways. Copper Center at the mouth of the Klutina River, mile 103 on the Richardson Highway, is the largest and oldest of these settlements. Gulkana and Gakona were established at about the same time (1898). Paxson and other roadhouses on the highway north of Gulkana were not built till after the route through the Delta River [Isabel] Pass came into use, sometime between 1907 and 1910. Other white settlements are the mining camps, most of which are not occupied throughout the year. They are not permanent settlements or at most are occupied for a limited number of years while mining is in progress.

The Indians, who were formerly more numerous and had their principal dwelling places along the river banks, still maintain their summer fishing camps at the rivers but occupy permanent quarters near the roadhouses or along the highways in winter. The largest Indian village is at Tetlin, in the upper Tanana valley.

The increased strategic importance of Alaska has altered many of the conditions relating to population as just given. Extensive construction projects for the building of roads, pipelines, and airfields brought large military and civilian forces to the Copper and Tanana valleys. New centers of population were established and old settlements were enlarged. Some of this increase in population and change in its distribution is temporary but some of it is permanent and will have a lasting effect on the development of the country.

TIMBER AND VEGETATION

Most of the region under consideration is a rugged mountain land which rises far above timberline. Yet the bordering lowland areas and the major stream valleys are below timberline and support a growth of timber that is good or poor depending on other conditions such as position with reference to the sun, character of the ground, and the drainage. In general it may be said that timber extends to an altitude of at least 3,000 feet above sea level and that under exceptional conditions, in a few small favored valleys, a good stand of timber thrives even at 5,000 feet. The prevailing trees are spruce, which has its best growth on the lower slopes of the mountains, on gravel terraces bordering the streams, and on the better drained ridges. Trees on the poorly drained lowland areas are commonly scrubby and of poor quality. Practically none of the better timber has commercial value for other than local use, and material for heavy construction such as bridge timbers and planking and the more desirable lumber for buildings is imported from outside.

In addition to spruce the timbered areas include certain kinds of deciduous trees, particularly balsam poplar, birch, and aspen, which grow on ridges and hill slopes and are a good indication of well-drained ground. Tamarack grows in places on the north side of the Alaska Range, but none was recognized east of the Delta River. Willows of various kinds are common everywhere but are not large enough for use other than as tent poles or firewood. Alders are also common, but they grow less luxuriantly than in the coastal regions.

Grasses and other plants suitable for forage for stock are abundant in many places but are almost lacking in others, especially the lowland areas. The best forage grasses are found near timberline and are commonly plentiful in the upper parts of the valleys at this altitude. They and such plants as the vetches (peavines) and equisetums ("horsetails" or "goose grass") are also found on the bars and terraces near the streams. Horses relish the tender shoots of the swamp grasses in early summer and browse on the leaves of certain willows at any time, stripping them from the branches with one sweep of the head.

Contrary to the belief of many, vegetation is luxuriant in much of central Alaska. Plant life of some sort continues above timberline to the regions of perpetual snow and at lower levels flourishes in a variety that is surprising. Many of the plants are conspicuous because of the abundance and beauty of their flowers which seem to vie with one another in accomplishing their missions before the short summer is over.

GAME

Animal life in an area of such extent and varied character as that described in this paper is certain to show considerable variety and inequality of distribution. The subject is of interest and importance but can not be treated adequately here, although it will be desirable at least to give a list of the more common game and fur-bearing animals.

Those who live in this part of Alaska think of game animals in connection with their usefulness as food, the value of their fur, their importance as predators and destroyers of property, as well as their part in attracting hunters from the outside and thereby increasing employment and the sale of hunting equipment and supplies.

The larger game animals, desirable for food, are the moose, caribou, and mountain sheep. The chief predatory animals are the bear, wolverine, wolf, and coyote. The more valuable fur-bearing animals are the fox, lynx, martin, mink, weasel (ermine), muskrat, and beaver. Of the game birds, grouse and ptarmigan thrive in some localities but vary greatly in numbers from year to year. Fish of different kinds, chiefly trout and grayling, are common in the clear-water streams and lakes. Salmon from the Copper River furnish much of the food of the Indian and his dogs and supply him with an article of trade with the white man.

The lives of game animals are so interrelated that the abundance or scarcity of one kind is likely to affect the others. An abundance of rabbits leads to an increase in the number of coyotes, foxes, and lynxes. The wolf follows the herds of caribou and preys on the stragglers. A small proportion of lambs with the ewes in bands of mountain sheep in summer is commonly believed to indicate depredation by coyotes. Wolves, coyotes, and foxes are responsible for the deaths of many young game birds. Such relationships are almost without end and often result in unexpected and undesirable conditions when they become unbalanced.

Moose spend most of their lives in the lowland areas but are more common in some localities than in others. They appear to be increasing in number in the Copper River valley and may become so accustomed to the sight of cars on the highway that they show little fear of them. Moose are more numerous on the north side of the range than on the south side. Caribou are not uncommon in the Copper River valley, but the large herds roam the hills on the Yukon-Tanana side of the range and considerable numbers come south through the passes in the fall. A relatively small number stay permanently on the south side, going into the high mountains in summer and returning to the river bars in winter. Mountain sheep are numerous in parts of the mountain area and are wholly absent from others because of natural causes, such as food supply, or of artificial causes, the chief of which is hunting. The most favorable range for all three animals is probably the area between the Nabesna and White Rivers, which has been a favorite hunting ground for many years. Large numbers of sheep, estimated by Capps (1916, p. 21) as at least 2,000 in the winter of 1913–1914, were killed by prospectors in the Chisana district in stampede days; but with the subsequent decreased population and the absence of hunters during war time, their number seems to be increasing slowly.

Both the grizzly and the black bear range through most of the area covered by this report. The grizzly is more numerous in the mountain areas and in certain localities. Several instances of attacks by grizzlies on men are known. The wolf is nearly always found in the vicinity of the caribou herds. He seeks cover in daytime and is so wary that he is less likely to be seen than many of the other animals. Unlike the coyote he is an old resident of Alaska. The coyote was unknown until after the coming of white men in the gold-rush days. He was seen by prospectors in the White River valley for the first time about 1910, but since then has extended his range to cover a large part of interior Alaska. His numbers have been reduced in the Copper River valley in recent years, probably because of the scarcity of rabbits. Rabbits as well as grouse and ptarmigan are subject to a variation in number that appears to be periodic but does not affect all districts at the same time. During a time of abundance the number of rabbits increases enormously, but this abundance gives place to a time of scarcity when the rabbits seem almost exterminated.

Fur-bearing animals are distributed throughout the timbered area under consideration, almost all of which is covered by trap lines in winter—the property of white trappers or Indians.

The game birds include several varieties of grouse, as the ptarmigan and spruce hen, and water fowl. Ducks and geese nest in most of the area but are more numerous in the spring and fall during the time of migration, when they stop temporarily in their flight to and from the breeding grounds farther north.

The lakes and most of the streams not too heavily loaded with silt from glacial sources are plentifully stocked with fish, of which the more common are the grayling, trout of several varieties, whitefish, and salmon. Until the coming of the white man, salmon was the chief source of food for the Indian who ate it fresh when the fish were running in the Copper River in early summer, or dried it for the use of himself and his dogs in winter. The salmon is almost the only kind of fish in the large streams in summer, for the muddy water from the melting glacier ice is avoided by the others. Grayling and trout are plentiful in many of the clear-water streams and lakes, and furnish excellent sport for fishermen. Some of the lake trout grow to large size. Whitefish also are found in some of the lakes but are taken with the seine rather than a hook. Pike or pickerel thrive in the shallow, grass-choked lakes of the upper Tanana drainage. They are numerous in Mineral Lake and other connecting lakes of Mentasta Pass.

DESCRIPTIVE GEOLOGY

OUTLINE OF THE GEOLOGY

The size of the area considered in this report and especially the fact that most of the region is occupied by folded sedimentary rocks that were deposited in several different geologic periods, subjected at intervals to recurring deformation, faulting, and alteration during times of mountain building, intruded repeatedly by igneous rocks, and planed down again and again by erosion, make the interpretation of its stratigraphy and structure difficult and at times uncertain. For these reasons a description of the geology of the eastern part of the Alaska Range and adjacent area, based on present knowledge, must be incomplete and may be incorrect in some respects. Errors in earlier work have already been discovered as succeeding field seasons give opportunity for revisiting difficult localities or for more extended examination.

The eastern part of the Alaska Range is made up largely of sedimentary rocks of widely differing ages, ranging from pre-Cambrian to Recent, but does not include representatives of all the intermediate parts of geologic time. The variety of rock types is considerable but the dominant rocks are of marine origin and were derived from muds and fine muddy sands. Beds of pure quartz sand, beds of gravel, and deposits of lime were also among the original sediments laid down in ancient seas and are now sandstone or quartzite, conglomerate, and limestone. A small proportion of the younger beds, made up chiefly of sandstone, conglomerate, sandy shale, and clay, and including beds of lignitic coal, accumulated as fresh-water deposits on the land.

The sedimentary rocks that are here assigned to definite geologic periods or epochs with certainty or a high degree of probability are representatives of pre-Cambrian time; the Middle and Late Devonian, Early Carboniferous, and Permian of the Paleozoic era; the Late Triassic, Late Jurassic, Early and Late Cretaceous of the Mesozoic era; and the Eocene or Miocene(?) of the Cenozoic era. The Pleistocene and Recent epochs are also represented.

All these sedimentary rocks have been involved in mountain-building movements and show folding, faulting, and metamorphism that varies with the age of the rocks and is greatest in the oldest. The older rocks have been changed to schist, gneiss, and crystalline limestone; but the youngest, excluding the unconsolidated morainal deposits and stream gravel, sand, and silt, are only partly consolidated and moderately folded.

In places the sedimentary rocks are interbedded with lava flows or are intruded by igneous rocks of types closely related to the flows. In places they were invaded by large bodies of granitic rock or by dikes and sills of many kinds. In the Wrangell Mountains district some of the sedimentary beds were buried under flows of Tertiary and Recent lavas.

The igneous rocks, like the sedimentary rocks, show various degrees of metamorphism and in places are so greatly altered as scarcely to be distinguished from the sedimentary rocks. The intrusive rocks apparently have almost as great a range in age as the sedimentary rocks, for the oldest are schistose or gneissic like the host rocks; and the most recent so far recognized within the region are unaltered and have invaded Cretaceous or younger beds.

The extrusives also have a long time range, for lava flows are interbedded with Devonian sedimentary rocks, and eruption of the Wrangell lava which began in Tertiary time has continued almost to the present.

The early geologic history of the eastern Alaska Range is obscure. The age of the oldest sedimentary beds is not known, although they probably are pre-Cambrian. These oldest rocks are definitely older than Middle Devonian, if their relative ages may be judged by degree of metamorphism, but they have not yielded fossils or other evidence by which the lower limit of their age may be determined.

As will appear more fully in later discussions the continuity of the geologic column is broken at a number of places by the absence of formations that normally should be found there. The breaks indicate either the failure of original deposition or the removal of beds by erosion and in either event stand for periods in which the land was above sea level. Some of the resulting structural unconformities are known from observation in the field, others are inferred. The principal stratigraphic breaks preceded the Middle Devonian, Permian (?), upper Triassic, Upper Jurassic, Upper Cretaceous, and Eocene depositions. Other breaks, including one between the Upper Jurassic and Lower Cretaceous, may have occurred but are not yet recognized with certainty.

The Alaska Range probably indicates a zone of weakness and the site of repeated mountain-building movements that date at least as far back as middle or late Paleozoic time. Events of special significance that stand out in the later history are the renewal of mountain-building processes and the intrusion of large bodies of igneous rock in late Mesozoic and early Tertiary time, the long period of erosion in Tertiary time, and the Pleistocene glaciation.

The table that follows gives a brief description of the bedded rocks of the eastern Alaska Range arranged according to their stratigraphic position. In most instances the thickness of the formations is estimated, for direct measurements were possible in only a few places.

Bedded rocks in the eastern Alaska Range and adjacent area

System and series	Formation	Lithologic character
Quaternary:		
Recent		Stream gravels, sands, silts, and loess.
Pleistocene		Glacial gravels and morainal deposits; includes the younger Wrangell lava.
Tertiary:		
Eocene or later	Nenana gravel	Gravel and sand, weathered, locally containing pieces of lignitized wood.
Eocene or Miocene(?).		Shale or clay, soft, yellow and buff; gray and yellowish, partly consolidated sand beds; conglomerate, clean white quartz grit and sand, and coal beds; sedimentary beds of fresh-water origin, at least 1,200 feet in total thickness; includes the older Wrangell lava which continues into Recent time.
Cretaceous:		
Upper Cretaceous		Arkosic sandstone, sandy shale, and conglomerate, well-consolidated, containing pieces of lignitized wood and other plant remains. Thickness 1,000(?) feet.
Lower Cretaceous and Upper Jurassic.		Slate-argillite-sandstone beds, banded or varved, with subordinate beds of conglomerate and grit and a few thin limestone beds; locally includes arkosic sandstone with coaly plant fragments and coarse conglomerate.
Triassic:		
Upper Triassic		Limestone, massive and crystalline, overlain by thin-bedded limestone; maximum known thickness 1,200 feet; includes some black shale, as shales on Snag River.
Permian	Mankomen	Sandstone, tuffaceous beds, lava flows, shales, and limestone in the type locality near Mankomen Lake; a large proportion of lava flows and intruded igneous members in the Chisana-White River district.

Bedded rocks in the eastern Alaska Range and adjacent area—Continued

System and series	*Formation*	*Lithologic character*
Carboniferous	Chisna	Conglomerates, quartzites, and tuffs in the type locality on the Chisna River; includes basic lava flows and intrusives.
Devonian:		
Upper and Middle Devonian.		Limestone, crystalline, associated with gray and black slate; hard, gray, siliceous beds; yellowish, sandy, and gritty beds; brown mica schist; and basic lavas or intrusives; appears to include both Upper and Middle Devonian sediments.
Pre-Cambrian or early Paleozoic.		Undifferentiated metamorphic rocks, largely of sedimentary origin, which include schist, gneiss, slate or phyllite, and crystalline limestone, together with many less altered bodies of intrusive igneous rock.

BEDDED ROCKS

UNDIFFERENTIATED PRE-CAMBRIAN ROCKS

Character and distribution.—The rocks designated as undifferentiated Paleozoic or pre-Cambrian (pls. 6, 7) are mainly schist and gneiss, intruded by and possibly interbedded with igneous rocks. They cover a larger area than any other consolidated geologic formation shown on the map, occupying most of the north side of the range and extending from the Delta River to the Tetlin River, a distance of approximately 120 miles. Some highly metamorphic rocks occupying a small area on the north side of the mountains between Beaver Creek and the Chisana River also are shown as part of this formation, although the age relations have not yet been established.

The schist and gneiss are derived partly from sedimentary rocks and partly from igneous rocks, which are believed to be mainly old intrusives but may include effusives also. No attempt was made to differentiate between the two types of original rock. Much of the schist and gneiss is highly siliceous and was probably derived from original beds of sandstone, quartzite, or other siliceous rock. Associated with the schist and gneiss of this kind is a variety of other rocks. They include a small proportion of phyllite or slate, much quartzite in places and a little crystalline limestone, which is more common in the eastern part of the area than in the western part. In a few places small bodies of black carbonaceous schist are interbedded with the lighter schist. A complete assemblage of the rocks of this group is not found in any one locality but the general aspect is much the same throughout the area covered by this report. The writer (1942, p. 119–120) has described the group as it occurs between the Delta and Tok Rivers as follows:

They [the schist and gneiss] occur in great variety, as would be expected in view of their origin, and show a wide range in degree of metamorphism. The colors are dominantly gray in varying shades but include green and black and suggestions of pink and lavender. Some of the more siliceous varieties have a bright silvery aspect, but the darker grays are more common. The texture grades from that of fine slate, with plane cleavage and constituent minerals so small as to be unidentifiable in the hand specimen, to that of coarse, crinkly schist and gneiss with easily recognizable mineral components. Garnet is a common constituent of the schist and occurs in bodies of all sizes from tiny, well-crystallized grains hardly visible with a hand lens to imperfect crystals almost an inch in diameter. Other metamorphic minerals are present also, such as hornblende, which occurs in one locality in thin blades several inches long associated with great numbers of tiny red garnets.

Aside from the variations of color and size of mineral constituents and the presence or absence of conspicuous metamorphic minerals such as hornblende and garnet, the schist and gneiss show no unusual features; yet one common type is worthy of special mention.

In many places the rocks are finely striated as if parallel lines had been ruled on a light gray surface.

This feature is best observed on a joint face or on a smoothly rounded boulder, and on examination is seen to be due to the alternation of thin layers of quartz with mica, or of quartz and subordinate feldspar with mica; the alternating layers are commonly less than one-sixteenth inch thick and actually are lenticular in form, as will be seen on close examination. The resulting cleavage is plane in most instances. Occasionally, however, the layers are folded and closely compressed, and the cleavage follows the layers of mica around the folds.

In the Gerstle River district some of the schist or gneiss having this character is plainly derived from igneous intrusives, but in other places the schist seems to be derived from siliceous sediments.

One feature of the area of metamorphic rocks that is universal and of much importance is the abundance of vein quartz. The largest and most conspicuous veins are bodies of milky white quartz that fill joints and other large fracture planes in the country rock; but the veins that are most important, both in number and in volume of material contained, are the small, contorted lenses and stringers that follow the cleavage planes of the schist and gneiss. Their hardness and resistance to weathering make them almost the only constituent in much of the unconsolidated materials derived from the old rocks. As will be seen later, the basal members of some of the gravel deposits are made up of this vein quartz.

The field relations make it evident that the schist exposed in some places was derived from original beds of sand and grit interstratified with beds of mud, among which the siliceous or sandy members seem to have predominated. The sand now appears as sheared quartzite or silvery siliceous schist, and the mud beds as gray schist. Thin beds of limestone were interstratified with the schistose members in a few localities, but, on the whole, limestone is notably absent throughout the area.

Most of the rocks that are referred to as gneiss are probably metamorphosed igneous intrusives of the more acid types. They show the constituent minerals of such intrusives and in many places have such field relations as suggest their intrusive nature. They differ from the later intrusives, which are not recrystallized and do not show any marked tendency to cleave in definite directions.

Thickness and structure.—The pre-Cambrian schist and gneiss is a complex of metamorphosed sedimentary beds and associated igneous rocks which has not been measured as a unit. As shown on the geologic map they occupy an area from 25 to 35 miles in width and several times as long. Distinctive beds that can be recognized from place to place and used as stratigraphic reference planes are not known. The constituent units probably differ much in age and because of possible unconformities, folding, faulting, erosion, and other disturbing factors do not lend themselves readily to measurement, though it is probably safe to say that the complex is thousands of feet thick.

The schist and gneiss are the oldest rocks so far recognized in this part of the Alaska Range. They have been involved in mountain-building disturbances that were recurrent and probably began far back in geologic history. They are intensely folded and are broken by faults of great displacement in addition to being altered physically and chemically under the influence of heat and pressure. The general strike of the beds is that of the trend of the range itself and varies from southeast near the international boundary to more nearly east at the Delta River. However, many local variations from the general strike came about as the result of intrusion of igneous bodies or merely because of the complicated character of the folding. The directions of the dips are highly variable, for the folding was extreme. Many limestone outcrops show closely compressed folds with horizontal axial planes. The same distortion was doubtless impressed on the associated argillaceous and siliceous rocks. The limestones, however, offer more help in deciphering the structure for they commonly indicate the trend of the folded beds. Most of them either were rather small lenticular beds originally or have taken on that appearance through folding or faulting, for they occur as single, elongated bodies or as groups of bodies alined in the direction of their strike.

The cleavage commonly dips to the south, but north-dipping and even horizontal cleavage are seen. Close folding has produced parallelism between the bedding and cleavage planes on the limbs of folds, so concordance of cleavage and bedding prevails except in the bends of folds.

Faulting has played an important part in determining the structure of the beds within the formation and their relation to younger adjacent formations. Faults within the formation are numerous but are not always easy to discover in the absence of contrasting, displaced strata. Some of them are revealed by the iron staining of the adjacent rocks.

Mendenhall (1905, p. 83) pointed out the great fault at the head of the Chistochina River, which marks the boundary between the schist and the younger rocks on the south, and estimated the displacement to be not less than 10,000 feet. This fault extends from some point west of the Delta River to the Little Tok and probably to the Tetlin River. It follows the valley of Canwell Glacier and the conspicuous depression between the head of Gakona Glacier and Gillett Pass. Eastward from Gillett Pass to the Little Tok River it does not have marked topographic expression but beyond the Little Tok probably follows Trail Creek valley.

Details of the fault structure have not been worked out. In general the fault is a zone of displacement and crushing rather than a single plane of fracture and movement. It has a high southerly dip throughout most of its extent, and the displacement is such that the older rocks on the north were raised relative to the rocks on the south. Evidence of the displacement is less clear east of the Little Tok River than west of it. Some northerly dips in the bedding of rocks near the fault east of the Little Tok River were seen, but in general the sandstone beds south of the fault dip to the northeast. It seems improbable that a change of dip from southwest to northeast takes place in a fault of such length and displacement and a suspicion arises that the dip of the sandstone between Trail Creek and the Tetlin River does not correspond with the dip of the fault.

The relation of the schist and gneiss to the adjacent rocks on the south is a relation that resulted, at least in part, from faulting, but a second possible relationship should be considered. It may be that the fault follows the boundary of a basin of deposition and that the schist and gneiss of this part of the range were not overlain by the younger rocks.

Age and correlation.—The problem of determining the age of the schist and gneiss of the north slopes of the Alaska Range involves many uncertainties. The sedimentary rocks are plainly older than the igneous rocks that intruded them. The sedimentary rocks themselves are old and may belong to more than one geologic period or even more than one era. Fossils have not been found in them and are not likely to be found, for metamorphic changes have destroyed most if not all the organic remains that may have been buried in the original sediments. In view of these conditions the age assignment given here, insofar as it depends on evidence furnished by the rocks of the Alaska Range, is based on differences in the intensity of folding and the degree of metamorphism shown by the schist and gneiss and the formations adjacent to them.

As far as is known at this time the oldest rocks in contact with the schist and gneiss on the south are not older than Middle Devonian. The different formations are separated by a great fault which determines the boundary line between them. The fault is a zone of disturbance, and the rocks near it are broken and displaced, but the rocks south of the fault are not schistose and show no such recrystallization or other metamorphic change as do the rocks north of the fault. The schist and gneiss have clearly been subjected to forces that the others have not experienced and are older; that is, they are at least as old as Middle Devonian and probably much older.

Mendenhall (1905, p. 30–32) described the pre-Cambrian rocks at the head of the Chistochina River under the name Tanana schist. That formation name is no longer in use but the rocks once designated by it are now included as part of the Birch Creek schist, a group of metamorphic sedimentary rocks that are widely distributed in the Yukon-Tanana region. As a result of many years of field work in that region, Mertie (1937, p. 46) divides the "ancient rocks" exposed there into three broadly defined units based on differences in age and lithology. The oldest, known as the Birch Creek schist, is of very considerable extent and consists of recrystallized pre-Cambrian sediments with which are associated metamorphic igneous rocks.

The Birch Creek schist, which is now defined (Mertie, 1937, p. 48) as including all the older pre-Cambrian metamorphic rocks that were originally of sedimentary origin, occupies a large area adjacent to the Tanana River north of the area under discussion. Mertie makes the following general statement about the schist:

> The Birch Creek schist consists principally of quartzite, quartzite schist, quartz-mica schist, mica schist, feldspathic and chloritic schists, and a minor proportion of carbonaceous and calcareous schist and crystalline limestone. Quartzite schist and quartz-mica schist appear to be the more common types. Most of these rocks are completely recrystallized, but in some of the more competent beds—for example, the quartzites—original detrital fabric and other evidences of their sedimentary origin are still preserved. In general, these rocks are characterized by a foliated or laminated structure, and many * * * show a distorted foliate or crenulated fabric that indicates the superposition of one cleavage upon an older structure of similar type. In a broad way the more quartzose metamorphic rocks are considered to represent the basement members of the sequence.

Mertie says further that in the Yukon-Tanana area calcareous schist and limestone make up a relatively small proportion of the formation and are restricted to the upper part of it. The Birch Creek schist is exposed along the north side of the Tanana River throughout most of the area covered by this report, except where it is displaced by igneous intrusives.

It is evident from the descriptions already given that the metamorphic rocks on the north side of the Alaska Range resemble the Birch Creek schist more nearly than either of the other units of the "ancient rocks". Furthermore, there appears to be no justification for differentiating similar rocks on the north and south sides of the Tanana River without evidence that is not now at hand. Consequently the schists of sedimentary origin forming the north side of the Alaska Range are here tentatively correlated with the Birch Creek schist of the Tanana-Yukon region.

South of the Tanana River the schist is not confined to the area between the international boundary and the Delta River but continues west along the north side of the range as far as the Kantishna River and probably extends into the lowland area west of that river. It is exposed in many localities throughout this district and is described by Capps (1912, p. 20) as being made up predominantly of highly contorted and fissile mica and quartz schists and phyllites of green, red, brown, and gray shades. Beds of metamorphosed quartzite that show some schistosity and secondary mica, and also beds of graywacke and fine black slaty schist, are interbedded with the mica schists.

The Birch Creek schist is now considered to be not only pre-Cambrian but early pre-Cambrian. The evidence for this conclusion is found in the upper Yukon Valley and is both lithologic and paleontologic. It has been summarized by Mertie (1937, p. 55, 56) in the paper previously cited. If the correlation made above is correct the schist and gneiss of the Alaska Range are much older than can be shown by the local evidence now available.

PALEOZOIC BEDDED ROCKS

DEVONIAN ROCKS

Character and distribution.—The rocks of Devonian age are mostly of sedimentary origin but some are igneous rocks that appear in part to be contemporaneous lava flows. Possibly some of the associated igneous rocks are younger than Devonian. The beds are folded and locally are schistose, yet they are distinctly less metamorphosed than the "ancient rocks" previously described. Unlike the assemblage of older rocks they include conspicuous limestone units. Their age assignment is based on the evidence of fossils that are characteristic of marine life in the Middle and Late Devonian epochs. Three areas of Devonian rocks will be described, although the limits of these areas are not well-defined and only one is shown independently on the geologic map. These three areas include Suslota Pass, Cheslina River and the Tetlin River, and Bonanza Creek in the Chisana district. In some extensive areas Devonian and Permian rocks are not well enough known to be differentiated from each other or even to be identified with certainty, so possibly the Devonian rocks are more widely distributed than now appears from the statement of their distribution given above. The diversity of types among the Devonian rocks will appear from the descriptions that follow.

The largest area of rocks that are assigned to the Devonian extends in wedge-shaped form from the head of Buck Creek southeast across the Tetlin River to the Nabesna River. These rocks have been described as follows (Moffit, 1941, p. 125–126):

The most conspicuous members of this group are limestone beds, which appear in interrupted but well-alined outcrops throughout the whole area of Devonian rocks. Most of the group, however, is made up of gray or black slate, hard, gray, siliceous beds, quartzite, yellowish, sandy and gritty beds, cherty conglomerate, and brown mica schist. These rocks are considered together because of their association in the field, and although some of the beds contain fossils that have been identified by the paleontologists as Middle and Upper Devonian most of them are without fossils and may possibly be in part of a different age.

All of the rocks are folded and most of them are more or less schistose, but those that display the most pronounced schistosity are the beds adjacent to the great body of granitic rocks that bounds the Devonian rocks on the northeast. It is evident that the intrusion of the granitic rocks brought about important changes in the invaded sedimentary rocks, such as the development of schistosity just mentioned, recrystallization of the original constituents, and the addition of material not originally contained in the sediments, particularly quartz.

The clastic rocks occupy much the larger part of the area described as Devonian. No volcanics, such as lava flows and tuff beds, were recognized, but dark granular intrusives were noted, interbedded with or cutting across the sedimentary members, and from the degree of their alteration they appear to be older than the diorite intrusive mass to the northeast.

The most conspicuous members of the Devonian group of sedimentary deposits are limestone beds. They owe their prominence to the peculiarity of their weathered outcrops, which because of their form and color are a notable feature of the landscape (fig. 24). The limestone is massive in structure, coarsely

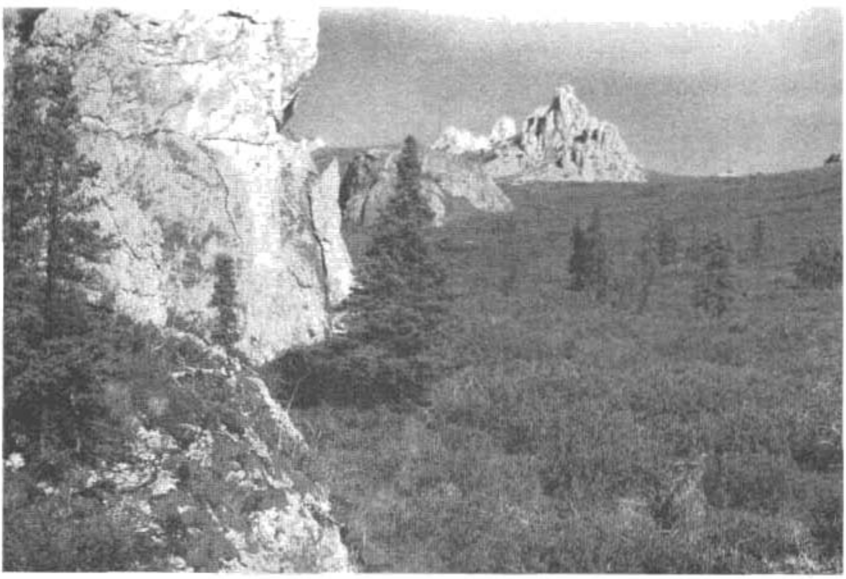

FIGURE 24.—Outcrops of Middle Devonian limestone in the low divide between the Tetlin and Cheslina Rivers.

crystalline, and light bluish gray. Its resistance to weathering and its granular texture, together with the accidents of folding and faulting, have combined to produce an alinement of light-gray pinnacles and crags that contrasts strongly with the darker background, which stands high above the associated rocks and makes it easy for the eye to follow the course of the beds for many miles across the country.

The limestone occurs in several distinct beds separated by phyllite or schist members derived from original mud and sand deposits. Because of folding and faulting these beds are difficult to distinguish from one another, and their exact number is not known. They do not crop out continuously. Doubtless some of the outcrops are parts of continuous beds, but others were either distinct lenses of limestone originally or are parts of beds that have been separated by faulting or folding and have no connection with one another.

In the divide between the north branch of Cheslina Creek [River] and the Tetling [Tetlin] River three distinct lines of outcrops seem to indicate three distinct beds of limestone. Possibly there are more. The outcrops extend north-northwest to the Buck Creek Valley, and in the opposite direction they continue down the Cheslina Valley and into the ridge between Cheslina Creek [River] and Nabesna River. Southwest of these are outcrops that indicate another distinct bed, which must be separated from the other limestone beds by a considerable thickness of clastic sediments; but whether this limestone is stratigraphically above or below the other beds was not learned.

The two remaining areas of Devonian rocks are not outlined on the geologic map. Their existence was not learned through field observation and recognition of their lithologic features and was not suspected till the fossils obtained from them were studied in the laboratory. In both areas collections of Devonian fossils were made from a single locality that was supposed to include only Permian rocks, in consequence of which it is necessary to designate these and other areas as undifferentiated Devonian and Permian rocks.

In 1914 Capps (1916, p. 31) collected Devonian fossils from a locality on Bonanza Creek near the mouth of Little Eldorado Creek, of which he says:

The rocks consist of basic lavas, agglomerates, and tuffs, associated with considerable black shale and minor amounts of graywacke. The beds lie beneath the Carboniferous (Permian) lavas and pyroclastics of lower Bonanza Creek, and so far as known are conformable with them. As the Devonian rocks include a dominant proportion of lavas and pyroclastic beds and have the same general structure as the Carboniferous (Permian) rocks they were supposed in the field to be Carboniferous (Permian), and the age determination has been based solely on the fossils which they contain.

The Devonian rocks include more shale than the nearby Permian rocks, but in the absence of fossils this feature can not be used as a criterion for distinguishing them. Capps concluded that the Devonian rocks may therefore be more widely distributed in the Chisana-White district than had been supposed, and that they may occupy some of the areas previously regarded as Permian.

The third locality from which Devonian fossils were collected is on the mountaintop 2 miles west of Suslota Pass. The rocks are argillite and a bed of limestone at least 75 feet thick, which were intruded by a small body of diorite. The argillite is whitened and the limestone is recrystallized and silicified, evidently as an effect of intrusion by the diorite. For reasons that will be given in the section dealing with the age of these rocks, the limestone and associated argillite are included among the Devonian rocks with much doubt concerning their extent and relationships.

Structure and thickness.—It has been stated that the Devonian rocks, as exposed in the area including Buck Creek and Cheslina River, comprise a notable variety of clastic sedimentary rocks, including shale, quartzite, grit, and others, which are associated with conspicuous limestone beds. Some of the clastic beds are schistose, especially near the large diorite body which borders them on the northeast, and the limestones are here recrystallized. All the beds are closely folded and tilted at large angles from their original horizontal position, but beds that could be used as horizon markers and identified from place to place were not discovered. The limestone beds are traceable in recurring exposures for long distances along their strike and may be repeated across the strike by folding. Although proof of this repetition is lacking, both the clastic rocks and the limestone beds are probably thus repeated. The number of limestone beds is not known. They are separated from one another by beds of the clastic rocks and together with them probably have a thickness greater than five hundred feet in the locality where the limestone is best exposed, possibly much greater. The distribution of the limestone beds suggests that they either were originally lenticular or acquired their present form and distribution through folding and faulting.

The thickness of the clastic beds exceeds that of the group of limestone beds but is even less susceptible to measurement, so any estimate of the total thickness of Devonian rocks is not much more than an informed guess. Nevertheless the thickness is probably several thousand feet.

Lower Devonian rocks have not been recognized in Alaska. It is therefore inferred that in Early Devonian time the land stood above sea level and underwent denudation. If this is true, the Middle Devonian sediments probably were deposited on the older rocks with structural unconformity. The depositional relation of the Middle and Upper Devonian is not known, nor is that of the Upper Devonian and the Permian, but all were folded together and faulted. The observed contacts of Devonian with pre-Devonian and post-Devonian rocks are either fault contacts or contacts with intruded bodies of igneous rock.

These two structural relationships appear in the valley of Buck Creek and the west branch of the Cheslina River. The boundary between the Devonian rocks of the valley and the Mesozoic rocks of the mountains on the southwest is a fault. The boundary on the northeast is along a contact with a mass of granitic intrusives which produced the schistosity and secondary minerals in the adjacent Devonian sedimentary rocks. These changes are greatest near the intrusive mass and diminish away from it. Between the two boundaries the sedimentary rocks are closely folded and in places the strata are vertical. The limestones are the most conspicuous of the Devonian rocks. They are fewer and less prominent in the areas of undifferentiated Devonian and Permian rocks and are less helpful in deciphering the geologic structure, although they furnish clues to the strike of the beds.

Age and correlation.—The group of bedded rocks here described as Devonian includes beds assigned to this period on the evidence of fossils collected from them and also includes a much larger body of rocks whose age is inferred from their association, as they have not yielded fossils within the area considered. It therefore follows that the beds do not constitute a well-defined group and that rocks older or younger than Devonian may be revealed by future fieldwork.

Cheslina River and Buck Creek valleys have furnished the largest number of fossils and the most diagnostic species so far collected from the Devonian rocks. Fossils have been found only in the limestone and are hard to recognize because the limestone is so recrystallized that they are obscured. Before they can be collected the enclosing rocks must have undergone the exact amount of weathering that is necessary to etch their outlines on its surface or free them from it without destroying them. Sixteen species of invertebrates were collected from the limestone of Buck Creek and Cheslina River. They were submitted to Edwin Kirk for identification and were determined by him to be of Middle and Late Devonian age.

The rocks of these two epochs were not differentiated on the geologic map, and evidently the separation can not be made without intensive study, for the limestones crop out in close association in the same locality and are distinguishable only by their fossils.

