

DESCRIPTION OF THE NEWCASTLE QUADRANGLE.

By N. H. Darton.

GEOGRAPHY.

Position and extent.—The Newcastle quadrangle embraces the quarter of a square degree which lies between parallels 43° 30' and 44° north latitude and meridians 104° and 104° 30' west longitude. It measures approximately 34½ miles from north to south and 25½ miles from east to west, and its area is 863½ square miles. It lies mainly in the eastern portion of Weston County, Wyo., but includes also a narrow area of western Custer and Pennington counties, S. Dak. The northeastern portion of the quadrangle lies on the slopes of the Black Hills, but the larger part of it belongs to the Great Plains, although these plains are lower here than in the greater part of adjoining portions of Nebraska and Wyoming. The district is drained by branches of the South Branch of Cheyenne River.

Being part of the Black Hills and the Great Plains, this quadrangle exhibits many features of both, but as its area is small, a general account of these provinces will be given before the detailed description of the quadrangle is presented.

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 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 bad lands. 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 sloping 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 depressed successively. The general smoothness of the region to-day was surpassed by the almost complete planation 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 freshet 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 plains rise to an altitude of 6200 feet at the foot of the Rocky Mountains, and maintain this elevation 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 through 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 a thousand feet into the drainage basin of Cheyenne River, one of the most important branches 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. It is in this lower portion of the plains that the Newcastle quadrangle is situated.

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, Moreau, Cheyenne, Bad, and White rivers. On the summit of Pine Ridge not far south of the escarpment is Niobrara River, which rises in the midst of 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, the Rio Grande, and Arkansas River, which crosses the plains to the southeast and affords an outlet for the drainage from a large watershed of mountain 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 is Republican River, rising near the one hundred and fifth meridian, and an extended system of local drainage in eastern Kansas and Nebraska.

THE BLACK HILLS.

General features.—In western South Dakota and eastern Wyoming a small group of mountains known as the Black Hills rises several thousand feet above the plains. Having abundant rainfall, it constitutes, through its vegetation and streams, an oasis in the semiarid region. The hills are carved from a dome-shaped uplift of the earth's crust, and consist largely of rocks which are older than those forming the surface of the Great Plains and which contain valuable minerals. The length of the more elevated area is about 100 miles, and its greatest width is 50 miles. The hills rise abruptly from the plains, although the flanking ridges are of moderate elevation. The salient features are an encircling hogback ridge, constituting the outer rim of the hills; next, a continuous depression, the Red Valley, which extends completely around the uplift; then a limestone plateau with infacing escarpment; and finally, a central area of high ridges culminating in the precipitous crags of Harney Peak at an altitude of 7216 feet. Two branches of Cheyenne River nearly surround the hills and receive many tributaries from them.

The central area.—The central area of the Black Hills comprises an elevated basin, eroded in crystalline schists and granite, in which scattered rocky ridges and groups of mountains are separated by park-like valleys. The wider valleys are above the heads of canyons of greater or less size, which become deeper and steeper sided as they extend outward to the northeast, east, and south.

The limestone plateau.—The limestone plateau forms an interior highland belt around the central hills, rising considerably above the greater part of the area of crystalline rocks. Its western portion is much more extensive than its eastern and is broad and flat, sloping gently downward near its outer margin, but being level near its eastern inner side, which presents a line of cliffs many miles long and often rising 800 feet above the central valleys. It attains altitudes of slightly more than 7000 feet locally, almost equalling Harney Peak in height, and forms the main divide of the Black Hills. The streams which flow down its western slope are affluents of Beaver Creek to the

southwest and of the Belle Fourche to the northwest. Rising in shallow, park-like valleys on the plateau, they sink into deep canyons with precipitous walls of limestone often many hundred feet high. The limestone plateau extending south swings around to the eastern side of the hills, where, owing to the steeper dip of the strata, it narrows to a ridge having a steep western face. This ridge is interrupted by the water gaps of all the larger streams in the southeastern and eastern portion of the hills, which rise in the high limestone plateau, cross the region of crystalline rocks, and flow through canyons in the flanking rocks of the eastern side to Cheyenne River. All around the Black Hills the limestone plateau slopes outward, but near its base there is a low ridge of Minnekahta limestone with a steep infacing escarpment from 40 to 50 feet high, surmounted by a bare, rocky incline which descends several hundred feet into the Red Valley. The minor escarpment and slope is at intervals sharply notched by canyons, which on each stream form a characteristic narrows or "gate."

The Red Valley.—The Red Valley is a wide depression that extends continuously around the hills, with long, high limestone slopes on the inner side and the steep hogback ridge on the outer side. It is often 2 miles wide, though it is much narrower where the strata dip steeply, and is one of the most conspicuous features of the region, owing in no small degree to the red color of its soil and the absence of trees, the main forests of the Black Hills ending at the margin of the limestone slopes. The larger streams flowing out of the hills generally cross it without material deflection, and their valleys are separated by divides which are usually so low as to give the Red Valley the appearance of being continuous. In its middle eastern section, however, it is extensively choked with Oligocene deposits.

The hogback rim.—The hogback range constituting the outer rim of the hills is usually a single-crested ridge of hard sandstone, varying in prominence and in steepness of slope. At the north and south locally along the middle western section it spreads out into long, sloping plateaus. It nearly always presents a steep face toward the Red Valley, above which the crest line rises several hundred feet, but on the outer side it slopes more or less steeply down to the plains that extend far off from the Black Hills in every direction. The hogback rim is crossed by numerous valleys or canyons, which divide it into level-topped ridges of various lengths. At the southern point of the hills Cheyenne River has cut a tortuous valley through the ridge for several miles, and the Belle Fourche does the same toward the northern end of the uplift.

TOPOGRAPHIC FEATURES OF THE QUADRANGLE.

The Newcastle quadrangle presents a considerable variety of topographic forms, comprising the western margin of a portion of the limestone plateau of the Black Hills, a zone of the Red Valley 20 miles long, and an extensive development of the hogback rim of the hills, which, north of Newcastle, spreads out into a plateau of considerable area. More than two-thirds of the quadrangle lies in the plains, a region of low ridges and wide valleys, here traversed by a low but distinct sandstone escarpment west of Beaver Creek, beyond which the plains extend for many miles at a gradually increasing height.

Drainage.—The drainage is to the south and southeast into Beaver Creek, which empties into Cheyenne River a short distance beyond the southeast corner of the quadrangle. The principal tributaries of Beaver Creek that come out of the Black Hills uplift do not flow down the direction of greatest slope, which is to the west; their valleys trend almost due south. Stockade Beaver Creek, the largest of these streams, rises in the plateau area of the Black Hills, flows out into the Red

Valley, which it traverses for several miles, and then passes out through a gate in the hogback range and continues its southward course to Beaver Creek along the base of the foothills. Its two principal branches are Whoopup Creek, heading in canyons in the limestone plateau, and Salt Creek, flowing through a deep canyon in the plateau to which the hogback range gives place north of Newcastle. Oil Creek and Little Oil Creek rise on the plateau north and northwest of Newcastle, and flow through canyons of considerable depth, out of which they pass westward into the plains, to join the main Beaver Creek near the center of the quadrangle. Main Beaver Creek flows across the quadrangle from northwest to southeast in a wide, shallow valley of low declivity cut in the shales of the plains. From the west it receives numerous small branches that rise on the higher levels of the plains. It is the outlet of a drainage basin comprising over a thousand square miles, but except in times of freshet it is a very insignificant watercourse.

Relief.—The surface features of this quadrangle are very closely related to rock texture, the thicker masses of hard rocks giving rise to ridges, the softer beds being excavated into valleys. Valleys cut in large areas of soft rock are wide; those which have been excavated through hard rock are narrow. The limestone plateau of the higher portion of the Black Hills extends a short distance into the northwest corner of the Newcastle quadrangle, presenting a tabular surface with altitudes ranging from 6000 to 6750 feet, deeply trenched by canyons having walls 500 to 600 feet high, and containing branches of Stockade Beaver and Whoopup drainage. These canyons open to the west and south and deepen rapidly from their heads. Northwest of the LAK ranch the limestone plateau terminates in a steep slope that is due to the steep westward dip of the rocks—a slope that presents high, rugged cliffs, some of which, in their brilliant coloring, are highly picturesque. A view of this portion of the range is shown in fig. 8 on the illustration sheet. The Red Valley crosses the northeast corner of the quadrangle, with a width varying from 3 miles in the portion east of Cambria to a quarter of a mile north of the LAK ranch, its narrowness here being due to the increased dip of the rocks. Southeast of the LAK ranch it averages less than a mile in width, but south of Elk Mountain it widens rapidly. It is occupied by Stockade Beaver Creek to the north, and extends through a low divide just east of the LAK ranch and thence southward along the eastern side of the Elk Mountain range. South of Newcastle the hogback range presents its typical features—a steep east-facing escarpment and gentler western slope—and varies in width from 1 mile to 3 miles. It attains its greatest prominence at Elk Mountain, which is somewhat over 5700 feet high. In its broader portion south of Elk Mountain its western slope is deeply trenched by numerous canyons. North of Newcastle the hogback range is spread out into a wide plateau sloping to the southwest. This plateau is deeply trenched by canyons of the branches of Oil Creek, and to the east, in its higher portions, considerable areas of it have been cut away by Salt Creek and its branches, leaving outlying portions of the plateau on the summits of an irregular series of ridges. Mount Pisgah is the most prominent of these, attaining an altitude of over 6350 feet. The canyons north of Newcastle average about 400 feet deep. The plateau is cut into long, irregular ridges by these canyons, the broadest area being in the vicinity of the Mount Zion ranch, southwest of Cambria. The altitudes here are from 4900 to 5200 feet. Along Oil Creek and two of the branches of Plum Creek the plateau remnants are the detached summits of several narrow ridges. On the west side of Oil Creek there is a continuous crest line of plateau, which slopes westward and ends in the valley of Skull

Creek. In the vicinity of Newcastle and for some distance east and west there is a subordinate hogback ridge separated from the main range by a narrow valley and a series of low divides. From the foot of these ranges a great region of rolling plains stretches far to the west, with altitudes ranging from 3750 to 4200 feet in greater part. It presents some low but sharply marked ridges, due to harder beds of rock lying near the base of the shale series. One of the most conspicuous of these ridges has a low escarpment extending from the northwest corner of the quadrangle to the LAK ranch. It is separated from the main hogback range by a valley which is 5 miles wide near Osage. East of Pedro, where the continuity of the ridge is somewhat broken, this valley narrows greatly, but it widens again to from 1 to 3 miles near Newcastle. The escarpment presents to the northeast a face from 10 to 50 feet high surmounting long, gentle slopes. To the southwest it merges into a zone of low, rocky ridges which finally slope into the plains south. West of the main Beaver Valley the plains are traversed from the northwest to the southeast by a low but distinct escarpment, from 50 to 150 feet high, which is surmounted by a region of rolling plains with many low cliffs and numerous detached buttes. Alkali Butte is one of the most prominent features of this region, attaining an altitude of 4500 feet; and although this is only about 200 feet above the adjoining rolling plains, the butte is so situated that it is a conspicuous landmark from the east.

GEOLOGY.

GEOLOGIC HISTORY.

The general sedimentary record.—The rocks appearing at the surface within the limits of the Newcastle quadrangle are of sedimentary origin—that is, they were deposited by water. They consist of sandstone, shale, limestone, sand, 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 early Carboniferous time to the present, and other sediments which underlie them extend the record back to the middle Cambrian. The composition, appearance, and relations of 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 are deposited in shallow water; pure limestones generally indicate open seas and scarcity of land-derived sediment. The fossils that strata contain may belong to species known to inhabit waters which are fresh, brackish, or salt, warm or cold, muddy or clear. The character of the adjacent land may be shown by the character of the sediments derived from its waste. The quartz sand and pebbles of coarse sandstones and conglomerates, such as are found in the Lakota formation, had their original source in the crystalline rocks, but 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 sediments and substances in solution. The older formations exposed by the Black Hills uplift were laid down from seas which 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 probably large islands of an archipelago, which was 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 Black Hills 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 expansion of an interior sea over the western central region. The submergence reached the Rocky Mountain province during the early Cambrian, and for a time the central portion of the Black Hills remained as one of the islands rising above the waters. From the ancient crystalline rocks, streams and waves gathered and concentrated sands and pebbles, which were deposited as a widespread sheet of sandstone and conglomerate on sea beaches, partly in shallow waters off shore, and partly in estuaries. Abutting against the irregular surface of the crystalline rocks which formed the shore are numerous exposures of these sediments containing much local material. Subsequently, the altitude being reduced by erosion and the area possibly being lessened by submergence, the islands yielded the finer grained muds now represented by the shales which occur in the upper portion of the Cambrian in some areas. In many regions the land surface of crystalline rocks was buried beneath the sediments.

