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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON THE

GEOLOGY AND UNDERGROUND WATER RESOURCES

OF THE

CENTRAL GREAT PLAINS

BY

N. H. DARTON

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Jos B Gossage
Rapid City
So Dakota

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ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Division of Hydrography,
Washington, D. C., July 21, 1903.

Sir: I have the honor to forward herewith a preliminary report on the Geology and Underground Water Resources of the Central Great Plains Region, by N. H. Darton, for publication as a professional paper.

Mr. Darton has been engaged for several years in studying the geology of the Great Plains region, and, although the investigation is by no means completed, it has been thought desirable to prepare some of the results for preliminary publication. The endeavor has been made to obtain all available information regarding the deep wells that have been bored, and a sufficient knowledge of the geology has been obtained to enable us to interpret their results and the bearing which they have on the prospects for further water supply in many portions of the region.

In the geologic map that accompanies the report there is presented all that is now known regarding the principal formations of the region, based on a large number of observations by Mr. Darton and his assistants, supplemented by data already published in various ways.

Very respectfully,

F. H. Newell,
Hydrographer in Charge.

Hon. Charles D. Walcott,
Director United States Geological Survey.

IVES THREE-COLOR PROCESS

PHOTOGRAPH BY N. H. DARTON

GATEWAY TO GARDEN OF THE GODS, WEST OF COLORADO SPRINGS, COLO.

PRELIMINARY REPORT ON THE GEOLOGY AND UNDERGROUND WATER RESOURCES OF THE CENTRAL GREAT PLAINS.

By N. H. Darton.

INTRODUCTION.

The area to which this report relates is shown in Pl. II. It comprises the greater portions of South Dakota, Nebraska, and Kansas, and the eastern portions of Colorado and of Wyoming, an area of about one-half million square miles. It is the result of my investigations during the past eight years, but includes also all available data from many sources. I have been aided by varions field assistants, those deserving special mention being Messrs. C. A. Fisher, C. C. O'Harra, J. E. Todd, the late C. M. Hall, G. B. Richardson, W. S. Tangier Smith, E. H. Barbour, and the late J. E. Macfarland.

On account of its size, the region presents relatively diverse geologic conditions, but comprises comparatively few formations, most of which are widespread. The question of water supply, both overground and underground, is one of great interest to the people in this district, and although considerable progress has been made in some sections in developing well waters, there are vast areas in which the present supplies are inadequate, even for local domestic use. In order to understand the relations of the underground waters it has been necessary to investigate the geology, especially the structure and stratigraphy of the water-bearing and associated formations. This part of the work has required a very large amount of special field study, and the present results show that extended investigation will be required before many important questions of geology can be fully understood.

GEOGRAPHY OF THE CENTRAL GREAT PLAINS.

GENERAL FEATURES.

