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Geology of the Mount McKinley Quadrangle, Alaska

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A synthesis of available information on stratigraphy, structure, and mineral deposits

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CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE MOUNT McKINLEY QUADRANGLE, ALASKA

By John C. Reed, Jr.

ABSTRACT

The Mount McKinley quadrangle, in south-central Alaska, includes parts of the Alaska Range, the Tanana and Kuskokwim lowlands, and the Kuskokwim Mountains. Schists of Precambrian age crop out in the northern foothills of the Alaska Range. Sedimentary and volcanic rocks of Paleozoic and Mesozoic age are exposed in the Kuskokwim Mountains, where little is known of their distribution and character, and in the Alaska Range, where they occupy the axial part and northern limb of a great synclinorium. Granitic batholiths, largely of Mesozoic age, intrude the Paleozoic and Mesozoic rocks in the Alaska Range.

Poorly consolidated and semiconsolidated deposits of Tertiary age occupy narrow structural depressions within the Alaska Range and probably underlie deposits of Quaternary age over broad areas in the lowlands to the north.

Northeastward-trending normal faults, possibly with major lateral displacement, are prominent structural features of the Alaska Range. Movement on some of these faults probably began as early as Cretaceous time and has occurred along several faults in this system in Recent time.

Glacial, alluvial, and eolian deposits of Pleistocene and Recent age occupy most of the lowlands of the quadrangle. In addition to Recent moraines, those of at least two earlier glaciations have been recognized. Detailed correlation of the alluvial and eolian deposits with the glacial sequence indicated by the moraines has not been attempted.

Deposits of gold, silver, and antimony occur in the Kantishna Hills, and lead-zinc deposits are found at Mount Eielson. Copper, lead, zinc, and mercury occurrences have been reported from the foothills of the Alaska Range west of the Muldrow Glacier.

INTRODUCTION

The Mount McKinley quadrangle comprises an area of about 6,400 square miles in the south-central part of Alaska about 140 miles southwest of Fairbanks and 160 miles north of Anchorage (fig. 1). It includes most of the western part of Mount McKinley National Park. Most of the area is drained by the Tanana and Kuskokwim Rivers, but a small part south of the crest of the Alaska Range is drained by tributaries of the Susitna River.

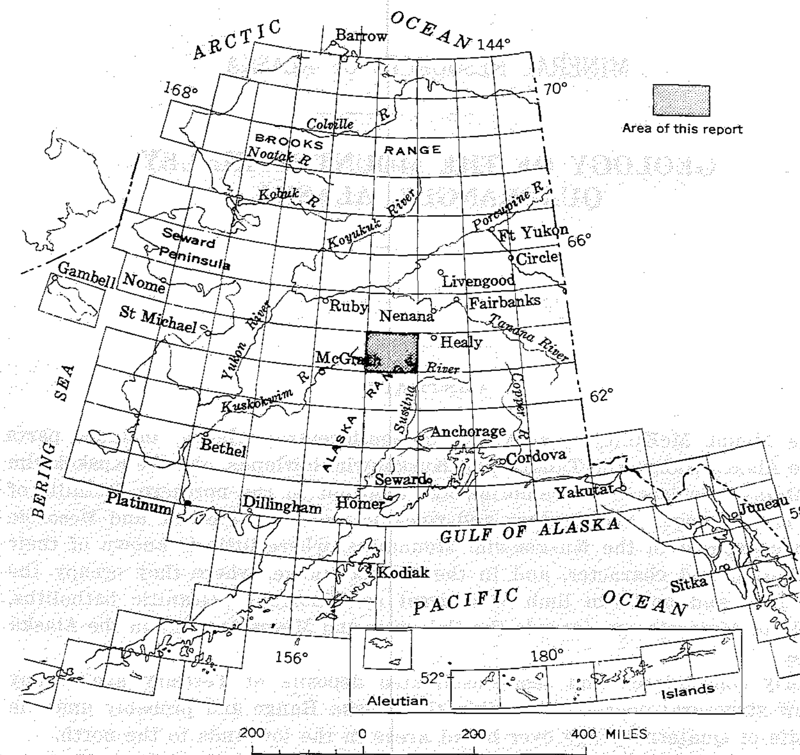

FIGURE 1.—Index map of part of Alaska, showing location of the Mount McKinley quadrangle.

The first geologic studies in the Mount McKinley area were made by A. H. Brooks and L. M. Prindle in 1902 and by Prindle in 1905 (Brooks, 1911). S. R. Capps studied parts of the Kantishna Hills and the northern flank of the Alaska Range in 1916 and 1925 (Capps, 1919, 1933); H. M. Eakin surveyed part of the area west of Lake Minchumina in 1915 (Eakin, 1918). In 1930 F. H. Moffit visited several mining claims (Moffit, 1933), and small mineralized areas were studied in 1932 by F. G. Wells near Kantishna (Wells, 1933) and by J. C. Reed at Mount Eielson (Reed, 1933). D. E. White made a detailed survey of the antimony deposit on Stampede Creek in 1941 (White, 1942).

This report summarizes all geologic information on the Mount McKinley quadrangle currently available to the Geological Survey. All published reports and available field notes of these earlier workers have been used. In addition, Bradford Washburn of the Boston

Museum of Science; Grant Pearson, former superintendent of Mount McKinley National Park; and Clyde Wahrhaftig, Florence R. Collins, and Florence Robinson of the Geological Survey have generously contributed unpublished information. The author made a general reconnaissance of the quadrangle in 1954 and devoted several weeks to detailed mapping of the Paleozoic and Mesozoic rocks along the Toklat River and near Anderson Pass.

In the preparation of the geologic map (pl. 1) some of the original data have been reinterpreted in the light of more recent studies, and older maps have been somewhat modified to fit the newer topographic base. Aerial photographs have been used extensively in adjusting the older maps and in supplementing field information in areas where little or no fieldwork has been done.

GEOGRAPHY

The major physiographic subdivisions of the Mount McKinley quadrangle are the Alaska Range and its northern foothills on the southeast, the Kuskokwim Mountains on the northwest, and a broad intervening lowland area which is continuous with the Tanana lowland to the northeast and the Kuskokwim lowland to the west.

The Alaska Range, one of the major mountain chains of North America, is part of a broad mountainous belt that extends in an arc parallel to the Pacific Coast of Alaska, connecting the Aleutian Range of the Alaska Peninsula with the Coast Range of western Canada and southeastern Alaska. The highest peaks in the Alaska Range are in the Mount McKinley massif, culminating in Mount McKinley, the highest peak on the North American continent. The northern slope of the range is one of the most abrupt mountain fronts in the world, rising from altitudes of 2,300 to 3,000 feet along its northern base to more than 20,000 feet at the summit of Mount McKinley (pl. 1). The perennial snowline on the north flank of the range is at altitudes of 7,000 to 8,000 feet, and all the higher valleys are occupied by glaciers, many of which extend down to altitudes of less than 4,000 feet.

Southwest of the McKinley River no major foothills lie between the Alaska Range and the lowland to the north. Between the McKinley River and the Toklat River, however, the Kantishna Hills, a group of low rugged mountains, extend as much as 20 miles north of the range. The highest peaks in the Kantishna Hills are a little more than 5,000 feet in altitude.

The Kuskokwim Mountains north and west of Lake Minchumina are characterized by gentle timbered slopes and broad rounded ridges with few exposures of bedrock. This area has not yet been adequately mapped topographically, and little is known about its geography and geology.

Between the Alaska Range and the Kuskokwim Mountains is a broad lowland of low relief, broken in a few places by low bedrock hills. The plain slopes northward from altitudes of 3,000 feet at the northern base of the Alaska Range to 650 feet at Lake Minchumina and 550 feet along the Kantishna River near the northern edge of the quadrangle. Although it appears flat when viewed from a distance, the lowland surface is actually studded with many low hills, scarps, ridges, and a myriad of lakes, ranging in size from permafrost pits and kettles a few feet in diameter to lakes several miles across. The major streams rise in the glaciers of the Alaska Range to the south and flow northward in broad alluvial valleys. Near the mountain front the valley floors are several hundred feet below the lowland surface but in the northern part, they are nearly level with the surface.

Timberline in the Mount McKinley quadrangle is between an altitude of 2,000 and 2,800 feet, reaching the highest altitude in sheltered parts of the major river valleys. The lowlands are timber covered, but over wide areas trees are stunted by permafrost, and timbered areas are interspersed with open swampy tracts. The principal trees are black spruce, white spruce, cottonwood, birch, aspen, and larch.

The only maintained road is the Denali Highway, a loose-surface graded road that connects the site of the old settlement of Kantishna with the Alaska Railroad at McKinley Park station about 90 miles to the east, and with the Richardson Highway near Paxson.

The Civil Aeronautics Administration maintains a landing field at Minchumina. In addition, there are small landing strips at several mines and prospects, but most of them are not regularly maintained. Many lowland lakes are also suitable for floatplane landings. A few winter sled trails cross the lowlands but most of the quadrangle is accessible in summer only by foot, horseback, or canoe. The only permanent inhabitants are a few prospectors and trappers and the personnel of the Civil Aeronautics Administration station at Minchumina.