Ordovician-Devonian conditions.—From the close of Cambrian to the beginning of Carboniferous time the Black Hills area presents a scanty geologic record, the Silurian and Devonian being absent and only a portion of the Ordovician being present at the north. This is probably because there was an extensive but very shallow sea, or 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 Black Hills area, but generally throughout the Rocky Mountain province.

Carboniferous sea.—Under the marine conditions that prevailed during early Carboniferous time there were laid down calcareous sediments which are now represented by several hundred feet of nearly pure limestone, the greater part of which is known as the Pahasapa limestone. As no coarse deposits occur, it is probable that no crystalline rocks were then exposed above water in this region, although elsewhere the limestone, or its stratigraphic equivalent, was deposited immediately upon them. In the latter part of the Carboniferous the conditions were so changed that fine sand was brought into the region in large amount and deposited in thick but regular beds, apparently with much calcareous precipitate, and with more or less ferruginous material, as is indicated by the color of many beds of the Minnelusa formation. Minnelusa deposition is believed to have been followed by an uplift, which appears to have resulted in ponding saline water in lakes, in which accumulated the bright-red sands and sandy muds of the Opeche formation. The Minnekahta limestone, which is the next in sequence, was deposited from sea water, and from its fossils we know with a fair degree of certainty that it is a product of the latest Carboniferous, or of Permian, time. It was laid down in thin layers and to a thickness now represented by only 40 feet of limestone, yet the very great uniformity of this formation over the entire Black Hills area is an impressive feature, probably indicative of widespread submergence.

Red gypsiferous sediments.—At the close of the epoch represented by the Minnekahta limestone there was a resumption of red-bed deposition and the great mass of red shales constituting the Spearfish formation was accumulated. These beds probably were laid down in vast salt lakes that resulted from extensive uplift and aridity. The mud accumulated in thin layers to a thickness of 500 feet or more, as now represented by the formation, and it is so uniformly of a deep-red tint that this is undoubtedly the original color. The color is present not only throughout the extent of the formation, but also through its entire thickness, as is shown by deep borings, and therefore is not due to later or surface oxidation. Either the original material of the sediments was red or it was colored during deposition by the precipitation of iron oxide. At various times, which were not the same for all parts of the region, accumulation of clay was interrupted by chemical precipitation of comparatively pure gypsum in beds ranging in thickness

from a few inches to 30 feet, and free from mechanical sediment. It is believed that these beds are the products of evaporation during epochs of little or no rainfall and consequently of temporarily suspended erosion; otherwise it is difficult to understand their nearly general purity. The Spearfish red beds have been supposed to represent the Triassic, but there is no direct evidence of this, and in part at least they may be Permian. Their deposition appears to have been followed by extensive uplift without local structural deformation, but with general planation and occasional channeling, which represents a portion of Triassic time of unknown duration, and was succeeded by the deposition of later Jurassic sediments.

Jurassic sea.—In the Black Hills 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. In the southeastern Black Hills region some of the earliest deposits are thin masses of coarse sandstone, indicating shore conditions, but generally there is shale lying directly on the Spearfish red shales, which was deposited in moderately deep water. Upon this shale is ripple-marked sandstone, evidently laid down in shallow water and probably the product of a time when sedimentation was in excess of submergence, if not during an arrest of submergence. The red color of the upper part of the medial sandy series in some portions of the Black Hills appears to show a transient return to arid conditions similar to those under which the Spearfish formation was laid down. An extensive marine fauna and limestone layers in the upper shales of the Sundance formation indicate the deeper water that followed. After this stage marine conditions gave place to fresh-water bodies, probably through widespread uplift. The first product was the thick body of fine sand of the Unkpapa sandstone, now a prominent feature in the eastern portion of the Black Hills, but thinner or absent elsewhere.

Cretaceous seas.—During the Cretaceous period deposits of various kinds, but generally uniform over wide areas, gathered in a great series, beginning with such as are peculiar to shallow waters 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 first deposits now constitute the Morrison formation, a widespread mantle of sandy shales, which is absent to the southeast, although probably originally deposited there to a greater or less thickness and then removed by erosion in consequence of slight but widespread uplift. The extent of this degradation is not known, but it gave rise to a general erosional unconformity at the base of the Lakota sandstone, the next succeeding deposit, which is of coastal and possibly estuarine origin. This formation consists mainly of coarse sands spread by strong currents in beds 30 to 40 feet thick, but includes several thin partings of clay and local accumulations of vegetable material. Next there was deposited a thin calcareous series, represented by the Minnewaste limestone, but apparently it was laid down only in a local basin in the southern portion of the Black Hills. Over this was spread a thin but widely extended sheet of clays of the Fuson formation. After the deposition of these clays there was a return to shallow waters and strong currents, as in Lakota times, and coarse sands of the Dakota formation were accumulated. At the beginning of the Benton there was everywhere in the region a rapid change of sediment from sand to clay.

During the great later Cretaceous submergence marine conditions prevailed, throughout the Benton, Niobrara, and Pierre epochs, and several thousand feet of clay were deposited. In Benton time there were occasional deposits of sand, two of them, in the later part of the epoch, that were general over the greater part of the Black Hills region, and one, earlier, that was local and produced the lenses of sandstone which are now found in the vicinity of Newcastle and elsewhere. Another marked episode was that which resulted in the general deposition of the thin Greenhorn limestone in the middle of the Benton sediments. The shale of the Benton was followed by several hundred feet of impure chalk, now constituting the Niobrara formation, and this in turn by over 1200 feet of Pierre shale, deposited under uniform conditions. The retreat of the Cre-

taceous sea corresponds with the Fox Hills epoch, during which sands were spread in an extensive sheet over the clay beds, and resulted in the development of extensive bodies of brackish or fresh water, which received the sands, clays, and marsh deposits of the Laramie. Whether these two last-named groups of sediments were deposited over the area now occupied by the Black Hills is not definitely known, but it is possible that they were, as they are upturned around two sides of the uplift.

Early Tertiary mountain growth.—The Black Hills dome developed to a moderate height early in Tertiary time—or possibly in latest Cretaceous time—and the larger topographic outlines of the region were established before the Oligocene epoch, the dome being truncated and its larger old valleys excavated in part to their present depths. This is indicated by the occurrence in them of White River (Oligocene) deposits, even in some of their deeper portions. Where the great mass of eroded material was carried is not known, for in the lower lands to the east and southeast there are no early Eocene deposits nearer than those of the Gulf coast and along the Mississippi embayment.

Oligocene fresh-water deposits.—Oligocene deposits were laid down by streams and in local lakes and finally covered the country to a level now far up the flanks of the Black Hills. Erosion has removed them from most of the higher regions where they formerly existed, especially along the western side of the hills, but in the vicinity of Lead small outliers remain at an altitude of over 5200 feet, and on the north end of the Bearlodge Mountains they are seen a thousand feet higher. In many places on the slopes of the uplift there is clear evidence of superimposition of drainage due to a former capping of Oligocene formations.

Later Tertiary mountain growth.—Following the Oligocene epoch the dome was raised several hundred feet higher and more extensively eroded. No representatives of the succeeding Loup Fork group—the Arikaree and Ogalalla formations—have been discovered in the immediate vicinity of the Black Hills, but they are extensively developed in Pine Ridge to the south and remain on some of the high buttes to the north, in the northwest corner of South Dakota. There was probably slow but continuous uplift during the Loup Fork epoch, and materials were contributed by the higher slopes of the Black Hills at that time, but whether the formations ever were deposited in the immediate vicinity of the hills is not ascertained.

Quaternary uplift and erosion.—During the early portion of the Quaternary period there was widespread denudation of the preceding deposits, and many of the old valleys were revived, with much rearrangement of the drainage, which on the eastern side of the Black Hills was caused mainly by increased tilting to the northeast. This rearrangement has caused several streams superimposed upon the Oligocene deposits to cut across old divides, in some cases connecting a valley with its next neighbor to the north. Such streams flow southeastward for some distance in pre-Oligocene valleys and then turn abruptly northward into canyons of post-Oligocene age, leaving elevated saddles to mark the southeasterly course of the old valleys. Some of the offsetting in the present drainage has been largely increased by early Quaternary erosion and recent stream robbing.

There was apparently still further uplift in late Quaternary time, for the present valleys, below the level of the earlier Quaternary high-level deposits, seem to be cut deeper than they would be in simply grading their profiles to the level of the Missouri and Cheyenne rivers. Wide, shallow valleys have developed in the soft deposits, and canyons of moderate extent and depth in the harder rocks. Erosion has progressed in the main without aggradation, but in some cases, with the shifting of channels, there have been accumulations of local deposits on small terraces at various levels.

DESCRIPTION OF THE ROCKS.

The stratified rocks in the Newcastle quadrangle have a thickness of about 6350 feet. The order of succession of the limestones, sandstones, and shales, and their general character, are given in the columnar section sheet.

CARBONIFEROUS SYSTEM.

Pahasapa limestone.—This formation is a limestone of light-gray color, weathering to a somewhat bluish or dove tint. The rock is massively bedded and presents steep walls in the sides of the canyons and slopes of the hills. The greatest thickness exhibited is in the steep monocline east of Stockade Beaver Creek in the southwest corner of Range 1, Township 1, in South Dakota, where about 500 feet are exposed, apparently representing about two-thirds of the formation. These are the lowest rocks exposed in the Newcastle quadrangle, their exposure being due to the removal of the Minnelusa formation in some of the canyons and along the steep western face of the ridge. The area of outcrop is small, being less than 5 square miles in all. The limestone underlies all of the adjoining region for many miles, but under the plains east of Newcastle it lies at a depth of 5000 feet or more. It was reached by the deep well at Cambria at a depth of 1947 feet and was penetrated to 2345 feet. The borings exhibited nearly pure limestone of light color, mostly white or light gray, but including some beds of pale pinkish and buff tints. At the top of the formation are a few feet of red sandy shale containing hard, lens-shaped siliceous concretions, mostly from 8 inches to 2 feet in diameter.

The Pahasapa limestone contains fossils of Mississippian age and is of approximately the same age as the Madison limestone of the Northwest. The principal species are *Spirifer rockymontana* and *Seminula dawsoni*.

Minnelusa sandstone.—This formation consists mainly of sandstones in which much of the cement is calcareous. The upper members comprise a hard white sandstone at the top, averaging about 70 feet in thickness, a red brecciated sandstone in the middle, from 100 to 140 feet thick, and a white sandstone below, which varies in thickness from 35 to 50 feet. The lower members consist of a succession of gray and buff slabby sandstones. These beds are best exposed in the steep-sided uplift east of the upper portion of the Stockade Beaver Valley, where there is an area of about 30 square miles of the Minnelusa formation. The beds rise rapidly from beneath the surface a short distance west of the State line, and then to the east lie nearly level, giving rise to an elevated plateau. The formation is extensively exposed in the canyons that are deeply incised in this uplift, the upper white sandstone being a conspicuous feature in the upper portions of their walls and forming gateways at their mouths. The brecciated sandstone is of a brownish red color and its brilliant-hued cliffs are picturesque features in many of the canyons. The thickness of Minnelusa beds exposed east of Stockade Beaver Creek is about 600

Section of Minnelusa sandstone in boring at Cambria, Wyo.