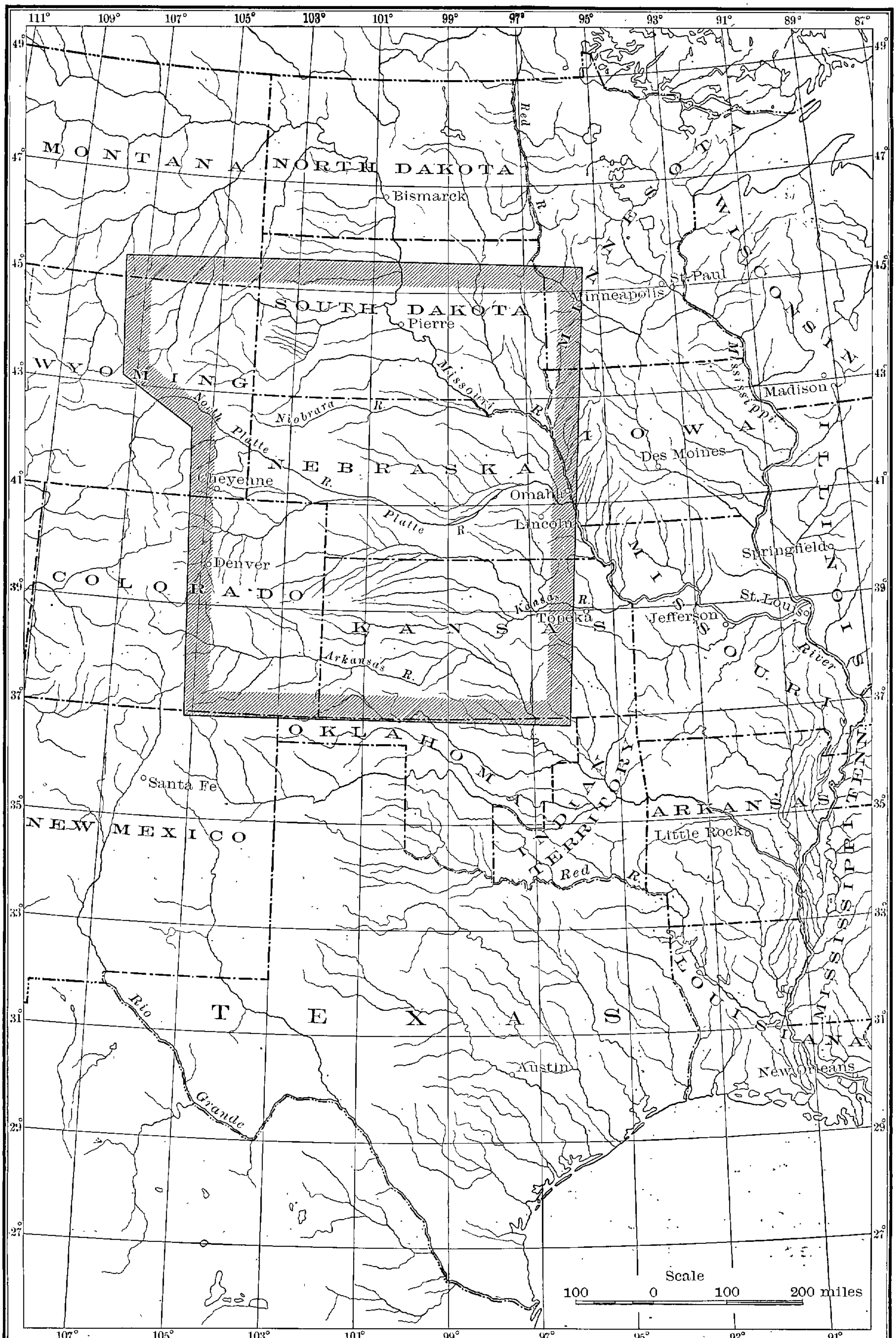
The Great Plains province is that part of the continental slope which extends from the foot of the Rocky Mountains eastward to the valley of the Mississippi, where it merges into the prairies on the north and the low plains adjoining the Gulf coast and the Mississippi embayment on the south. The plains present wide areas of

tabular surfaces traversed by broad, shallow valleys of large rivers rising mainly in the Rocky Mountains, and they are more or less deeply cut by the narrower valleys of the lateral drainage. Smooth surfaces, such as are shown in Pl. III, and eastward-sloping rolling plains are the characteristic features, but in portions of the province there are buttes, extended escarpments, and local areas of badlands. Wide districts of sand hills surmount the plains in some localities, notably in northwestern Nebraska, where sand dunes occupy an area of several thousand square miles. (See Pl. VI.)

The province is developed on a great thickness of soft rocks, sands, clays, and loams, 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, during earlier times in the sea, and later either by streams on their flood plains or in lakes. Aside from a few 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 apparently almost complete planations of the surface during earlier epochs. Owing to the great breadth of the plains and their relatively gentle declivity, general erosion has progressed slowly, notwithstanding the softness of the formations, and as at times of freshets many of the rivers bring out of the mountains a larger load of sediment than they can carry to the Mississippi their valleys are now being built up rather than deepened.

ALTITUDES AND SLOPES.

The Great Plains province as a whole descends to the east about 10 feet in each mile from altitudes of about 6,000 feet at the foot of the Rocky Mountains to those of about 1,000 feet near Mississippi River. The altitudes and rates of slope vary considerably in different districts, particularly to the north, along the middle course of Missouri River, where the general level has been greatly reduced. West of Denver the central plains have an altitude of 6,200 feet at the foot of the Rocky Mountains, and this elevation is sustained far to the north along the foot of the Laramie Mountains. High altitudes are also attained in Pine Ridge, a great escarpment which extends from near the north end of the Laramie Mountains eastward through Wyoming, across the northwest corner of Nebraska, and for many miles into southern South Dakota. Pine Ridge (see Pl. IV, *B*) 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.