In the following tables the Middle and Upper Devonian fossils and their localities are given separately. Kirk says of the Middle Devonian species, "The foregoing lots with the possible exception of 34 AM–F8 (2693) are of Middle Devonian age."[4]

[4] Quoted by J. B. Reeside in a letter dated March 25, 1935, in the files of the Alaskan Geology Branch, U. S. Geological Survey.

Middle Devonian fossils from the eastern Alaska Range [1]

	2690	2691	2692	2693	2694
Amplexus sp	×	×	------	------	------
Amplexus? sp	------	×	×	------	×
Cyathophylloid coral, genus uncertain	------	------	------	×	------
Favosites sp	------	------	×	------	×
Favosites sp. (digitate form)	------	×	------	------	------
Favosites sp. (massive form)	×	------	------	------	------
Alveolites sp	×	------	------	------	------
Reticularia sp	------	×	------	------	------

2690. 1½ miles southeast of the small lake at the head of Buck Creek.
2691. Divide between Tetlin River (Bear Creek) and a branch of the Cheslina River. Approximate position, lat. 62°21′ N., long. 142°43′ W.
2692. ¾ mile south of locality 2691.
2693. 2 miles west of the east side of Suslota Pass.
2694. Limestone float from the east slope of the mountain 2 miles west of the east side of Suslota Pass.

[1] This and other lists of fossils included in this report are based on old published and unpublished lists, which are dated in the text. A revision of the nomenclature would involve complete restudy of all collections.

Upper Devonian fossils from the eastern Alaska Range

	38AM-F6	38AM-F7	38AM-F8
Chonophyllum sp	×	----------	----------
Phillipsastraea sp	×	×	----------
Cladopora sp	×	----------	----------
Coenites sp	----------	×	----------
Stromatopora sp	----------	×	----------
Macgeea? sp	----------	----------	×
Productella sp	----------	----------	×
Gypidula sp	----------	×	----------
Camarotoechia sp	----------	×	----------

38 AM-F6. Head of the north branch of the Cheslina River.
38 AM-F7. Head of the north branch of the Cheslina River, 4½ miles southeast from the Tetlin River.
38 AM-F8. Head of the north branch of the Cheslina River, 4½ miles southeast from the Tetlin River.

Two species of invertebrates were collected from Bonanza Creek by Capps (1916, p. 33) and were determined by Kirk to be of probably Middle Devonian age. These fossils were found in shale beds associated with lava flows and pyroclastic beds. Kirk's report on them is as follows:

> Lot No. 4. From agglomerate series on Bonanza Creek, just below the mouth of Little Eldorado Creek: *Pentamerella?* sp., *Dalmanella* sp. The pentameroid is most clearly allied to *Pentamerella*, and seems clearly indicative of the Devonian age of the containing beds. It is probably referable to the Middle Devonian. A very similar if not identical species occurs at Freshwater Bay, in southeastern Alaska.

The Middle Devonian fossils from the Suslota Pass locality are from an area that has furnished a distinctive Permian fauna and like the

Permian fossils are from massive limestone beds. This locality has yielded crinoids and several species of corals, some of which Kirk regards as clearly Middle Devonian; at least one is inconclusive. In view of the dominance of the Permian limestone in the area this one limestone bed and associated argillite are assigned to the Middle Devonian with a feeling that they may represent only a small infolded or infaulted mass of the older rocks.

Devonian rocks are exposed in other widely separated parts of Alaska, but their relationship to the Devonian rocks of the eastern Alaska Range has not been determined. Rocks of Devonian age are extensively developed on the south side of the Alaska Range in the vicinity of the Nenana River and on both sides of the range still farther west within the Mount McKinley National Park. As described by Capps (1930, p. 251, pl. 4), they make up "a thick series of metamorphosed sedimentary rocks that includes conglomerate, shale, slate, graywacke, quartzite, and thin-bedded and massive limestone" and are regarded as upper Middle Devonian or lower Upper Devonian (1915, p. 25–26). These rocks may extend east along the Alaska Range between the Nenana and Delta Rivers but have not been identified there.

Rocks that may be the equivalents of the Devonian rocks of the Cheslina valley are exposed at Wellesley Mountain between the Chisana River and the international boundary. Wellesley Mountain is 35 miles south-southeast of the most easterly of the limestone beds of the Cheslina valley. It is made up in part of conglomerate and slate, to which Brooks (1900, p. 470–472), gave the name Wellesley formation, referring it to the Devonian or Carboniferous period on the evidence of a small collection of fossils. Large exposures of limestone that were not known to Brooks occur on the west side of Wellesley Mountain. This limestone is in strike with the limestone beds of the Cheslina valley and possibly is their eastward continuation. Mertie (1937, p. 92–93), however, has given reasons for considering the Wellesley formation to be Carboniferous rather than Devonian, although he states that these reasons are not conclusive. Until more evidence is at hand, the possible correlation of the limestone beds of the Cheslina valley and Wellesley Mountain must be deferred.

CARBONIFEROUS(?) ROCKS

Character and distribution.—Two groups of rocks that are exposed in the Copper River basin present problems of interpretation even more difficult than that of the Devonian rocks and have not yet been assigned a definite position in the stratigraphic column.

A group of little-altered rocks that comprises both sedimentary and igneous units and is exposed along the south side of the Alaska

Range westward from the Middle Fork Chistochina River as far as the Maclaren Glacier was tentatively assigned to the early Carboniferous or Devonian in earlier publications of the Geological Survey. It includes the Chisna formation, first described by Mendenhall (1905, p. 33–35), and other rocks that were thought by Mendenhall and the writer (1912, p. 27–29) to be correlatives of the Chisna formation.

A second group of metamorphic rocks that are exposed in the low, rounded hills north of the West Fork Gulkana River and the Susitna River was described by the writer (1912, p. 26, pl. 2) as probably pre-Carboniferous. They were later described by Chapin (1918, p. 23–26, pl. 2) as Carboniferous or older.

These two groups of rocks have never been studied in detail. They are complex in their make-up and differ in degree of metamorphism, the rocks of the southern group being more altered. Further study probably will prove that both groups should be subdivided, but as each group includes rocks that have been more or less doubtfully referred to the Carboniferous, they will be considered together in this section. The second and larger group will be described first.

The rocks of the second group are more altered than those of the first group. They are exposed south of the main Alaska Range in the round-topped hills forming the succession of ridges north of the West Fork Gulkana River. This west-trending belt of low mountains or hills continues beyond the limits of the geologic map into the area within the great bend of the Susitna River, but it is less well defined east of the Richardson Highway. These hills, because of their isolation and more particularly because of the absence of any known mineral deposits, have received little attention from geologists. The rocks are of various kinds and if judged by the degree of their metamorphism must be regarded as among the oldest rocks of the Copper River basin. They include greenstone, schist, a relatively small amount of limestone, slate, and quartzose sedimentary rocks, and granitic and basic intrusives.

The rocks described as greenstone are altered effusives and intrusives and appear to make up the larger part of the group. Their apparent dominance, however, may be because of their superior resistance to weathering rather than their relative abundance. The schistose structure is unequally developed but is locally notable in some of the rocks. Limestone is uncommon yet is conspicuous in a few localities. It is recrystallized and occurs in massive outcrops that have not revealed much more of the structure than the trend of the beds. This group of rocks has evidently been intruded by igneous bodies at more than one period in its history, as some of the intrusives are much altered and others are fresh.

Included in this group are the Klutina group (Schrader, 1900, p. 410) and Dadina (Mendenhall, 1905, p. 27, 28) schist of the Chugach and Wrangell Mountains respectively and the Strelna formation (Moffit, 1938, p. 23) of the Chitina valley, which have been correlated tentatively. The Strelna formation comprises a variety of rocks—schist, gneiss, slate, and recrystallized limestone—all of which show notable metamorphism. It was assigned to the lower part of the Carboniferous (Mississippian) on the evidence of fossils collected from widely separated places, but its correlation with the rocks of the West Fork Gulkana River depends entirely on lithologic similarities, as fossils have not been found in the rocks of the West Fork. A correlation of the Klutina group with Devonian deposits rather than Carboniferous is a possibility that should be recognized. Although Devonian rocks have not been identified in the Copper River basin, they occupy a considerable area on the south side of the Alaska Range on the upper Nenana River and may have representatives in the group of rocks under discussion.

Metamorphism in rocks of this group is much less advanced than in the ancient rocks on the north side of the Alaska Range; on this basis the rocks of the Copper River basin are considered younger.

Notwithstanding the uncertainties that have been mentioned, the rocks of this group appear to bear more resemblance to the known Carboniferous rocks than to other possible correlatives and are tentatively assigned to that system.

The remaining group includes the Chisna formation and other rocks that have been correlated with it. The Chisna formation is made up of sedimentary and igneous units and was described by Mendenhall (1905, p. 33–35) from their occurrences in the valley of the Chisna River. The sedimentary units at the type locality are tuffs, quartzites, and conglomerates, which are cut by porphyritic intrusives. The bedded igneous units include amygdaloidal and porphyritic lava flows and tuffs. Both the sedimentary and igneous units are intruded by diabasic and dioritic bodies. Some of the tuffs, as well as quartzites, are pyritiferous and some are slightly calcareous.

The Chisna formation in general is not distinctly metamorphosed or notably deformed. Nearly everywhere the mountains composed of the Chisna formation are conspicuous because of their red color, which results from the oxidation of the pyrite disseminated through the tuffs and quartzites. Apparently the igneous units, including the intrusives, dominate the sedimentary units.

Rocks of the Chisna formation make up most of the south part of the block of mountains between the Chistochina River and the Middle Fork, and also the smaller block between the Chistochina River and the West Fork. They are not recognized with certainty east of the

Middle Fork, although the adjacent mountain east of the upper Slana River is made up of volcanic rocks and shows the same bright coloration. A thick deposit of conglomerate, shale, gravel, and sand of Tertiary age conceals the older rocks between the West Fork and the Gakona Glacier and cuts off exposure of the Chisna formation along the strike to the west. Rocks that have been correlated with the Chisna formation crop out north of Phelan Creek and in the mountains north of Eureka Creek. Some doubt exists regarding the correctness of this correlation, at least as to the extent of the Chisna formation in this area, as it is now known that some of the rocks in those places are of Permian age.

Measurements of the thickness of the Chisna formation were not attempted; estimates are not feasible until more is known of the composition and structure, but it is the writer's belief that the thickness will be expressed in hundreds if not thousands of feet.

The beds of the Chisna formation are folded and in general have strikes that conform to the trend of the range. The rocks are more metamorphosed than the Permian rocks that lie north of them but they are not schistose. They are separated from the Permian rocks by a strike fault that follows the valley of lower Slate Creek and the upper Chisna River. This fault is parallel to the great fault that marks the south boundary of the ancient schists and gneisses still farther north.

If the structure of the formation involved only simple folding, the strike of the beds would carry them into the area of Permian rocks across the Middle Fork on the southeast and into the area of Tertiary rocks on the northwest. Probably the Tertiary rocks overlie and conceal the Chisna formation. The relation of the exposures on the Middle Fork, however, suggests possible cross faulting sufficient to displace the formations and offset them in the vertical direction. Similar faulting may also have taken place along the West Fork.

Age.—The assignment of the rocks of the Chisna formation to the Carboniferous is provisional. It does not rest on the evidence of fossils but on structural and lithologic considerations, which seem to indicate that the rocks included in the Chisna formation are older than the nearby rocks of the Mankomen formation of Permian age. A few crinoid joints have been found in the Chisna formation, only sufficiently diagnostic to suggest an age assignment within wide limits. Future detailed study will probably show that rocks of Permian age have been included in the Chisna formation.

PERMIAN ROCKS

Character and distribution.—Permian rocks have been described, in many earlier reports of the Geological Survey dealing with

Alaska, as representatives of the closing epoch of the Carboniferous period. As the Permian is now considered to be a geologic period equal in rank to the Carboniferous period, the rocks here described are no longer referred to as Carboniferous but as Permian.

The Permian bedded rocks of the eastern Alaska Range and adjacent area include a variety of types but are characterized by the abundance of volcanic lavas and tuffs, and calcareous sediments. They are exposed throughout almost the entire length of the part of the Alaska Range considered in this report and continue for an undetermined distance to the south and possibly to the west beyond it. Permian sedimentary rocks are exposed on the Delta River and between the West Fork of the Chistochina River and the Slana River, especially in the mountains north of Mankomen Lake. Small isolated areas of Permian strata, chiefly limestone, are exposed on Indian Creek, Ahtell Creek, and Suslota Creek, and on Soda Creek, a tributary of Platinum Creek. A great area of Permian rocks lies south of the Nabesna River and extends southeast from the Nabesna across the White River into Canadian territory on the east and the valley of the Nizina River on the west. However, the area shown on the geologic maps as occupied by Permian rocks is not continuous throughout this distance, for the beds are covered in places by younger sedimentary rocks. It is narrowest near the Delta River and at the head of the Chistochina and, as far as is known, reaches its greatest width in the Chisana and White River district, where, however, much of the Permian rock is buried under Tertiary lava.

In all the localities mentioned the sedimentary rocks are associated with lava flows and other volcanic rocks. Where interbedded with the sedimentary rocks the lava flows are assigned to the Permian period. Where such evidence is lacking determination of the age of the volcanics is less certain and is especially difficult where Devonian volcanic rocks are also present.

The Permian rocks of the Copper River region were first identified by Mendenhall (1905, p. 40–47) who saw them in the upper Chistochina valley, north of Mankomen Lake, and gave them the name Mankomen formation. This locality has since been looked on as the type locality for the Permian (Mankomen formation) of the upper Copper River region, although the section exposed near Mankomen Lake is not typical of the Permian beds in the Chisana-White River district.

The Permian rocks are marine sedimentary deposits interbedded with lava flows and tuffs. The sedimentary units include limestone, shale, limy tuff, grit, sandstone, and a variety of intermediate, related types. The igneous units are dark, fine-grained lavas, some of which are amygdaloidal, and tuff beds that are calcareous in most places and range from calcareous tuff to tuffaceous lime. In addition to the contemporaneous lava flows, the Permian sequence includes in places a large proportion of igneous rock, similar in composition and appearance to the flows, which was intruded into the Permian bedded rocks. These intrusive masses are more common in the Chisana district than in the type locality of the Mankomen formation.

The presence of intrusive, sill-like bodies that are easily confused with the surface flows, and the differences in the Permian stratigraphic section in different parts of the region make it difficult to separate the igneous units of the Permian and Devonian periods. It has therefore been necessary to show some areas on the geologic map as undifferentiated Devonian and Permian rocks. No place has yet been found in

FIGURE 25.—Permian limestone cliffs on the east side of the Middle Fork, Chistochina River.

this part of the Alaska Range where the base of the Permian section is definitely recognized. For this reason some of the igneous rocks that underlie the Permian and are shown on the map as of Permian age may belong to an older period.

A generalized stratigraphic section that would adequately represent the principal features of the Permian bedded rocks of the eastern Alaska Range is not practicable, as the section varies much in different localities and the members of the succession have not been correlated. Instead, individual sections of the Permian rocks of the type locality north of Mankomen Lake and of sections in the Chisana district will be described. The type locality will be considered first.

The valleys of Eagle Creek and Canyon Creek and the east side of the valley of the Middle Fork (fig. 25) offer excellent opportunities for a study of the Permian stratigraphic section in the Chistochina area. The rocks, which are well exposed, are not closely folded but have been broken and displaced by numerous faults, which are the chief source of difficulty and possible error in interpreting the relationships, thickness, and structure of the different units. In general the lowest rocks of the section are fine-grained, amygdaloidal lava flows. The lava flows are overlain by beds of coarse, soft tuff which include a few thin sheets of andesitic lava and become finer grained and calcareous in the upper beds. Locally they give place to hard, gritty limestones and hard, coarse brown sandstones. Still higher in the section are thick beds of massive limestone and thin-bedded limestone, together with thick beds of black shale and a little sandstone. The top unit of the sequence is black shale. Limestone beds are distributed throughout the section but are best developed in the upper part, where they occur as massive, cliff-making units. Beds of sandstone and grit are common in the lower part of the section, but there are few conglomerate beds. Buff or brown weathering is characteristic of the lower part of the section.

The Permian rocks of the Chistochina section north of Mankomen Lake are disposed so that the oldest and lowest rocks appear on the slopes of the mountains on the south side of the area. The highest beds, mainly black shale, form the tops of the mountains on the north side adjacent to the valley that separates the Paleozoic rocks from the pre-Cambrian schist exposed on the slopes of Mount Kimball. A westward extension of the Permian rocks occupies most of the area between this valley and a minor valley or line of valleys which leads from Trout Lake to the mouth of Slate Creek, and thence continues to West Fork Glacier. Black shales are the prevailing rocks exposed in this area. Still farther west the Permian rocks crop out in the mountains east of Phelan Creek and the Delta River. They probably make up the greater part of the rocks exposed along the south slope of the range west of the Delta River, though it may be that they are associated with rocks of the Chisna formation (p. 103).

Toward the east the sedimentary beds of the Mankomen formation end abruptly at the Slana River.

Mendenhall (1905, p. 40) examined the Permian rocks in the ridges on both sides of the Eagle Creek valley and described them as forming a stratigraphic section between 6,000 and 7,000 feet thick, the lower part of which consists mostly of arenaceous and tuffaceous beds, the upper, larger part of prevailingly calcareous beds. A composite section of these beds, based on barometric measurements, is shown in figure 26. The thickness there indicated as 6,700 feet is doubtless somewhat less than the original thickness of the beds as some of the upper deposits have been removed by erosion.

The prevailing strike of the Permian rocks is north-northwest and the dip is low to the east-northeast, but the strike and dip are not

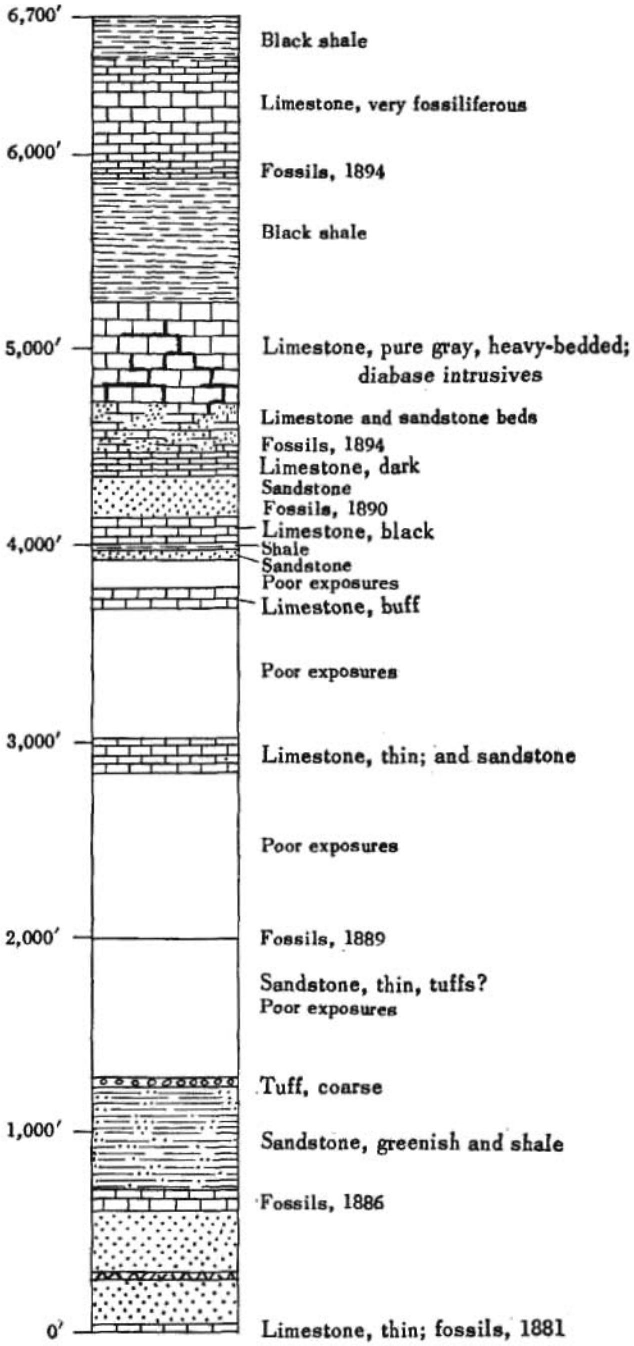

FIGURE 26.—Section of Permian sedimentary rocks north of Mankomen valley as measured by Mendenhall. Locally numbers refer to list of Mendenhall's fossils, p. 117.

constant. Part of the south slope of the mountain north of Mankomen Lake, between Canyon and Eagle Creeks, is practically a dip slope although the southerly dip of the beds is slightly greater than the slope of the mountain side. This structure probably involves faulting.

The Permian rocks are limited on the north by a great fault which brings them into contact with the pre-Cambrian schist (p. 92). The fault dips to the south and is many miles long; it extends west beyond the Delta River and eastward an even greater distance. The effect of the faulting was to elevate the older rocks on the north relative to those on the south, with a displacement of probably many thousands of feet, though the full amount is not known.

The fault involves a zone or inclined tabular mass of rock of widely varying thickness, in which the movements of adjustment were distributed, rather than a single fracture plane along which displacement occurred. It includes many minor faults with various strikes and dips, some of which extend outside the principal fault zone. Parallel faults—such as that between the Carboniferous and Permian rocks of Slate Creek and the upper Chisna River, which are apparently distinct from the great fault but doubtless are related to it in origin—displace the rocks in numerous places. Cross faults making large angles with the prevailing strike of the bedding also offset the beds. This complicated system of faulting increases the difficulty of interpreting the geologic structure of the area for it adds to the problems already presented by folding and erosion.

The stratigraphic section of the Mankomen formation displayed in the type locality is not duplicated elsewhere. The Permian rocks of the Delta River locality show a larger proportion of argillaceous material. Those of the Nabesna and White River areas include a larger proportion of lava flows. It appears that the type locality of the Mankomen formation was a place of dominant lime deposition.

Two small areas of Permian limestone and clastic beds are exposed on Indian and Ahtell Creeks within the mountain group between the Copper and Slana Rivers. These isolated localities suggest that the Permian sedimentary rocks once occupied a much greater area in the upper Copper River region than they do now. The smaller area, 12 miles south-southeast of Mankomen Lake, was described by the writer (1938, p. 20) as follows:

A small patch of Permian sedimentary rocks, less than 1 square mile in area, occupies the highest part of the ridge between the two main branches of Indian Creek, about 6 miles north of the place where these two branches come together. The lower part of the section is dark-gray calcareous grit containing scattered crinoid stems and a few fragments of thick-shelled brachiopods. On this rests about 50 feet of light bluish-gray crystalline limestone, locally containing abundant crinoids and brachiopods. These beds rest on igneous rocks, chiefly a porphyritic granitoid rock of varying degrees of coarseness containing feldspar, hornblende, and a little quartz, and are overlain in places by a thin covering of igneous rock. Their thickness is between 100 and 200 feet, and they are only moderately folded, appearing nearly horizontal in most places. On the evidence of the fossils the beds are correlated with the Mankomen formation.

The Permian rocks of Ahtell Creek occupy a considerably larger area than those of Indian Creek. They extend northeast from Ahtell Creek and make up most of the mountain east of Porcupine Creek. These rocks appear to overlie volcanic rocks although their contact is in part a fault contact. The beds are dominantly volcanic tuff and lava flows but include clastic and calcareous sedimentary rocks. A gulch on the east side of Porcupine Creek, 2½ miles south of the little lake in the low pass leading to Ahtell Creek, shows more than 500 feet of beds that include coarse sandstone or grit; fine conglomerate; argillite; shale; coarse, rough black conglomerate with tuffaceous base; calcareous grit; and limestone interstratified with dark, fine-grained lava flows or intrusives. The beds strike N. 25° E., and dip 30° ESE. A coarse brown sandstone or grit, overlain by a 6-foot bed of limestone on which rest limy shale beds, forms the top of the ridge and is exposed for nearly a mile. This upper group is fossiliferous, as are some of the underlying beds. Accurate correlation of this group with beds in the Mankomen formation is not attempted, yet the prevalence of volcanic units suggests that it more probably represents some part of the lower half than the upper half.

East of the Slana River and north of Suslositna Creek and Suslota Pass is a group of rocks made up dominantly of dark, fine-grained igneous rocks, argillite, shale, conglomerate, and subordinate limestone beds. Most of the limestone beds as far north as the headwaters of the streams draining into Station (Mentasta) Creek have yielded Permian fossils. The largest area of Permian limestone, and the first to be discovered, is about 2½ miles north by east of Suslota Lake. This limestone is bluish gray and massive. As it is faulted into its present position, its stratigraphic relation to the nearby rocks is obscure. Other limestone beds, however, are plainly interbedded with the associated clastic beds and bear evidence that at least some of the clastic beds are to be referred to the Permian period.

One other small body of Permian limestone occurs north of the Nabesna River. It occupies the north brow of the mountain between Platinum and Totschunda Creeks, overlooking Soda Creek. At this place a massive gray limestone bed about 50 feet thick is overlain by thin-bedded limestone that is folded and broken and shows yellowish surface weathering. The limestone yielded a few Permian fossils.

The rocks between the Slana and Nabesna Rivers mapped as Permian are nearly all volcanic flows and tuffs interbedded with a little shale and intruded in places by granitic rocks. The massive limestone near Soda Creek may originally have been an isolated lenslike body deposited on and possibly interstratified with lava flows, like the Permian limestone between the branches of Indian Creek, but probably had a considerably greater extent than the small area that now caps the mountain.

From the Nabesna River to the Chisana River and thence to the White River the Permian rocks are exposed continuously on the lower slopes of the Wrangell Mountains except where they are interrupted by intrusive bodies. South of Beaver Creek much of the Permian rocks, which here are made up almost wholly of volcanic lava flows and tuffs and are associated with an unknown proportion of Devonian rocks, are hidden in large part by Tertiary lava flows.

The Permian rocks include amygdaloidal basalts, limestone, shale, arkosic sandstone, grit, and conglomerate. The sedimentary units, however, make up less than one-half of the stratigraphic section and are less widely distributed than the basalts.

In a general way the Permian bedded rocks of this area include upper and lower units made up of lava flows and tuffs that are separated by a middle unit, which is notably calcareous and consists of limestone, limy tuff, shale, and minor lava flows. According to Capps (1916, p. 39) the Permian rocks of the Chisana and White River areas may be further separated into several stratigraphic divisions which are shown in the following generalized section, the youngest being at the top:

1. Basic bedded lavas, with little sedimentary material.
2. Massive limestone beds of Skolai Creek, with interbedded lavas and minor amounts of shale and conglomerate.
3. Lavas and pyroclastic rocks, with small amounts of sedimentary rocks.
4. Massive limestone, associated with shales, thin-bedded limestones, and a little sandstone and conglomerate.
5. Lavas and pyroclastic beds, with some shales.

This section represents several thousand feet of rock of which only the lower part is believed to be represented in the area shown on plate 6, covering the valleys of Beaver Creek and the upper Chisana and Nabesna Rivers. This belief is based on the association of Permian with Devonian rocks and on the appearance of the section, but it has not yet been proved.

A section of the Permian rocks exposed on Cross Creek and a second smaller section on Baultoff Creek were studied because they offered favorable opportunities and are reproduced herein from an earlier report (Moffit and Wayland, 1943, p. 120).

The first section is on the north side of Cross Creek, 2½ miles below the glacial moraine; here the beds are only moderately folded and nearly horizontal. This section is represented in figure 27. Approximately 3,000 feet of sedimentary rocks and lava flows is shown. The limestone is about 250 feet thick and the upper part of the section consists chiefly of argillite and slate. The limestone is abundantly fossiliferous, but the overlying beds have not yet yielded fossils; they are tentatively included in the section in the expectation that further investigation may show that they include some Mesozoic sedimentary rocks. Upper Triassic limestone and Upper Jurassic shale are associated with the Permian rocks of this mountain mass in the vicinity of Camp Creek northwest of Cross Creek near the Nabesna River. The Permian rocks of Cross Creek were invaded by granitic intrusives and by dikes and sills of dark basaltic rock which broke through and offset the sedimentary beds; in many places where sills were forced along bedding planes within a group of beds, these intrusives produced the appearance of several separate limestone units. This condition is more noticeable on the south side of Cross Creek than on the north.

A smaller section of Permian rocks (see fig. 28), representing a thickness of nearly 400 feet of bedded materials and including lava flows, andesitic tuff, and clastic sediments, was measured on Baultoff Creek. These beds have yielded diagnostic fossils and are probably at or near the base of the Permian section. They include only a part of the Permian exposed on Baultoff Creek, but the variety of materials in the sedimentary units is greater than that in the section on Cross Creek. Like the Permian of Cross Creek the Permian bedded rocks of Baultoff Creek are faulted and are intruded by granitic rocks, which caused crystallization of the limestone and silicification of the banded argillite and the limestone. Thinly banded or varved slate-argillite or slate-sandstone units occur in both the Permian sequence and the overlying Mesozoic beds and are difficult to differentiate.

Thickness and structure.—Measurement of the thickness of the Permian rocks involves a number of difficulties, among them the facts that the base of the sequence has not been identified and the structural relation of the Permian to the Devonian rocks has not been observed. Further uncertainties are due to a lack of information needed to correlate sections in widely separated localities and to assign a top to the Permian sequence. The approximate thickness of the thickest section known will probably represent a minimum thickness for the sequence and will be the most informative estimate that can be given.

A wide variation in the thickness of the rocks in different localities is apparent and arises in part from the effects of erosion, in part from

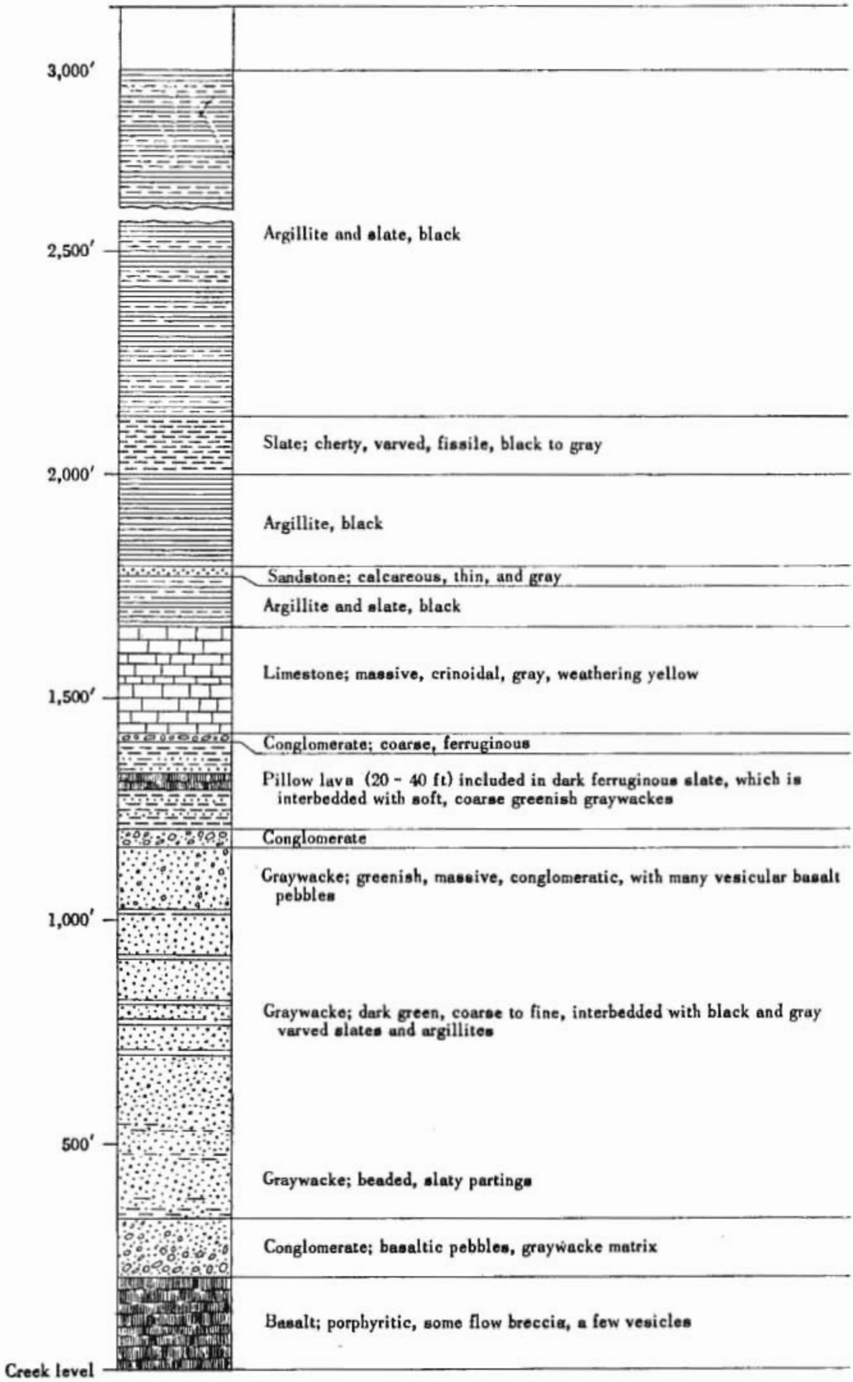

FIGURE 27.—Generalized section of Permian rocks on the north side of Cross Creek. Measurements are based on barometric readings and estimates.

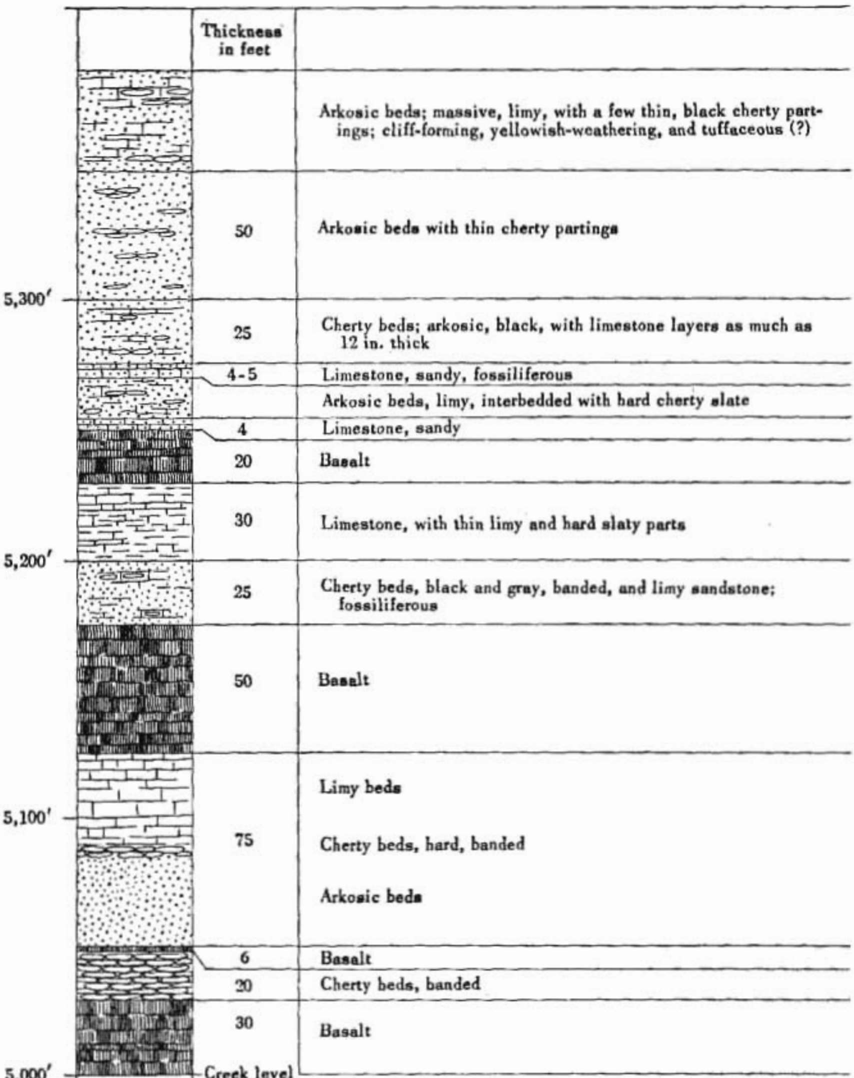

FIGURE 28.—Section of Permian sedimentary units on Baultoff Creek, about 4 miles southeast of the pass to East Fork. Thicknesses are based on barometric readings and estimates.

the presence or absence of interbedded lava flows in the sedimentary units, and probably in part from differences in original deposition.