	Thick- ness in feet.	Depth of base in feet.
Hard, pinkish calcareous sandstone.....	4	1100
Light-buff sandstone, very little lime.....	17	1117
Chocolate sandstone, somewhat calcareous	8	1125
Buff calcareous sandstone.....	10	1135
Dark-brown calcareous sandstone.....	5	1140
Buff calcareous sandstone.....	45	1185
Buff limestone, sandy.....	6	1191
Light-brown limestone, sandy.....	4	1195
Light-buff limestone, some sandy.....	12	1207
Light-tan-colored calcareous sandstone...	15	1222
Hard, brownish-red sandstone, some lime...	3	1225
Light tan-colored calcareous sandstone...	15	1240
Light pinkish buff calcareous sandstone...	60	1300
Pink sandstone, very little lime.....	90±	1390
Pink calcareous sandstone.....	40±	1430
Pale-pink sandstone, little lime.....	40±	1470
Chocolate sandstone, little lime.....	2	1472
Dark-gray sandstone.....	2	1474
Light-gray shale, no lime.....	4	1478
Black shale, 30 per cent carbon.....	3	1481
Light-buff calcareous sandstone.....	9	1490
Brownish-buff sandstone and shale.....	6	1496
Alternations of light-gray and buff sand- stone, but little lime.....	95	1591
Black calcareous shale.....	4	1595
Dark-gray sandstone and shale.....	2	1597
Light-gray and buff calcareous sandstone	43	1640
Dark shale.....	2	1642
Gray and pale buff calcareous sandstones	67	1709
Dark-gray calcareous sandstone.....	4	1713
Nearly white sandstone.....	9	1722
Light-brown sandstone.....	3	1725
Nearly white sandstone, some lime.....	13	1738
Gray sandstone, upper part calcareous...	62	1800
Greenish-gray shale, some lime.....	8	1808
Gray sandstone, but little lime.....	2	1810
Chocolate-brown sandstone, very little lime.....	83	1893
Brown sandstone, with gray limestone layers.....	54	1947

feet. In its outcrops the sandstones of the formation appear to be porous, but in the deep boring at Cambria, which penetrated the formation from 1096 feet to about 1947 feet, much of the material was found to be thoroughly cemented by carbonate of lime. Nearly all of the rocks in the boring were very compact and fine grained. It is apparent, therefore, that the predominance of sand in the surface outcrops is due to the leaching away of a portion of the calcareous cement, for it is not likely that the original character of the beds was greatly different in areas so closely adjacent. The increase of thickness to 850 feet in the area to the west, as shown by the well record, is an interesting and unexpected feature.

The only fossils observed in the Minnelusa formation were some remains of brachiopods found in the upper member near Hot Springs. These appear to be of Pennsylvanian age, but are not sufficiently distinctive to furnish conclusive evidence in this regard.

Opeche formation.—This thin series of red beds lying next above the Minnelusa sandstone averages 75 feet in thickness and consists of moderately soft, brownish red sandstones, usually in beds varying in thickness from 1 to 4 inches, and red sandy shales. It is observed mainly in slopes beneath the escarpment of overlying Minnekahta limestone. In Gillette Canyon a thin local bed of gypsum is included. At the top of the formation, for the first few feet below the Minnekahta limestone, there are shales which invariably have a deep purple color. The formation may be seen in the walls of many small canyons which cut through the Minnekahta limestone in the slopes along the east side of the valley of Stockade Beaver Creek and the Red Valley southeast of the LAK ranch, and also in Redbird and Gillette canyons. The age of this formation has not yet been definitely determined, for so far it has yielded no fossils. From the fact that the overlying Minnekahta limestone is of probably Permian age and that there are red deposits in the upper part of the Permian of Kansas and eastern Nebraska, it is supposed that its age is Permian.

Minnekahta limestone.—This formation, formerly known as the "Purple limestone," is prominent in the Black Hills region, but occupies only a limited area in the northeast corner of this quadrangle. It is thin, averaging slightly less than 40 feet in thickness, but owing to its hardness and flexibility it gives rise to prominent topographic features. Its outcrop is marked by a series of rocky ridges rising with steep slopes out of the Red Valley and extending some distance up the long declivities of the Minnelusa formation. Its surface is usually bare or covered with scattered bushes and its edge is always marked by escarpments that present nearly the entire thickness of the formation. Ordinarily the cliffs appear to consist of massively bedded rock, but on close examination it is seen that the layers are thin and clearly defined by slight differences in color. On weathering it breaks into slabs usually 2 to 3 inches in thickness. The color as a whole is a light gray, but there is always a slight pinkish or purplish tinge, from which the term "Purple limestone" originated. Its composition varies somewhat, mainly in the proportion of carbonate of magnesia, usually present in considerable amount, and of clay, which is a small but constant ingredient. In some of the layers flakes of clay or impure limestone give a mottled appearance to the weathered bedding planes of the rock. The dip of the formation is mainly to the west along the east side of Stockade Beaver Valley, being steep at first and diminishing in amount as the formation extends eastward over the rounded slope of the monocline. In Redbird and Gillette canyons it passes over an undulating anticline that pitches south-southwest. There are frequent local variations in the amount and direction of the dip, as the limestone is a thin, relatively hard bed of homogeneous rock lying between masses of softer beds, and consequently was much affected by local conditions of pressure. The thin layers of the limestone are often minutely crumpled and faulted, but, considering the large amount of deformation to which the formation has been subjected, the flexures are but little broken. In its contacts with adjoining formations the Minnekahta limestone presents an abrupt change in material but no evidence of unconformity. The formation is classed

as Permian because of fossils which it has yielded in the region west of Hot Springs.

TRIASSIC (?) SYSTEM.

Spearfish formation.—The outcrop of this series of gypsiferous red beds extends along the eastern side of the Newcastle quadrangle, giving rise to a valley of varying width, occupied for several miles by Stockade Beaver Creek and thence continuing southward along the eastern side of Elk Mountain. Two small areas of the formation are revealed by erosion in the valley of Salt Creek and one of its branches northeast and east of Cambria. The thickness of the formation averages 500 feet, as nearly as could be determined, and 496 feet of it were found in the deep well at Cambria. Its materials are red sandy shale with intercalated beds of gypsum which sometimes are 30 feet thick, and it outcrops extensively in wide, bare slopes and high buttes of bright-red color, with outcrops of snow-white gypsum in striking contrast. The bedding is generally thin and moderately distinct. Red clay, fine sand, and occasional flakes of mica are the principal constituents. The gypsum occurs in the formation at various horizons, but is most prominent at the top and near the bottom. Some of the larger gypsum beds extend continuously over wide areas. There are also throughout the formation small veins of gypsum due to secondary deposition. In the lower portion of the valley of Stockade Beaver Creek the formation is hidden to some extent under alluvial deposits. In the range of hills culminating in Mount Pisgah the formation extends high up the slopes, outcropping in great cliffs of brilliant hue, which to the north have a height of nearly 200 feet in some places. At the top of the formation in this vicinity there is a continuous bed of gypsum from 10 to 15 feet thick, and in the valley 2 miles southeast of Mount Pisgah there is a series of thick beds of gypsum near the base of the formation. On the eastern slopes of Elk Mountain and southward along the west side of the Red Valley the Spearfish beds rise high in the slopes and their brilliant red color makes them conspicuous features in the landscape. A 3-foot bed of gypsum occurs at the top. In the region of steep dips in the Stockade Beaver Valley, for some distance above the LAK ranch, the outcrop of the Spearfish formation is narrow and is mostly covered by alluvial deposits. A measurement was made a mile and a half north of the LAK ranch, in which there were found 450 feet, or possibly more, of the formation, including two thick beds of gypsum. In this section there is a lower bed of gypsum about 150 feet above the Minnekahta limestone, then about 40 feet of red clays, a 2-foot bed of gypsum, 15 feet of red clays with two thin gypsum beds near the top, a bed of gypsum which locally attains a thickness of 30 feet, and, at the top, about 200 feet of red shale and red sandy shale, which extend to the base of the Sundance formation. The principal bed of gypsum, in the center of the formation, extends northward for several miles. Another gypsum bed appears at the top of the formation and soon attains a thickness of from 10 to 12 feet, the amount gradually increasing northward. This upper bed is overlain by dark shales, here constituting the base of the Sundance formation. Northeast of Cambria there are 25 feet of gypsum at the top of the formation, several thick beds in its center, and a local thin bed of gypsum at its base, lying directly on the Minnekahta limestone. In the boring at Cambria the members of the Spearfish formation were reported as follows:

Section of Spearfish formation at Cambria, Wyo.

	Feet.
Gypsum.....	8
Red clay.....	28
Red and dark clay.....	28
Red clay.....	181
Gypsum.....	7
Red clay.....	58
Gypsum.....	4
Red clay and gypsum.....	78
Gypsum.....	12
Red clay lying on Minnekahta limestone.....	88

No fossils have been discovered in the Spearfish formation, and its precise age is not known. From the fact that it lies between the Permian limestone below and the marine Jurassic above, it has been regarded as Triassic in age, but it may prove to be Permian. It is separated from the Jurassic by an unconformity which may possibly represent all of Triassic time.

JURASSIC SYSTEM.

Sundance formation.—The rocks of the Sundance formation comprise a series of shales and sandstones which vary but little from place to place in order and character. At the top are 150 feet or more of dark greenish-gray shales, usually including thin layers of limestone which are highly fossiliferous. Next below are sandy shales of reddish color, underlain by buff sandstone, including a prominent layer about 25 feet thick. At the base are dark shales, averaging about 60 feet thick. The total thickness averages 350 feet throughout.

The formation lies unconformably on the Spearfish formation and its outcrop occupies a portion of the slope which rises from the Red Valley to the crest of the hogback range. In the vicinity of the LAK ranch and farther south, near and beyond Elk Mountain, the outcrop zone is narrow and the rocks are often partly covered by talus. To the north, where the dips are low, Salt Creek has cut away the overlying Lakota and Morrison formations for some distance, giving rise to a wide outcrop area of Sundance formation, which extends through passes in the divides and connects with the areas lying along the slopes next west of the valley of Stockade Beaver Creek. A small area is also exposed in the deep canyons of Oil and West Plum creeks near the northern margin of the quadrangle.

A typical section of the Sundance formation is as follows:

Section of Sundance formation on west side of valley of Stockade Beaver Creek, Wyo.

	Feet.
Morrison shales at top.....	
Greenish shales with fossiliferous limestone layers.....	150
Red sandy shales.....	60
Thin sandstones and shales.....	25
Light-buff, massive sandstones, some beds ripple marked.....	30
Greenish-gray shales lying on gypsum at top of Spearfish red shales.....	70

In the eastern front of Elk Mountain similar features are presented, but the thickness of the lower members is less. The following section is representative of this region:

Section of Sundance formation near Elk Mountain, Wyo.

	Feet.
Morrison shales at top.....	
Greenish shales with fossiliferous limestone layers.....	150
Light-colored, thin-bedded sandstones and shales.....	25
Pale-red sandy shales.....	35
Gray sandy shales and thin sandstones.....	35
Massive cream-colored sandstone.....	15
Thin sandstones and soft sandy shales.....	10
White sandstones.....	3
Dark-green shale lying on a 3-foot gypsum bed at the top of the Spearfish red shales.....	55

The sandstone in the lower part of the Sundance formation is the most prominent feature in the outcrops, being marked by a distinct bench and precipitous ledge in the general shaly slope (see fig. 9). In the valley of Salt Creek this sandstone gives rise to numerous benches, terraces, and low buttes. In the canyons northwest of Cambria the Sundance formation is not far below the surface, and on Oil and West Plum creeks, which cut somewhat deeper than the other streams in that region, its upper beds are revealed for a few miles, rising from below the Morrison shales on the gentle dip to the southward. Fossils are very abundant both in the thin limestone layers or concretions in the upper green shales and in the buff sandstones in the lower part of the formation. They occur also in the other beds, but in much less number. The most characteristic species is *Belemnites densus*, represented by cigar-shaped bodies varying in size from an inch or less to 4 inches in length, of dark color, and radiated structure when seen in transverse section. This fossil occurs mainly in the upper green shales.

In the boring at Cambria the Sundance formation was entered at a depth of about 150 feet, but the well record was not sufficiently explicit to note the slight change in the character of the shales in passing out of the Morrison formation. The beds named in the next table were reported from 150 feet to 496 feet, where gypsum at the top of the Spearfish formation was found.

The total thickness of these beds is 346 feet. The red series in the middle of the formation is finer grained than in the surface outcrops, but the other features are about the same, including the basal dark shale and its overlying soft buff sand-

stone and the thick mass of gray shales at the top of the formation.

Section of boring at Cambria, Wyo.