GEOLOGY

PRECAMBRIAN ROCKS

BIRCH CREEK SCHIST

The Birch Creek schist crops out throughout the Kantishna Hills and in the low hills to the southwest, near Castle Rocks. The most widespread facies of the formation is a quartz-sericite schist in which mica flakes are oriented parallel to a well-defined foliation generally parallel to bedding. This schist weathers to shades of gray, green, brown, or red. Other common varieties are chloritic, sericitic, and graphitic schist; calcareous schist and schistose limestone; sericite phyllite; black slate; and massive quartzite. All of these facies are interbedded in varying proportions. Also interbedded with the rocks of sedimentary origin are greenstone bodies, which probably represent metamorphosed basaltic sills or flows.

Quartz veins of at least two ages cut the schist, some parallel with the foliation and following its contortions, others crosscutting the structures of the schist and apparently postdating the deformation.

Foliation is generally parallel to bedding, but locally shows crosscutting relationships in small drag folds. A fracture cleavage that fans around the axial planes of minor folds is particularly well developed in the quartz-rich beds. Intersection of the fracture cleavage with the bedding-plane foliation produces a lineation on the foliation surfaces marked by minor grooves and wrinkles parallel to the axes of small folds. Cross joints are locally well developed normal to this lineation.

The limited information on the regional structure in the Kantishna Hills indicates that the Birch Creek schist is folded into a series of gentle northeastward-trending anticlines and synclines, slightly asymmetrical to the northwest and complicated by faults, minor drag folds, and cross folds. (See Wells, 1933, p. 344–345; White, 1942, 335–337.)

According to Mertie (1937, p. 55–56) the Birch Creek schist is early Precambrian at its type locality in the Yukon-Tanana region. Rocks of the same lithology have been traced with minor interruptions along the north side of the Alaska Range into the Kantishna Hills area by Mertie (1937, pl. 10), Moffit (1954, pl. 7), and Capps (1912, pl. 2; 1940, pl. 3). Along the Toklat River some of the basal beds of the Paleozoic sequence strongly resemble facies of the Birch Creek schist, and possibly some areas mapped as Birch Creek schist in this report may contain infolded bodies of lower Paleozoic rocks.

PALEOZOIC ROCKS

TOTATLANIKA SCHIST

The area shown on plate 1 as Totatlanika schist is taken from Capps (1919, pl. 1). The rocks in this area are described in Capps' field notes (dated 1916) as "sandy slate, carbonaceous slate, and siliceous gneiss." At its type locality, 60 miles east of the Mount McKinley quadrangle, the Totatlanika schist consists largely of porphyritic (or porphyroclastic?) schist or augen gneiss probably derived from rhyolite flows (Capps, 1940, p. 105; Brooks, 1911, p. 149–150). Recent investigations (Clyde Wahrhaftig, written communications, 1954, 1957) have shown that the typical Totatlanika schist of the type locality interfingers westward near the Teklanika River with feldspathic schist, marble, variously colored phyllite, and stretched conglomerate. These rocks, rather than the Totatlanika schist of the type locality, probably make up most of the area mapped as Totatlanika schist in the Mount McKinley quadrangle. This area was not studied in the field during the present investigation, and the exact nature of these rocks is unknown. Fossils collected by Clyde Wahrhaftig during the summer of 1954 tentatively date the Totatlanika schist east of the type locality as no older than Silurian and no younger than Mississippian.

UNDIFFERENTIATED PALEOZOIC ROCKS

A group of metamorphosed sedimentary rocks believed to be largely of Paleozoic age crop out along the north flank of the Alaska Range and in several isolated belts in the foothills near Mount Sheldon. In previous reports (Brooks, 1911, pl. 9; Capps, 1919, pl. 2, Capps, 1933, pl. 4) these rocks have been subdivided into several mappable units, including the Tatina and Tonzona groups, but because of the distance from the Mount McKinley quadrangle to fossil-bearing localities of known age and because of uncertainties regarding the correlation, these rocks are mapped as a single unit in this report.

The most continuous section of these rocks in the Mount McKinley quadrangle is in the upper basin of the Toklat River, between the Denali Highway and the Denali fault. The oldest beds are probably those exposed to the south, between the headwater glaciers of the Toklat River and the fault. This area has never been studied in the field, but the rocks are probably similar to those several miles east along their strike that were described by Capps (1940, p. 101–102) as

> a series several thousand feet thick composed mainly of alternating layers of black slate or of argillite and graywacke or quartzite that exhibit varying degrees of schistosity * * * Intermingled with these rocks are some hard siliceous conglomerates, thin-bedded black limestone, and in places black or gray limestone beds that reach a thickness of 20 or 30 feet. All these rocks are abundantly seamed with quartz veins that attain 3 or 4 feet in thickness and show reticulating veinlets of calcite.

According to Capps, the base of the sequence is a dark-brown to black conglomerate 200 to 1,000 feet thick overlain by 50 to 200 feet of conglomerate consisting of white quartz in a white to gray siliceous matrix.

Dark-gray slate, argillite, and limestone occur in the upper part of the glacier basin at the head of the westernmost fork of the Toklat River. These rocks are similar lithologically to rocks which were described by Capps (1940, p. 102) from areas east of the Mount McKinley quadrangle and which overlie the sequence described above. Overlying the sequence of dark-gray slate, argillite, and limestone is a bed of massive gray limestone, commonly intensely sheared and cut by numerous calcite veinlets, that crops out at many places within the Alaska Range between the Nenana River and Rainy Pass. In exposures in the upper basin of the Toklat River the limestone is 300 to 400 feet thick, but locally it wedges out entirely, owing to original variations in thickness or to deformation. The limestone is very resistant to erosion and forms rugged cliffs and towers, and commonly caps ridges and peaks. The limestone can be traced eastward into the Healy quadrangle where it has yielded Middle Devonian fossils in several localities (Capps, 1940, p. 104; Moxham and others, 1953, p. 8–9). Middle Devonian fossils have also been collected from a similar limestone unit near Rainy Pass southwest of the Mount McKinley quadrangle (Brooks, 1911, p. 77–78).

Along the Toklat River the massive gray limestone is overlain by a sequence of several thousand feet of thin (1- to 6-in.) alternating layers of dark-gray or blue chert, and fine-grained sandstone, argillite, and limestone. Alternating layers of chert and limestone make up most of the lower part of the sequence; upward the layering is similar but the bands are black argillite and buff crossbedded sandstone, commonly graywacke. Sandstone beds are commonly crossbedded and have sharp lower contacts and gradational upper contacts, and the surfaces of some argillite beds have markings that may be worm tracks or tubes. However, none of these characteristics has proved to be of stratigraphic value. Thin intraformational conglomerate beds composed of angular chert fragments are common. The banded sequence weathers light brown and forms rather smooth rounded slopes. Near the upper forks of the Toklat River the sequence is cut by many stocks and sills of greenstone, described below.

The upper part of the undifferentiated Paleozoic sequence exposed near Highway Pass is composed of banded limestone, brown sandy phyllite and argillite, and a few beds of sedimentary breccia composed of angular white and black chert pebbles. Possibly these upper beds are separated from the underlying banded sequence by an unconformity.

Undifferentiated Paleozoic rocks crop out in two narrow northeastward-trending belts between Stony Creek and the Toklat River north of the Denali Highway. The two belts are separated by a narrow syncline of Cretaceous rocks on Mount Sheldon. Here the oldest rocks are probably the highly contorted quartz-sericite and quartz-graphite schist exposed along the modern edge of the northern outcrop belt.

The foliation is parallel to the bedding; lineation due to crinkling of mica flakes parallel to northeastward-trending fold axes is well developed. Quartz pods parallel to the foliation are common. This schist closely resembles phases of the Birch Creek schist, and possibly should be mapped with it. Southward and presumably stratigraphically upward, the schist grades without a sharp break into a black slate series that contains massive black resistant quartzite beds 50 to 100 feet thick. There is no evidence of structural discordance or noticeable differences in degree of deformation between the black slate and quartz schist sequence. Farther to the south the black slate is interbedded with many 2- to 3-foot beds of dark-gray limestone. Near Mount Sheldon, folds in the Paleozoic sequence are truncated by the massive basal conglomerate of the overlying Cretaceous Cantwell formation.

The Paleozoic rocks immediately south of Mount Sheldon are identical with the black slate-limestone sequence to the north; in fact, only a few hundred yards of Cantwell rocks separate the two belts in the bottom of the Toklat River valley.

No identifiable Paleozoic fossils have been collected in the Mount McKinley quadrangle. The age assigned to most of the Paleozoic rocks is based primarily on their association with the Middle Devonian limestone and on their similarity to beds of the Tatina and Tonzona groups north of Rainy Pass. Ordovician fossils have been collected from the Tatina group in several localities in the McGrath quadrangle (Brooks, 1911, p. 72–73). Capps (1919, p. 33–34) collected some poorly preserved corals from a limestone bed associated with Tonzona rocks near the head of the Sushana River in the Healy quadrangle; the corals were reported by the late T. W. Stanton of the Geological Survey to be similar to corals from Triassic limestone in other parts of Alaska and he thought them to be Triassic in age. Possibly some Mesozoic beds are included with the undifferentiated Palezoic rocks shown on plate 1.

