DESCRIPTION OF CLOUD PEAK AND FORT McKINNEY QUADRANGLES.

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INTRODUCTION.

Position and extent.—The Cloud Peak and Fort McKinney quadrangles embrace the half of a square degree that lies between parallels 44° and 44° 30′ north latitude and meridians 106° 30′ and 107° 30′ west longitude. Taken together these quadrangles measure about 34½ miles from north to south and nearly 50 miles from east to west, and comprize an area of about 1713 square miles. They include the greater part of the northwest quarter of Johnson County and the east-central portion of Bighorn County, Wyoming. The central part of the area embraces the highest portion of the Bighorn Mountains; its western quarter lies in the Bighorn Basin, and its eastern third lies on the Great Plains, in the basin of Powder River. As these quadrangles thus cover part of both the Bighorn Mountains and the Great Plains, they exhibit many characteristics of both, but, as their area is small, a general account of these provinces will be given, to afford a better conception of the relations and significance of the local features.

THE BIGHORN MOUNTAIN REGION.

CONFIGURATION.

General features.—The Bighorn Mountains, an outlying portion of the Rocky Mountain Range, extend from north-central Wyoming into south-central Montana. They rise out of the Great Plains, which here have an altitude of 4000 to 5000 feet, to heights that range from 10,000 feet to slightly over 13,000 feet in the higher summits. They trend north-northwest in the northern part of their course, nearly due north and south in their south-central part, and northeast-southwest toward their southern termination, which is at Bridger Creek. The uplift is in a measure continued westward by an east-west range known as the Bridger Range and the Owl Creek Mountains.

The northern end of the Bighorn Mountains is at the canyon of Bighorn River, but north of this canyon the same uplift is continued in the Pryor Mountains, a range of moderate elevation, which extends but a short distance. West of the Bighorn Mountains there is a wide area of plains known as the Bighorn Basin, which extends to the foot of the Shoshone Range on the west and to the Bighorn, Bridger, and Owl Creek ranges on the south. It is traversed by Bighorn River in a deep canyon having an altitude of about 3500 feet. The Bighorn Mountains rise abruptly from the plains, tho they are flanked by several lines of low hogback ridges. Their salient features are the central area of high ridges of granite, the summit plateaus at the northern and southern ends of the uplift, the front ridge of sedimentary rocks, and the hogback ranges.

Central range.—The central area of the higher portion of the Bighorn Mountains is a region of rugged ridges rising toward the main divide along the center of the uplift. In the part of this divide that lies between the headwaters of Piney and Goose creeks on the east and Paintrock, Shell, and Tensleep creeks on the west the granite ridges rise in a cluster of high mountains culminating in Cloud Peak, which has an altitude of 13,165 feet.

In this high area the ridges rise from 3000 to 4000 feet above the valleys and the general configuration is very rugged, presenting some of the boldest alpine scenery in the country. There are many precipices over 1000 feet high, especially about the cirques among the higher summits. Several of these cirques contain glaciers, one of which, on the east side of Cloud Peak, has a length of nearly one-half mile. Extensive snow banks remain all summer in many of the higher portions of the range. The drainage of this area is peripheral and in the main direct. The divide and its numerous branch ridges present serrated outlines and are crost by deep wind gaps. The higher parts of this central area exhibit strong erosion, due largely to the intensity of frost action, the steep declivity, and the abundance of water to carry off the débris. The topography is youthful, and the granite floor on which the sedimentary rocks were deposited has been so cut away by erosion that its original configuration can only be surmised. The higher region has been extensively glaciated, so that most of its topographic features are those characteristic of glacial erosion. The most marked of these are the many deep cirques that are cut back to or nearly to the main divide. Glacial deposits occur in the lower valleys of the central area, impeding the drainage by producing many small lakes. Other lakes occur in rock basins excavated in granite, mostly by glaciation.

The timber line is at an altitude not far below 10,000 feet, above which height the surfaces are mainly almost bare rock masses, in part disrupted from their original ledges. Many of the steeper slopes consist of talus of huge granite blocks.

Central plateau.—The sedimentary rocks arch over the northern and southern portions of the Bighorn Mountains, giving rise to an elevated plateau which has an altitude of about 9000 feet in its northern part and about 8000 feet in its southern part. It presents broad areas of tabular surface, especially near the divides, but is deeply trenched by numerous canyons, the most notable of which is that of Little Bighorn River. Much of the plateau surface is covered by forests which are interspersed with parks that are extensively utilized as grazing grounds for cattle and sheep during the short summer season. Portions of the plateau also extend northward and southward, partly encompassing the central granite area.

Front ridge.—Along the sides of the Bighorn Mountains there are abrupt slopes to the plains on the east and to the Bighorn Basin on the west. In some districts the central plateau terminates in high cliffs, but in others, especially along the eastern side of the mountains, it is flanked by a distinct ridge of "rim rock" that rises slightly above an inner valley but slopes steeply toward the plains. West of Sheridan and Buffalo this front ridge presents an imposing line of mountain slopes, in many places 2000 feet high, extending southward and southeastward. It is composed of sedimentary rocks that dip steeply to the northeast and east, and nearly everywhere it presents to the west a high cliff of limestone. (See figs. 16 and 17, illustration sheet 2.) Thru this front ridge the creeks and rivers that rise in the central area find their way out to the plains, some of them in canyons having walls nearly 2000 feet high. The most notable of these canyons are those of Little Bighorn and Tongue rivers, on the east side of the mountains, and Shell, Paintrock, and Tensleep creeks, on the west side. Across the north end of the range Bighorn River flows in a deep canyon that terminates the mountains to which the name Bighorn is applied. This river also, in its upper portion, cuts across the southwest end of the Bridger Range, separating it from the Owl Creek Mountains.

Hogback ridges.—Along the foot of the Bighorn Mountains, on each side, there is a series of hogback ridges, which appear very insignificant in comparison with the great mountain slopes they flank. They are due to the outcrop of sandstones of moderate hardness and rise only from 100 to 200 feet above the adjoining valleys. These valleys mark the outcrop of the "Red Beds," which extend along the foot of the mountains, but owing to the steep dip of these beds and to their relative hardness the valleys are not so distinct as the Red valleys in the Black Hills and some other regions. The hogback rim is crost by numerous valleys, or canyons, which divide it into level-topped ridges of various lengths, and in many places along the east side of the mountains these ridges merge into a continuous terrace capped by deposits of Quaternary gravels and sands extending from the foot of the higher slopes of the mountains.

Drainage.—From the higher portion of the Bighorn Mountains flow many large streams, those on the east side draining into Tongue River and its branches, mainly thru Crazy Woman, Clear, Piney, and Big Goose creeks. Down the west slopes flow branches of Tensleep, Paintrock, Shell, and other creeks that cross the east side of the Bighorn Basin and empty into Bighorn River. This great stream, after traversing the Bighorn Basin from south to north, turns northeastward and crosses the north end of the Bighorn Mountains, finally flowing into the Yellowstone in southeastern Montana. One of its larger branches, Little Bighorn River, drains a portion of the plateau on the east side of the Bighorn Mountains near the Montana line and flows out of the mountains in a canyon whose walls are over 2000 feet high.

ROCKS.

The Bighorn Mountains are due to a great anticline of many thousand feet uplift, which has elevated a thick series of Paleozoic and Mesozoic sedimentary rocks high above the plains. (See figs. 5 and 6, p. 13.) Owing to the deep erosion of the crest of this uplift the mountains present a central nucleus of pre-Cambrian granites, the sedimentary rocks forming the front ridges and the plateaus at either end. The formations exhibited in the Bighorn uplift are similar to those exposed extensively in other portions of the Rocky Mountain province and show great uniformity thruout the uplifted area. The granites are red and gray, massive in structure, and constitute the floor under sediments of Acadian (Middle Cambrian) age. These Cambrian rocks are sandstones, shales, and limestones, nearly a thousand feet thick, which apparently do not include sediments of Saratogan (Upper Cambrian) age. The Ordovician is represented mainly by a massive limestone of Trenton age, but the earliest Ordovician and part of the late Ordovician, as well as all the Silurian and Devonian, are not represented. The Carboniferous presents about 1500 feet of beds, belonging mostly to the Mississippian series, but extending up into the Pennsylvanian. Its ends in a persistent sandstone member that ordinarily constitutes the lower outer slope of the limestone front ridge. Next above come the "Red Beds," which extend around the foot of the mountains, as in the Black Hills and other uplifts of the Rocky Mountain province. They attain a thickness of over 1000 feet and are either all of Permian age or in part Triassic. The marine Jurassic, which lies next above, is similar to that of the Black Hills and of southeastern Wyoming, containing an abundant middle to upper Jurassic fauna. It is overlain by the Morrison shales, only about 200 feet thick but remarkably persistent in the Rocky Mountain province. Representatives of the Dakota sandstone appear in the Bighorn uplift, but with greatly diminished development as compared with that seen on the Black Hills and in other regions farther south. The hard sandstone supposed to represent the Lakota formation is the most conspicuous feature of these beds. The great series of Upper Cretaceous shales attains a thickness of over 4000 feet in the plains adjoining the Bighorn Mountains. At the base is the Benton group, in which, however, the usual medial limestone member (Greenhorn) is not developed. The chalky element which is so conspicuous in the Niobrara farther south is absent, as are also the fossils which elsewhere characterize the formation. The presence of the Niobrara is indicated, however, by apparently unbroken sedimentation from the Benton to the Pierre. The latter has a thickness ranging from 2000 to 3500 feet near the Bighorn Mountains and presents the usual monotonous succession of gray shales with fossil-bearing concretions. It is terminated by a mass of sandstone, possibly representing the Fox Hills sandstone, which in turn is succeeded by a great development of fresh-water deposits comprizing representatives of the Laramie and probably later formations. These fresh-water deposits occupy a wide area between the Bighorn Mountains and the Black Hills and also a large syncline in the Bighorn Basin. They consist of the usual succession of sandstones and shales, with extensive beds of lignite, but along part of the eastern side of the range they comprize conglomerate near the base, consisting of local materials, indicating uplift and erosion, probably in early Laramie time. The Tertiary system is not well represented in the Bighorn uplift. In the basin to the west are considerable deposits of the Wasatch, and along the southern end of the uplift there is a general overlap of the Bridger formation. In the mountains there evidently was extensive uplift and denudation in Tertiary time. Some small remnants of supposed Tertiary beds have been found high up in the range, but their identity is not established. The Quaternary deposits consist of high terraces and old alluvial fans along the lower slopes of the mountains, glacial detritus, and the alluvial plains along the streams, which merge into the flood plains of the present period. The higher portions of the Bighorn Mountains have been extensively glaciated, there having been two principal epochs of glaciation. Small glaciers still remain on the higher slopes near Cloud Peak.

THE GREAT PLAINS PROVINCE.

General features.—The Great Plains province is that part of the continental slope which extends from the foot of the Rocky Mountains eastward to the valley of the Mississippi, where it merges into the prairies on the north and the low plains adjoining the Gulf coast and the Mississippi embayment on the south. The plains present wide areas of tabular surfaces traversed by broad, shallow valleys of large rivers that rise mainly in the Rocky Mountains, and they are more or less deeply cut by narrower valleys of the lateral drainage. Smooth surfaces and eastward-sloping plains are the characteristic features, but in portions of the province there are buttes, extended escarpments, and local areas of badlands. Wide districts of sand hills surmount the plains in some localities, notably in northwestern Nebraska, where sand dunes occupy an area of several thousand square miles. The province is developed on a great thickness of soft rocks, sands, clays, and loams, in general spread in thin but extensive beds that slope gently eastward with the slope of the plains. These deposits lie on relatively smooth surfaces of the older rocks. The materials of the formations were derived mainly from the west and were deposited, layer by layer, either by streams on their flood plains or in lakes

and, during earlier times, in the sea. Aside from a few very local flexures, the region has not been subjected to folding, but has been broadly uplifted and deprest successively. The general smoothness of the region to-day was surpassed by the almost complete planations of the surface during earlier epochs. Owing to the great breadth of the plains and their relatively gentle declivity, general erosion has progressed slowly notwithstanding the softness of the formations, and as at times of freshets many of the rivers bring out of the mountains a larger load of sediment than they carry to the Mississippi they are now building up their valleys rather than deepening them.

Altitudes and slopes.—The Great Plains province as a whole descends to the east about 10 feet in each mile from altitudes approaching 6000 feet at the foot of the Rocky Mountains to about 1000 feet above sea near Mississippi River. The altitudes and rates of slope vary considerably in different districts, particularly to the north, along the middle course of Missouri River, where the general level has been greatly reduced. West of Denver the central plains have an altitude of 6200 feet at the foot of the Rocky Mountains, and this elevation is sustained far to the north, along the foot of the Laramie Mountains. High altitudes are also attained in Pine Ridge, a great escarpment which extends from near the north end of the Laramie Mountains eastward thru Wyoming, across the northwest corner of Nebraska, and for many miles into southern South Dakota. Pine Ridge marks the northern margin of the higher levels of the Great Plains, and presents cliffs and steep slopes descending 1000 feet into the drainage basin of Cheyenne River, one of the most important tributaries of the Missouri. From this basin northward there is a succession of other basins with relatively low intervening divides, which do not attain the high level of the Great Plains to the south.

Drainage.—The northern portion of the Great Plains above described is drained by the middle branches of Missouri River, of which the larger members are Yellowstone, Powder, Little Missouri, Grand, Cannonball, Owl, Cheyenne, Bad, and White rivers. On the summit of Pine Ridge not far south of the escarpment is Niobrara River, which rises in the plains some distance east of the northern end of the Laramie Mountains. To the south are Platte River, with two large branches heading far back in the Rocky Mountains, Arkansas River, and the Rio Grande, which cross the plains to the southeast and afford an outlet for the drainage from a large watershed of mountains and plains. Between the Rio Grande and the Arkansas are Cimarron River and numerous smaller streams heading in the western portion of the plains. Between Arkansas and Platte rivers are Republican River, rising near the one hundred and fifth meridian, and extensive systems of local drainage in eastern Kansas and Nebraska.

TOPOGRAPHY OF THE CLOUD PEAK AND FORT MCKINNEY QUADRANGLES.

RELIEF.

This area comprizes the high granite ridges and peaks of the highest portion of the Bighorn Mountains, the limestone and sandstone front ridges on either side of the mountain, a portion of the red valley on the west side, and a wide area of Great Plains on the east side. Among the higher slopes there are extensive features which have resulted from glaciation.

Central range.—The central range of the high mountains consists of a main divide ranging in altitude from 9900 to more than 13,000 feet at the north and from 8300 to somewhat over 10,000 feet at the south, the lowest portion being at a point where the divide passes into the area of limestones and sandstones at the southern edge of the Cloud Peak quadrangle. The greatest height is attained in Cloud Peak, the altitude of which is 13,165 feet. Numerous other peaks in this vicinity rise to heights between 12,000 and 13,000 feet and their topography is so rugged that the region presents notable alpine scenery. The crest line of the range is moderately uneven both in course and in profile. Its general trend is slightly west of north. The highest peaks are on or near the divide and are separated by shallow gaps, most of them less than 500 feet deep. At the head of the east prong of East Fork of Big Goose Creek there is a gap in the divide having an altitude of 9900 feet, while the summits on either side rise to heights above 11,400 feet. Another deep gap, in which the altitude is 11,850 feet, lies between Cloud Peak on the north and a 12,887-foot summit on the south. At the head of North Fork of Clear Creek the divide has an altitude of 11,050 feet, which is more than 1200 feet below the summits of the high points on either side. Thence southward for several miles the cross depressions are shallow. South of the headwaters of Sour Dough Creek the altitude of the ridge shows marked diminution, and near the head of Powder River it descends into a wide park having an altitude of about 9000 feet. A small group of high mountains, however, lies east of the main divide in this area, with several summits reaching over 10,000 feet in Hazelton Peak and vicinity. South of Hazelton Peak the altitudes rapidly decline to less than 8500 feet. Thruout its course the central range is deeply cut into by the heads of valleys of the larger drainage features of either side of the range. Most of these valleys are steep sided and those that lie north of the heads of East Tensleep Creek and of the south prong of South Fork of Clear Creek head in deep cirques that extend to or very nearly to the crest line of the mountains. The walls of many of these cirques are more than a thousand feet high and the valleys leading out from them are steep sided for several miles. These cirques will be described in detail in connection with the discussion of the glacial erosion of the region, for they owe their origin to glaciers that formerly occupied the greater part of the higher area. The outer slopes of the central granite region consist mostly of rocky ridges, several hundred feet high, alternating with valleys that contain accumulations of glacial drift. North of Hazelton there are wide plains or open prairies, partly covered with gravels and sands, and similar but smaller areas occur at intervals as far north as Clear Creek, beyond which the high granite ridges extend eastward nearly to the eastern front ridge.

Western front ridge.—The western limestone front ridge crosses the Cloud Peak quadrangle from northwest to southeast and generally rises high above the adjacent slopes of granite and the soft beds of the Deadwood formation. Its altitude in the northern part of the quadrangle ranges from 9200 to 9500 feet, but toward the south gradually diminishes to about 8500 feet. It usually presents to the east a cliff of limestone 300 feet or more high, and to the west relatively gentle limestone slopes, which continue far down the mountains to the overlying sandstones. Altho the crest line of the limestone ridge is uniform in altitude, it is frequently interrupted by canyons of streams that rise in the main divide and flow westward toward the Bighorn Basin. One of the most prominent of these canyons is that of Tensleep Creek, the limestone walls of which range in height from 500 to 1500 feet. The canyons of Paintrock Creek and of the branches of Medicinelodge Creek are also cut deep into the limestone ridge and make wide breaks in its escarpment.

Red valley.—The west side of the mountains presents long, easy grades, that extend into the east side of the Bighorn Basin, the steeper slopes and deeper canyons ending in the wide red valley that occupies the greater portion of the southwestern corner of the Cloud Peak quadrangle. In this red valley the altitudes range from 4300 to 5000 feet, yet many of the low ridges, owing to their bright-red color, are conspicuous topographic features.

Eastern front ridge.—One of the most prominent topographic features in the area treated in this folio is the high front ridge that extends from north to south across its eastern side. This ridge, consisting mainly of hard limestones, rises steeply about 2000 feet out of plains and rolling hills that stand at altitudes very uniformly near 5500 feet. In the southeastern part of the area, where the rocks dip at low angles, the front ridge is from 3 to 4 miles wide and its higher summits reach an altitude of about 8000 feet. The lower slopes are the steeper, the grade decreasing toward the top of the ridge. North of Crazy Woman Hill the ridge narrows rapidly and most of its summits are near 7500 feet above sea level. The front ridge is not continuous but is broken at frequent intervals by deep, steep-sided canyons having limestone walls, notable breaks appearing where it is crost by the forks of Crazy Woman Creek and by Clear, French, Johnson, and Sayles creeks and South Fork of Rock Creek. On North Fork of Rock Creek the ridge gives place to granite slopes for a short distance, owing to a fault. Near Clear Creek it is cut by a wide gap at a high level. Just east of this gap, on opposite sides of Clear Creek, lie two great bowlder deposits on high terraces known as Bald Ridge (6900 feet) and North Ridge (6800 feet), the products of an earlier drainage or glacier which flowed thru the front ridge. Thruout its course the front ridge presents high limestone cliffs toward the west, facing the slopes of the central mountain area. South of Clear Creek these slopes are low and there is a wide intermontane area of rolling park country interspersed with ridges of only moderate prominence.

Plains area.—East of the front ridge is a zone, about 2 miles wide, of low hogback ridges due to uplifted hard beds, and east of these the relief is very low and the features are typical of the Great Plains. The valleys are wide and flat-bottomed and the divides are low and are cut into long, sloping ridges or buttes. On the sides of Clear Creek Valley these buttes and ridges are prominent, owing to cappings of hard clinkers formed from shale that has been baked by the burning of coal or coaly shale. These ridges show a northwest-southeast linear arrangement, parallel to the strike of the beds. Terraces extend along many of the valleys, notably on the north side of Crazy Woman and Clear Creek valleys, and old terrace remnants cap many divides, some of them extending to the base of the steep mountain slopes. One of the most extensive of these terraces near Klondike affords an easy grade for the principal wagon road ascending the mountain. A widely extended system of terraces constitutes the low divides between Clear and Rock creeks west and north of Buffalo, and caps many ridges east of Cross T ranch, southeast of Buffalo. The great high terraces of the front ridge on the sides of Clear Creek west of Buffalo have been referred to above.

DRAINAGE.

Streams.—Numerous streams rise on both sides of the divide of the Bighorn Mountains, those on the east flowing into branches of Powder River and those on the west into branches of Bighorn River. All the streams rising near the divide carry large volumes of water, in great part derived from the melting of snow and ice, a process which continues all summer. In the early summer, when the heavy snows begin to melt rapidly, there are floods, which in some years last for weeks. The largest streams on the east slope are the two forks of Piney Creek, which rise on the north and east sides of Cloud Peak in several great cirques that contain large snow banks and small glaciers. Three forks of Clear Creek head in the high granite central ridge and flow eastward in valleys containing a large amount of glacial drift. North Fork of Powder River is a stream of moderate size draining a small basin between the main divide and Hazelton Peak. Three head branches of East Fork of Big Goose Creek rise in the high divide near the northern margin of the Cloud Peak quadrangle. Little Goose, South Fork of Rock, Sour Dough, North and Middle forks of Crazy Woman, and Doyle creeks are small streams rising in the lower granite slopes east of the main divide. On the west side of the mountains the two largest streams in the area are Tensleep and Paintrock creeks, which drain the highest part of the range, carrying a large volume of water to Bighorn River. Tensleep Creek has many large flowing branches, of which Canyon Creek is the largest. The two forks of Brokenback Creek are small streams heading on the limestone slopes. Tensleep Creek empties into No Wood, a very long creek carrying a moderate volume of water, which flows across the southwest corner of the Cloud Peak quadrangle. Paintrock Creek heads in many branches at the foot of Cloud Peak. Its largest branch is Medicinelodge Creek, which heads in the higher mountains and joins Paintrock Creek at Hyattville. In the northwest corner of the Cloud Peak quadrangle are Shell Creek and one of its branches, Trapper Creek. The main stream rises on high ridges and soon gathers a large flow, which finally reaches Bighorn River in the center of the Bighorn Basin.

Lake De Smet.—Lake De Smet is a remarkable feature, the origin of which is not clear. It lies in a shallow basin that was originally the valley of a small stream heading south, which has been robbed by Boxelder Creek. Its northern end is dammed slightly by clinker beds formed from shale that has been baked by burning coal, and probably this burning has caused the shale to fall in such manner as to dam the basin. Possibly wind assisted in excavating the basin from alluvium and soft sandstones before it held water, for its axis lies northwest and southeast, or in line with the direction of the stronger winds.

CLIMATE.

No detailed meteorologic data for the area are available, but the general conditions may be stated. Owing to the elevation and high latitude, the winters are long and cold and the summers are of moderate warmth. On the mountains there are heavy snows, which usually begin about the middle of September and continue into April. The snow gathers to great depths, and banks of it remain thruout the summer in protected places in the more elevated areas. A moderate amount of rain falls in summer on the mountains, the total precipitation being estimated at 35 inches. On the lower lands the climate is much more arid, the snowfall is light, and the rain is scanty, the average precipitation being about 12 inches. Rains fall mostly in heavy showers during the summer and usually there is a series of moderate rains in early spring. Owing to the clearness of the air there is much heat from the direct rays of the sun, especially in summer.

GEOLOGY.

THE ROCK FORMATIONS.

GENERAL SUCCESSION.

The rocks in the Cloud Peak and Fort McKinney quadrangles are granites and overlying sandstones, limestones, and shales in thick and widespread sheets. The granites are pre-Cambrian and the sedimentary strata comprize a succession ranging in age from Acadian (Middle Cambrian) to Recent, in which representatives of the Silurian and Devonian and of minor portions of other periods are lacking. The thickness of sedimentary rocks is about 16,400 feet in the Fort McKinney quadrangle and about 4400 feet in the Cloud Peak quadrangle. Their characters, thicknesses, and classification are shown on the columnar section sheet. The granites are traversed by dikes, mainly of diabase. Glacial deposits occupy areas of considerable size in the higher mountain region and

Table showing general correlation of the formations in the Northwest.

System.		Bighorn Mountains.	Black Hills.	South-central Montana.
Cretaceous.	Upper Cretaceous.	De Smet.	Laramie.	Laramie.
		Kingsbury.		
		Piney.		
		Parkman.	Fox Hills.	Montana.
		Pierre.	Pierre.	
		Colorado.	Niobrara. Carlile. Greenhorn. Graneros.	Colorado.
	Lower Cretaceous.	Cloverly.	Dakota. Fuson. Lakota.	Dakota.
		Morrison.	Morrison.	Cascade ?
Jurassic.		Sundance.	Sundance.	Ellis.
Triassic ?		Chugwater.	Spearfish. Minnekahta. Opeche.	Absent.
Carboniferous.	Permian ?			
	Pennsylvanian.	Tensleep.	Minnelusa.	Quadrant.
		Amsden.		
	Mississippian.	Madison.	Pahasapa. Englewood.	Madison.
Ordovician.		Bighorn.	Whitewood.	Jefferson ?
Cambrian.	Acadian.	Deadwood.	Deadwood.	Gallatin. Flathead.
Pre-Cambrian.		Granite.	Granite, etc.	Granite, etc.

remnants of old gravel terraces lie in portions of the highlands, extend along parts of the flanks of the front ridge, and cap many of the divides farther east, in the plains region.

PRE-CAMBRIAN ROCKS.

GRANITE.

General relations.—Somewhat more than half the area of the Cloud Peak and Fort McKinney quadrangles lies within the granite area of the central portion of the Bighorn uplift. The granite constitutes an extensive group of high mountains, culminating in Cloud Peak and comprizing the greater portion of the main divide and the adjoining slopes for a width of about 10 miles on either side. To the west and south it passes beneath the Cambrian and overlying formations, so that it lies somewhat over 4000 feet below the surface in the southwest corner of the Cloud Peak quadrangle, and about 16,000 feet below along the eastern margin of the Fort McKinney quadrangle. In several of the valleys in the central area the granite is hidden beneath glacial deposits and on a portion of the main divide between North Fork of Powder River and Canyon Creek and in the wide flats about Hazelton it is covered by deposits of supposed Tertiary age. In most of the mountain area, however, it presents continuous outcrops of bare rock ledges which, in the higher region, are extensively broken into huge masses that constitute the surface above timber line. The granite is traversed by many narrow dikes, mostly of diabase.