The most favorable section for measurement is that north of Mankomen Lake, and the best available estimate of its thickness was made by Mendenhall (fig. 26) which may be changed somewhat when more detailed measurements are available. The Mankomen formation, as determined by barometric measurement, comprises 6,700 feet of marine sedimentary rocks and tuff beds. This does not include a considerable thickness of basal lavas of indeterminate age, although they probably are part of the series of thin flows interbedded with the fossiliferous tuff beds in the lower part of the section.

The Permian sedimentary rocks of Indian Creek consist of limy grit overlain by 50 feet of limestone, the whole thickness being somewhere between 100 and 200 feet. The Permian section of Ahtell and Porcupine Creeks is thicker. The beds there include more than 500 feet of coarse, limy, clastic beds, tuffs, and a little limestone, which are interbedded with dark, fine-grained igneous rocks and probably are to be correlated with the basal part of the Mankomen formation. The massive, fossiliferous limestone on Suslositna Creek is associated with other Permian rocks, but all are much folded and faulted and do not offer a favorable place for measurements.

The Permian section of Cross Creek comprises 3,000 feet of bedded rocks, mostly graywacke, argillite, slate, and limestone. It includes one interbedded, 20-foot lava flow and about 200 feet of basal lavas which like the basal lavas of the Mankomen section may be older than Permian. No other known section in the Nabesna and Chisana areas is as favorable for measurement as that on Cross Creek for in most places the rocks are folded or faulted or have been so eroded that only a fraction of the original deposits remains.

The section on Baultoff Creek shown on figure 28 includes 106 feet of lava flows and 284 feet of arkosic beds, cherty and limy beds, and limestone, giving a total thickness of 390 feet. These beds are probably low in the Permian section and only part of the beds originally deposited are present, an unknown part having been eroded.

From this review of the different localities it is apparent that the section north of Mankomen Lake affords the greatest thickness of Permian rocks in the area considered. It probably indicates a thickening of the sedimentary part of the section in that part of the Alaska Range.

Capps (1916, p. 39) recognized the difficulty of measuring the section in the Chisana-White River district and the uncertainty of the results but suggested that an estimate of 10,000 feet for the thickness of the Permian was not excessive. However, this estimate includes a considerable thickness of lava flows, underlying and overlying the middle section of dominantly sedimentary origin, that are not present in the section on Cross Creek. Later studies by the writer (1938, p. 35, 42) indicate that the Nikolai greenstone of the Chitina Valley is in part if not wholly of Permian and Triassic(?) age, and if it is included with the Permian rocks of the upper White River and

Nizina River district, the thickness of the series can hardly be less than 10,000 feet and may be more. The Nikolai greenstone, however, has not been recognized in the Alaska Range.

The structural relations of the Permian rocks to the Carboniferous and Devonian rocks were not made clear by field observations. As no deposits have yet been identified to be of Pennsylvanian or late Carboniferous age, it is assumed that this part of Alaska was land in Pennsylvanian time. Thus the Permian rocks were deposited unconformably on the eroded surface of Devonian or older beds in the Chisana district and on Carboniferous or older beds in the Chistochina district. Black shale of Late Triassic age lies unconformably on Permian limestone on Skolai Creek (Moffit, 1938, p. 35) in the Nizina district. It therefore seems evident that the Permian rocks are separated by unconformities from both the underlying and the overlying rocks, and that they themselves were folded to a considerable degree before Late Triassic time. However, they are not schistose or notably metamorphosed except where they are faulted or intruded by igneous rocks. On the other hand they are extensively faulted, and in numerous places their contacts with adjacent formations mark faults of great displacement and longitudinal extent.

Age and correlation.—The sedimentary units of the Permian rocks, including the tuffaceous beds, are notably calcareous and fossiliferous. Moreover, where fossils are found they are commonly abundant, and good collections have been made; they are diagnostic, and little doubt exists regarding the age of most of them. Most of the collections so far made were submitted to Mr. G. H. Girty for identification and determination of age. From his study it appeared that the fauna is more closely related to the Permian of Russia than to that of more southern parts of North America. One or two of the collections suggested Carboniferous time but since the Pennsylvanian (Moffit, 1938, p. 28) is probably not represented in most of Alaska, if at all, and as the associated rocks include no known Mississippian, any question concerning the age of the fossils has been provisionally decided in favor of the Permian.

Some early collections, including the fossils collected by Mendenhall from the type locality of the Mankomen formation, were identified by Charles Schuchert. They were reviewed by Girty, who was in essential agreement with the original determinations, but are not included in the table of fossils of later collections. They are here given in a separate table, as the present terminology is somewhat changed from that of the early reports and the inclusion of the early collections would require extensive revision of names.

Permian fossils from the eastern Alaska Range and adjacent area

	6755 (29AM-F1)	7046 (31AM-F1)	7046a (31AM-F2)	7439 (34AM-F9)	8012 (35AM-F1)	8013 (35AM-F2)	8014 (35AM-F3)	8015 (35AM-F4)	8016 (35AM-F5)	8017 (35AM-F6)	8018 (35AM-F7)	8019 (35AM-F8)	8020 (35AM-F9)	8021 (35AM-F10)	8022 (35AM-F11)	8023 (35AM-F12)
Cyathaxonia suggested				×												
Triplophyllum sp															×	
Zaphrentis sp							×									×
Cyathophyllum sp		×														
Aulophyllum sp		×	×													
Lithostrotion sp									×							×
Lithostrotion? sp							×									
Lonsdaleia sp		×														
Cladochonus? sp																×
Crinoid stems (columns)	×			×								×				
Tabulipora sp					×	×	×	×								
Batostomella sp							×		×				×			
Bryozoan, probably belonging to Batostomella or Leioclema				×												
Phyllopora? sp							×									
Polypora sp undet				×				×								
Rhombopora sp	×	×	×							×		×				
Rhabdomeson sp							×									
Fenestella sp									×							
Futeletes? sp									×							
Orthotichia aff. *O. morganiana*		×														
Schizophoria aff. *S. resupinoides*																×
Derbya or some cognate form				×												
Streptorhynchus? sp								×	×							
Streptorhynchus pearyi?												×			×	
Chonetes aff. *C. flemingi*			×													
Chonetes aff. *C. granulifer*							×	×	×	×						
Chonetes sp							×	×								
Productus (*Productus*) aff. *P. gruenewaldti*							×	×	×	×	×	×				
Productus (*Echinoconchus*) aff. *P. fasciatus*			×				×	×	×			×				
Productus (*Horridonia*) aff. *P. timanicus?*								×	×			×			×	×
Productus (*Horridonia*) sp															×	
Productus (*Linoproductus*) aff. *P. cora*									×							×
Productus (*Linoproductus*) aff. *P. koninkianus*								×		×						
Productus (*Pustula*) aff. *P. pseudaculeatus*							×									
Productus (*Pustula*) *wallacianus*			×													
Productus (*Avonia?*) aff. *P. tuberculatus*																×
Productus (*Waagenoconcha*) aff. *P. humboldti*							×	×								
Productus (*Waagenoconcha*) aff. *P. irginae*									×			×				
Productus (*Buxtonia*) aff. *P. porrectus*			×				×	×							×	
Productus (*Productus*) *semireticulatus* group				×												
Productus apparently related to *P.* (*Buxtonia*) *peruvianus*				×												
Productus with fine striae				×												
Productus sp							×					×				
Marginifera aagardi?											×	×				
Marginifera aff. *M. cristobalensis*										×						
Marginifera aff. *M. involuta*							×	×	×						×	
Marginifera aff. *M. timanica*			×													
Marginifera aff. *M. typica* var. *septentrionalis*	×											×				
Marginifera? sp													×			
Camarophoria aff. *C. mutabilis*												×				
Camarophoria? sp							×									
Rhynchopora aff. *R. nikitini*	×									×		×				×
Rhynchopora sp							×									
Rhynchopora? sp									×							
Dielasma aff. *D. truncatum*									×							
Dielasma sp																×
Heterelasma sp																×
Spirifer aff. *S. fasciger*	×						×	×	×	×						

Permian fossils from the eastern Alaska Range and adjacent area—Continued

	6755 (29AM-F1)	7046 (31AM-F1)	7046a (31AM-F2)	7439 (34AM-F9)	8012 (35AM-F1)	8013 (35AM-F2)	8014 (35AM-F3)	8015 (35AM-F4)	8016 (35AM-F5)	8017 (35AM-F6)	8018 (35AM-F7)	8019 (35AM-F8)	8020 (35AM-F9)	8021 (35AM-F10)	8022 (35AM-F11)	8023 (35AM-F12)
Spirifer aff. *S. ravena*																×
Spirifer aff. *S. schellwieni*?												×				
Spirifer sp												×				
Spirifer several sp. fragments				×												
Spiriferella arctica?	×															
Spiriferella aff. *S. saranae*												×				
Squamularia aff. *S. perplexa*																×
Squamularia sp												×		×		
Squamularia? sp															×	
Martinia? sp	×															
Spiriferina aff. *S. laminosa*									×							
Spiriferina sp	×									×						×
Aviculipecten sp			×													
Aviculipecten? sp								×								
Streblopteria? sp									×							
Pleurotomaria sp									×							
Pleurotomaria? sp								×								
Paraparchites sp									×							

6755 (29AM-F 1). Top of mountain, 6½ miles north-northeast of the forks of Indian Creek. Same locality as 1863 and 1864 of Mendenhall's collection. Fred H. Moffit, 1929.
7046 (31AM-F 1). 3 miles north-northeast of Suslota Lake. Same locality as 5875. Frank C. Schrader, 1902.
7046a (31AM-F 2). 3 miles north-northeast of Suslota Lake. Fred H. Moffit, 1931.
7439 (34AM-F 9). 6½ miles N. 83° E. of the mouth of Suslositna Creek. Fred H. Moffit, 1934.
8012 (35AM-F 1). Northeast tributary of lower Suslositna Creek, 3¾ miles north of the north end of Suslota Lake. Fred H. Moffit, 1935.
8013 (35AM-F 2). Fossil Creek, 3 miles N. 20° E. from the north end of Suslota Lake. Fred H. Moffit, 1935.
8014 (35AM-F 3). 3⅓ miles N. 15° E. from the north end of Suslota Lake, ½ mile north of locality 7046. Fred H. Moffit, 1935.
8015 (35AM-F 4). On mountain side ¼ to ½ mile east of Fossil Creek and locality 7046. Fred H. Moffit, 1935.
8016 (35AM-F 5). Head of Fossil Creek, near locality 8014. Fred H. Moffit, 1935.
8017 (35AM-F 6). 4 miles N. 35° W. of Suslota Pass. Fred H. Moffet, 1935.
8018 (35AM-F 7). ¼ mile east of locality 8017, or about 4 miles N. 35° W. of Suslota Pass. Fred H. Moffit, 1935.
8019 (35AM-F 8). Limestone ledge 8½ miles S. 70° E. from the Indian village of Mentasta Lake. Fred H. Moffit, 1935.
8020 (35AM-F 9). 10 miles S. 67° E. of the Indian village of Mentasta Lake. Fred H. Moffit., 1935.
8021 (35AM-10). On Eagle Trail, Porcupine Creek, 3 miles from Ahtell Creek. Fred H. Moffit, 1935.
8022 (35AM-11). 5½ miles N. 4° E. from the mouth of Ahtell Creek. Fred H. Moffit, 1935.
8023 (35AM-12). Top of ridge above gulch where lot 8022 was collected, 3.7 miles N. 8° E. from the mouth of Ahtell Creek. Fred H. Moffit, 1935.

Permian fossils collected by Mendenhall in the Copper River basin, Alaska

	1894	1891	1890	1889	1886	1881	1864	1863
Goniocladia sp		×				×		
Orthotichia sp								×
Orthothetes sp						×		×
Chonetes cf. *C. uralica* Moeller								
Chonetes cf. *C. granulifer* Owen						×		
Productus sp. 4 (group of *P. multistriatus*)		?				×		
Productus semireticulatus var	×	×	×		×	×		
Productus sp. 7 (group of *P. semireticulatus*)						×		
Productus sp. 9 (group of *P. cora*)						×		×
Productus sp. 11 (group of *P. cora*)	×							
Productus sp. 15 (group of *P. undatus*)	×							
Productus sp. 17	×							
Productus sp. 18 (group of *P. humboldti*)				×				
Productus sp. 20 (group of *P. humboldti*)		×						
Marginifera sp. 1	×							
Marginifera longispinus (Sowerby)					×	×		
Camarophoria near *C. pinguis* Waagen		×						
Camarophoria sp. 2	×							
Rhynchopora near *R. nikitini* Tsch	×	×						
Reticularia cf. *R. lineata* (Martin)	×							
Martinia sp. 1						×		

Permian fossils collected by Mendenhall in the Copper River basin, Alaska—Con.

	1894	1891	1890	1889	1886	1881	1864	1863
Martinia sp. 2				×				
Spirifer sp. 1 (group of *S. striatus*)	×					×	×	×
Spirifer sp. 6 (group of *S. striatus*)			×					
Spirifer sp. 3 (group of *S. arcticus*)		×					×	
Spirifer sp. 3a (group of *S. arcticus*)							×	
Spirifer sp. 4 (group of *S. supramosquensis*)		×			×			
Spirifer sp. 5 (group of *S. supramosquensis*)						×		
Spirifer sp. 7 (group of *S. supramosquensis*)		×						
Spirifer sp. 7a (group of *S. supramosquensis*)	×							
Spirifer sp. 8 (group of *S. alatus*)	×							
Spiriferina sp. 1		×	×					
Straparollus sp. undetermined				×				
Total	12	9	3	3	3	11	3	4

1863–1864. 100-foot limestone bed on upper Indian Creek; same locality as 6755. W. C. Mendenhall, 1902.
1881. Near base of spur between Mankomen and Slana Valleys. W. C. Mendenhall, 1902.
1886. Top of buff limestone, 700 feet above locality, 1881. W. C. Mendenhall, 1902.
1889. Thin dark limestone near top of spur between Mankomen and Slana Valleys. W. C. Mendenhall, 1902.
1890. Upper part of ridge between Eagle Creek and Slana Valley. W. C. Mendenhall, 1902.
1891. Top of ridge between Eagle Creek and Slana Valley. W. C. Mendenhall, 1902.
1894. Base of upper limestone, west of Eagle Creek. W. C. Mendenhall, 1902.

Permian rocks, formerly treated as belonging to the latest epoch of the Carboniferous period, are found in many parts of Alaska, although they are somewhat less extensive than the Mississippian rocks. Their occurrence has been summarized by Smith (1939, p. 25–34) and includes localities as widely separated as southeastern Alaska, Canning River on the Arctic Coast, and Goodnews Bay near the mouth of the Kuskokwim River. One of the best-known localities of Permian rocks is on the Yukon River just above the mouth of the Nation River. This section is notable for having yielded a larger Permian fauna than any other Alaskan locality, rather than for containing a typical assemblage of Permian beds. The Permian rocks of the Yukon River differ further from those of the Mankomen formation in the entire absence of volcanic members.

MESOZOIC BEDDED ROCKS

The Mesozoic bedded rocks of the eastern Alaska Range and adjacent area represented on the geologic map (pls. 6, 7) include marine rocks and subordinate terrigenous deposits which are practically restricted, as far as is known, to the part of the range southeast of Suslota Pass.

The large, eastern area of Mesozoic sedimentary rocks, comprising the Nutzotin Mountains and part of the Mentasta Mountains, is a rugged country in which all three periods of the Mesozoic era are represented. A small part of the area is occupied by Upper Triassic limestones and shales that are exposed in the Snag River and upper Nabesna River valleys and near Cooper Pass. Most of the Mesozoic area, however, is made up dominantly of slate or argillite and sandstone, in part of Late Jurassic and in part of Early Cretaceous age.

Fresh-water beds, including conglomerate, sandstone, and sandy shale of Late Cretaceous age, comprise the remaining part of the Mesozoic section of the area. The fresh-water beds are greatly subordinate in extent to the marine deposits and are erratically distributed. These Upper Cretaceous rocks are known only in a few isolated localities in the Chisana district.

The Mesozoic rocks of the Mentasta and Nutzotin Mountains are not well enough known to permit even a rough differentiation of the rocks of different periods, except the Upper Triassic limestone and the Upper Cretaceous terrigenous beds. This differentiation will require intensive study, for the lithologic similarity of beds and the scarcity of fossils in most places make it difficult to distinguish the rocks of different epochs. The problems can be solved only by more detailed field study.

UPPER TRIASSIC ROCKS

Character and distribution.—Upper Triassic sedimentary rocks are restricted to the eastern part of the section of the Alaska Range under consideration. They have not been recognized between Suslota Pass and the Delta River, although possibly some of the black shale overlying the Permian beds in the Chistochina area may be Late Triassic in age.

The known Triassic rocks of the extreme eastern part of the Alaska Range include several small, widely distributed areas of limestone, thin-bedded limestone, and limy argillite, and a single area of limy arkose and shale. The limestone because of its color and cliff-forming character is nearly always conspicuous, and a careful search for fossils is usually rewarded with success. The argillaceous beds of the Triassic sequence on the other hand have little lithologic character to distinguish them and when fossils are lacking the arkosic and shaly members are not readily differentiated from some of the younger Mesozoic rocks. They may prove eventually to be more widely distributed than is now known.

Practically all of the post-Permian limestone deposits of this part of the range are of Late Triassic age, although a few thin beds of limestone are interstratified with the younger Mesozoic slates and their associated sandy beds. In general the Triassic limestone is less deformed and less distinctly crystalline than the Permian limestone, except where it is intruded by igneous rocks.

It may be divided into a basal part, made up of thick beds, and an upper part, which consists of thin beds and a small proportion of shale. This limestone is well exposed north of the Nabesna River at White Mountain (fig. 29), where Schrader (Mendenhall and Schrader, 1903, p. 34) gave it the name Nabesna limestone, and on the headwaters of Jack Creek. South of the Nabesna River it is exposed in

FIGURE 29.—White Mountain on the Nabesna River. On the left the Wrangell lava overlies Upper Triassic limestone; in the center it rests on Permian lava flows and intrusive rocks.

the vicinity of Cooper Creek, in the valley of the Snag River, and possibly in the valley of Baultoff Creek.

The largest and best exposures of the Upper Triassic rocks are those at White Mountain and in the low hills, locally known as the Raven Hills, between Jack Creek and the lower part of the Jacksina River. At White Mountain the formation consists of 1,200 feet of massive light-gray dense or crystalline limestone and about 800 feet of overlying thin-bedded light-gray limestone. The thin-bedded limestone consists of beds that commonly do not exceed 6 inches in thickness, are separated by thin shaly layers, and are themselves less pure than the limestone of the thick underlying beds, probably containing a small proportion of argillaceous material. Near the Nabesna gold mine the limestone has been greatly altered by the intrusion of dioritic rock. At the Raven Hills only the lower massive part of the Upper Triassic limestone is exposed. In some earlier reports the limestone of this vicinity was assigned with much hesitation to the Permian, as the nearest limestone of known age, on Platinum Creek, is Permian and the association of rocks is similar. However, the field work of 1940 leaves little doubt that it is correctly assigned to the Upper Triassic.

The Upper Triassic rocks are conspicuous on Lost (figs. 30, 31) and Trail Creeks, northern tributaries of Jack Creek, where they include

FIGURE 30.—View on Lost Creek shows dark Permian lava flows in the foreground. The lava flows are overlain, in turn, by thick and thin beds of Upper Triassic limestone. The dark rocks of the mountain tops are shale and sandstone of Late Jurassic and Early Cretaceous age.

massive limestone and calcareous thin-bedded shale and argillite units, which strongly resemble the thin-bedded argillites (Moffit, 1938, p. 58) of the transition beds between the Nizina limestone and McCarthy shale of the Nizina district. Not less than 400 feet of limestone is exposed on Lost Creek, where it appears to be overlain by a much greater thickness of thin-bedded argillite. These rocks are adjacent

FIGURE 31.—Contorted thin bedded Upper Triassic limestone on a small tributary of upper Lost Creek.

to one of the major fault zones of the district and are so folded and fractured that their structural and stratigraphic relations are obscure.

Triassic fossils were collected from limestone beds in Cooper Pass by Schrader (Mendenhall and Schrader, 1903, p. 37) in 1902, but the presence of both Permian and Upper Triassic limestone was not known until later. The Upper Triassic limestone of Cooper Pass is well exposed in the ridge between the winter and summer trails. Both the massive beds and the upper thin-bedded part of the formation are present, and the thickness of the beds exposed here may be as great as that at White Mountain, although it is not known. The beds are much folded and faulted and in many places stand on edge. Massive beds of the formation are also exposed on the south side of Notch Creek, 5 miles southeast of the summit of Cooper Pass. They form a conspicuous ridge on the west side of the valley, where they are faulted against amygdaloidal lava flows and are separated by only a short distance from Permian limestone. The fault dips to the northeast and marks a zone of great disturbance, which affects both the limestone and the basalt. These amygdaloidal lavas are not only closely folded but are overturned toward the southwest. The Upper Triassic limestone of Cooper Pass and Notch Creek is distinguished from the nearby Permian limestone by fossils and by the degree of recrystallization, which in general is greater in the older rocks.

The Upper Triassic limestone of the Snag River valley appears in several small isolated areas in the mountains southwest of the East Fork. All the beds that are definitely identified as Upper Triassic on the evidence of fossils, belong to the upper, thin-bedded part of the formation. Although locally massive beds of limestone crop out near the thin-bedded Upper Triassic limestone, they appear to belong among the Permian beds. Limestone of unquestioned Late Triassic age was not recognized in the valley of Baultoff Creek, but some thin beds that may prove to be Upper Triassic crop out southwest of the pass to the East Fork. Thin-bedded limestone that is abundantly fossiliferous is exposed on the principal western tributary of Crescent Creek, a local name for a southern tributary of the East Fork, 2½ miles from the pass to Baultoff Creek. It also crops out at the head of another southern tributary 1½ miles below Crescent Creek, and between the head of the Snag River and its largest tributary on the west. The age of all these deposits is known by the characteristic Upper Triassic fossil, *Monotis* (*Pseudomonotis*) *subcircularis* Gabb, which is abundant in places.

The irregular distribution of the limestone in both the Nabesna and the Snag River areas is noteworthy and probably has a number of causes, chief of which are folding and faulting, combined with erosion of much of the original material. It is not clear why only the upper part of the limestone is present in the Snag River valley. Possibly this is the result of faulting, or it may be that the more massive, older beds never were deposited or were removed during a minor period of uplift and erosion before the thin-bedded units were deposited, as has been suggested regarding the limestone of the Chitina valley. (See Moffit, 1938, p. 51.)

Shale or arkose, lithologically comparable to the McCarthy shale overlying the Upper Triassic limestone of the Chitina Valley, has been found at only one place in the Nabesna and Chisana districts. This locality is the mountain between the branches of the Snag River, where a narrow belt of coarse arkosic and limy beds is enclosed by areas of Permian volcanics. The belt trends east and includes a considerable thickness of folded marine strata that have yielded Upper Triassic fossils. Possibly several hundred feet, stratigraphically, of the formation is present.

The occurrence of these clastic beds in such thickness suggests that similar or equivalent beds may be present in other parts of the Mesozoic area but have not been recognized because they either lack distinguishing petrographic features or have not yielded identifying fossils. It is possible that some of the shale in the high mountains between Cooper and Notch Creeks and the Nabesna River may prove to be Upper Triassic and that similar shales may be found in the Nutzotin and Mentasta Mountains. On the other hand, the seeming absence of an Upper Triassic shale comparable to the McCarthy shale may mean that the greater part of the once widely distributed shale has been removed by erosion.

Thickness and structure.—The Upper Triassic rocks of the Nutzotin Mountains appear in relatively small isolated areas and evidently are remnants of deposits that once extended much more widely. At no place is a complete section of the beds to be seen, so estimates of thickness are based on a consideration of exposures at different localities. The stratigraphic section is made up dominantly of limestone but includes an unknown thickness of overlying shale.

The most favorable locality for examining the limestone is at White Mountain on the Nabesna River, where the beds lie in a nearly horizontal position and have their greatest known thickness. As was previously stated the lower massive part of the Upper Triassic limestone of White Mountain is 1,200 feet thick. These lower, massive beds are overlain by about 800 feet of thin-bedded limestone with shaly partings, thus giving a total thickness of about 2,000 feet for the entire sequence. This is about 1,000 feet less than the thickness of the Upper Triassic Chitistone and Nizina limestones of the Chitina Valley, but it is much greater than the thickness at any other place in the Nutzotin Mountain area, with the possible exception of Cooper Pass. The limestone beds of Lost Creek and the Snag River belong in the upper thin-bedded part of the section and are not more than a few hundred feet thick.

The thickness of the limy, arkosic beds of the Snag River locality cannot be estimated for the beds are associated with younger Mesozoic rocks from which they were not distinguished. The thickness is apparently some hundreds of feet but without much doubt is considerably less than that of the limestone.

The Upper Triassic limestone and shale were laid down, probably with structural unconformity, on older rocks which include Permian and possibly Devonian sedimentary rocks and interbedded lava flows. They underwent repeated deformation and were faulted and so closely folded that in places they now stand on edge or are overturned; in White Mountain and the Raven Hills, however, the beds are not closely folded and are only moderately tilted. The seeming absence of Lower and Middle Jurassic sedimentary rocks in this part of Alaska suggests either that the land was above the sea during this time or that any sediments then deposited were removed by erosion before Late Jurassic time, when shale and sandstone were laid down on the eroded surface of the Upper Triassic rocks. Thus the Upper Triassic limestone and shale are separated from both the older and the younger adjacent formations by unconformities representing uplift and erosion and, further (see p. 123), may include a minor unconformity within themselves.

Age.—Although the areal distribution and boundaries of the Upper Triassic rocks, especially the shale unit, are not accurately known, the age assignment of both the limestone and shale is based on fossils collected from them at practically all exposures mapped as Upper Triassic. The fossils collected from the limestone represent few but diagnostic species, and the age assignment is sure. Those collected from the arkosic beds of a single locality in the Snag River valley represent a much larger number of equally diagnostic species.

A list of fossils and the localities from which they were collected is given on page 126. The fossils were examined and classified by John B. Reeside, Jr., of the U. S. Geological Survey.

UPPER JURASSIC AND LOWER CRETACEOUS ROCKS

Character and distribution.—Upper Jurassic and Lower Cretaceous rocks make up the greater part of the Mesozoic of the Mentasta and Nutzotin Mountains and are almost restricted to that area. Most of the rocks of these two epochs are not distinguished from each other on the geologic map. Furthermore, the area assigned to them may include unrecognized small areas of Upper Triassic shale and possibly other sedimentary rocks. Beds of dark argillite alternating with lighter, more siliceous argillite and interbedded argillite and sandstone are the dominant Upper Jurassic and Lower Cretaceous rocks, but the group also includes much conglomerate and a few thin beds of limestone. The sedimentary beds are intruded by dikes and sills which probably are offshoots of some of the larger bodies of dioritic rock in nearby areas.

It is evident even from a cursory examination that a great part of these sedimentary deposits accumulated in a sea where the deposition

Upper Triassic fossils from the eastern Alaska Range and adjacent area

	18086 (31AM-F16)	16261 (31AM-F6)	16262 (31AM-F7)	16263 (31AM-F8)	16264 (31AM-F10)	16265 (31AM-F11)	16266 (31AM-F12)	16267 (31AM-F13)	16268 (31AM-F14)	16269 (31AM-F15)	18083 (38AM-F2)	18084 (38AM-F3)	18087 (38AM-F12)	18336 (40AM-F3)	18337 (40AM-F4)	18338 (40AM-F5)	18341 (40AM-F17)	18342 (40AM-F18)	18343 (40AM-F19)	18344 (40AM-F20)	18345 (40AM-F20a)	18346 (40AM-F22)	18347 (40AM-F26)	18348 (40AM-F27)	18351 (40AWa-F1)	18352 (40AWa-F2)	18353 (40AWa-F3)	18354 (40AWa-F4)	18584 (40AM-F23)	18585 (40AM-F24)	18586 (40AM-F25)
Isastraea ? sp.																													X		
Thecosmilia sp.																													X		
Astrocoenia, n. sp., identified by J. W. Wells as not older than Triassic.							X																								
Spongiomorpha sp.											X																				
Crinoid stems, pentagonal cross section, possibly *Pentacrinus*.															X																
Echinoid spines, large fragments, probably cidarid.															X														X		
Rhynchonelloid brachiopod like *Halorella*.																										X					
"*Rhynchonella*", indet sp.																									X						
Dielasma ? n. sp.							X																								
"*Terebratula*" spp.							X																						X	X	
"*Cyrtina*" sp.							X																						X		
Spiriferina aff. *pittensis* Smith											X																				
Spiriferina cf. *S. yukonensis* Smith							X																								
Spiriferina yukonensis Smith																													X		
Spiriferina spp.							X																						X		
Conocardia, n. sp.							X																						X		
Dimyopsis, n. sp.							X	X																							
Posidonia sp.																													X		
Gervillia ? sp.																												X			
Cassianella sp.							X																								
Monotis (*Pseudomonotis*) *subcircularis* Gabb.	X													X		X	X	X	X	X	X	X	X	X							X
Monotis sp.							X																								
Halobia sp.																													X		
Myophoria sp., prob. n. sp.																											X				
Aviculopecten ? sp.							X																					X			
Dimyodon storrsi Smith ?																												X			
Lima aff. *L. kimballi* Smith																												X	X		
Myoconcha cf. *M. nana* Smith																												X			
Pelecypod fragments, indet.			X																												
Omphaloptycha sp.							X			X																					

Turbo? sp.							×																								
Gastropod fragments, indet.			×																												
Trachyceras (*Protrachyceras*) cf. *T. beckeri* Smith												×																			
Arcestes sp.												×																			
Spherical bodies with, apparently, a papillose surface	×	×			×	×		×	×	×			×																		

Localities at Which Upper Triassic Fossils Were Found

16086 (31AM-F16). Head of first large creek west of Lost Creek, latitude 62°35.5′ north, longitude 143°19.0′ west. F. H. Moffit, 1931.

16261 (31AM-F6). South side of pass between Suslositna Creek and west branch of large creek southwest of Bock Creek [Little Tok River]. F. H. Moffit, 1931.

16262 (31AM-F7). Threeway pass, same as 16261. F. H. Moffit, 1931.

16263 (31AM-F8). Head of Platinum Creek. F. M. Moffit, 1931.

16264 (33AM-F10). Lost Creek. F. H. Moffit, 1931.

16265 (31AM-F11). Lost Creek, same as 16264. F. H. Moffit, 1931.

16266 (31AM-F12). Head of Lost Creek. F. H. Moffit, 1931.

16267 (31AM-F13). Head of first large creek west of Lost Creek, a tributary of Jack Creek. F. H. Moffit, 1931.

16268 (31AM-F14). Same as 16267. F. H. Moffit, 1931.

18629 (31AJ-F15). Same as 12267. F. H. Moffit, 1931.

18083 (38AM-F2). Headwaters of the Little Tok River, south side of the pass to the head of Suslositna Creek. F. H. Moffit, 1938.

18084 (38AM-F3). Head of Tetling (Tetlin) River, 3 miles from the divide on the southwest. Limestone boulder in conglomerate. F. H. Moffit, 1938.

18087 (38AM-F12). Head of Lost Creek, 5½ miles from the Lost Creek crossing of the highway [Nabesna road]. F. H. Moffit, 1938.

18336 (40AM-F3). Notch Creek, south side, 7 miles southeast of the lake in Cooper Pass. F. H. Moffit, 1940.

18337 (40AM-F4). Notch Creek—, south side, near locality 18336. F. H. Moffit, 1940.

18338 (40AM-F6). One-half mile south of south end of lake in Cooper Pass. F. H. Moffit, 1940.

18341 (40AM-F17). Tributary of East Fork, Snag River, 2 miles below Crescent Creek, 1 mile from the mouth. F. H. Moffit, 1940.

18342 (40AM-F18). Tributary of Crescent Creek, 1½ miles above the East Fork, Snag River. F. H. Moffit, 1940.

18343 (40AM-F19). East Fork, Snag River, at forks of small southern tributary, 3 miles from the mouth. F. H. Moffit, 1940.

18344 (40AM-F20). East Fork, Snag River, ridge at head of small southern tributary, 3 miles from its mouth. F. H. Moffit, 1940.

18345 (40AM-F20a). East Fork, Snag River, ridge at head of small southern tributary, 3 miles from its mouth. F. H. Moffit, 1940.

18346 (40AM-F22). Western tributary of Crescent Creek, a tributary of East Fork, 1 mile from its mouth. F. H. Moffit, 1940.

18347 (40AM-F26). Half a mile southwest of mountain at head of Snag River between the mountain and Carl Glacier. F. H. Moffit, 1940.

18348 (40AM-F27). Head of tributary of Snag River, 3 miles north-northwest of the lower end of Carl Glacier. F. H. Moffit, 1940.

18351 (40AWa-F1). Nutzotin district. Limestone cliff facing south, 1½ miles east of the Nabesna mine. R. G. Wayland, 1940.

18352 (40AWa-F2). Same locality as 18351. R. G. Wayland, 1940.

18353 (40AWa-F3). Same locality as 18351. R. G. Wayland, 1940.

18354 (40AWa-F4). Same locality as 18351. R. G. Wayland, 1940.

18584 (40AM-F23). Tributary of Snag River, 2½ miles above mouth of East Fork. F. H. Moffit, 1940.

18585 (40AM-F24). Same locality as 18584. F. H. Moffit, 1940.

18586 (40AM-F25). Forks of tributary of Snag River that joins it 2½ miles above the mouth of East Fork. F. H. Moffit, 1940.

of thin beds of fine sand grading upward into mud was rhythmic and long continued. Great thicknesses of rock show alternating, ribbon-like bands of dense, dark argillite and lighter sandstone or quartzite, which commonly do not exceed a few inches in thickness. Presumably this banding was caused by seasonal changes in deposition. The material of the slightly coarser, more sandy, lower part of each bed gradually changed to the dark, finer grained mud of the upper part as the season advanced. When the deposition of the coarser material was renewed at the beginning of the next cycle, the change from fine to coarse material was abrupt. The banding may not appear on a freshly broken surface of the rock but is clearly revealed by weathering, which brings out a contrast of color depending on slight differences in the chemical composition of the bands. These varved deposits lose their characteristic appearance where the beds are thicker, the material of the more siliceous beds is coarser, and the change from coarse to finer material is abrupt—differences that may be observed in the upper part of the stratigraphic section. It may be that such beds were deposited locally in the basin of accumulation, as the thin beds of the banded rocks do not uniformly give place to thicker beds, which range from a few inches to many feet in thickness. In places feldspathic sandstones are present, also gritty sandstone and fine conglomerate with well-rounded pebbles. These fine- and medium-textured conglomerate and sandstone beds are to be distinguished from a succession of thick, interbedded conglomerates and sandstones that overlie them. The conglomerate beds of this overlying succession have an entirely different appearance. They are coarse and contain a large proportion of limestone fragments ranging from small pebbles to blocks several feet in diameter. They also contain many rounded boulders of light-colored granitic rock.

The Upper Jurassic, Lower Cretaceous, and some Upper Triassic beds are exposed in an area that extends from Suslota Pass to Beaver Creek at the international boundary and probably continue into Canadian territory. This area is fully 90 miles long in Alaska. Between Suslota Pass and the Nabesna River the width of the area is approximately 10 miles; between the Nabesna and Chisana Rivers the width reaches a maximum of 20 miles; southeast of the Chisana River the boundary is irregular and the width diminishes to a few miles. In addition to this large, continuous area of Upper Jurassic and Lower Cretaceous rocks a number of small isolated areas of Upper Jurassic rocks have been recognized.