Eakin (1918) has mapped a group of sedimentary rocks consisting of thick limestone beds associated with dark, commonly siliceous or cherty, calcareous slate, along the North Fork of the Kuskokwim River just west of the Mount McKinley quadrangle. Middle Devonian fossils were collected from this area, indicating that rocks equivalent to at least part of the undifferentated Paleozoic sequence in the Alaska Range occur in the extreme northwest corner of the quadrangle.

UNDIFFERENTIATED PALEOZOIC OR MESOZOIC ROCKS

Eakin (1918, pl. 2) mapped a series of slightly metamorphosed sedimentary rocks in the hills between the Kantishna River and the North Fork of the Kuskokwim. According to his description, the sequence consists almost entirely of chert and slate with some conglomerate, and sandstone. The chert occurs in beds ranging from a few inches to about 10 feet in thickness and has a wide range of colors, including black, gray, green, red, and intermediate shades. Some metamorphosed phases of the chert contain secondary mica.

The slate, acording to Eakin, is a compact, even-grained rock with a very regular cleavage. It occurs in beds from 10 feet to more than 100 feet thick and commonly underlies topographic depressions between hills that are capped by the more resistant beds of chert.

Along the northwest shore of Lake Minchumina the rocks mapped by Eakin (1918) as part of this sequence are dark- to medium-gray siliceous shale and gray and brown massive to thin-bedded chert with some chert breccia, large amounts of massive gray quartzite, and finely laminated flaggy sandstone (F. R. Collins and Florence Robinson, oral communication, 1957).

The structure of these rocks is apparently complex with much close folding and faulting. Collins and Robinson report that a major anticline with a northwestward-trending axis is exposed northeast of Lake Minchumina.

No fossils have been collected from these rocks, and the age of the sequence is therefore uncertain. Eakin (1918, p. 31–33) assumes a late Paleozoic or early Mesozoic age on the basis of lithologic and structural similarities to rocks in the Ruby, Innoko, and Iditarod districts. He also notes the similarity of these rocks to parts of the Tonzona group in the Alaska Range.

MESOZOIC SEDIMENTARY AND VOLCANIC ROCKS

TRIASSIC GREENSTONE

Between the Toklat River and the terminus of the Muldrow Glacier the undifferentiated Paleozoic rocks on the north flank of the Alaska Range are overlain unconformably by a series of altered basaltic lava flows, attaining an aggregate thickness of about 3,500 feet in the mountains north of the Denali Highway. This altered basalt, or greenstones, weathers to a deep chocolate brown and forms bold cliffs. Where hydrothermal alteration has taken place the greenstone is light tan or white in contrast to its common more somber shades.

The most common facies of the greenstone is a dark-grayish-green aphanitic rock, intricately joined and cut by numerous veinlets of white calcite, green chlorite, and serpentine minerals. A less common type contains phenocrysts of light-greenish-gray altered feldspar as much as 1 cm long scattered through a fine-grained groundmass. Amygdaloidal rocks are common; some amygdules are as much as 1 foot in diameter. Pillow structure, suggestive of submarine extrusion, is well displayed. A close inspection of outcrops usually fails to reveal any indication of the dip of the formation, but when viewed at a distance or studied on aerial photographs it shows a distinct banding, which probably marks the traces of lava flows. Gabbro and dolerite dikes and sills cutting the Paleozoic rocks are probably the same age as the lava flows; they are described in detail in a later section.

The age of the greenstone has not been definitely determined. The formation overlies the undifferentiated Paleozoic rocks and in its lower parts contains pod-shaped bodies of altered limestone and black shale similar in appearance to the underlying rocks. The sequence is cut by sills and dikes of granodiorite (Reed, 1933, p. 253). East of the Toklat River the greenstone is unconformably overlain by the basal conglomerate of the Cantwell (Cretaceous) formation.

Altered basalt and andesite mapped by Moffit (1915, p. 26–28) in the Broad Pass area, south of the Alaska Range, were tentatively dated by him as Triassic. Capps (1940, p. 129) noted that

> In many other parts of Alaska there are extensive basalt flows that are in part Permian and in part early Mesozoic, and the greenstones in Mount McKinley National Park may well belong to that same period of volcanism. No closer age assignment can now be made for them.

Triassic fossils have been collected from sedimentary rocks at the base of the greenstone sequence in the Windy Creek area 36 miles east of the Mount McKinley quadrangle along the strike of the formation (Moxham and others, 1953, p. 13–15).

UNDIFFERENTIATED MESOZOIC ROCKS

East of Mount Mckinley and south of the Muldrow Glacier the peaks of the Alaska Range are sculptured in a thick sequence of sedimentary rocks probably largely of Mesozoic age.

Near Anderson Pass this sequence consists mostly of jetblack slate interbedded with thin sandstone layers alternating with massive layers several hundred feet thick of coarse graywacke and breccia composed of angular pebbles of chert and quartz in a matrix of graywacke. The graywacke consists of angular or subangular grains of quartz, chert, detrital carbonate, and fragments of low-grade metamorphic phyllite and greenstone in a matrix of chlorite and sericite. Locally beds of shattered light-gray limestone as much as 50 feet thick occur in the sequence, and one band of highly contorted chlorite schist was observed by the author. Bedding in these rocks stands out plainly on aerial photographs because of the contrast in color and resistance to erosion between the beds of black slate and massive graywacke.

Black slate and coarse graywacke like those which comprise most of the sequence southwest of Anderson Pass are the predominant rock types in the moraines of the Muldrow Glacier. Similar slate has been recorded by Capps (in his field notes, dated 1925) in the moraines of the Peters and Foraker Glaciers, and by Bradford Washburn (written communication, 1949) from the slopes of Pioneer Ridge and from the North Peak of Mount McKinley (fig. 2).

One poorly preserved fossil was collected from the black slate on the moraine of the small glacier that flows west from Anderson Pass. The specimen was identified by Roland W. Brown (written communication, 1954) as the fucoid *Retiphycus hexagonali* Ulrich, probably the remains of a marine algae. Brown states that "the locality may be lower Cretaceous."

Capps (1933, 1940) and Ross (1933) described Triassic and younger Mesozoic rocks in the drainage basin of the West Fork of the Chulitna River east of the southeast corner of the Mount McKinley quadrangle. According to Capps (1940, p. 109) the sequence between the Chulitna River and Windy Creek consists of

> Triassic limestone associated with a thick series of slates and graywackes, and a thick group of black argillites and slates in which Jurassic fossils were collected at a single horizon * * * [The rocks] are almost everywhere steeply tilted and folded and have been sufficiently metamorphosed for the argillaceous materials to show some degree of slaty cleavage; frequent alternation of thin beds of argillaceous rocks with coarse-grained materials is widespread; and ripple marks and mud cracks are commonly seen, attesting their shallow water origin.

Capps (1933, pl. 4; 1940, pl. 2) mapped an area of Cantwell formation near the West Fork Glacier westward to Anderson Pass. On plate 1 it was necessary to group the Cantwell formation in this area with the undifferentiated Mesozoic rocks. Possibly beds of the Cantwell formation are included with the undifferentiated Mesozoic rocks in other areas in the Alaska Range.

CANTWELL FORMATION

The Cantwell formation comprises a sequence of continental clastic sedimentary rocks and associated volcanic rocks of Cretaceous age that have been recognized along the Alaska Range from the headwaters of the Tonzona River as far east as the vicinity of Mount Hayes, 60 miles east of the Nenana River.

The best exposures of the Cantwell formation within the Mount McKinley quadrangle are along the Toklat River north of the Denali Highway. Here the formation crops out in two belts separated from each other by a narrow belt of Paleozoic rocks. The basal beds are 400 to 500 feet of massive coarse conglomerate composed of pebbles of white quartz which average 2 or 3 inches but which locally may be as much as 8 inches in diameter. The basal conglomerate is overlain by a sequence of interbedded sandstone and conglomerate with 5- to

FIGURE 2.—Denali Pass, Harper Glacier, and the South and North Peaks of Mount McKinley, looking west. Quartz monzonite of the McKinley batholith makes up the South Peak of Mount McKinley and is exposed in the cliffs south of Harper Glacier. Its intrusive contact with the black slate and graywacke of the undifferentiated Mesozoic sequence can be seen halfway up the cliff on the north side of Harper Glacier. Photograph by Bradford Washburn, July 9, 1947.

10-foot-thick coalbeds. Stem imprints and bits of carbonized wood are abundant in many of the sandstone beds. This basal sequence is exposed in a syncline on Mount Sheldon in the northern outcrop belt of the formation, where it overlies Paleozoic shale and limestone and along the southern edge of the southern outcrop belt where it overlies Triassic greenstone. In the southern outcrop belt the Cantwell formation is composed predominantly of dark shale with some beds of light-colored pebbly sandstone as much as 10 feet thick. The lateral continuity of the formation is variable, and individual beds or units may pinch out in a few thousand feet along the strike.