Character and distribution.—The greater part of the granite is a gray rock of moderately coarse grain and massive structure, altho on close examination it often exhibits an incipient tendency toward schistosity, a feature which is brought out by weathering. This gray granite merges gradually into other varieties and presents a number of local variations of different kinds. All the granite is believed to be part of one great mass of probably batholithic nature. In the northwestern portion of the Cloud Peak quadrangle, along the branches of Medicinelodge, Trapper, and Paintrock creeks, there is an area of massive red granite which extends into the quadrangle from the north. This rock occurs also at a few points along the southwestern margin of the crystalline rock area. The red granite has a light-grayish appearance at a distance, but on closer view it presents a more or less pronounced reddish tinge. It is traversed by widely placed joints and weathers into bold rounded forms. Its surface is usually rough, owing to differential weathering, which often gives the larger feldspar crystals considerable prominence. In the ridges south of bench mark 8812, southwest of Doyle Creek, there is an area, about a mile in diameter, of a nearly white granite, which apparently merges into the gray variety, and small developments of this white rock occur at many other points, notably on the ridge east of Tensleep Lake, at the head of Paintrock Creek. Nearly all of the higher mountain mass constituting the main divide north of the head of Canyon Creek consists of a hard, coarse-grained, massive granite of medium-gray to dark-gray color.

Petrography.—The granitic rocks present variations in character, but the different kinds of rock are so irregularly distributed that it is not possible to indicate their limits on the map. The predominant variety, especially in the higher portions of the mountains, is a coarse-grained, dark-gray rock, varying considerably in texture, but consisting mainly of feldspar, quartz, and mica, the large feldspar crystals giving it a porphyritic appearance. The mica is mostly biotite, and altho it occurs in variable proportion its amount is much less than that of the other minerals. The quartz usually is less in amount than the feldspars, which comprize plagioclase, orthoclase, and microcline, the proportions of these varying irregularly in different portions of the region. In some areas there is a preponderance of the plagioclase and the rocks are quartz diorites, but in the greater part of the region the potash feldspars are in greater proportion, while intermediate types of quartz monzonites occur in places. These rocks grade into one another and it has not been practicable to map them separately. Apatite, magnetite, and titanite occur as common accessory minerals; rutile and zircon occur less often. As is usually the case in rocks of this sort, all the minerals are crystalline and in general the grains are nearly uniform in size. The quartz occurs in scattered, irregular patches, often interstitially arranged between the larger feldspars. Hornblende occurs mostly in zones, in small amounts, but at a few localities portions of the rock contain much of this mineral. One of these is near Clear Creek Canyon a mile south of bench mark 6477, and another is near the east margin of the granite area 2 miles southwest of Sisters Hill. Much of the gray granite shows evidences of shearing in small amount, but only in very few areas would the rock be regarded as gneiss. In some areas micrographic intergrowths of quartz and feldspar are common, and secondary minerals of various kinds occur in much of the rock. In places portions of the biotite are altered to chlorite and some of the feldspar is altered to kaolin and sericite. In a few local areas dark minerals predominate, giving to the rock a very dark appearance.

In the red granite the minerals are feldspar, quartz, mica, and a few minor accessories. The feldspars are mainly orthoclase and microcline, but these are accompanied by a small proportion of plagioclase, usually oligoclase. The reddish color is due mainly to the dissemination of small particles of iron minerals in the orthoclase. The microcline is sufficiently fresh to present the characteristic cross-hatched structure. The quartz generally occurs in rather prominent crystalline grains, altho sometimes it is interstitially arranged between the larger feldspars. The mica is biotite (often chloritized). Hornblende occurs but sparingly. Magnetite is present in small particles, in moderate amount, and the individual crystals have formed without external interference. Minute crystals of apatite are recognizable in some specimens of the rock. The red granites are generally characterized by a relatively smaller proportion of the darker minerals and an increased amount of microcline.

The white granites, or granite-aplites, consist of orthoclase, quartz, microcline, plagioclase, and mica in varying proportions. At the head of Paintrock Creek microcline predominates, and in the area southwest of Doyle Creek orthoclase is the most abundant mineral. At the former locality the mica is muscovite and at the latter it is bleached biotite, in subparallel arrangement. The rocks are medium to fine grained, granular, with the feldspars and quartz in grains of about the same size.

Gneissic granite.—An area of gneiss, or gneissic granite, extends from near the north boundary of the Fort McKinney quadrangle to North Fork of Clear Creek. It is a medium- to fine-grained, dark-colored rock, showing distinct banding on the surface. The planes of schistosity are nearly vertical or lean slightly toward the center of the mountain range, and the strike is roughly north-south, or nearly parallel to the outer rim of the uplift. The rock weathers into large plates or slabs having rounded outlines. In thin section it shows small grains of quartz, biotite, and a few minor accessories, which surround the larger components in a typical gneissoid structure, the whole having a banded appearance when examined by the aid of a low power of the microscope. Micrographic intergrowth of quartz and feldspar is common and secondary minerals occur along the cleavage cracks of the feldspar. The quartz shows cloudy extinction, and microcline is sometimes interstitially arranged between the larger constituents. The minerals composing the gneiss are the same as those of the granite from which it was derived, with the addition of a few secondary products. Other small areas of gneissic granite lie along the headwaters of North Fork of Crazy Woman Creek and in the region south of Hazelton. The rock in these areas shows no essential difference in character from that described above. In a small area southeast of Hazelton a hornblendic gneiss is found.

Age.—On account of its massive structure, it is believed that the granite is of Algonkian age, for in most portions of the Rocky Mountain province the older granites have been extensively sheared. No contact with any older schists and gneisses has been observed. That the granite and associated rocks are pre-Cambrian is proved by the unconformable overlap of the Cambrian sandstones of the Deadwood formation.

DIABASE.

Occurrence.—The granites of the Cloud Peak and Fort McKinney quadrangles are penetrated by numerous dikes, most of them of diabase. Many of these dikes trend north of east and south of west, across the axis of the uplift, but some extend in various other directions. They are most numerous in the higher portion of the area; otherwise their distribution shows no special features. They vary in width from a few inches to 150 feet, but the majority of them are between 20 and 40 feet wide. Their length is variable, but many are over 5 miles long. One dike that crosses the central ridge begins near the head of North Fork of Powder River and ends at the overlap of Deadwood sandstone a short distance south of Clear Creek Canyon, extending over 22 miles; another crossing the central range south of Middle Fork of Clear Creek is more than 14 miles long. Most of the smaller dikes range from one-fourth mile to 2 miles in length and many are very short; probably numerous small ones are hidden under talus or fallen timber, where they were not discovered. Usually the shorter dikes are the narrower. The dike rocks are black, so that the dikes generally are very conspicuous as black streaks in the mountain slopes, and as they are very hard they stand out at many places in ridges. In places where the rock is much weathered it breaks into squarish fragments, mostly 2 to 6 inches across, and the ultimate product of its decomposition is a reddish-brown residual soil which presents a striking contrast to that derived from most of the granite. The largest and perhaps most notable dike of diabase follows the ridge just north of Cloud Peak. It begins north of Lake Solitude and extends east-northeast thru the ridge north of Cloud Peak, passing thru the peak known as Blacktooth. Its width varies from 50 to 150 feet, and on Blacktooth it sends off a small branch dike 40 feet wide, which constitutes the highest summit. A small northeast-southwest dike extends along the west side of Cloud Peak, crossing the divide about a mile north of the peak. Two large dikes lie a short distance north of the large one, extending to Kearney Lakes, and two others with branches extend east-west along the high slopes south of North Fork of Paintrock Creek. Two long, wide dikes extend across heads of the north branches of North Fork, and another extends from a point near the head of Shell Creek Valley eastward across the divide to Cross Creek. In the ridges east and south of Cloud Peak are numerous dikes of various lengths and widths. The largest of these begins north of West Tensleep Lake and extends nearly due east across the divide and down the ridge north of Sherd Lake, to and beyond Little Sour Dough Creek, in the Fort McKinney quadrangle. North and east of East Tensleep Lake are several dikes, 10 to 50 feet wide, most of them trending southeast and northwest.

The dike on the divide south of Sour Dough Creek, which extends to the granite-sandstone contact near the canyon of Clear Creek, has at some places a width of 100 feet and gives rise to short ridges and knobs at many points. A few rods north of this dike is a smaller dike, which runs parallel to it for some distance, but finally diverges and disappears southeast of bench mark 7831. Two large dikes outcrop in the ridges west of South Fork of Clear Creek, one having a width of 100 feet extending eastward from the basin of Tensleep Creek. They cross each other north of bench mark 7831. Other smaller dikes occur west of this bench mark and a number of them appear about the head of the branches of Rock Creek. South of Hazelton diabase dikes occur every mile or two and trend with parallel courses eastward and northeastward. They are from 5 to 40 feet wide, but the width varies somewhat in the same dike. In this vicinity veins of quartz occur along some of the diabase-granite contacts, and similar quartz veins occur in connection with the diabase dikes at several other localities. The mineral shades in color from pale bluish to white and often forms large hexagonal pyramids. In width these veins vary from a few inches to 2 feet, but usually they are of limited extent. The pre-Cambrian age of the diabase as well as of all other crystalline rocks of the Bighorn Mountains is proved by the fact that they are unconformably overlain by sandstones of Cambrian age.

Petrography.—Nearly all the rocks are very fine grained, dark, and hard. The constituent minerals of the diabase are feldspar, augite, and quartz, with biotite, magnetite, chlorite, and apatite in smaller amounts. The feldspars range from oligoclase to labradorite and are usually in lath-shaped crystals which generally have clearly defined boundaries. They contain a medium to high percentage of lime. Twin lamination on the albite and Carlsbad laws is common and pericline twinning is sometimes seen. The ordinary pyroxenic constituent is augite, which usually occurs without crystal outlines and in thin sections is nearly colorless. In places it has been altered to a fibrous serpentine. Quartz is present in scattered patches of varying dimensions and is often cracked and broken. A light-brown biotite occurs as an accessory, but is usually chloritized. The iron minerals include magnetite and perhaps ilmenite, frequently in skeleton forms. Needle-like crystals of apatite are not uncommon.

A typical diabase from a dike on a southern prong of East Tensleep Creek a mile southwest of the 11,676-foot summit shows the following characters: Its texture is ophitic, but differs somewhat from the usual ophitic texture in that the feldspar occurs in smaller laths and bunches. Augite forms about half of this rock. The feldspar is plagioclase, probably labradorite, and nearly equals the augite in amount. The rock contains some magnetite, as do most of the dikes. On the mountain side 2 miles southwest of the head of Kearney Lakes there is a beautifully exposed contact between quartz diorite and a fine-grained diabase. It exhibits a curving line, in places somewhat jagged. The diabase is very fine grained at the contact, but farther away it is porphyritic, with plagioclase phenocrysts. These phenocrysts are lath shaped and the groundmass is fine ophitic. Near the contact the groundmass is darker and finer grained, there is almost no plagioclase, and the hornblende and magnetite increase, there being much more magnetite near the contact than elsewhere.

OLIVINE GABBRO.

A large dike of a rock rich in olivine extends across the axis of the Bighorn uplift, crossing the divide about 2 miles northwest of Cloud Peak. It begins southeast of Paintrock Lakes and, trending eastward, crosses the valley of North Fork of Paintrock Creek at an altitude of 8700 feet and passes a short distance north of the 12,503-foot summit on the divide. In this vicinity it bends to east-northeast and, passing a short distance north of the Blacktooth, finally disappears beneath the glacial drift east of Kearney Lakes. It averages nearly 200 feet in width for the greater part of its course and has a few small branches. Two other small dikes of the same sort of rock were discovered, one a mile east of the upper end of Lake Solitude and another 1½ miles northeast of Black Butte. The rock is black, its structure is coarsely granular, and in places it shows narrow black phenocrysts up to one-fourth inch in length. Under the microscope the texture is seen to be hypidiomorphic granular. The constituent minerals appear to vary somewhat in proportions, the femic minerals exceeding the salic in quantity. In most of the rock the chief minerals are augite, plagioclase, olivine, hypersthene, biotite, and hornblende, listed in order of abundance, with magnetite, apatite, and rutile as accessory minerals. Another variety, also from the west side of Cloud Peak, is classed as lherzolite, consisting of orthorhombic pyroxene (enstatite), olivine, monoclinic pyroxene (diopside), and smaller amounts of plagioclase, biotite, and magnetite.

HORNBLENDE DIORITE.

A wide dike of hornblende diorite extends north-northeast from a point near bench mark 8548 up the valley of North Fork of Powder River and across the head branches of North Fork of Crazy Woman Creek, a distance of about 10 miles. Its width varies from 100 to 200 feet. It cuts granite, except for about one-half mile in the Powder River Valley, where it either cuts, is cut by, or merges into an amphibolite or hornblende schist. As the contact was not clearly exposed the relations of the two rocks were not determined. The rock is granular and, as more than half of the constituents are dark, it is of dark color. Under the microscope its texture is seen to be hypidiomorphic granular and its chief constituents ar

plagioclase, green hornblende, and biotite, with magnetite, titanite, and apatite as accessory minerals, and sericite, muscovite, and epidote as secondary minerals.

HORNBLENDE SCHIST.

A narrow belt of amphibolite-hornblende schist extends across the granite area from the headwaters of Middle Fork of Crazy Woman Creek to Canyon Creek near bench mark 9069. West of Powder River it is mostly covered by terrace deposits. Its greatest width is 3000 feet. It appears to blend into the granite at some points, but no clear exposures of contact were found. The rock is similar to aggregations of dark minerals occasionally found in irregular streaks and blotches in the granite, but probably in this area it is a separate dike. Much of the material is schistose and breaks into plates having glistening surfaces covered with hornblende crystals in parallel arrangement. Under the microscope the texture is seen to be schistose, flattened hypidiomorphic granular. The principal constituents are green hornblende (generally unstriated) and plagioclase. Quartz is present in small amount. Magnetite, apatite, and titanite occur as accessory minerals, the titanite often surrounding the magnetite.

A mile southeast of bench mark 9568, near bench mark 9851, south of East Tensleep Lake, there is a mass of amphibolite that is supposed to be a dike. It is a dark-gray or nearly black schistose rock, with black, glistening hornblende crystals mingled with white specks, all very small and fine grained. Under the microscope the texture is seen to be hypidiomorphic, and the femic and salic minerals are about equal in amount. The chief constituents are plagioclase (in part labradorite), green hornblende, and lesser amounts of intersertal quartz and biotite, with magnetite and apatite as accessory minerals. The present structure has obliterated the original structure.

CAMBRIAN SYSTEM.

DEADWOOD FORMATION.

Relations and outcrop.—The lowest member of the sedimentary series in the Bighorn Mountains consists of Middle Cambrian beds that closely resemble the Deadwood formation of the northern Black Hills. Its outcrop extends along the inner sides of the front ridges, except for short distances near South Fork of Sayles Creek, North Fork of Rock Creek, and North Fork of Powder River, where it is cut out by faults. Along this course the beds dip at various angles, to the east on the eastern side of the mountains and to the west on the western side. At most places the outcrop zone is marked by slopes surmounted by high cliffs of Bighorn limestone. In the eastern front range north of Crazy Woman Creek there are steep-sided granite ridges on the west, but south of that creek the margin of the granite region is less elevated and rugged, and as the Deadwood deposits here have a greatly diminished rate of dip they extend far westward up the slope, reaching nearly to Hazelton at one point. They also extend along the southern margin of the area mapped, south and southwest of Bull Camp. Faults on South Branch of Sayles Creek and North Fork of Shell Creek bring small areas of the formation to the surface east of the mountains. In the vicinity of Trapper and Medicinelodge creeks the outcrop is narrow, owing to the moderately steep dips, but from Paintrock Creek southward it is wide, except on West Tensleep Creek, where also the formation is extensively covered by morainal accumulations. The formation is extensively exposed in the valleys of Paintrock Creek, Soldier Creek, Tensleep Canyon, and the slopes adjoining Lee Creek, Canyon Creek, and Onion Gulch. Some of the most complete exposures on the east side of the mountains are on Johnson Creek, Billy Creek, Poison Creek, and Middle Fork of Crazy Woman Creek.

Rocks.—The rocks comprize sandstones, shales, limestones, and conglomerates. Owing to the large amount of shale it contains the formation is easily eroded, so that it gives rise to depressions, or saddles, 300 feet or more in depth, on the divides between the streams that pass out of the mountains. Owing also to its softness and possibly in part to its chemical composition, the shale is unfavorable to forest growth, and its slopes are usually bare of trees. The thickness of the formation is somewhat variable, averaging 900 feet northwest of Buffalo, increasing to 1150 feet in the vicinity of Sisters Hill, and gradually diminishing to about 1000 feet toward the south and to about 900 feet along the western side of the mountains. The lower part of the formation, lying on the granites, consists of 50 to 400 feet of brown sandstone and conglomerate. Upon this rest 200 to 300 feet of shales, succeeded above by an alternation of dark-greenish shales and glauconite sandstones, usually beginning with a prominent bed of sandstone; and above this series, at the top, are about 200 feet of alternating slabby limestones, sandstones, shales, and limestone conglomerate with characteristic flat limestone pebbles. Local variations occur in the thickness of the basal sandstone, which is thin on Rock Creek, 400 feet thick on Johnson and French creeks (see fig. 17 of illustration sheet 2), 80 feet on Clear Creek, 380 feet near the head of Kelley Creek southwest of Buffalo, 125 to 150 feet on Middle Crazy Woman Creek, and 100 feet on Beaver Creek. On the north side of the Sisters Hill road the sandstone and some of the overlying beds are cut out by a small local fault. On the west side of the mountain the thickness of the basal sandstone averages 50 feet, but it increases locally to over 200 feet in the vicinity of Lee Creek. This sandstone forms the broad outcrops south of Muddy Creek, especially on the plateaus on both sides of Middle Fork of Crazy Woman Creek, and extends far up the granite slopes in the divides between North Fork and Middle Fork of Paintrock Creek and the several divides farther east, as far as the ridge west of West Tensleep Creek. It is also a prominent feature in the divides between East Tensleep Creek and Onion Gulch, where it attains its maximum development.

The basal sandstone is usually a coarse-grained, coffee-colored to reddish-brown rock, massively bedded, and in places very hard. At its base it is generally dark red-brown in color and more or less conglomeratic, the conglomerate being a prominent feature in the gold prospects at the head of Kelley Creek, north of Sisters Hill. The contact with the granite is usually nearly smooth, but low ridges and gullies are seen at some localities. Toward the southeast, on and near Poison Creek, where the sandstone is about 125 feet thick, it is parted into three hard layers by intervening softer beds. The shales overlying the basal member present but little variation in thickness or composition. They contain occasional thin layers of highly glauconitic sandstone and fossiliferous limestones, and are mostly very soft, so that they outcrop in rounded slopes. The top member varies mainly in the succession of its beds, limestone predominating to the north and west and sandstone to the southeast. Its uppermost beds include much pinkish limestone and its lower ones contain gray or greenish limestone. The thickness of the top member averages 200 feet. This member is rather thin bedded, its layers weathering out in flat slabs and comprizing many beds, 6 inches to 2 feet thick, of the very characteristic flat-pebble conglomerate shown in fig. 20 of illustration sheet 2. This conglomerate consists of flat gray or pink limestone pebbles, often intermixed with twisted and broken thin layers of limestone. The matrix is in places so highly glauconitic as to give a bright-green aspect to the rock and especially to the surface of the pebbles. It is an intraformational conglomerate such as is characteristic of the Acadian (Middle Cambrian) horizon in many portions of the West. Some of the layers of the upper series consist principally of grains of glauconite mixed with carbonate of lime. The sandstones are fine grained, thin bedded, gray, purplish, dull red, and greenish gray in color, and their bedding planes at some places exhibit tracks, probably of crustaceans. A clear exposure of the upper member on the east side of Poison Creek Canyon 5 miles northeast of Hazelton shows the green shales overlain by about 60 feet of thin-bedded sandstone and sandy shales, with limy layers, especially above the middle. The colors are gray, purplish, dull red, and greenish gray. Some layers consist of flat-pebble limestone conglomerate, above described; some portions are highly glauconitic, and a few beds consist of granular mixtures of glauconite and carbonate of lime. The beds are from one-eighth inch to 3 inches thick in greater part. Numerous tracks of crustaceans and scattered crinoid fragments occur on some of the surfaces.

Fossils.—Fossils of Acadian (Middle Cambrian) age are found in the limestones, shales, and sandstones of the Deadwood formation. *Dicellomus politus* is the principal form occurring in the shales and limestones and often constitutes large colonies, especially in limestone lenses in the shales. In the lower sandstone *Ptychoparia oweni* occurs in moderate number. On account of the similarity between the rocks and fossils in this area and those at the type locality in the Black Hills the name Deadwood is used for the formation in the Bighorn uplift.

ORDOVICIAN SYSTEM.

BIGHORN LIMESTONE.

Relations and outcrop.—Probably the most conspicuous sedimentary formation in the Bighorn Mountains is a hard, massive limestone that outcrops in huge ledges surmounting long slopes of Deadwood rocks. Its thickness averages 300 feet, this measurement comprizing an upper series of about 100 feet of softer, thinner bedded limestones and a thin basal sandstone, which have been included in the formation mainly because of their Ordovician age. Altho the Bighorn formation shows no discordance in dip and no marked evidence of erosion at its upper and lower contacts, it is separated from the Deadwood formation by a hiatus representing later Cambrian time, and from the Madison limestone by a break or gap representing Devonian and Silurian time.

The principal exposures of the Bighorn limestone are in a line of cliffs extending along the inner side of the limestone front ridges and facing the granite mountains of the central area. In the deep canyons of Tensleep and Paintrock creeks the outcrop zone extends far to the west, for the dip of the beds is gentle and the canyons are cut very deep. The outcrop is interrupted for short distances by moraines near bench mark 8581 and by a fault on one of the east branches of Canyon Creek. The formation has been carried far below the surface by the fault south of North Fork of Powder River a short distance east of bench mark 8337, in the southeast corner of the Cloud Peak quadrangle. Two outliers of the formation, capped by Madison limestone, lie on high ridges between Paintrock and Buckskin Ed creeks and another occurs east of Tensleep Canyon. The most prominent exposures are in cliffs along the west side of Paintrock Creek, especially near bench mark 8876. In the limestone front ridge on the east slope of the mountains the formation is a conspicuous feature, presenting long lines of high cliffs. On North Fork of Rock Creek and South Fork of Sayles Creek the formation is cut off by faults, so that it does not appear on the mountain slopes, and in this vicinity other faults bring up small areas of the formation a short distance east of the foot of the mountains. A few outlying areas form prominent buttes east of Hazelton, and several small outliers, apparently dropt somewhat from their original position, appear south and southwest of Bull Camp. On Two Creek west of these small outliers the formation is cut out by a local fault. A characteristic outcrop of the formation is shown in fig. 17.

Lower limestone.—The massive limestone that constitutes the greater part of the formation is commonly of light-buff color, somewhat darker when weathered, and is filled with a coarse, matted network of irregular siliceous masses, most of them ranging in diameter from a half inch to an inch. On weathering, this siliceous material stands out a half inch or more on the rock surface as a ragged network, the limestone rock between having been dissolved. The appearance of this weathered surface is shown in fig. 18. This feature and the very massive bedding are characteristic of the lower limestone. Owing to the softness of the underlying Deadwood shales, the hard, massive Bighorn limestone forms high cliffs, with a talus of huge blocks of limestone on the slopes below. (See fig. 17.) Where streams cross the formation there are close, high canyon walls surmounted by nearly vertical cliffs.

Basal sandstone.—The massive limestone of the Bighorn formation is generally underlain by white to gray sandstone, which is sharply separated from the adjoining beds. This sandstone is fine grained and moderately hard, and some portions of it are quartzitic. In the eastern front ridge its thickness ranges from 20 to 35 feet, but on the west side of the mountain, about Lee Canyon and farther south, it is only about 2 feet thick and is mottled red in places. On South Fork of Rock Creek northwest of Buffalo it is 20 feet thick.

Upper member.—The upper member of the formation consists of limestones which are softer and purer than those below. Their bedding is thinner, their color is white to gray, and parts of the rock are very compact or fine grained. Locally shaly limestones appear, notably on South Fork of Rock Creek, where they contain numerous fossils. This upper member shows considerable variation in its local features and ranges in thickness from 75 to over 100 feet. In the greater part of the area it includes a bed of hard, massive limestone with a network of silica, similar to the bed in the great lower member, but less marked in character and only 15 to 25 feet thick. The two members are separated by fine-grained white limestones containing numerous corals. Some shaly and sandy limestone beds also occur locally in the upper member. It is difficult to separate the top of the formation from the Madison limestones owing to similarity of the rocks and the absence of marked unconformity.

Fossils and age.—Very few fossils are found in the lower massive member, but large coiled shells of the genus *Maclurina* and fragments of the "sunflower coral" *Receptaculites* are occasionally observed. The age is Trenton. In the lower portion of the upper member there are usually 2 or 3 feet of beds containing numerous corals, principally of the genera *Halysites*, *Columnaria*, and *Calapœcia*. Large numbers of corals were observed in the lower portion of the upper series in the high ridges on the west side of Lee and Canyon creeks. The following forms were collected by Mr. E. O. Ulrich near Lee Creek: *Halysites catenulatus* var. *gracilis*, *Columnaria alveolata*, *C. halli* var., and a *Calapœcia* resembling *huronensis* and *anticostiensis*. This association of species is regarded as indicating Richmond age. At a horizon 5 feet lower the following species were collected: *Streptelasma rusticum*, *Leptæna* cf. *nitens*, *Rhynchonella? argenturbica?*, *Liospira* cf. *micula*, *Lophospira acuminata*, *Helicotoma* cf. *marginata*, and a small *Straparollus*-like shell, the whole constituting a Richmond faunule. About 50 feet lower, in the same vicinity, there was found in the massive member a *Platystrophia*, perhaps of a new species, but believed to be the same as one found in the Trenton limestone of Tennessee.