The varved or banded rocks are abundant in the vicinity of Suslota Pass and continue southeastward throughout the area, but other deposits with thicker beds of argillite and sandstone appear as the beds are followed southeastward. The interbedded massive sandstone and conglomerate with limestone and granite boulders appear in the upper part of the mountains, north of the headwaters of Suslota Creek, and extend southeastward in the highest peaks, on the southwest side of the area, at least as far as the Nabesna River. They probably continue into the area between the Nabesna and Chisana Rivers but were not seen.

Rocks that are probably of Late Jurassic age are exposed on Gravel Creek near Horsfeld. They include fossiliferous graywacke or feldspathic sandstone and are associated with a massive bed of conglomerate containing boulders of dark fine-grained basaltic rock and deeply weathered granite as much as five feet in diameter. These boulders are presumably derived from a nearby source and furnish one part of the evidence for the upper age limit of the granite batholith north of Beaver Creek.

Thickness and structure.—The Mesozoic sedimentary rocks of the Mentasta and Nutzotin Mountains, principally the Upper Jurassic and Lower Cretaceous rocks, form a great synclinorium of folded beds that were laid down unconformably on the eroded surface of older rocks. In their turn they are deeply eroded; much of their material was removed by streams and glacial ice. Areally, they appear to be limited on the northeast and southwest by faults of great extent and probably great displacement. They have been intruded by igneous rocks that are widely distributed but are inconspicuous in most places. In most of the area occupied by the sedimentary Mesozoic rocks, the individual beds are without distinguishing features that would make them clearly recognizable from place to place, and stratigraphic sections and measurements of thickness require careful study and are difficult to make. Thus, without more detailed investigation than has yet been undertaken, suggestions as to the thickness and structure of the beds are tentative.

Lower and Middle Jurassic rocks have not been recognized in the district and are believed to be absent. The Upper Jurassic beds were laid down on an eroded surface that had been formed on folded Upper Triassic and older rocks. The oldest of the Upper Jurassic beds are shale or argillite which at least locally are without pronounced banding. They are succeeded by a great thickness of many hundred feet of varved deposits and by others that are even more conspicuously stratified, comprising argillite, sandstone, grit, and fine conglomerate. These conspicuously bedded rocks are more widely exposed and noticeable in the central and southeastern part of the area. The change from varved rocks to rocks with more strongly marked bedding may be a stratigraphic change or an areal change, but probably it is both.

The youngest beds of the Upper Jurassic and Lower Cretaceous sequence are believed to include the massive conglomerate, sandstone, and argillite beds of the high mountains on the southwest side of the area. Beds of coarse conglomerate as much as 200 feet thick, interstratified with massive beds of sandstone as much as 60 feet thick, form many of the higher cliffs and the rugged tops of the mountains in the area between the west branch of the Little Tok River and the headwaters of Suslota Creek. Similar conglomerate and sandstone beds appear at the head of the Tetlin and Cheslina Rivers. The coarser rocks everywhere are notable for the abundance of limestone inclusions which range from small fragments to blocks several feet thick. Fossils were found in some of the limestone boulders but were not sufficiently diagnostic to furnish more than presumptive evidence of Late Triassic age for the limestone.

This conglomerate and sandstone group points to an unconformity within the Upper Jurassic and Lower Cretaceous sequence and indicates that limestone of probable Mesozoic age (Late Triassic?) as well as older beds was exposed to erosion in some nearby locality. Such an unconformity may have been either local or regional and would mean an erosion interval between the deposition of the Upper Jurassic and the Lower Cretaceous beds, for it probably is later than Late Jurassic. The actual surface of unconformity was not seen.

The major synclinal structure of the Upper Jurassic and Lower Cretaceous strata includes many minor folds which trend with the range and appear to be more closely compressed on the northeast side of the area than on the southwest. Thus a section across the Upper Jurassic and Lower Cretaceous synclinorium at the head of Soda Creek, between the Nabesna and Tetlin Rivers, shows a succession of folds that are open on the southwest side of the synclinorium and closely compressed, even overturned in places, on the northeast side. Doubtless the same beds are repeated, although repetition cannot be clearly demonstrated because of the difficulty of recognizing individual beds. Close folding, repetition of beds, and lack of horizon markers make it difficult to estimate the thickness of the rocks, and although measurements of parts of the section were made, no places favorable for the measurement of the whole section or a composite section were found.

The areal extent of the Mesozoic rocks and the relief of the mountains carved from them, exceeding 6,000 feet, suggests that their thickness will be expressed in thousands rather than tens or hundreds of feet. Capps (1916, p. 51) found the structure of the Jurassic and Cretaceous slates on Bonanza and Chathenda Creeks to be somewhat less complicated by folding than in other localities visited by him and suggested a minimum thickness of 3,000 feet for the beds in that locality. This estimate is conservative, yet it gives an idea of the great quantity of clastic material accumulated in the deposits. No more favorable locality for measurements was seen.

Upper Jurassic and Lower Cretaceous rocks, which may be compared with those of the Nutzotin Mountains, are exposed in the Chitina Valley and reach their greatest thickness in the Nizina district. Upper Jurassic black shale is there recognized by fossils in only two localities, where it is associated with Lower Cretaceous black shale. Its extent and thickness are not known. The Lower Cretaceous rocks, consisting of shale, sandstone, and conglomerate are believed (Moffit, 1938, p. 78) to have a thickness of at least 6,000 feet. This figure represents a composite measurement that may be equalled by future measurements in the Nutzotin Mountains.

Age and correlation.—Marine fossils are numerous in some of the Upper Jurassic and Lower Cretaceous rocks at several known localities in the Mentasta and Nutzotin Mountains, but in general they are so sparsely distributed that, unless discovered by accident, they can be found only after careful search. The number of species of fossils that have been collected is small, but, fortunately, some of the forms are diagnostic and leave no doubt about the age of the rocks containing them. These fossils were collected over a period of years and were referred as collected to Dr. T. W. Stanton or to Dr. J. B. Reeside, Jr., for identification. The results of their examination are given in the tables of Upper Jurassic and Lower Cretaceous fossils. Several collections of fossils from the Nutzotin Mountains contain forms that are too poorly preserved for definite determination or have too long a range in time to be diagnostic. Among them are forms of *Inoceramus*, *Buchia*, *Entolium*, *Phillipiella?*, and fragments of gastropods and pelecypods, all of which, however, suggest late Mesozoic age.

Upper Jurassic fossils from the eastern Alaska Range and adjacent area

	5722 (08AM–F35)	5723 (08AK–F27)	16921 (34AM–F3)	16922 (34AM–F4)	18082 (38AM–F1)	18086 (38AM–F9)	18089 (38AM–F11)	18349 (40AM–F33)
Serpula sp.								×
"*Rhynchonella*" sp., indet.								×
Buchia (*Aucella*) cf. *B. pallasi* (Keyserling)			×	×				
Buchia (*Aucella*) species with fine radiating ribs					×	×	×	
Buchia (*Aucella*) like *A. bronn* (*Rouillier*	×	×						×
Cardinia sp.								×
Pecten? sp.								×

5722 (08AM–F35). Trail on Notch Creek. F. H. Moffit, 1908.
5723 (08AK–F27). Mouth of Jacksina Creek. Adolph Knopf, 1908.
16921 (34AM–F3). Two and two-thirds miles east of Suslositna Creek. F. H. Moffit, 1934.
16922 (34AM–F4). Gravel bar at camp 6, near head of Tetling [Tetlin] River (Bear Creek). F. H. Moffit, 1934.
18082 (38AM–F1). At foot of glacier at the head of the south fork of the Little Tok River. F. H. Moffit, 1938.
18086 (38AB–F9). Head of Totschunda Creek, south of the pass to Cheslina [River]. Float. F. H. Moffit, 1938.
18089 (38AM–F11). One and one half miles east-northeast of the forks of Lost Creek. F. H. Moffit, 1938.
18349 (40AM–F33). Jacksina Creek, 1 mile southwest of mouth. F. H. Moffit, 1940.

Lower Cretaceous fossils from the eastern Alaska Range and adjacent area

	16085 (31AM–F9)	16259 (31AM–F4)	18085 (38AM–F5)	18339 (40AM–F8)
Inoceramus sp.			×	
Buchia (*Aucella*) *crassicolis* (Keyserling)		×		×
Buchia (*Aucella*) *crassicolis* (Keyserling)?	×			
Buchia (*Aucella*) *crassa* Pavlow, as figured by F. M. Anderson				×
Buchia (*Aucella*) *piriformis* Lahusen, as figured by F. M. Anderson				×

16085 (31AM–F9). Head of Lost Creek, lat. 62°36.0′ N., long. 142°19.0′ W. F. H. Moffit, 1931.
16259 (31AM–F4). Talus near head of west tributary of first large stream southwest of Buck Creek [Little Tok River]. F. H. Moffit, 1931.
18085 (38AM–F5). Southern tributary of Tetling [Tetlin] River, 5½ miles east of Tetlin Glacier. Float on creek at elevation of 4,000 feet. F. H. Moffit, 1938.
18339 (40AM–F8). Mouth of Bonanza Creek. Boulders in stream gravel. F. H. Moffit, 1940.

It is to be noted that Lower and Middle Jurassic rocks, which are well developed in the Alaska Peninsula and Cook Inlet regions, have not been recognized in the eastern Alaska Range. Except for some Lower Jurassic rocks of the Arctic Coast, apparently no marine Jurassic rocks (Martin, 1926, p. 477) were deposited north of the Alaska Range. Cretaceous rocks, however, are widely distributed in Alaska.

Martin's account of the Mesozoic rocks of Alaska described the Upper Jurassic deposits as laid down in a sea that was restricted to the area south of the Alaska Range. Later, when the Lower Cretaceous sea invaded the land, it extended over the greater part of Alaska, as is indicated by the wide distribution of Lower Cretaceous rocks.

In the Chitina Valley the Upper Jurassic rocks are relatively unimportant, as far as is known. The most characteristic rocks of the Early Cretaceous are a massive sandstone and several thousand feet of black shale, which in some measure were deposited contemporaneously; they are notably lacking in limestone.

A summary statement of the character and distribution of the Jurassic and Lower Cretaceous rocks is given by Smith (1939, p. 40–58) in his account of the areal geology of Alaska. Alaska furnishes the most complete section of Jurassic rocks in North America and shows an especially fine development of them on the Alaska Peninsula and the west side of Cook Inlet. Probably the greatest continuous area of Cretaceous rocks is north of the Brooks Range in northern Alaska, but they are found in nearly all parts of the Territory.

UPPER CRETACEOUS ROCKS

Character and distribution.—The rocks that are here assigned to the Late Cretaceous epoch are dominantly well-consolidated arkosic sandstone, sandy shale, carbonaceous shale with thin seams of impure lignite, and conglomerate. Interbedded with them in places are tuff and lava flows. The beds are moderately folded, but they are much less compressed than the older Mesozoic rocks of the district and are practically unaltered. Leaves and stems of plants and pieces of lignitized wood have been found in them, but no marine fossils; they are looked on as estuarine or fresh-water terrigenous deposits.

Only three small isolated areas of the Upper Cretaceous rocks are recognized within the territory covered by this report and as shown on the geologic map they are only about 6 square miles in area. These three areas include the lower slopes of Euchre Mountain adjacent to the Chisana Glacier and river bars, the ridges between Chathenda (Johnson) and Rhyolite Creeks, and the east side of the valley between California and Beaver Creeks northeast of Beaver Lake. In each of these localities the Upper Cretaceous rock appears to rest on Permian or Permian and Devonian rocks.

The Upper Cretaceous rocks of Euchre Mountain are well-consolidated grayish-green arkosic sandstones that have yellowish or brownish weathered surfaces. They occur as thick, massive beds separated by shaly partings, though in places the texture of the beds suggests an admixture of tuffaceous material. The exposures are poor except along the margin of the gravel bars, and the overlying morainal and other unconsolidated material hides the borders of the deposits and makes them difficult to locate. The contact of the Upper Cretaceous with the underlying Permian lavas was not seen.

The beds are folded and show dips of 50° NW. at the east margin of the area and 20° E. at the west margin near the glacier. The observations suggest a synclinal structure with the axis of the syncline trending somewhat east of north.

The two remaining areas, one north of Rhyolite Creek and the other east of the pass from California Creek to Beaver Creek, or northeast of Beaver Lake, were first noted by Capps (1916, p. 53–58), who described the eastern or larger of the two areas as follows:

> The lowest beds exposed consist of hard sandstones and fine conglomerates composed of small pebbles of quartz, slate, and various igneous rocks embedded in an arkosic matrix. Some shale, which on weathering quickly breaks down to soft mud, was seen, and thin layers of lignitic material 2 inches or less in thickness occur in places. Above these clastic beds of relatively fine materials there occurs a thick conglomerate, with some gritty sandstones. Some of the pebbles are a foot or more in diameter, and they are composed for the most part of igneous rocks such as are found in the Carboniferous (Permian) terranes of this district, including diorite, lavas, and pyroclastic materials in an arkose matrix. The conglomerate covers an area of several square miles and forms prominent cliffs 200 feet or more in height. The beds have been mildly tilted, the general strike being a little west of north and the dips 5°–20° E.

Of the locality north of Rhyolite Creek, Capps says:

> The formation there consists of conglomerates, sandstones, and shales, with some volcanic tuffs and interbedded basic lava flows. Some carbonaceous shales with thin beds of impure lignite are present, but no coal beds of workable thickness have yet been found. The beds form a synclinal trough, which is folded down into the older lavas and pyroclastic rocks and has an easterly strike.

Thickness and structure.—The Upper Cretaceous rocks exposed at Euchre Mountain and on Chathenda Creek are remnants of deposits that were more extensive before erosion reduced them to their present limits. They were laid down unconformably on Permian and Devonian rocks and were involved with the older rocks in the later mountain-building processes by which they were folded and fractured. The folding is moderate although definite. A dip of 50° was noted in the sandstones at Euchre Mountain but the recorded dips in the larger area near California Creek do not exceed 20°. An unexpected divergence of trend in the folds takes place at these localities as the synclinal axis changes from northerly at Euchre Mountain to easterly at Rhyolite Creek.

Detailed stratigraphic sections of the Upper Cretaceous rocks were not measured. The greatest observed thickness is in the California Creek area where, according to Capps (1916, p. 57) at least 1,000 feet of beds is exposed. This measurement includes a massive conglomerate bed 200 feet thick which is the most conspicuous and widely extended unit of the sequence. The sandstones and shales of Euchre Mountain, because of insufficient exposures, gave little opportunity for measurements but appear to be at least 400 feet and possibly 500 feet thick. The thickness of the beds north of Rhyolite Creek probably is greater than at Euchre Mountain but less than at California Creek. These quantities can hardly represent the original thickness of the deposits, for an unknown but possibly large part of them has been removed by erosion.

Age and correlation.—The similarity of the younger group of conglomerate, sandstone, arkose, and shale beds of the Chathenda (Johnson) Creek valley to the lignite-bearing beds of Rocker Creek south of Beaver Creek, near the international boundary, led naturally to the correlation of the rocks of these localities. This correlation also appeared to be justified by the evidence of fragmentary plant remains that Capps (1916, p. 57) collected on Chathenda Creek near the mouth of Rhyolite Creek. The plants were believed to indicate Tertiary age for the beds containing them and thus to confirm the correlation with the beds of Rocker Creek, which were regarded as Tertiary because of their lignite deposits. In 1940 additional plant remains were collected from the newly found beds of the Euchre Mountain locality and were submitted to R. W. Brown of the U. S. Geological Survey for identification with a request that he reexamine the collection from

Rhyolite Creek. After examining the new collection and reexamining the older one, Mr. Brown was of the opinion that the plants of both localities are Upper Cretaceous rather than Tertiary. The Upper Cretaceous assignment is therefore adopted here. The identifiable plants of the two collections and the localities from which they came are as follows:

Upper Cretaceous fossils from the eastern Alaska Range and adjacent area

	6806	8908 (40AM-F7)
Gleichenia nordenskiöldi Heer [1]	×	
Equisetum	×	
Cladophlebis septentrionalis Hollick		×
Sequoia reichenbachi (Geinitz) Heer		×

[1] An Upper Cretaceous species of Greenland.
6806. From sandstone of Chathenda (Johnson) Creek, just above the mouth of Rhyolite Creek. S. R. Capps, 1914.
8908. From greenish sandstone, one-half mile from end of Chisana Glacier, at margin of flood plain, north side. F. H. Moffit, 1940.

The character, areal extent, and distribution of the Upper Cretaceous rocks of Alaska is in contrast with those of the Lower Cretaceous. Martin (1926, p. 477) states that the major tectonic features of Alaska appear to have been outlined by the beginning of Late Cretaceous time, and the distribution of Upper Cretaceous sediments was controlled by this condition. Both the character and extent of the deposits was influenced by it. The sea withdrew from Alaska after the Lower Cretaceous deposits were laid down, but at sometime after the beginning of Late Cretaceous time a moderate submergence of the land took place and allowed the sea to invade the lower valleys of the Yukon, Koyukuk, and Kuskokwim Rivers. The sequence of Upper Cretaceous beds in the lower Yukon Valley includes a basal conglomerate overlain by fresh-water sandstones and shales, which are overlain in turn by marine sandstones and shales. Then follow terrestrial, coal-bearing rocks which may include thin beds of marine deposits. Only the younger, terrestrial deposits extend into the upper Yukon Valley. They accumulated during the earlier part of the Late Cretaceous epoch and possibly include the deposits of the Chisana area. Marine deposits that are still younger were laid down on the Pacific and Arctic coasts but have no known counterparts in the interior.

The Upper Cretaceous rocks of Alaska show some unexpected differences. In the Chugach Mountains of the Pacific coast border, marine graywacke and slate that are believed to be Late Cretaceous in age are closely folded, somewhat metamorphosed locally, and are lithologically similar to the Lower Cretaceous slate and arkosic beds of the Nutzotin Mountains. On the other hand some of the deposits like those of the Chisana area are little more consolidated than the Tertiary coal-bearing beds and are only moderately folded.

Recent search for petroleum on the Arctic slope of Alaska has resulted in the discovery of a great thickness of Upper Cretaceous rocks, extending in at least four tongues of interstratified marine, deltaic, and terrestrial deposits. The Upper Cretaceous rocks of interior Alaska, however, appear to be terrestrial. The relation of the Upper Cretaceous rocks of the Chisana area to those rocks of the Yukon Valley are in agreement with the succession of events outlined by Martin (1926).

CENOZOIC BEDDED ROCKS

TERTIARY ROCKS

The rocks of the Cenozoic era that are exposed in the eastern Alaska Range and adjacent area are terrestrial; they were formed on the surface of the land and not in the sea as were most of those previously described. They comprise fresh-water deposits of different kinds, beds of coal, lava flows, volcanic breccias, and tuffs. These rocks fall naturally into two groups depending on the method of their origin, although both may be described as bedded rocks.

Sedimentary rocks of Tertiary age are exposed in many places along the flanks of the Alaska Range and are notably developed in the north-central part, in the valley of the Nenana River. In the eastern part of the range the sedimentary rocks are widely distributed, but they occupy a much smaller area east of the Delta River than west of it.

The Tertiary sedimentary rocks of the Alaska Range accumulated as fresh-water deposits on an old land surface that was raised above sea level in Cretaceous time, and has since undergone long, uninterrupted erosion. These deposits nowhere contain marine sediments but everywhere are made up of materials that were laid down in streams, lakes, or ponds, or in the swamps and marshes of poorly drained lowland areas of a mature land surface. The rocks are dominantly soft conglomerate, grit, sandstone, and sandy shale, commonly of a yellowish or buff color. In many places a basal bed of white quartz fragments is present, and beds of lignite and deposits of unconsolidated weathered gravel and variegated clay are interbedded with the other clastic materials.

These fresh-water rocks belong to two groups—a group of older, fairly well consolidated beds containing important coal or lignite units and a group of younger, weathered, slightly consolidated coarser deposits, without lignite beds, to which the name Nenana gravel is applied. The two groups have been well described by Capps (1930, p. 272–284) who studied them in their type localities in the Kantishna and Nenana River districts, where they occupy areas of considerable extent, accumulated in bedded deposits thousands of feet thick.

Beds belonging to the older group, or the Tertiary coal-bearing formation, are exposed in the low rounded ridge between the Delta River and Jarvis Creek, on the north side of the range, and are of economic interest because they include coal beds that may become of local importance. The rock deposits may be more extensive than is shown on the geologic map, as much of the coal-bearing formation in that locality probably is covered by the Nenana gravel. Exposures of beds that are similar in appearance but include less lignite crop out on hill slopes or are exposed by stream cutting in many places on the south side of the range, from the Delta Valley to the West Fork Chistochina River. The area occupied by them is doubtless greater than is apparent from the map, for much of the rock in the lowland area is concealed by the overburden of unconsolidated outwash gravel and morainal material.

The Nenana gravel is extensively exposed along the lower slopes of the mountains on the north side of the range, west of the Delta River, but has its greatest development beyond the limits of the geologic map. It is recognized in a few places in the Jarvis Creek and Gerstle River drainage basins east of the Delta River and doubtless will be found elsewhere. It has not been identified in the Delta River basin on the south side of the range, though gravel deposits corresponding to it may be expected there. One small area of weathered gravel at Gold Hill in the Chisana district is tentatively correlated with the Nenana gravel.

In addition to the clastic fresh-water coal-bearing beds and the Nenana gravel the Tertiary rocks include a large area of volcanic deposits, andesitic lavas, and fragmental material that are exposed principally in the Wrangell Mountains and are known as the Wrangell lava. They form a continuous succession of interbedded flows and tuff beds and are partly of Tertiary age and partly of Quaternary age. They might appropriately be described with the Tertiary bedded deposits. On the other hand they do not form part of the section of Tertiary sedimentary rocks and will be described with the igneous rocks (p. 165–167).

TERTIARY COAL-BEARING FORMATION

Jarvis Creek area

Character and distribution.—The coal-bearing formation of Tertiary age makes up a large part of the low ridge between the Delta River and Jarvis Creek, southeast of the old Donnelly telegraph station, and insofar as its economically important outcrops are concerned seems almost restricted to that locality, although fragments of float coal indicate the presence of coal beds on the east side of

Jarvis Creek valley north of Riley Creek. Possibly other occurrences in this vicinity may be hidden by the Nenana gravel or by morainal deposits and glacial outwash gravels.

The coal-bearing beds between Jarvis Creek and the Delta River occupy an area as now known of about 12 square miles. The rocks include conglomerate; soft, yellow shale or clay; gray and yellowish sand beds; clean white quartz grit and sand; and many beds of coal. Concretions as much as 4 feet in diameter were seen in the lower beds. Many of the smaller concretions contain plant remains. Characteristic features of the clastic rocks are the abundance of mica scales derived from the underlying schist and the well-rounded form and small or moderate size of the pebbles of the conglomerate. These beds are exposed for a distance of about 5 miles along the east side of the ridge, from the sag east of Donnelly Station to a second sag between the head of Little Gold Creek and a small stream called Ruby Creek that runs into the Delta River. The best exposures are on the upper part of Little Gold Creek, a small unnamed parallel creek west of Little Gold Creek, and the little stream locally called Sargent Creek which marks the north boundary of the area.

Structure and thickness.—The coal-bearing beds of the Jarvis Creek area rest unconformably on ancient metamorphic rocks and are practically horizontal throughout the area, although beds of conglomerate and shale that strike N. 55° W. and dip 40° SW. are exposed on Sargent Creek. The small size of the area, the attitude of the beds, and particularly the displacement of the Tertiary beds by the older rocks of the ridge on the west suggest that the coal measures were deposited in a small valley or a depression in an uneven land surface, or were folded or faulted into the older rocks. The west boundary of the area possibly is at a fault, although no fault was seen.

So far as is known the greatest thickness of coal-bearing beds is on Little Gold Creek where it is indicated by the difference in altitude of the creek bed and the top of the ridge on the west. This relief is about 1,200 feet. The formation ends abruptly at the sag at the south end of the area and thins out toward the north. About 800 feet of beds is exposed in the cirquelike basin of the unnamed creek west of Little Gold Creek.

Wherever the base of the formation was seen the lowest bed consists of fragments of clean, white vein quartz (fig. 32) and ranges in thickness from less than one foot at the north end of the area to about 100 feet at the south end. The quartz fragments range from sand grains to pieces 4 inches in greatest dimension, although most of them are about one inch in diameter. Fragments that exceed 1½ inches commonly are rounded, but practically all the smaller fragments are angular. All the beds of the thick part of the section show a conspicuous cross bedding and a tendency toward assortment of fragments according to size. Small beds or lenses of quartz sand are included in the coarser deposits. This material is sufficiently consolidated to stand with a vertical face but is easily broken down with the pick. Some beds are more firmly consolidated than others and where they overlie softer beds have been eroded into curious, mushroomlike forms. This basal quartz deposit, like the corresponding deposit in the Nenana district, is residual material probably derived from the abundant quartz veins of the schistose rocks of the mountains on the south. In a similar way the shale and sandstone overlying the quartz bed show

FIGURE 32.—Bed of white quartz fragments at the base of Tertiary rocks near the head of Little Gold Creek. The dark ledge above the quartz is a 10-foot bed of coal, overlain by sandstone.

the source of their material by the abundance of mica flakes, which like the quartz fragments are resistant to weathering and decomposition.

The best display of the coal-bearing beds to be seen in one place is at the head of the cirquelike valley west of lower Little Gold Creek (fig. 33), where rapid erosion has kept the steep mountain face free from vegetation. At this place a section is exposed that includes over 600 feet of soft sandstone, shale and sand, with interbedded lignite. Nearly a score of horizontal lignite beds ranging in thickness from a few inches to 8 feet were counted in the mountain side. The base of the formation is not exposed but the thickest beds of lignite are in the lower part of the section. Two thick beds of coal—one 8 feet thick, the other 7 feet—crop out near the bottom of the exposed section. A third bed, 4 feet thick, crops out near the middle, and a persistent fourth bed, 3 feet thick, is exposed near the top.

FIGURE 33.—Beds of coal in sandstone and sandy shale on a small tributary of Jarvis Creek, west of Little Gold Creek. The largest bed shown is about 4 feet thick.

The complete stratigraphic section of the coal-bearing beds of Jarvis Creek was not measured, but a part of it, including only the lower beds exposed in a small isolated hill on the west side of Little Gold Creek, was examined with care and measured. The section is as follows:

Stratigraphic section of lower coal-bearing beds of Jarvis Creek

	Ft.	In.
Yellow-weathering or buff-weathering shale	10	
Coal	1	6
Bone		8
Coal	1	6
Bone		6
Coal	5	
Shale, dark-gray		10
Shale, light-gray	1	8
Shale, buff, sandy	3	
Sandstone, buff, fairly hard	2	6
Shale, buff	5	
Coal	2	6
Sandstone, shaly	4	
Coal	8	
Shale, gray, with sandy beds, white sand, and bony coal	20	
Sandstone and shale; contains many large bouldery and fantastic white sandstone bodies probably produced by erosion; fairly hard, but readily picked down and crumbled under fingers	100(?)	
Total thickness	166(?)	8

Coal also crops out in the gulches of the ridge of the small hill. On the north side of the saddle which marks the south boundary of the coal area the lower beds of the coal-bearing formation are well exposed. The saddle is occupied by the white quartz bed which grades upward into sandy shale and sandstone, and these are overlain by 10 feet of coal which crops out about 100 feet higher than the saddle. Another thick bed of coal is exposed in the brow of the ridge at the top of the steep slope north of the saddle. Midway between the two is a bed 4 feet thick. The associated beds are shale and sandstone in which are many concretions of yellow-weathering sandstone containing fragments of fossil plants.

Coal-bearing rocks, south side of Alaska Range

Coal-bearing beds are present in various places on the south flank of the Alaska Range, but the principal deposits are in the Delta, Gulkana, and Gakona River drainage areas. The deposits, however, are less distinctive than on the north side of the range, as the proportion of conglomerate and partly consolidated gravel is greater, the material in general is coarser, variegated clays are more conspicuous, and the number and thickness of lignite beds are less.

The Tertiary rocks are exposed principally where streams are cutting their channels through lowland deposits and where isolated patches of residual beds occupy hillslopes. Most of the area of the coal-bearing formation has moderate relief, and is covered with a mantle of younger unconsolidated morainal material and outwash gravel. This overlying material not only conceals some of the coal-bearing formation but in places may be confused with beds belonging to it. The formation boundaries shown on the geologic map are consequently approximate in part.

Outcrops (of the beds) appear at various places in the Phelan Creek drainage area and eastward as far as the head of the Chisna River. The deposits are buff-colored conglomerate, sandy shale and sandstone, gray sands, variegated clays, and lignite. The large proportion of conglomerate is notable, as is also the poor sorting of the material with respect to size of fragments. This is especially true in the upper beds, which contain cobbles and even boulders that are more suggestive of the Nenana gravel (p. 144) than the coal-bearing formation. The largest area shown on the geologic map is between Gakona Glacier and the West Fork Chistochina River and was described by Mendenhall (1905, p. 52–53) as the Gakona formation. His description of it follows:

* * * What appears to be the basal member [of the Gakona formation] is a heavy bed of coarse conglomerate, not less than 500 feet thick, which is well exposed along the east side of the Gakona Glacier about 5 miles above its foot. * * * It dips eastward and is believed to pass beneath the soft, fissile or massive, gray or buff-colored shales which, with interbedded gravel, sand, and

lignite beds, make up the greater part of the terrain that extends through to the head of the West Fork.

The degree of consolidation of these beds shows considerable variation. The basal conglomerate is thoroughly indurated. The shales on the upper Gakona, nearest the base of the series, are likewise compact and fissile. The higher beds near West Fork are slightly indurated clays or sands, and the highest recognized member, an iron-stained pebble bed, is not sufficiently well consolidated to be termed a conglomerate—it is rather a cemented gravel. These soft upper beds, which appear in that part of the section farthest from the mountains, make definite outcrops only under the most favorable conditions. Usually they are buried under the general mantle of glacial gravel, so that their extent is problematical.

It is estimated that there can not be less than 2,000 feet of these beds and it is probable that their total thickness is much greater than this.

Along the south flank of the eastern Alaska Range, conditions controlling the formation of coal appear to have been less favorable than along the north flank, as the beds are neither so extensive nor so thick. A section of the coal-bearing beds is exposed in the canyon of the small eastern tributary of Phelan Creek near McCallum. The stream that made the canyon flows for nearly two miles across the formation and cuts it to a depth of several hundred feet. The beds exposed in the canyon may be divided into two groups:

1. In the west end of the canyon the lower group is exposed. This includes beds of buff-colored conglomerate, locally containing cobbles as large as 5 inches in diameter; grit; sandy shale; and sandstone. The conglomerate beds predominate. The beds dip gently north and have a thickness of not less than 500 feet.

2. The overlying group consists largely of buff-colored sandy shale, sandstone, and sand. Near the bottom of this group are gray sands, some of a dirty white color; lenses of white sand; clays; and lignite. Near the top is coarse conglomerate with cobbles and boulders. This group is as thick as the underlying group and together they form a stratigraphic section not less than 1,000 feet thick.

The principal exposure of coal near McCallum is in a gulch on the south side of the creek about half a mile from the highway. The coal beds are in the lower part of the upper group of Tertiary rocks and are associated with sandy shales and soft clays which, when wet, flow down over the steep slope of the hill and cover the coal. The lowest coal bed is a bed of lignite, 30 inches thick, which crops out on the east side of the gulch and is separated from a 2-foot bed above by 6 feet of sandy shale. Several other thin beds are exposed in the next 75 feet of overlying clastic material. The lignite is of an inferior quality and contains pieces of wood in which knots and grain are plainly seen. The beds appear to be lenticular and probably do not extend over a large area. This deposit has been looked on as possible source of coal for fuel, but manifestly the beds now exposed are less promising than those of Jarvis Creek.

Smaller deposits of coal have been found at several other places in the adjacent areas east of the Gakona Glacier. In the early days of placer mining on Slate Creek a bed of lignite associated with sandstone and shale in the creek channel was uncovered by mining operations, and furnished a small supply of fuel that was used locally. The coal appears to be part of a small block of Tertiary rocks faulted or folded into the older beds.

Coal is present on Coal Creek, a small northern tributary of the upper Chisna River. This locality is in an area of Paleozoic rocks, and the coal appears to be included in shales that are faulted into the Paleozoic rocks. The bed is small and possibly older than Tertiary.

The coal-bearing beds of the south flank of the range have their greatest known thickness in the Gakona formation which, according to Mendenhall (1905, p. 53) is probably more than 2,000 feet thick. It is probable that part of the original deposit was removed by glacial ice and streams, for the soft beds are easily eroded. In general the beds are not much folded but in places are faulted.

Age of the coal-bearing beds

Tertiary fresh-water rocks, including beds of coal that range from lignite to subbituminous in grade, are found in many places in Alaska. They commonly have been assigned to the Eocene epoch with the realization that they may not be of contemporaneous age, although they probably accumulated under similar geologic conditions. Some of them have been described under the name Kenai formation but in more recent years that formation name has been restricted to rocks of the type locality on the Kenai Peninsula.

Such rocks were laid down on both flanks of the Alaska Range and perhaps reach their greatest development in the Nenana coal fields. The coal-bearing beds of the Delta River area and its vicinity belong among these rocks, and at least those of Jarvis Creek appear to be correctly correlated with the coal beds of the Nenana River, although they may have accumulated in an isolated basin.

Fossils have been collected from the coal-bearing beds and furnish the means of determining their age. Most of the fossils are plant remains, but Schlaikjer (1937, p. 1–3) found fossil fish, which he believes to be of Miocene age in beds in the vicinity of the Suntrana coal mine in the Nenana district, thus raising a doubt about the correctness of the assignment of the coal beds to the Eocene. The answer to this problem must await future investigation.

All the fossils so far collected from the coal-bearing beds of the Delta River area are plant remains. Mendenhall (1905, p. 53) found trunks of trees, now altered to lignite, scattered through the upper horizons of the Gakona formation and collected plant remains from a calcareous bed lower in the formation. These were submitted to Dr. F. H. Knowlton who reported on them as follows:

This collection consists of eighteen pieces of matrix on which I find the following species of fossil plants preserved:

Sequoia sp. A broken fragment of a cone.

Taxodium tinajorum Heer. Several fine branchlets.

Taxodium distichum miocenum (Brongniart) Heer. A large number of finely preserved branchlets.

Corylus macquarrii (Forbes) Heer. The most abundant dicotyledon in the collection.

Juglans nigella Heer. Represented by portions of two leaflets.

Tilia alaskana? Heer. A single fragment that appears to be of this species.

These plants are all abundantly typical of the so-called Arctic Miocene, now believed to belong to the upper Eocene.

The soft shale and sandstone of the coal-bearing beds of Little Gold Creek in the Jarvis Creek area are not the kind of material from which fossil plants can easily be collected and shipped. Yet they contain many plant remains and have yielded a small collection (Moffit, 1942, p. 130). This collection was submitted to R. W. Brown for identification of the species and determination of their age. He identified three forms tentatively as follows: *Glyptostrobus europaeus* (Brongniart) Heer, *Alnus* sp., and *Fagus intipofi* Abich. He says of them, "There is no doubt of the Tertiary age of these fossils, but knowledge of the Alaska Tertiary floras is not yet sufficiently detailed to permit a more precise statement of age."

It is thus apparent that the age of the coal-bearing measures has been determined only within rather wide limits. It is generally believed that they were deposited in early Tertiary time, yet their position in the Tertiary system is not definitely known. It is quite possible that the Tertiary coal-bearing formations and the overlying Nenana gravel, next to be described, may represent both the Eocene and Miocene epochs. They appear definitely to be involved in the growth and sculpturing of the present Alaska Range.

Nenana gravel

Character and distribution.—The name Nenana gravel is applied to a group of unconsolidated, or, locally, slightly cemented gravel and sand deposits that are extensively developed on the north side of the Alaska Range in the vicinity of the Nenana River. From this type locality the formation may be traced both east and west along the front of the Range.