Volcanic rocks including flows, tuff, agglomerate, and hypabyssal intrusive bodies make up a major part of the Cantwell formation near the terminus of the Muldrow Glacier (fig. 3) and between the Herron and Straightaway Glaciers. Similar volcanic rocks are well exposed along the Denali Highway at Polychrome Pass, in the Healy quadrangle. The volcanic rocks are not at a definite stratigraphic horizon within the formation but are probably of slightly different ages in different areas.

Light-colored rhyolitic tuff, flows, and agglomerate that weather in shades of pink, red, white, and yellow make up the greatest part of the volcanic sequence. Thick flows of dark-gray andesite showing columar jointing and thinner flows of greenish-black, black, or dark-brown basalt are common, although subordinate to the rhyolite in total volume. Sandstone and conglomerate beds are common in the volcanic sequence and are identical with sedimentary rocks in the nonvolcanic parts of the Cantwell formation. The brilliant colors of the volcanic rocks stand in sharp contrast to the predominantly dull-gray and brown shades of the sedimentary beds. Sills, dikes, and small plugs similar in composition to the volcanic rock of the Cantwell formation are abundant in the sedimentary beds of the formation and also occur in the underlying Paleozoic rocks. Thick andesite sills are particularly common.

Within the Mount McKinley quadrangle the Cantwell formation crops out only as narrow infolded and faulted blocks in the underlying rocks. The structure within these blocks is complicated somewhat by faulting and small-scale folding but is in general simple. Folds are fairly tight and are overturned to the north with minor crenulations and drag folds on the limbs. The shale-sandstone sequence is more tightly folded than the more massive conglomerate and sandstone beds.

At least 3,500 feet of the lower conglomerate-sandstone sequence is exposed in the syncline on Mount Sheldon. The thickness of the shale-sandstone sequence exposed in the belt to the south is unknown,

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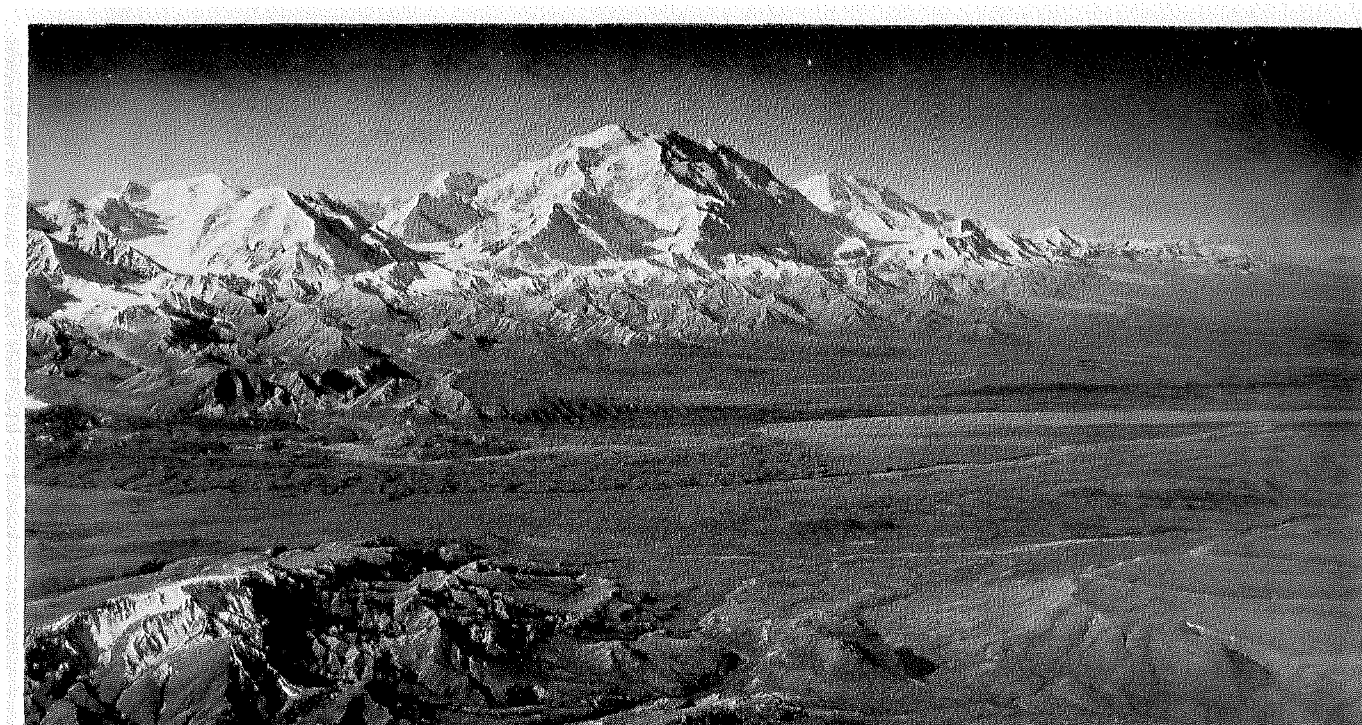

FIGURE 3.—Abrupt north face of the Alaska Range and the plain to the northwest, looking southwest toward Mount McKinley from the head of Moose Creek. Hills in the foreground to the left of the pond are composed of volcanic and sedimentary rocks of the Cantwell formation; flat-topped hill to the right of the pond is Nenana gravel. Irregular dark jumbled topography in the valley in the middleground is the till-covered stagnant lower part of Muldrow Glacier. Tributaries of this glacier can be seen in the valleys on the left side of Mount McKinley at the right; Mount Silverthrone is to the left of the view. Photograph by Bradford Washburn, August 19, 1949.

but it is probably several thousand feet. The Cantwell formation has been assigned to the upper part of the Lower Cretaceous (Albian) on the basis of plant fossils collected by R. W. Chaney and S. R. Capps (Imlay and Reeside, 1954, p. 235).

MESOZOIC INTRUSIVE ROCKS

DOLERITE AND GABBRO SILLS AND STOCKS

Many stocks and sills of altered gabbro and dolerite intrude the undifferentiated Paleozoic rocks along the Toklat River. Similar intrusive bodies were mapped by Brooks (1911, pl. 9) in the Paleozoic rocks southwest of the Straightaway Glacier. Except for their grain size, the rocks in these bodies are petrographically similar to the Triassic greenstone. The rocks are dark green and coarse grained, locally containing feldspar laths as much as 6 inches long. Gabbroic pegmatite layers and veinlets are very common, especially in the thicker sills. These intrusive bodies weather to a deep chocolate brown and form rugged cliffs and bold outcrops in contrast to the smoother slopes of the surrounding sedimentary rocks. The intrusive bodies are surrounded by a light-tan or yellow bleached zone several hundred feet wide in the enclosing rocks, which contrasts sharply with both the deep-brown shades of the intrusive rocks and with the lighter browns, tans, and grays of the unbleached sedimentary rocks. The sills are commonly several hundred feet thick and are connected directly to stocklike bodies a few hundred yards in diameter. No evidence has been found that these bodies cut the Cantwell formation, and because of their similarities to the greenstone they are tentatively dated as Triassic.

GRANITIC ROCKS

Granitic intrusive rocks cut the Paleozoic and Mesozoic sedimentary rocks in many areas throughout the quadrangle. Some of these intrusive bodies are stocks, dikes, and sills of small areal extent; some are of batholithic dimensions and form major elements in the makeup of the Alaska Range. According to Capps (1933, p. 285), granitic rocks intrude rocks as young as the Cantwell formation east of the Mount McKinley quadrangle, but all the major intrusions seem to have antedated deposition of the earliest Tertiary beds. Some intrusive rocks are pre-Cantwell, as the conglomerate of the Cantwell formation contains pebbles of granitic rocks derived from within the range.

The rocks of the grantic intrusive bodies are largely granite, quartz monzonite, and quartz diorite, but some syenite, diorite, gabbro, and periodotite are associated. The major intrusive bodies are clearly related to one another, but each shows variations in mineralogy.

Whether the emplacement of these bodies was contemporaneous or at slightly different times is not yet known.

The McKinley batholith, which crops out in the highest part of the Alaska Range, is intruded into the black slate and graywacke of the undifferentiated Mesozoic sequence. The highest peak of Mount McKinley and most of the southern and western flanks of the mountain are sculptured in the rocks of this batholith.

The predominant rock in the batholith is quartz monzonite, characterized by abundant quartz, with plagioclase and potash feldspar in about equal proportions, but with plagioclase generally slightly predominant. The common ferromagnesian mineral is biotite, but in the higher parts of the batholith a decrease in the amount of biotite and an abundance of muscovite and tourmaline may indicate a concentration of volatile constituents near the roof of the body. The potash feldspar is orthoclase with perthitic intergrowths and microcline in lesser amounts. The plagioclase is zoned, the cores of the crystals being oligoclase-andesine whereas the outer rims are albite-oligoclase.