Higher in the upper member fossils of undoubted Richmond age occur, notably at a locality on the South Fork of Rock Creek where, at a horizon about 100 feet above the massive lower member, there are 20 feet of limy shales which weather to a reddish clay and yield large numbers of beautifully preserved shells, corals, and bryozoa. The following forms from this locality, indicating late Richmond age, have been determined by Mr. E. O. Ulrich: *Streptelasma rusticum*, *Streptelasma* cf. *robustum*, *Streptelasma* n. sp. (with trilobate calyx), *Lindstromia* n. sp., *Favosites asper*, *Proboscina* near *P. frondosa*, *Monotrypella quadrata*, *Batostoma manitobense*, *Bythopora striata*, *Leioclemella* sp. undet., *Rhinidictya* sp. nov., *? Goniotrypa lateralis*, *Sceptropora facula*, *Plectambonites* n. var. or sp. (near *P. sericea*), *Leptæna nitens*, *Strophomena* n. sp. (between *S. neglecta* and *S. planodorsata*), *Dalmanella meeki* Winchell and Schuchert (? Miller), *Dalmanella tersa*, *Dinorthis* n. sp. (distinguished from *D. subquadrata* by its coarse ribs), *Plectorthis whitfieldi* (small variety), *Rhynchotrema perlamellosa*, *Rhynchotrema increbescens* (n. var.), *Lophospira* (cast) sp. undet., *Cylora depressa?*, *Eurychilina manitobensis*, *Primitia lativia*, and *Schmidtella* sp. undet.

The massive limestone at the base of the formation at this locality contains a few fossils, including *Maclurina manitobensis*, and in its upper part *Receptaculites oweni*, both characteristic species of the Galena-Trenton limestone of the northern Mississippi basin.

In the region south of the area to which this folio relates remains of fossil fish of Black River age were found in the basal sandstone member, which afford a basis for correlating this member with the Harding sandstone of Colorado.

In Muddy Creek Canyon a number of fossils were obtained from beds immediately above the

massive lower member, but nearly all were of new species or too poorly preserved to permit accurate specific determination. The following report upon them was prepared by Mr. E. O. Ulrich:

Liospira cf. *americana*, differs from *L. americana* in having whorls slightly turriculated; *Lophospira* cf. *perangulata* and *acuminata*, is small, round-whorled, broadly umbilicated; *Straparollus*-like gasteropod, material not in condition to determine genus satisfactorily; *Trochomena*, sp. undet., shell small, sharply angulated, with fine, sharp lines of growth; *Orthoceras*, sp. undet., a small species with nearly flat, thin septa and comparatively coarse longitudinal lines; *Cyrtoceras*, sp. undet., a small slightly curved shell; *Ctenodonta*, sp. undet.; *Isochilina*, sp. nov.; *Aparchites*, sp. undet.; *Primitia*, sp. undet.; *Bythocypris*, sp. undet. On the whole the fauna appears to be younger than Trenton, to which age the underlying massive limestone is referred, and I am inclined to refer them to the Richmond group.

This opinion is influenced by the probable hiatus representing a considerable part of Cincinnati time at the top of the massive limestone member.

Fifty feet higher in the Muddy Creek section were found *Girvanella* cf. *richmondensis*, ? *Schizolopha mooresi*, *Leperditia* cf. *cœcigena*, *Isochilina* n. sp., *Primitia* aff. *humilis*. This faunule evidently should be referred to the Richmond. Except the *Girvanella*, perhaps, the species are not identical with known Richmond forms, but they are nearer to these than to species of any other fauna. Species to which they are related occur well up in the Richmond of Ohio and Indiana.

Some distance higher were found an undetermined fucoid, possibly of the genus *Lycrophycus*, and a poorly preserved *Protarea* resembling the species *verneuili* and probably of Richmond age. The corals which are so abundant at some places in the lower part of the upper member were not found in the Muddy Creek section, but on Crazy Woman road, less than a mile north, they occur in moderate numbers. At this place were collected *Halysites catenulatus* var. *gracilis*, *Columnaria halli* var., and *Ceraurus* resembling *milleri*. These forms are known to occur in the Richmond group, or uppermost Ordovician. Apparently in the Bighorn region there is, between the two upper members of the Bighorn limestone, a widespread hiatus representing later Trenton, Utica, Eden, and Lorraine time. Locally perhaps the earlier Richmond also is absent at the top of the formation. Earlier Ordovician beds older than Black River are absent.

CARBONIFEROUS SYSTEM.

MADISON LIMESTONE.

Relations and outcrop.—The greater part of the thick limestone series flanking the slopes of the Bighorn Mountains constitutes the formation known as the Madison limestone. It averages about 850 feet in thickness and is of earlier Carboniferous age, being correlated with the Madison limestone of Montana and the Pahasapa limestone of the Black Hills. It lies unconformably on the Bighorn limestone, but without discordance of dip, and is overlain with apparent conformity by the Amsden formation. The Madison outcrop forms the crest and outer slopes of the limestone front ridge, lying in a belt which varies in width from 1 to 4 miles on the greater part of the west side of the mountains and is considerably narrower on the east side. It extends far down the valleys of streams flowing westward, especially along Tensleep and Paintrock creeks and the branches of Medicinelodge Creek. In the canyons of these streams it appears in walls that are in places a thousand feet high, including the cliff of Bighorn limestone. The most notable of these exposures are in Tensleep Canyon, down which the formation extends nearly to the mouth of Canyon Creek. The formation is also bared for a short distance in the lower portion of the canyon of South Fork of Brokenback Creek. Along the fault which extends down the valley of Canyon Creek the formation appears at intervals in cliffs overlooking slopes of the Amsden, Tensleep, and Chugwater formations. Along the eastern extension of this fault the formation is in contact with the Deadwood shales for a short distance, and is again cut out for about a mile in the southeast corner of the Cloud Peak quadrangle, east of bench mark 8337. Along the eastern front ridge the outcrop is nearly continuous, but it is interrupted for short distances by faults at North Fork of Rock Creek and South Fork of Sayles Creek. North of Crazy Woman Hill, where the dips are steep, the outcrop zone is narrow, varying in width from 1 mile west of Mowry Basin to less than 1000 feet on Clear, French, and Johnson creeks. In the southern portion of the area mapped it widens, especially in a low anticline and syncline south of Billy Creek, where its width is nearly 3 miles. It underlies the southwest corner of the Fort McKinney quadrangle, but on Two Creek its outcrop is cut off by a fault in which the overlying Amsden formation is brought into contact with the granite. Owing to faults along the east side of the front ridge the Madison limestone has been brought into contact with the Kingsbury conglomerates northwest of Buffalo, and by the prolongation of one of the faults is brought to the surface 1 mile east of the foot of the mountains, in the divide south of Sayles Creek.

Thickness.—The Madison limestone is 900 feet thick in the northern part of the area mapped, but its thickness gradually diminishes toward the south. On Canyon Creek it is about 750 feet thick and at the southern margin of the Fort McKinney quadrangle it is 600 feet or less.

Character.—The Madison limestone comprizes two principal members. The upper one consists of 175 to 250 feet of light-colored, nearly pure, massive-bedded limestone, which weathers to a light dove color and gives rise to pinnacled forms and caverns. This upper member generally lies on the higher eastern slopes of the front ridge, and parts of it are stained red by wash from the red shales of the overlying Amsden formation. A characteristic view of it is given in fig. 16. The lower member consists of 400 to 700 feet of harder, darker colored limestones, mostly in beds less than 3 feet thick, which usually constitute the crest of the front ridge. Some of the beds are sandy, and some shaly limestones appear locally. In general each member is nearly uniform in character thruout, and the lower one shows a gradual diminution of thickness toward the south. The most extensive and instructive exposures of the formation are in canyons, especially those of South Fork of Rock Creek, Kelley, North, Middle, and South forks of Crazy Woman Creek, and Muddy, Billy, and Beaver creeks.

Fossils and age.—Fossils occur thruout the Madison limestone, but are most abundant in and above the middle beds. They are correlated with the Waverly horizon in the Mississippian series (Lower Carboniferous). The formation is equivalent to the Madison limestone of Montana and approximately to the Pahasapa limestone of the Black Hills. The most abundant species are *Spirifer centronatus*, *Chonetes loganensis*, *Seminula humilis*, and *Eumetria verneuiliana*.

The lower beds seldom yield determinable fossils. A few remains obtained on Muddy Creek a few feet above the Bighorn limestone were identified as follows: *Syringopora surcularia*, *Schuchertella inæqualis*, *Camarotœchia sappho? ?*, *Fistulipora* sp., *Fenestella* sp., and *Seminula?* sp. A short distance north the same beds yielded the two forms first mentioned, together with *Spirifer centronatus* and *Rhipidomella?* sp.

In the medial beds at the head of North Fork of Shell Creek the following species were collected: *Schuchertella inæqualis*, *Chonetes loganensis*, *Spirifer centronatus*, *Spiriferina solidirostris*, *Seminula humilis*, *S. madisonensis* var. *pusilla*, *Eumetria verneuiliana*, and *Camarotœchia metallica*. All these fossils were determined by Mr. G. H. Girty.

AMSDEN FORMATION.

Relations and outcrop.—Upon the Madison limestone lies a series of red shales, limestones, sandstones, and cherty beds, which has been designated the Amsden formation. Its average thickness is between 200 and 250 feet. Its outcrop extends along the middle slopes of the front ridges on both sides of the mountains. On the west side, where the dips are mostly low, its extent is great, especially in the area lying between Paintrock and Canyon creeks. It is also exposed far up the divides between Paintrock and Medicinelodge creeks and in portions of the region farther northwest. There are extensive exposures along the high ridge west of South Fork of Paintrock Creek, in the ridges on either side of the forks of Brokenback Creek, in the lower portion of Tensleep and Canyon Creek canyons, and in Canyon Creek Canyon northeast of Rome, where it is cut off by a fault. An outlying area appears south of North Fork of Powder River, where it is brought into contact with the Bighorn limestone and Deadwood formation by a fault.

For some distance west of Buffalo and north of North Fork of Rock Creek the formation is cut off by the faults and does not reach the surface.

Character.—The basal member of the Amsden formation usually is a red sandy shale or a fine-grained red sandstone, averaging 100 feet in thickness. Owing to its softness its outcrop is marked by a slight saddle, east of which overlying limestones often rise in a knob or bench. Along the east side of the mountains the red member generally lies directly on the massive blue limestone at the top of the Madison formation, without evident unconformity. In an extensive exposure of the Amsden formation in the canyon of North Fork of Crazy Woman Creek there are, at the base, about 60 feet of fine-grained sandstones, mostly red but with some ledges of buff color; then 80 feet of fine, white, very compact limestones with red and buff shale intercalations; a few feet of impure, light-colored limestones filled with light-colored chert; 40 feet of light-colored limestones with partings of purplish shale; 30 feet of impure limestones with much gray to brown chert; and, at the top, 25 feet or more of alternations of impure limestone and sandstone—225 feet in all. This exposure is shown in fig. 16. About 1½ miles south of Johnson Creek, 320 feet of Amsden formation were measured, including the thick mass of basal red beds and a succession of fine, white, compact limestones, containing less chert and sandy admixture than the beds farther south.

On the west slope of the mountains the lower red shale member of the Amsden formation is separated from the Madison limestone by a local bed of cross-bedded sandstone which attains its maximum development in the vicinity of Tensleep Creek, where it has a thickness of over 40 feet. It is coarse grained, of gray color, and cross-bedded. The red shales next above are from 30 to 50 feet thick and are conspicuous all along the higher middle slopes on the west side of the mountain. In some of the canyons this red shale is less noticeable, being covered by talus from the cliffs above. On the west slope the upper member of the Amsden formation consists largely of slabby sandstones, in part calcareous, which in its lower portion contain beds of fine-grained, pure white limestone, similar to lithographic stone, and in its upper portion beds of very cherty limestone. In the slopes west of Black Butte the basal sandstone is not more than 10 feet thick, while the red shales are more than 50 feet thick and are succeeded by 10 feet of hard, fine-grained limestone, containing much chert. The upper portion of the formation consists of about 120 feet of slabby sandstones, shales, and white limestones. The basal sandstone is a conspicuous feature near Canyon Creek, altho it is there of somewhat diminished thickness. It also appears in exposures south of North Fork of Powder River. Owing to the sandy nature of the deposits in the upper portion of the formation, it is not always practicable to distinguish the contact line with the Tensleep beds.

Fossils and age.—Fragmentary fossils occur at many places in some of the limestone and cherty beds, but they are usually indeterminate. Some fairly good ones collected from the heavy chert beds near the top of the formation on the slopes south of North Fork of Crazy Woman Creek comprize the following species: *Productus nebraskensis*, *Edmondia nebraskensis*, *Archæocidaris* sp., *Murchisonia* near *M. lasallensis*, *Orthothetina* n. sp., *Aviculopecten occidentalis?*, *Pleurophorus* near *P. subcostatus*, *Euomphalus catilloides?*, *Pleurotomaria scitula?*, *Bellerophon?* sp., *Fenestella* sp., *Entolium aviculatum*, *Orthonema?* sp., *Euphemus?* sp., and *Phillipsia major*. These forms were determined by Mr. G. H. Girty, who regards them as representatives of the upper portion of the Pennsylvanian (Upper Carboniferous) of the Mississippi Valley section. In another portion of the uplift an earlier Carboniferous fossil (*Menophyllum excavatum*) was found in the lower limestones, which may indicate that the lower beds comprize a portion of the Mississippian series.

TENSLEEP SANDSTONE.

This sheet of sandstone extends along the lower slopes of the Bighorn Mountains, usually marking the first rise above the red valley.

West slope.—On the west side of the mountains its thickness is from 100 to 150 feet, with frequent local variations. It consists almost entirely of moderately fine-grained, massive, cross-bedded sandstone of light-gray color. Toward the top there are one or two limy layers, and in its lower portion there is a less massive, more regularly bedded sandstone, which is not easily separable from the top sandy members of the Amsden, into which it merges.

The formation extends far up the divides between Paintrock and North Fork of Brokenback creeks and south of Tensleep Canyon, constituting low, steep-sided ridges and outlying buttes. It presents extensive exposures along the lower portion of Tensleep and Canyon Creek canyons, the name being derived from the former. In the ridge adjoining North Fork of Powder River it occurs on a faulted block, in which it abuts against the Madison limestone for a mile or more. A similar relation exists for several miles along the fault north and northeast of Rome post-office. Owing to a low anticline trending northwestward, outcrops of the formation extend far down the two forks of Brokenback Creek, and several small areas show in shallow canyons in the ridge north of bench mark 4522.

East slope.—On the east side of the mountains the formation is a massive white sandstone, locally of buff color, usually hard, about 250 feet thick at the north, its thickness gradually increasing to 350 feet toward the south. From North Fork of Crazy Woman Creek southward it extends far up the mountain slopes, rising over a thousand feet on the spurs, but is deeply trenched by streams, which pass thru it in narrow gateways. To the north, as the dips steepen, it gives rise to a ragged ridge of pinnacles or plates of sandstone which extends nearly to Clear Creek, where the formation is cut off by the fault and ceases to outcrop for several miles. It again appears on the slopes west of Mowry Basin, extending to the fault at North Fork of Rock Creek.

Fossils and age.—Only a few fossils have been discovered in the formation, and these occur in chert nodules in its middle beds, on the slopes southwest of Buffalo. Of the fossils collected, Mr. G. H. Girty identified *Productus cora*, *Strophostylus nanus?*, and *Pleurotomaria?* sp.—forms which indicate later Carboniferous (Pennsylvanian) age.

TRIASSIC SYSTEM (?).

CHUGWATER FORMATION.

General features.—The Chugwater formation consists of red shales and sandstones which outcrop along the base of the steeper slope of the front ridge of the Bighorn Mountains. Its thickness averages 1200 feet on the east side of the mountains and 800 feet on the west side. Owing to low dips and an anticline, its outcrop area is wide in the southwestern portion of the Cloud Peak quadrangle, attaining on Brokenback Creek a width of 10 miles. South of Tensleep Creek and still farther southwest, where the dips are steeper, the outcrop averages about 3 miles in width. The surface is barren and bears but little vegetation, and as some of its beds are hard the formation is extensively exposed in numerous prominent bare ridges and buttes. One of the finest lines of red cliffs extends northwestward from Rome along the south side of Canyon Creek Valley; another notable one is on the west bank of No Wood Creek, at the mouth of Tensleep Creek. On the east side of the mountains the outcrop is mostly from one-third to one-half mile wide, but west of Buffalo the formation is cut off by a fault for some distance, so that it does not reach the surface. The formation begins abruptly at the top of the Tensleep sandstone, but no signs of unconformity appear at the contact.

Character.—The Chugwater rocks consist mainly of soft, massive red sandstones with bodies of sandy red shales at intervals and at the top and bottom. Near the base there is everywhere a stratum of thin-bedded purplish limestone; a short distance higher up, or about 80 feet above the base, there is a layer of massive limestone which acquires a peculiar spongy texture on weathering. Near the top there are some thin but persistent layers of white slabby limestones, intercalated among red and

purplish shales. Gypsum occurs in the Chugwater formation in local beds, mostly near its summit and base. The brilliant red color of the formation makes it a conspicuous feature in the landscape, contrasting sharply with the light-colored Tensleep sandstone of the adjoining mountain slope.

Sections on west side.—On Paintrock Creek the upper Chugwater beds consist of a 16-foot limestone layer, which is followed above by 60 feet of red sandy shales, 10 feet of gypsum, 30 feet of red shales, 100 feet of red shales with some gypsum below and thin limestone above, 2 feet of white limestone, and, at the top, 6 feet of red shale, capped by a 6-foot layer of sandy limestone filled with Jurassic fossils. On Tensleep Creek the formation contains the two limestone beds toward the base, and the lower 100 feet of red sandy shales include three beds of gypsum, each about 8 feet thick. This series is followed by massive, soft red sandstones, several hundred feet thick, merging upward into a bed of red sandy shale 100 feet thick, containing near its base a 5-foot layer of hard, thin-bedded gray limestone. Higher up are several beds of gypsum and at the top several thin beds of white slabby limestone.

Section on east side.—The Chugwater stratigraphy on the east side of the mountains presents several local variations. At the base of the formation there are red shales lying directly on the Tensleep sandstone with perfect conformity of dip, but presenting an abrupt change in sediments. From 15 to 20 feet above the contact there is everywhere a bed of thinly laminated pinkish limestone from 2 to 5 feet thick, so similar in relations and character to the Minnekahta limestone of the Black Hills as to strongly suggest that they represent the same horizon, but thinner and with an attenuated representative of the Opeche beds below. In an excellent exposure of nearly vertical beds in the slopes north of South Fork of Rock Creek the lower limestone is overlain by 200 feet of soft red sandstone containing much impure gypsum. Next there is a 20-foot bed of pure gypsum over a few feet of red shales, and then a 3-foot bed of impure limestone containing considerable silica and weathering to a brown porous rock, a characteristic member at this horizon. This is followed by 500 feet of red sandstone, terminated by a 13-foot bed of very hard white limestone, which rises in a sharply marked local ridge, especially prominent near the small cross fault. It is overlain by 180 feet of soft, reddish-brown, massive sandstone, including in its middle a thin fossiliferous limestone bed and near its top a 3-foot bed of hard white limestone. In the southern part of the area mapped the local relations of these beds vary somewhat, mainly in the intervals between the upper limestones. In the first draw south of Mowry Creek there is an interval of 240 feet between a 4-foot limestone bed marking the summit of the Chugwater formation and the heavier bed below, which is here 12 feet thick and whose outcrop, owing to its hardness and its steep dip, is marked by a line of jagged ridges. The underlying red beds here are 1230 feet thick. On Sayles Creek similar relations and thicknesses were observed. Near the head of Sand Creek, southwest of Buffalo, where the beds are nearly vertical, there are, first, 150 feet of red beds with the thin bed of limestone near their base; then over 100 feet of gypsum, in part pure; 700 feet of soft red sandstones; then the lower limestone of the upper limestone series, 6 feet thick, followed by 180 feet of red shales and sandstones that extend up to a succession of red shales, 70 feet thick, containing thin basal and medial beds of limestone and a 6-foot bed of limestone at the top. In the region south of Sisters Hill the upper series, with limestones, diminishes in thickness. There are several feet of red shale at the top and then a 3- to 4-foot bed of limestone lying on red shales containing two thinner limestones. The thin-bedded purple limestone lies 30 feet above the Tensleep sandstone, and 40 to 50 feet higher is a 5-foot bed of dark limestone, weathering to a rock of porous texture. Several gypsum beds occur in the overlying shales for the next 100 feet. Near Beaver Creek an 8-foot bed of this mineral occurs locally near the top of the formation.

Fossils and age.—A few imperfect fossils collected in the upper limestone of the Chugwater formation were found by Mr. T. W. Stanton to comprize a probable ostracod crustacean, numerous small bivalves resembling *Astarte*, and a few small naticoid gasteropods, which are not sufficiently characteristic to decide the age of the formation. In other portions of the area a few indistinct fossils which are believed to be Permian occur in the lower limestones of the Chugwater. It is probable that the lower portion of the formation is equivalent to the Opeche red beds and Minnekahta limestone of the Black Hills and southern Wyoming, which are regarded as Permian. It is thought likely that the great overlying mass of red beds may comprize Triassic sediments, especially at the top, but there is no direct evidence on this point.

JURASSIC SYSTEM.

SUNDANCE FORMATION.

Relations and outcrops.—On the outer margin of the outcrop of Chugwater red beds there is a narrow outcrop zone of the shales and sandstones of the Sundance formation. It extends continuously southward along the east side of the mountains, from the head of Sand Creek and from South Fork of Sayles Creek nearly to North Fork of Rock Creek, but is cut out by faults for some distance west of Buffalo and north of Rock Creek. Outcrops are abundant, but along the streams and on the divides south of the head of Kelley Creek the formation is hidden in places by superficial deposits. West of the mountains the outcrop extends for some distance along the east side of No Wood Creek and the slopes east of that creek nearly to the mouth of Tensleep Creek. A short distance south of Tensleep post-office the dips steepen rapidly and change in direction to south, so that a narrow zone of outcrop extends westward. This reaches nearly to the western margin of the Cloud Peak quadrangle, where the dips again flatten and, changing to west, cause the outcrop area to widen. Southeast of Tensleep post-office the formation is extensively overlain by the later formations, but it is exposed along both sides of No Wood Creek and in several valleys of small branches, as well as in the high ridge a mile south of bench mark 5097, where it is a prominent feature. The formation lies unconformably on the red beds of the Chugwater formation, but without perceptible discordance of dip and usually without marked evidence of erosion. The hiatus at its base represents middle and early Jurassic time and doubtless some if not all of Triassic time.

Thickness.—The thickness of the formation is about 320 feet on Rock Creek, 365 feet on Sayles Creek, and 450 feet south of Sisters Hill. South of North Fork of Crazy Woman Creek the amount diminishes gradually to 380 feet on Beaver Creek. On the west side of the mountains the thickness is 325 feet.

Character west of the mountains.—In the region adjoining No Wood Creek the Sundance deposits consist largely of greenish-gray shales with occasional sandy and limy layers. In the upper 50 feet there are three thick beds of limy sandstones filled with fossils, a member which is prominent in the two 5000-foot summits south of bench mark 5097. Toward the base of the formation soft greenish-gray sandstones appear and in places a bed of dark-gray fossiliferous limestone.

Character east of the mountains.—South of Sisters Hill the basal member is a 3-foot bed of conglomerate consisting of chert pebbles up to an inch in diameter, mixt with sand, but this is of small extent. Northwest of Buffalo the basal bed is shale, which always is succeeded by a thin but hard stratum of sandstone or sandy limestone, generally highly fossiliferous. The basal shales disappear south of Poison Creek, but the hard fossiliferous bed continues, capping a ridge or westward-facing escarpment of "Red Beds." It has a thickness of 3 to 5 feet usually, but of 25 feet at one point near Beaver Creek. It is succeeded by 75 to 100 feet of sandy beds of pale greenish-gray to pale buff color, varying from massive to thinly laminated, usually soft, but sometimes including hard layers and in places having near its lower portion some sandy shales containing *Gryphæa calceola* var. *nebrascensis*. On Beaver Creek the basal sandy series is nearly 200 feet thick, comprizing much massive white sandstone in its upper portion, some shales, and several hard layers. The next member is greenish-gray shale averaging from 100 to 120 feet thick thruout and containing thin layers of highly fossiliferous limestone and sandy layers with abundant *Belemnites densus*. Fossiliferous, calcareous, lens-shaped concretions also occur in these shales. They are succeeded by a hard sandy layer containing many fossils, usually followed by several feet of shales or a thin mass of gray sandstone. Next above is another hard fossiliferous bed, 3 or 4 feet thick, marking the summit of the formation. These two upper hard beds give rise at many places to small ridges that rise sharply above slopes of the greenish-gray shales.

Fossils.—Fossils are abundant in all exposures of the Sundance formation. One of the most conspicuous forms is *Belemnites densus*, a cigar-shaped fossil 3 or 4 inches long, smooth on the outside, but having a radiated structure within. These occur mostly in sandy layers in the upper shale member and often weather out on the surface, and thus become a notable feature. In the lower sandy shales there are large numbers of a small oysterlike shell, *Gryphæa calceola* var. *nebrascensis*, and in the hard layers higher up are found *Camptonectes bellistriatus*, *Ostrea strigilecula*, *O. engelmanni*, *Dosinia jurassica*, *Eumicrotis curta*, *Trigonia elegantissima*, *T. americana*, *T. conradi*, *T. montanaensis*, *Pentacrinus asteriscus*, and other forms, all determined by Mr. T. W. Stanton. The formation is equivalent to the Sundance formation of the Black Hills and the Ellis formation of Montana and the Yellowstone Park region. It may be correlated with the lower part of the European upper Jurassic.

CRETACEOUS SYSTEM.

MORRISON FORMATION.

Relations and outcrops.—This formation outcrops along a narrow zone in the foothills at the base of the mountains, except west and northwest of Buffalo, where, for a few miles, it is cut off by faults. As it consists principally of soft deposits, its outcrop zone is marked by a shallow valley lying between knobs of Cloverly sandstone on the east and the ridge of the upper sandstone of the Sundance formation on the west, and it is mostly covered by sod or talus. In the valleys and on the wide divides south of Sand Creek it is at many places buried beneath Quaternary deposits. It outcrops in a broad area along both sides of No Wood Creek south of Tensleep post-office and in a narrow zone in the region of steep dips west of the mouth of Tensleep Creek. In a portion of the area south of Tensleep post-office the formation extends far up the slopes of the ridge of Sundance beds and is cut into outliers by several small branch streams.