The deposits are made up of bedded, water-worn materials that were derived from the rocks of the Alaska Range and are believed to have been laid down in large part by streams flowing from it. They consist chiefly of gravel which is well-rounded and of fairly uniform medium coarseness but in places includes large cobbles and boulders. Minor lenses or beds of sand and silt are interstratified with the gravel. The Nenana gravel is free from typical glacial material. A characteristic feature is its yellow or brownish color. This color is due to weathering, which is particularly noticeable in the fragments of granular intrusives and other readily decomposed rock. Weathering, color, and, in a certain measure, the relative coarseness of the material are features of the Nenana gravel that are important for its identification.

It is believed that the Nenana gravel was once a fairly continuous deposit along the front of the range and was formed by the coalescing of the gravel deposits laid down by streams issuing from the mountains on the south. The present distribution in isolated areas is the result of erosion or of concealment of some of the gravel by overlying younger deposits. Nenana gravel makes up a significant part of the unconsolidated or slightly consolidated deposits of the eastern Alaska Range.

The largest areas of Nenana gravel are west of the Delta River, outside the limits of the geologic map. They are the remnants of a body of gravel that probably was unbroken at one time but was divided and partly removed by glacial erosion and stream cutting. These areas have not been studied in detail and were not visited by the writer.

East of the Delta River, on the north side of the Alaska Range, gravel deposits that are correlated with the Nenana gravel are exposed in a few small areas. They appear to be the most easterly of the typical deposits and include some gravels that are referred to the Nenana gravel with considerable assurance, and others that are somewhat in doubt.

The Nenana gravel has not been recognized as such on Phelan Creek and in the other areas of Tertiary rocks on the south side of the Alaska Range, although it seems probable that beds of a corresponding age must have been deposited.

Farther east in the Alaska Range the only occurrence of weathered gravel that is regarded as a possible equivalent of the Nenana gravel is the deposit of Gold Hill west of Bonanza Creek in the Chisana district.

Future investigation will probably show that the extent of the Nenana gravel east of the Delta River is greater than is indicated on the map, particularly between the Delta and Johnson Rivers.

Deposits of gravel that are clearly not related to the present stream gravels or the most recent glacial outwash gravels, and yet are younger than the coal-bearing beds, are exposed at several places between the

Delta and Gerstle Rivers within or at the north margin of the highland area between the central mountain mass and the Tanana lowland. The material composing them is derived in part, if not wholly, from the mountains on the south and in most places contains a large proportion of granitic and other hard rocks that resisted erosion more successfully than the schist. In places these gravel deposits are unconsolidated but elsewhere they are slightly cemented. The cemented gravel has a yellowish or buff color where it is weathered but commonly is gray on fresh surfaces. Many of the constituent pebbles and cobbles of the granular rocks are deeply weathered but the highly siliceous forms remain unchanged. When isolated outcrops of the gravel are found, the weathered pebbles and cobbles furnish an important test by which to distinguish the older deposits from the unweathered glacial outwash and stream gravels. This test is not always conclusive, however, for some of the glacial deposits also contain weathered granitic rocks.

The uncemented gravel is gray and its presence is sometimes revealed at a distance by conspicuous light patches on the hillsides. In the few places where it was examined it contains a large proportion of granite and gray quartz or quartzite in pebbles and well-rounded cobbles as large as 8 inches in diameter. This gravel, as exposed on the hillslopes, commonly shows less fine material than the cemented gravel, probably because the fine material was removed by surface water. It is correlated with the cemented gravel with some doubt although the composition is the same. These gravel deposits are exposed on the ridge west of McCumber (Macomber) Creek. Similar gravels cover the hillslope on the north side of McCumber Creek. The older, weathered gravel deposits, both the cemented and the uncemented, are believed to antedate the Pleistocene glacial deposits and are tentatively correlated with the Nenana gravel.

The cemented gravels are well exposed on McCumber and Morningstar Creeks and on the west side of the ridge west of the Gerstle River at the margin of the Tanana lowland. Possibly the gravel deposits at the canyon of the Gerstle River and on the east side of Jarvis Creek opposite the north end of the Tertiary coal-bearing beds may belong in part to this same group of gravel deposits.

The cemented beds of the Nenana gravel on McCumber Creek at the mouth of Morningstar Creek are exposed in a gravel bluff over 100 feet high. The upper part of the bluff is a bluish-gray bouldery stream or glacial-outwash deposit consisting in large part of angular pieces of schist. The lower 60 feet is gravel that is yellowish on the exposed surface but light-gray within and is slightly consolidated, yet easily cut with the pick. It includes lenses and beds of sand, as much as 30 inches thick, through which small pebbles are scattered.

The gravel has a sandy or gritty matrix. The prevailing pebbles and cobbles are granite and quartz or quartzite, few of which exceed 8 inches in diameter. All are well rounded, and the granite cobbles are so deeply weathered that they are easily mashed with the flat of the hammer. The quartz pebbles are gray and white and perfectly fresh in appearance as they are highly resistant to weathering. Some of the gray pebbles are banded and they look like agate when wet; they attract the attention because of their lustre. Similar pebbles are found in the uncemented gravels. These gravel deposits are well bedded and only slightly tilted.

Deposits of gravel that are correlated with the Nenana gravel are exposed at the border of the Tanana lowland near the Gerstle River.

FIGURE 34.—Tilted gravel beds (Nenana) near the margin of the lowland area west of the Gerstle River.

The low ridge west of the river and the lower slopes around the headwaters of the first small stream west of the ridge show a succession of distinctly bedded sands and gravels that dip steeply to the north (fig. 34). When first seen they were thought to be outwash gravel that spilled over the ridge from the front of the Gerstle River glacier. The sand and gravel are composed of materials that are rudely sorted with respect to size, and are sufficiently cemented that some beds stand in relief on the hillside.

The material of the sand and gravel deposits is mostly well rounded quartz and granite and thus differs from the more angular and fresher looking material of the glacial deposits. The beds have a thickness of hundreds of feet but were not measured. The steep northerly dip of the gravel is suggestive of the line of tilting which Capps (1912, p. 31) saw between Nenana and Wood Rivers and interpreted as having been an important line of movement when the foothill belt was uplifted.

The summit of Gold Hill, the mountain southwest of the saddle between Bonanza Creek and Glacier Creek in the Chisana district, is overlain by unconsolidated gravels. According to Capps (1916, p. 55) the deposits consist of rudely stratified coarse gravels alternating with finer gravels or with sandy layers and have a close structural resemblance to the gravels now being laid down by the present streams. Although they appear to be of great age they are entirely uncemented. The pebbles are well rounded and generally small. Cobbles and boulders up to one foot in diameter were seen but most of the pebbles are only a few inches in diameter. The most numerous rock types are lavas and pyroclastic rocks like those of the nearby Devonian and Permian terranes, but a small proportion of argillite and graywacke derived from the Mesozoic sediments is present. The pebbles and cobbles that are most susceptible to decay are deeply weathered. Pieces of lignitized wood also occur in the gravels. A prospecting shaft was sunk 150 feet in the gravel but failed to discover workable gold deposits, though a little gold was found. The material taken from the shaft was of a reddish or brownish color, and many of the pebbles were so decayed that they fell to pieces on being handled.

These gravels are not deformed but clearly are old deposits which accummulated under conditions that made it possible for extensive deposits of well-worn gravels to be laid down and preserved on a mountain top more than 1,000 feet above the nearest streams. They are distinguished from the fresh, unaltered material of the recent glacial and present stream deposits by the deep decay of their granite and other less resistant components, and on this account they are tentatively correlated with the Nenana gravel, although the possibility remains that they may be outwash gravels of an early glacial period.

Age of the Nenana gravel.—The gravel deposits that are now known as the Nenana gravel were once thought to be Pleistocene glacial deposits, but after Capps (1912, p. 30–34) had studied them in the Bonnifield region, he concluded that these gravels, which are extensively developed on the east side of the Nenana River, are older than the glacial deposits and in fact are the youngest of the Tertiary deposits in that region. Capps was the first to apply to them the name "Nenana gravel."

It is believed that the Nenana gravel in general rests conformably on the coal-bearing beds where both formations are present, although in a few places what appears to be normal Nenana gravel rests unconformably on the coal formations. Capps regards such places as representing, not the lowest part of the Nenana gravel, but a higher portion of the formation which overlapped coal beds that were folded and eroded locally before the higher beds of the Nenana gravel were deposited. Deposition of the Nenana gravel thus was later than that of the coal measures and probably resulted from uplift and consequent revival of stream erosion while the growth of the present Alaska Range was in progress.

It was stated that the coal-bearing beds underlying the Nenana gravel have been considered to be of Eocene age, probably late Eocene, and that only recently the finding of fish remains (see p. 143), regarded as of Miocene age, raised doubt as to the correctness of this assignment. Further investigation will be required to settle the differences of opinion that have resulted from the study of plant and vertebrate fossils. Meantime it appears to be safe to look on the Nenana gravel as the youngest of the Tertiary deposits now known in this region.

QUATERNARY DEPOSITS

UNCONSOLIDATED PLEISTOCENE AND RECENT DEPOSITS

Character of the deposits

Pleistocene and Recent deposits of the eastern Alaska Range and adjacent area include glacial deposits of various forms, waterlaid deposits, beds that were deposited by wind, and lava flows and volcanic fragmental materials. As far as is known all Pleistocene and Recent clastic deposits within the area shown on the geologic map are unconsolidated except locally where portions of them have been cemented by lime- or iron-bearing solutions. Some of the glacial deposits contain material that is deeply weathered but in general the Quaternary deposits are fresh and do not have the yellow and buff colors of the Tertiary gravels and sands. The Wrangell lava, which began to accumulate at about the same time or somewhat later than the Tertiary coal measures, will be described as Tertiary volcanic deposits, although an unknown part of them was erupted in Quaternary time. Pleistocene and Recent time are not separated by any outstanding event in the history of the eastern Alaska Range, and the deposits of the two epochs are described without attempting to give them limiting dates. These epochs overlap, for the glacial period is not yet ended in parts of Alaska.

The deposits described in this section are varied but have common characteristics. They are made up of fragments from a great variety of sedimentary and igneous rocks, and are unconsolidated although sufficiently compacted in places to stand with vertical faces. They are the products of weathering and erosion of the older formations and show differences of composition and form that depend on their sources, the manner in which they were transported to their present places, and the conditions under which they were laid down. A large part of the thicker deposits is permanently frozen.

The unconsolidated deposits include the mantle of loose rock fragments on hill slopes; the accumulations of debris in talus piles, glacial moraines, till and outwash gravels; fragmental materials ranging from coarse gravel to sand and silt laid down by streams and lakes; windblown sands and dust in dunes and loess deposits; and volcanic ash ejected from craters and transported by wind. These different deposits are overlapping and their boundaries are so commonly hidden by vegetation that more time and labor would be required to differentiate them than is available in reconnaissance mapping. Accordingly they have all been represented by one color on the geologic map (pls. 6, 7), except in a few localities where conspicuous moraines are shown.

Deposits of unconsolidated materials, which must have existed in the valleys and adjacent lowlands of the Alaska Range and Wrangell Mountains at the time Pleistocene glaciation began, either have been removed by the advancing ice or have been covered by the younger deposits, for excepting the Nenana gravel, preglacial gravels have not been recognized. It would therefore appear that much of the existing unconsolidated deposits, with the probable exception of some deposits in the Copper and Tanana River valleys, were formed after the time of maximum extent of the ice, although they derive part of their components from older deposits which have been reworked and redeposited.

One class of unconsolidated deposits is not shown on the geologic map. This includes the first products of weathering and is made up of unsorted rock fragments that accumulate on the surface of the land wherever erosion and disintegration of the bedrock is in progress. Disintegration begins whenever the land is raised above the sea and rocks are exposed to air, water, and changes of temperature. Part of the rock may be removed in solution but the remainder is left in fairly angular blocks and fragments not yet attacked by streams or glacial ice. Such deeply weathered, decomposed surface bedrock is not known to exist anywhere in the Copper River basin, although oxidation extends to a considerable depth in some ore bodies. The absence of such a zone may be the effect of glaciation, which was recent and intense and would have removed soft, decomposed surface rocks.

This explanation seems to be supported by the findings of Van Alstine and Black who (personal communication, 1944) have reported the existence of surface weathering in the granite rocks exposed in road cuts along the Alaska highway north of the Tanana River, in an area that was unaffected by the ice movement.

Rock fragments that have accumulated since the disappearance of the ice constitute a veneer that is irregular in thickness and distribution and in many places is covered by vegetation. It has not been shown on plates 6 and 7.

Glacial deposits

The glacial deposits are of two principal kinds—deposits that were dropped by the melting ice with little sorting by water, and outwash deposits that were laid down by streams issuing from the ice. Some of these water-laid glacial deposits differ little if any from the deposits of the present glacial streams and are almost indistinguishable from them. The unsorted glacial deposits consist of rock fragments that differ widely in size but commonly have an angular form. They were laid down as moraines or spread out as sheets of till.

The more extensive but less conspicuous glacial deposits are the till deposits or ground moraine. Sheets of unsorted, angular rock fragments and silt, commonly without distinctive topographic expression, were left in much of the lowland area, as the debris-laden ice melted, and now appear as surface deposits or are interbedded with unconsolidated water-laid material. The water-laid deposits are chiefly gravel, sand, and silt which were deposited by lakes and streams that existed because of glacial conditions. From time to time some of them were overridden by advancing bodies of ice which left their burden of glacial debris on melting, and thus the two are interbedded. The water-laid deposits will be described more fully below.

Individual till sheets are not continuous throughout the lowland areas. They are irregularly distributed, depending on local conditions governing the advance and melting of the ice. Some exposed sections of the unconsolidated deposits of the Copper River basin show two or more sheets of till interbedded with stratified sand and gravel (Mendenhall, 1905, p. 64). Although it seems evident that the Copper River basin was completely filled with ice to a depth of many hundreds of feet at the time of greatest glaciation, the deposition of the till sheets belongs chiefly to the later stages of glaciation and took place most extensively near the margins of the basins. The retreat of the ice was not steady but fluctuating, giving rise to the temporary lakes and streams in which the greater part of the unconsolidated deposits were formed, just as they are being formed at present.

In some places, but not everywhere, till makes up the surface deposits. It is commonly covered with vegetation and may be associated with morainal deposits of more conspicuous form. Eskerlike ridges in the ground moraine of the broad flat southeast of Slana were utilized locally during the construction of the Nabesna highway in order to avoid swampy ground.

Well-defined terminal and lateral moraines are uncommon in most of the area shown on the geologic map. Some of the best examples are on the north side of the range in the Delta River district. There the relatively short advance of the ice streams from the mountains during the later glaciation is proved by morainal deposits that indicate their outer limits. In the eastern part of the range there is a well-preserved terminal moraine across the Beaver Creek valley below Carl Creek, and a smaller one across the valley leading from Horsfeld Creek to Baultoff Creek, near Eureka Creek. Conspicuous moraines of the kame and kettle type are seen along the Richardson Highway in the vicinity of Donnelly Dome. They also appear along the Alaska Highway on the lower Gerstle and Little Gerstle Rivers. Similar deposits are even more extensively developed in the Slana valley west of Mentasta Lake.

Ridges or morainal debris extending along the lower courses of small glaciers in the valleys of the Nutzotin Mountains hide cores of ice and eventually will disappear through melting of the ice. Such accumulations are not terminal moraines. Terminal moraines are formed where melting is so adjusted to the movement of the ice that the glacier front is stationary for an extended time, allowing the debris discharged at the front to accumulate. These deposits are apt to be destroyed by the water from the ice and are less likely to survive than lateral moraines.

Water-laid deposits

The water-laid deposits include gravel, sand, and silt that were laid down in the flood plains of the streams or were deposited in lakes and ponds. They may be described as stream, lake, and bench or terrace gravels, although these designations refer partly to form and position and do not clearly indicate origin. From a geologic point of view all the materials of which these deposits are composed are in process of being transported from their bedrock source to the sea. This journey may be interrupted by many temporary halts and may require a vast time. It may even be completed through subsidence of the land itself.

The constituent materials of the present water-laid deposits are reworked glacial debris; older water-laid deposits; and fragments of various kinds and sizes derived directly from original bedrock sources, chiefly the country rock of the rugged headwater areas of the streams. They therefore consist of a great variety of rocks, which may have travelled far from the place of their origin. In general, the fragments are smaller and of more uniform size as distance from the source increases.

The stream deposits were formed by running water; in general they are composed of coarser and less thoroughly sorted materials and are less well bedded than the lake deposits; but they are more subject to removal and redeposition. The heavily loaded streams of the Alaska Range are continually shifting their channels over their flood plains through a process of building up deposits at one place and cutting them down at another. When gravel accumulates in excess on one part of the flood plain the stream automatically shifts its channel to another place and the process of cutting and building begins again.

In this way terraces are sometimes formed where streams lower their channels below old levels. They may be a few feet or many feet higher than the adjacent present flood plains, but their surfaces show where the streams once flowed. The terraces themselves may be attacked and removed.

High terraces of a different kind were formed in some places by streams flowing along the margins of former glaciers, in other places by water spilling over drainage divides into the valleys of adjacent areas and depositing gravel and sand. Gravel deposits of this kind are seen in the high terraces of the upper Suslositna Creek, which were formed when the valley of Suslota Creek was filled with ice, and drainage belonging to the Copper River was diverted to the Little Tok valley.

Lake deposits accumulate in relatively quiet water and commonly are composed of finer and more thoroughly sorted materials than the stream deposits. They also are apt to show better stratification and are more regular in deposition. Most of the quiet-water deposits were laid down in lakes and ponds of the lowland areas where they are interbedded with stream and glacial deposits. Some accumulated in the waters of temporary lakes that formed when glacial ice dammed the mouths of side valleys or when water was confined between the land and ice at the side of a glacier. These deposits became terrace deposits when the ice melted. Possibly the gravels of the high bluff at Slana were laid down in waters impounded behind an ice barrier.

The distinction between water-laid and other unconsolidated deposits is not made on the geologic map, and it is desirable to point out further that the boundaries of the unconsolidated deposits themselves are approximate in most places. The water-laid deposits are distributed throughout the area shown on the map as unconsolidated deposits and occupy much the greater part of it. They occur in great variety depending on local conditions, which varied from place to place. Consequently, close correspondence of sections in different localities is not to be expected. It will not be necessary to say more of the deposits of the smaller streams, but it is desirable to describe more fully some of the larger bodies of unconsolidated deposits that

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were laid down by streams and lakes in the Copper River basin and the Tanana River valley.

The lowlands of the Copper and Tanana valleys have the greatest accumulations of unconsolidated materials shown on the geologic map. These accumulations are distributed in three principal areas—the Copper River basin, the Tanana valley below Johnson River, and the upper Tanana valley above Cathedral Rapids. They are composite deposits and include both glacial and water-laid materials so intimately intermingled that generally they can not be differentiated. Whatever is known about the structure and distribution of the deposits is learned chiefly from stream cuts, as drill records, except those of several shallow holes at one locality north of Copper Center, do not exist, and geophysical methods have not been tried. The valleys are filled to a great depth with materials transported by streams and glacial ice from the adjacent mountains and laid down as stream and lake deposits or as morainal till. It is believed that the deposits of both the Tanana River areas are dominantly washed gravel and sand which probably are in part old, reworked Tertiary gravel, in part original Pleistocene and Recent deposits, but, like the deposits of the Copper River basin, may include undisturbed Tertiary beds.

Streams of the Copper River basin have incised their channels in the unconsolidated deposits to depths ranging from a few feet to 600 feet and many sections of the sands and gravels are exposed. The upper Tanana area, which includes Tetlin Lake and the thousands of small, unnamed lakes and ponds of the poorly drained country between Tetlin Lake and the international boundary, is covered by deposits which the streams have not yet dissected. Only that part of the surface not covered with water and vegetation is exposed for examination, and no information regarding the vertical section is yet available.

Somewhat more is known of the lower Tanana area, for the Delta River has cut its wide, canyonlike channel to a depth of at least 200 feet in the deposits between Beales Cache and Jarvis Creek bridge. The deposits appear to be dominantly waterlaid. Near the borders of the lowland, morainal materials cover some of the older unconsolidated deposits, but beyond the lowland the surface gravels near the highway are outwash gravels. Possibly these deposits include till as well as water-laid material and may consist in part of Nenana gravel.

Other streams east of the Delta River have cut similar channels in the unconsolidated deposits, but neither they nor the Delta River have exposed the full thickness of the filling.

Most of the area of the Copper River valley to which the descriptive name basin applies is north of the latitude of Copper Center and within the area shown on the geologic map. Extensions of the central basin continue into the upper and lower valleys of the Copper River and into the upper valleys of many of its tributaries. Except a small part, all this area is occupied by unconsolidated deposits into which the low mountains or hills project.

The deposits of the Copper River lowland are believed to differ from those of both the areas of the Tanana Valley in that they include a greater proportion of original glacial matter. They accumulated in an open, basinlike valley surrounded by high mountains; at one time the valley was completely filled with ice and for a much longer time glacial debris was poured into it from all sides by valley glaciers and the streams flowing from them. At a later time the rate of filling was slower as the result of warping or other causes, and the streams began to destroy the deposits. They have entrenched themselves most deeply in the southern part of the Copper River basin and have exposed many sections of gravels that are favorable for study, except that the steep faces are often hard to reach or may be hidden by loose material.

The deposits show wide variation from place to place in the character of the material and in its arrangement, but all the deposits are plainly those that would be produced under the changing conditions accompanying the irregular retreat of an ice front. They include sand, gravel, silt, clay and wind-blown dust, and till or boulder clay. The gravel and sand may be well bedded or poorly bedded. Cross bedding is common. The clays and fine sands may be blocky or finely laminated. Many of them have pebbles or even small cobbles scattered through them, probably distributed by floating ice. A notable characteristic is the mingling of materials from widely separated, distant sources. If numerous sections were studied throughout the Copper River basin and the age of the different beds accurately correlated, it doubtless would be found that various kinds of deposits were being laid down simultaneously, and that probably none of the deposits forms a continuous, unbroken sheet throughout the area.

The greatest depth of deposits is not known. Presumably the gravels thin toward the margin of the basin and are thickest at some point distant from the margin. The Copper River has incised its channel to a depth of about 600 feet near the south boundary of the basin; smaller streams, the Klutina, Klawasi, Tazlina, Gulkana, Gakona, and others, have excavated channels of somewhat less depth (fig. 35), but neither the Copper nor its tributaries have cut through the gravel deposits to bedrock. Mendenhall (1905, p. 67) measured a section in the northern part of the lowland, in the divide between the Gulkana and Delta Rivers, that showed about 600 feet of coarse and fine gravel and sand. This section and the bluffs of the Copper River give the

FIGURE 35.—Entrenchment of the Copper and Gakona Rivers in unconsolidated Pleistocene deposits of the Copper River basin, on the west side of the Gakona River. In the foreground is the broad flood plain of the Copper River. In the middle distance, on the left, is the trench of the Gulkana River. The Gakona roadhouse and bridge are near the center. (Air photograph by Bradford Washburn.)

highest measurement of thickness known at this time, but at neither place is the section complete. Knowledge of the depth of the gravels and the form of the underlying bedrock surface will be needed to understand fully the structure of the Copper River basin.

Most of the unconsolidated deposits are perpetually frozen to a depth of many feet, except a shallow surface zone that thaws in summer. Efforts to obtain water from dug wells have not been successful except from shallow wells near stream courses, some of which cannot be used in winter. A well at Kenney Lake on the branch road leading from the Richardson Highway to Chitina was reported many years ago to have been sunk 80 feet in frozen ground without finding water and gradually was closed by the formation of ice. More recently several holes were drilled between Copper Center and Gulkana in an effort to get water for use at the new airfield. It is reported that the drill went through about 190 feet of frozen ground and then entered unfrozen gravel that yielded water. The water at that place, however, was too strongly charged with mineral substances to be usable.

Until recently, permanently frozen ground offered problems that were of concern chiefly to the placer miners, since it added to the difficulties of mining some placer gold deposits and made possible more economical mining of others. But, when heavier and more elaborate structures became necessary in the operations of the Army and the business of civilians, knowledge of the distribution of permafrost and its effects on the foundations of bridges, buildings, and other structures was recognized as of great importance and has led to special study of the subject in different parts of Alaska.

The problems of the origin of the Copper River basin and the nature of the Pleistocene deposits accumulated there were studied by Mendenhall (1905, p. 62–74), who examined the gravel bluffs along the stream channels at many places and whose writings are the principal source of information about them. Two sections measured by Mendenhall give a clearer idea of the diversity of the materials than can be given in words. The first (fig. 36) is 1½ miles above the mouth of the Klawasi River, opposite Copper Center. It shows stream deposits, lake deposits, wind-blown sand, and glacial deposits and bears evidence of at least two invasions by ice, as indicated by sheets of till. The second section (fig. 37) is on the west bank of the Copper River just below the mouth of the Tazlina River. This section is mostly water-laid material but includes one 10-foot bed of boulder clay. Further evidence of ice invasion is given near this locality by distorted silt beds that were pushed into a series of synclines and anticlines by the overriding of the ice and subsequently were covered by glacial deposits.

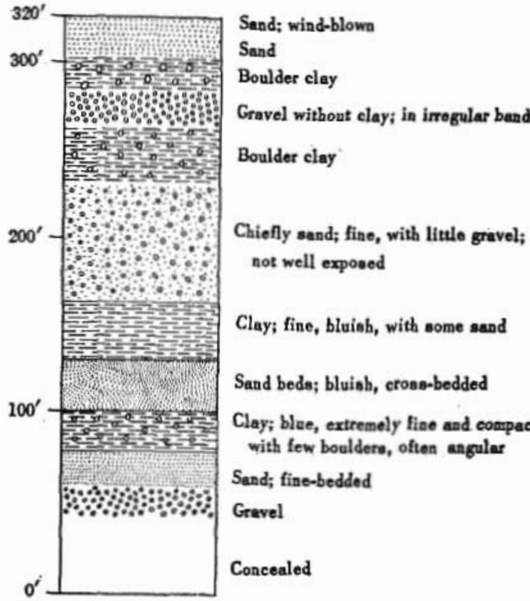

FIGURE 36.—Section of Pleistocene deposits on the Klawasi River. After Mendenhall.

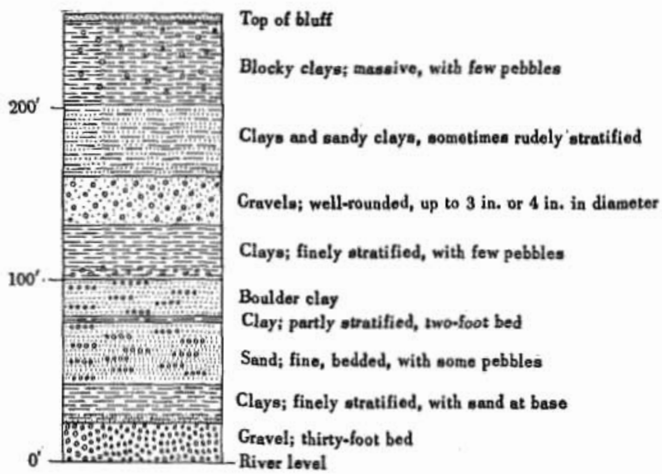

FIGURE 37.—Section of Pleistocene deposits on the west bank of the Copper River just below the mouth of the Tazlina River. After Mendenhall.

After describing the unconsolidated deposits in different localities, Mendenhall (1905, p. 68) states his conclusion regarding them in this way:

These descriptions serve to bring out the fact that in the southern and central parts of the Copper basin the Pleistocene filling consists of laminated and massive silts, pebble-bearing clays, stratified sands, gravels, and till in greatly varying proportions, and that in the northern and marginal parts of the basin it consists of sands, gravels, till, and morainal deposits.

This may be understood as indicating that a large proportion of the deposits of the southern part of the basin were laid down in the quiet waters of lakes and ponds and, in contrast, that a larger proportion of the sands and gravels on the northern part were deposited by streams. This contrast continues, for at the present time extensive quiet-water deposits are accumulating in the lakes along the border of the Chugach Mountains.

The largest known area of lake deposits that are attributed to a single body of water is in the upper valley of the Tanana River. This whole lowland area was apparently occupied at some period in Pleistocene or Recent time by water impounded behind an ice dam, probably in the vicinity of Cathedral Rapids on the Tanana River. Warping of the bedrock surface may have assisted in extending the boundaries of the lake. The shore line has not been determined. The northern border was recognized by Van Alstine and Black (personal communication, 1943) at places along the Alaska Highway from the Tanana River bridge to the international boundary. Lake sediments consisting of conspicuous light-colored bedded sands and silts were deposited along this shore line as high as 350 feet above the [old] Tanana bridge, as shown by barometric measurements. No more is known about the lake than is revealed by the shore deposits seen along the highway. The location of the south shore probably will be found if it is looked for, but it may be more difficult to identify than that of the north shore, as it may be concealed by younger stream and morainal deposits. Possibly, also, the south shore may have been determined in part by an ice front formed by the glaciers issuing from the valleys of the Nutzotin Mountains.

Lakes of equal or greater extent may have existed in the Copper River valley in Pleistocene time. The topographic setting for a large lake seems favorable, but evidence for it has not yet been recognized. Smaller, temporary lakes and ponds such as are seen today have occupied parts of the lowland at different times since the area was freed from ice. Much of the unconsolidated material of the lowland area that has been described accumulated in small lakes that existed for a time and disappeared, as has the greater lake of the upper Tanana Valley.

Wind-blown deposits

Finely divided rock fragments or fine sand and dust are shifted from place to place over the river flood plains or are carried long distances by the wind and deposited as beds with other sedimentary deposits. Such fine material is commonly of uniform size and the deposits are of even texture. They may accumulate in beds many feet thick. Two sources have contributed material for such deposits in the area shown on the geologic maps. The principal source is the fine sand and rock flour of the flood plains of the larger streams, especially those of the swift braided glacial streams. A second source is material ejected explosively from volcanoes during sporadic eruptions.

Dunes and loess.—Deposits formed by the wind include sands that are too heavy to be lifted and carried far but are swept into dunes and moved slowly over the flood plains of the streams, and the lighter sands and dusts that are picked up and perhaps carried a long distance before settling to the ground.

Sand dunes are uncommon in most of the area because conditions favorable for their formation are usually lacking, yet typical dunes as much as 10 feet high may be seen on Riley Creek, tributary to Jarvis Creek, and on the Chisana River. Small mounds of sand are formed in many places on the gravel bars where a log or clump of brush breaks the force of the wind.

Recent investigation connected with the study of permanently frozen ground in the upper Tanana valley has shown the existence of considerable areas of dune sands, in addition to lake deposits, morainal material, and outwash gravel, in the lowland crossed by the Chisana, Nabesna, and Tetlin Rivers and once covered by the ancient Tetlin Lake (R. E. Wallace, personal communication). These dune deposits are overgrown by scrubby spruce and other smaller vegetation, beneath which is a thin bed of volcanic ash. This indicates that the dunes are not of present-day origin. Their structure indicates that the prevailing winds which formed them must have been northwesterly. They are probably another feature of the land surface that was dependent on the conditions prevailing in late glacial time.

The wind-blown deposits of the second kind, which are much more extensive than the dunes, seem to be characteristic of glacial conditions and glacial streams. They are deepest in the terraces bordering the flood plains of the streams and became thinner with increasing distances from them. In places they have attained a depth of many feet and are still accumulating. The process may often be seen. Clouds of dust, swept along by the wind blowing from the cool mountains to the warmer lowland areas, are commonly seen on summer days in valleys where the streams have extensive, bare flood plains. On the north side of the range dust clouds are particularly notable on the Delta River, Jarvis Creek, Gerstle River, and Johnson River. The terrace gravels bordering the flood plains of these streams are overlaid in places by a cover of wind-blown sand 20 feet or more thick. Deposits of wind-blown materials have accumulated in much greater quantity than the heavier sands that drift over the floors of the valleys.

They are a substantial part of the unconsolidated deposits exposed in the bluffs along the larger streams.

Deposits of fine sand and dust built up by the wind are no less common in the Copper River valley than on the north side of the Alaska Range. Although they are not restricted to the lowland area, they are more noticeable in the bluffs along the streams that cross the lowland than in other parts of the region. Thick deposits of loess are exposed in the banks of the Copper, Klutina, and Tazlina Rivers, and wherever the larger streams have cut deeply into the unconsolidated deposits. Locally, the deposits form ridges like railway embankments at the top of the gravel bluffs that border the river valleys. The swirling currents of air sweep upward along the steep faces of the exposed gravel and drop their load of dust and fine sand as they spread out over the edge of the bluff. Most of the load is lost immediately, but a considerable part is carried farther from the river. Clouds of dust carried by the strong winds are commonly seen in summer along the Copper River, just as on streams of the Tanana River side of the Alaska Range, and the trees and vegetation near the banks are covered with fine sand and dust. Undoubtedly a considerable amount of fine material is added to the soil in this way.

Volcanic ash.—Deposits of recent volcanic ash are locally extensive but are chiefly of geologic interest. Only one thin deposit of unconsolidated ash is known within the area covered by this report. It occurs in the Chisana and lower Nabesna River districts and comprises the western, marginal extension of deposits that are conspicuous on White River in the vicinity of the international boundary and cover many miles of Canadian territory to the east. The deposit may be seen in the cut banks of streams or in newly dug pits in the Chisana district; it consists of a thin layer of white ash, in most places from less than an inch to 2 inches thick, underneath the peat or other cover of vegetation and soil overlying the gravel. The center of eruption that expelled the ash is believed to be near the international boundary not far south of the White River, but its site has not been determined definitely. The ash deposits of the White River were described by Capps (1915, p. 59–64; 1916, p. 81–83) who estimated the area covered by them and was able to give an approximate date of their eruption.

The ash, an andesitic pumice (Moffit and Knopf, 1910, p. 42–44), is a frothy white glass, light enough to float in water, in which are small, hexagonal plates of biotite, short prisms of hornblende, less conspicuous crystals of glassy feldspar, and rare grains of magnetite.

South of the White River, in a small area presumably near the source, the ash accumulated to a depth of scores of feet. In many places where it was drifted by the wind or heaped up by streams it accumulated in more than average thickness or formed deposits distinct from the original bed. In this way an appearance of more than one fall was simulated locally although probably only one fall occurred. Over most of the area, however, the ash has remained practically as it fell, and a bed, 2 feet thick, on the north side of the White River 8 miles below Russell Glacier, is probably typical of the original undisturbed ashfall. It overlies a deposit of peat 30 feet thick and is overlain by an additional 7 feet of peat which furnished Capps the clue for calculating its age. The creamy-white color of the ash in contrast with the dark brown of the peat in the gravel terrace more than one mile long, makes the deposit stand out distinctly.

From reports of the occurrence of the ash made by various observers at many widely separated localities Capps found that the area affected by the ashfall, much the larger part of which is on the Canadian side of the international boundary, is not less than 140,000 square miles and is probably far greater. By an ingenious interpretation of the rate of accumulation of the peat deposit overlying the ashbed on the White River he calculated the time since the eruption to be approximately 1,400 years.

The Chisana district was apparently not in the direct path of the winds that carried the greater load of ash at the time of eruption but seems to have received its share of ash during the later part of the eruption when the wind may have shifted from the west to the south and carried the ash far to the north of its source. The deposit west of the international boundary as far north as the Yukon River is therefore thin, and, although present at most places, it may easily be overlooked.

IGNEOUS ROCKS

Igneous rocks of several kinds make up a large proportion of the rocks of the eastern Alaska Range and adjacent area; in many places they are readily distinguished from associated sedimentary rocks or from one another by contrasts of color or of resistance to weathering. They include lava flows and tuffs that were interstratified with the sedimentary rocks or were poured out over them, and intrusives that were injected into the sedimentary beds and the older igneous host rocks. Some of the igneous rocks occupy large areas. They were formed in different geologic periods, ranging in age from early Paleozoic or even pre-Paleozoic to the present, and show corresponding degrees of alteration, ranging from schist and gneiss to fresh, unaltered rock. The lava flows and tuffs resemble the stratified rocks in their structure and are often conveniently described with them; but the intrusive masses because of the irregularity of their forms and their seemingly erratic distribution, can not be treated as part of the stratigraphic sequence. Their petrographic character and the circumstances of their origin are different. The time of their intrusion is difficult to discover, for they do not contain fossils, and determination of their age depends on knowing the age of the rocks that they intrude, on the degree of their metamorphism, or on their structure.