The contacts of the intrusive body are sharp and are clearly visible on aerial photographs. Near the contacts the slate is converted to hornfels with porphyroblasts of cordierite. According to Bradford Washburn (written communication, 1949), inclusions of slate in the granite are abundant near the top of the South Peak of Mount McKinley.

The small intrusion on Pioneer Ridge opposite Mount Carpe is similar to the granite of the McKinley batholith. A sample from it contains tourmaline and muscovite with only a trace of biotite.

The intrusive mass at the head of the Straightaway Glacier is largely of syenitic composition (Barry Bishop, oral communication, 1957)—very distinct from the rocks of the McKinley batholith.

Granitic rocks of the McGonagall batholith crop out extensively along the northern flank of the range between the Foraker Glacier and the Muldrow Glacier. The intrusions near Mount Eielson are probably parts of the same body. The chief rock in the McGonagall batholith is light-colored coarse-grained quartz diorite that is locally porphyritic. Fine-grained hornblende diorite porphyry is widespread in dikes and small irregular bodies within the batholith.

The quartz diorite contains abundant quartz and plagioclase, subordinate amounts orthoclase, and biotite (partly altered to chlorite and epidote) as the ferromagnesian constituent. Some specimens contain orthoclase in amounts nearly equal to plagioclase. The plagioclase is more strongly zoned than in the rocks of the McKinley batholith. The cores of the crystals are andesine; the outer rims are albite or oligoclase. The orthoclase contains many perthitic stringers of albite.

The hornblende diorite porphyry is darker colored and finer grained than the quartz diorite. Phenocrysts are chiefly weakly zoned labradorite but there are a few phenocrysts of orthoclase and quartz. Hornblende, which occurs as phenocrysts, is the ferromagnesian constituent. The groundmass is a fine-grained aggregate of feldspars and their alteration products.

Reed (1933, p. 254–259) reports that the intrusive mass near Mount Eielson is composed of granodiorite, some gabbro, and a few bodies of intermediate composition. The granodiorite is commonly a greenish-gray porphyry with phenocrysts of hornblende and zoned plagioclase (oligoclase or andesine). The nonporphyritic granodiorite is generally light gray, but in some places has a pink or lavender tinge. It is composed predominantly of plagioclase (andesine), abundant quartz, and some orthoclase. The chief ferromagnesian constituent is biotite.

McGonagall batholith intrudes the undifferentiated Paleozoic sedimentary rocks, and in many areas large blocks are included within the granitic rocks. The country rocks are cut by many dikes and sills of granitic rocks near the contact, and widespread silicification and epidotization of certain zones in the wallrocks occurred during emplacement of the batholith. In the Mount Eielson district the granodiorite is cut by basalt dikes, which are probably feeders of flows in the Cantwell formation (Reed, 1933, p. 259). The contacts of the McGonagall batholith with the Paleozoic rocks are favorable loci for mineralization.

A poorly exposed body of fine-grained hornblende granite crops out from the head of the North Fork of Moose Creek eastward at least as far as the Toklat River. The contacts of this body have not been examined in the field, but it probably intrudes the Birch Creek schist to the north and lies in fault contact with the Cantwell formation and Paleozoic sedimentary rocks to the south. Widely scattered specimens indicate that the rock is predominantly fine-grained even-textured granite containing conspicuous amounts of hornblende.

The rock weathers to shades of yellow and brown, and the hillsides are covered with fine talus. Fresh outcrops are rare. The granite breaks down to yellow or orange arkosic sand that is easily confused at a distance with the oxidized Tertiary gravel.

A body of coarse-grained biotite granite makes up the conspicuous outcrop at Castle Rocks. The intrusive body is probably less than 1 mile in diameter. The wallrock is not exposed, but float indicates that it is Birch Creek schist.

The rock is composed predominantly of quartz and perthitic orthoclase with minor amounts of plagioclase. Biotite is the ferromagnesian constitutent. The plagioclase is zoned, with a core of andesine and an outer rim of albite-oligoclase.

QUARTZ PORPHYRY STOCKS

Within the Kantishna Hills and in the foothills northeast of the terminus of the Muldrow Glacier are several small stocks and dikes of rhyolite and dacite porphyry. These rocks are light greenish gray, buff, or white, and differ from the granitic rocks in texture, having an aphanitic groundmass with phenocrysts of clear quartz, glassy or milky sanidine, plagioclase, and in some facies, hornblende and biotite. The quartz phenocrysts are conspicuously rounded, whereas those of feldspar have angular outlines. In the larger bodies the phenocrysts form 30 to 40 percent of the rock and may attain 5 mm in length. In dikes and smaller stocks the phenocrysts are inconspicuous or absent.

The quartz porphyry stocks and dikes cut the Birch Creek schist in the Kantishna Hills, the undifferentiated Paleozoic rocks along the Toklat River, and the Triassic greenstone near Camp Eielson. A dike of dacite, which appears in thin section to be identical with these rocks, was observed by Prindle (from field notes, dated 1902) near the head of Slippery Creek in the granitic rocks of the McGonagall batholith. Their hypabyssal character and strong similarities in texture and composition indicate that the quartz porphyry bodies very likely are closely related to the volcanic rocks of the Cantwell formation, although some of them are widely separated geographically from present outcrops of the volcanic rocks of the Cantwell.

TERTIARY ROCKS

A sequence of continental sedimentary rocks of Tertiary age rests unconformably on the pre-Tertiary rocks in broad basins and structural depressions. These rocks are poorly or moderately well consolidated and include conglomerate, sandstone, shale, and in some parts of the sequence, beds of subbituminous coal. The sequence includes the Tertiary coal-bearing formation and the overlying Nenana gravel, but owing to insufficient field information they have not been mapped separately.

The Tertiary beds have been extensively studied in the Healy quadrangle to the east (Wahrhaftig, 1944, 1951, 1953, 1958; Wahrhaftig and others, 1951). According to Wahrhaftig (1958, p. 10–11) the coal-bearing formation was determined by Roland W. Brown of the U.S. Geological Survey to be Eocene in age, and the Nenana gravel to be Miocene or Oligocene in age.

Volcanic rocks of possible Tertiary age occur in several localities. Capps (in his field notes, dated 1916) records a columnar basalt flow interbedded with the Tertiary rocks on Stony Creek about 2½ miles north of the Denali Highway. White (1942 and written communication, 1954) reports a body of basalt east of the Clearwater Fork of the Toklat River opposite the mouth of Little Moose Creek, which he believes is of Tertiary age because of undevitrified basaltic glass around the margins of the body.

Most of the Tertiary rocks in the Mount McKinley quadrangle are buried beneath a thin veneer of stream gravel or glacial deposits, so that their presence can only be inferred from the physiographic setting, partly mantled bedding traces, and outcrops in cut banks along streams where the Tertiary beds are exposed. Where Tertiary beds within a few feet of the surface can be inferred, any overlying Quaternary deposits have been ignored in mapping.

Below the unconformity at the base of the Tertiary sequence the underlying rocks are deeply weathered. Wahrhaftig (1953) reports pre-Tertiary weathering to depths of 100 feet near Healy. Deformation since the deposition of the Tertiary beds has produced dips of as much as 25° along the borders of some of the Tertiary basins. On the northwest flank of the Kantishna Hills, between Moose Creek and Rock Creek, and along the mountain front east of the Toklat River the Tertiary beds dip northward into the adjoining basins. For some distance above the upper limit of outcrop of the Tertiary beds the stripped pre-Tertiary unconformity is exposed, forming a series of truncated spurs in the pre-Tertiary rocks. The smooth surface of the southwest end of the Kantishna Hills may represent an extensive part of the pre-Tertiary unconformity from which the Tertiary beds have been removed.

STRUCTURE

The general synclinal structure of the pre-Tertiary rocks of the Alaska Range and the arrangement of structural axes parallel to the range was recognized by Brooks (1911, p. 111). The pattern is complicated by minor folds within the major structure, subsequent faulting, and unconformable relations between major stratigraphic units. However, the Paleozoic and Mesozoic geologic units are arranged in bands parallel to the range with the oldest rocks on the north and south and the youngest toward the axis of the structure. The Mount McKinley quadrangle includes the axial parts and northern flank of this synclinorium.

The faults parallel to the axis of the range are part of a fault system which has been traced from near Bristol Bay along the arc of the Alaska Range to the Canadian boundary and which probably joins the north-northeastward trending fault system of southeastern Alaska (St. Amand, 1957, figs. 4 and 6). The largest of these faults in the Mount McKinley quadrangle, the Denali fault, controls the course of the Muldrow Glacier for more than 15 miles. Other parallel faults control long topographic depressions within the foothills of the range and form boundaries between many of the pre-Tertiary geologic units. The abrupt northern front of the mountains between the Muldrow Glacier and the Straightaway Glacier is a scarp along one of these faults. A scarp along another of the faults marks the mountain front southwest of the Straightaway Glacier.