Its thickness is less than 150 feet northwest of Buffalo, but increases southward, and its amount is 250 feet in several sections south of Sisters Hill. It again diminishes somewhat in thickness south of Poison Creek and is 160 feet near Beaver Creek. On No Wood Creek it is 250 feet thick.

Possibly there is conformity between the Morrison and Sundance formations, and perhaps also transition thru a few feet of greenish-gray sandstones which lie above the hard fossiliferous ledge near the top of the Sundance, but no positive evidence was found as to the precise limits of the two formations. At the top of the Morrison formation there is an abrupt change of sediments to the Cloverly conglomerate, but probably without hiatus representing any considerable time interval.

Character.—The formation is composed principally of hard clay or massive shale of a greenish or maroon color, with darker clay at its summit, all having a peculiar chalky appearance, and includes several beds of light-gray or buff sandstones ranging in thickness from 2 to 20 feet. These sandstones are usually soft and, on weathering, exhibit thin, irregular bedding planes, which generally have a peculiar wavy surface, suggestive of incipient cross-bedding.

Sections east of the mountains.—The best exposures are in Mowry Basin, on Sand Creek, southeast of Sisters Hill, on Muddy Creek and its north fork, and at intervals from Poison Creek to Beaver Creek. In the first hollow south of South Fork of Rock Creek there are, above the hard fossiliferous layers near or at the top of the Sundance formation, 40 feet or more of soft greenish-gray and pale-buff sandstones, which possibly should be regarded as the base of the Morrison formation, or perhaps as a transition series; then follow 80 feet of clays, 15 feet of the typical sandstone above described, and, at the top, 30 feet of clays of maroon, buff, and greenish colors below and dark above.

A mile south of Muddy Creek is the clearest exposure of the Morrison formation in the area. It exhibits, at the top, 10 feet of reddish shale, grading down into dark shale, succeeded by 240 feet of hard, chalky clays of maroon and green tints, with occasional thin sandstone partings and, 100 feet below the Cloverly sandstone, a 6-foot bed of hard, light-colored sandstones. The sandstones weather in thin beds with irregular, wavy surfaces. Near its base the clay is red. Next below the above-described beds is an 8-foot bed of white sandstone, separated from the fossiliferous Sundance ledge by a few feet of soft gray and buff sandstones. On Poison Creek the features are very similar to those near Muddy Creek. A mile north of Middle Fork of Crazy Woman Creek the upper part of the formation consists of 125 feet of clays, partly maroon and partly green, with thin sandstone layers near their bottom, resting on a 5-foot ledge of light-gray sandstone underlain by 40 feet of shales and soft sandstones lying on the top of the Sundance formation. A mile south of Middle Fork of Crazy Woman Creek there are, at the top, 80 feet of chalky clays, light-green above and maroon below, underlain by a 6- to 12-foot bed of grayish-buff sandstone containing plants and saurian bones; 70 feet of maroon and light-green chalky clays with thin sandstone layers; 12 to 15 feet of white, soft, massive sandstone resembling the Unkpapa sandstone, which lies in a similar position in the Black Hills, and, at the bottom, a 20-foot bed of greenish sandy clays, which lies next above the hard fossiliferous bed on the top of the Sundance formation and possibly belongs to that formation. Near Beaver Creek the upper part of the formation consists of 50 feet of light-green to maroon chalky clays containing a 2-foot bed of limestone 10 feet below the Cloverly sandstone. These clays are underlain by a succession consisting of a 4-foot sandstone bed; 25 feet of clays, in part maroon; several layers of sandstone; 10 feet of shale; 1½ feet of thin limestone; 25 feet of red to maroon clays with thin sandstone layers; 2 feet of thin-bedded sandstone; 20 feet of soft, massive white sandstone; and, at the base, a few feet of clays lying on the hard fossiliferous bed at the top of the Sundance formation.

No Wood Valley.—In No Wood Valley the rocks consist of the usual admixture of clay and fine sand, or sandy clay, in greater part massive bedded, containing layers of gray sandstone. The principal colors are greenish-gray and maroon, but some beds are white, purplish, gray, or nearly black. The lower beds are of dull pinkish color. In the vicinity of Tensleep post-office, where the thickness is about 250 feet, the formation consists of greenish-gray sandy shales below, then a sandstone member 5 to 8 feet thick, followed above by 50 feet of maroon to red clay, 100 feet of greenish-gray clays, and, at the top, 40 feet of darker shales, which extend to the base of the Cloverly sandstone.

Fossils and age.—The only fossils discovered in the Morrison beds are fragments of bones of large saurians, apparently similar to those occurring in the formation in other regions. Opinions are divided as to whether these remains are of late Jurassic or early Cretaceous age, but, because of the stratigraphic relations of the beds in the Black Hills and Rocky Mountains, they are provisionally classed in the early Cretaceous.

CLOVERLY FORMATION.

Outcrop and relations.—This formation consists of sandstone and sandy clay supposed to be the stratigraphic equivalent of beds formerly referred to as "Dakota" sandstone. Its outcrop extends in a narrow zone a short distance east of the mountains, and its sandstone member generally is marked by knobs and low ridges on the divides. In a few areas the sandstone is too soft to be prominent, while in the valleys and on some of the high terraces on the east slope of the mountains the formation is covered by Quaternary deposits. In part of the area northwest of Buffalo it is cut out by faults.

The outcrop extends along the slopes west of No Wood Creek for some distance and crosses that stream at a point one-half mile south of Tensleep post-office, appearing in a small exposure on the north bank. To the west and south of this

exposure for some distance the formation is covered by alluvium. It reappears at a point three-fourths of a mile southwest of Tensleep post-office, dipping very steeply southward and extending westward in a narrow zone.

The basal sandstone appears to lie conformably on the Morrison formation, altho there is an abrupt change in sediments at the contact, especially where there are local lenses of conglomerate in the basal beds. There appears to be gradation from the top of the formation to the succeeding Colorado.

Character.—The lower half of the formation is characterized by a coarse-grained, partially cross-bedded, massive sandstone, usually in one body consisting of indurated quartz sand. The color is mostly pale buff or light brown, but locally it is light gray or white. Most of the outcrops bear a few scattered pine trees, and the areas of the Cloverly formation may in some places be thus readily distinguished, for such trees do not grow on outcrops of the adjoining formations. The sandstone is at most places about 30 feet thick, but southeast of Sisters Hill for a mile or more it is 60 feet thick. It is thinnest on the north side of South Fork of Rock Creek, where its thickness diminishes to 10 feet for a short distance, but increases again to 30 feet on the slopes 2 miles farther south. At one locality south of Clear Creek the formation may be absent, but the exposure is too obscure to be decisive.

In the slopes east of the main Cloverly sandstone ridge there is a thin body of clays, but owing to their softness they are rarely exposed. The principal material is reddish to ash-colored clay, merging upward into dark-gray shale of the Colorado formation and having a thickness of 20 to 40 feet so far as could be observed.

On No Wood Creek the formation consists of a massive light-colored sandstone about 40 feet thick, overlain by 30 to 60 feet of light-colored shale, mostly massive, and, at the top, a thin bed of harder buff and reddish-brown sandstone 8 to 10 feet thick. A mile west of Tensleep post-office the basal sandstone is coarse grained and cross-bedded, and nearly pure white in color. The overlying shale is 60 feet thick and at the top are 8 feet of sandstone varying in color from white to buff and brown.

Correlation.—The Cloverly formation is believed to represent the Lakota sandstone, Fuson formation, and Dakota sandstone of the Black Hills region. Apparently the Dakota sandstone (Upper Cretaceous) is not well developed except in local masses of sandstone which sometimes overlie the clay member. Possibly also it is represented by transition shale beds and thin sandstones at the top of the formation. However, as there is apparently no unconformity between the Cloverly and the Colorado sediments, some representative of the Dakota horizon must be present. So far the formation has not yielded any fossils which throw light on its age—only a few fragments of leaves and pine needles. On the basis of the above correlation it represents the last deposits of the Lower Cretaceous and the earliest deposits of the Upper Cretaceous.

COLORADO FORMATION.

Outcrops and relations.—The thick mass of shales constituting the greater part of the Colorado formation outcrops in a narrow zone extending north and south a short distance from the foot of the mountains. This zone varies in width from less than 300 yards northwest of Buffalo to half a mile or more in the region farther south, where the dips are low. The beds outcrop extensively in this area, but at the north they are locally cut out by faults and overlapped by later beds, and on many of the divides to the south they are covered by Quaternary deposits. The formation is about 1300 feet thick from Sayles Creek southward, but on approaching South Fork of Rock Creek its thickness rapidly diminishes, and in one measurement just north of that creek it is about 800 feet, the decrease here possibly being due to faulting and crushing. The formation also occupies a small area in the southwest corner of the Cloud Peak quadrangle.

The formation consists mainly of dark-colored fissile shales that contain toward the bottom thin layers of brown sandstone and near the middle a conspicuous member of hard, thin-bedded, fine-grained sandstones and hard shales, which has been separated as the Mowry member. The lowest 100 to 200 feet of the Colorado shales contain many thin beds of brown sandstone which weather out on the slopes and give a characteristic rusty appearance to the outcrops. The top of the Colorado formation is somewhat indefinite, for there is a continuous succession of gray shales between the Mowry member and the Parkman sandstone. The top is placed arbitrarily at the base of beds containing Pierre fossils, or about 500 feet above the horizon of concretions with *Prionotropis*, a horizon which characterizes the upper member of the Benton shale in other regions. The gray shales in the upper part of the formation probably represent the Niobrara formation, but, owing to the absence of carbonate of lime in them, they lack the characteristics which distinguish the formation in the region farther south. At its base the Colorado formation is in conformable succession to the Cloverly formation.

East slope.—On the east side of the mountains the Colorado formation presents the character above described, together with some local features. In the upper portion of the basal member, or "rusty series," there is a persistent horizon in the shale containing numerous dark-gray globular concretions, mostly from 1 inch to 1½ inches in diameter, which in places accumulate in considerable numbers on the shale slopes. They have a radiate crystalline structure and consist of impure phosphate of lime, evidently a replacement of the iron sulfide mineral marcasite. They occur thru a vertical interval of only 3 or 4 feet in the shale, but appear in greater or less number in all exposures. On Sayles Creek the horizon is not over 60 feet above the base of the formation; a mile south of Muddy Creek and near Beaver Creek it is 100 feet above, but near Crazy Woman Creek it appears to be much higher. Above the "rusty series" there is a variable thickness of dark-gray shales, mostly very fissile, carrying lens-shaped concretions, from a few inches to several feet in diameter. Some of these concretions are composed of carbonate of lime; others of carbonate and oxide of iron. Near the middle of this series lenticular deposits of light-colored sandstones occur locally. One of these appears southeast of Sisters Hill, where the rock is 10 feet thick, white, and massive. It lies 450 feet above the base of the formation. It shows again in a low but conspicuous knob a short distance south of the Sisters Hill road and on the slope a mile south of Muddy Creek, where it is 15 feet thick and 350 feet above the base of the formation. It appears to be represented by several thin layers of gray sandstone on Beaver Creek and by a thin layer of brown sandstone at some other localities.

Upon the shales above described lies the Mowry member, a series, about 150 feet thick, of thin-bedded but hard, dark-gray, fine-grained sandstones and hard gray shales or slates, which become light colored on weathering and, from their hardness, form ridges of considerable prominence, usually bare of sod but often supporting a few scattered pine trees. Most of the beds contain large numbers of fish scales and occasional fish teeth and bones. By some observers this member was supposed to be Niobrara, but it lies below beds containing distinctive Benton fossils. Its position was carefully determined along several measured section lines and it was found to lie between 750 and 850 feet above the base of the formation as far north as Sayles Creek, beyond which the interval diminishes rapidly, being 600 feet a mile south of South Fork of Rock Creek and 225 feet a short distance north of that creek, a diminution apparently due largely to faulting and crushing. The Mowry member merges up into about 300 feet of dark shales carrying occasional layers with Colorado fossils, above which are 20 to 30 feet of shales containing lens-shaped lime concretions, of buff color when weathered. These concretions are 2 to 4 feet in diameter in greater part and contain frequent remains of *Prionotropis woolgari*, a species characteristic of the upper layers of the Benton (Carlile formation) in an extensive area in the Rocky Mountain province. This fossil is an ammonite with spines on the outer margin of its whorls, and in this region it usually attains a diameter of a foot or more. The top member of the Colorado formation consists of about 500 feet of light-gray shales containing no fossils.

West slope of the mountains.—The area of Colorado formation in the southwest corner of the Cloud Peak quadrangle constitutes a portion of the high hills and ridges lying south and west of No Wood Creek. The rocks are mainly the usual succession of dark shales with local sandstones. One hundred feet above the base is a 6-foot bed of sandstone, and about 400 feet higher is the Mowry member, consisting of lighter gray, harder shales, with interbedded, fine-grained, dark sandstone, having a thickness of 100 feet or more and capping the higher ridges. This upper series weathers to a light silver-gray color and the shales contain large numbers of fish scales. At the top of the formation there are several hundred feet of gray shales, the upper portion of which is believed to represent the Niobrara formation.

Fossils and correlation.—Fossils rarely occur in the Colorado formation in the Bighorn region. The ammonites above referred to and a few flat specimens of *Inoceramus* in its top beds are the principal remains found in it except the large numbers of fish scales in the Mowry member.

The Colorado formation in the Bighorn region comprizes the Benton and Niobrara formations of the Rocky Mountain and Great Plains region farther south and east. The stratigraphic position of its lower limit is somewhat indefinite, owing to the almost general absence of separable Dakota sandstone at its base. The Benton in other regions consists of Graneros shale, Greenhorn limestone, and Carlile shale, but these subdivisions are not apparent in the vicinity of the Bighorn Mountains, owing to the lack of distinctive development of the middle formation. In the Black Hills region and farther south the Mowry member occurs considerably below the middle of the Graneros shale, while on the east side of the Bighorn uplift it lies only about 500 feet below the top of the entire Colorado formation, so that this 500-foot interval comprizes the representatives of the upper Graneros, Greenhorn, and Carlile deposits. The occurrence of the concretions with *Prionotropis* and other ammonites appears to indicate the presence of the member which is characteristic of the top of the Carlile formation in other regions, and as there is no evidence of hiatus in any portion of the Benton formation in the Bighorn region it is reasonable to believe that the subdivisions are all present but in attenuated form and with the Greenhorn limestone horizon not characterized either by lime sediments or by the distinctive fossil *Inoceramus labiatus*.

The upper beds of the formation are gray shales, which probably represent the Niobrara formation, but the only evidence of the existence of this formation in the Bighorn region is the apparently continuous sedimentation from the Benton to the Pierre. The shales seem to contain no carbonate of lime, so that they lack the characteristics which distinguish the formation in the region farther south. The thickness of the beds between the highest Benton and the lowest Pierre fossils is about 500 feet and no organic remains have been found in this interval.

PIERRE SHALE.

The outcrop of Pierre shale extends in a narrow belt from North Fork of Rock Creek to South Fork of Sayles Creek, and from the head of Sand Creek, southwest of Buffalo, to the southern margin of the Fort McKinney quadrangle. A small area of the formation occurs in the hills in the southeast corner of the Cloud Peak quadrangle. In the Mowry Basin, where the dips are nearly vertical, the outcrop is less than a half mile wide. Southwest of Buffalo it gradually increases in width from less than half a mile to 3 miles on Middle Fork of Crazy Woman Creek and 4 miles on Beaver Creek, the increase being due mainly to diminution of dip. The thickness farther north is 2000 feet, as measured in vertical beds on Sayles Creek, but it appears to be somewhat greater than this in the region southwest of Buffalo. The material is a monotonous succession of soft dark shales, with an occasional thin lens of brown sandstone and scattered concretions consisting mainly of carbonate of lime. At the bottom the shales merge into slightly lighter colored shales at the top of the Colorado formation, and at the top there is an abrupt change from the Pierre shale to the Parkman sandstone. In much of the area a thin bed of brown sandstone lies about 600 feet below the top of the formation. Fossils occur sparingly, mainly in concretions, and they comprize a considerable variety of typical Pierre forms.

PARKMAN SANDSTONE.

Outcrop.—The outcrop of the Parkman sandstone extends diagonally across the Fort McKinney quadrangle, but for several miles west of Buffalo and north of North Fork of Rock Creek its continuity is interrupted by faults. In the Mowry Basin and on Kelley Creek, where the dips are steep, the outcrop zone is only a few hundred yards wide, but farther south it broadens considerably, its width being nearly 2 miles on Billy Creek. To the north it lies near the foot of the mountains, but from Kelley Creek southward the space between it and the mountains widens, so that on Beaver Creek its western margin is more than 4 miles east of the slopes of Tensleep sandstone.

Character.—The material of the Parkman beds is mainly a very massive, soft sandstone of buff color, with darker, harder, concretionary portions. Its course usually is marked by a ridge or belt of rocky ridges that rise with moderate prominence above the rolling lands of Pierre shale to the west. The transition of the Pierre shale to the Parkman formation is rapid, but the Parkman merges upward into sandy shales of the Piney formation. The Parkman formation is about 500 feet thick. Its most extensive exposures are south of North Fork of Crazy Woman Creek and in the Mowry Basin. A section on one of the branches of North Fork is as follows:

Section of Parkman formation 2 miles southeast of Sisters Hill, Wyoming.

	Feet.
Olive-green clay with thin sandstone layers, probably Piney formation	100
Light-colored sandstone with few concretions	50
Dull-green clay with streaks of red sandstone	45
Light-green and olive sandstone with thin layers of hard, rust-red sandstone	30
Greenish-gray clay with occasional thin brown sandstone layers	75
Alternating layers of hard and soft sandstone of dull-green color	45
Greenish sandy clay	35
Olive-green sandstone with layers of large brown concretions, abundant marine fossils in upper 3 feet	60
Olive sandstone	15
Buff to greenish-gray clay	6
Flesh-colored sandstone with large brown concretions	15
Greenish-gray clay with few thin layers of concretionary sandstone and thin brown sandstone	100
Black shale (Pierre).	

Above the top bed lie 70 feet of gray sandy clay with pale-blue and maroon streaks and 600 feet of dark-green to gray clay, which may possibly be Parkman. This clay is surmounted by typical Piney sandstone. The 100-foot bed of basal greenish-gray clays is regarded as a transition member, thru which the Parkman grades into the Pierre.

At Hesse ranch the following section was measured in beds dipping 20°:

Section of Parkman formation near Hesse ranch, Wyoming.

		Feet.
Piney (?) formation	Dull-gray clay with streaks of sandstone	60
	Light-gray massive sandstone	20
Red to buff clay		45
Massive gray sandstone		20
Light-colored sandstone capped by green and red concretionary sandstone, weathering out in small "toadstools"		90
Alternations of light- and dark-green and buff clays with thin layers of green to brown sandstone		50
Light-greenish sand containing a few rust-colored concretions; marine fossils		30
Brown sandstone, thin bedded at base, more massive at top, weathering into small "toadstools"		6
Olive-green sandstone; many marine fossils		60
Buff and light-green clay with alternating thin layers of gray sandstone		50

Fossils and correlation.—Fossil shells are of frequent occurrence; they include the following forms, collected at various localities and determined by Mr. Stanton:

Cardium speciosum, *Ostrea glabra*, *Avicula linguiformis*, *A. nebrascana*, *Liopistha* (*Cymella*) *undata*, *Thracia subgracilis*, *T. subtortuosa*, *Tellina equilateralis*, *Lunatia subcrassa*, and *Sphæriola? cordata*.

These forms were formerly believed to be characteristic of the Fox Hills age, but, in part at least, they are now known to occur also at a lower horizon. On this account the Parkman sandstone can not be definitely correlated with the Fox Hills sandstone.

PINEY FORMATION.

Occurrence and character.—The name Piney is proposed for the lowest formation of the thick series of fresh-water sandstones and shales of later Cretaceous age, formerly designated "Laramie," lying in the great basins adjoining the Bighorn uplift. The name is derived from Piney Creek, northwest of Buffalo, on which the beds are extensively exposed.

It is difficult to separate the base of the Piney formation from the top of the Parkman, for apparently one formation grades into the other and possibly at a somewhat different horizon in different portions of the area. In the steep-dipping strata southeast of Buffalo the Piney formation has a thickness of about 2000 feet. The lowest beds are sandstones and shale of light color and the upper members consist of white, red, and green sands and sandstones alternating with layers of green and yellow clays, dark shales, and iron concretions, the latter composed of sand cemented by iron oxide. The formation is extensively exposed along the north side of Rock Creek southwest of Lake De Smet; also on the west slope of the high ridge south of Johnson Creek, and notably in the slopes a mile southeast of the T A ranch, where it forms badlands. At the latter place the beds are dark-gray, green, and black shales, with an occasional layer of brown sandstone, which in places is of concretionary nature. The Piney formation is more extensively exposed here than elsewhere, to a thickness of at least 1500 feet, and dips 20° to the east. Two miles southeast of Sisters Hill the beds between the Parkman sandstone and the sandy members of the Piney formation consist of several hundred feet of light and dark greenish-gray to rust-colored shales with occasional 4-inch to 6-inch layers of rust-red sandstone. These beds have yielded no fossils and may belong in either formation, for they grade into both.

Correlation.—The few fragmentary fossil plants found in the Piney formation do not afford any definite evidence as to its age. From its general stratigraphic relations, however, it is believed to represent part of the Laramie formation.

KINGSBURY CONGLOMERATE.

Along a portion of the central eastern slope of the Bighorn uplift the Piney formation is overlain by a thick mass of conglomerate, which is the product of a local uplift of later Cretaceous time. For this formation the name Kingsbury conglomerate is proposed, from Kingsbury Ridge, southwest of Buffalo, in which it is extensively exhibited. The conglomerate extends across the northern and central portions of the Fort McKinney quadrangle to Crazy Woman Creek, where it rapidly dies out or gives place to fine sediments. It attains its greatest prominence in the high ridge east of North Fork of Rock Creek, where for several miles there are ledges over a hundred feet high, which are conspicuous for a long distance. The materials are pebbles and bowlders, mostly of Madison limestone and the very distinctive flat-pebble limestone conglomerate of the Deadwood formation of the mountains lying to the west—ingredients which indicate uplift and deep degradation. Granite pebbles were not observed in any of the exposures. A characteristic outcrop of the conglomerate is on the ridge north of Rock Creek in the central portion of range 83. The bowlders vary greatly in size and occur in great disorder as to sizes and position, as if deposited by rapid streams. At the west end of this ridge the conglomerate abuts against a low mound of Deadwood shale and limestone overlain by Bighorn limestone, mostly in broken ledges, apparently part of the old shore from which the fragmental materials were derived. The contact was not observed at this locality, owing to talus from the disintegrated conglomerate. The thickness here is 2000 feet or more. In the ridges between Sayles and French creeks similar coarse conglomerates abut against Deadwood rocks and overlying limestones along the foot of the main mountain slope, where they are conspicuously exposed. Extensive faults occur in this area, but in part, at least, they are earlier than the Kingsbury conglomerate, which extends across them.

On Clear Creek the conglomerate is completely covered by the old high terrace deposits. It reappears a short distance south, in Kingsbury Ridge and its continuation, which extends nearly to Crazy Woman Creek, gradually trending away from the foot of the mountains southward as the dips diminish. This ridge is 700 feet high south of Sand Creek and excellent exposures of the beds occur in the gap thru which that creek passes. The formation in this area includes numerous layers of sand, yellow clay, and conglomerate. The latter is in part hard and in part appears to be a loose deposit of pebbles. In places it merges into coarse sandstone and this in some layers gives place to clay. In this vicinity the formation is about 2500 feet thick. Southeast of T A ranch it consists of alternating layers of gray sandstone and green, yellow, red, gray, and black clays, with the conglomerate mostly in layers 3 to 4 feet thick, which stand out in small ridges on the slopes. The dip is 20°. In this region the formation is not over 400 feet thick.

Fossil shells and plants occur in the upper beds of the conglomerate in sec. 14, on the south side of Johnson Creek. According to Mr. T. W. Stanton they are *Unio danæ*, *Sphærium*, and *Viviparus retusus*, which have so wide a range that they do not indicate the precise age of the beds. They are, however, supposed to be late Cretaceous.

DE SMET FORMATION.

General features.—The extensive series of coal measures lying east of the Bighorn Mountains has been designated the De Smet formation, from Lake De Smet, where the beds are well exposed. The formation occupies about half of the Fort McKinney quadrangle, extending to the foot of the mountains west and northwest of Buffalo, but its western limit is farther out on the plains south of the head of Kelley Creek. The area it covers comprizes low hills, ridges, and buttes, few of which rise more than 250 feet above the intervening valleys, except the ridges southwest of Buffalo, which are somewhat higher. In the greater part of this area the beds dip gently northeastward, but toward the foot of the mountains the inclination of the strata gradually increases, and finally, near the western margin of the area, the dips are 10° to 15° or more.

The formation comprizes sandstones, shales, sandy shales, and coal beds. Some of the shales baked by the burning coal give rise to clinker beds, which cover wide areas and have prominent outcrops.

Coal measures.—The coal-bearing beds of the De Smet formation lie next above the Kingsbury conglomerate and extend eastward to the margin of the quadrangle, having a width of about 18 miles on Clear Creek. The dips are 10° to 20° near the conglomerate, but the amount decreases rapidly toward the east. They are to the northeast near Buffalo and to the east near Crazy Woman Creek. The beds comprize 5000 feet or more of alternating shales and sandstones, the former mostly carbonaceous and the latter soft and massive. The stratigraphy is variable and no regular succession of beds could be established. The coal occurs in local beds at various horizons, and altho most of the deposits appear to be of limited extent a large amount of coal is available. There are four principal horizons lying near together a few hundred feet above the base of the series. In the region northeast and east of Buffalo part of the coal has burned out near the surface and the heat has baked the adjoining shales into red clinker over wide areas. At some localities the coal is still burning, notably at an abandoned coal mine near the southeast corner of Lake De Smet.

The lowest member of the coal measures is sandstone, lying on the Kingsbury conglomerate and merging upward into coaly shale, which extends north and south for some distance in the region north and west of Buffalo. On the east side of Rock Creek, in the northeast corner of T. 51, R. 83, it is about 6 feet thick and contains three or four streaks of coal of poor quality. The principal coal deposits of the Buffalo region occur considerably higher in the formation. One series outcrops along a zone extending from the southeast corner of Lake De Smet to the mouth of Rock Creek and thence east of Buffalo. Near Lake De Smet the old mines have caved in, but they appear to have worked about 4 or 5 feet of coal, which is overlain by a bed of clinker. Near the mouth of Rock Creek, at the Bodan coal mine, a tunnel has been run in on a 12-foot bed of good coal. The section at this place is as follows:

Section at Bodan coal mine, near Buffalo, Wyo.