	Thick- ness in feet.	Depth of base in feet.
Shales, light gray.....	150	300
Shales, sandy, pinkish.....	10	310
Shales, red.....	39	349
Shale, sandy, light gray.....	30	379
Sandstone and sandy clay, light green- ish gray.....	22	401
Shale, sandy, very pale greenish gray.....	9	410
Sandstone, soft, buff.....	25	435
Shale, dark greenish gray, lying on 8 feet of gypsum.....	61	496

CRETACEOUS SYSTEM.

Morrison shale.—The Sundance shales are overlain by a series of massive shales with layers of fine-grained sandstones which have been called the Beulah shales or clays, but have been ascertained to be equivalent to the Morrison formation. This formation extends along the eastern front of the Rocky Mountains and to the "Como stage" of central Wyoming. The deposits are mostly of light-gray color, but portions are buff, pale green, and maroon. Their thickness averages a little more than 150 feet, being greatest to the north, and they outcrop mainly along the inner side of the hogback range below the cliffs of Lakota sandstone or conglomerate. In the region east of Salt Creek they occur in extensive outliers overlain by protecting caps of Lakota sandstone, and in the sloping plateau north of Newcastle they are revealed in the deep canyons. Outcrops of the formation are often obscured by talus derived from the sandstone cliffs above and by soil and wash that accumulate on the slopes. The contact with the Sundance formation shows an abrupt change in the character of the material. From its relations and fauna in other regions it is believed that the Morrison shale is of fresh-water origin.

At Cambria a drill hole in the floor of the coal mine penetrated 12 feet of sandstone with coaly layers at the base of the Lakota formation and passed through the following beds, probably all belonging to the Morrison formation:

Section of drill hole in floor of coal mine at Cambria, Wyo.

	Feet.
Fire clay, gray.....	3
Sandstone, light gray, moderately hard.....	1½
Fire clay.....	7½
Sandstone, gray, upper half very hard.....	4
Shales, lead colored, soft at base.....	11
Shale and fine sand.....	3
Shale, bluish gray.....	18
Sandstone, moderately hard.....	1
Clay, bluish and purplish, hard below.....	20

The deep drill hole near by began on a level with the base of the 7½ feet of fire clay and passed through about 150 feet of the formation, as nearly as could be ascertained from the well records. The Morrison shale contains bones of saurians, and, in the northern portion of the Black Hills, a few fresh-water shells. By some paleontologists the saurians of this formation are thought to be of later Jurassic age, but others class them as early Cretaceous. From the stratigraphic relations of the Morrison beds in northern Oklahoma and southeastern Colorado they are believed to be of early Cretaceous age.

Lakota formation.—The Lakota formation is one of the most prominent members brought to the surface by the Black Hills uplift. It is mainly a massive sandstone of considerable hardness which, together with the overlying Dakota sandstone, gives rise to the prominent hogback rim of the hills. Its prominence is enhanced by the softness of the underlying shales, above which it rises in high cliffs. Its thickness usually varies from 150 to 200 feet, but locally the amount may be somewhat greater. The sandstones are coarse grained, cross bedded, and massive, with partings of shale or thin-bedded sandstone of no great thickness. The color varies from light gray or even white to buff, the last named being most frequent. At or near the base there is a coal horizon, in which coal of excellent quality attains a thickness of from 5 to 7 feet in an area of moderate extent about Cambria. This coal appears not to occur east and south of the gap in which the ranges crossed by Stockade Beaver Creek. In the Elk Mountain region and farther south the formation lies in a gently westward-dipping monocline that gives rise to a long, deeply canyoned mountain slope terminating in a line of high cliffs fronting east. The rocks comprise a thick bed of moderately coarse, brown conglomerate at the base

of the formation, overlain by a pinkish quartzite sandstone, which is a prominent feature on Elk Mountain and some of the high summits to the south. The upper beds are gray to buff sandstones, moderately hard, massive and cross bedded, with occasional intercalations of thinner bedded sandstones. The thickness here averages 200 feet.

East and northeast of the LAK ranch, where the beds are all tilted at a high angle, the Lakota formation occupies a zone 200 feet wide marked by a high ridge cut into knobs by the cross valleys. Northwest of the ranch, where the dips diminish, the outcrop widens into a high, tabular ridge, sloping to the south. To the north and west, where the dips are low, the outcrop of the formation spreads widely, forming the extensive plateau about Cambria. To the east of this region Salt Creek and its branches have cut away much of a former plateau, and detached areas of Lakota sandstone remain, capping a series of high ridges lying between the valleys of Stockade Beaver and Salt creeks. West of Salt Creek the plateau presents a long line of cliffs of Lakota sandstone, rising gradually to the north on the gentle dip. The plateau is deeply

trenched by canyons of Little Oil, East Plum, West Plum, and Oil creeks and their branches. In their deeper portions these cut through to the Morrison shales and expose the entire thickness of the Lakota formation in their precipitous walls. The presence of a valuable coal bed and numerous variations in stratigraphy give the formation special interest. In the plateaus north of Newcastle the upper member of the Lakota formation is a massive sandstone of gray color, usually about 90 feet thick, often with conglomeratic streaks. At the base of this member there is considerable evidence of local unconformity, and often a thin series of coaly shale. Next below is a massive, finer grained, even-textured sandstone, usually light-ash-gray near the top, but often darker below, and locally rusty or tan colored throughout. It averages about 50 feet thick. Under it is found the main coal series, which, with the thinner bedded sandstones and shales underlying the coal in some places, attains a thickness of 25 feet. Often where the coal is thin or absent its horizon is either immediately above the Morrison shale or an intervening thin layer of sandstone. The area in which the coal is 5 feet or more in thickness and the outcrop of the coal horizon are indicated on the economic geology map. Outside of the Cambria basin the coal thins rapidly and merges into a shale that contains thin beds of coal or carbonaceous shale. Along the west side of East Plum Creek the main coal horizon is represented by 12 to 14 feet of coaly shale containing scarcely any usable coal. In the upper sandstone of the Lakota in the region west of Newcastle there are two horizons containing more or less gravel, which are seen in most of the exposures. The upper of these horizons contains small, gray gravel, constituting conglomerate layers in a massive, tan-colored sandstone. The lower horizon contains coarse, rust-red gravels scattered more or less thickly through a bed 10 to 12 feet thick, which lies about 30 feet above the coal horizon. The two horizons are separated by a light-tan-colored, massive sandstone varying in thickness but averaging about 20 feet. The horizon of carbonaceous shale, usually occurring in the middle of the Lakota formation, is well devel-

oped on Oil Creek and its branches, but it is of variable thickness and composition. It contains some thin coaly layers and has been prospected in places with the hope that it would be found to contain an upper coal horizon. Some typical sections of the Lakota and immediately associated formations are here given, the first being at Cambria in the bore hole of the Antelope mine.

Section of Lakota and associated formations at Cambria, Wyo.

	Feet.
Dakota.....	20
Fuson.....	40
Lakota.....	20
Morrison.....	54+

In the canyon just southwest of Mount Zion ranch the Lakota and associated formations are as shown in the next table.

In Oil Creek and Blacktail canyons the Lakota varies in thickness from 125 to 160 feet. A typical section on the west side of Oil Creek Canyon 1½ miles below the mouth of Plum Creek has the

Section of canyon of Little Oil Creek below Cambria, Wyo.

	Feet.
Dakota.....	20
Fuson.....	30
Lakota.....	15±
Morrison.....	40±
	45
	6
	20±
	90

The formation passes beneath the surface a short distance north of Newcastle, where the dip rapidly changes from 3° to 22°.

On the east side of the ridge 2 miles south of Cambria the bluff exposes the following section of the Lakota and associated formations:

Section on east side of ridge 2 miles south of Cambria, Wyo.

	Feet.
Dakota.....	33
Fuson.....	17
Lakota.....	40
	12
	60
	8

On the west side of the ridge, opposite, there are many scattered outcrops in which the sandstones show considerable local variations in color. At one point a 5-foot coal bed is exposed. The following section sets forth the principal features:

Section on west side of ridge 2 miles south of Cambria, Wyo.

	Feet.
Dakota.....	30
Fuson.....	35
Lakota.....	60
	35
	35
	4
	12
	14
	2
	5
Morrison.....	Shales.

On the west side of East Plum Creek, near the northern margin of the quadrangle, is presented a thickness of about 160 feet of massive, light-colored sandstones with local conglomeratic streaks and some intercalations of thinner bedded members about 70 feet above the base. The details of a partly well-exposed section on the west side of East Plum Creek just north of Deford's ranch, 2 miles northwest of Cambria, are as follows:

Section on west side of East Plum Creek 2 miles northwest of Cambria, Wyo.

	Feet.
Dakota.....	20
Dakota.....	53
Fuson.....	40
	15
	22
	12
Lakota.....	18
	24
	6
	3
	7
	6
	2
	30
	15
Morrison.....	90+

In the canyon just southwest of Mount Zion ranch the Lakota and associated formations are as shown in the next table.

In Oil Creek and Blacktail canyons the Lakota varies in thickness from 125 to 160 feet. A typical section on the west side of Oil Creek Canyon 1½ miles below the mouth of Plum Creek has the

Section in canyon southwest of Mount Zion ranch, Wyo.

	Feet.
Dakota.....	30
Fuson.....	20-30
	115
	1
	3
	4
Lakota.....	1
	2
	40
Morrison.....	Shales, greenish.

following components, including also the Fuson and Dakota formations:

Section on west side of Oil Creek Canyon 1½ miles below mouth of Plum Creek, Wyo.

	Feet.
Dakota.....	9
Dakota.....	2
	1
	5
	25
Fuson (in greater part).....	10
	2
	1
	3
	12
	15
	30
	25
	2
Lakota.....	19
	20
	30
Morrison.....	80

Two miles farther north, above the mouth of Plum Creek, the cliffs on the west side of Oil Creek Canyon exhibit the following section:

Section on west side of Oil Creek Canyon 2 miles above mouth of Plum Creek, Wyo.

	Feet.
Dakota.....	55
	3
	24
Fuson and Lakota.....	50
	15
	36
	8
	1
Lakota.....	25
	1
	6
	14
	24
	30
Morrison.....	6

Owing to a local flattening of dip a short distance north, the lower sandstone descends to the water level and crosses the valley, but it soon rises again, and near the northern margin of the quadrangle it is over 150 feet above the creek; there, however, its thickness is greatly diminished.

Fuson formation.—Lying between the massive sandstones of the Lakota and Dakota formations there is a thin series of shales and thin-bedded sandstones which have been designated the Fuson formation. The shales are often red or maroon in color, but are mostly gray and buff. They merge into sandstones that are thin bedded and contain shaly partings in most cases. Possibly in some localities the formation is absent, but in nearly all clear exposures it appears to be separable from the adjoining beds. For much of its course it is hidden by talus derived from the sandstones above. Its thickness varies from 10 or 15 feet to as much as 40 feet in exceptional cases. East of Clifton it often consists of alternations of pink clay and thin-bedded sandstone 30 feet thick. The clearest exposures are in the canyons of Oil, Plum, and Little Oil creeks and along the western slope of the ridge south of Elk Mountain. No fossils were found in the formation in this area, but in the Hay Creek region numerous plant remains of lower Cretaceous age were obtained by W. P. Jenney from his "Division No. 2" of the "Dakota group," which includes the Fuson.

Dakota sandstone.—This formation lies along the lower western slopes of the hogback range, but north of Newcastle it appears to extend far to the

north, capping the long sloping plateaus. Its thickness varies from 50 to 100 feet. The most characteristic feature of the formation is a lower member of hard sandstone with massive structure and reddish brown color. The upper member is a series of thinner bedded sandstones. The formation gives rise to tabular surfaces, ending in precipitous cliffs from which the rock of the lower member generally breaks off in great vertical slabs or irregular columns. A very characteristic aspect is shown in fig. 13 of the illustration sheet. In some localities this massive character is lacking, especially in portions of the region north of Newcastle, where the formation is softer or thinner bedded. A most exceptional phase of the formation is exposed in the canyon of Little Oil Creek just above Newcastle, where it is represented by a series of alternating sandstones, mostly thin bedded, and shales of dark color. As the Fuson formation is less distinctive here than usual it is difficult to recognize the precise dividing line between the two formations. In the valleys of the branches of Plum Creek the formation has been extensively eroded, but small outliers remain on the summits of some of the adjoining ridges. Its identity here is in some cases doubtful. In the region north of Newcastle there is a general thinning of the formation to the north and northeast. On the high tables about Cambria the thickness varies from 40 to 60 feet, the massive lower bed appearing in the thicker portions.