Some of the igneous rocks, having a genetic relationship to specific ore deposits, have been studied in detail, but most of them have been examined only briefly, for identification. The descriptions that follow, therefore, are not given as a completed petrographic study but as an account of the occurrence and distribution of the larger igneous bodies and some additional facts concerning their composition and associations.

VOLCANIC ROCKS

The volcanic rocks may be separated into two groups—an older group, consisting of lava flows and fragmental materials that are more or less metamorphosed, and a younger group, the Wrangell lava, that is practically unaltered. Some of these rocks were poured out in a molten state on the surface of the earth or in the sea. Others were ejected explosively from their volcanic sources as fragmental material and have since been consolidated into firm beds. All the lavas considered are dark colored and commonly of fine grain. Some of the late Paleozoic lavas are considerably altered but are not very schistose. In places they are vesicular, or are porphyritic and show small, light- or dark-colored crystals in a dense ground mass. Most of them are basaltic; the Wrangell lava is andesitic.

Lava flows were not identified in the old schistose rocks on the north side of the range. These schists are believed to be dominantly altered sedimentary rocks and although they include altered intrusives, they are so greatly metamorphosed that the original characteristic features of most of them are destroyed. If volcanic rocks are present they are so changed that they are not easily recognized.

OLDER VOLCANIC ROCKS

The oldest volcanic rocks of the Alaska Range that were identified are basic lavas and pyroclastic materials interbedded with black, Devonian shale and are exposed on Bonanza Creek in the Chisana area (Capps, 1916, p. 30). These volcanics are similar in appearance to the previously known Permian volcanics with which they are associated and their different age was not suspected until Devonian fossils were found in the shales.

Lava flows and tuffs are abundant in the Carboniferous(?) rocks of the Chistochina and Indian Creek areas. They make up a large part, if not the greater part, of the rocks mapped as Carboniferous(?) in the mountains between the Chistochina and Chisna Rivers and in the area of undifferentiated Paleozoic rocks of Indian and Ahtell

Creeks. Some of the volcanic rocks in these areas may be Permian but it is doubtful if any of them are younger. They have been much folded and faulted and were invaded by coarse-grained basic and acidic intrusives, forming a complex of dissimilar rocks. An isolated belt of basaltic flows extends west-northwest for 16 miles from Mineral Lake to a stream locally called Bone Creek that drains the lake in Sikonsina Pass. This belt of dark, fine-grained rock forms the crest of the high mountains north of Mentasta Pass. It is interstratified with sedimentary beds which are of undetermined age.

Permian time is notable in the eastern Alaska Range as a time of volcanism, which began and ended with a great extrusion of lavas and tuffs. Deposition of the Permian limestone and shale was interrupted repeatedly by the flow of molten rock or the fall of ash and larger fragments thrown out from many sources. The eruptions, however, were not continuous but were separated by time intervals sufficient for the deposition of hundreds of feet of limestone and shale. The earliest and latest lavas are most extensively developed in the White River district at the south border of the area covered by this report. In the Chistochina area, the lowest members of the Mankomen formation of Permian age are lava flows, but they have not been definitely correlated with the section on White River, though they probably correspond to its lower part. They are succeeded by limy tuffs, occasional thin flows, and limestone and shale. The lavas are of basaltic type, commonly finely porphyritic, in places vesicular.

Lava flows and tuffs are exposed in areas that are designated on the map as undifferentiated Paleozoic rocks but are not separated from them. Some of these lavas, as may be seen in the mountain between Jack Creek and Platinum Creek, are now highly vesicular; when the filling of the vesicles is removed by weathering, the fillings resemble some of the younger lavas of the Wrangell Mountains.

A belt of dark-colored volcanic rocks extends west from the vicinity of Summit Lake on the Richardson Highway many miles beyond the boundary of the area described. It forms a prominent chain of rugged mountains considerably lower than the Alaska Range but parallel to it and not everywhere sharply separated from it. The belt is made up in large part of slightly metamorphosed volcanic rock—basalt and andesite flows—but includes a relatively small amount of argillite and some other sedimentary material. Black and dark-green basalt predominates. It is amygdaloidal in places and like the other rocks associated with it shows the development of secondary minerals when studied under the microscope. The lava flows were intruded by diabase and less basic, light-colored dikes. The thickness of the deposits is not known but is several thousand feet. Chapin (1918, p. 27) estimated that 3,500 feet of these flows are exposed on Butte Creek west of the Susitna River.

The upper flows and fragmental beds of this belt of volcanic rocks are assigned tentatively to a place at the base of the Upper Triassic series. The whole group of lava flows, volcanic fragmental beds, and included sediments occupies a place in the geologic column beneath sedimentary rocks of established Late Triassic age, and presumably above the Permian limestone and shale. Thus it is in a position comparable with that of the Nikolai greenstone of the Chitina Valley (Moffit, 1938, p. 37–42).

WRANGELL LAVA

CHARACTER AND DISTRIBUTION

Wrangell lava is the formation name first used by Mendenhall (1905, p. 54–62) to designate the volcanic deposits of the Wrangell Mountains. These mountains have already been described as an independent group which lies within the acute angle formed by the meeting of the Alaska Range and the Coast Range mountains. They include the highest peaks seen from the central Copper River valley and are built up of congealed lavas, tuffs, and other fragmental materials that were poured out or ejected from underground sources onto the surface of the land. In general the volcanic rocks of the Wrangell Mountains are closely related members of one rock family with andesite as its prevailing type.

The lavas and tuffs were emitted from a number of definitely identifiable vents and probably in greater quantity from fissures that are not now indicated by existing topographic features. Mounts Sanford, Drum, Wrangell, and Jarvis are the highest peaks of the area shown on the map and were centers of eruption. They probably indicate the sites of the more explosive types of eruption and are not all of identical age. Judged by the extent of sapping by ice and weather, Mount Drum is the oldest and Mount Wrangell much the youngest. Mount Wrangell is the only volcano of this group that still shows signs of activity.

The Wrangell lava occupies an irregular, elongated area extending from the lower western slopes of Mount Drum to the international boundary, a distance of about 130 miles. Its greatest width from north to south is approximately 65 miles and is near the west end of the area. Considerably less than half the area occupied by the Wrangell lava lies within the boundaries of the geologic map.

The lavas and tuffs were erupted on an old land surface of considerable relief. In places the streams have carved their valleys deep in the lavas, removing great volumes of rock and attacking the older formations beneath. Such erosion is more noticeable on the south side of the area and at its east end. South of Beaver Creek the lava beds are horizontal and are not so thick as in the western half of the area.

Nearly all the larger streams between Beaver Creek and the White River have cut through the lavas and now occupy channels far below the level of their base, leaving remnants of the flows as capping on the adjacent hills. A similar pattern of isolated patches of lava separated by narrow valleys was carved out by the upper western tributaries of the Nabesna River. Between the Nabesna and Sanford Rivers the flows have a gentle dip to the north and west, merging into the general surface of the lowland, and have not yet been cut through by the streams.

The proportion of fragmental beds, tuffs, and agglomerate is much greater in the western part of the area, near the volcanic centers. Mendenhall (1905, p. 55) gives the following description of the beds in Mount Drum:

> The succession in Mount Drum, as roughly estimated from below, is a basal series of varicolored tuffs approximately 1,000 feet thick, above which are 300 or 400 feet of massive flows, succeeded in turn by another series of variegated tuffs from 1,000 to 2,000 feet thick. The upper 4,000 or 5,000 feet of the mountain appear to be a succession of lavas, with little or no interbedded fragmental material. These hard beds are especially well displayed in the narrow eastern horn of the crescentic summit.

This section includes more than the usual proportion of fragmental beds, which may be accounted for by its nearness to the vent.

The flows of Wrangell lava, particularly the younger flows, are quite fresh and commonly are black or dark gray in color, although less commonly they show colors of brick red, brown, and tan. Most of the lava is porphyritic and much is highly vesicular. In some places the vesicles are filled with chalcedony. Columnar structure is exceptionally well developed in many of the flows, and a sheeting parallel to the surface occurs locally. Glassy phases of the lava appear to be more numerous in the upper part of the section. A few thin beds of conglomerate made up of the same material as the flows have been noted but sedimentary deposits are absent.

The Wrangell lava of the northwest side of the Wrangell Mountains was examined by Mendenhall in 1902. The lava of the northeast side, on the Copper and Nabesna Rivers, was examined by Schrader the same year. Their descriptions and part of their material were reexamined and summarized by Wayland (Moffit and Wayland, 1943, p. 153–158). The material, including thin sections and chemical analyses, indicates that the most abundant rocks are andesites and their close relatives. The less abundant rocks include diabasic olivine basalt, dacite, and augite andesite and also, locally, obsidian and basaltic tuff.

The thickness of the Wrangell lava varies with distance from the vents. In the neighborhood of Mount Sanford the thickness may be 12,000 feet or more, but as the base of the deposits is an uneven surface, a definite measurement of thickness applies to only one locality. The thickness is less around the margin of the area but even in the hills south of Beaver Creek exceeds 1,000 feet in most places. It should be noted, however, that the boundary lines of the flows are only approximate in this locality.

AGE OF THE WRANGELL LAVAS

The age limits of the Wrangell lava can be stated more certainly than the age limits of many other formations of the Alaska Range. The lava of the earliest flows and the fragmental material of the first eruptions were spread out on the surface of a land that had long been undergoing erosion and was partly covered with gravel, sand, variegated clays, and other deposits, and with living plants or the remains of plants. These unconsolidated Tertiary materials in the Wrangell district were buried under the volcanic deposits which preserved them just as they lay when the eruptions began. Although the base of the Wrangell lava has not been examined in many places and the rocks on which the lavas rest are not well explored, the underlying Tertiary deposits give suggestions of the geologic conditions that prevailed and, more particularly, give evidence of the age of the deposits themselves. The Tertiary beds at one locality are about 300 feet thick and include gravel, sand, and clays in which are local thin seams of coal and leaf-bearing beds. Fossil plants were collected from such beds in Skolai Creek valley by the writer (1938, p. 97) and were identified by E. W. Berry and assigned by him to the flora of the Kenai formation of Eocene age. The name Kenai was formerly used to designate all the Alaska fresh-water, sedimentary rocks of Eocene age but is now restricted to the Eocene rocks of the type locality on Kenai Peninsula.

It thus appears that the extrusion of the Wrangell lava probably began in Eocene time and has continued intermittently to Recent time, for the lavas are interstratified with the earlier glacial deposits of the White River valley described by Capps (1916, p. 64) and have broken through more recent unconsolidated glacial deposits in the Copper River valley. Mount Wrangell has not discharged lava within the time that the Copper River valley has been known to white men, but it has emitted steam and ash on various occasions.

INTRUSIVE ROCKS

Igneous rocks have been injected as dikes, sills, or larger bodies of irregular form into practically all the bedded formations and older igneous rocks of the eastern Alaska Range. They are the products of different periods of intrusion and show various degrees of metamorphism. Some of the rocks that are believed to be metamorphosed granitoid intrusives are so greatly altered that their original character has not yet been definitely determined. Others, although altered in some measure, still retain their characteristic petrographic features and are readily identified. They include a large variety of rock types, most of which are variants of a dominant type. This dominant type is intermediate between the true granites and diorites. Granite, diorite, and gabbro are less common, but granodiorite, quartz monzonite, quartz diorite, and other closely related rocks are widely distributed. The granitoid rocks may often be identified at a distance by their contrasting color or their superior resistance to weathering and by their rugged topography. They form many of the highest and most notable peaks, although they may merely top the peak and make up only a small proportion of the whole mountain mass.

The more highly metamorphosed intrusive rocks of the north side of the range were not differentiated from the older sediments with which they are associated and are not represented separately on the geologic map, but many less altered small bodies, including some of the numerous younger dikes and sills and several large batholithic masses are shown. The less-altered rocks evidently were intruded much later than the disturbances that caused the schistosity of the host rocks.

Other granitoid intrusives of probable Paleozoic age are included in the area designated "undifferentiated igneous rocks of various ages" (pls. 6 and 7). The rocks to which Mendenhall (1905, p. 38–39) applied the name Ahtell diorite are exposed in this area, which extends eastward from the Chistochina River across the Slana River to Suslota Lake and thence southeastward. These intrusives are darker in color than most of the later intrusives and are more basic in composition, dominantly diorite and quartz diorite. They show considerable alteration in places and appear to have been intruded earlier than the intrusive rocks that are most widely distributed in this part of the Alaska Range.

The later intrusives are more abundant, less altered, and occur in larger bodies. In most places the larger bodies of intrusives, although probably of late Mesozoic age, are associated with Paleozoic or older sedimentary beds. Six principal areas of granitoid rocks, ranging in size from approximately 70 square miles to more than 400 square miles, are shown on the map between the Delta River and the international boundary. They include (1) the large batholith near Horsfeld in which Klein Creek and other streams have cut their valleys, (2) one with unknown limits at the head of the Nabesna River, (3) one forming the mountain between Buck and Tuck Creeks, (4) one between Ahtell Creek and the Slana River, (5) one forming the Macomb Plateau east of Johnson River and extending across to the north side of the Tanana River, and (6) Granite Mountain east of Jarvis Creek.

In addition to these larger areas and many dikes and sills are several irregular areas only a few square miles in extent. Granodiorite is the prevailing rock type in most of these intrusive bodies.

1. The batholith cut by Klein Creek, which ranks second in size among the bodies mentioned, is 21 miles long, has a maximum width of 10 miles, and is exposed in an area of more than 120 square miles. The batholith consists chiefly of granular rock which in the hand specimen shows plagioclase feldspar, biotite, and hornblende. Biotite and hornblende may occur together or separately. Quartz and orthoclase are recognizable in places. This is the dominant type from which there are many variations of texture and mineral composition. Its petrographic character was described by Wayland (Moffit and Wayland, 1943, p. 143) as follows:

As seen under the microscope the granodiorite displays a hypidiomorphic granular texture. The plagioclase feldspar is commonly andesine. The ferromagnesian minerals are biotite, hornblende, and some augite. Orthoclase feldspar is usually present in subordinate amounts but may total as much as 15 percent of the rock, and quartz may constitute as much as 25 percent. Magnetite, titanite, and apatite are accessory minerals. Secondary alteration products, such as chlorite, sericite, calcite, epidote, and zoisite, are prevalent.

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The parts of the batholith exposed at the head of Gravel Creek and Baultoff Creek, north of the pendant, are in general more basic than most of the rest of the batholith.

At the head of Gravel Creek the rock is darker owing to the presence of darker feldspar and an increase in the proportion of dark minerals. Under the microscope it shows some orthoclase but only a minor amount of quartz. It is classed as monzodiorite. Still farther northeast on Baultoff Creek the rock is even more basic, the proportion of ferromagnesian minerals is greater, and the color is dark gray. The microscope shows zoned feldspar with labradorite cores and andesine rims. There is no quartz or orthoclase and the dominant ferromagnesian minerals are hornblende with some augite and magnetite. The accessory minerals are apatite and titanite and the secondary minerals are chlorite, a little epidote, and leucoxene. This rock is classed as diorite.

On Crescent Creek, a southern tributary of East Fork Snag River, 5 miles northwest of the Baultoff Creek locality the rock is again a typical granodiorite. These changes in composition and the presence of pendants of the host rock on Gravel and Baultoff Creeks indicate that the part of the intrusive body exposed there is near the roof of the batholith, a deeper section of which is exposed on Klein Creek.

The intrusion of the batholith brought about conspicuous changes in the invaded rocks. These changes include recrystallization of the

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limestone and silicification of the banded argillites and limestone. More noticeable, however, is a pronounced yellow-reddish color that is seen in many places and is caused by the alteration of iron sulfide which either was in the rock originally or more probably was introduced by the batholith.

One of the smaller bodies of granodiorite of this district forms most of the mountain between Chathenda (Johnson) Creek and Wilson (Chavolda) Creek. This body intrudes Middle Devonian and Permian rocks and is faulted against Mesozoic sedimentary rocks of the Nutzotin Mountains on the north.

Several exposures of granitoid intrusives of much more basic composition were found in the Beaver Creek area. The largest is a mass of gabbro which forms the mountain top northwest of Carden Lake. It consists largely of augite which is accompanied by labradorite and bytownite feldspar and is much altered.

A smaller body of porphyritic gabbro crops out at the mouth of Ptarmigan Creek near the international boundary southeast of Horsfeld. It is made up chiefly of augite and labradorite accompanied by hornblende and magnetite and a little secondary biotite. The rock at this locality is mineralized and contains a little gold associated with arsenopyrite, pyrrhotite, pyrite, chalcopyrite, quartz, and calcite.

2. In the mountains between the Notch Creek-Cooper Pass valley and the Nabesna River and on the west side of the Nabesna are large exposures of granodiorite. These exposures probably indicate one large body of the intrusive although the continuation of the batholith through the high mountain mass has not been traced.

On Notch Creek the granodiorite batholith cuts lava flows and limestone of probable Permian age. The most abundant facies of the intrusive on Notch Creek and in Cooper Pass is a typical granodiorite much like that of Klein Creek. The hand specimen shows the ferromagnesian minerals biotite and hornblende, some quartz, and light-gray feldspar. Under the microscope the rock shows a granular structure of medium grain. The light minerals are andesine, quartz, and orthoclase. The dark minerals are biotite and hornblende, which are chloritized. The accessory minerals are magnetite, titanite, and apatite. Alteration products are sericite and zoisite from the light minerals and calcite and epidote from the dark.

On Notch Creek at the east end of the batholith some of the rock is more basic. Hand specimens show medium grain. About two-thirds of the rock is gray feldspar and one-third is ferromagnesian minerals. This rock is a quartz diorite. Small dikes of fine-grained granite cut the granodiorite of Notch Creek. Another abundant intrusive rock associated with the granodiorite is dense, light-gray dacite porphyry.

The dominant intrusive rock at Bond and Monte Cristo Creeks on the Nabesna River side of the batholith is granodiorite similar to that of Cooper Pass and Klein Creek. Some variations of texture, composition, and alteration are noted. A quartz diorite facies is common and at Orange Hill is mineralized with disseminated chalcopyrite, pyrite, and molybdenite. Dacite porphyry and andesite are common. Diorite is exposed at the mouth of the Jacksina River. At White Mountain, near the Nabesna mine, a stock of quartz diorite associated with dioritic and andesitic dikes cut the Triassic limestone, bringing about extensive contact metamorphism and the deposition of gold ores. The contact effects at White Mountain are pronounced and are of two kinds: recrystallization of the limestone, and the formation of new, contact silicate and oxide minerals in an uncommon rock to which the name tactite is applied. Tactites have been formed in a similar manner by the intrusion of limestone at Orange Hill and Cooper Pass.

3. The greater part of the mountain ridge north of the depression formed by the valleys of Buck Creek and the west branch of the Cheslina River is a complex of granitoid rocks that appear in general to be slightly more basic than the dominant rocks of the batholith cut by Klein Creek. The ridge is deeply incised by streams but owes its present height and form in considerable measure to differential weathering; for the igneous rocks, more resistant than the overlying and surrounding sedimentary beds, were not broken down and removed as easily.

This complex of igneous rocks is exposed in an area about 28 miles long and more than 6 miles in maximum width. It extends from the Cheslina River to the Little Tok River in a continuous body which at one time may have been connected with the smaller mass west of the Little Tok River. The complex of granitoid rocks consists dominantly of diorite and quartz diorite. Granite and dark basic rocks made up chiefly of hornblende with a little feldspar are less common variants of the dominant types. A conspicuous member of the group, found throughout the length of the body, is a coarsely porphyritic, light-gray rock containing abundant chunky crystals of feldspar twinned according to the Carlsbad law. The crystals are nearly as wide as long and commonly range from less than one inch to 2 inches in largest dimension. They make up a large proportion of the total volume of the rock.

The shape of this intrusive is not clearly evident. The mass represents more than one intrusion but forms a single body that appears to rest on the sedimentary beds into which it was intruded. Furthermore, the host rocks and the intrusives have been folded and faulted and their structure is thereby obscured.

Sills of granitoid rock, of somewhat finer grain, darker color and fresher appearance than the dominant intrusives north of Buck Creek, invaded the Mesozoic and older rocks on the south side of the Buck Creek valley. If these intrusives are apophyses of the main body of diorite north of Buck Creek, as they appear to be, they give information concerning the time when at least one stage of the intrusion took place, for the sills are later than the intruded rock and therefore are late Mesozoic or younger.

The Devonian sedimentary rocks adjacent to the main intrusive body have undergone extensive alteration which is more notable near the intrusive mass. The effects of the intrusion were seen in many places, especially along the south border of the intrusive. The chief changes are the development of schistosity and contact-metamorphic minerals such as garnet.

4. The highest part of the detached group of mountains drained by Ahtell and Indian Creeks is between Ahtell Creek and the Slana River; it is made up of light-colored granitoid rocks which are clearly distinct from the more altered granitic rocks of the neighboring mountains on the southwest. This body of rocks occupies an area 20 miles in length and about 5 miles in average width. It consists chiefly of coarse-grained quartz diorite and diorite which often may be recognized at a long distance by the strong contrast in color between them and the surrounding darker rocks. Throughout the mass, the texture is coarse and even-grained. Porphyritic phases similar to the abundant porphyritic rocks of Buck Creek were not seen. In places, apparently in the border zone, the rocks have been somewhat altered. On disintegration the diorite yields light-colored boulders and gravel that outline the gulches and creek beds distinctly on the mountain slopes. As this diorite is not in contact with any rocks whose age has been determined, it has not been possible to fix the time of its intrusion.

5. The highland that includes the Macomb Plateau east of the Johnson River is the largest area of granitic rocks within the eastern Alaska Range. It is part of a batholith that extends from the high mountains west of Johnson River eastward across the Tanana River and includes more than 550 square miles of territory of which over three-fifths lies south of the Tanana River. In this highland area the valley of the Tanana River is narrowest and the grade of the river is steepest. The rocks of the area are granitic intrusives of considerable variety but dominantly are types intermediate between the granite and diorite and include quartz monzonite, granodiorite, and quartz diorite. Mertie (1937, pl. 2) shows the granitic rocks along the Tanana River below Tanana Crossing as granite and quartz diorite. On the Johnson River quartz monzonite is a common rock which in places has been

altered to gneiss. South of Independent Ridge a western tributary of Johnson River exposes a coarsely porphyritic phase of the granitic rocks, containing occasional feldspar crystals as large as eight inches in greatest dimension and three-fourths of an inch thick. The crystals average about 1¼ by ⅝ inches in size and in places have a parallel orientation suggesting flow structure. At this locality the rocks are crushed and somewhat altered.

The metamorphic rocks adjacent to the granitic body are cut by various kinds of igneous intrusives ranging from types with few dark minerals to those made up of augite and dark mica, most of which are much more basic than the prevailing granitic rocks. These dikes and sills are probably offshoots from the nearby larger body of intrusives or from an underlying body not yet exposed to view by erosion.

Intrusion effected various changes in the rocks that were invaded, one common effect being the discoloration of the host through the introduction and oxidation of iron sulfide minerals. The intrusives in their turn were subjected to the distorting forces that brought about the elevation of the Alaska Range and were folded and crushed together with the host rocks.

6. Granite Mountain, between Jarvis Creek and the Gerstle River, is a more homogeneous mass of intrusive igneous rock than the mass forming the Macomb Plateau. The dominant type is coarse-grained granodiorite which is considerably weathered on the surface. Hornblende, biotite, quartz, and feldspar are easily recognized in the hand specimen. Granite Creek follows the contact of the granodiorite on the north and the metamorphic rocks on the south. The boundary is a zone of much disturbance and probably indicates an important fault. Intrusion of the granodiorite seems to have affected the host rock in an unusual degree. The schist near the granodiorite of Granite Creek is coarse, silicified, and contains many quartz veinlets. In places it is notably colored with iron oxide. Several miles east of the head of Granite Creek the schist is larded with small dikes and lenses of coarse-grained and fine-grained rock showing no dark minerals. Fine-grained dikes of the same kind, some of them not more than one-quarter inch thick, cut the granitic rocks also and probably represent a later phase of the intrusion.

AGE OF THE INTRUSIVES

The time of intrusion of deep-seated igneous rocks is indicated partly by the age of the rocks that they intrude and partly by their own characteristics. There are several criteria by which relative age may be tested. (1) Intrusives are younger than the rocks they intrude. (2) The occurrence of fragments of an intrusive in associated clastic rocks indicates that the clastic rocks are younger than the intrusive. (3) The degree of metamorphism of the intrusive and the associated rocks may be indicative of their relative ages, although such evidence is not always conclusive. Unfortunately, some of these tests are not widely applicable in the eastern Alaska Range; or they give indifferent results. However, the information derived from them may be extended by knowledge of the igneous rocks of the districts.

The Yukon-Tanana region, as shown by Mertie (1937, p. 198–201), has experienced five principal periods of intrusion by deep-seated igneous rocks. Two of these were in pre-Cambrian time, and one each in the Paleozoic, Mesozoic, and Cenozoic eras. Intrusives from several of these eras may be present in the Alaska Range, but only those that cut rocks of Mesozoic age have been identified as of a definite period.

The larger intrusives that have been described above occur in areas where the prevailing host rocks are of Permian age or older. In a few places the intrusives adjoin Mesozoic sedimentary rocks that show no contact metamorphism. Some such contacts are due to faulting and may give no indication of the original relationships. All the Mesozoic formations, however, are cut by dikes and sills, many of which are regarded as offshoots of the larger intrusive bodies and as furnishing evidence that these intrusives not only are younger than Permian but are not older than late Mesozoic. An example of intrusion that took place in Mesozoic or later time is the quartz diorite at White Mountain which invaded the Upper Triassic limestone. Other examples are the dikes and sills cutting the slates and sandstones of the Nutzotin Mountains. In the Nizina district, such intrusives cut Lower Cretaceous shale and thus are Early Cretaceous or younger in age.

The batholith cut by Klein Creek, however, seems to have been intruded before Early Cretaceous time, which consequently indicates that the time of more active intrusion was in the Jurassic period. The massive conglomerate on the north side of Gravel Creek valley in the Horsfeld area is correlated with nearby shale beds that yielded Upper Jurassic fossils. This conglomerate contains boulders of the granodiorite, indicating that the granodiorite batholith was already exposed on the surface and subject to erosion in Late Jurassic time. If these interpretations are correct, the batholith was intruded into Permian sedimentary rocks before the Upper Jurassic conglomerate was deposited. The period of intrusion, however, was not ended, for, as has been shown, dikes that cut the Upper Jurassic and Lower Cretaceous rocks indicate further intrusion in either late Mesozoic or early Tertiary time.

No igneous rocks were found that cut the Upper Cretaceous sandstones and conglomerates and the Tertiary coal-bearing formations, but the area occupied by these rocks is too small to justify a positive statement regarding the apparent absence of intrusives in them.

Mountain building that affected the whole Pacific coast line of North America took place in Jurassic or Cretaceous time and was accompanied by the intrusion of vast amounts of granitic rock, including diorite, granodiorite, monzonite, and other less plentiful rock types. It is believed that the intrusives that accompanied the mountain-building movements of the middle or late Mesozoic comprise the larger part of the granitic intrusives of the eastern Alaska Range. The bodies of igneous rocks that are referred to this most important period of mountain building and intrusion were not formed by a single act of intrusion but probably were built up by injections that were repeated as the mountain-building movements took place and were conitnued through a long time. Much of the intrusion took place before the Upper Jurassic or Lower Cretaceous beds were deposited, but intrusion continued beyond this time, as appears from the evidence in this and other regions.

STRUCTURAL GEOLOGY

The structure of the Alaska Range is complex. The bedded rocks represent a vast span of geologic time, reaching from an indefinite point in the pre-Cambrian to the present. Many parts of the time scale, however, are not represented by sedimentary rocks, either because the land stood above the sea during those intervals and no sediments were deposited or because erosion has removed whatever deposits accumulated. Some formations may have been destroyed entirely, leaving no trace of their existence; others were partly removed. The parts that survived were the more resistant or more favorably situated beds and often were left in isolated areas without apparent relationship to one another. In places the remaining beds were covered by later sedimentary or igneous deposits and thus were protected from further destruction. The folding and faulting of rocks of this varied character produced complicated structures, difficult to interpret.

The site of the Alaska Range is one of the parts of Alaska where the mountain-building processes—folding, faulting, intrusion of igneous bodies, extrusion of lavas and tuffs, and erosion—apparently have been repeated in different geologic epochs. Because these processes interrupted the orderly accumulation of deposits, the distribution of some formations seems to be erratic, and the structure cannot be understood without knowledge of the underlying causes.

Ancient metamorphic rocks form the backbone of the Alaska Range from the Susitna River to the Tetlin River. They are bordered on the south by younger rocks that range from Middle Devonian to Tertiary in age. In places, as in the Chistochina area, the rocks adjacent to the metamorphic rocks are younger than those at a greater distance. This suggests the possibility of synclinal structure, yet the only part of the Range shown on the geologic map that seems beyond doubt to have synclinal structure is the group of Mesozoic bedded rocks of the Nutzotin Mountains.

All the bedded rocks from the oldest metamorphic to the youngest Tertiary unconsolidated gravels show some measure of folding. In general the degree of folding depends on the age of the rocks. It is intense in the oldest, the pre-Cambrian schist, and doubtless represents more than one period of mountain building. Structure in these older folded rocks is intricate. The distortion was intense enough in many limestone beds, in which the structural lines are commonly more easily recognized than in the schist and gneiss, to bring the axial planes of closely compressed folds into a horizontal position. The general trend of the beds is commonly revealed by the trend of the limestone outcrops and does not vary greatly from the strike of the planes of schistosity, but the true dips of beds and the structure of folds are less apparent.

The Carboniferous and Devonian rocks are locally schistose, but nowhere in the same degree as the pre-Cambrian schist. Being the oldest of the Paleozoic rocks they have been involved in all the folding and faulting of late Paleozoic and later time. The massive Upper Triassic limestone was competent to withstand some of the deforming forces and, although faulted, is not closely folded; but the overlying thin-bedded part of the limestone and the shales are much distorted where they were not protected by the massive beds. The Upper Jurassic and Lower Cretaceous rocks show open folds in places, but more commonly are so compressed that the limbs of folds are parallel and the axial planes are slightly overturned. The interbedded slate and sandstone of many bare cliffs in the Nutzotin Mountains show on a large scale the folding that was impressed on the Mesozoic formations. The Upper Cretaceous and Tertiary terrigenous rocks are little disturbed and are practically horizontal in most places, but locally they are folded, or folded and faulted. The folding is open, but dips as great as 50° were seen in the Upper Cretaceous rocks of Euchre Mountain and 40° in the Tertiary coal beds of Jarvis Creek. The oldest Wrangell lava was extruded when the Tertiary coal beds were forming. In places the lava beds have a slight tilt, which may be an original structure or the result of later movement. They do not appear to have taken part in the folding that affected the coal beds, although some steeply dipping lava flows occur near Russell Glacier, on the White River, interbedded with unconsolidated gravel beds, soft shale, a little sandstone, and tillite (Capps, 1916, p. 64).

Although the older formations are closely compressed and highly distorted and even the Nenana gravel is somewhat deformed, faulting, as a factor in structure, is no less characteristic of the Alaska Range than folding. Faulting took place on a scale that was not realized until after the early isolated investigations in different parts of the Alaska Range were extended and correlated. Mendenhall (1905, p. 83, 84) recognized the existence of a great fault between the Permian beds of the Chistochina valley and the metamorphic rocks to the north. He concluded that the faulting took place in post-Eocene time and estimated the displacement to be not less than 10,000 feet. Later investigations have shown that the longitudinal extent of this fault is greater than was apparent to Mendenhall. The fault probably continues toward the west, merging into the great east-west fault of the Mount McKinley National Park area, and extends east-southeast at least to the Tetlin River (Capps, 1930, p. 248, 266, 270).

Within the area covered by this report as far as is known, the great fault lies between the ancient metamorphic rocks which form the backbone and highest peaks of this part of the Alaska Range, and younger Paleozoic rocks. This relationship persists from the Delta River to the Tetlin River except in a few localities where younger granitic intrusives take the place of the Paleozoic sedimentary rocks. West of the Delta River the fault extends into the valley of the Black Rapids Glacier, an area that has never been explored. The existence of the fault from the Delta River to the foot of the Nenana Glacier, a distance of 68 miles, is inferred from topographic features only.

Eastward from the Delta River the older rocks, those on the north, are on the higher or upthrown side of the fault. This relation holds in the Mount McKinley National Park area also; but near the Nenana River the older rocks are on the south side, which implies rotation in the movement of the walls of the fault. This and other evidence, including direct observation in a few places, suggests that the dip of the fault is generally high.

Related faults of great length and large displacement play an important part in the geologic structure of the Slana valley and the Nutzotin mountain area. The straight northeast front of the Nutzotin Mountains is believed to have been determined by a major fault. Evidence of this appears between Beaver Creek and the Snag River and in Buck Creek valley. In both places the boundary between the Mesozoic slate and sandstone and the older formations follows a zone of disturbance indicated by shearing and iron staining, although most of the fault zone is concealed by unconsolidated gravel deposits and vegetation.

Another important fault follows the southwest border of the Nutzotin Mountains but on this side lies between the Mesozoic and Paleozoic rocks. It extends from the Klein Creek batholith through Cooper Pass and Totschunda Creek valley to Platinum Creek and the headwater tributaries of Jack Creek. Its course beyond that is less certainly known but the fault probably continues through the valley of the Slana River.

These faults or zones of faulting have both topographic and geologic expression, for in most places they not only determine the boundaries between different formations having anomalous positions but follow notable topographic depressions that doubtless were places of weakness where erosion went on more rapidly than in the adjacent, less disturbed rocks. All of them are partly concealed by unconsolidated deposits and none has been mapped in detail. The two faults inclosing the Nutzotin Mountains apparently are branches of the great fault passing through the Chistochina area, or it may be that one of them is the principal fault itself.

Displacement probably took place on these major faults at different times corresponding to different periods of mountain building, although evidence for early movements is vague. It is certain, however, that displacement of much consequence occurred after the Tertiary coal beds were formed, for small bodies of the coal measures were folded and faulted into the floor of Slate Creek valley (Mendenhall, 1905, p. 123–234) and the north valley wall of the upper Chisna River (Chapin, 1919, p. 138). This folding and faulting took place during the elevation of the Alaska Range and is evidence that the range did not reach its full development until after the Tertiary coal-bearing beds were deposited. The Tertiary coal measures derived a large part of their constituent material from rocks of the Alaska Range and in the Nenana area were deposited on the folded and eroded beds of the Cantwell formation (Upper Cretaceous) and older rocks. The character of the material does not indicate vigorous stream erosion; it is therefore presumed that the Alaska Range, although fully outlined, had been considerably reduced before the formation of the fresh-water coal beds began. The coarser materials of the Nenana gravel indicate renewal of erosion, probably following renewed uplift of the range.

The system of faults includes many displacements that are locally large but are small in comparison with the major faults that have been described. Detailed mapping would show that the number of these minor faults is large. The fault that passes through the valleys of lower Slate Creek and the upper Chisna River is one of the minor faults. It separates the Carboniferous from the Permian rocks and has been traced westward as far as the West Fork Glacier, at the head of the Chistochina River.

So far reference has been made chiefly to the great strike faults, or faults that have the same trend as the major folds of the bedded rocks, in general the trend of the range itself. Cross faults with displacements comparable to those of the strike faults were not recognized although the existence of large cross faults in one or two places is suspected. A vast number of smaller faults, with diverse strikes and dips, that were determined by local rather than regional conditions cut the bedded rocks and the intrusives, or in many places separate them. These small faults and the joints, possibly to an ever greater degree, played an important part in relieving the pressure and distributing the adjustments that were made necessary by the deforming forces.