	Feet.
Clinker	6
Yellow sandy clay with 6 feet of concretionary sandstone at base	30
Reddish-yellow clay	4
Dark shale with plants	2
Coal	12
Light-gray shale	2

The coal appears to be in a lens-shaped deposit and thins considerably to the north and south. A short distance north an 8-inch coal bed underlies the clinker bed. A mile east of the Bodan mine and at a somewhat higher horizon is the old Foot mine, in which an 8-foot bed has been worked. It is overlain by a succession of 20 feet of light sandy clay, 20 feet of dark shale with thin coaly streaks, and 15 feet of yellow sandy clay. This coal deposit is on fire and has been burning for several years. The section (fig. 1) at Monker & Mather's mine, 1 mile east of Buffalo, shows the principal succession in that region. The lower 7-foot bed is probably the lowest important bed in the formation. The upper 7-foot bed reaches the surface near the mouth of Rock Creek and has been mined in the Bodan, Foot, and Lake De Smet mines. The next bed lies some distance above and is worked at the Mitchell mine, 2½ miles east of Buffalo, a short distance below the lower clinker bed. It is 6 to 8 feet thick.

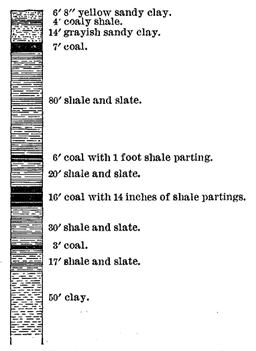

FIG. 1.—Section of part of De Smet formation at Monker & Mather's coal mine, 1 mile east of Buffalo, Wyo.

The highest coals in this region are found in isolated areas in buttes and plateaus among the clinker beds 10 miles northeast of Buffalo. The coal beds apparently are remnants of deposits which are burned out elsewhere. They are included in strata that are free from clinker and are in part capped by gray sandstone and clay like those which cap the upper clinker bed at some other places in the region. (See fig. 2.) A number of such occurrences were observed in and adjoining the northwest corner of T. 51, R. 80.

In their southern extension the De Smet coal measures contain coal, but no large deposits. There is an irregular succession of sandstones and shales with coaly layers at intervals. The stratigraphy is less marked than in the region farther north, and the only noticeable feature is the occurrence of clinker for a short distance in two lines of small buttes south and southwest of Long's ranch. Coal 6 feet thick is mined 2 miles southwest of Long's ranch, but it is not of very good quality.

Clinker beds.—The uppermost beds of the De Smet formation in the region consist largely of clinker beds capping the slopes and divides between Clear, Dry, and Boxelder creeks east of Buffalo. The section, fig. 2, shows the salient features, but there is considerable local variation.

The clinker beds are prominent features in a wide area of the De Smet outcrop in the northeastern portion of the Fort McKinney quadrangle. They cap extensive plateaus and buttes in all the region about Lake De Smet and east and southeast of Buffalo, along both sides of Clear Creek Valley.

Owing to the hardness of the clinker the topography is rugged and the bright red color of the rock makes it very noticeable. The material is clay or shale, baked and often partially fused by the burning of the associated coal beds. The thickness of the clinker beds varies from a few inches to 20 feet or more. The clinker occurs principally at two horizons. The upper bed forms a deep-red cap at the top of a series of buff sandy clays and sandstones that range in thickness from 150 to 200 feet. Usually the sandstone is soft, but in places it thickens and becomes very hard, forming a massive gray ledge weathering into small castellated forms, which are conspicuous along Boxelder Valley northeast of Lake De Smet. This upper clinker bed ranges in thickness from 10 to 60 feet and in character from highly burned clinker at the top to almost unaltered clay at the bottom. There is evidence at some localities that the upper clinker bed was originally a mixture of coal and clay and that the coal has burned out.

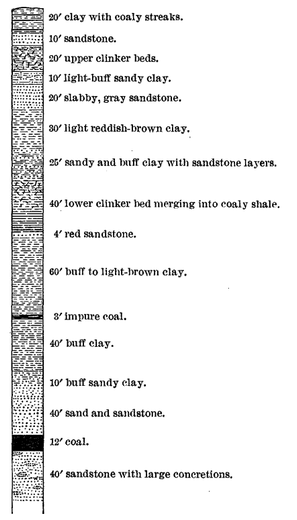

FIG. 2.—Section of De Smet formation on east side of Clear Creek 10 miles northeast of Buffalo, Wyo.

The lower clinker bed occurs in a series of buff to light-brown and green clays, light-colored sandy clay, sands, sandstones, and a few layers of leaf-bearing shale and coal. Between the two clinker beds there probably was originally considerable coal, but it is burned out at most localities. At a point in the southwest corner of sec. 36, T. 52, R. 81, some of the coal is exposed. The bed appears to be lens shaped, 2 to 6 feet thick, and overlain by a series consisting of 2 feet of clay, burned to clinker at some points, impure coal and coaly shale (10 to 12 feet), coaly shale (4 to 6 feet), and clay (10 to 15 feet) capping the butte. Above the upper clinker series is a massive sandstone of dull-gray color, 10 to 15 feet thick, which caps the higher portions of the plateau divides on either side of Clear Creek Valley. In places this sandstone is overlain by clay with local masses of clinker which rise in low mounds on a few points on the divides in townships 51 and 52, ranges 80 and 81, and at a place 2 miles east of the north end of Lake De Smet. The largest area is in the southwest corner of T. 52, R. 80, where the upper clinker bed is overlain by dull-gray massive sandstone, 6 to 12 feet thick, containing the fossil *Unio*, and this is in turn overlain by clay with impure coaly beds, in places partly converted to clinker. These are the highest beds in the region.

Fossils and correlation.—Fragmentary fossil leaves from beds underlying the lower clinker bed 2 miles north of Buffalo appear to comprize *Sequoia langsdorfii?* (Brgt.) Heer and *Musophyllum complicatum ?* Lesq., according to determinations by Mr. F. H. Knowlton, who states that they indicate early Tertiary age. The fossils found in the upper gray sandstones overlying the upper clinker bed in the northeast corner of the Fort McKinney quadrangle, 3 miles northeast of bench mark 4279, are casts of a *Unio* resembling *U. cryptorhynchus* White, which is a Judith River species. At present there is no satisfactory evidence as to the age of the De Smet formation, and no correlation is desirable until a detailed investigation is made of the formation in its wider extension. In general it may be stated that at least a part of the formation probably represents a portion of the "Laramie."

TERTIARY SYSTEM.

Distribution.—At several localities in the mountain area there are deposits of sands, gravels, and bowlders, apparently, in greater part at least, of pre-Pleistocene age. These are here provisionally classed in the Tertiary system. The largest areas of these deposits are in that part of the main divide lying between the heads of North Fork of Powder River and Canyon Creek, at altitudes ranging from 8700 to 9100 feet, and in the wide parks extending north and east of Hazelton.

Other areas occur in the valleys of Little Sour Dough and Clear creeks, near the heads of Canyon and Lee creeks, east of Soldier Creek, on the high ridge west of the lower portion of North Fork of Paintrock Creek, west and north of Black Butte, north of the mouth of Middle Fork of Paintrock Creek, on South Fork of Brokenback Creek at an altitude of 8000 feet, near the head of Lee Creek, on the divide between Lee and Canyon creeks, and on the divides adjoining Doyle Creek and North Fork of Powder River in the southeast corner of the Cloud Peak quadrangle. The high terraces of Bald Ridge and North Ridge on Clear Creek in the Fort McKinney quadrangle, as well as several small outliers of similar material farther north, appear to belong to the same period. Some of the deposits are older than others, but it is not possible to classify them satisfactorily.

Canyon Creek area.—The deposits are most extensively exposed on the slopes east of Canyon Creek, especially at a point a mile south of bench mark 9069. A section at this locality, made by Mr. Bastin, is as follows:

Section 1 mile south of bench mark 9069, east of Canyon Creek.

	Feet.
Sandy clay soil	6
Gravel of crystalline rock, with lenses of volcanic ash near the base, and with occasional bowlders up to 2 feet in diameter	60
Volcanic ash, arkose, fragments of igneous rock, etc., indistinctly stratified	73
Conglomerate, cemented by lime carbonate—bowlders up to 4 feet in diameter and generally well rounded	22

The amount of volcanic ash in this section is large and it appears to have been laid down by water, altho some of the finer portions may be wind blown. The nearest eruptions from which it could have been derived, so far as known, are in the great volcanic area west of the Bighorn Basin. As most of these eruptions occurred in Tertiary time and as volcanic ash is generally characteristic of the Tertiary beds in the Black Hills region and in areas farther east, the Bighorn deposits are provisionally referred to this age, but no evidence has yet been discovered to justify their correlation with any of the divisions of the Tertiary found elsewhere. Some features of this deposit suggest that it is separable into two members, an upper gravel bed and a lower conglomerate with lime matrix. The upper gravel bed constitutes the surface of the extensive area of prairie about the head of Powder River. A view of this prairie is shown in fig. 21. The conglomerate with lime matrix appears at intervals south of the exposure above described, constituting low bluffs near the top of the plateau east of Canyon Creek.

Outlying areas on west slope.—The areas of Tertiary deposits on the two divides east of Soldier Creek lie west of bench mark 9810 and both are at an altitude of about 9100 feet. The conglomerate with lime matrix and the volcanic ash appear again at these localities, together with a large number of decayed bowlders. Extensive areas cap the high ridge west of the mouth of Middle Fork of Paintrock Creek, at altitudes exceeding 8000 feet. The thickness of the deposit here is 50 feet at some points, and most of the material consists of bowlders and granite débris. A small outlier occurs farther west, at an altitude of 8500 feet, and another farther east, on the ridge between North and Middle forks of Paintrock Creek, capping Deadwood beds at an altitude of 9000 feet. A small area caps a knoll at an altitude of 8300 feet, a mile west of Black Butte. It consists mostly of large bowlders and sand. Other deposits cap the small ridges along the Deadwood outcrop at intervals between Medicinelodge Creek and the northern boundary of the quadrangle. The altitudes range from 8900 to 9100 feet. The materials are mostly granite bowlders and sand.

Bald and North ridges.—One of the most conspicuous occurrences of supposed Tertiary deposits constitutes the pair of high ridges at the mouth of Clear Creek Canyon west of Buffalo. The southern one is known as Bald Ridge and the northern one as North Ridge. Their altitudes are 6900 and 6800 feet, respectively. Their summits are nearly flat and but slightly lower than the limestone front ridge, from which they are separated by shallow saddles. The materials in these two ridges are granite bowlders packed thickly in arkose sand and gravel and showing no evidence of stratification. The larger bowlders range in diameter from 2 to 6 feet, but some are even larger. They are mostly rounded and have the appearance of being the delta deposit of a large stream. Most of the rocks are deeply decomposed and the bowlders of medium and small size are completely rotted. Apparently there are no limestones or sandstones in the deposits, notwithstanding the proximity of ledges of these rocks to the west. The thickness was not ascertained satisfactorily, but it amounts to several hundred feet. Near the mountain slope it appears not to be cut thru by Clear Creek, altho farther east the underlying Piney sandstones appear. The precise limits can not be determined because of the extensive talus of loose bowlders on the slopes. Small outlying masses of the same material appear on the summit of Kingsbury Ridge, also on the divides north of French and Johnson creeks, where they abut against the limestone, and on the northern margin of the quadrangle, where they cap a small but prominent knob a short distance east of the limestone ridge. Along the north side of Clear Creek Valley west of the limestone front ridge extends a wide, high terrace floored by gravel and bowlder deposits. These are evidently not quite so old as the bowlder beds of Bald Ridge, for they lie at a lower level than the top of that ridge and are trenched by the creek canyon. They extend westward up the valley to an altitude of about 7100 feet, or nearly to the outer margin of the glacial moraines of the earlier glacial epoch.

Sour Dough area.—Five miles farther south, on the divides adjoining Little Sour Dough Creek, is a deposit of gravel and small bowlders which covers an area of considerable extent, at altitudes mostly from 7000 to 8100 feet. It floors a level area or series of parks among the granite slopes.

Hazelton region.—This extensive area of intermontane gravel plain extends east and northeast from Hazelton to North Fork of Crazy Woman Creek, and some small detached areas occur on the north side of that valley. The wide rolling plains and open parks are a conspicuous feature. The altitudes range from about 7800 to 8300 feet in greater part, there being a general downward slope toward the east. Apparently the original area of the deposit was somewhat greater than at present, for Poison Creek and North Fork evidently have removed portions of it. A view of a part of the plain near Hazelton is shown in fig. 21. There is an extensive exposure of one of these deposits on North Fork of Crazy Woman Creek a short distance southwest of bench mark 7714. The deposit consists partly of light-colored sandy loam with hard concretions, and partly of conglomerate of bowlders with carbonate of lime cement. It is similar in appearance to some of the Oligocene deposits in the Black Hills, but can not be definitely correlated with them. It appears to be a rather small deposit occupying a depression in granite, but possibly it extends southeastward under the high terrace gravels that form the surface from this point to the head of Billy Creek. The exposure is in a bank 30 feet high, and altho search was made for bones and other fossils, none were found.

Other similar plains, mostly covered by gravel, lie south and southeast of Bull Camp, at altitudes ranging from 7500 to 8100 feet. These deposits appear to have been products of an earlier period of topographic development and mark the course of streams that flowed thru gaps in the limestone front ridge at a much higher level than those of the present drainage system. Such gaps are strongly suggested by the configuration of the slopes above the canyons of Clear, Billy, and some other creeks.

Bowlders and sands of possible Tertiary age cap a number of ridges and divides adjacent to North Fork of Powder River. One of the most extensive of these lies along Doyle Creek north and southwest of bench mark 8381.

Age and origin.—The age and origin of the deposits above described have not been ascertained. The deep decomposition of the bowlders in Bald Ridge, North Ridge, and the other outliers shows that the deposits are much older than any of the morainal materials of the glaciers, and this may indicate either earliest Quaternary or late Tertiary age. The bowlders show no signs of glaciation, but, owing to their decay, striæ, if formerly present, probably would not be preserved. Evidently the deposits originally extended over a broad area east of the mountains, as shown by the widely scattered remnants, especially the one on Kingsbury Ridge, and since their deposition there has been extensive erosion to the present low level of the plains. It would have required streams of great power to carry bowlders as large as those in Bald Ridge and the other areas, but floating ice may possibly have been a factor in their transportation.

QUATERNARY SYSTEM.

The formations that are classified under this head in this folio comprize the terrace deposits east of the mountains, moraines of two glacial epochs, and alluvium in the bottoms of valleys.

HIGHER TERRACE DEPOSITS.

Under the term higher terrace deposits have been grouped the terrace remnants lying east of the mountains, at a considerably lower level than the deposits above described. These terraces remain on most of the divides at the foot of the steeper mountain slopes and occur at intervals farther east. They are capped by deposits of gravel and sand, from 10 to 40 feet thick, and usually have smooth surfaces that slope gently eastward at a rate which increases in amount toward the mountains and is greatest in the highest terraces. One of the most conspicuous remnants extends from the foot of the Tensleep sandstone slope south of North Fork of Crazy Woman Creek, where it affords an ascent of moderate grade for the main road over the mountains. Broad areas of older terraces remain west and north of Buffalo and cap the high ridges east and southeast of the Cross T ranch. Gravel-capped terraces extend along the north side of Clear Creek Valley below Buffalo and along the north side of the valley of Crazy Woman Creek, most of them lying from 50 to 100 feet above the present bottom. A few small areas of deposits of an earlier terrace period were observed northwest of Tensleep postoffice on the slopes north of Tensleep Creek and north of Rome on the east side of Canyon Creek. The materials of these terrace deposits are different in different areas, showing much crystalline rock near the valleys of streams that head far back on the mountains, and local material along the smaller valleys. The nearer the mountains the coarser the material. Judging from these remnants, especially those on the higher divides, it appears probable that much if not nearly all of the region east of the mountain slope was at one time covered by deposits of gravel and sand which have since been removed along the lines of more vigorous erosion.

GLACIAL GEOLOGY.[1]

By Rollin D. Salisbury.

There is evidence that the Bighorn Mountains were occupied by glaciers during two widely separated glacial epochs, and there is some suggestion that there may have been glaciers at a still earlier time. The glacial history of these mountains is complex, and the great glaciers that have left the most distinctive records of themselves were the successors of earlier ones, the marks of which have been partly effaced by weathering and erosion. Several small glaciers remaining in the higher portions of the Bighorn Mountains are diminutive remnants of much more extensive bodies of ice that formerly occupied the principal valleys of the highlands. Because of the unequivocal nature of the phenomena connected with the last epoch of glaciation and the obscure nature of the phenomena connected with earlier glaciation, it is best in discussing the glacial history and deposits, not to follow the chronological order, but to consider first the record of the last glacial epoch.

THE LAST GLACIAL EPOCH.

GENERAL FEATURES.

Proofs of glaciation.—The phenomena that point with certainty to recent glaciation in the Bighorn Mountains are (1) the great body of drift that occupies many of the valleys and that has both the disposition and the constitution of true glacial drift; (2) the shapes of the valleys in which the drift lies; (3) the smoothed and striated surface of the rock of the sides and bottoms of the valleys in which the drift occurs; (4) the peculiarities of drainage in these valleys, especially the numerous lakes and the narrow gorges of the streams where they break thru the greater aggregations of drift. These distinctive marks are characteristic of all recently glaciated mountain valleys.

Extent of glaciation.—By means of these criteria it has been found that the principal valleys of the Bighorn Mountains within an area about 40 miles long by 27 miles wide were recently glaciated. Within this area, however, less than one-third of the surface (about 300 square miles) was covered by moving ice. About three-fourths of this was within the Cloud Peak quadrangle. The associated snow fields, which have left no very definite record of their extent, may have covered additional large areas. Indeed, at the time of maximum glaciation it is probable that snow and ice were essentially continuous from the northernmost limit of the ice in the valley of Tongue River (Dayton quadrangle), in latitude 40° 41′, to its southernmost limit in the valley of Tensleep Creek, in latitude 40° 6′. The continuity was probably interrupted by a few peaks and narrow divides whose slopes were too steep to permit the lodgment of snow, and by numerous precipitous slopes along the sides of those valleys which were occupied, but not filled, by the ice. The westernmost point reached by the ice of this epoch is in the valley of Shell Creek (longitude 107° 32′) and the easternmost is in the valleys of North and South forks of Clear Creek (longitude 106° 58′). At the time of maximum glaciation in the last glacial epoch bodies of snow and ice were two or three times as extensive, relatively, in the Bighorn Mountains as they now are in Switzerland, for tho the area covered by snow and ice in the Bighorns was probably not more than half that now occupied by snow and ice in Switzerland, the area of Switzerland within which there is snow and ice is about five times as great as the area within which there were glaciers in the Bighorns. The largest of these glaciers was considerably larger than the largest existing glacier in Switzerland.

From the snow fields that centered about the upper parts of the range glaciers descended all the principal valleys. The number of sources from which they started was little less than a hundred, and most of them were within the area considered in this folio; but, in descending, various glaciers united as their valleys came together, so that at the time of maximum glaciation the number of separate glaciers or systems of glaciers, as determined by the number of lower termini, was but 19, and the number wholly or partly within the area represented by this folio was 16. Two of these glaciers were simple (not made up of two or more) and very small, but most of them were compound. Thus the ice of Paintrock Glacier started from fully 20 sources. Before the ice reached its maximum extent, therefore, and again after decadence had set in, the number of separate glaciers was greater than when the ice was at its maximum. In a few cases, especially on the western slopes, a continuous body of snow and ice divided as it moved, giving rise to several lower termini. This division resulted from the overfilling of certain basins and the spread of the ice thru low cols to adjacent valleys.

The map shows that the glacial systems on the east and west sides of the range were about equally numerous. It also shows that those on the west side were much larger than those on the east, covering in the aggregate almost twice as great an area, and that those on the east fell short of those on the west in width rather than in length. This difference appears to have been due to two factors. The precipitation was probably heavier on the west side, because of the prevailing westerly winds, and the catchment basins on the west side were wider and shallower than those on the east. It is true that the greater capacity of the basins on the west at the present time is partly the result of the greater glaciation on that side, but it is also true that the greater glaciation was in large part the result of the greater original capacity of the basins. This inequality was determined by the general configuration of the range, the western slope of which is less abrupt than the eastern. The existing glaciers are all on the east side, the one shown on the west side on the topographic map having disappeared by 1903, according to observations by Mr. Bastin.

[1] This account of the glacial geology of the Bighorn Mountains is based on the work of assistants operating under the direction of Rollin D. Salisbury, who has prepared the account. Most of the investigations were conducted by Eliot Blackwelder, who prepared a report on the drift of the east side of the range, and by Edson S. Bastin, who studied the drift of the west side. Mr. Blackwelder was assisted by W. H. Emmons and F. W. DeWolf, and Mr. Bastin by A. D. Hole, E. D. Leffingwell, S. R. Capps, W. W. Magee, and A. E. Taylor.

The survival of the glaciers on the east side may be due to the better protection of the cirques on that side from the sun, and perhaps also to the westerly winds, which drift much snow over the crest of the range, to lodge on the lee side.

Altitude necessary for glaciers.—The altitude necessary for the generation of glaciers in the Bighorn Mountains during the last glacial epoch seems to have ranged from 9500 to 11,500 feet, the variation being due to differences in the exposure and the size of the catchment basins. A southern exposure was less favorable than a northern one, and a small catchment basin less favorable than a large one. As the map shows, the largest glaciers radiated from the highest part of the range—that is, from the vicinity of Cloud Peak.

Lower limits of glaciers.—The glaciers descended to very unequal altitudes, the point reached depending on the amount of ice, the topography of the bed, and other conditions. Some of the smallest glaciers, such as that at the head of Middle Fork of Clear Creek, descended but little below 10,500 feet, while some of the largest, such as the glaciers of Paintrock and Tensleep creeks, descended to about 6500 feet.

Many of the mountain valleys consist of (1) an upper portion in the mountains proper, often cirquelike and always deep, in many places with gradients of 600 to 800 feet per mile; (2) a relatively shallow, open part where they cross the plateau on either side of the higher part of the range; and (3) a second narrow, gorgelike part where they cross the Paleozoic terranes. The smallest glaciers did not descend below the uppermost of these sections, while the longest crost the plateau and entered the valleys in the Paleozoic formations. None of them reached the plains beyond.

Thickness of the ice.—The thickness of the ice in the several glaciers varied greatly. The ice in Paintrock Valley was probably deepest, exceeding at a maximum 1500 feet. From this maximum the thickness of the ice ranged down to less than 500 feet in the thickest part of some of the smallest glaciers.

The glaciers of the range are listed below, and the table gives their approximate areas and lengths and the approximate altitude of their sources and termini.

The Bighorn glaciers of the last glacial epoch.

Rank.	Name of glacier.	Area covered at maximum extension.	Maximum length.	Altitude of source or sources.	Altitude of terminus.
		Sq. miles.	*Mi.*	*Feet.*	*Feet.*
1	Paintrock	56.0	16	10,500+	6,300
2	West Tensleep	40.6	17	11,000+	6,500
3	Shell Creek	35.2	14	10,200+	7,500
4	Dome Lake	19.5	8	10,000+	8,000
5	Lighter	18.6	9	10,500+	8,000
6	Kearney Lake	18.4	12	11,500+	7,800
7	East Tensleep	16.0	7	10,500+	8,700
8	South Medicinelodge	15.5	9	10,500+	7,700
9	South Fork Clear Creek	15.0	7	11,000+	8,100
10	North Fork Clear Creek	12.1	10	11,500+	7,900
11	Meade Lake	10.4	8	12,000+	8,800
12	Tongue River	9.6	6	9,800+	8,400
13	Buckskin Ed	7.8	6	11,000+	9,000
14	Willitt	4.0	4	10,300+	8,900
15	North Medicinelodge	3.7	5	10,500+	8,400
16	Lake Creek	2.1	4	11,000+	8,700
17	Trapper Creek	2.1	3	10,500+	8,900
18	Glacier a half mile north of Pass Creek	0.4	1	11,000	10,400
19	Middle Fork Clear Creek	0.3	1	11,300	10,400

Dome Lake, Tongue River, and Willitt glaciers were wholly within the Dayton quadrangle; Shell Creek, Lighter, and Kearney glaciers were partly in the Dayton and partly in the Cloud Peak quadrangles; the others were entirely in the Cloud Peak quadrangle.

Distinctive features of glaciated valleys.—The distinctive features of glaciated mountain valleys are the following:

1. Their upper ends are often *cirques;* that is, they end bluntly above, against high, steep cliffs, and are hemmed in on both sides for a greater or less distance by cliffs of the same sort. The head of South Fork of Clear Creek, just south of the 12,271-foot peak, is an excellent example, and another equally good one lies just across the crest to the west, and is shown in figs. 12, 13, and 14 on illustration sheet 1.

2. The valleys which were occupied by considerable glaciers have rounded bottoms; that is, they are somewhat U-shaped in cross section. This is well shown on the topographic map, as in the case of the valleys of North and South forks of Clear Creek, and in fig. 8.

3. The cirques, and often the upper parts of the valley below the cirques, are, as a rule, relatively free from loose material of all sorts, solid rock appearing at the surface of the bottoms and on the sides. They were cleaned out by the moving ice.

4. Such bosses of rock as appear in the valley are often smoothed down to the forms known as roches moutonnées, and their surfaces, as well as the surface of the rock in the valley, are locally planed, striated, and grooved.

5. The drift or moraine matter is generally most abundant near the lower limit of ice advance, but is generally plentiful for some distance above. Where the valleys of these mountains were overspread by vigorous glaciers, drift is meager in the upper halves of the glaciated basins, but abundant in the lower halves. Where the glaciers were feeble, bare rock is less prevalent, even in the upper parts of the basins thru which the ice moved.

6. The drift is disposed chiefly in (*a*) broad *terminal moraines,* which cross the valleys and often rise several hundred feet above the bottom of the valley outside, and in (*b*) *lateral moraines,* which lie along the sides of the valleys for considerable distances above the terminal moraines, which they join below. There are many subordinate lateral and terminal (recessional) moraines inside the outer and major ones. Ground moraine covers the surface more or less generally for some distance above the terminal moraines, and less generally just inside the lateral moraines. The abundance of ground-moraine matter over the basins varies greatly from valley to valley.