Graneros formation.—The lowlands lying next west of the slope of the hogback range are underlain by a thick mass of soft, fine-grained deposits, of the Graneros formation, varying in thickness from 950 to 1100 feet, the greater thickness being in the vicinity of Newcastle and a short distance north. The formation consists mainly of shales of dark gray to black color. It includes, about 175 to 275 feet above the base of the formation, an elongated lens of sandstone, which attains a thickness of 30 to 40 feet in the vicinity of Newcastle. West of Oil Creek this sandstone thins rapidly, and in the vicinity of Osage it finally is lost or becomes inconspicuous among other thin sandstone layers in the formation. In the Whoopup Creek region it has a thickness of 15 to 20 feet and the rocks are spread out by some low flexures in which the Graneros sandstone caps several prominent ridges. To the south, near Clifton, it passes beneath alluvial deposits and does not appear again. The rock is hard and always gives rise to a ridge of greater or less height, which from the LAK ranch to Oil Creek rises in prominent hogbacks just south of the main range of Dakota sandstone, from which it is separated by a line of narrow valleys underlain by the basal black shales. Immediately west of Newcastle this ridge attains a height of 500 feet. In this vicinity the rock contains petroleum, which at several points flows out in natural springs of small volume (for location see economic geology map). A section of the lower members of the Graneros formation at an oil spring 4 miles west of Newcastle is as follows:

Section of lower members of Graneros formation 4 miles west of Newcastle, Wyo.

	Feet.
Sandstone, hard, slabby, shale partings, oil spring	8
Sandy clay, light colored	1½
Shale, very dark	3
Sandstone	1½
Shale, dark	6
Sandstone, slabby, ripple marked, buff	2
Shale, dark, few thin sandstone layers	20
Sandstone, massive, light buff; contains oil ..	15½
Sandstone	1
Shales, dark, to top of Dakota sandstone	250

Several hundred feet of the lower portion of the Graneros formation were penetrated in two deep borings for oil a short distance south of Newcastle. The following beds were reported in one of these:

Partial section of Graneros formation in Shreve oil well, Newcastle, Wyo.

	Thickness in feet.	Depth of base in feet.
Gravel, sand, and clay	50	50
Shale	150	200
Sand, some oil (?)	15	215
Shale	188	403
Shale, much gas	8	411
Sand with gas	15	426
Shale	204	630
Sand with oil and water, main "oil sand"	10	640
Shale with few layers of sandstone	160	800
Sandstone, much water	20	820
No record	492	1312

This boring is about a half mile southwest of the railroad station and was made several years ago. The main "oil sand" appears to be 630 feet below the surface in this boring, and if so the Dakota sandstone probably was reached at a depth of about 820 feet and furnished the principal flow of water.

In a boring made in 1902 about a quarter of a mile due south of the above the following beds were reported:

Partial section of Graneros formation in Well No. 1, Northern Pacific Oil Company, Newcastle, Wyo.

	Thickness in feet.	Depth of base in feet.
Shale	150	150
Hard sandstone	14	164
Dark shale	289	408
Hard sandstone (concretion)	2	405
Light-colored shale	7	412
Dark shale	52	464
Very hard sandstone (concretion) ..	2	466
Gray shale	8	474
Very hard, coarse sandstone	14	488
Very hard, fine-grained rock	4	492
Shale	7	499
Sandstone, water and oil, main "oil sand"	32	531
Dark shale	30	561
Sandstone	7	568
Shale and sandstone	5	573
Shale	200+	
Sandstone (Dakota) to bottom		900

The beds in this well are nearly the same as in the first, for the strata rise but slightly to the north. The main "oil sand" at 630 feet in the first well is probably the same as the one at 499 feet in the second well. The precise thickness of the underlying shale below 531 feet was not reported, but it is said that the Dakota sandstone was entered at about 800 feet, which indicates a thickness of about 270 feet.

Near the LAK ranch the sandstone in the Graneros formation is underlain by only 175 feet of shales, but the amount increases somewhat to the south. In the gorge above Newcastle the thickness is 205 feet, not including some doubtful beds of passage into Dakota sandstone.

West of Newcastle the stratigraphy of the sandstone series in the lower part of the Graneros formation is variable, there being frequent changes in the thickness of the sandstone beds and the succession of intercalated shales. A section at the mouth of Oil Creek Canyon shows the following beds:

Section of Graneros formation at mouth of Oil Creek Canyon.

	Feet.
Shale, black	50+
Shales, dark, with thin sandstone layers ..	67
Sandstone, brick red to maroon	7
Shale, black	8
Sandstones, thin bedded, rust colored	5
Shale, light gray to buff	5
Sandstone, massive, light buff	15

The lower or principal sandstone bed thins gradually from this point northward. In the vicinity of Osage it varies in thickness from a few inches to 6 feet and a still lower sandstone series comes in. In one locality, a mile east of Osage, there are two 10-foot layers of hard, massive sandstone separated by 4 feet of dark sandy shales and overlain by a succession of thin sandstones and sandy shales 17 feet thick capped by the sandstone bed, here 6 feet thick, which extends far southward.

Overlying the sandstone of the lower portion of the Graneros formation are 800 feet of shales, which are mostly black and fissile below and dark gray above. A few feet above the sandstone there is a conspicuous series of hard, light-bluish-gray sandy shales, containing a large number of fish scales. These shales weather nearly white and form a characteristic horizon. Their best exposures are in the railroad cuts 1 to 2 miles west of Newcastle. In the shales lying next above are some thin beds of sandstone and numerous lens-shaped concretions of hard material. At the top of the formation, especially in outcrops northwest of Pedro, there are many large concretions in gray shale lying below the Greenhorn limestone. In the region near Newcastle the upper members include some limy beds constituting beds of passage to the Greenhorn limestone. Owing to many variations in structure along the margin of the Black Hills uplift, the Graneros formation presents considerable diversity in its surface distribution. From the S & G ranch to Clifton it is spread out widely by very low dips and gentle undulations, and this is also the case north of Clifton, where the lower beds have a wide

outcrop area, but there the beds above the sandstone dip steeply and occupy a narrow belt extending to the LAK ranch. South of Newcastle there are low dips in the upper beds and they occupy a wide area for a few miles. The outcrop zone narrows rapidly west of Little Oil Creek and for some distance is only a quarter of a mile across. From Pedro to Osage low dips are again found and the outcrop widens correspondingly. The sandstone here caps the low ridge northeast of the railroad. The Graneros shales contain very few fossils except the fish scales above referred to. Some molluscan remains observed in this region and elsewhere are of lower Benton species.

Greenhorn limestone.—Near the center of the Benton group there is a thin but very distinctive series of beds of hard, impure limestone, known as the Greenhorn limestone, which, owing to its hardness, usually gives rise to a prominent ridge or east-facing escarpment lying a few miles west of the hogback range. This feature is most conspicuous north of Pedro, south of Newcastle, and west of the S & G ranch. Between Oil Creek and Little Oil Creek and from the LAK ranch southward to beyond Clifton Siding, where the formation has a steep dip, its presence is marked by a small but prominent ridge, often with a companion ridge just west, due to a bed of hard sandstone in the Carlile formation (see fig. 11 on illustration sheet). The thickness of the Greenhorn limestone averages 50 feet or less, the limits being somewhat indefinite. Beds of passage into the adjoining formations are calcareous shales, but in the center of the Greenhorn limestone there are found 20 to 30 feet of hard, thin-bedded, impure limestone with some shale intercalations. The rock is characterized by vast numbers of impressions of *Inoceramus labiatus*, a fossil which is of infrequent occurrence in other formations of the Benton group (see fig. 12 on illustration sheet). The limestone appears to gain hardness on weathering, for on the hill slopes it breaks up into hard, pale-buff slabs covered with impressions of the distinctive fossil. In other regions the limestone usually is distinctly separated from the black shales of the Graneros formation, but in the Newcastle region there are beds of passage.

Carlile formation.—This formation consists mainly of shales with occasional thin beds of sandstone. Its thickness averages about 700 feet. The outcrop area extends diagonally across the Newcastle quadrangle from northwest to southeast, the beds dipping to the southwest in the northern portion of the quadrangle and almost due west in a narrow zone of outcrops extending south from LAK ranch. In this zone the dips are steep, as they are also between Little Oil Creek and Oil Creek. South of Newcastle the formation is spread out in an area of considerable extent, and northwest of Pedro, where the dips are very low, its outcrop has an average width of 3 miles. The usual order of beds in the Carlile formation is a basal series of dark shales and alternations of gray shales with thin-bedded sandstones, then an extensive series of drab shales, and at the top gray shales containing numerous large concretions. Two typical sections are as follows:

Section of Carlile formation 3 miles west of Newcastle, Wyo.

	Feet.
Niobrara chalk at top	
Dark shales, with light-colored concretions near top	190
Dark shales	200
Calcareous concretions	3
Sandy shales, with thin sandstones	170
Brown sandstone	4
Dark shales	200
Greenhorn limestone	

Section of Carlile formation north of Pedro, Wyo.

	Feet.
Niobrara chalk at top	
Drab shales, with numerous concretions near top	550
Thin-bedded sandstone	5
Shale	30
Sandstone, drab below, reddish above	30
Dark shale	50
Thin-bedded, light-brown sandstone	35
Gray shales	90
Greenhorn limestone	

The sandstones in the Carlile formation give rise to sharp ridges, and where the beds have steep dips these present a very ragged crest line. This is notably the case for some miles west of Little Oil Creek and in the ridge west of Clifton Siding. At some points west of Newcastle one of the lower sandstones, of light-brown color, has a concretionary

structure, which is shown by the development of disks from 2 to 3 feet in diameter, locally termed "cart wheels." The Carlile formation contains fossils, mainly mollusks and fish remains of upper Benton age.

Niobrara formation.—This is the least conspicuous formation in the Newcastle quadrangle, and owing to the softness of the materials the beds are rarely well exposed. In most places it underlies a shallow valley lying at the foot of the slopes of the harder rocks of the Carlile formation. The material is soft, shaly limestone or impure chalk, containing a greater or less admixture of fine sand and clay. Its weathered outcrops have a bright-yellow color which is characteristic, but in unweathered exposures the material is usually light gray in color. The thickness of the formation, including some obscure beds of passage into the adjoining formations, averages about 200 feet, as nearly as could be ascertained. In the Niobrara formation are often found thin beds of hard limestone consisting of an aggregation of shells of *Ostrea congesta*, a fossil very distinctive of the formation when it occurs in this manner (see fig. 12 on illustration sheet).

In the beds of passage at the top of this formation in the vicinity of Pedro are some thin lenticular masses of a peculiar white clay known as bentonite, which has the capacity of absorbing several times its bulk of water and is of considerable commercial value. Its principal exposures are in a very small ridge a half-mile east of Pedro Siding and on the hill slope a mile west of that siding, where it has been excavated for shipment. When dry the clay is massive and moderately hard, breaking with conchoidal fracture, but when moist it is like soft soap in consistency and gives rise to miry "soap holes." Three miles northwest of Osage a similar deposit occurs in the Graneros shale.