The simplest section of the Alaska Range appears to be that in the vicinity of Mount Kimball, east of the Middle Fork Chistochina River. This section shows the Mankomen formation in its type locality, dipping moderately north-northeast and abutting against the metamorphic rocks, from which it is separated by the great fault. Thus stated the structure is described in much too simple terms, because no account is taken of minor faulting and other complications. Along the Delta River and farther west are outcrops of large intrusive bodies and beds of the Tertiary coal measures, but the general structure is still simple. Eastward from the Chistochina River the structure is more and more complicated by large bodies of igneous rocks, both intrusive and extrusive, and by additional sedimentary formations.

A section extending northeastward across the Mentasta Mountains from White Mountain near the Nabesna River (pl. 6) shows the greater complexity of the Paleozoic and younger rocks of this part of the range. The internal structure of the different formations as represented is diagrammatic although based on field observations. The section shows the Mesozoic rocks of the Nutzotin Mountains to be included between Devonian sedimentary rocks on the northeast and Permian volcanic rocks on the southwest. The Devonian and undifferentiated Paleozoic rocks abut against the pre-Cambrian schist and gneiss and are intruded by a mass of dioritic rocks which appears to cap the sedimentary beds and owes its prominent position to differential weathering. The position of the diorite and the outline of its boundary suggest that it is the remnant of a great elongated lens or laccolith that was injected into sedimentary beds, which have since been folded and faulted. The Permian volcanics and the Upper Triassic limestone are overlain in part by the Wrangell lava. Their structural relations are complicated by faulting and intrusion and cannot be shown accurately on the small scale of the section. Major faults separate the Mesozoic beds from the adjoining Paleozoic beds on both sides and bring the undifferentiated Paleozoic beds into contact with the schist and gneiss. The direction of dip and the location of this latter fault are inferred, for the bedrock of this part of the section is covered with unconsolidated deposits. The other faults are placed with more assurance.

GEOLOGIC HISTORY

PRE-QUATERNARY HISTORY

Some of the outstanding events in the geologic history of the eastern Alaska Range, as revealed by its rocks, have been mentioned or suggested in the discussion of the several formations. The account is incomplete, because the evidence is fragmentary and our understanding is more obscure with the remoteness of geologic time. Only for the later epochs is it possible to give a fairly complete outline of the geologic history of the region. The attention here given to these later events may therefore be out of proportion to their importance and time value.

The earliest events in the long geologic history of the eastern Alaska Range include the deposition of sedimentary beds of prevailingly siliceous character, and the operation of the processes of intrusion and metamorphism by which these beds were changed to the schist and gneiss now exposed along the north side of the range. These processes required a vast period of time for their completion, beginning far back in Paleozoic or pre-Cambrian time, and it is possible to give only a general account of them. The relationships of the beds to one another have not yet been learned, nor can they be given a definite assignment in time. As no fossils have been found in the rocks, other characteristics must be used in assigning positions in the geologic column.

No Cambrian, Ordovician, or Silurian rocks have been identified in this area although rocks of these three periods are known in neighboring territory. Lower Devonian rocks have not yet been found anywhere in Alaska. That epoch is therefore inferred to have been, "one of the great periods of mountain building and diastrophism" in Alaska (Smith, 1939, p. 18).

With the ending of the Lower Devonian epoch, however, the record becomes somewhat clearer. In the main it is a story of changes that took place in the position of land and sea. The changes make up a recurrent cycle that includes submergence of the land below sea level and deposition of marine sediments, followed by reelevation and the renewal of subaerial erosion. At times the changes included movements that were of mountain-building proportions, such as those that produced the Alaska Range.

The long period of denudation that is believed to have persisted through Early Devonian time was ended by submergence of the land beneath an invading sea. Then followed the deposition of marine sediments, notably limestone, and the eruption of volcanic material, including both lava flows and tuffs. This series of events took place in Middle and Late Devonian time and gave rise to the rock sequence that is exposed on the Cheslina and Tetlin Rivers and in the Chisana area. These rocks are not known farther west, between the Tetlin and Delta Rivers, where they either were not deposited or were removed by erosion. Presumably the Devonian beds were deposited unconformably on early Paleozoic or pre-Cambrian rocks. They have not yielded evidence to show the relation of the Upper Devonian to the Middle Devonian or the relation of either series to the Carboniferous(?) beds. What took place during these time intervals is therefore not known.

The Carboniferous period has left little record in the eastern Alaska Range. The only rocks assigned to the Carboniferous are assigned to it tentatively. They are exposed in the Chistochina River area many miles from the Devonian area of the Tetlin River valley and are of little value in determining the historical and structural relations of the rocks of the two areas.

A noteworthy characteristic of the Carboniferous sequence, however, is the abundance of lava flows and tuff beds, which suggests that, as in the Yukon-Tanana region, the deposits accumulated in a time of unusual volcanic activity. According to Mertie (1937, p. 223) the greatest outpouring of lavas in the entire geologic history of the Yukon-Tanana region took place in early Carboniferous time.

The late Carboniferous (Pennsylvanian epoch) seems to be almost unrepresented by marine deposits in Alaska. Like the Early Devonian, therefore, it may have been a time when most of the region of the eastern Alaska Range stood above sea level.

During Permian time parts of Alaska were submerged and covered with marine deposits notable for the large proportion of limestone and the local abundance of fossil invertebrates. The Permian rocks of the Alaska Range are also notable for the abundance of lava flows and limy tuffs, indicating that the sediments were deposited during a time of exceptional volcanism. The base of the Permian succession has not been recognized but presumably, as the highest members of the Carboniferous system are not represented, the lowest beds of the Permian were laid unconformably on the underlying beds and thus indicate the renewal of deposition at the end of an erosion period. Permian time closed with a great outpouring of lavas that may have continued well into the Triassic in areas adjacent to the Alaska Range. These later lavas are not certainly known in the Chistochina area although lavas and tuffs are abundant there in the lower part of the Permian sequence.

The Permian beds were folded and, at least in places, raised above the sea, thus beginning another period of erosion which was followed by resubmergence in Late Triassic time and the deposition of Upper Triassic limestone and shale.

The probability that the Upper Triassic rocks were raised above sea level, extensively eroded, and then resubmerged in Jurassic time is indicated by the incompleteness of the Upper Triassic stratigraphic section and the irregularity of thickness and distribution of the Upper Triassic beds in the Nabesna area. The period of erosion probably lasted through the Early and Middle Jurassic for both of these epochs seemingly are unrepresented by sedimentary rocks in the eastern Alaska Range. The apparent absence of such deposits, however, may also be accounted for by assuming their complete removal by erosion or possibly by failure to recognize them. Probably an erosion period that was at least of local effect preceded the deposition of the Lower Cretaceous marine sediments, and without doubt extensive erosion took place before the deposition of the moderately folded Upper Cretaceous fresh-water sediments. The similarity of the Upper Cretaceous beds to the Tertiary coal measures that follow them immediately suggests that similar conditions of land elevation and subaerial exposure controlled the deposition of both.

In middle or late Mesozoic time, intrusion of deep-seated granitic rocks, associated with mountain-building movements, took place on a large scale, accompanied by extensive mineralization that was widespread in Alaska and formed some of its most important ore deposits. Many intrusive bodies of the Alaska Range belong to this period of igneous activity. The granodiorite batholith of Klein Creek in the Chisana district is believed to have been emplaced after the deposition of the Upper Triassic and before the deposition of the Upper Jurassic strata. The age of the batholith at the Tetlin River locality and of similar bodies is less well established, but they are correlated with the batholith of Klein Creek and are considered to be contemporaneous with it. All the Mesozoic sedimentary deposits of the Nutzotin Mountains were intruded by dikes and sills of granitic rock with the possible exception of the Cretaceous fresh-water deposits. It appears that, although the time of most notable intrusion was in the Jurassic, intrusion continued into the Tertiary period. According to Capps (1930, p. 286) most of the intrusion of granitic rocks in the Mount McKinley National Park region took place after deposition of the Cantwell, a formation of Late Cretaceous age, but probably before the Tertiary coal-bearing formations were laid down, although there was considerable intrusion of granitic material during Eocene time. The Tertiary beds of Jarvis Creek and the Delta River valley were not invaded by igneous rocks, as far as is known. They are believed to be much younger than the batholith of Granite Mountain.

Volcanism appears to have had little part in building up the bedded deposits of late Mesozoic time in the Nutzotin Mountains. The Jurassic and Cretaceous sedimentary rocks show very little volcanic material, either as tuffaceous deposits or as interbedded lava flows. Volcanism was renewed locally in Tertiary time however, probably in late Eocene, and is recorded in the Wrangell lava, which may still be accumulating. The eruption of the Wrangell lava began after some of the fresh-water coal measures had already been formed. It continued, probably with diminishing strength, through the remainder of the Tertiary and Pleistocene time. What part of the lava flows and tuffs accumulated before Pleistocene glaciation began is not known.

The elevation of the present Alaska Range took place largely in Tertiary time, probably as a result of earth disturbances that began sometime before the Tertiary period. The Alaska Range acquired its present height and form as the result of progressive, intermittent uplifting of the land, carving out of valleys by subaerial erosion, and abrasion by glacial ice.

The rocks of the Alaska Range, including the Cantwell formation of Late Cretaceous age of the Nenana district, were folded and were partly reduced by erosion in early Tertiary time, and the material derived from them and probably from other sources was laid down in terrestrial deposits, together with beds of plant remains, to form the coal measures.

While the Tertiary deposits were forming, a renewed or accelerated uplift of the land stimulated erosion by the streams flowing from the Alaska Range and yielded the coarser materials of the Nenana gravel. Apparently the Nenana gravel is the youngest of the unconsolidated Tertiary deposits of the eastern Alaska Range. It is somewhat deformed locally which testifies that mountain building was still in progress at that time.

Accumulation of the Wrangell lava also began in Tertiary time, but not until erosion of the land was far advanced and an unknown thickness of Tertiary land deposits had formed.

The climate of the early Tertiary period probably was humid and cool and was favorable for the growth of vegetation, such as formed the peat bogs that later were turned to lignite. Fossil leaves and other plant remains bear evidence that the forests and vegetation of that time were much like those of the present.

By the end of the Tertiary period the combined action of mountain-building forces and erosion had given to the Alaska Range an outline and surface which resembled that of the present in general aspect. The land had considerable relief and the present major drainage system was in large measure established.

PLEISTOCENE GLACIATION

Glacial ice has left unmistakable evidence of its recent domination in the Alaska Range and Copper River valley. The work of the ice is seen on all sides, but for better understanding it must be considered in its relation to glaciation in other parts of Alaska as well as to its effects in this particular region.

Alaska was not covered by a continental ice sheet in Pleistocene time, as was most of the Canadian territory to the east. Much of the central part of Alaska was unglaciated, although the mountain ranges and some of the intermontane areas, such as the Copper River basin and Prince William Sound, were occupied by masses of ice of great extent and depth.

At the beginning of the Pleistocene epoch most of the Alaska Range owed its surface forms chiefly to the processes of weathering and normal stream erosion, which produce -shaped valleys, overlapping spurs, and other, less notable, but characteristic, features. Most of these long-established land forms were then modified by moving ice, which previously had exerted only a minor influence, if any, on the development of the topography.

The causes of the ice age are not fully understood but probably do not imply great changes in climate or other extraordinary conditions. They involve a relation between precipitation and temperature such that more snow falls in a period of years than melts during the same period. Recrystallization of the snow produces a body of ice which increases in volume as long as the surplus of snow is maintained.

The beginning of glaciation was unobtrusive and the advance of the ice front was gradual, as was also the retreat. Snow fell in the high mountains and formed ice fields from which streams of ice flowed into the heads of the valleys. As the supply of ice increased the ice streams moved farther down in the valleys till they reached the lowlands outside the mountain area. There they either melted away or united with other valley glaciers to form piedmont glaciers.

The advance of the ice front in the valleys and over the lowlands probably was not continuous but took place by a succession of slow forward movements interrupted by temporary recessions, which constituted a cycle in which the forward movement prevailed. When the changing climate brought about a decrease in snowfall, the ice lost by melting was not equally renewed, and the ice diminished.

Evidence of at least two general advances of the ice has been found (Capps, 1940, p. 155). Other earlier advances corresponding to the principal known glacial stages in Canada and the United States may have occurred in Alaska also, although the facts have not been established. Of the two known advances affecting the Alaska Range, the latest, which presumably corresponds to the Wisconsin stage of glaciation of the northern United States, appears to have been the more extensive, and in many places, has destroyed all evidence of the earlier stage. In other places, as on the north side of the range, the earlier ice front extended beyond the limits of the second (see p. 152). The most prominent evidence of glaciation seen now is that of the more recent advance.

The extent and duration of glaciation present interesting contrasts. Precipitation was doubtless the controlling influence on the relative extent of the glaciers originating in the Alaska Range. On the north side, where precipitation is small, the ice streams did not advance far into the lowland area and did not override the outer ends of spurs between streams, as is shown by deeply weathered ledges of schist in exposed places where they could not have withstood the force of moving ice (fig. 38). On the south side, where fed by more abundant

FIGURE 38.—Weathered masses of schistose granite on the ridge west of the Gerstle River, 2.5 miles northeast of Bradford Creek.

snow, the glaciers not only moved into the lowland, but they joined with ice streams from neighboring mountains and covered the whole lowland area.

When glaciation was at its maximum the ice occupied the entire drainage basin of the Copper River and spilled out in all directions into neighboring drainage areas. Ice covered the lower mountains to an altitude several thousand feet above the valley floors, and only the higher peaks stood above its surface.

Although the principal outlets for the great mass of ice accumulating in the Copper River drainage basin were to the west and south, other important outlets for ice streams opened to the north and east through the canyons of the Delta, Tok, Nabesna, and Chisana Rivers. Through these passed ice and water, together transporting great quantities of morainal debris and washed gravel to the Tanana Valley, probably sweeping most of the older gravel deposits out of the mountain area and redepositing them in the main valleys of the larger streams. In this manner the present principal deposits accumulated after the time of greatest extension of the ice and during and after its decrease.

Effects of glaciation are conspicuous in both the highland and the lowland areas. In the highlands they are distinctive topographic forms, most of which are modifications of the forms previously carved out by the more common processes of erosion. Outstanding among these are cirques, U-shaped cross sections of the valleys, straightened valley walls, truncated spurs, rock benches on the mountain sides that mark temporary but long-maintained positions of the ice, morainal deposits, abandoned stream channels on mountain slopes or across divides, washed gravel on flat mountain tops, and diverted drainage—all of which are found within the mountain area.

In the lowland areas the glacial ice left deposits of morainal material that locally have regular geometric forms but more commonly are only irregular heaps of rock fragments laid down with little or no sorting by water. In many places the resulting uneven surface has produced swamps, ponds, and lakes as yet undrained by any erosion process.

Changes in stream courses and drainage took place where the advancing glacial ice blocked the established courses and diverted the water to unnatural channels. Small valleys with insignificant volume of water were occupied and enlarged and became trunk-stream valleys. The canyon of the Delta River and the valleys of the Tok, Nabesna, and Chisana Rivers owe their present size and form—perhaps their existence—to erosion by water and ice that had been forced to find new outlets when the old were no longer available. Greater volumes of water and steeper gradients probably assisted in this by giving the streams more power to erode their channels. They also increased the ability of the streams to carry loads and thus contributed to the filling of the valley lowlands. The innumerable lakes and ponds of the Tetlin area occupy the site of a greater lake or succession of lakes that formed probably when the ice of Pleistocene glaciers dammed the Tanana River. Although Tetlin Lake and some of the other smaller bodies of water may be surviving parts of this old glacial lake system, many smaller ponds in the Tetlin area are being formed at present by the melting of frozen ground and ice and the caving of surface material. At the same time other lakes are being destroyed by the growth of vegetation and by filling with sand and silt deposited by streams.

The length of time that has elapsed since the "retreat of the ice" varies from place to place and cannot be stated precisely. The ice probably disappeared from the Copper River lowland long before it melted in most of the mountain areas where existing glaciers testify that the cycle is not yet completed or may possibly have been reversed. Notwithstanding the errors necessarily involved, estimates of the time that has elapsed since the ice disappeared in different localities are helpful in forming an idea of the progress of glacial events.

Such an estimate was made by Capps (1916, p. 74), who, by comparing the annual rings of spruce trees and the thickness of peat accumulated under certain conditions, estimated the average rate of increase in thickness of the peat bed in the north bank of the White River to be 1 foot in 200 years. Although this rate admittedly may be considerably in error, it still gives a basis for an estimate of the minimum time elapsed since the withdrawal of the glacier that occupied the White River valley from the site of the peat bed. Adopting this rate and using the measured thickness of the bed, Capps reached the conclusion that the ice disappeared from that locality at least 8,000 years ago, but stated his belief that the estimate falls considerably short of the time that actually elapsed. He further concluded that it "seems safe to say that the last great ice advance in Alaska was contemporaneous with the late Wisconsin continental glaciation."

This estimate was made many years ago but is still the best approach to the problem in Alaska that has yet been made. It applies to the time of retreat of the ice at a particular locality and not to the time of greatest extent of the ice, which was much earlier. It does not imply that the ice age is ended. Many glaciers that reached their greatest development in Pleistocene time have not yet disappeared from the higher mountains. In most places the glacier fronts appear to be receding, but the recession is so slow and fluctuating that it is impossible to say positively whether the movement is a recession or possibly a temporary halt in a general advance.

Ice fields and many Alpine glaciers are seen in the mountains represented on the geologic map. The largest accumulations of ice occupy the highest slopes and valleys of the Wrangell Mountains and together they cover an area of many square miles. In general the glaciers of the eastern Alaska Range are smaller than those of the Wrangell Mountains, though they form a more intricate pattern on the map and cover a large area, possibly 50 percent of the central mountain area between the Tok and Delta Rivers, where practically every high valley and many of the lower valleys are filled by ice.

Most of the present valley glaciers show no unusual features, and their ordinary movements are such as to be unnoticed in short intervals of time. The Black Rapids Glacier (fig. 39), however, is an exception among the glaciers of the Alaska Range. It occupies a valley west of the rapids of the Delta River, near mile 233 on the Richardson Highway, and attracted wide attention by an extraordinary advance in the winter of 1936–1937, when it renewed or accelerated the movement of the ice in its lower course and pushed its front out onto the floodplain of the Delta River (Moffit, 1942, p. 143–157). This movement continued for only a few months and then stopped abruptly. Although a similar movement had not previously taken place since the glacier became known to white settlers, such movement is recurrent and will probably be repeated at some future time. Little change, other than the normal melting of the ice in summer, has occurred in the Black Rapids Glacier since early 1937.

FIGURE 39.—Black Rapids Glacier from the gravel terrace above the Richardson Highway, 2.1 miles south of the Rapids roadhouse. The Delta River is in the foreground. September 6, 1937.

ECONOMIC GEOLOGY

INTRODUCTION

Gold, copper, and other economic metals have been deposited by geologic processes at many places in the eastern Alaska Range and adjacent areas. Since 1898 practically all the easily accessible part of the range has been prospected at one time or another. The search has led to the establishment of two productive placer-gold camps and the discovery of one lode-gold mine. Many other prospects were found that either proved to have no commercial value or have not yet been sufficiently explored to determine their value. It is the purpose of this section to discuss the types of deposits and to summarize the known facts regarding the occurrence of the ores, rather than to repeat detailed descriptions of ore deposits and mining operations that have been given in earlier papers. However, references will be made to most of these papers in the appropriate places.

The mineral deposits, like the intrusive rocks, are not restricted in their associations to any one type of host rock or to the rocks of a particular period, although it is true that more gold placer deposits and lodes of other metals have been found in areas underlain essentially by pre-Mesozoic rocks than in areas underlain by Mesozoic or younger rocks. However, the writer knows of no conclusive evidence that any of the ore bodies so far found in the areas underlain by Paleozoic or older rocks of the eastern Alaska Range were formed before Mesozoic time. If such earlier deposits exist, they almost certainly are subordinate in importance to the deposits of the late Mesozoic period. The mountain-building movements that took place in late Mesozoic time affected the whole Pacific coast of North America. They were accompanied by the intrusion of vast quantities of igneous rock and the deposition of ore minerals. These movements and intrusions were continued into early Tertiary time, but less intensively, and it is probable that most of the original ore bodies were formed before the Tertiary sedimentary beds were laid down.

The gold-bearing lodes of the Nabesna mine at White Mountain are contact-metamorphic deposits, formed at or near the contact between Upper Triassic limestone and a quartz diorite intrusive. The copper-molybdenum deposits of Orange Hill, near the foot of the Nabesna Glacier and only a few miles from White Mountain, are also contact-metamorphic deposits and probably belong to the same period of ore deposition as the gold ores of White Mountain, which were formed later than the deposition of the Upper Triassic limestone. Small concentrations of placer gold have been found in the stream gravels of valleys eroded in the Upper Jurassic and Lower Cretaceous rocks. This may indicate that some mineralization took place in Late Cretaceous or early Tertiary time and may have accompanied the intrusion of the granitic dikes and sills that cut the beds. Although mineral deposits may have been formed in more than one geologic period, it seems reasonably certain that the most important mineralization was an accompaniment of the intrusion of the granitic rocks, and that most of it took place in middle or late Mesozoic time.

Placer deposits are commonly formed when native metals or heavy metallic minerals are freed by weathering and erosion from a source in bedrock and are concentrated in gravel by the sorting action of water. Such deposits are usually thought of as being geologically recent or still in process of formation. This is true of many deposits, but long experience with Alaskan gold placers has led the author to the belief that much of the gold or other heavy metal in gravels that are themselves recent is nevertheless derived from older placer gravels that have been reworked and resorted. It is probable that much of the placer gold was freed from its sources in the solid rock during the long period of erosion that prevailed throughout Tertiary time and in a sense may be looked on as "fossil" gold.

The metals and metallic minerals that have been found in the eastern Alaska Range in sufficient quantities to give them definite or possible commercial value are gold, silver, platinum, copper, antimony, molybdenum, lead, and zinc. Minerals containing bismuth also are present in some placer deposits; in others tin-bearing minerals have been reported.

Gold has been mined from the placer deposits of the headwater streams of the Chistochina River since 1898 and in the Chisana district since 1913. A little gold has been mined in the valley of Ahtell Creek near Slana. Prospecting for placer gold has been carried on at many other places: Ober Creek, a tributary of Jarvis Creek; the Robertson River; Moose Creek, a tributary of Tuck Creek; and the Cheslina River. In all the later-named places a little gold was found, but not enough to pay for mining.

Lode gold has been mined at only one place, the Nabesna mine, but other gold-bearing lode prospects are known and show some promise of future production. The metalliferous deposits of Orange Hill near the foot of the Nabesna Glacier were originally staked as copper prospects but contain, in addition, molybdenum, gold, and zinc. Copper-bearing lodes were also staked on the Snag River. Other lodes which have been partly developed or prospected include a deposit of stibnite on Stibnite Creek in the upper part of the valley of the Tok River and a deposit of molybdenite at the head of Rock Creek near mile 84 of the Nabesna road.

The total mineral production of the part of the Alaska Range east of the Delta River, including the output of the Nabesna mine, was estimated in 1941 to have a value of approximately $5,840,000, calculated on the price of gold then current. Of this production more than two-thirds was from the gold placers and came from the Chistochina district ($3,000,000), and the Chisana district ($970,000). Ahtell Creek has produced only a few thousand dollars' worth of gold associated with a small amount of silver. Productive mining was discontinued in 1942.

The total output of the Nabesna mine until its closing in 1940 was valued at $1,870,000, as stated in reports to the stockholders of the Nabesna Mining Company. Most of the product was gold, although a little silver, copper, and lead are contained in the ore.

PLACER DEPOSITS

CHISTOCHINA DISTRICT

The headwaters of the Chistochina River drain the south slopes of the Alaska Range in the vicinity of Mount Kimball and also two groups of mountains on the south, set off from the higher peaks of the range by a narrow, east-west valley that is occupied by the Chistochina Glacier and the upper stretches of the Slana River. The gold placers of the Chistochina district lie within these two groups of mountains, which are made up largely of Carboniferous and Permian sedimentary rocks and lava flows, cut by numerous sills and dikes. Small blocks of Tertiary coal-bearing beds have been folded or faulted into the older rocks at a few places. This district was once covered by glacial ice that left traces in the form of the valley walls and the morainal deposits on the valley floors. Only a few streams in this area have afforded gold-bearing gravel deposits of commercial value. They include the Chisna River; Slate Creek; Miller Gulch; Ruby Gulch; Lime Creek (formerly called Lake Creek) flowing into Trout Lake; and Eagle Creek (pl. 7).

Auriferous gravels were discovered on the lower Chisna River by Hazelet and Meals in 1898. In 1900 gold was discovered on Slate Creek and Miller Gulch by Messrs. Coles, Jacobson, Kraemer, and Lovell. This proved to be much the richest ground of the district, which has become known as the Slate Creek district.

Slate Creek and neighboring placer streams of the district are remote from sources of supply and transportation costs are high. There is no road connecting with the highways of the Copper River valley; trail conditions up the Chistochina River are unfavorable for summer travel, and it has been the usual practice to bring supplies to the creeks by sled in winter. Since the airplane has come into use, each of the operating creeks has had its own airstrip.

Slate Creek and most of the Chisna valley are above timberline. The altitude and the east-west orientation of the Slate Creek valley prevent early melting of the winter snow and make the stream subject to early freezing, thus shortening the working season and frequently causing a shortage of water available for sluicing.

CHISNA RIVER

The productive gravels of the Chisna River are along the lower course of the stream about 2¼ miles from its mouth, in a broad open valley outside the mountain area (Moffit, 1944, p. 29–31). The stream here cuts a short, shallow canyon in diorite, which probably had an influence in controlling the currents and concentrating the gold at this place. The gravels are shallow and are made up of materials derived by erosion from the mountains of the northern part of the valley and from reworked glacial deposits, some of which are from distant sources. The stream gravel includes a large proportion of boulders of the more resistant rocks, especially granite.

Gold is present in the stream gravel and in the bench gravel adjacent to the stream but productive mining was restricted to the stream gravel in the canyon and a short distance below it. Most of the gold so far recovered came from deposits at the mouth of the canyon.

After the first few years following the discovery of the gold little mining was attempted on the Chisna River till 1938. In 1941 the Acme Mining Company installed equipment and prepared to continue mining in the canyon but later abandoned the project.

RUBY GULCH

Ruby Gulch is one of the small headwater tributaries of the Chisna River and is located within the area underlain by rocks of the Mankomen formation of Permian age (Moffit, 1912, p. 75). The creek leaves its mountain valley through a shallow canyon and has cut its channel in a broad alluvial fan below. Its gravels are mostly shale fragments but include some granite and greenstone boulders. The gravels are gold bearing and were mined near the head of the fan within the gulch and below it. The gold was concentrated on a false bedrock of thin, gravelly clay only a few inches thick, where mining had to be done carefully so as not to break through into the underlying, low-grade or barren gravel. There has been no mining on Ruby Gulch in recent years.

SLATE CREEK AND MILLER GULCH

Slate Creek and its tributary, Miller Gulch, have yielded most of the gold obtained from the Chistochina district (Mendenhall, 1905, p. 110–112; Chapin, 1919, p. 137–141; Moffit, 1944, p. 31–34). Slate Creek joins the Chistochina River a short distance below the end of the Chistochina Glacier. The stream is about 4 miles long and in the middle course flows westward through a narrow valley which follows the boundary between the slates of the Mankomen formation and the conglomerate, quartzite, and tuff of the Chisna formation. These two Paleozoic formations are the common rocks of the adjacent mountains but a small body of auriferous Tertiary beds, faulted or folded into them, was uncovered in the bed of the creek by mining operations. These younger beds are dominantly soft cemented conglomerate, but include sandstone and shale.

Miller Gulch is a steep, narrow gulch, about one mile long, which joins Slate Creek from the north, almost two miles from its mouth. The claims on Miller Gulch and Slate Creek at and below Miller Gulch afforded the richest gravels of the district. The gravel deposits of the lower part of Slate Creek, near the place where the stream passes into the Chistochina Valley, are too deep for economical drainage and have not yet been mined successfully, though they contain gold. The soft slates of Miller Gulch weather easily and load the stream with debris, which accumulates too rapidly to be removed by the small stream of water flowing in the gulch. Angular fragments of slate make up most of the deposits but cobbles of greenstone and granite derived from the "round wash" are present. The gravel deposits are permanently frozen. Insufficient water for sluicing and lack of room for the disposal of tailings have interfered with mining operations on Miller Gulch from the earliest days of mining. In spite of these difficulties, the gravels of Miller Gulch, because of their superior richness and ease of working, produced much of the gold from the district in the early years. The gold of Miller Gulch was flat and smooth and increased in coarseness toward the head of the gulch. It is said to have had an assay value of $18 per ounce at the old value of gold. Associated with the gold are small nuggets of copper, cinnabar, magnetite, and silvery fragments of some of the platinum metals. According to Chapin (1919, p. 130), who visited Slate Creek in 1917 to learn the possibilities of increasing the production of platinum, the placer gold is derived from three groups of gravel deposits. The first concentration was in the Tertiary conglomerate, sandstone, and shale which are cemented and contain both gold and platinum. A second concentration took place in the glacial deposits of the benches, and a third in the present creek gravels.

The original bedrock source of the gold has not been determined. Gold-bearing lodes have not been found in the country rock of Miller Gulch, where the greatest concentration of placer gold took place, but the area drained by Miller Gulch is an area of disturbance that underwent folding, faulting, and intrusion by dikes of igneous rocks. Although the Tertiary rocks and "round wash" contain material not found as bedrock in the immediate vicinity, it seems improbable that a large concentration of gold and heavy metals was transported far from its bedrock source, notwithstanding the fact that the agents of erosion must have broken down and removed a great volume of bedrock in freeing the gold.

BIG FOUR CLAIMS

A small body of gold-bearing gravel, which is included in a property long known as the Big Four claims, occupies a cirquelike valley on the mountainside facing the Chistochina Glacier, northwest of the head of Miller Gulch (Mendenhall, 1905, p. 115). This gravel body is high above the glacier and is a remnant of old gravel deposits that formerly were much greater in extent. It consists of well-rounded cobbles and pebbles and has been known to the miners by the name "round wash." Similar high gravels have been found at other places in the district and are thought by some to be the immediate source of the gold in the present stream gravels. The gold of the Big Four claims is somewhat finer and smoother than that of Miller Gulch and Slate Creek, which seems to indicate that it is more distant from its original source. Repeated attempts have been made to mine the gravel deposits of the Big Four claims, but insufficient water and small gold content of the gravel have discouraged most prospectors.

MIDDLE FORK

At intervals for many years, auriferous gravels have been mined near the head of the Middle Fork Chistochina River on streams known as Kraemer Creek, Limestone (Lime or Lake) Creek, and Bedrock Creek (Moffit, 1944, p. 34–40). The principal mining operations in both early and recent years have been on Limestone Creek. The camp on Limestone Creek is now served by an airstrip nearby on the flood plain of the Middle Fork and is connected with the camp on Slate Creek by a good but little used trail which follows the valleys of Limestone Creek, the upper Chisna River, and Slate Creek.

Kraemer, Limestone, and Bedrock Creeks flow across an open, timberless bench, nearly one mile wide, sloping gently eastward from the foot of the mountains to the river flood plain. The bedrock, where exposed, is Permian limestone or dark, fine-grained igneous rock like that of the mountains on the west. This bench has an undulating bedrock surface which was planed off by glacial ice that moved across it from the high mountains on the north. The unconsolidated deposits on the bedrock bench are glacial deposits and outwash gravel consisting of some local and some foreign material in which are basaltic rocks, granite boulders, and blocks of schist. Drilling has shown that the deposits reach a thickness of at least 70 feet but in general range from 30 to 40 feet. The deposits contain gold and were mined in the early days on Limestone and Kraemer Creeks. The gold recovered was taken from the benches and not from the stream channels. A little gold also was taken from the benches of Bedrock Creek. In recent years a part of the bench area was drilled systematically by the Middle Fork Mining Company, and although no definite paystreak was outlined, a zone of fairly high grade gravel seems to have a southeasterly trend across the bench. A ditch line was built in 1941 and a hydraulic plant was installed with the expectation of continued mining operation, but the outbreak of war prevented carrying out this plan.

EAGLE CREEK

Eagle Creek is a tributary of the East Fork Chistochina River (Moffit, 1944, p. 40–42). Its upper, northern half occupies a valley carved in Permian rocks. Its lower half crosses a lowland area and joins the river below Mankomen Lake. This is the type locality of the Mankomen formation of Permian age which here is made up largely of limestone and limy tuff, although the lava flows of the lower part of the formation crop out along the lower south front of the mountains. Eagle Creek leaves its upper valley through a shallow canyon cut in these igneous rocks, which are much disturbed by faulting and are brightly colored with iron oxides formed by the weathering of iron sulfide minerals in the lava flows. The gravel deposits in this canyon are gold bearing and were prospected in the early days. More recently, in 1942, a small hydraulic plant was installed at the upper end of the canyon and mining was begun but the work was discontinued because of war restrictions on gold mining. The gold of Eagle Creek is associated with native copper, much magnetite, barite, and other heavy minerals. Platinum is reported and probably is present for it is found in other placers of the Chistochina district.

AHTELL CREEK

Ahtell Creek is a tributary of the Slana River and joins that stream about one mile from its junction with the Copper River (Moffit, 1938, p. 48–50; 1944, p. 42–44). This creek drains most of the eastern side of the independent group of mountains between the Slana and the Copper Rivers. The mountain mass between Ahtell Creek and Porcupine Creek on the east is a local center of mineralization, and the gravel deposits of the small streams that drain it contain gold and other metallic minerals, of which magnetite is much the most abundant. Grubstake Creek drains the west side of the mountain and is the best known of these streams. It is 2 miles long and has 2 branches which unite about 1¼ miles from its mouth. These 2 branches occupy open valleys above timberline, but the main stream below the forks is in a narrow V-shaped valley which follows a fault zone in the bedrock. The bedrock is made up dominantly of dark, fine-grained lava flows and coarsely granular diorite intrusives which are associated with dark-gray silicified rocks derived from graywacke and slate. In places they are much stained with iron oxide.

The unconsolidated deposits near the forks and below the mined area include rounded stream gravel, glacial debris, and angular slide rock from the mountain sides. This material is poorly sorted and contains a large proportion of boulders. The heavy minerals taken from the sluice boxes are magnetite, ilmenite, native copper, silver, and gold. Magnetite is abundant and occurs in pieces that range from grains of sand to boulders a foot or more in diameter. Most of the gold and silver are little battered and worn and appear to have travelled only a short distance from their bedrock source. As Grubstake Creek has a small and uncertain supply of water, the work season has often been short. The total gold production has been only a few thousand dollars.

The streams flowing into Porcupine Creek on the opposite side of the mountain from Grubstake Creek carry gold, and also magnetite, native copper, native silver, and minerals containing bismuth. A little gold has been found on other tributaries of Ahtell Creek and on Granite Creek, a tributary of the Slana River, which heads against Ahtell Creek. None of these streams has produced gold in profitable amounts.

OBER CREEK

Ober Creek, on the north side of the range, is a western tributary of Jarvis Creek and lies outside of the mountainous area, at the margin of the Tanana lowland (Moffit, 1942, p. 143). It is in the area of old schist and gneisses which were here overrun by the glacier that moved northward through the Delta River valley and in most places were covered by morainal deposits left by the ice. In early days prospecting was done near the head of Ober Creek about 4 miles northeast of the old Donnelly telegraph station. The gravel deposits are frozen and require thawing in order to be handled. As the ground is at practically the altitude of timberline, the scarce local timber was early exhausted and additional supplies had to be brought from a distance. Dumps from old shafts and an abandoned boiler for thawing are the principal evidence of former mining operations. The production of Ober Creek, if any, is not known to the writer but doubtless was small.