7. Many of the glaciated valleys contain lakes, which range in position from the heads of the cirques to the terminal moraines below. This distribution of lakes is shown in numerous valleys of this quadrangle, but nowhere better than in those of South Fork of Clear Creek, and Lake Creek, a tributary to North Fork of Clear Creek from the south. Some of the lake basins are the result of glacial erosion and some of deposition. These features are well shown in a number of figures on the illustration sheets.

While these are the prominent features of glaciated valleys in general, they are not all conspicuous in every valley which the ice occupied. Where the area of snow and ice accumulation was a broad and shallow basin rather than a narrow mountain valley, or where the glaciers were small, some of the above features are poorly developed, or even absent. Some of these features are the result of glacial erosion and some of glacial deposition.

Striæ.—Glacial striæ, grooves, and all other familiar types of glacial scoring are found at one point or another in the glaciated valleys, but they possess no peculiarities which demand consideration here. Their directions were controlled primarily by topography. The courses of a few of them are shown on the map.

Nunataks.—Within the glaciated area two small tracts were found which appear to have been surrounded but not covered by the ice. One lies in the area of Paintrock Glacier. The ice on the sides of the valley in which this area lies reached heights as great as that of this hill, but the hill itself shows no evidence of glaciation. Against one side of it there is a lateral moraine. The second tract is in the upper part of the same basin, but in this case the ridge rises far above the level attained by the ice.

GLACIAL EROSION.

To glacial erosion must be ascribed (1) the development of the cirques, (2) the cleaning out of the upper parts of the valleys thru which the ice past, (3) the rounding and widening of the valley bottoms, (4) the polishing of the rock surfaces in the valleys, and (5) the excavation of some of the lake basins.

Erosion in the cirques.—The cirques are perhaps the most striking result of the erosive action of the ice in these mountains. The distinction between valleys with cirque heads and those without them may be illustrated by a comparison of the topography near the 10,545- and 10,307-foot peaks about the head of Middle Fork of Crazy Woman Creek, in the southeast corner of the Cloud Peak quadrangle, with the topography near the 12,271-foot peak just north of the head of South Fork of Clear Creek, in the same quadrangle. Had the mountains of the first of these localities given rise to vigorous glaciers, the heads of the valleys there would doubtless now be similar to those of the other locality.

The pronounced cirques of the range are centered about its higher part, from South Fork of Clear Creek to North Fork of South Piney Creek on the east side, and from the northern tributaries of East Tensleep Creek to the head of Paintrock Creek on the west. The more conspicuous ones are well shown on the topographic map and on illustration sheet 1.

The manner in which cirques are formed has been described elsewhere (Matthes, Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 167–190) with special reference to these mountains. Suffice it here to say that before the ice affected the mountains, the valleys were probably comparable to other mountain valleys which have not been glaciated, and that the tendency of the ice and the attendant weathering was to wear the heads of the valleys back farther and farther into the mountain, at the same time that their depths were increased.

It is not generally possible to determine just how much a cirque was deepened by the ice or how far it was worn back into the mountain. The cliff of cirque 66 at the head of South Fork of Clear Creek is about 1600 feet high, and those at the heads of cirques 7 and 17 (see geologic map) are about 1500 feet high at the highest points and are in places nearly vertical (75° or more). While these figures are in excess of the amount of downward erosion by the ice in the cirque, they nevertheless give some idea of the effectiveness of ice wear under the conditions that existed in these mountains. Cirques were widened as well as deepened. A little more widening of cirques 28 and 29 would have eliminated the divide between them, and the two would have become one. Some wide cirques originated in this way, altho it is not certain that the Bighorn Mountains furnish illustrations. The length of a cirque may give some suggestion of the distance thru which the head of the valley was carried back, under the powerful erosive action of the ice, but is not a measure of it, being generally, if not always, excessive. The bottom of a cirque may descend by steps, so that the upper part may be in topographic unconformity with the lower. Cirques 7 and 14 of the map are illustrations. Lake basins may be gouged out below the steps, as well as at the heads of cirques.

Cirques were not developed at the heads of all the valleys that contained glaciers. Indeed, at the very heads of some valleys there is little evidence of glaciation, altho ice movement was pronounced below. This was the case, for example, in some of the southerly valleys (1, 2, and 3 on the map) which contributed to the ice of the East Tensleep Glacier, in some of those (especially 8) which contributed to West Tensleep Glacier, in most of those on the north side of both main divisions of Paintrock Glacier (18 to 21 and 30 to 35), and in most of those which fed South Medicinelodge and Shell Creek glaciers. The perfection of the development of cirques seems to have been a function of the strength of the glaciation. In most cases weak glaciers did not develop them, and strong ones did; but to this general rule there are some exceptions, for the little glacier at the head of Middle Fork of Clear Creek developed a very perfect little cirque, while other basins which sent out much ice (notably 30 and 31, Paintrock Glacier) did not. The topography and the structure of the rock at the heads of the valleys were the other factors which appear to have influenced the development of cirques, and where these were unfavorable even severe glaciation did not produce them.

During the development of the cirques, and as a part of the process, the upper ends of the valleys were cleaned out and the surface of the solid rock over which the ice moved was smoothed and polished. The cleaning out of the upper ends of the valleys is, as a rule, more conspicuous where the glacier was confined to a narrow valley, tho to this general rule there are exceptions, as shown on the north side of Paintrock Glacier (30 to 32). Most of the well-developed cirques were cleaned out, and it is in them that the evidences of ice erosion are most obvious. Most of the cirques within 3 miles of Cloud Peak and some of those farther south (4, 5, 10, 13, and most of those on the east side of the range) are not only well cleaned out, but the bare rock of their bottoms and sides is polished, striated, and grooved, and projecting masses are reduced to roches moutonnées. In some places the finer markings have been obscured by postglacial weathering; in others postglacial talus from the cliffs above has covered the bare rock which the ice left.

Another evidence of glacial erosion is found in the numerous rock basins of the glaciated valleys, especially those that head in cirques. Some of these basins were probably gouged out at the bases of the steep slopes at the heads of the cirques, but since the upper end of a cirque retreated as glaciation progressed, the basins developed in this way are not all confined to the present heads of the cirques, and some of them were probably developed below the heads of the cirques at the outset. The rock basins are often irregular, the borders of the lakes that fill them being marked by miniature capes, headlands, and peninsulas of resistant rock, while in some cases bare knobs of rock appear as islands in the lakes.

Erosion below the cirques.—As the ice moved down a valley it not only gathered and carried in its bottom the loose débris of the lower slopes and bottom of the valley, but, by means of the débris which it carried, it deepened the valley by wear at its bottom and widened it by wearing back its lower slopes on either side. The erosion effected by a valley glacier is not dependent altogether on the load which the ice carries. The rock is usually jointed, and under favorable conditions the ice may remove joint blocks bodily without the aid of the débris already in the ice. This process of *plucking* is especially effective on the bottom where the slope is very steep, and on the sides where their surfaces are jagged. In many cases erosion by plucking was greater than that effected by means of the débris carried. While the bottom and sides of the valley were being smoothed and worn, projecting bosses of rock in the valleys were reduced to roches moutonnées. It is rarely possible to determine how much a valley was deepened by glacial erosion, but some idea of the deepening may be gained by a study of the slopes. On this basis Mr. Blackwelder estimates that not a few of the valleys may have been deepened 400 to 700 feet in their upper parts, while in some valleys, as in that below the cirque 3 miles northnortheast of Cloud Peak, the deepening may have been considerably more. Some idea of the amount of deepening may in places be had from the topographic unconformity between the main valley and its tributaries. Tributary valleys that end well above the level of their mains are called *hanging valleys,* and while they are not very common in the Bighorn Mountains, illustrations are found at several points. Among the more conspicuous examples are the three cirques leading north from the highest part of the range to North Fork of South Piney Creek, all of which are from 500 to 700 feet above the main valley, and the cirque just west of the 12,271-foot peak in the basin of the West Tensleep. In some places glaciers appear to have eroded very little. Near the point where the 9500-foot contour crosses Medicinelodge Creek there is an area where the ice failed to remove all the decayed rock, tho rock surfaces close by show severe wear. Such cases are so exceptional as to be conspicuous.

Changes in drainage.—Glacial erosion sometimes effected changes in drainage. These mountains afford an example of what may be called *glacial piracy,* at the head of North Fork of Clear Creek. The course of the uppermost mile and a half of the valley of this creek indicates that it was developed by a tributary of Tensleep Creek and that its present course is secondary. Near the elbow of the creek, striæ show that the ice of the cirque in which the creek heads followed the original course of the drainage and joined Tensleep Glacier. It appears that the divide between the two creeks was cut back by the cirque-developing activity of the glacier that occupied North Fork of Clear Creek, until it reached the channel of Tensleep Creek. When the ice disappeared the drainage from the upper part of the former Tensleep Valley found its way, by a sharp turn, into the valley of North

Fork of Clear Creek. Fig. 3 illustrates the conditions as they are conceived to have been before the piracy; fig. 4, the present topography, the result of the piracy.

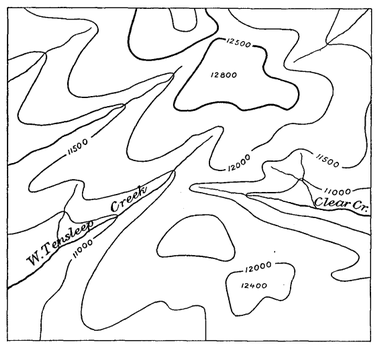

FIG. 3.—Conjectured preglacial drainage about the heads of North Fork of Clear Creek and West Tensleep Creek.

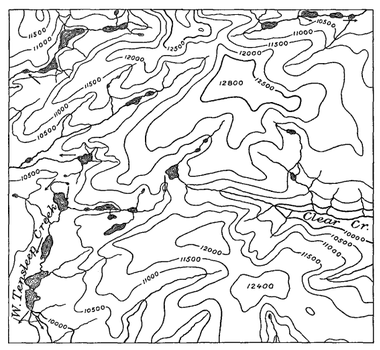

FIG. 4.—Present drainage about the heads of North Fork of Clear Creek and West Tensleep Creek, derived from the conjectured drainage shown in fig. 3. The arrows indicate the direction of glacial striæ.

GLACIAL DEPOSITS.

As already stated, the drift was deposited chiefly near the borders of the ice and is aggregated largely in terminal and lateral moraines. The size of these moraines has some relation to the vigor of the glaciation and so to the effectiveness with which the upper parts of the valleys were eroded. Thin and weak glaciers, such as many of those of the Dayton quadrangle, eroded less than most of the glaciers of this area and developed less massive moraines, even when they gathered material from a greater area.

Lateral moraines. — Lateral moraines usually become prominent about where the upper and deeper part of a glacier's valley or basin joins the shallower part below, or, in other words, where the glacier emerged from its upper canyon. In these mountains this point is usually at an altitude of about 10,000 feet. The lateral moraines often appear first just where the rock ridges which confined the glacier break down. From their upper ends the lateral moraines, one on each side of the glaciated valley, are generally continuous down to the terminal moraines which they join. The map shows the positions of the heavier lateral moraines.

The characteristic features of a well-developed lateral moraine are (1) a relatively narrow and even crest; (2) a long slope toward the valley and a short slope in the opposite direction, giving the moraine an asymmetric cross section; (3) an outer slope, about as steep as the drift will lie. The inner slope is much more variable, often less steep and more undulating, especially if the drift be thick.

From this ideal form the lateral moraines depart, sometimes widely. Tho their crests are often so even as to look like railway grades when seen from a distance, their surfaces, seen at close range, are usually marked by some unevennesses. This is especially the case where the moraines widen, as they sometimes do, into broad ridges. Among such irregularities depressions are more conspicuous than elevations. In some cases lateral moraines take the form of benches, or terraces, against the valley slopes. This is well seen, for example, in places (latitude 40° 20′) on the west side of the valley occupied by Paintrock Glacier. The lateral moraines, whatever their form, are subject to interruptions. Their failure here and there is usually assignable to some peculiarity of topography, often a slope too steep to permit the drift to lodge.

The stronger lateral moraines of this region are the following:

1. Those of North Fork of Clear Creek, especially the one on the south, the crest of which rises about 600 feet above the creek within and 150-200 feet above the surface without. Its inner face is marked by subordinate (recessional) lateral moraines at some points. The north lateral moraine of this glacier is also well developed, its inner slope being often markedly undulating.

2. Those of North Fork of South Piney Creek, especially the one on the south, which, next to the south lateral moraine of North Fork of Clear Creek, is the strongest lateral moraine on the east side of the range. It has a maximum inner slope of 600 to 700 feet and an outer slope of 100 feet.

3. Those of West Tensleep Glacier, the west one being the longest lateral moraine (about 10 miles) in the range. Its upper end has an altitude of about 10,100 feet and it descends to about 8200 feet. The moraine determined the position of a drainage line (Dry East Tensleep Creek, intermittent) for some distance. The east lateral moraine of this glacier is less strong, with a broad crest and an undulating inner slope.

4. Those of North Medicinelodge Glacier, the northern moraine especially having a well-developed crest line for 1½ miles below the 9000-foot contour.

5. Those of Paintrock Glacier, the inner faces of which are terraced.

6. Those of East Medicinelodge Glacier, especially that on the west, above Black Butte.

Interlobate or medial moraines.—Several pronounced moraines appear along the lines of junction of coalescing glaciers. Some of these take the form of two contiguous lateral moraines, with a distinct depression between. Examples of interlobate moraines are best seen (1) in the valleys of South Fork of Clear Creek, (2) in the midst of the area covered by West Tensleep Glacier, where the two coalescing lobes were separate only in their basal parts, and (3) in the basin of the Paintrock Glacier below the upper nunatak (an unglaciated hill that rose thru the ice).

On the map the interlobate and lateral moraines are not distinguished.

Terminal moraines.—Terminal moraines differ notably from lateral moraines in topography, their surfaces being characterized especially by knobs and kettles (fig. 15, illustration sheet 2) and short ridges and troughs of unequal heights and depths. They are generally much broader and more massive than lateral moraines. Seen from the down-valley side the terminal moraines appear as plugs in the valleys, many of them presenting steep fronts, some of them 500 feet high, as in Sherd Lake Valley. The angle of slope is often as much as 30°, and in some cases even a little more. The inner slope is less steep than the outer and its descent is notably less, usually less than 100 feet. The undulations of the surface often amount to as much as 100 feet.

A somewhat persistent feature of the terminal moraines on the east side of the range is an outer bench below and beyond the main summit. The bench is usually less than half a mile wide, and appears to indicate that the ice receded from its position of maximum advance before making its final stand and its main terminal deposit. On the west side of the range these outer benches are not so marked, but many of the terminal moraines have two crests, one a mile or less within the other. These double crests on the west may have the same significance as the outer benches on the east.

Where the glaciers descended below the area of crystalline rock they entered narrow valleys in the zone of the Paleozoic deposits, and in such places their terminal moraines are not strongly developed. This was the case, for example, in the valleys of several of the larger glaciers on the west side of the range. The ends of the narrow tongues of ice in such valleys may have oscillated more than the larger ends of other glaciers and so developed broad rather than high terminal moraines. The narrowness of the valleys also had much to do with their lesser development.

The more massive terminal moraines of this area are on the east side of the range. That of South Fork of Clear Creek has been mentioned. No other moraine of the range has a longer or steeper outer slope, and none has a rougher topography. Its undulations of surface are as much as 100 feet, at least. The terminal moraine of North Fork is about 300 feet above the valley outside, and its topography is markedly irregular. It has a well-developed outer bench about a third of the way up the slope. The terminal moraines of Meade, Kearney (partly in the Dayton quadrangle), East Tensleep, South Medicinelodge, and Trapper glaciers have outer faces 150 to 200 feet high and the topography of most of them is strongly relieved. Even moraines that are not so high show very rough surfaces. The terminal moraine of Paintrock Glacier is relatively small and is seemingly out of keeping with the size of its glacier. The terminal moraine of West Tensleep Glacier is wide and massive, but not high.

There are recessional moraines in a number of the glaciated valleys, but they are not generally conspicuous. They often obstruct the drainage temporarily, giving rise to lakes, most of which have now been drained or filled.

Lateral moraines not only grade into terminal moraines as they descend, but in some places the topographic distinction between the two types is lost. There appears to have been a sideward motion along the edges of even the narrowly confined valley glaciers, and the massive lateral moraines were accumulated largely beneath the sideward-moving edges. Where the edges oscillated in position the lateral moraines simulate a terminal moraine, and this is often true of the inner slopes where it is not of the crest and outer slope.

Ground moraine.—The thick drift inside the lateral and terminal moraines is mostly ground moraine, which has less distinctive topographic characteristics than the lateral and terminal moraines. In general it covers considerable areas inside the terminal and lateral moraines and occurs in smaller patches, even to the heads of many of the glaciated valleys. The map shows in a general way where the drift is thick. Ground-moraine matter is more widespread in those valleys in which glaciation was feeble than in those in which it was vigorous. Where the ground moraine is meager the bottoms of the valleys are often a succession of bare roches moutonnées rising above the intervening depressions which have soil enough to support vegetation.

Composition of the drift.—The drift in the Bighorn Mountains differs in no essential respect from the drift of other mountain valley glaciers, unless it be in the rocks that enter into its composition. On the east the drift consists wholly of igneous and metamorphic rock derived from the axis of the range. On the west, where some of the glaciers descended to the Paleozoic formations, materials from them are mingled with those derived from the higher part of the range.

The drift, like that of mountains in general, is coarse. Bowlders are the most conspicuous constituent, and they range in size up to 40 feet in diameter, tho those more than 10 or 15 feet in diameter are relatively rare. Most of them are of light-colored rock, and their smooth, unetched surfaces, essentially free from lichens, give to the surface of the moraine a whiteness which is often conspicuous even at the distance of several miles.

Thickness of drift.—The thickness of the drift is not easily determined in many places. The heights of the terminal moraines as seen from the outside, 500 feet or less, probably represent the maximum thickness of the drift. Postglacial cuts of streams thru terminal moraines are rarely more than 150 feet deep and do not reach the bottom of the drift.

Changes of drainage.—Greater changes of drainage were effected by the deposition of drift than by glacial erosion. Altho most of these changes were slight, a few of them may be mentioned to show their general nature and extent.

Sherd Lake Valley probably drained into South Fork of Clear Creek before the massive moraine diverted it to Middle Fork. The glacier of North Fork of Clear Creek seems to have been headed down the valley of French Creek, as if that were the former outlet for the upper portion of this valley. The east lateral moraine of Kearney Glacier shifted South Fork of South Piney Creek to the east. The creek doubtless followed the edge of the ice while the glacier existed, but later crost the lateral moraine to North Fork. Drainage from the Paintrock Lakes region was probably formerly southwestward to Medicinelodge Creek. There were other minor changes of the same general type.

Névé deposits.—Under the term nivation Matthes (op. cit.) has described certain phenomena of these mountains which deserve mention in this connection. In many valleys and against many cliffs where glaciers, or at any rate well-defined glaciers, did not exist, snow accumulated in quantity. In some places the snow merely made great snowdrifts, many of which no doubt persisted from year to year. Beneath and about the snow the fine material washt down from above was deposited, and the snow tended to prevent the removal of such material, the result being that considerable quantities of it accumulated. Where cliffs projected above drifts of snow, débris from them rolled down over the snow banks, and often lodged below.

Altho the snow and ice in such positions had no motion in some places, they probably had some in others. It is conceived that this motion was in some cases incipient glacier motion, too feeble to leave demonstrative record of itself; that in others it was a slow creep, such as is likely to affect all great masses of snow on slopes; and that in still others it amounted to sliding. Furthermore, the accumulated débris itself was subject to sliding, and the fine mud even to flowing, during summer seasons when the edges of the accumulation were unfrozen. It was also subject to expansion as the result of freezing when the summer came to an end, and it has been subject to most of these changes ever since the ice epoch. The result of all these processes was the accumulation of débris, not distinctly glacial, but with distinctive peculiarities of topography, often slightly ridged, sometimes marked by low mounds, occasionally simulating mud streams. Striking phenomena of the same sort elsewhere have been called "talus glaciers."

Nivation characterizes the heads of some valleys which were distinctly glaciated below. The heads of such valleys are not cirques. Some of the heads of both the East and West Tensleep glacial systems afford illustrations. Nivation is also distinct in many valleys where there is no evidence of distinct glacial movement, and appears to have affected the inner slope of the west lateral moraine of West Tensleep Glacier since the ice retired, and is in progress now at other points, according to Mr. Matthes. Several areas of nivation are shown on the map, and there are doubtless others.

Valley trains.—The streams that carried off the water from the melting glaciers carried bowlders, gravel, and finer material down the valleys, developing valley trains. Tho generally distinct for a short distance below the moraines, such trains are as a rule surprizingly small. Their inconspicuousness is the result, primarily, of poor development, not of subsequent removal. On the west side of the range, where most of the glaciers ended in canyon-like valleys, the valley trains are so poorly developed that they have been omitted from the map. Elsewhere their remnants appear as low terraces. It is probable that the streams were so swift at the time the ice was melting that all fine material was carried and distributed far below the moraines. Thruout the whole region, however, the amount of fluvio-glacial material which can be connected with the late glaciation is surprizingly small.

Drainage from the ice helped to fill some shallow lake basins developed just outside the glaciers, where the ice, and later the lateral moraines, obstructed the drainage. The larger lake flats of this type occur east of East Tensleep and West Tensleep glaciers.

Running water also made some deposits inside the moraines after the glaciers retreated from their most advanced positions. Such deposits are usually not conspicuous except where the drainage entered lakes. In some places shallow lakes appear to have had their basins filled by inwash. Soldier Park, in the valley of North Fork of Clear Creek, is a good example. Other similar deposits occur above the terminal moraine of Kearney Glacier and in the upper part of the basin of East Tensleep Glacier, and there are smaller ones at many other points.

THE LAKES AND LAKE DEPOSITS.

The lakes of the Bighorns are all due directly to glaciation. The basins of some of them were due to glacial erosion, those of others to glacial deposition. Of the latter, some lie just outside the

moraines, but more within. Of those outside, Elk Lake, east of Cloud Peak, is the largest. While the ice lay in the valley to the north it obstructed the drainage of the basin above the lake, and when the ice melted its lateral moraine continued the obstruction. Numerous lakelets were formed in similar situations, but most of them have been drained. The sites of several such lakes, now flat meadows, are shown on the map, the largest being east of the Tensleep glaciers.

Of lakes within the terminal moraine there are several types, namely, (1) those in rock basins; (2) those in basins made by drift dams; (3) those in basins that are partly of rock and partly of drift; and (4) those that lie in depressions in the drift itself. Several types are represented on the illustration sheets.

Probably half the lakes and ponds of the range large enough to be represented on the map occupy rock basins. Lakes of this class are especially numerous in the upper parts of the glaciated valleys west and southwest of Cloud Peak and on the east side of the range. Around the shores of many of these lakes continuous bare rock may be seen; around others the rock of the shore is somewhat encumbered by drift, but in such relation as to leave no doubt as to the nature of the basin. The lakes in the heads of the cirques are mostly in rock basins, tho rock basins are not confined to that position.

Most of the larger lakes, such as East and West Tensleep lakes and Lake Solitude, are probably held in by drift dams, or at least have had their basins made deeper by the building up of their rims by drift. Paintrock Lakes are examples of lakes held in, largely at least, by drift dams, and most of the lakes that lie just above the terminal and recessional moraines belong to the same category. Many of the small ponds, especially in terminal moraines, occupy depressions in the surface of the drift. The depths of the lakes have not been determined.

EARLIER GLACIAL DRIFT.

Besides the glacial drift described above and referred to the last glacial epoch, there are various sorts of loose material, of the general nature of drift. Some of it is glacial, some of it may have had a glacial origin, so far as now known, and some of it is not glacial. Of that which is certainly glacial some is much older than the moraines already described.

At numerous points just outside the terminal and lateral moraines of the last glacial epoch there are limited areas of glacial drift. Within the area described in this folio this extramorainic drift occurs outside the new moraines of the Kearney, Meade Lake, North and South forks of Clear Creek, East Tensleep, Paintrock, and South Medicinelodge glaciers. In its physical and lithologic constitution some of it is very like that of the new moraines. This is especially true of that outside the late moraines of the Tensleep, Paintrock, and South Medicinelodge glaciers, as noted by Mr. Bastin; but even in these places it generally has a somewhat older look than the late moraines, due to greater decay and to less abundant surface bowlders, and especially to the absence of those topographic features that are distinctively characteristic of drift, and to the presence of drainage lines of mature aspect. The extramorainic drift on the east and north sides of the mountains, on the other hand, has more unmistakable marks of age, according to Mr. Blackwelder, especially in the physical condition of the drift and in the amount of erosion that has taken place since its deposition. The great erosion shows itself both in the patchy distribution of the drift and in the great deepening of the valleys since it was deposited.

If the extramorainic drift of East Tensleep, Paintrock, and South Medicinelodge basins ever had the topography that is characteristic of the new drift its great antiquity would be clear. On the other hand, its relative freshness and its limited distribution just outside the new moraines would be consistent with the interpretation that it was deposited during a temporary advance of the ice beyond the position of the main moraines, that it was never more than a thin body of drift, and that it never had the topography characteristic of thick drift. If made early in the last glacial epoch its materials may have been more decayed at the time of deposition than those of the moraines. Furthermore, it is not irrational to assume that early in the glacial epoch, before glacier erosion had notably deepened the valleys, the ice spread somewhat more widely, at least laterally, than at a later time, after the valleys had been made more capacious by glaciation. But altho such an interpretation might perhaps be entertained for the extramorainic drift of the basins last mentioned, it does not seem to fit that on the east side and north end of the range, where the great age of this kind of drift is evident, not only in its topography, but in its physical constitution and in the erosion observed by Mr. Blackwelder, which has taken place since it was deposited. Much if not all the extramorainic drift is therefore regarded as the product of an earlier glacial epoch, when the glaciers, especially those at the east and north, were somewhat more extensive than those of the later glacial epoch.