Pierre shale.—The wide region of low plains and valleys occupying the central portion of the Newcastle quadrangle is underlain by Pierre shale, a thick mass of dark-colored clay or shale, weathering light brown and relatively uniform in composition throughout. Its outcrop area is a region of low, rounded hills sparsely covered with grass and not very useful for agriculture. The formation is about 1250 feet thick, but it is only rarely that its thickness can be ascertained, and where the dip is gentle it is almost impossible to measure it. At a horizon about 1000 feet above its base it includes scattered lenses of limestone, usually containing numerous shells of *Lucina occidentalis*. Although these lenses also occur sparingly at lower horizons, they are most characteristic of the horizon mentioned, and as they occur at intervals nearly all over the area they throw much light on the structure of the formation. It is from this evidence that the cross sections and the determination of depth to Dakota sandstone have been made in the Pierre shale area. The limestone lenses with *Lucina* vary in size from 2 to 3 cubic feet to masses 20 feet in diameter and 6 or 8 feet thick and usually of irregular lens shape. When these lenses are uncovered by erosion they give rise to low, conical buttes resembling in form a very squat tepee, and they have therefore been designated "tepee" buttes. Their height varies from 20 to 50 feet in most cases. The Pierre beds are usually somewhat steeply tilted along their eastern margin from Pedro to the southern boundary of the quadrangle, but to the west the dips diminish and there are wide areas in which the beds lie nearly level or are traversed by gentle undulations. Numerous concretions appear in the Pierre shales at various horizons and usually contain large numbers of very distinctive fossils, especially in the upper beds. The more abundant are of the following species: *Baculites compressus*, *Inoceramus sagensis*, *Nautilus dekeyi*, *Placentiaceras placenta*, *Heteroeras nebrascense*, and an occasional *Lucina occidentalis*. The concretions are generally of small size, of a siliceous nature, and break into small pyramidal fragments which are scattered more or less abundantly all over the shale surfaces.

Fox Hills formation.—West of the wide valley region in which the Pierre formation occurs there rises a low escarpment due to a series of thin beds of hard sandstone which belongs to the Fox Hills formation. There are two or three thin layers of this sandstone, with shaly beds intercalated, and an underlying series of soft, clayey sandstones having

a thickness of only 50 feet. The basal members contain abundant distinctive fossils, including at some places large numbers of *Veniella*. There is a conformable transition to Pierre shale through 20 or 30 feet of sandy shales lying near the base of the slope. Farther south, lower sandy beds of the formation often contain large, fairly well-defined concretions due mainly to local increase of lithification. The two following sections (figs. 1 and 2) show some of the distinctive features and the topographic relations.

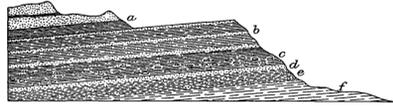


FIG. 1.—Section of escarpment in Fox Hills formation in Weston County southeast of Newcastle, Wyo.

Laramie formation: a, sandstones and clays. Fox Hills formation: b, sandy shale with thin, hard sandstone beds; c, 30 feet of sandy gray shale with soft fossiliferous concretions; d, thin layer of ferruginous sand; e, lead-colored sandy clay. Pierre shale: f, gray fossiliferous shale.

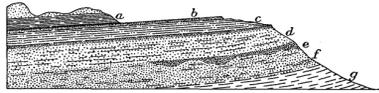


FIG. 2.—Section of escarpment in Fox Hills formation in Weston County west of Clifton Siding, Wyo.

Laramie formation: a, shales. Fox Hills formation: b, brownish-gray sandstone; c, sandy shale; d, 35 feet of greenish to gray, soft, thin-bedded sandstone; e, very fossiliferous lenses of harder gray sandstone; f, 50 feet of massive, soft, pale-greenish-buff sandstone and sandy shale. Pierre shale: g, gray clay.

The breadth of the outcrop of the Fox Hills formation is not over a mile in most places and is often considerably less. South of Robbers Roost Creek it widens to 5 miles. The thickness of the formation is from 150 to perhaps 200 feet, increasing southward, but gradually diminishing to the north to 75 feet, the decrease being largely in the lower beds. There is some doubt as to the upper limit of the formation, and there are indications that the line of lithologic change is not a constant horizon throughout; thus it may be that some of the lower members represented as Laramie formation in this region belong to the Fox Hills in other districts.

Laramie formation.—The extreme western and southwestern portions of the Newcastle quadrangle are occupied by the Laramie formation. This consists of soft, massive sandstones intercalated with carbonaceous sandy clays. The thickness is 700 to 800 feet, as nearly as can be ascertained. The beds dip very gently to the west. The region is one of irregular slopes, steep where there are sandstones, gentler where there are shales, and with many detached buttes and hills. The highest of these, known as Alkali Butte, is a prominent landmark from the east, although it rises only about 200 feet above the adjoining rolling hills. The section it exposes is as follows:

Section exposed in Alkali Butte, Weston County, Wyo.

	Feet.
Light-brown sandstone, hard.....	20
Light buff, massive sandstone, coarse but soft.....	50±
Brownish buff, massive sandstone, with a few large, irregular concretions.....	20
Dark, sandy, and lignitic clays, with thin sandstone partings.....	60±
Hard, brown sandstone.....	3
Soft, massive stone.....	25±
Hard, brown sandstone.....	2
Light-gray sandstone, with dark-gray, hard sandstone layers and concretions.....	40±

Below the beds exposed in this butte there is an alternation of several hundred feet of sandstone and carbonaceous shales in beds from 30 to 40 feet thick in greater part. Next above the Fox Hills beds are 80 feet of gray clays overlain by sandstones. The sandstones of the Laramie formation consist mainly of fine-grained, loosely cemented sand of light-buff color, often having a thickness of 40 feet. They contain very characteristic concretions of gray color and great variety of shape. This material is simply the sand locally lithified to increased hardness and slightly darkened. The size of the concretions varies from a few inches to many feet. They are usually elongated, with rounded outlines, but spherical and lens-shaped concretions abound. Some representative forms are shown in fig. 10 of the illustration sheet. The beds of shale which occur interbedded among the sandstones of the Laramie formation are usually of dark-gray color and in places lignitic, but no coal deposits have been found in them in this region.

QUATERNARY SYSTEM.

The Quaternary formations of the Newcastle quadrangle comprise alluvial deposits along the stream valleys and upland gravels and sands occupying old terraces which are remnants of a previous epoch of topographic development.

Alluvium.—The principal alluvial deposits are

in the wide valleys excavated in the Pierre and Graneros shales, but narrow areas of recent alluvium extend up all the valleys and merge into the general talus and wash on the hill slopes. Only the larger alluvial areas are represented on the map. The most extensive of these are in the valleys of Beaver Creek, Oil Creek and its branches, South Beaver Creek, the lower portion of Blacktail Creek,

Stockade Beaver Creek, and the valley extending along the foot of the hogback range from Whoopup Creek to the S & G ranch. Alluvial flats of considerable size also extend up portions of Red-bird and Gillette canyons and along Stockade Beaver Creek in the Red Valley. The materials of these deposits are mainly loams and sands, with some admixture of coarser material. Along Oil

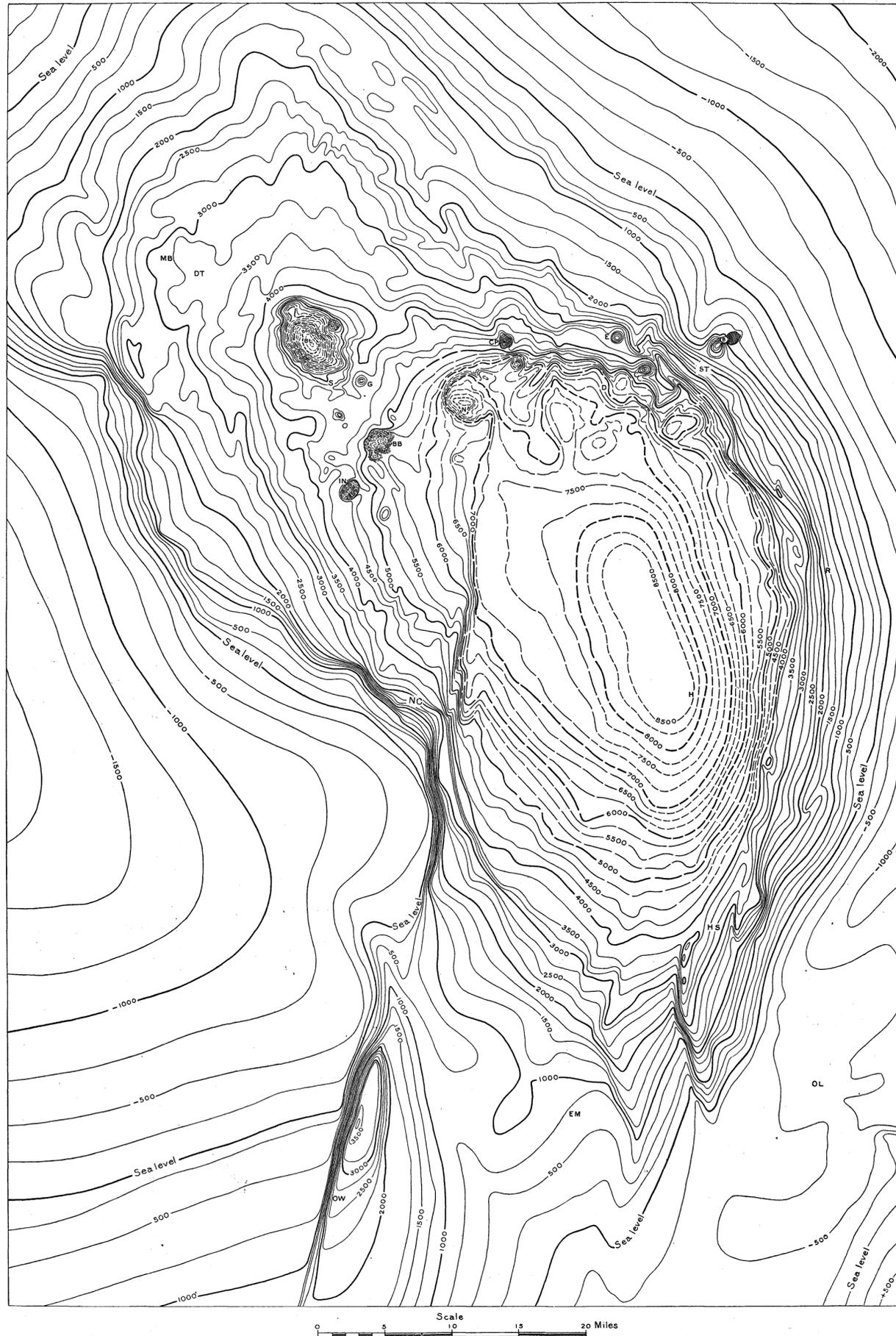


FIG. 3.—Black Hills uplift represented by contours on the surface of Minnekahta limestone. Where the Minnekahta limestone has been removed by erosion the calculated position of the contours is shown by broken lines. Long dashes indicate areas from which Minnekahta and overlying formations have been eroded; short dashes, areas from which all sedimentary rocks have been removed. Contour interval, 250 feet.

B, Bear Butte; B B, Black Butte; B L, Bearlodge Range; C, Crook Mountain; C P, Crow Peak; D, Deadwood; D T, Devils Tower; E, Elkhorn Ridge; E M, Edgemont; G, Green Mountain; H, Harney Peak; H S, Hot Springs; I N, Inyanakara Mountain; M B, Little Missouri Buttes; N, Nigger Hill; N C, Newcastle; O L, Oelrichs; O W, Old Woman Creek; R, Rapid; S, Sundance; S T, Sturgis.

Creek there is considerable reddish material of a predominantly sandy character. This owes its reddish color to sediments brought down from the Red Valley, which is drained by Oil Creek north of the northern margin of the Newcastle quadrangle. The deposits along Beaver Creek are mostly the dark clays from the Pierre shale, which it traverses. Their thickness varies from 15 to 20 feet. In many places the creek cuts through the deposit and exposes the underlying Pierre shale, but, owing to the numerous caved banks, it has not been possible to map this feature in detail. Several low knolls of shale rise through alluvium in the valley.

Terrace deposits.—The earlier terrace deposits cap some of the low ridges, mostly in the Pierre and Graneros shale region, and extend on shelves up some of the valleys of the higher lands. They mark the courses of old streams which have since cut to lower levels, and undoubtedly they were much more extensive originally, but with the degradation of the country a large amount of the material has been removed or widely scattered, especially in areas where it was thin. One of the most conspicuous deposits remains in detached outliers capping the deeply dissected ridge which lies between Stockade Beaver and Blacktail creeks. A continuation of probably the same deposit is found on the ridges southeast, south, and west of the S & G ranch, on benches along the foot of the hogback of Dakota sandstone to and beyond Clifton Siding, and at intervals on the ridges south of the LAK ranch. It lies from 150 to 200 feet above the surrounding valleys in greater part, and there are higher portions on the summit of the hogback range west of Whoopup Creek. Other deposits are found on terraces on the sides of the valley of Stockade Beaver Creek north of the LAK ranch. These deposits undoubtedly owe their origin to a predecessor of Stockade Beaver Creek which had a course approximately the same as the present valley. Small gravel deposits are found on the ridges adjoining Skull Creek from southwest of Newcastle north to the northern margin of the quadrangle. They lie from 125 to 150 feet above the creek and evidently represent an earlier period of deposition from the same drainage basin that is now occupied by Skull Creek. Many small outliers of gravel lie on the ridge between Oil Creek and Blacktail Creek, representing a terrace which has been very nearly all removed by erosion.