CHISANA DISTRICT

The Chisana gold placer district formerly called the Shushanna, or Chusana, district, lies east of the upper Chisana River but its gold placers seem to be nearly worked out (Capps, 1916, p. 89–126; Moffit, 1943, p. 170–173). Its most important productive streams were Bonanza Creek and a small northern tributary named Little Eldorado. Bonanza Creek is a northern branch of Chathenda (Johnson) Creek which flows westward to the Chisana River. Northwest of Bonanza Creek is Wilson (Chavolda) Creek, another Chisana tributary, which is separated from Bonanza Creek by a low ridge and is a little more than 3 miles distant. The mountain west of Bonanza Creek and Little Eldorado Creek is known locally as Gold Hill. Several small tributaries of Wilson (Chavolda) Creek drain the north and west slopes of Gold Hill. These tributaries of Wilson Creek together with Bonanza and Little Eldorado Creeks are the productive gold-bearing streams of the Chisana district (fig. 40).

Rumors of a discovery of placer gold caused a small stampede of prospectors from Dawson to upper Beaver Creek in 1902 but did not lead immediately to the finding of gold deposits of value, though it aroused interest in the district and encouraged further prospecting which finally was successful.

Placer gold was discovered near the mouth of Bonanza Creek early in the summer of 1913 by William James, N. P. Nelson, and a Mrs. Wales, all of whom had come into the district from the Canadian side

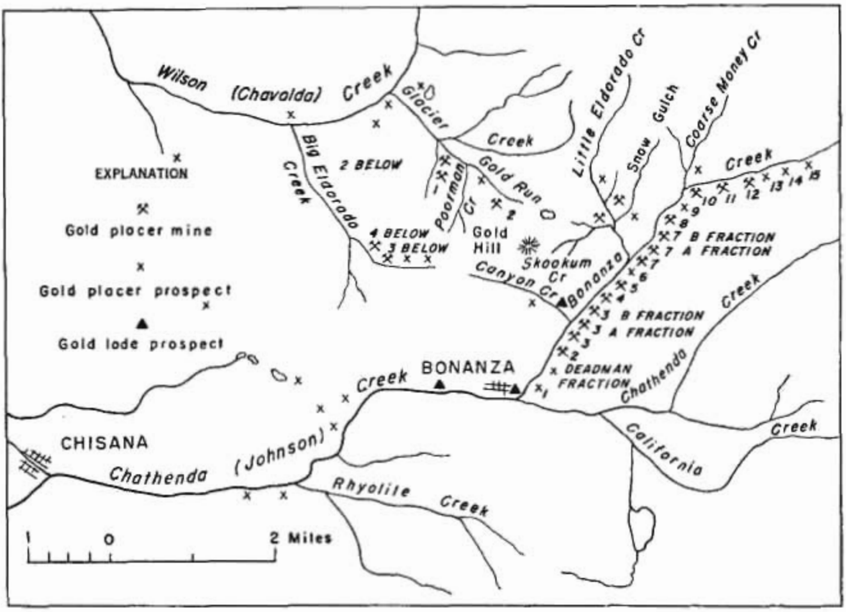

FIGURE 40.—Sketch map of the immediate vicinity of the placer mines of the Chisana district, showing approximate position of mines and prospects as described by Capps.

of the international boundary. When the importance of the find became evident Nelson and Andrew Taylor, who had been prospecting in that vicinity, returned to Dawson for supplies and some simple equipment to begin mining. During their absence James prospected the upper part of the stream and discovered the rich ground of Little Eldorado Creek. The reports of Nelson and Taylor in Dawson started a stampede of prospectors to the district during the fall and winter of 1913–14, and several thousand men visited it, many of them inexperienced and most of them unprovided with food and proper equipment. The scanty provisions of the camp were soon exhausted, and the later part of the winter was a time of hardship for many. Hundreds of claims of no value were staked and then abandoned when the small area of the gold-bearing gravel was learned. A few of the early comers who had obtained the most valuable ground remained, and some of them have been mining their claims to the present time. In 1940 the total gold production of the district was estimated to be about $970,000 and since that time has not increased materially.

Upper Bonanza Creek and upper Little Eldorado Creek, all of Wilson (Chavolda) Creek and the lower courses of its tributaries previously mentioned are in an area of Mesozoic sedimentary rocks intruded by a few dikes and sills of igneous rock. Lower Bonanza Creek and some of the headwater parts of the Wilson tributaries are within the area occupied by Devonian and Permian volcanic rocks, interbedded sediments and a large intrusive body of diorite. Between the two areas of Paleozoic and Mesozoic bedded rocks is a great fault.

The valleys of all the streams of the district were buried deeply under ice during the last glacial advance and are strongly glaciated, as is shown by their topographic forms. Since the disappearance of the ice the streams have been readjusting their channels to the glaciated valleys and in places have cut canyons in the valley floors. The lower part of Bonanza Creek from the mouth to Canyon Creek is in a deep box canyon which gradually opens out above Canyon Creek and ends below Little Eldorado Creek. Above Little Eldorado Creek the valley is open.

The creek gravels are commonly a mixture of material from both the older and younger rocks exposed in the adjacent areas but include a certain small proportion of foreign material transported by ice from more distant sources. In general the gravel deposits are shallow and are permanently frozen except at the surface where they are exposed to the warm air in summer. They therefore are uncovered by the removal of any insulating vegetation or muck and allowed to thaw before they are mined and washed.

The richest deposits of placer gold mined in the Chisana district were on Little Eldorado Creek and Bonanza Creek. Placer gold was not restricted to the gravel of these two streams, but the distribution of gold in their gravel deposits and the relative scarcity of gold in the gravel deposits of streams within the area underlain by Mesozoic sedimentary rocks give strong support to the belief that the original source of the gold was in the older rocks in the vicinity of Gold Hill. Probably little if any of the gold-bearing gravel of Bonanza and Little Eldorado Creeks was deposited until after the ice disappeared. Although the gold is of local origin it probably is in large part a secondary concentration from old Tertiary gravel deposits, most of which have been destroyed by erosion. The old, deeply weathered gravel that caps Gold Hill contains gold and is believed to be a remnant of a much more extensive deposit from which a large part of the gold in the present placers was derived. A small proportion of the gold, however, in particular that from gravel in the area of diorite west of Gold Hill, is so little worn as to suggest that it was freed from its bedrock source at a later time, after the "retreat" of the ice.

As would be expected from the presence of gold in the valley of Bonanza Creek, the gravel deposits of Chathenda Creek also were found to contain gold, although nowhere enough to be mined profitably. The lower claims on Bonanza Creek included the canyon, where the channel was narrow and the gravel difficult to mine. The benches as well as the creek gravel carried a small amount of gold, but mining there was little more than sniping. Mining on claim No. 2, which is below Canyon Creek, showed that the canyon now occupied by Bonanza Creek is cut in the bedrock, which contained gold-bearing gravels, below higher and older channels that were cut in slide rock from the mountain side. The reports of miners and the production of the claims show that an increase in the gold content of the gravel was observed as the creek was followed upstream. The richest gravels were just below the mouth of Little Eldorado Creek. The benches east of claims Nos. 4 and 5 also carried gold that was mined profitably. A few rich spots were found on Bonanza Creek a short distance above Little Eldorado Creek, but these were soon worked out. The upper part of Bonanza Creek, above claim No. 12, was without gold deposits of value. Skookum Creek, a short western tributary of Little Eldorado Creek, has some rich ground, but the upper part of Little Eldorado was unproductive. Gold Run and Poorman Creeks, tributaries of Glacier Creek, which in turn is a tributary of Wilson (Chavolda) Creek, have gold-bearing gravels that have been mined on a small scale since the early days but have not been important producers. They, like Big Eldorado Creek toward the west, appear to have derived part of their gravels from Gold Hill. The upper part of Big Eldorado Creek lies within the area of diorite and is notable because of the character of the gold in its gravel deposits. According to Capps (1916, p. 113) the gold of upper Big Eldorado Creek, claim No. 3 below Upper Discovery, is found on or in the diorite bedrock.

* * * From 2 to 4 feet of the diorite is removed in mining. The gold is bright, coarse, and very rough. Few pieces that showed signs of much wear were seen and most of the particles are angular and sharp, some crystal faces being discernible. Many pieces show the imprint of crystals of vein quartz upon them, and gold with some quartz attached is common. The gold is markedly different in appearance from the well-worn, smooth gold of Bonanza and Little Eldorado Creeks, and it is evidently of local origin. The present creek placer is probably a primary concentration of gold derived from the rocks that form the upper basin of this stream.

Gold-bearing veins in bedrock are not known by the writer to occur in the immediate vicinity of Gold Hill but have been found near the mouth of Bonanza Creek and in the mountain to the west. A gold-bearing vein was staked at the mouth of Bonanza Creek many years before the discovery of the placer gold and was in fact the lure that brought the discoverers of placer gold to this stream.

The heavy concentrates from the gravels of Bonanza Creek and the other gold-bearing streams of the district have not been studied to determine their mineral content, but a variety of minerals is reported, including gold, silver, copper, galena, cinnabar, and molybdenite. The distribution of these minerals, if determined, might give some information regarding the source of gold. The mining operations on the bench claims east of Bonanza Creek and below the mouth of Little Eldorado Creek led the miners to believe that the gold of the old channel there was from the same source as the gold from Little Eldorado Creek, as galena was not found with the gold in the sluice boxes.

Assays of the gold, furnished by the owners or operators of several claims, showed a range of value, then current, from $16.35 to $16.90 an ounce (Capps, 1916, p. 105). In general the gold of most of the claims was coarse, smooth, and well-worn except a small proportion that appears to be either a product of later erosion at a nearby source or possibly a part of an older deposit that escaped reconcentration. The largest nugget of gold found in the district had a reported value of over $130.

The miners of the Chisana district have labored under many adverse conditions. The district is remote and without adequate transportation facilities. Several dangerous glacial streams had to be crossed to reach it. Wages were high and labor in such a distant place was not plentiful. As Bonanza Creek is above timberline, timber for mining and wood for fuel had to be brought over a difficult trail from the spruce-covered bars of the Chisana River. The gravels were frozen and the working season was short, commonly averaging between 90 and 100 days for surface mining. All these factors worked together to increase the cost of producing gold and consequently required gravel of a high gold content to make mining profitable. In the early days of the camp most of the supplies and equipment were brought to the creeks by sled in winter or by pack horses in summer. The route from Dawson was abandoned after the first rush of prospectors and the pack trail over Skolai Pass to McCarthy on the Copper River railroad became the established way of approach. Although a pack trail from Chisana to the Nabesna highway is available and sometimes used, the miners in recent years have employed airplane transportation for both men and freight, and a landing field is maintained at Chisana.

OTHER PROSPECTS

Few streams in the Chisana district and adjacent areas have escaped the visits of prospectors in search of gold. Traces of gold have been found in many of the gravel deposits but gold-bearing gravels that can be mined at a profit were not discovered outside the vicinity of Bonanza Creek. Bryan Creek, which is a small stream a few miles south of Chathenda Creek, held some promise for a time. A number of places were prospected and a little gold and many copper nuggets were recovered, but the creek was finally abandoned. Cheslina River, one of the streams on the north side of the Nutzotin Mountains west of the Nabesna River, has gravel deposits that carry gold. These deposits have been prospected at various times without yielding gold that could be recovered profitably. Little Jack Creek, one of the branches of Jack Creek, was also prospected for gold. A prospect pit was sunk in the gravels near the head of the stream but with disappointing results. This stream is in the area underlain by Mesozoic sedimentary rocks cut by granitic dikes and sills. Its prospected gravel deposits are of local origin, and it appears to be fairly certain that the gold also is of local origin and therefore that the original veins were of late Mesozoic or still later age.

LODE DEPOSITS

The discovery of lode deposits containing valuable metals preceded the discovery of placer gold deposits in the eastern Alaska Range. The search for mineral deposits began about 1898 and was carried on by prospectors who came from both sides of the international boundary. None of the prospects that were staked in the early days have yet become mines although considerable time and money have been spent in exploring some of them. Gold, copper, molybdenum, and antimony are the metals that have attracted most attention. The productive mines and the prospects where considerable development has been done are the Nabesna Gold mine, the copper-gold-molybdenum deposit at Orange Hill, copper prospects on the Snag River, a molybdenum deposit on Rock Creek, and an antimony deposit on Stibnite Creek near the head of the Tok River. A brief description of these localities will be given. Other prospects are known but have not held much encouragement to those who tried to exploit them.

THE NABESNA GOLD MINE

The Nabesna gold mine (Wayland, 1943, p. 175–195) is on the south slope of White Mountain near the head of the Nabesna River. The mine buildings and mill are at the foot of the mountain, at an altitude of 3,000 feet and just below the upper limit of timber. An automobile road 105 miles long, the Abercrombie trail or Nabesna road, connects the camp with the Richardson Highway. In addition, the camp has ready access to Reeve Field, five miles away, on the bars of the Nabesna River and about 45 miles from Slana, on the Slana-Tok highway. The original claims were located in the years 1903–05 by A. J. Fjeld and Paul Paulson who formed the Royal Development Company under which the first development work began. A small mill was brought from Valdez and installed and 60 tons of ore was milled in 1907. The results of the mill operation were not profitable, but the company continued assessment work on the claims till about 1914 when it abandoned the property. The ground was restaked by Carl F. Whitham in 1924. Mr. Whitham discovered the Bear Vein the following year, organized the Nabesna Mining Corporation in 1929, and installed a mill which began operation in 1931. By 1940 the original ore bodies near the mill site had been worked out, but other ore bodies belonging to the corporation were waiting development and were conveniently located for exploration from the Nabesna camp. Work was started on one of them in 1941 but was discontinued after the entry of the United States into World War II. The ore deposit of the Nabesna mine was examined by Russell G. Wayland shortly before mining was discontinued. His report (1943, p. 175–195) is the source of the following information.

The ore bodies of the Nabesna mine are contact-metamorphic deposits which were formed where an irregular, elongated stock of quartz diorite was intruded into the lower, massive, nearly horizontal beds of the Upper Triassic limestone. The intrusion of the diorite produced extensive changes in the adjacent limestone along the east side of the stock, recrystallizing it and introducing new minerals that are characteristic of contact-metamorphic deposits. Among the principal introduced minerals, as determined by Wayland (1943, p. 175), are andradite, vesuvianite, diopside-hedenbergite, and magnetite. They with other less abundant minerals are characteristic of a limestone that has been altered to tactite. Other metamorphic minerals resulting from the intrusion and later alteration are: apatite, brookite, calcite, epidote, gypsum, hessonite, limonite, penninite, pyrite, serpentine, specularite, sphalerite, spinel, titanite, thuringite, wollastonite, and uralite.

The ore minerals are irregularly distributed and occur most abundantly in the limestone although they also occur sparingly in parts of the diorite. They include pyrite, chalcopyrite, galena, sphalerite, and gold. Calcite is a common gangue mineral and quartz occurs in the upper parts of some veins.

Wayland describes three types of mineralization at the Nabesna mine: (1) bodies of magnetite with pyrite, calcite, and some gold; (2) veins and pockets of pyrrhotite with or without pyrite and gold; and (3) veins of auriferous pyrite with calcite which follow fractures in the limestone or along contacts of intrusives and limestone. The third type is the only one that so far has been important as a producer of gold. Most of the veins average about 5 feet in width and are parallel to the contact between the quartz diorite and limestone, which below the 200-foot level of the mine dips steeply to the east. The pyrite veins replace the limestone along fractures and contacts of the diorite and limestone. Movement has taken place along some of the veins since they were formed.

The outcrop of the Bear Vein which was the point of original discovery of the Nabesna mine is in a little sag in a spur of the mountain, 1,000 feet above the camp. The vein was faulted and crushed, and the interstices of the crushed vein material in its upper part were filled with ice. When mined and allowed to thaw the ore slacked down to a mass of angular fragments. The contact between the limestone and diorite was explored down to the 650-foot level, but no ore was found below the 550-foot level. Most of the gold recovered after 1936 came from ore bodies between the 250-foot and 450-foot levels. The gross production of the mine at the time when mining ended in 1940 was $1,869,396, of which a small part was from silver and copper recovered at the smelter.

LODE GOLD PROSPECTS

In addition to the Nabesna lode mine which has already been described, several other auriferous mineral deposits are known that have not been mined although they have been prospected by stripping, opencuts, or adits. The deposit at Orange Hill is one of these, but its copper content is such that it is more properly considered in connection with that metal.

A gold-bearing deposit that has been known for a long time is situated near the head of the small stream about 2½ miles west of Rock Creek. This prospect is near the head of the valley, about 1,000 feet higher than the road, and is reached by a trail beginning at Mile 82 on the Nabesna road. It is within the area mapped as Permian volcanic rocks. At this place, according to a personal communication from R. E. Van Alstine, a trachyte dike 8 feet thick, which strikes N. 55° W. and dips 45° NE., cuts diorite gneiss. Stringers of quartz, calcite, pyrite, galena, and sphalerite from ¼ inch to 2 inches thick form a vein zone ranging from 6 to 12 inches in width. An adit was driven N. 65° E. to cross-cut the vein but was caved at the time of visit (1942). West of the adit and across the creek is another trachyte dike that shows slight pyritization along the contact. The gold content of these veins was not learned.

Several gold-bearing veins have been staked in the vicinity of Bonanza Creek. One of these at the entrance to the canyon near the mouth of Bonanza Creek was known before the discovery of the placer gold and was the immediate cause of that discovery. The mineralized body is in the west wall of the creek which is here formed by a dike of porphyritic intrusive rock of pink to gray color which contains abundant pyrite. Oxidation of the pyrite has stained the surface a rusty red. The dike is intruded into the Paleozoic rocks; it strikes N. 20° W. and dips 75° N. It is cut by small quartz veins and incloses bunches of pyrite. It is said that free gold may be panned from this dike rock (Capps, 1916, p. 118).

A number of other gold-bearing veins in the Bonanza Creek area have been described (Capps, 1916, p. 118–119; Moffit, 1943, p. 163–164), but none of them arouse active interest at present.

COPPER

Native copper of local origin was known to the Indians of the Nabesna-Chisana-White River district and was used by them before the white men came among them. In 1902, Schrader (Mendenhall and Schrader, 1903, p. 40) purchased copper nuggets from the natives on Cross Creek and states that the nuggets were reported to come from a small stream on the west side of the Chisana Glacier, about 6 miles from its front. As far as is known all the native copper is associated with the Permian volcanic rocks and is found in them at many widely distributed localities. Many copper nuggets have been picked up on bare hilltops where the old volcanics have been exposed to weathering.

Copper has not been produced commercially in the eastern Alaska Range. The gold placer deposits of both the Chistochina and Chisana districts yield native copper, and lode deposits made up in part of copper and iron sulfide minerals have been prospected in the Nabesna and Chisana districts. All the lode deposits that gave promise of copper in sufficient quantity to be of value are in the Paleozoic rocks although the deposits themselves probably are of Mesozoic age. Several copper deposits in the valley of the White River were discovered in the early days but are outside the area considered in this report. The mineral deposits of Orange Hill were at first valued for their copper and gold, and exploratory work on them was begun with those metals in mind. Copper prospects were found at two places in the Snag River area but were given up after considerable work had been done on them. These deposits are within the area of the Permian volcanics on the East Fork. The two prospects are known locally as the O'Hara (Pilgrim, 1931, p. 75; Moffit, 1943, p. 169–170) and the Reynolds prospects although the mining operations were conducted under the name of Chisana Mines, Inc. The O'Hara prospect is near the top of the spur between the Snag River and the East Fork at an altitude of 5,400 feet, or 1,200 feet above the camp on the Snag River 2½ miles from the mouth of the East Fork. The prospect is just over a little saddle in the ridge, on the East Fork side. The saddle marks the boundary between amygdaloidal basalt on the north and southwest-dipping Mesozoic sedimentary rocks on the south.

An adit was driven to the northwest in a fracture zone in andesitic and basaltic flows resting on an adesitic flow breccia. An opencut a few feet higher than the adit, which was 87 feet long when Pilgrim visited it in 1930, shows pyrite and copper sulfides in the sheared country rock and a coating of malachite and copper sulfate on the walls. The zone of fracturing extends northwestward across the knob that forms the top of the spur and contains copper minerals at several places.

The Reynolds prospect is 2 miles southeast of the O'Hara property, on the west side of the valley of a small tributary of the East Fork. A trail leads from the mouth of the creek to the prospect 900 feet higher on the mountain side. Here are several opencuts in the amygdaloidal basalt or greenstone which show small veins containing malachite, bornite, specularite, and chalcocite with calcite. The exposures do not indicate a well-defined shear zone but rather a net of small veins distributed through the fractured basalt.

ORANGE HILL

Orange Hill is a round-topped, isolated knob on the east side of the Nabesna River, near the end of the Nabesna Glacier, 12 miles from the Nabesna mine and the road. It owes its existence to differential weathering and glacial erosion and its name to the color of the iron-stained rocks that form it. The hill is part of a mass of quartz diorite of probable Jurassic age intruded into the group of bedded Permian rocks that includes basic lava flows, graywacke, and a thick deposit of limestone. The geologic conditions at Orange Hill are thus much like those at the Nabesna mine.

The vicinity of Orange Hill attracted the attention of the first prospectors in the district, and many claims were staked as early as 1899. Gold and copper were sought at first; molybdenum was later of prospective value, and, still later, zinc. These metals and silver all contribute to the value of the claims owned by the Alaska Nabesna Corporation, which has done the more recent exploratory work in this vicinity.

The latest investigation of Orange Hill by the U. S. Geological Survey was carried on by R. E. Van Alstine in 1942, and by Van Alstine and R. F. Black in 1944. Their work[5] has been freely used in the preparation of this description.

The top of Orange Hill rises about 650 feet above the flood plain of the river and is separated from the steep mountain slope on the east by a canyon and shallow saddle. Orange Hill and the lower slope of the mountain are composed of quartz diorite. To the southeast the entire ridge is formed by the moderately dipping bedded rocks, including the massive limestone which here constitutes the face of the ridge. The limestone was profoundly altered by the intrusion of the

[5] Van Alstine, R. E., and Black, R. F., 1944, Mineral deposits at Orange Hill, Alaska: U. S. Geol. Survey open-file rept.

quartz diorite batholith and the associated dikes and sills, for it is recrystallized and in places changed to tactite resembling the tactite at White Mountain.

Copper, molybdenum, zinc, and gold- and silver-bearing minerals occur in both the quartz diorite and the adjacent limestone. The quartz diorite is altered hydrothermally, and weathered and colored by iron oxides and molybdite, the yellow oxide of molybdenum. The sulfide minerals in the quartz diorite, in decreasing order of abundance, are pyrite, chalcopyrite, and molybdenite. They occur disseminated through the quartz diorite and in veinlets cutting it and are there associated with quartz, gypsum, and calcite. Chalcopyrite is the chief copper mineral in the quartz diorite. Molybdenite occurs not only with gangue minerals in the veinlets and as disseminated grains in the rock but also as films on joint faces and slickensided surfaces.

The principal body of limestone overlies interbedded argillite and graywacke and dips to the southwest at an angle lower than the mountain slope. The metamorphic effects of the intrusion of the quartz diorite on the limestone extend at least one mile from Orange Hill or from any surface exposure of the intrusive. The contact metamorphic and tactitic minerals include calcite, wollastonite, garnet, magnetite, hematite, pyrrhotite, pyrite, chalcopyrite, bornite, tetrahedrite, sphalerite, molybdenite, quartz, and gypsum. Garnet replaces limestone beds to form banded garnetite and occurs as disseminated grains or veinlets in the crystalline limestone. One of the unusual phases of the altered limestone is a rock made up wholly of garnet and gypsum.

Alteration products derived from the contact-metamorphic minerals are chlorite, limonite, hematite, covellite, chrysocolla, malachite, and azurite.

The principal copper minerals of the limestone area are bornite and chalcopyrite. They are found extensively with other sulfides in veins and pockets or irregularly shaped bodies near the base of the limestone. They also occur as disseminated grains in the limestone and garnetite. Molybdenite is widely distributed in small quantity in the limestone. Zinc also is widely distributed as sphalerite in association with the other sulfide minerals and at one place is exposed in a vein of considerable surface area.

Underground development work and extensive prospecting with the diamond drill were carried on by the Alaska Nabesna Corporation to test the extent and value of its holdings. This drilling was done at a time when copper and gold were thought to be the valuable metals present and was not originally planned to test the molybdenum content of the ores. The increased demand for molybdenum suggests the desirability of further drilling to delimit the ore body and determine its content of molybdenite. The ore minerals of Orange Hill are of surprisingly wide distribution, but the proportion of valuable metals in the mineralized bodies is small, and their successful exploitation apparently will depend on the value and recovery of all the metals, rather than a single metal.

ANTIMONY

Antimony in the form of the sulfide, stibnite, is known at several places in the eastern Alaska Range, two of which will be described (Moffit, 1944, p. 44, 45). The largest deposit found up to this time is on Stibnite Creek (Van Alstine, 1942, U. S. Geol. Survey unpub. rept.), in the Tok River valley. Another, smaller deposit occurs near the Rapids roadhouse, east of the Delta River.

Stibnite Creek is a small northern tributary of the upper Tok River which it joins two miles east of the trail that leads from the Tok to the Robertson River. The most convenient route for reaching Stibnite Creek at the present time is up the valley of the Tok River from the Slana-Tok highway near the mouth of the Little Tok River. Stibnite Creek has two branches that occupy narrow, canyonlike valleys and unite about one mile from the Tok River. The stibnite prospect is on the east branch nearly a half mile from the forks.

The deposit was discovered (Brooks, 1916, p. 63) in 1914 but was abandoned after some exploration had been done; it lay idle until 1941 when another attempt was made to exploit it and recover some of the richer ore for shipment.

Stibnite Creek is within the area underlain by early Paleozoic or pre-Cambrian schist and gneiss which here appear to consist, for the most part, of altered sedimentary rocks. The metamorphic rocks are intricately folded, much faulted, and are intruded by granitic igneous rocks. Some of the intrusives are sheared and altered but much less so than the enclosing rocks. The alteration of the granitic rocks is not uniform, which may be owing to local conditions or may indicate different times of intrusion. Many veins of quartz and calcite cut the country rock.

The stibnite vein crops out as a projecting ledge in the canyon wall at the edge of the flood plain and cuts a bed of brown-weathering schist about 100 feet thick which strikes N. 65°–70° W. and dips 50° S.

The deposit is inclosed by fault planes that have slightly different strikes and dips and converge upward so that the ore body, which measures nearly 20 feet across the exposed face at the level of the flood plain, is reduced to 2 feet at 25 feet above the flood plain and then is covered by the vegetation and loose slide rock. The thickness of the ore body appears to be somewhat less than 20 feet but is difficult to estimate because of the faulting and uncertainty regarding the true shape of the body. The deposit is made up of a central part, 6 feet thick, of high-grade ore consisting of stibnite and a little quartz, and border zones of lower grade. On the southwest or hanging-wall side the proportion of quartz is greater than in the central part and on the northeast side it is still greater. The stibnite of the central body is chiefly coarse, bladed crystals intergrown with gray, coarse-grained and fine-grained quartz. In places, however, the stibnite is fine-grained. Some of it is stained with a red alteration product, probably kersenite, of no economic value. Vugs in the ore body show fine, hair-like crystals of stibnite. A few grains of pyrite occur in some low-grade ore.

In the early part of 1941 Mr. Sam Gamblin of Gulkana mined and prepared for shipment some of the easily won, higher grade ore from this deposit. The ore was piled on the bars of the creek, but the spring thaw came before it could be hauled to the Nabesna road, now a portion of the Slana-Tok highway. The ore has since been scattered by the high flood waters and lost.

A small deposit of stibnite (Van Alstine, 1942, U. S. Geol. Survey unpub. rept.) was found 1½ miles south of the Rapids roadhouse and ⅓ mile east of the Richardson Highway, opposite the Black Rapids Glacier. This deposit is at about the same altitude as the highway and, like the deposit of Stibnite Creek, is within the area of schist and gneiss. It has been explored by an opencut, stripping, and an adit which is now caved.

The schist is believed to be an altered sedimentary rock; it has a foliation that strikes N. 70° W. and dips 45° N. An opencut 10 feet long in the schist revealed a vein of quartz and stibnite having a maximum thickness of 12 inches but averaging 6 inches. This vein strikes N. 70° E. and is about parallel with the foliation of the schist. The stibnite occurs as coarse, bladed crystals and makes up about one-half of the vein matter. This deposit appears to include no other sulfide minerals and contains little if any gold and silver. Faulting took place after the vein filling was introduced.

Stripping the loose surface material from the bedrock about 30 feet north of the opencut exposed a vein of quartz containing a little pyrite and stibnite, but the quantity was too small to encourage further development work.

The adit, which is the third place of exploration in this vicinity, is 250 feet west of the stripped area and was driven on a vertical vein of quartz which ranges from 1 to 3 feet in thickness and strikes N. 70° E. A little pyrite is associated with the quartz but no stibnite appears to be present in the material now exposed. This vein otherwise is like that in the stripped area and possibly is the same vein.

MOLYBDENUM

In recent years molybdenum has been in great demand because of its increased use as an alloy with iron. The sulfide, molybdenite, is reported as a constituent of several mineral deposits in the eastern Alaska Range and has already been described as occurring in association with copper, gold, silver, and zinc at Orange Hill. Another ore deposit in the eastern Alaska Range has been prospected solely to test its commercial value as a source of molybdenum. This prospect is near the head of Rock Creek (Moffit, 1941, p. 150–153), which is in the eastern part of the Copper River drainage basin and crosses the Nabesna road (Abercrombie trail) at mile 84½. The stream is small and heads in a rugged mountain between the highway and Suslota Creek. Most of the Rock Creek valley is carved in the dark Permian lava flows, but a small part of the upper valley extends into an area of lighter colored granitic rocks.

The molybdenum prospect is a little less than 4 miles by trail from the highway and almost 2,000 feet higher. At its upper end the narrow valley of the southeast branch of Rock Creek divides into two steep gulches. The outcrop of the molybdenum deposit, several opencuts, and an adit are located in the narrow ridge between these gulches.

The geology of the area is complicated because of the variety of igneous rocks. The Permian lava flows are somewhat altered locally and were intruded at different times by igneous rocks of several kinds. The boundary between the area of basaltic flows on the southwest and the granitic rocks on the northeast is below and southwest of the discovery outcrop. According to Van Alstine (1942, U. S. Geol. Survey unpub. rept.), the coarse-grained granitic rocks in the vicinity of the adit may be differentiated into a pink syenite gneiss, and dark quartz diorite gneiss. The syenite gneiss forms a belt about 1,000 feet wide, trending N. 50° W. It has been traced for three miles northwest and southeast from the adit and probably extends along the whole southwest side of the area of granitic rocks. Interlaminated with the syenite gneiss are bands of biotite schist ranging in thickness from a fraction of an inch to 4 feet. Small dikes of syenite cut the quartz diorite, and dikes and lenses of pegmatite cut the syenite gneiss and biotite schist.

The molybdenite occurs mainly in a pegmatite dike that cuts the syenite gneiss between the gulches. This dike, which strikes N. 20° W. and dips 60° SW., has a thickness ranging from a few inches to 2 feet and was traced for about 70 feet along the hillside. The molybdenite occurs as plates, lumps, and tiny veinlets and is irregularly distributed in the pegmatite. Some plates of molybdenite are as much as 1½ inches in diameter and ¼ inch thick. Vugs in the pegmatite are lined with dolomite and calcite intimately associated with molybdenite.

Flakes of molybdenite were found in places in the syenite and the biotite schist.

Samples of the molybdenum-bearing pegmatite, taken from the discovery outcrop by a representative of the Kennecott Copper Corporation, indicated a deposit of commercial value if the size of the ore body were sufficient to justify the expense of opening it up. The company undertook the exploratory work and drove an adit nearly 170 feet long in the ridge 100 feet below the discovery outcrop and opencut. This adit failed to uncover molybdenite in sufficient quantity, and exploration was stopped.

OTHER PROSPECTS

A few other prospects are known that are of interest because of their mineral associations, their possible value, or because more than superficial exploratory work has been done on them.

A deposit of lead and zinc minerals is reported to be exposed in a gulch on the north side of Cross Creek, a western tributary of the Chisana River, near the lower end of the glacier. This deposit has not been fully investigated. Although sphalerite is present in a good many vein deposits of the district it is not known in large amount and had not been regarded with interest until a sharply increased demand for zinc supplies during World War II stimulated a search for zinc deposits not previously exploited.

The group of mountains between the Copper and Slana Rivers, drained in large part by Ahtell and Indian Creeks, shows mineralized zones in which galena is prominent (Moffit, 1931, p. 121–124; 1938, p. 45–48). The area was one of the first to be prospected in the Copper River basin, and a number of its mineral deposits were discovered as early as 1898 or 1899.

Silver Creek, as it is called locally, is a small southern tributary which joins Ahtell Creek about one mile below Flat Creek. The stream is in an area of undifferentiated igneous rocks, which at the prospect are mainly medium-grained diorite and a dark basaltic-looking rock that was not definitely identified. About one mile from its mouth Silver Creek is crossed by a fault zone at least 30 feet wide made up of steeply dipping minor faults, most of which range in strike from N. 45° to 70° W.

The fault zone includes many veins of mineralized quartz that were exposed by opencuts, shafts, and an adit. The adit, which is near the north side of the creek, was driven in a crushed vein that shows quartz stained with copper and contains sphalerite, a little pyrite or chalcopyrite, and galena. A shallow inclined shaft, 100 feet higher on the hillside, was sunk in a zone of crushed vein matter that is about 4 feet thick and is highly stained with iron oxide. Veins and knots of quartz containing granular tetrahedrite, sphalerite, and pyrite or chalcopyrite are stained with a conspicuous blue copper stain. Similar mineral assemblages are seen in an opencut 25 feet northeast of the shaft and in the material on the dump of a caved shaft 50 feet to the southwest. The silver contained in the ore is probably carried by the tetrahedrite.

A mineralized vein containing quartz and metallic sulfides was found on the west branch of Ahtell Creek, 1½ miles from the mouth (Moffit, 1938, p. 47). It crops out on the north side of the valley on an open hillside 100 feet higher than the creek and was explored by a short adit. The country rock of the locality is diorite that is somewhat altered and much fractured. The ore minerals were deposited in a shear zone in a fine-grained phase of the diorite. The shear zone, which has a maximum width of 8 feet at the tunnel, strikes N. 30° E. and dips steeply west. The fractured country rock is cut by veins of quartz up to 8 inches in thickness, containing galena and iron sulfides, and has a surface staining of blue and green copper oxidation products.

Indian Creek has two principal branches which unite 5½ miles north of the Slana-Tok highway and drain an area west of Ahtell Creek occupied almost wholly by igneous rocks of various kinds, both intrusive and extrusive (Moffit, 1931, p. 122–124). The high mountain ridge between the east branch of Indian Creek and a small lake that drains into the west branch of Ahtell Creek is crossed by a series of vertical, east-west fracture planes distributed over a distance of 100 to 200 feet from north to south. This locality is 9 miles northeast of the forks of Indian Creek, at the head of a small stream draining into Indian Creek, and is 1,800 feet higher than the mouth of the creek. The country rock is a dark greenish, coarse-grained, porphyritic variant of the granodiorite-diorite group of igneous rocks of the district. Most of the exposures of vein quartz and ore minerals are on the Indian Creek side and slightly below the crest of the ridge.

The largest exposure of quartz is a milky white vein at least 10 feet wide that stands 6 feet above the adjacent hillside and can be traced several hundred feet down the mountain slope. Where it crosses the ridge 75 feet higher toward the east the width is reduced to 18 inches. Several opencuts on other veins exposed cavernous quartz containing galena, chalcopyrite, and probably pyrite. The quartz is stained with iron oxide and copper. Galena is by far the most abundant sulfide and occurs as well-defined veins in the quartz and as bunches with angular outlines distributed irregularly through the quartz. The proportion of sulfide minerals to quartz is small.

A mineralized quartz vein, similar in composition and manner of occurrence to that just described, is exposed in the ridge between the branches of Indian Creek. A small eastern tributary joins the west branch 5½ miles north of the forks. It drains an area of coarse-grained porphyritic rock that differs from the rock of the first locality in being a little less coarse-grained and in having a pinkish instead of greenish color. A vein of white quartz crops out on the west side of the spur between the two headwater branches of the creek. It is not well exposed but can be traced a short distance by the float. The quartz vein carries galena and is identical in appearance with the vein at the east branch of Indian Creek. The mineralization, however, is less.

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