The extramorainic drift shown on the map on the east side of the range is not all known to be of glacial origin, but glaciated bowlders were found in it in the valley of North Fork of Clear Creek in the Fort McKinney quadrangle nearly 2 miles below the later moraine, on the divide between North Fork of South Piney Creek and North Piney Creek, and in similar positions in two localities in the Dayton quadrangle. The finding of glaciated bowlders in these several localities, quite out of the range of the ice and of the drainage of the last glacial epoch, demonstrates the glacial origin of at least parts of this drift. If some of it is of fluviatile origin, such drift can not be readily separated from the glacial. The paucity of glaciated bowlders is not strange when the fewness of the exposures and the extent of weathering since this drift was deposited are considered.

The older drift is not continuous over the areas indicated on the map. These areas are rather the areas within which it is known to occur. Especially between North and South forks of Clear Creek is the drift discontinuous, and within this area no glaciated material was found. One of the largest remnants caps the divide between North Fork of Clear Creek and French Creek. It consists of a thick deposit of bowlders mixt with more or less gravel and sand. Owing to erosion the morainal character has been somewhat effaced and probably much of the original deposit has been removed. Its original limit to the east is not apparent, but probably it was near the west margin of the Fort McKinney wood reservation.

RECENT EPOCH.

TIME SINCE LAST GLACIAL EPOCH.

To casual observation one of the most striking features of the recent glacial drift in the Bighorn Mountains is its freshness. The first impression is that the drift is notably younger than the Wisconsin drift of the interior. This impression is perhaps deceptive, (1) because the rock in this region probably weathers less rapidly than the rock of the interior; (2) because the drift is much coarser than in the interior, so that bowlders are relatively conspicuous; and (3) because the bowlders are largely of light color, and so give the appearance of freshness.

The less obvious weathering of the rock in the mountains is probably the result of the climate. The average temperature of the year is much lower than in the interior of the continent, restricting chemical change, and for a large part of the year the bowlders are protected by snow against notable daily changes of temperature. Furthermore, weathering by exfoliation, which is effective in summer, leaves fresh-looking surfaces. Exfoliation has been too rapid to permit the development about the bowlders of the weathered zones that are due to the action of the atmosphere. The lack or the slightness of chemical action is also shown in sections of the drift, for they do not show appreciable leaching, while the drift of Wisconsin age in the northern interior usually shows leaching to the depth of 2 to 4 feet.

POSTGLACIAL CHANGES.

Few changes have taken place since the ice disappeared. The freshness of the drift and of the glaciated rock surfaces is among the most striking features of the valleys that were occupied by ice. The changes include (1) weathering, especially that resulting from changes of temperature, and (2) stream erosion, especially where the creeks cross the terminal moraines. Several lakes have been lowered by the lowering of their outlets.

In most places the amount of talus that has been split off from the rock walls in postglacial time is not great, but there are some striking exceptions. Matthes noted a trail thru the pass at the head of North Fork of Clear Creek which had been abandoned in 1899 because of the accumulation of talus, tho it had been in use but ten years before. The amount of postglacial talus is also great at the bases of not a few cirque cliffs, as at the heads of the valleys of Kearney Glacier, in cirque 4; of East Tensleep Glacier, where the talus from opposite sides meets at some places in the bottom of the valley; and in cirque 6 of West Tensleep Glacier. Large amounts of postglacial talus lie at the bases of cliffs that escaped severe glaciation or that are composed of rock which breaks up readily as a result of changes in temperature. Altho the postglacial results of temperature changes have not been great, they are evident in many places in the exfoliation of bowlders and of exposed rock surfaces. The effectiveness of this exfoliation is shown by the fact that advertisements painted on bowlders have been extensively defaced by the shelling off of the surface on which they were painted. That this, and not the weathering of the paint, explains their disappearance is certain, because exfoliated shells about the bases of the bowlders and rock walls often show the paint but little dimmed.

Where streams flow over solid rock the amount of work they have done in postglacial time is hardly appreciable. In two cases (cirques 5 and 7) striæ were observed in the channels of streams. The wear in the upper parts of the valleys is very slight, because they contain very little material that is fine enough for the streams to carry, all fine material having been removed by the ice.

The work of streams flowing in channels in the drift has been limited to carrying away the finer material. Even in the channels of the swifter streams the accumulated bowlders set free by the removal of the fine material offer effective resistance to further erosion. The postglacial stream channels cut in the ground moraine are rarely as much as 25 feet deep. Only where streams cross terminal moraines are their gorges pronounced. That of East Tensleep Creek approaches 200 feet at a maximum, and those of West Tensleep and South Medicinelodge creeks approach 150 feet. Of the remaining gorges none are much more than half as deep. All these cuts are V-shaped, with slopes of 25° to 35°.

EXISTING GLACIERS.

There are numerous perennial snow fields and a few small glaciers in the Bighorn Mountains. The topographic map shows three glaciers on the east side of the range—two at the head of North Fork and one at the head of South Fork of South Piney Creek. The last is much the largest. In 1902, according to W. H. Emmons, there was a fourth incipient glacier on this side of the range, in one of the more southerly cirques of South Fork. This glacier and those at the head of North Fork are all very small, tho possessing characteristics which indicate glacial movement. The principal glacier at the head of South Fork lies in a cirque whose almost vertical walls are nearly 1600 feet high at their highest point. (See fig. 9 on illustration sheet 1.) The glacier is therefore well protected from the sun. It has a distinct terminal moraine, 10 to 25 feet high, and a lateral moraine on either side. Its surface carries much dust and is marked by dust wells and bowlder-capped ice pillars. Superglacial streams have cut channels 3 to 4 feet deep in the ice, revealing layers of ice, some clean and some débris charged, which are turned up near the end of the glacier at angles ranging from 20° to 25°.

ALLUVIUM.

In the higher portions of the Bighorn Mountains most of the streams are engaged in active erosion and the declivity is so great that the products are carried far away. Small amounts of alluvium are deposited along the wider portions of some of the valleys, but they are usually transient and are removed by the heavier floods. They are too small for representation on the geologic map. In the lower lands of the region, which are underlain by softer rocks, the valleys are wide and many of the alluvial deposits have considerable extent. Along Clear and Crazy Woman creeks they are in places a mile wide. They constitute nearly level tracts, thru which in places the streams meander from side to side, usually in very shallow trenches. In times of flood the streams rise out of these trenches and overflow the alluvial bottom land to a greater or less extent, so that the alluvial deposits are in places increasing in thickness. The materials are sands and loams, often mixt with more or less gravel and small bowlders derived from the mountains and the adjacent highlands.

The largest deposits west of the mountains are along Tensleep Creek below the mouth of its canyon, where for a short distance there are alluvial flats from a half to three-fourths of a mile wide on either side of the stream. They grow narrow near Tensleep post-office, where they join other alluvial flats that extend up the valley of No Wood Creek. A notable accumulation of alluvium lies in the valley of Canyon Creek, extending from Rome to the fault. Its width varies from a half to three-fourths of a mile.

STRUCTURAL GEOLOGY.

STRUCTURE OF THE BIGHORN UPLIFT.

The Bighorn Mountains are due to a great anticline of many thousand feet uplift, rising in south-central Montana and extending about 125 miles southeastward and southward into central Wyoming. It lifts a thick series of Paleozoic and Mesozoic formations high above the plains and, owing to the deep erosion of its crest, presents a central nucleus of pre-Cambrian granites, from which sedimentary rocks dip at varying angles on either side. The most elevated portion of the uplift is in latitude 44° 30′, where one of the granite summits, Cloud Peak, rises to an altitude of 13,165 feet, or about 9000 feet above the adjoining plains. Figs. 5 and 6 show the configuration of the principal structural features of the uplift. The greatest vertical displacement of the strata, as indicated by the height at which the granite floor is now found, with moderate allowance for erosion, amounts to about 25,000 feet. For the greater part of its course the anticline is relatively simple in shape, but there are numerous local variations in the steepness of its sides and the shape of its top and many complexities due to the presence of extensive faults. In general its eastern side is much steeper than its western, especially in the central portion of the uplift. At its northern end both sides are relatively steep and the top is remarkably flat. In the portion of highest uplift, which is probably near Cloud Peak, the sedimentary rocks have been removed over a considerable area and the form which the flexure would have if the eroded portions of the granite and the overlying sedimentary beds were restored can only be conjectured. Apparently in this region there is a long uniform rise from the west, a similarly gentle downward grade to the east for some distance, and then the steep dips which are now found in the foothills on that side. In its southern extension the uplift is relatively even crested, but it exhibits a local doming of moderate prominence near its southern termination. The main uplift bears a number of subordinate flexures, the most notable being the one in Dry Fork Ridge east of Bald Mountain. This is an anticline rising about 2500 feet on the northeast-dipping limb of the main anticline. Several small anticlines and synclines extend southeastward out of the average trend in the vicinity of Mayoworth, Greub, and Houck, and northward at No Wood, Bigtrails, and Hyattville. There are a number of faults in the uplift, some of them extending along the strike and others crossing it at various angles. The most notable fault is northwest of Buffalo, where the strata are displaced 9000 feet. This dislocation was effected mainly in Laramie time and its extension eastward is covered by Laramie or later deposits. Other profound faults of this variety extend along the east side of the range west of Buffalo. A prominent fault crosses the uplift east of Tensleep, varying in throw from 500 to 1000 feet, with the drop on the south side. South of this fault is a great hook-shaped displacement, with one fault line extending along the west side of the crest of the mountain to the southern termination of the uplift, and the other fault extending eastward and southeastward out of the moun-

tain. Along the north-south fault there is uplift of 500 to 2000 feet on the east side, while on the other there is downthrow of about the same amount on the west side, so that the faulted block has revolved slightly. The axis of this movement passes halfway between Mayoworth and Tensleep.

Near the southern end of the uplift the north-south fault divides into several irregular faults.

In the Bald Mountain region there are several local faults with displacements which are mainly along the strike and follow the steep upturn along the western margin of the uplift. Another local strike fault extends along the east side of Walker Mountain.

STRUCTURE OF THE QUADRANGLES.

WEST SLOPE.

General features.—The Cloud Peak quadrangle includes the highest part of the Bighorn uplift and a portion of its western slope. Altho the sedimentary rocks have been eroded from the northeastern half of the area, it is apparent, judging from the relations in adjoining regions, that the strata originally extended over that section in a broad, high dome or elongated anticline, as shown in fig. 6. For the beds to have overarched Cloud Peak, a dip of only about 12° is required, making allowance for 1000 feet of erosion, and this rate of dip is about the average now found in the strata lying opposite Cloud Peak on the west slope of the range. Along the slopes that occupy the southwestern half of the quadrangle the general dip is to the west and west-southwest at angles mostly from 9° to 12°. In the vicinity of Black Butte and farther north the strike turns to the north and the dips increase somewhat in amount. The prominence of this butte is due to the change in strike and the sudden increase of dip in the Bighorn and overlying limestones. There are local variations in strike along the mountain slopes, especially in the Amsden and Tensleep beds north of North Fork of Brokenback Creek, but their effects are small. In the area of the Chugwater red beds the dips are all very low owing to a low anticline which begins on the divide between South Fork of Brokenback Creek and Tensleep Creek and extends northwest for many miles, passing out of the quadrangle in latitude 44° 10′. It is plainly exhibited in Tensleep sandstone in the two forks and north branch of Brokenback Creek and in the high ridge of lower Chugwater red beds north of bench mark 4522. In this ridge small canyons cut thru the red shales and expose the top of the Tensleep sandstone. Faults are not very numerous on the western slope, and those which are prominent occur at the southern margin of the uplift, as shown on the geologic map. A small fault on Trapper Creek, in the northwest corner of the Cloud Peak quadrangle, is shown in fig. 19, illustration sheet 2.

Fault near Rome.—Near the southern margin of the Cloud Peak quadrangle the strata are dislocated by two faults trending east and west. The larger fault is a strongly marked feature along the north side of Canyon Creek Valley north and northeast of Rome post-office. In its greatest development, which is north of Rome, it has a vertical displacement of 600 feet, bringing upturned Tensleep sandstone in contact with Madison limestone, the latter rising in a cliff capped by Amsden and Tensleep beds. This cliff extends eastward for about 7 miles from a point a short distance east of bench mark 5097. The throw of the fault gradually diminishes toward the east to the point at which it crosses Canyon Creek Canyon, where it is entirely in Madison limestone, with a throw of about 400 feet. East of this point its throw increases somewhat and it is exhibited in the Madison and Bighorn limestones and the Deadwood formation, the latter being entirely cut out southwest of bench mark 8429, where, for a short distance, the Bighorn limestone and the granite are in contact. It passes entirely into the granite south of bench mark 8429, and could be traced no farther. One of the finest exposures of the dislocation is at the place where Canyon Creek crosses the fault northwest of Rome and enters a deep canyon in Madison limestone. South of the entrance of this canyon there is a wide valley of Chugwater red shales, and this rock and some ledges of underlying Tensleep sandstone are steeply upturned against the fault. The amount of displacement is about 400 feet. West of the entrance of this canyon the throw diminishes rapidly and at one point near by the upturned Chugwater red shales are in contact with red Amsden shale. Near bench mark 5097 the fault has merged into a flexure which thence extends due west for some distance.

Upturn near Tensleep.—This flexure is marked by a narrow zone of steep southerly dips which appear in a ridge of Chugwater red shales that extends along the south side of Tensleep Valley just south of Tensleep post-office. This zone crosses No Wood Creek just above the mouth of Tensleep Creek, giving rise to a narrow ridge of steep, southward-dipping beds, ranging in age from upper Chugwater to lower Colorado, which extends to the western margin of the Cloud Peak quadrangle. The dips are nearly vertical for a few hundred yards, but give place abruptly to nearly horizontal dips to the north and south.

Powder River fault.—A prominent fault crosses the southeast corner of the Cloud Peak quadrangle east and south of bench mark 8337. It crosses North Fork of Powder River, with a throw of about 1500 feet, bringing the upper part of the Madison limestone against the lower sandstone of the Deadwood formation. It here trends due east and west and, on the adjoining slopes, the basal sandstones of the Deadwood and Amsden formations are in contact. South of bench mark 8337 its course changes to southwest and its throw rapidly becomes less, the full series of Deadwood, Bighorn, and lower Madison beds rising to the surface on the west side of the fault, while Amsden and Tensleep beds rise on the east side. It passes into the quadrangle lying immediately south of the Cloud Peak quadrangle, where it gives place to a flexure.

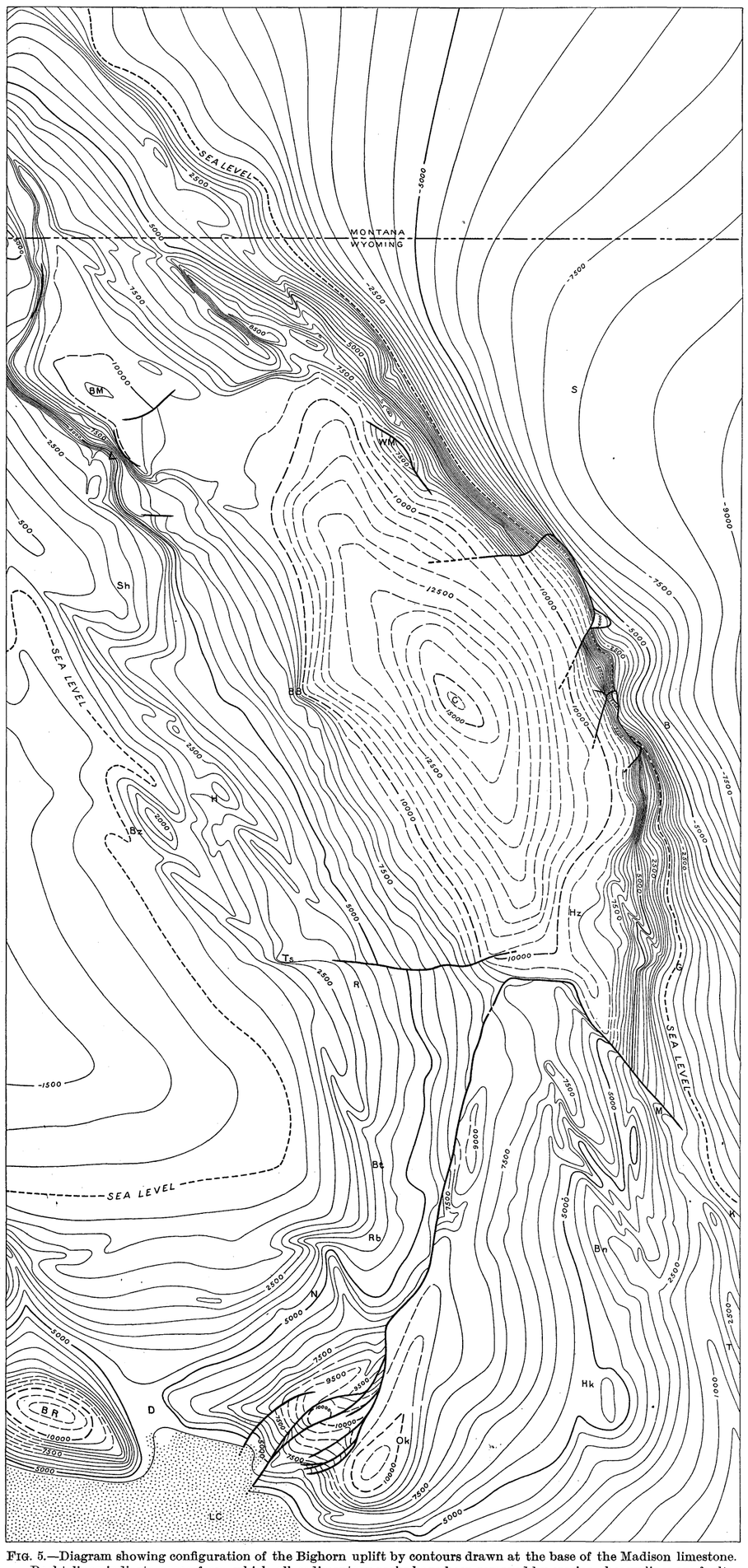

FIG. 5.—Diagram showing configuration of the Bighorn uplift by contours drawn at the base of the Madison limestone. Dasht lines indicate areas from which all sedimentary rocks have been removed by erosion; heavy lines are faults; dotted pattern represents area covered by Tertiary deposits.

Scale: 1 inch=10 miles. Contour interval is 500 feet. Datum is sea level.

B, Buffalo; BB, Black Butte: BM, Bald Mountain; Bn, Barnum; BR, Bridger Range; Bt, Bigtrails; Bz, Bonanza; C, Cloud Peak; D, Deranch; G, Greub; H, Hyattville; Hk, Houck; Hz, Hazelton; K, Kaycee; LC, Lost Cabin; M, Mayoworth; N, No Wood; Ok, Okie's store; R, Rome; Rb, Redbank; S, Sheridan; Sh, Shell; Ts, Tisdel's ranch; WM, Walker Mountain.

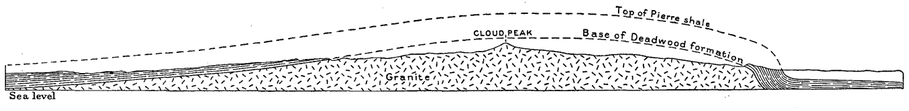

FIG. 6.—East-west section across the highest part of the Bighorn Mountains, showing the extent of erosion of the uplift.

Vertical and horizontal scales: 1 inch = 10 miles.

EASTERN FRONT RIDGE.

In the limestone front ridge and foothills on the east slope of the mountains in the Fort McKinney quadrangle the strata rise on a monocline which is steep in its northern part and relatively gentle in its southern part. As shown in section F–F, there is at first a relatively steep rise near the flanks of the mountain and then very marked flattening of the dips toward the west. An anticline of moderate prominence appears on the monocline north of Crazy Woman Creek and crosses the range diagonally, passing out into the granite west of bench mark 7866, near Muddy Creek. This anticline is a marked feature on the north side of Middle Fork of Crazy Woman Creek west of Greub, where it is exhibited in a high ridge of Tensleep sandstone with a valley of Chugwater red shale extending westward up the syncline for some distance. At North Fork of Crazy Woman Creek there is a sudden increase of steepness in the beds of the front ridge, some features of which are shown in fig. 16 of illustration sheet 2. North of this place the dips are mostly more than 45° and they become nearly vertical near Clear Creek. Steep dips prevail north of Clear Creek, with local moderate diminution on the slope of the front ridge west of Mowry Basin. In this portion of the region the ridge is traversed and paralleled by a number of profound faults, partly of late Cretaceous and partly of later age. The first of these from the south develops in the granite 5 miles north of Sisters Hill, crosses the front ridge diagonally, and extends along its eastern side for several miles, in part under a covering of later formations. From Clear Creek to Johnson Creek Kingsbury conglomerate lies in contact with the Madison limestone along this dislocation. North of Johnson Creek the fault divides, its eastern branch passing under Kingsbury conglomerate and the other bringing the Chugwater and Deadwood formations into contact, as shown on section B–B of the structure-section sheet. Near this section another fault develops on the west side of the front range, which trends first north-northeast and then northeast, finally passing out under Kingsbury conglomerate on the south line of sec. 8, T. 52, R. 83. On South Fork of Sayles Creek a branch of this fault extends northward and then northwestward, dying out in the Deadwood basal beds. Near the point at which the fault bifurcates the granite is in contact with Tensleep sandstone and apparently Chugwater red beds, above which it rises in a prominent knob. Another fault appears northwest of the canyon of South Fork of Rock Creek, trends northeastward, and crosses all the formations from Deadwood to Piney. On North Fork of Rock Creek the Mowry shales are in contact with the granite along this fault, and farther north it brings Deadwood and Piney formations into contact. A short distance south of the head of North Fork of Shell Creek it turns eastward and extends under the Kingsbury conglomerate, which is here in contact with the Bighorn limestone and the Deadwood formation. A small branch fault continues northward and brings the

Cambrian shales and Madison limestone into contact along the foot of the limestone front ridge, which here begins again, having been cut out by the main fault in the slopes adjoining North Fork of Rock Creek. These faults in their maximum development have from 5000 to 9000 feet throw, with the drop on the east side. Doubtless some of them extend far southwestward into the granite area, but they could not be traced in that direction. In the southwest corner of the Fort McKinney quadrangle there is a small area in which the sedimentary rocks extend up the slope of the granite from the south and southwest and are cut off by the Powder River fault, described above.

THE PLAINS.

In the eastern half of the Fort McKinney quadrangle the strata lie in a monocline, dipping gently northeastward near Buffalo and nearly due eastward in the vicinity of Crazy Woman Creek. In the ridge of Kingsbury conglomerate the dips are mostly from 15° to 20°, but they gradually diminish toward the east until, near the eastern margin of the quadrangle, they are mostly from 2° to 4°.

GEOLOGIC HISTORY.

The general sedimentary record.—The rocks appearing at the surface within the Cloud Peak and Fort McKinney quadrangles comprize granites of pre-Cambrian age and an overlying thick series of sedimentary strata. The sedimentary strata consist mainly of sandstone, limestone, shale, sandy loam, and gravels, all presenting more or less variety in composition and appearance. The principal materials of which they are composed were originally gravel, sand, or mud derived from the waste of older rocks, or chemical precipitates from salty waters.

These rocks afford a record of physical geography from Middle Cambrian time to the present. The composition, appearance, and relations of the strata show in some measure the conditions under which they were deposited. Sandstones ripple-marked by waters and cross-bedded by currents, and shales cracked by drying on mud flats were deposited in shallow water; pure limestones generally indicate open seas and scarcity of land-derived sediment. The fossils that the strata contain may belong to species known to inhabit waters that are fresh, brackish, or salt; muddy or clear. The character of the adjacent land may be shown by the nature of the sediments derived from its waste. The quartz sand and pebbles of coarse sandstones and conglomerates, such as are found in the Deadwood, Tensleep, Cloverly, and some other formations, had their original source in crystalline rocks, but in part, at least, have been repeatedly redistributed by streams and concentrated by wave action on beaches. Red shales and sandstones such as make up the "Red Beds" usually result directly from the revival of erosion on a land surface long exposed to rock decay and oxidation and hence covered by a deep residual soil. Limestones, on the other hand, if deposited near the shore, indicate that the land was low and that its streams were too sluggish to carry off coarse sediments, the sea receiving only fine sediment and substances in solution. The older formations exposed by the Bighorn uplift were laid down from seas that covered a large portion of the central-western United States, for many of the rocks are continuous over a vast area. The land surfaces were to some degree coextensive with the present Rocky Mountain province, but the peripheral shores are not even approximately determined for any one epoch, and the relations of land and sea varied greatly from time to time. Pursuing these general ideas in greater detail, one finds that the strata brought to view by the Bighorn uplift record many local variations in the ancient geography and topography of the continent.

Cambrian submergence.—One of the great events of early North American geologic history was the wide extension of an interior sea over the western-central region. The submergence reached the Rocky Mountain province in Middle Cambrian time, when, for a while, it formed an irregular shore line of great extent. From the ancient crystalline rocks of these shores waves and streams gathered and concentrated sands and pebbles, which were deposited as a widespread sheet of sandstone and conglomerate, partly on sea beaches, partly in shallow waters offshore, and partly in estuaries. Numerous exposures of these sediments, containing much local material, now abut against the surface of the crystalline rocks that formed these shores. The central portions of the Bighorn Mountains and the Black Hills may have been islands in the earlier stage of this period, and the Laramie Range and Rocky Mountain front range were lands rising out of the Cambrian sea. After these earliest conditions the higher lands were reduced by erosion and, the area possibly being also lessened by submergence, some of the islands yielded the finer grained muds now represented by the shales and limestones that occur in the upper portion of the Cambrian, but in many regions the land surface of crystalline rocks was buried beneath the sediments. The limestone conglomerates at the top of the Deadwood formation indicate recurrence of shallow-water conditions, the latter probably marking the beginning of emergence, which lasted thru the later part of Cambrian and the earlier part of Ordovician time. During this time the area considered in this folio probably was part of the land extending northward from the Laramie Range.

Ordovician sea.—In Black River–Trenton time the northern part of the Bighorn area was submerged, at first with deposition of sand and then with extensive deposition of lime carbonate, now constituting the greater part of the Bighorn formation. After this epoch of deposition there was uplift, probably resulting in widespread emergence. This was followed in late Ordovician time by submergence, during which the Richmond deposits accumulated in at least part of the region.

Silurian-Devonian conditions.—From the close of Ordovician to early Carboniferous time the Bighorn Mountains present no geologic record, the Silurian and Devonian being absent. This lack of sediments representing these periods is probably due to the fact that the region was covered by an extensive but very shallow sea, or by land so low as to leave no noticeable evidence of erosion. Whether it remained land or sea, or alternated from one to the other condition, the region shows no evidence of having undergone any considerable uplift or depression until early in Carboniferous time, when there was a decided subsidence, which established relatively deep-water and marine conditions, not only over the Bighorn area, but generally thruout the Rocky Mountain province.