STRUCTURAL GEOLOGY.

Structure of the Black Hills uplift.—The Black Hills uplift, if not eroded, would present an irregular dome rising on the northern end of an anticlinal axis extending northward from the Laramie or Front Range of the Rocky Mountains (see fig. 3.) It is elongated to the south and northwest, has steep slopes on the sides, is nearly flat on top, and is subordinatedly fluted. The greatest vertical displacement of the strata, as indicated by the height at which the granite and schist floor is now found, amounts to about 9000 feet.

In the northern hills there are numerous local domes and flexures, due mainly to laccolithic igneous intrusions, but no similar features are indicated by the structure of the southern hills.

Faults are rarely observed; of those seen, not many amount to more than a few feet in vertical displacement, and these are short breaks due to igneous intrusion.

Structure sections.—The sections on the structure-section sheet represent the strata as they would appear in the sides of deep trenches cut across the country. Their position with reference to the map is on the line at the upper edge of the blank space. The vertical and horizontal scales are the same, so that the actual form and slope of the land and the actual but generalized relations of the rocks are shown. The structure where buried is inferred from the position of the strata observed at the surface and from determinations of their thickness where they are uplifted.

Structure of the Newcastle area.—The Newcastle quadrangle embraces a portion of the southwestern slope of the Black Hills uplift, with rocks dipping more or less steeply to the southwest, and a portion of the Great Plains, in which the beds lie nearly level. There are local irregularities in the monoclinal structures, consisting mainly of variations of strike and pitch and the presence of several low

diagonal undulations of the strata. In the northeast corner of the quadrangle there is a portion of the crest of the dome of the general uplift of the Black Hills in which the rocks lie nearly level. Near the State line the dip rapidly steepens and in some localities there are nearly vertical dips. This is notably the case in the steep westward-dipping monocline shown in the exposures of the Minnelusa and Minnekahta formations in the steep slopes northeast of the LAK ranch (see fig. 8 of illustration sheet.) At several points in this portion of the monocline the beds are nearly vertical and the harder sandstone and limestone ledges give rise to a succession of saw-toothed ridges of brilliantly colored beds. This steep-dipping corrugation of the monocline trends south by west and passes into higher and higher beds in succession, being continued nearly to the southern margin of the quadrangle, where it affects the upper members of the Benton group. In the zone of low dips next east there is a downward pitch to the south, which spreads the outcrop area of Minnekahta limestone about Redbird and Gillette canyons, and widens the hogback range at Elk Mountain and for some distance southward. It finally passes out into the Graneros shales, which, near Clifton Siding, are spread out widely under its influence. West of the steep-dipping portion of the monocline above described there is a rapid diminution of inclination of the beds. At the north there is a wide valley of Spearfish formation and a broad zone of Sundance formation with outlying ridges capped by Lakota sandstone. The dips are mainly to the west at low angles and there are several very low corrugations and a general pitch to the south. In the Cambria region the monocline dips very gently southwestward and the hard sandstones of the Lakota and Dakota formations are spread out into a wide, sloping plateau deeply dissected by canyons. The change of dip from west to southwest takes place gradually in the latitude of Cambria, but farther south, in the vicinity of the LAK ranch, there is a very sudden change in direction, marked by an almost right-angle bend in the strike about the LAK ranch. South of Newcastle there is a broad area of relatively low dips, west of which for some distance the Graneros to lower Pierre beds dip at a steep angle. The dips are to the southwest and are steepest between Oil Creek and Little Oil Creek. They diminish in steepness toward Pedro and to the northwest they are low. In the center of the quadrangle, in the Pierre shale region, the steep inclinations west of Newcastle and south of the LAK ranch rapidly diminish and there is a broad area of almost horizontal ledges traversed by a few very low undulations. West of Beaver Creek there is a general low dip to the west-southwest which continues to the margin of the quadrangle. The maximum dips observed in this region are less than 3 degrees.

No faults of any appreciable amount are found in the area of the Newcastle quadrangle. Occasional small slips are exposed, but no notable dislocations. There have been many landslides along cliffs of the Lakota sandstone where the soft underlying shale is inadequate to sustain the heavy masses of overlying rock. Joint planes extensively developed in the Dakota sandstone trend nearly due northeast in most cases observed.

MINERAL RESOURCES.

SOILS.

Derivation.—The soils in this region are closely related to the underlying rocks, of which they are residual products due to decay and disintegration, except when they are formed as alluvial deposits in the larger valleys. In the process of disintegration, residual soil develops more or less rapidly on the several rocks of the region 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 the Minnelusa 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, varying 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 where there are 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 the 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, and thus by softening and washing give rise to soils. If they are sandy, sandy soils result; 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, such, for instance, as shales and sandstones 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 formation 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 washed down and mingled with or covered the soils derived from the rocks lying immediately beneath. Soils of this class are known as overlaid, and a special map of large scale would be required to show their distribution.

Distribution.—The arable lands of the Newcastle quadrangle are underlain mainly by shale and alluvium. The Pierre shale covers the most extensive area, and as it consists mostly of clay its disintegration gives rise to a stiff gumbo, which is not only very barren in itself but is acidic from decomposing pyrites and too sticky for agricultural use. It is covered with grass, which originally afforded excellent pasturage, but in some areas it has been grazed down by excessive herding. As the soil is not rich and the climate is semiarid, the grass grows slowly, and after close grazing requires some time to regain its former growth.

In almost all the wide valleys in the Pierre shale region there are alluvial deposits, which are usually fertile. Along main Beaver, Stockade Beaver, South Beaver, Skull, and Oil creeks these deposits are wide and would be well suited for agriculture if they could be irrigated. Along the main Beaver Valley above the mouth of Oil Creek the deposits contain so much clay that their soil is in places a gumbo. In the valley of Oil Creek there is a reddish, sandy loam of moderate fertility. The soils of the formations of the Benton group are mostly thin and poor. The Niobrara formation from Pedro west and north underlies a narrow valley the soils of which are somewhat more fertile than those of the surrounding areas owing to the calcareous nature of the formation, but in the Beaver Valley the formation is mostly covered by alluvium. The hogback range of Lakota and Dakota sandstones has a thin, sandy soil which supports more or less forest growth. It has been tilled in the vicinity of Mount Zion ranch, where there are several large fields under cultivation. The Sundance formation outcrops in a wide area along Salt Creek Valley, and the soil would be mostly fertile if the climatic conditions were not so arid. The red, sandy clays of the Spearfish formation produce a relatively barren soil, but along Stockade Beaver Creek in the Red Valley there is a series of alluvial flats which have been irrigated and produce excellent crops. In fact it is in this valley, from the LAK ranch northward for 8 or 9 miles, that the principal farms of the quadrangle lie. The soils are rich and there is a good supply of creek water for irrigation. The Minnekahta limestone presents rocky slopes with thin soils, supporting a growth of bushes and cedars. The Minnelusa sandstone, which occupies

the northeast corner of the quadrangle, has considerable soil on the gentler slopes and the higher plateau surfaces, which sustains an extensive forest of pines and other trees, with grass in the more open spaces.

The region occupied by the Fox Hills and Laramie formations is in greater part sandy, barren, and dry. There are some narrow strips of loamy soils derived from the sandy shales in the Laramie formation, but they are mainly on the higher land and entirely too dry for agriculture. Along the larger valleys in this region there are occasional flats of considerable width which yield an excellent growth of hay and which, by irrigation, could in some cases be made to produce other crops. The Laramie formation usually supports an excellent growth of grass, and in some districts there are wide areas of good grazing grounds.

WATER SUPPLY. SURFACE WATERS.

The average annual rainfall of the region about Newcastle, as nearly as can be ascertained, is about 15 inches, the amount being considerably greater in the high lands east of Stockade Beaver Creek. A portion of the precipitation is in the form of snow, and the remainder falls mostly in heavy showers of short duration during the spring and early summer months. As most of the surface of the country has a very thin soil and only limited areas present porous rocks, the water of rains and melting snow runs off rapidly, usually in freshets that follow storms or the melting of snow, the latter often melting very rapidly during the sudden warm spells in spring. In consequence of these conditions there is but little running water in the region during the greater part of the year. Springs are rare and of small volume in the lower lands. A large amount of the run-off in this region could be saved by dams and made available for irrigation. There are suitable dam sites at many localities, especially along the slopes of the Black Hills. One dam southwest of Clifton Siding holds a large volume of water, as shown in fig. 11 of the illustration sheet. It was built in a small valley, across a narrow gap due to vertical beds of hard Greenhorn limestone and Carlile sandstone.

Stockade Beaver Creek.—This fine stream rises in ravines heading in the Minnelusa sandstone and Pahasapa limestone in the northeast corner of Weston County, Wyo., and carries a large volume of water to the main Beaver Creek, into which it empties in the southeast corner of the county. It receives water from a number of springs in the Minnekahta limestone east of Newcastle, one of the most prominent of which lies a short distance west of the foot of Fannie Peak. Another source of water is Salt Creek, which brings a small volume of saline water from the springs northeast of Cambria. Portions of the valley contain flats suitable for moderately extensive agriculture by irrigation, and several small ditches are now in operation east of Newcastle, notably one for irrigating the extensive alfalfa fields of the LAK ranch. Stockade Beaver Creek receives the drainage of the western slope of Elk Mountain and of a wide area of the western portion of the limestone plateau and slopes in the northwest corner of Custer County and the southwest corner of Pennington County. Two of the most extensive drainage basins empty through Redbird and Gillette canyons, but the waters of these rarely reach the main creek. Redbird Canyon has at its head two branches—Antelope Spring and Preacher Spring—which yield small flows of water that sink in a short distance. This also is the case with Buck Spring and some minor seeps of the adjoining limestone area. Nearly all the springs of this series and others at the head of Stockade Beaver Creek are near the contact of the Minnelusa sandstone and Pahasapa limestone, where there are porous, water-bearing beds.

Beaver Creek.—This stream occupies the valley lying between the western slope of the Black Hills and the escarpment of Fox Hills sandstone in the southeastern portion of Weston County, Wyo. The origin of its water is difficult to determine, but west of Newcastle it has considerable volume, which flows more or less continuously to its junction with Stockade Beaver Creek. The combined waters of the two streams flow into Cheyenne River in the northwest corner of Fall River County, constituting the principal volume of water to Edge-

mont. The main Beaver Creek receives several branches that probably carry more or less water as underflow. Those heading in the Fox Hills and Laramie regions to the west are dry at the surface. Oil Creek and its two branches, Skull Creek and Little Oil Creek, contain running water in the canyons north and northeast of Newcastle, but in dry weather their waters do not flow to the main Beaver Creek. The waters of Oil Creek are used for irrigation west of Newcastle, just north of the railroad. The valley of Beaver Creek is wide and contains some land that could be irrigated, but no attempts have yet been made to utilize it.

UNDERGROUND WATERS.

Throughout this quadrangle there are prospects of water supplies from wells of greater or less depth. The succession of formations, as is shown in the columnar section, includes several beds of water-bearing sandstone, which receive water supplies at the surface in the higher ridges and slopes of the Black Hills. These sandstones are carried underground in the general outward dip on the flanks of the hills, and, owing to the relative steepness of this dip, soon attain considerable depth. In most parts of the quadrangle the inclination of the strata diminishes away from the Black Hills, and there is a wide area of the surrounding country under which the water-bearing beds lie at a depth that is within reach of the well borer. As the region is semiarid, with surface waters often containing much "alkali," at most places there is great need of underground water. The principal water-bearing horizons all rise above the surface on the slopes of the Black Hills in regular succession, as described on a previous page. They outcrop in wide zones encircling the hills, and receive a large amount of water, not only from the rainfall on their surface, but from the streams which at many points sink into them in whole or in part in crossing their outcrops. The sinking of streams in this manner is to be observed in almost every valley leading out of the central rock area. Few of the streams carry more than a small portion of the total original run-off of their watersheds into Cheyenne River, as much of it sinks underground in crossing the sandstones, particularly those of the Minnelusa, Lakota, and Dakota formations. The waters thus trapped by the sandstone pass far beneath the surface, as the water-bearing beds descend on the slopes of the Black Hills uplift.