Movement along some of these northeastward-trending faults began as early as Cretaceous time, for in the Healy quadrangle, Wahrhaftig (written communication, 1954) has found pebbles of Birch Creek schist derived from the north side of one of the faults in conglomerate of the Cantwell formation on the south side of the fault. Tertiary orogeny, during which the coal-bearing formation and the Nenana gravel were tilted and folded, was also marked by movement along these faults. Fault scarps offsetting Recent stream gravel and glacial moraines in the valleys of Coal Creek and the East Fork of Clearwater Creek indicate that movement on the fault along the northern front of the mountains in this area has occurred very recently. Similar recently formed scarps have been reported along the Denali fault in Foggy Pass and along Little Windy Creek in the Healy quadrangle (Wahrhaftig, 1958). The dips of most of these faults are not known, but their straight traces suggest relatively steep dips. Washburn (written communication, 1949) reports that the Denali fault dips 35° to 40° N. in Gunsight Pass. In many places the apparent stratigraphic throw on the faults is not in the same sense as the latest movements indicated by recent scarps and by physiographic considerations. This may indicate either that there has been much lateral movement along some of the faults, or that recent movement has occurred in the opposite sense.

QUATERNARY DEPOSITS

The Quaternary deposits of the Mount McKinley quadrangle comprise a complex array of unconsolidated sediments of glacial and nonglacial origin. The details of the stratigraphy of these deposits is undoubtedly complex. They have been subdivided largely on the basis of their topographic expression and physiographic position in order to map them by photogeologic methods (pl. 1).

MORAINES

Superglacial moraines.—Morainal systems on the surfaces of modern glaciers have been plotted on plate 1 as they appeared in 1951–52 when the aerial photographs used in the map compilation were taken.

Péwé (written communication, 1957) reports that in the spring of 1957 the Muldrow Glacier was advancing rapidly after a long period of quiescence. The system of superglacial moraines shown on the map has now undoubtedly been completely changed.

In general the superglacial moraines stand as sharp ridges 50 to 200 feet above the surface of the neighboring clean ice. In many places the debris is only a few feet thick, and most of the relief is due to the insulating effect of the debris mantle, which protects the underlying ice from ablation. In the lower reaches of the glacier the individual ridges coalesce into a chaotic jumble of irregular hummocks and hollows having a local relief of as much as several hundred feet.

The superglacial moraines are composed chiefly of angular and frost-riven material that has fallen onto the glacier surface. Finer constituents comprise only a very small proportion of the deposit. These moraines are almost entirely unvegetated except for a few types of moss and lichens.

Recent moraines.—Near the snouts of most of the present glaciers are one or more terminal moraines probably deposited within the last few hundred years. These moraines are completely unmodified by erosion and in many places are underlain by stagnant glacial ice. In some places these deposits include several sets of moraines: an outer older set on which grasses, mosses, and lichens have begun to grow, and an inner set, which has little or no vegetation. The material in these deposits is similar to that of the superglacial moraines.

Older undissected moraines.—Two distinct groups of fresh, slightly modified moraines occur in all the major valleys and, on the basis of topographic expression and physiographic setting they are probably correlative with the Riley Creek and Carlo moraines along the Nenana River (Wahrhaftig, 1953). These moraines extend 10 to 12 miles north of the mountain front in the valleys of the Herron and Foraker Rivers, 25 miles from the mountains in the McKinley River valley, and 9 miles in the valley of the Toklat River. An inner set of moraines lies 3 to 6 miles inside the outer set. In some places the inner set includes several recessional moraines several miles apart. (See, for example, moraines in the McKinley and Herron River valleys shown in pl. 1.)

The topography of these moraines is almost unmodified. They are not dissected by secondary streams except in the immediate neighborhood of major streams. Kettle holes are numerous—between 60 and 80 per square mile are found in many places. The kettles are small, steep sided, and few have external surface drainage. They are separated by sharp-crested ridges. Alinement of ridges and depressions is prominent in many of the moraines and has been indicated on the geologic map (pl. 1).

Along the Denali Highway southeast of Wonder Lake, the moraine is composed of gravelly till with minor amounts of clay and sand. The gravel is composed of black slate, graywacke, banded chert and limestone, and granitic rocks. Erratics of granite are common on the surface of these moraines.

Older dissected moraines.—The oldest moraines so far recognized in the Mount McKinley quadrangle are a series of highly dissected and modified moraines, which lie far beyond the limits of the undissected moraines and are evidently much older; they may be correlative with the Healy moraines of Wahrhaftig (1953). They differ from the younger moraines in that they are much modified by dissection and mass wasting, their drainage is much better integrated, slopes are gentler and the ridges are more rounded. Depressions in the morainal topography are larger and fewer, averaging 20 to 30 per square mile in a typical area. Erratics of granite are numerous on the surface of these moraines, although not so common as on the younger moraines. The composition of the till in the older dissected moraines is unknown.

Deposits of still earlier glaciations have not been identified in the Mount McKinley quadrangle, but analogy with the better established glacial sequence along the Nenana River (Wahrhaftig, 1953) suggests that evidence of earlier advances may eventually be found.

OUTWASH DEPOSITS

Outwash fans deposited during the different glacial advances have been traced for many miles northward beyond the respective terminal moraines. The outwash deposits are probably composed mainly of stratified sand and gravel; they are identified on aerial photographs by their flat surfaces, which bear many channel scars (fig. 4).

Outwash correlative with the older dissected moraines has been largely concealed beneath younger deposits except in a few areas where it stands as low terraces above the later outwash. Outwash correlative with the older undissected moraines covers wide areas; in some places it overlaps the earlier moraines, leaving only isolated segments standing above the outwash plain.

Recent outwash deposits have been mapped with the undifferentiated alluvial deposits in plate 1.

UNDIFFERENTIATED ALLUVIAL AND COLLUVIAL DEPOSITS

This category includes a variety of deposits most of which are probably of Recent age. The principal deposits included are: (a) vegetated stream terraces and alluvial fans composed of stratified sand and gravel chiefly of nonglacial orgin but including some outwash materials of historic glacial advances; (b) talus fans and other

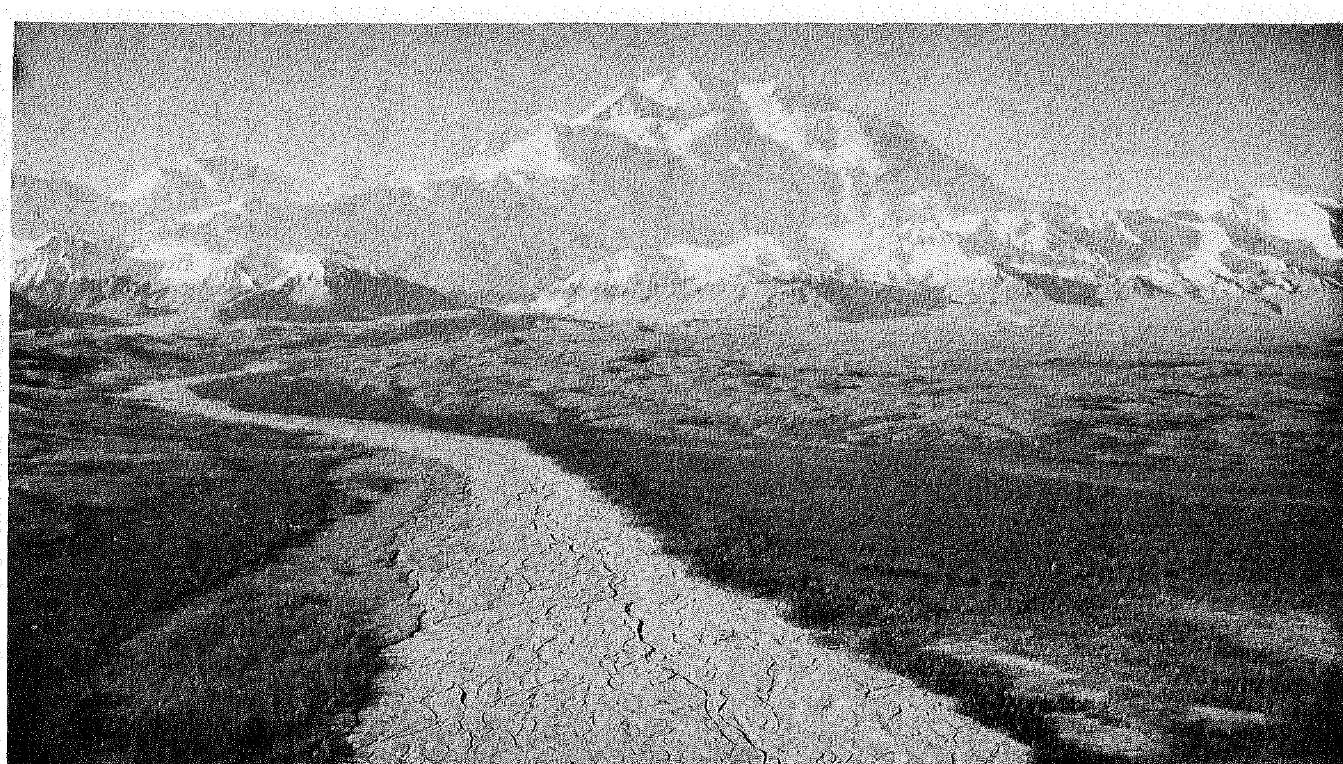

FIGURE 4.—View south up the Muddy River to Peters Glacier and Mount McKinley. The Denali fault lies in the trench between the low mountains and Mount McKinley. Muddy River in the foreground is a typical braided stream flowing on an outwash plain between morainal hills. Photograph by Bradford Washburn, August 15, 1949.

colluvial deposits in mountain areas, and (c) valley-fill deposits in the northwestern part of the quadrangle, which are probably composed largely of reworked windblown silt.