Carboniferous sea.—Under the marine conditions of the early Carboniferous there were laid down calcareous sediments, which are now represented by nearly a thousand feet of limestone, known as the Madison limestone. As this formation comprizes no coarse deposits, it is thought that no crystalline rocks were exposed above water in this region, altho in regions farther south the limestone, or its stratigraphic equivalents, was deposited directly upon them. Later in Carboniferous time the conditions changed and a sheet of red shale of wide extent was deposited. This was followed by alternations of pure limestones, sandy limestones, and local sand deposits several hundred feet thick, constituting the Amsden formation. This deposition was followed by an uplift, during which shallow waters and strong currents deposited a thin but extensive sheet of sand, known as the Tensleep sandstone. In the southern portion of the Bighorn area this condition gave place to deposition of clay and then carbonate of lime, now constituting the Embar formation. Then followed a period of uplift, which culminated, in late Carboniferous or Permian time, in a widespread lake of saline water in which the Chugwater formation was laid down. This great mass of red shales, with its extensive interbedded deposits of gypsum, presumably products of an arid climate, accumulated to a thickness of over a thousand feet in parts of the area. There is such uniformity of the deep-red tint that this is undoubtedly the original color. It is present not only over the entire outcrop of the formation, but also thruout its thickness, as is shown by deep borings, and is therefore not due to later or surface oxidation. This deposition of red mud was interrupted from time to time by chemical precipitation of comparatively pure gypsum, in beds ranging in thickness from a few inches to 30 feet and usually free from mechanical sediments. It is apparent that these beds are the products of evaporation at times when mechanical sedimentation was temporarily suspended, doubtless during periods of greatly diminished rainfall; otherwise it is difficult to account for their nearly general purity. Most of the red deposits were laid down in shallow water, so that subsidence must have kept pace with deposition most of the time. At an early stage in the deposition of the "Red Beds" there was a period of widespread interruption in the shale sedimentation, during which a thin but wonderfully persistent bed of limestone was laid down. This is only a few feet thick in the Bighorn Mountain region, but in the Black Hills and some other localities it is 50 feet thick and is known as the Minnekahta limestone. It contains fossils that are believed to be Permian, and as fossils supposed to be of that age occur also in local limestone beds near Thermopolis, at horizons within 150 feet of the top of the "Red Beds," most, if not all, of these beds are apparently of that age. Possibly their deposition extended into Triassic time, but there is no definite evidence on this point. In most localities there is evidence of uplift and erosion of the "Red Beds" in an interval prior to the deposition of the marine Jurassic beds of the Sundance formation.

Jurassic sea.—In the Bighorn Mountain region the Jurassic was a period of varying conditions, shallow and deep marine waters alternating. The materials are nearly all fine grained and indicate waters without strong currents. Some of the earliest deposits are fine-grained sandstones or sandy shales, in part ripple-marked, evidently laid down in shallow water and probably the product of a time when sedimentation was in excess of subsidence, if not during an arrest of subsidence. An extensive marine fauna and limestone layers in the upper shales of the Sundance formation indicate that deeper water followed, but more sandy sediments appear near the top, indicating the resumption of shallower water conditions.

Cretaceous sea.—During the Cretaceous period deposits that are of various kinds yet are generally uniform over wide areas gathered in a great series, beginning with such as are characteristic of shallow seas and estuaries along a coastal plain, passing into sediments from deep marine waters, and changing toward the end to fresh-water sands and clays with marsh vegetation. The earliest deposits constitute the Morrison formation, a widespread mantle of fine-grained materials, mixtures of clay and fine sand, with thin, irregular bodies of coarser sand, deposited by streams or along shores, and with occasional thin beds of limy sediments. Huge saurians were abundant, as is shown by the frequent occurrence of their remains in the deposits, altho it is possible that the numerous remains are due mainly to increased mortality or to more favorable conditions of preservation, or both.

The close of Morrison time was marked by an abrupt change to conditions under which the coarse-grained, cross-bedded, massive basal conglomerates and sandstones of the Cloverly formation were deposited. Altho the character of the deposits changes abruptly and there is occasional local channeling of the surface of the soft Morrison beds, the erosion appears to be remarkably small in amount—no more than would be expected to result from strong currents bearing coarse sands and pebbles. It is believed that there was no great uplift-erosion interval following Morrison deposition, for if there had been the soft beds would have been widely removed. It is a significant fact, indicating regular succession, that some of the saurians of Morrison time apparently continued into the next epoch. The coarse deposits of the lower part of the Cloverly were derived from sources not fully located and were spread by strong currents over an extensive area. In the earlier stages there were some coaly deposits, but apparently no such coal beds as are found in the Black Hills region. The coarser beds are usually less than 50 feet thick and give place to massive clays and sandy clays, mostly of light color, not unlike the Morrison beds, which at most places have a thickness of less than 100 feet and are supposed to represent the Fuson formation of the Black Hills. The Dakota sandstone usually is not recognizable, but as there is no unconformity at the top of the Cloverly formation the sediments of Dakota time are no doubt represented by deposits which are not characteristic. At the beginning of the Benton there was everywhere in the region a rapid change of sediments to dark-colored fissile shales. These are the products of a later Cretaceous submergence in which marine conditions prevailed and which continued until several thousand feet of clays were deposited, during the Benton, the Niobrara, and the Pierre epochs. In Benton time there were occasional thin deposits of sand, especially at first and at the end, and in the middle some fine-grained sandy beds were laid down, now known as the Mowry member. The calcareous sediments of the Greenhorn limestone in the middle of the Benton are not represented in the Bighorn region, and the Niobrara sediments were clays lacking the chalky ingredient which characterizes them in other regions. The period of Pierre deposition was long, for over 3000 feet of dark clays, deposited slowly under very uniform conditions, accumulated in most parts of the region. The retreat of the sea during later Cretaceous time resulted in extensive bodies of brackish water, which spread sand over the clay beds; and then in fresh waters, which deposited sands, clays, and marsh materials of the Piney and later (Laramie) formations. In this region there was an uplift of moderate prominence in the early part of this time, in part, at least, forming a fault along a portion of the east slope of the Bighorn Mountains. It was of sufficient magnitude, however, to afford erosion products from beds down to the Deadwood formation, some of the materials of which appear in a long lens of Kingsbury conglomerate extending from a point southwest of Sheridan for 40 miles southward to Crazy Woman Creek. Deposition of finer grained materials progressed during and following this uplift, and several thousand feet of shales and sands of the De Smet formation accumulated, including scattered beds of carbonaceous materials which are now lignite coal, in some places 20 feet or more in thickness. It is believed that this epoch extended to and perhaps into early Eocene time.

Early Tertiary mountain growth.—There was extensive uplift in the Rocky Mountain province in early Tertiary time. This fact is clearly indicated in most of the mountain regions, where Oligocene deposits lie on an eroded surface having the general configuration of the present topography—a relation which indicates that the uplifts were truncated and the larger outlines of their topography established in earlier Eocene time. Where the great mass of eroded material was carried is not known, but some of it was swept to the west and southwest of the Bighorn Mountains, where it constitutes the Bridger and Wasatch beds. Some idea of the extent of the erosion in the Bighorn uplift is given in fig. 6, which represents approximately the profile of the Pierre and underlying formations continued over the uplift. Probably some of the formations overlying the Pierre extended over the dome.

Later Tertiary fresh-water deposits.—Oligocene and overlying deposits were laid down by streams and local lakes and finally covered much of the Northwest to a level now far up the flanks of the various mountain ranges. Erosion has removed them from most of the higher regions where they formerly existed, especially along the steeper slopes. Various deposits of supposed Tertiary age remain on the lower slopes of the granite area of the Bighorn Mountains at altitudes of 8000 to 9000 feet and along the higher slopes of the limestone front ridge at altitudes of 6000 to 7000 feet.

Quaternary conditions. — During Quaternary time the Bighorn region has been subjected to extensive and prolonged erosion. Extensive ice sheets existed in the higher portion of the range at an early period in the Quaternary, but most of the fragmental products to which they gave rise were removed by subsequent erosion. Some of these deposits and other materials gathered by the streams were spread in extensive alluvial fans at the foot of the mountains and their remains now cap some of the divides. Smaller glaciers continued in some of the higher mountain slopes and accumulated moraines of moderate extent. Remnants of some of these glaciers still exist, lying in cirques cut deeply into some of the higher mountain slopes.

The streams flowing out of the mountains have cut wide valleys in later Quaternary time, and in the lower portions of these have deposited alluvium in low flats which merge into the present freshet plains.

ECONOMIC GEOLOGY.

SOILS.

Derivation.—The soils in this region are closely related to the underlying rocks, of which they are residual products of decay and disintegration, except those formed as alluvial deposits in the larger valleys or those spread by winds. In the process of disintegration residual soil develops on the several rocks of the region more or less rapidly according to the character of the cement holding the particles together. Siliceous cement dissolves most slowly, and rocks in which it is present, such as quartzite and sandstones, are extremely durable and produce but a scanty soil. Calcareous cement, on the other hand, is more readily dissolved by water containing carbonic acid, and on its removal clay and sand remain to form, often, a deep soil. If the calcareous cement is present in small proportion only it is often leached out far below the surface, the rock retaining its form, but becoming soft and porous, as in the case of part of the Tensleep sandstone. If, as on the limestone plateaus, the calcareous material forms a greater part of the rock, the insoluble portions collect on the surface as a mantle that varies in thickness with the character of the limestone, being thin where the latter is pure, but often very thick where the rock contains much insoluble matter. The amount of soil remaining on the rocks depends on erosion, for on slopes the erosion is often sufficient to remove the soil as rapidly as it forms, leaving bare rock surfaces. Crystalline schists and granitic rocks decompose mostly by hydration of a portion of their contained feldspar, and the result is usually a mixture of clay, quartz grains, mica, and other materials. Shales are disintegrated in consequence of changes of temperature, by frost, and by water, thus by softening and washing giving rise to soils. If they are sandy, sandy soils result, and if they are composed of relatively pure clay a very clayey soil is the product. The character of the soil thus derived from the various geologic formations being known, their distribution may be approximately determined from the map showing the areal geology, which thus serves also as a soil map. It must be borne in mind that some of the geologic formations present alternations of beds of various materials—shales and sandstones, for instance, alternating with limestone. These give abrupt transitions in the character of their disintegration products, soils which differ widely in composition and agricultural capabilities occurring side by side. The only areas in which the boundaries between different varieties of soil do not coincide with the boundaries of the rock formations are in the river bottoms, in the sand dunes, in the areas of high-level gravels, in the smaller valleys, and upon steep slopes, where soils derived from rocks higher up the slope have washt down and mingled with or covered the soils derived from the rocks below. Soils of this class are known as overplaced, and a special map of large scale would be required to show their distribution.

Distribution.—The principal arable soils of the Bighorn region are the alluvial deposits along the larger valleys on either side of the mountains. The distribution of these deposits is shown on the areal geology sheet. The widest areas occupy the valleys of Clear and Crazy Woman creeks and their larger branches. Sand Creek, southwest of Buffalo, has a wide valley floor of alluvium, and there are areas of considerable extent along North Fork of Shell Creek, in the upper portion of Boxelder Creek Valley, and south of Lake De Smet. The alluvial deposits above Buffalo on Clear Creek consist mostly of bowlders and coarse sand, but below that town there are many cultivated areas; the principal crop is hay. There are large fields under cultivation at the T A ranch and at other localities along the valley of Crazy Woman Creek. There is a wide area of bottom land along Tensleep Creek above Tensleep post-office, the soils consisting of very fertile sandy loams. This material was derived from the mountains and consists of minute grains of various rocks, deposited by the flood waters of the creek. Some portions are predominantly sandy, and along the stream there are often accumulations of bowlders. Excellent crops, mainly of hay, are raised by irrigation in this valley. Along No Wood Creek above the mouth of Tensleep there are narrow alluvial areas, which are utilized to some extent for agriculture, but in the region farther north most of the alluvial areas are narrow and consist largely of local wash from the "Red Beds." The wide alluvial flat on Canyon Creek below Rome is underlain by a loam soil which yields extensive crops of hay.

The crops depend principally on irrigation, which is effected by numerous long ditches that carry water from the creeks to ranches in many of the valleys. The high terrace deposits have fertile soils, but are usually coarse grained and difficult to keep moist, and many of them lie above the ditch lines, so that they can not be irrigated with the present system. The soils of the Piney and De Smet formations appear to be fertile, except in local areas where there is too much sand or cinders, but they are little cultivated. Much of the area is covered with grass, which affords excellent pasturage in most localities. The shales and sandstones that outcrop along the foot of the mountains usually carry little soil, but in some places sustain a moderate growth of grass.

The wide area of "Red Beds" in the southwestern part of the Cloud Peak quadrangle has but little soil and that is usually barren. In places it is covered by a moderate growth of grass, affording scanty pasturage. The conditions are somewhat similar in the overlying Jurassic and Cretaceous beds farther southwest. On the limestone front ridge rocky ledges prevail, and altho limestones give rise to rich soil, these are not so situated as to be available for cultivation. In the granite area of the mountains farther west much of the surface consists of rocky ledges, and altho there are numerous open parks favorable for tilling, they stand at an altitude too high for agriculture. The parks and many of the slopes are covered with grass and various plants that afford rich pasturage for sheep and cattle during the brief summer season.

WATER SUPPLY.

Surface waters.—Many large streams head in the high divide of the Bighorn Mountains and flow across the Cloud Peak and Fort McKinney quadrangles. In the more elevated portions of the region there is a large amount of running water, not only in the larger creeks but in the many small branches. In the higher ridges much snow remains thru the summer and by its gradual melting furnishes a considerable portion of the running water. The numerous meadows and wooded slopes and the broken rocks above the timber line greatly diminish the rapidity of run-off and aid in sustaining a steady flow. On account of the rapid melting of snow at the beginning of summer, the largest flow of nearly all the streams occurs in June, and their volume at this time is usually ten to twenty times greater than during the middle and later summer months. On the limestone and sandstone ridges in the eastern and southwestern portions of the area there is but little running water, except in early summer and immediately after heavy showers.

The principal streams on the east slope are branches of Clear, Piney, Powder, and Crazy Woman creeks—large streams of flowing water which also cross the plains farther east. Clear Creek is much the larger of these, for it receives the drainage from the east side of Cloud Peak and adjoining ridges, where large bodies of snow and ice continue to melt during all the summer. The average monthly discharge of this creek at Buffalo is about 100 second-feet, but in autumn it usually diminishes to about half this amount, while in May and June it often rises to from 250 to 350 second-feet. From the north it receives a number of branches that rise in the mountains. The first of these, French Creek, is normally a stream of very small flow, but its supply has been greatly increased by a diversion ditch from North Fork of Clear Creek. Rock Creek is the principal affluent of Clear Creek from the north. It rises on the lower slopes of the granite area and receives water from two main forks and from Sayles and Johnson creeks. Its total average flow is estimated to be about 25 second-feet. The various forks of Crazy Woman Creek lie on the lower granite slopes and carry a moderate volume of water, which is so extensively diverted for irrigation on the plains that the volume of water in the main stream farther east is very small, and in dry weather the flow ceases entirely.

The two forks of South Piney Creek drain the east side of Cloud Peak and adjoining ridges and have, together, about the same volume as Paintrock and Tensleep creeks.

North Fork of Powder River rises in the southeastern part of the Cloud Peak quadrangle and gathers a moderate flow from the granite slopes at the south end of the main high range. Its volume near the road is estimated to be about 15 second-feet in midsummer.

The principal streams on the western slope are Tensleep, Paintrock, Canyon, Medicinelodge, Brokenback, Lee, Buckskin Ed, Shell, and Trapper creeks. The heads of branches of Big Goose, Little Goose, and North Piney creeks are near the northern margin of the Cloud Peak quadrangle. No Wood Creek, a branch of Bighorn River, flows across the southwest corner of the quadrangle.

Tensleep Creek drains the southwestern slopes of the high central granite ridge south of Cloud Peak. It has several branches, the largest of which is Canyon Creek, and it empties into No Wood Creek at Tensleep post-office. Its average summer flow is probably about 75 second-feet near its mouth.

Paintrock Creek and its various forks drain the west side of the high district about Cloud Peak and is a stream of about the same size as Tensleep Creek. Medicinelodge Creek, which has two forks, is its principal affluent, joining the main creek a short distance below Hyattville, several miles west of the Cloud Peak quadrangle.

The waters from the mountains are of very fine quality for all uses, but on the plains surface waters soon become contaminated with minerals from the large bodies of shale, often to such an extent as to be unsatisfactory.

Underground waters.—The problem of underground water supply is of no importance in the central area of the Bighorn Mountains, and there is an abundance of surface waters for most needs in the adjoining plains to the west. It is probable that in the red valley, in the southwestern portion of the Cloud Peak quadrangle, artesian waters might be obtained by drilling into the Tensleep sandstone, especially along Tensleep, No Wood, and some of the other valleys. The relations of these strata may be seen in sections C–C and D–D of the structure-section sheet.

Under the plains region, on the east side of the mountains, there are numerous sandstone members which carry underground waters. Some of these are deeply buried; others lie near the surface. Owing to the steep dips and the faults along the front ridge the lower water-bearing beds sink rapidly to depths that are too great to be reached by ordinary well boring. This is particularly the case with the Deadwood, Tensleep, and Cloverly sandstones, which appear to receive and carry underground a considerable amount of surface water. The Parkman sandstone doubtless is a water bearer, altho its texture is so fine that the volume of water in it can not be very large. The conditions under which this formation extends underground are shown in the cross sections on the structure-section sheet. It will be seen that, owing to the steep dips, the formation passes rapidly to a great depth beneath the surface and at no great distance east of its outcrop zone lies at depths of more than 2000 feet.

In the many sandstones in the Piney and De Smet formations there are probably water supplies that might be utilized in wells of moderate depth, but as most of these deposits lie at low levels it is not likely that flowing wells could be obtained from them, except possibly along some of the valleys. Owing to the irregular stratigraphy of these two formations it is not practicable to predict that any special beds of sandstone will be likely to yield water supplies, and the only light to be obtained on this subject must be gained by experimental borings. It is probable that the Kingsbury conglomerate extends eastward under a portion of the plains region and that it contains a large volume of water. Probably it becomes finer grained to the east and northeast, but doubtless for many miles it is coarser than the adjoining sandstones. Shallow wells usually obtain water without difficulty in the plains region, mostly from the De Smet sandstone or from the alluvium along the bottoms of the valleys. These waters vary greatly in quality and some of them contain a considerable proportion of mineral matter.

MINERAL RESOURCES.

General statement.—The principal mineral resource of the Bighorn region is lignitic coal, which underlies much of the adjoining basins. Gypsum occurs in the Chugwater formation; small amounts of copper and gold have been found in the granite area of the mountains; and vast quantities of limestone are obtainable from the Bighorn, Madison, and Amsden formations. Building stones are abundant in most areas, and clays suitable for brick making are available at many places.

Many of the dike rocks contain small amounts of magnetite and titanic iron, but they are intimately intermixed with the other constituents and are consequently of no use. Much of the higher mountain region has not been prospected systematically, especially along the central ridge, where the great dikes of diabase and other rocks may possibly have mineral deposits associated with them—not only gold but platinum and the rare earths which now have considerable economic importance.

Coal.—The coal deposits of the De Smet formation in the Fort McKinney quadrangle are of considerable economic importance and are mined extensively for local use. There are four principal beds, which outcrop in a zone of moderate width, developed principally in the vicinity of Buffalo. The beds vary from 5 to 12 feet in thickness in greater part and lie in a series of rocks, about 200 feet thick, which dips very gently to the northeast. The coals are lignites of high fuel value but poor keeping qualities, as they slack on exposure to the weather. The principal mines are within 3 miles of Buffalo. Monker & Mather's mine is about 1 mile east of the town and is the principal producer. Its annual output averages about 2000 tons, which sell at about $1.50 a ton at the mine. The workings are underground and the section is shown in fig. 1 (p. 8). The lower 7-foot bed is probably the lowest important bed in this region. The upper 7-foot bed of this mine appears to be at the surface at the Bodan mine, 1 mile farther north, near the mouth of Rock Creek, where it locally thickens to 12 feet. Here it is mined to a moderate extent in winter. A mile farther east is the abandoned Foot mine, where the coal is 8 feet thick, but the deposit here is on fire. The coal of this bed or an adjoining one shows at intervals northward to the south end of Lake De Smet, where its thickness is about 5 feet and where it was formerly worked.

At the Mitchell mine, 2½ miles east of Buffalo, a coal bed 6 to 8 feet thick is worked. It lies a short distance below the lower clinker bed. Two miles southwest of Long's ranch a coal bed 6 feet thick is mined to a moderate extent for local use. Its quality is said to be not very good.

Gold.—Considerable prospecting for gold has been done in the granite area, but apparently without satisfactory results. The quartz veins and diabase contacts show small amounts of gold at several localities. Portions of the basal sandstone of the Deadwood formation contain gold, and a 3-stamp mill was built several years ago on the head of Kelley Creek, which obtained a small product, but apparently without sufficient profit to give encouragement to further operations. Faint traces of gold are in some places obtainable in the gravels in the canyons leading out of granite areas, but it is not known that any notable amount of the metal has been found.

Copper.—Copper minerals, mainly malachite and red oxide, appear occasionally in the granite, and considerable prospecting for these has been done in the vicinity of Bull Camp. Small amounts of moderately high grade ores are obtained, mainly from quartz veins along the contacts of the diabase dikes. The principal prospects lie east and southwest of Bull Camp, one of the most extensive being near Beaver Creek, 3 miles east-southeast of that place. Here a shaft has been sunk, but only a small amount of copper ore was obtained. Apparently the mineral is in minute veins widely scattered thru the rock, for no bodies of economic importance have been developed.

Gypsum.—For the greater part the Chugwater formation contains gypsum deposits that are pure and sufficiently thick for the manufacture of stucco or plaster of Paris. This material is prepared by heating the gypsum to drive off most of the chemically combined water and grinding the product to

a fine powder. The value of this material is not sufficiently great to cover freight for distant shipment, so that the mineral will not be of value until the country is more thickly settled and there is local demand.

Limestone.—The limestones of the Bighorn, Madison, and Amsden formations are in greater part sufficiently pure for burning into lime or for use as flux in smelting operations, but at present there is very little demand for this product.

Building stone.—Many of the rocks in the mountainous portion of the area are available for use as building stone. Some of the granites are massive, have a fine appearance when polished, are relatively free from minerals that cause stains on weathering, and may at some time be valuable for shipment as building stone. Some of the limestones in the Madison formation are of very satisfactory texture and appearance and possibly some of them could be worked for marble, especially the upper member. The Tensleep sandstone is usually massive, even textured, and of white or light-buff color, so that, if nearer to markets, it might be advantageously worked as a freestone.

The red sandstones of the Chugwater formation are of very pleasing color but they are mostly too soft to be of value for building. Large supplies of rough stones for foundations and similar uses are obtainable from the Piney, De Smet, Parkman, Cloverly, and Tensleep sandstones and the hard ledges in the Sundance formation.

Phosphate.—The spherical concretions occurring in the lower portion of the Colorado formation consist mainly of phosphate of lime and as they could be obtained in large numbers by means of suitable excavating machinery, they may at some time be utilized as a source of phosphate.

Asphalt.—A deposit of asphalt occurs in the Tensleep sandstone on the west slope of the Bighorn Mountains, in secs. 28, 29, 32, and 33, T. 52, R. 89. The thickness is stated to be 6 feet, but the area has not been ascertained. The material consists of asphalt intimately mixt with coarse sand. Analyses made by A. W. Dow in Washington gave from 10 to 14 per cent of bitumen, the rest sand, most of which would pass thru 60- to 100-mesh sieves.

TIMBER.

The mountainous area in the Cloud Peak and Fort McKinney quadrangles is partly forested, and altho there have been numerous fires, considerable timber remains. The greater part of the highlands is included in the Bighorn Forest Reserve, the limits of which are shown on the maps in this folio. A detailed description of the forests, with maps, is given in the Nineteenth Annual Report of the United States Geological Survey, part 5, pages 165 et seq. Nearly all the trees on the reserve are pine, mainly of one species, *Pinus murrayana*, which is called "white pine," "yellow pine," "jack pine," and "lodgepole pine," the different names being applied in part on account of differences in development. The wood is coarse grained and knotty; few of the trees yield large logs, and as the lumber warps and cracks considerably it is not regarded as valuable. Trees of another species of pine, *Pinus flexilis*, grow among the others. The Engelmann spruce grows in some moist areas along the mountain slopes and in the higher portions of some of the canyons. The pine forests stand at altitudes ranging from 6000 to nearly 10,000 feet. The forest areas in the Fort McKinney quadrangle are mostly of moderate size and widely scattered, and parts of the older forests have been greatly damaged by fire. Nearly all the divides along the western border of the quadrangle bear young forests of small trees growing closely together. The largest forest areas are on and near the front range, especially adjoining Rock Creek, North and Middle forks of Crazy Woman Creek, and Beaver Creek. There are several areas of moderate size on the divides at the head of Sour Dough Creek and between the two forks of Crazy Woman Creek.

The principal areas of forest in the Cloud Peak quadrangle are in the valleys of South Piney and West Tensleep creeks, and extend from North Fork of Clear Creek in an almost continuous body to Doyle Creek. Other areas occur in the upper valleys of North Brokenback, Canyon, South Fork of Paintrock, East Fork of Big Goose, and North Fork of Medicinelodge creeks, and at intervals along the limestone front ridge all the way across the quadrangle. The high central area extending from the head of Canyon Creek to the northern margin of the quadrangle is above timber line, as are also Hazelton Peak and surrounding ridges. Extensive forest fires have burned the greater part of the timber along North Fork of Clear Creek, South Fork of Rock Creek, and North Fork of South Piney Creek, as well as in portions of the valleys of South Fork of Paintrock, Tensleep, and Lee creeks. Much of the timber in the forested area can not be classed as merchantable. According to F. E. Towne, the best areas of timber available for sawing and tie making are, on Trapper Creek, about 640 acres; Black Butte, 200 acres; head of Paintrock Creek, about 480 acres; head of Brokenback Creek, 960 acres, and near Tensleep and Paintrock lakes, about 6000 acres.

June, 1905.