Dakota-Lakota sandstones.—The Dakota and Lakota sandstones are the principal formations in which water supplies are to be expected in the plains portion of the Newcastle quadrangle. They pass beneath the overlying shales with dips varying considerably in amount (see cross-section sheet), but which finally carry them far below the surface. In a zone of greater or less width adjoining the hills their depth is less than 1000 feet, and they afford an important source of water supply. They have been tested by a number of wells and found to contain water which rises to the surface and overflows in moderate volume. These wells are at Argentine, the next railroad siding south of the S & G ranch; at Clifton; north of Clifton; at Newcastle; and at Jerome, a siding 7 miles north of Osage. The horizon is the same as that which yields a vast volume of water to the numerous wells in eastern South Dakota and in Nebraska. In the Newcastle quadrangle and vicinity the water varies greatly in quality, in some localities being too highly mineralized for use. At Clifton water of good quality is obtained from a well 300 feet deep sunk into the Lakota sandstone a few rods west of the Dakota sandstone ledges. The Argentine well is 550 feet deep and has a moderately large flow of water containing 56 grains of mineral matter per gallon, mostly sulphate of soda. A flowing well 4 miles north of Clifton Siding, at the side of the railroad, just south of Whoopup Creek, yields water too highly mineralized to be of any use. Its depth is 1002 feet, and there are flows at 72, 210, 490, and 925 feet. Its present flow is less than a half gallon a minute and the pressure is very low. Its log as reported by the well drillers is given in fig. 4.

The upper 20-foot sandstone, which contains water, appears to be in the lower part of the Graneros shales, which outcrop in the small ridge east of the well. The Dakota sandstone extends from 200 to 255 feet and yielded the flow at 210 feet.

The Fuson formation appears to extend from 255 to 270 feet, or possibly lower, and then there are several hundred feet of Lakota sandstone, with some shale in its upper portion, extending to a depth of 537 feet or possibly lower. It yielded the flow at 490 feet. The limits of the Morrison and Sundance beds are not clearly indicated by the report of the borings, the sand rocks reported at 582 and 652 feet probably being sandy portions of the Morrison formation. The 120 feet of so-called red

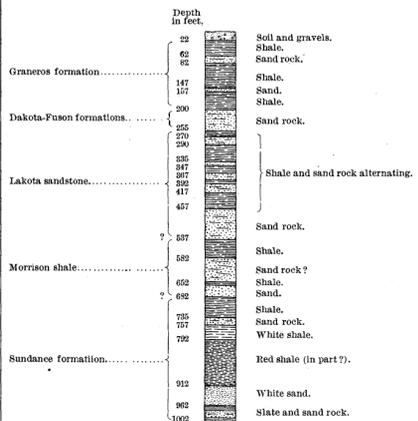


FIG. 4.—Log of artesian well at Whoopup, 4 miles north of Clifton Siding, Wyo.

beds reported to extend from 792 to 912 feet probably are in part the usual red member of the upper part of the Sundance formation, but also include some of the adjoining shales which are not red. The white sand and sand rock from 912 feet down, which yields a flow at 925 feet, is probably the sandstone near the bottom of the Sundance formation. There is another flowing well a mile and a half farther north, which yields a supply of very saline ferruginous water. Its depth could not be ascertained.

In the various borings which have been made for oil about Newcastle more or less water has been found in the Dakota-Lakota sandstone. Two miles west of the town there is a boring said to be 1950 feet deep, sunk for oil. Unfortunately a complete record could not be obtained. The oil sand, 40 feet thick, was found at a depth of 95 feet, under shales. At 600 feet a flow of water was found, apparently in the lower part of the Lakota sandstone, which is still running in good volume, but the water is too highly mineralized to be of use.

A boring a half mile southwest of Newcastle, also sunk for oil, has a depth of 1340 feet, or 1312 feet according to another account; its record is given on page 5. A small flow of water which was found at a depth of 820 feet is probably from the top of the Dakota sandstone; it is mixed with oil from the oil sand at 630 feet. In another well, sunk in 1902, a mile and a half southwest of the town, a large supply of water was found at 650 feet.

There is a flowing well at Jerome Siding, on the Burlington and Missouri River Railroad, 7 miles north of Osage Siding, just outside of the Newcastle quadrangle. It indicates a continuation of the artesian conditions northward from Newcastle in the lowlands bordering the western slopes of the Black Hills. The depth of the Jerome well is 520 feet. It begins in Graneros shales and extends into Lakota sandstone. The railroad company has kindly furnished the following analysis:

Analysis of artesian water from Jerome, Wyo.	
	Grains per gallon.
Sodium chloride	0.7
Sodium sulphate	29.8
Magnesium sulphate	7.0
Lime sulphate	2.3
Magnesium carbonate	.5

Morrison, Sundance, and Spearfish formations.—The great succession of shales lying below the Lakota sandstone appears to contain no water supplies either at the surface or for deep wells. They have been tested by a number of borings for oil and yielded no water. Their aggregate thickness is 1000 feet.

Minnekahta and Opeche formations.—The Minnekahta limestone is too dense to carry water, and although in some places it is cavernous, it appears not to be a water-bearing formation. The underlying Opeche red sandstones are also barren of water.

Minnelusa formation.—In its outcrops the Min-

nelusa formation appears to consist of very porous sandstone, likely to imbibe much surface water and to constitute a water-bearing horizon available in deep wells, and a number of small springs emerge from the top beds of the formation at several localities, notably at a point 4 miles north of the LAK ranch, but when the formation was penetrated by the deep boring at Cambria it was found to consist of very fine-textured rock, the sand grains being so closely cemented by lime that the interstices are filled up. Accordingly it is probable that this formation will yield no water supply to deep boring anywhere in the Newcastle quadrangle, for there is no likelihood that its character changes materially in other portions of the region.

Pahasapa limestone.—The deep boring at Cambria was begun just below the base of the Lakota sandstone and continued to a depth of 2345 feet for the purpose of testing all the formations down to the granite, which, it was expected, would be found not far below 2500 feet. When the boring was at 2345 feet the owners concluded to test a water supply found at about 2115 feet, before going farther. The water at that depth was found to yield 200 gallons a minute and its quality was entirely satisfactory, so that it has been adequate for the needs of the town. The log of the boring is given in the following figure:

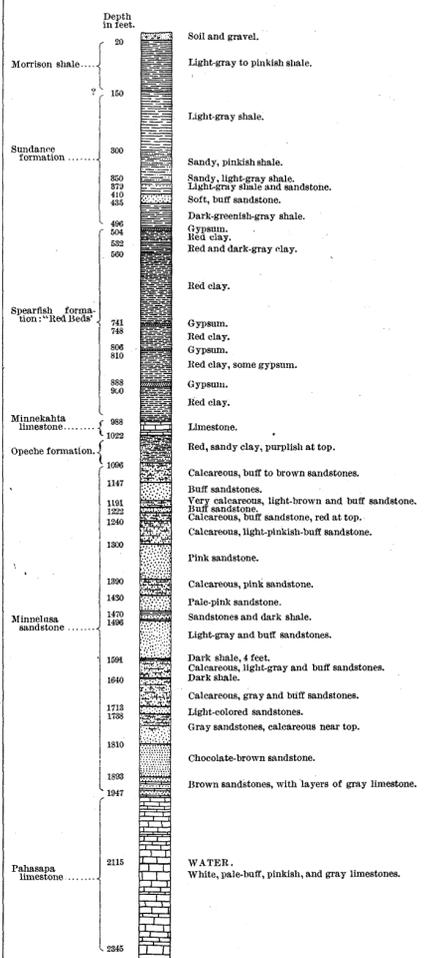


FIG. 5.—Log of well at Cambria, Wyo.

The log has been compiled from samples sent to Washington and from a set of borings admirably preserved in glass tubes by Mr. Mouck, the superintendent of the Cambria mines. It throws very important light on the underground geology of this portion of the Black Hills region. It reached the base of the Sundance formation at 496 feet, passed through the distinctive gypsiferous red deposits of the Spearfish formation from 496 to 988 feet and then through the 40 feet of Minnekahta limestone below. Next came 74 feet of Opeche formation, extending to 1096 feet, as nearly as could be ascertained, and then a great thickness of Minnelusa sandstone, mainly calcareous, extending to 1947 feet. The lowest beds are light-colored, nearly pure limestones of the Pahasapa formation. The water-bearing horizon may be the same as the one which yields numerous springs, often of large volume, at the contact of the Pahasapa limestone and the Minnelusa formation in the outcrop region east, appar-

ently rising through fissures and caverns in the limestone. If so, the Cambria well indicates an extension of a water-bearing horizon far underground and its availability under a large area of the country on the slope of the Black Hills. On the artesian water sheet of this folio there is represented the depth to this horizon in the region lying east of the hogback range of Lakota sandstone. Farther west it lies too deep to be available for ordinary wells. In the town of Newcastle, for instance, it should be expected at a depth of about 2740 feet.

Deadwood sandstone.—Below the Pahasapa limestone lies a series of shales and sandstones which probably contain a water supply. It lies below about 600 feet of Pahasapa limestone, has a thickness of probably 200 feet, and is underlain by schists and granite. The Deadwood formation is too far beneath the surface in this quadrangle to be reached by ordinary boring operations.

COAL.

In the vicinity of Cambria, north of Newcastle, there is a coal basin of considerable extent, the principal coal bed in which is 7 feet or more in thickness and of excellent quality. Coal has been mined at Cambria for the last decade, and during this time nearly 4,000,000 tons have been produced, having an average shipping value of about \$1.50 per ton. The product for 1889 was over a half million tons, valued at over \$800,000. A portion of the product is converted into coke, which is shipped to smelting works in the northern Black Hills.

The mines are at Cambria, 6½ miles north of Newcastle, where a settlement of about 500 inhabitants owes its existence and sustenance to the mining and coking operations (see fig. 7 of illustration sheet). It is connected with Newcastle by a branch line from the Burlington and Missouri River Railroad. The distribution of coal and the structural relations of this region are shown by the economic geology map of this folio. It will be seen that the coal underlies all of the plateau on the west side of Salt Creek, but the coal measures have been cut through by Little Oil Creek, Oil Creek, Plum Creek, and their branches. To the south and west they dip below the surface, and pass beneath a thick mass of overlying sandstone and shale. The structure is shown in the cross sections. The coal in this area varies greatly in thickness and purity, but, as shown on the map, there is a large area in which it is 5 feet thick or more, and in places it reaches a thickness of over 7 feet. In adjoining areas its thickness rapidly diminishes and the coal becomes extremely impure, in greater part giving place to dark carbonaceous shales. The principal basin of purer, thicker coal trends northeast and southwest, its center passing through Cambria. To the northeast it has been entirely eroded away by Salt Creek, and, although some Lakota sandstone remains on the high ridges east of the valley of that stream, it appears not to be underlain by coal. To the southwest the coal dips gently downward, lying from 250 to 325 feet below the surface of the table, to the Mount Zion ranch, beyond which an abrupt increase in dip carries it rapidly below the surface. In the canyon a few rods southwest of Mount Zion ranch, the following section was measured:

Section near Mount Zion ranch, Wyo.

	Feet.
Bony coal	½
Hard sandstone	3
Good coal	4
Sandstone with coaly streaks	½ to 1½
Coal	2

This section is 150 feet below the top of the plateau. The overlying formations are sandstone and conglomerate. Underneath there are 40 feet of very light-colored, massive sandstones, in part cross bedded, lying on the Morrison shale. A mile northeast of this locality two shafts were sunk in

Section in Camp Canyon, Wyo.

	Feet.
Coal	2½ to 3
Shale and bone	1½
Coal	6

which the coal was found at depths of 312 and 324 feet, exhibiting a thickness of from 5½ to 6½ feet. A mile farther northeast are the mines of which the workings to the year 1902 occupy the area indicated on the economic geology map. In the mines