MAP OF CENTRAL-WESTERN UNITED STATES, SHOWING AREA TREATED IN THIS REPORT.

The Rocky Mountains rise abruptly out of the plains in a front range which has an average height of about 5,000 feet above the adjoining lowlands, with some

FIG. 1.—Topographic map of a typical portion of the great sand-hill area in western Deuel County, Nebr. Contour interval, 20 feet. From Browns Creek topographic sheet, U. S. Geological Survey. Scale, 2 miles to the inch.

of the higher summits rising to much greater elevations. The Black Hills rise gradually out of the plains in western South Dakota and eastern Wyoming and

present mountainous summits about 4,000 feet higher than the adjoining plains. The Bighorn Mountains rise steeply and have about the same relative prominence as the Rocky Mountain Front Range.

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 the Yellowstone, Powder, Little Missouri, Grand, Cannonball, Owl, Cheyenne, Bad, and White. On the summit of Pine Ridge, not far south of the escarpment, is Niobrara River, which rises in the plains some distance east of the north end of the Laramie Mountains. To the south is the Platte with two large branches heading far back in the Rocky Mountains, the Rio Grande, and the Arkansas, the two last crossing the plains to the southeast and affording an outlet for the drainage of a large watershed of mountains and plains. Between the Rio Grande and the Arkansas are Cimarron River and numerous smaller streams heading in the western portion of the plains. Between Arkansas and Platte rivers is the Republican, rising near the one hundred and fifth meridian, and an extended system of local drainage in eastern Kansas and Nebraska.

GEOLOGY OF THE BLACK HILLS REGION.

GENERAL RELATIONS.

The Black Hills uplift is an irregular, dome-shaped anticline, embracing in its more obvious features an oval area 125 miles in length and 60 miles in breadth, with its longer dimension lying nearly northwest and southeast. It is situated in a wide area of nearly horizontal beds underlying the great east-sloping plains that extend from the Rocky Mountains to the Mississippi, and has brought above the general level of the plains an area of pre-Cambrian crystalline rocks about which there is upturned a nearly complete sequence of the Paleozoic and Mesozoic rocks from Cambrian to Laramie, all dipping away from the central nucleus. There are also extensive overlaps of the Tertiary deposits which underlie much of the adjoining plains area. The region is one of exceptionally fine exposures, which afford rare opportunity for a study of stratigraphic relations and variations. Many of the rocks are hard, and the streams flowing out of the central mountain area have cut canyons and gorges, in the walls of which the formations often are extensively exhibited. The structure presented locally on the sides of the uplift is that of a monocline dipping toward the plains. The oldest sedimentary rocks constitute the escarpment facing the crystalline rock area, and each stratum passes beneath a younger one in regular succession outward toward the margin of the uplift. Section 2, Pl. X, is a cross section showing the general relations of the formations. The sedimentary members consist

of a series of thick sheets of sandstones, limestones, and shales, all of which are essentially conformable in succession, except the overlapping areas of the Tertiary deposits, which extend across the edges of the older formations. The stratigraphy presents many features of similarity to the succession of rocks in the Rocky Mountains of Colorado and of Wyoming, but it possesses numerous distinctive local features. The principal stratigraphic features are shown in the first column in Pl. XII.

STRATIGRAPHY.

The following is a list of the formations which are exhibited in the uplift, with a generalized statement as to the thickness, characteristics, and age:

Generalized section in the Black Hills region.