FLOOD-PLAIN DEPOSITS

Materials on unvegetated flood plains are intermittently transported by the present streams during high-water periods or in the course of shifting of the braided channels. They are distinguished from the terrace deposits of the previous unit by their lack of vegetation. The materials are virtually the same: stratified sand and gravel on the upper flood plains, grading to predominantly fine sand on the lower flood plains of the major streams.

SWAMP DEPOSITS

Large areas bordering the lower reaches of the major streams are poorly drained and are characterized by meandering stream channels, many oxbow lakes, and small thaw pits. These areas are probably underlain by alluvial silt and clay admixed and interlayered with peat, organic muck, and windblown silt. Natural levees along reaches of larger streams bordered by swamps are generally composed of fine sand.

In many areas terrace and alluvial-fan deposits grade into swamp deposits without a noticeable topographic break. Here the contacts between the units are mapped chiefly on the basis of differences in drainage patterns.

In some places, swamp deposits are presently accumulating rapidly, as on the delta of the Foraker River, which is filling the east end of Lake Minchumina. In other places the deposits may be much older.

EOLIAN OR ALLUVIAL SAND

A broad, nearly level plain marked by many linear and parabolic dunes and by shallow, straight-sided lakes extends from the Foraker River south and southwest to the headwaters of the Kuskokwim. Large remnants of the same or a similar surface are on both sides of the Kantishna River (Florence R. Collins and Florence Robinson, oral communication, 1957), and similar areas of dunes are known to the northeast as far as the Tanana River and to the southwest as far as McGrath (Black, 1951, p. 101).

The surface of the plain is cut by alluvial fans younger than the last extensive glaciation and by modern streams, which locally are incised 50 to 100 feet. Southwest of the Foraker River the boundary between the plain and the silt-mantled lowland to the south is marked by a straight northward-facing scarp as much as 150 feet high, possibly a fault scarp.

Collins and Robinson (oral communication, 1957) have examined cuts along the Foraker River and along the Kantishna River just outside the Mount McKinley quadrangle which expose as much as 100 feet of fine- to medium-grained crudely bedded sand underlying the plain surface. The dunes are composed of similar sand mantled by a few inches of gray windblown silt.

The altitude of the sand plain ranges from almost 900 feet along its southeastern edge between the Foraker River and the Slow Fork of the Kuskokwim to less than 550 feet in some of the remnants along the Kantishna River north of Diamond.

The dunes, which rise 50 to 150 feet above the surface of the plain, are linear or parabolic ridges. They are oriented with their long limbs about N. 55° E. and were probably formed by winds blowing toward the southwest. The dunes are now stabilized and support a growth of birch, aspen, and white spruce, in contrast to the stunted black spruce and muskeg of the interdune areas.

Many shallow lakes occupy the interdune areas. These lakes characteristically have straight shores parallel with and perpendicular to the long axes of the neighboring dunes, and many are crudely rectangular in map view. The shapes of some of the larger lakes suggest that they have been formed by the coalescence of two or more small lakes. The lakeshores are gently sloping, and the level of the lakes is only a few feet below the surface of the sand plain. Commonly the lakes are slightly convex on their southwest ends and seem to be deepest in their northeast parts.

The origin of the sand plain is unknown. The dunes are clearly of eolian origin, but whether the bulk of the sand is windblown or waterlain is not known. The material was probably derived originally from the Alaska Range during one or more of the Pleistocene glacial stages.

OTHER UNCONSOLIDATED DEPOSITS

In a broad belt north of the oldest recognized moraines are large areas of low rolling topography with irregular or oval, steep-walled depressions; many of the depressions are occupied by lakes. Caved banks along some of the lakes and shallow pits dug on the divides between lakes expose blue-gray silt, which is frozen to within a few inches of the surface even in midsummer.

The lakes are commonly in steep-walled, flat-floored depressions. The smaller depressions are crudely circular, the larger are somewhat irregular. The walls of the depressions are uniform in height and make an abrupt angle at the top with the gently rolling or smooth topography of the upland. The lakes rarely occur along streams, but are most common on crests of ridges and interfluves and on sloping hillsides. On slopes they are at the downhill ends of elongate depressions, as if the lakes had migrated downslope, leaving steep-walled, flat-floored depressions behind them. The hills in the areas of the lakes are commonly flat topped or gently rounded and rise to an almost uniform height. Locally, where the lakes are closely spaced, the hills are steep sided and sharp ridged.

Areas of this type of topography are clearly cut by outwash terraces entrenched several hundred feet below the upland surface.

The topography is probably a thermokarst type developed on silt-mantled alluvial plains. Wahrhaftig (written communication, 1955) suggests the following sequence for the formation of such a topography:

1. A broad alluvial outwash apron is formed during preglacial time.
2. This outwash is covered with windblown silt. At the same time, certain favored abandoned channelways are converted into drainageways to carry water from the alluvial-fan surface.
3. As the channelways are deepened and their numbers reduced by capture, thaw sinks and thaw lakes form on the interfluves. Many of these migrate down the slope and eventually are breached, giving an irregular topography to the once-smooth slope. Some of these breached thaw sinks contribute to the reorientation of the drainage. Gradually a parallel or radial drainage is converted into an extremely haphazard pattern. The lakes slowly enlarge as the spacing of the drainageways increases, providing the relief does not increase appreciably. Possibly windborne silt is added periodically. Eventually a topography of large irregular thermokarst lakes develops.

The early stages in the development of such a sequence can be observed on some parts of the outwash aprons along the Slow Fork of the Kuskokwim River.

MINERAL DEPOSITS

HISTORY OF PROSPECTING AND MINING

During their unsuccesful attempt to climb Mount McKinley in 1903, Judge James Wickersham and his party found placer gold along Chitsia Creek (Wickersham, 1938, p. 269) and filed several claims. In 1904, according to Capps (1919), prospectors visited the basin of the Toklat River and found gold in encouraging amounts, but it was not until the spring of 1905 that the discovery of rich placers on Glacier Creek by Joseph Quigley and Jack Horn caused a rush to the Kantishna area. Capps (1919, p. 75) writes:

> Late in the summer and in the fall of 1905 the Kantishna district was the scene of great excitement. Several thousand people then arrived, most of them

coming by boat up Kantishna River and its tributaries, the Bearpaw and McKinley Rivers, during the season of open water, and by dog and sled later in the fall after snow had fallen. Practicall every creek that heads in the Kantishna Hills was staked from source to mouth, and the benches and intervening ridges were not ignored. Within a few weeks a number of towns were built, the largest of which were Glacier, on Bearpaw River at the mouth of Glacier Creek; Diamond, at the mouth of Moose Creek; and Roosevelt and Square Deal on Kantishna River. At each of these places log cabins, stores, hotels, and saloons were erected, and between them and the creeks a constant stream of gold seekers traveled back and forth. By midwinter, however, it became generally known that rich shallow diggings, the eternal hope of the prospector, were restricted to a few short creeks, and an exodus began. The richest ground was mined vigorously during the summer of 1906, but by fall the population had dwindled to about 50, those who remained being the few who had staked paying claims or who were convinced that thorough prospecting held out sufficient promise of new discoveries.

By the spring of 1906, Roosevelt, Square Deal, and Diamond were almost completely deserted. The settlement of Glacier was used by miners for winter quarters for some years but it is now abandoned.

The existence of lode deposits in the Kantishna Hill from which the placer gold was derived was recognized by early miners and the search for gold lodes led to the discovery of antimony deposits on Slate, Caribou, and Stampede Creeks in 1904–05 and lead-silver deposits between Friday and Eureka Creeks.

Since the richest placer ground was exhausted in 1906, prospecting and mining in the Kantishna area has been done on a small scale. By 1931, slightly more than 1,300 tons of ore had been shipped from the district, mainly lead-silver ore from the Quigley claims on Friday Creek. There was little further activity in the area until the late 1930's when much development work was done on the lodes on Friday and Eureka Creeks. In 1940, the district produced $139,000 in gold from lodes and placers. Since then production of lode gold has been negligible, and production of placer gold has been limited to a few hundred dollars worth annually.

Although the antimony deposits of the Kantishna hills had been known since 1904–05, no effort was made to develop them until about 1915. During 1915–16 about 150 tons of ore was produced from the deposit on Stampede Creek, and some exploratory work was done on the Slate Creek deposit. None of the ore was shipped, and no further work was done until the midthirties. In the winter of 1936-37 active operation on the Stampede deposit resumed with the production of some hand-picked high-grade ore. Sporadic production continued until 1943 when the mine was closed owing to lack of supplies, equipment, and labor. From 1937 through 1942 about 2,639 tons of ore containing 1,410 tons of antimony was shipped. During the summer of 1940 the deposit was studied by the Geological

Survey (White, 1942) and during 1942, exploratory work was done by the U.S. Bureau of Mines (Ebbley and Wright, 1948).