Age.	Formation.	Principal characters.	Thickness.
			Feet.
Cretaceous	Laramie	Massive sandstone and shale	2,500
	Fox Hills	Sandstone and shale	250–500
	Pierre shale	Dark-gray shale	1,200
	Niobrara	Chalk and calcareous shale	225
	Benton group:		
	Carlile formation	Gray shales with thin sandstones, limestones, and concretionary layers.	500–750
	Greenhorn limestone	Impure slabby limestone	50
	Graneros shale	Dark shale with lenses of massive sandstone in its lower part at some places.	900
	Dakota sandstone	Massive buff sandstone	35–150
	Fuson	Very fine-grained sandstone and massive shales, white to purple.	30–100
	Minnewaste limestone	Gray limestone	0–30
	Lakota	Massive buff sandstone, with some intercalated shale.	100–350
	Morrison	Pale grayish-green shale	0–150
Jurassic (?)	Unkpapa sandstone	Massive sandstone, white, purple, red, buff.	0–250
Jurassic	Sundance	Dark drab shales and buff sandstones; massive red sandstone at base.	60–400
Triassic (?)	Spearfish	Red sandy shales with gypsum beds	350–600
Carboniferous (Permian).	Minnekahta limestone	Thin-bedded gray limestone	30–50
	Opeche	Red slabby sandstone and sandy shale	90–130
Carboniferous (Pennsylvanian?).	Minnelusa	Sandstones, mainly buff and red, in greater part calcareous; some thin limestone included.	450–750
Carboniferous (Mississippian).	Pahasapa limestone	Massive gray limestone	250–700
	Englewood limestone	Pink slabby limestone	25–50
Ordovician	Whitewood limestone	Massive buff limestone	0–80
Cambrian	Deadwood	Red-brown quartzite and sandstone, locally conglomeratic, partly massive; greenish-gray shale; and limestone breccia.	4–450

CAMBRIAN.

Deadwood formation.—This representative of the Cambrian appears entirely to encircle the Black Hills, but has been removed completely from the central area. Probably it did not originally cover the entire area of crystalline rocks in this region, a portion of these old rocks forming the surface during the greater part of Cambrian time and furnishing the material for the earlier sediments. Its beds lie unconformably across the upturned edges of the schists and granites on a relatively smooth surface with local shallow channels. The formation is thick in the northern hills, attaining a thickness of over 400 feet in the Deadwood region (see Pl. XIII, *A*), but thinning gradually to the south and especially to the southeast. In the region west of Fairburn exposures were found in which the formation is represented by only 4 feet of coarse sandstone lying on pre-Cambrian schists. On Rapid Creek its thickness averages about 200 feet.

The materials of the formation are always predominantly sandy and the colors dark reddish-brown or dirty buff. The basal member ordinarily is a hard massive reddish-brown quartzite with pebbly streaks. As the formation thickens this member is seen to be overlain by thinner bedded softer sandstones, in some cases interbedded with more or less shale. Portions of the basal beds of the Deadwood formation are conglomeratic, ranging from those with a sprinkling of quartz pebbles in the sandstone to a very coarse heavy conglomerate of large rounded masses of crystalline rocks and vein quartz in a red-brown matrix. Outcrops of the Deadwood formation vary greatly in prominence, but their extent in general is small. For many miles they lie in the slope below the high escarpments of the Pahasapa limestone, where the ledges are often deeply buried under talus from the cliffs above. This is particularly the case on the western side of the uplift. On the eastern side, where the dip is steeper, the hard quartzitic basal member gives rise to knobs or long bare rocky slopes of considerable prominence, one of which is shown in Pl. XIV. The many canyons cutting back into the western escarpment and those crossing the ridges on the eastern side of the uplift often afford excellent exposures of the formation.

In the region about Deadwood the formation comprises about 30 feet of basal conglomerate, overlain by 30 feet of sandstone, followed by 200 to 400 feet of gray shales, with layers of flaggy limestone, limestone conglomerate, and sandstone. Near the top is a very characteristic member of hard massive sandstone 5 to 12 feet thick, overlain by 20 to 45 feet of green shales of supposed Cambrian age. The limestone conglomerate consists of flat pebbles and flakes of limestone more or less thickly sprinkled with glauconite grains, a characteristic feature of the Cambrian of the Northwest. The formation yields

middle Cambrian fossils, mainly *Obolus*, *Hyolithes*, *Dicellomus*, *Asaphiscus*, *Olenoides*, *Ptychoparia*, and *Acrotreta*.

ORDOVICIAN.