Mining and development work were done on the Stampede deposit at different times between 1942 and 1952. Some stibnite ore was shipped during this period. In 1953 Earl R. Pilgrim began exploratory underground and surface work on the property with the aid of a Defense Minerals Exploration Administration loan. This exploration plus some additional work that was privately financed was still in progress in 1955. No ore was shipped during 1952-54, partly owing to unfavorable price and market conditions.

During 1942 some development work was done by the Bureau of Mines on the Slate Creek deposit, and in 1942, 1943, and 1944 a few tons of hand-picked high-grade ore was produced. Production stopped after 1949.

Several mining claims on the lead-zinc deposits of the Mount Eielson district were staked in 1920 by J. B. and Fanny Quigley and in 1921 by O. M. Grant and F. G. Jiles. Except for three short adits and several prospect pits and trenches little development work has been done. There has been no production from these deposits. The geology and mineral deposits of the Mount Eielson district have been described by Reed (1933), Gates and Wahrhaftig (1944), and Muir and others (1947).

Gold, copper, and mercury deposits on Slippery Creek were discovered by William Shannon in 1921. Some exploratory work was done on prospects on this creek during the 1930's, but these prospects are now abandoned. Several lode claims in the headwaters of Clearwater Creek have been staked, but none were developed and all are now abandoned.

METALLIFEROUS DEPOSITS

LODE DEPOSITS OF THE KANTISHNA HILLS

All the lode deposits in the Kantishna Hills are in veins cutting the Birch Creek schist. Wells (1933) reports that in the Kantishna area most of the veins strike N. 50° to 70° E. and dip from 90° to 60° SE., crosscutting the foliation of the schist. A few veins dip steeply to the northwest. Milky-white massive quartz lenses parallel to the foliation are not mineralized. Many of the mineralized veins are concentrated along the axis of an anticline in the schist, and strike parallel to the axis. The veins are crudely tabular but pinch and swell considerably; the maximum width reported by Wells (1933) is 32 feet.

The gangue minerals are quartz, calcite, siderite, and epidote, with minor amounts of scheelite and rhodonite. The chief metallic minerals are gold, arsenopyrite, pyrite, sphalerite, chalcopyrite, galena, stibnite, and tetrahedrite. Small amounts of stromeyerite, bournonite, stephanite, and pyrargyrite also occur. Alteration products include scorodite, azurite, cerussite, melanterite, stibiconite, and kermesite.

On the basis of the mineralogy Wells (1933) recognized three types of vein deposits: (a) quartz-arsenopyrite-gold veins with scattered bodies of galena and sphalerite; (b) galena-sphalerite-tetrahedrite-pyrite-chalcopyrite veins with carbonate gangue in small amounts; (c) stibnite-quartz veins, practically free of other minerals.

Although the veins are all oxidized to depths of a few feet, frozen ground has prevented extensive surface enrichment and the gold and silver content of the veins does not seem to diminish with depth. Wells concluded that all the veins are fracture fillings deposited by solutions emanating from the quartz-porphyry intrusions. Detailed descriptions of mines and prospects in the Kantishna Hills are given by Capps (1917, 1919), Wells (1933), Moffit (1933) White (1942), and Ebbley and Wright (1948).

The Stampede antimony deposit has been described by Capps (1919), Moffit (1933), and White (1942).

PLACER DEPOSITS OF THE KANTISHNA HILLS

Placer gold occurs in virtually all the streams draining the Kantishna Hills and is undoubtedly derived locally from veins in the Birch Creek schist (Capps, 1919). Associated with the gold in placer concentrates, in addition to the sulfide minerals common in the veins, are garnet, magnetite, and ilmenite, and small amounts of rhodonite, scheelite, and cassiterite.

Most of the placers that have been worked in the past are either in the streambeds or on low terraces nearby, although some of the higher benches may contain gold in paying quantities.

The influence of glaciation on the distribution of placer gold has not been carefully studied. Some productive streams were occupied by ice during the earlier of the two extensive glaciations; the placers along Moose, Glacier, and Caribou Creeks lie below the levels of terraces attributed to the later extensive glaciation. It is assumed, therefore, that much of the concentration has taken place since the last extensive glaciation. With virtual exhaustion of the richest known placers in the district, it seems that some effort to locate preglacial deposits beneath the terrace gravels should be made. Preglacial concentrations of placer gold may be concealed beneath outwash and terrace gravels along the lower part of Moose Creek and along Caribou, Glacier, and other creeks beyond the limits of the glaciers.

ZINC-LEAD DEPOSITS IN THE MOUNT EIELSON DISTRICT

The mineral deposits of the Mount Eielson district have been described by Capps (1919), Moffit (1933), Reed (1933), Gates and Wahrhaftig (1944), and Muir and others (1947).

The chief ore minerals are sphalerite, galena, and chalcopyrite, which occur as replacement deposits in thin-bedded limestone, calcareous shale, and graywacke near the contacts of a large granodiorite intrusion. The sulfide mineralization has been accompanied by widespread epidotization and silicification of the sedimentary rocks, especially in certain favorable beds. Hundreds of dikes and sills emanating from the granodiorite cut the sedimentary rocks. Gates and Wahrhaftig (1944) report that ore commonly occurs along the contacts of dikes with limestone and especially at the top of headed dikes. The ore-bearing zone can be traced for about 4 miles along the contact between the sediments and the granodiorite body on the north slopes of Mount Eielson. The belt in which the mineral deposits occur is about 2,000 feet wide.

Although some development work has been done on several claims in the Mount Eielson district, no ore has been produced.

MINERALIZED AREAS BETWEEN MULDROW AND STRAIGHTAWAY GLACIERS

Several mineralized areas have been discovered along the mountain front between the terminus of the Muldrow Glacier and the Straightaway Glacier. The mineralized areas lie in altered sedimentary rocks adjacent to the contact with the McGonagall batholith; some may be in sedimentary rocks included in the batholith. The country rocks are siliceous and argillaceous sedimentary rocks, schist, and schistose limestone, probably part of the undifferentiated Paleozoic sequence. They are intruded by dikes of basalt and granitic rocks. Some of the black schist is cut by many quartz veins. The ore minerals that have been recognized in these deposits are pyrrhotite, chalcopyrite, sphalerite, galena, native copper, and cuprite. Alteration products include malachite, azurite, chalcanthite, and sooty manganese oxide. The ores occur in irregular masses, veins, and disseminated crystals in the country rock (Moffit, 1933).

Deposits of this type have been described by Moffit (1933) from near the head of the East Fork of Clearwater Creek, at the lower forks of Carlson Creek, and on the ridge between Iron Creek and the east fork of Slippery Creek.

Near the head of the west fork of Slippery Creek, just east of the small glacier, is a mineralized area in which black-and-gray banded shales and siliceous beds interlayered with basalt sills are cut by light-colored, fine-grained dikes. Moffit (1933) reports that blocks of stibnite 1 foot in diameter were found in this area and that he observed seams of calcite, quartz, and cinnabar. Native mercury was also found in this deposit. During the late 1930's some exploratory work was done but the property was abandoned about 1939 according to Grant Pearson (oral communication, 1955).

NONMETALLIFEROUS DEPOSITS

COAL

Beds of lignite or subbituminous coal in the Tertiary coal-bearing formation crop out in several places within the Mount McKinley quadrangle, and similar beds probably occur where Tertiary sedimentary rocks are covered by younger gravel deposits. The coal deposits of the Mount McKinley quadrangle will probably never be economically important because of larger and more accessible deposits nearby. However they might furnish a valuable local source of fuel.

Capps (1919) reported that 3 beds of lignite 1 to 4 feet thick crop out in Highway Pass about 3 miles west of the Toklat River. A 20-foot-thick coal bed in the Tertiary coal-bearing formation crops out on the south side of Moose Creek about 1½ miles west of the Moose Creek-Stony Creek divide, and a 12-foot-thick bed was noted by Capps (1919) on the north side of Moose Creek in the same area. A coal bed 10 feet thick crops out along the south bank of the North Fork of Moose Creek about 2 miles above its mouth. Fragments of coal have been found in the bars of Glacier Creek, indicating that coal beds probably occur in the Tertiary deposits in that area.

Several 5- to 10-foot-thick coal beds occur in the basal part of the Cantwell formation on Mount Sheldon. Although these beds are less accessible, they might be expected to be of higher rank than the Tertiary coals.

CERAMIC CLAY

A small deposit of clay suitable for ceramic purposes crops out on the west shore of the north bay of Lake Minchumina about 3½ miles northeast of the airfield. According to Florence R. Collins of the Geological Survey (written communication, 1954) the clay is derived from weathering of a gray, noncalcareous, thin-bedded siltstone. The outcrop is about 2 feet high and 4 to 5 feet long and lies just above the level of the lake. The siltstone bed from which the clay is derived is overlain conformably by medium-gray sandy graywacke.

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INDEX

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