Whitewood limestone.—This formation is a conspicuous member in the northern Black Hills, particularly about Deadwood, where it has a thickness of 80 feet and outcrops extensively in a number of canyons, a typical exposure being in Whitewood Canyon below Deadwood. It thins to the southeast and southwest and finally disappears. The rock is a massive tough limestone, of buff color with brownish spots or mottlings. It contains large *Endoceras*, *Maclureas*, and corals of Ordovician age. In part of the area it is overlain by several feet of greenish shales which may possibly be of Devonian age, though no fossils have yet been found in them.

CARBONIFEROUS.

In the Black Hills region the Carboniferous rocks comprise several formations apparently representing continuous deposition throughout the period. The many formations of Mississippian and Pennsylvanian age, which compose the Carboniferous in the central United States, are not differentiable in the Black Hills, unless possibly in their broader faunal relations. There appear to be five formations separable—the thin Englewood limestone at the base, the massive gray Pahasapa limestone next above, the thick mass of Minnelusa sandy beds, the Opeche red beds, and the Minnekahta limestone, the latter, at least, of Permian age. The Carboniferous lies directly on the Cambrian in the central and southern parts of the Black Hills, but to the north it is separated from the Cambrian by the Whitewood limestone and overlying green shales described above.

Englewood limestone.—This formation consists of a series of thin-bedded, pale, pinkish-buff limestones, which appears to extend continuously around the Black Hills, everywhere immediately underlying the Pahasapa limestone. It averages 25 to 50 feet in thickness and presents frequent outcrops in the lower slopes of the limestone escarpment and in numerous canyons. It merges rapidly into the overlying limestone, occasionally with a few feet of impure buff limestone intervening. Generally it is sharply separated from the Deadwood formation or the Whitewood limestone, but only by a sudden change in the nature of the materials. It is usually fossiliferous, containing numerous corals and occasional shells. The following forms have been reported: *Fenestella*, *Orthothetes*, *Leptæna*, *Spirifer*, *Chonetes logani*, *Reticularia peculiaris*, *Syringothyris carteri*, and crinoids. It is correlated with the "Chouteau" or "Kinderhook" of Mississippi Valley.

Pahasapa limestone.—This prominent member, formerly known as the "gray limestone," has an extensive outcrop area in the Black Hills uplift, constituting much

of the high, wide plateau west of the central region of crystalline rocks and being characteristically exhibited in the great lines of cliffs in the escarpment surrounding that region. It consists of a thick deposit of massive gray limestone, usually outcropping either in precipitous cliffs with many picturesque irregularities of form or in wide, flat surfaces.

The most extensive exposures of the Pahasapa limestone are in the great plateau west of Custer. Here the formation begins in a line of high cliffs, surmounting slopes consisting of crystalline schists and of the relatively thin sheets of Englewood limestone and Deadwood sandstone. In Pennington County the plateau has a width of 10 miles of continuous limestone outcrop, constituting the most elevated area in the Black Hills, except the small summit of Harney Peak. To the west the limestone passes beneath the sandstone of the Minnelusa formation, but it is exposed again in the arch of the steep anticline near the Wyoming-South Dakota line. East of the crystalline-rock area the limestone stands out on many conspicuous knobs or lies on the eastern slopes of ridges due to the Deadwood quartzite, but does not attain the high altitude which it has farther west. The more rapid dip to the east soon carries the formation below the surface in that direction, but it constitutes the walls of many of the canyons of the streams from Beaver Creek northward, notably in the deep canyon of Spearfish Creek.

The thickness of the Pahasapa limestone in the central and southern Black Hills varies from about 450 feet at the northwest to 225 feet at the east and southeast. All along the southeastern side of the hills it remains at 225 feet, with slight local variations; then increases to 300 feet near Rapid, 350 feet on Elk Creek, and from 400 to 500 feet in the Deadwood region. In Spearfish Canyon 700 feet is reported by Jaggar. The formation does not present any noteworthy lithologic subdivisions, but its upper part is often siliceous and flinty and stained red to a greater or less extent from the overlying red beds of the Minnelusa formation. Fossils occur sparingly throughout the formation, including *Spirifer centronatus*, *Seminula subtilita*, *Productus*, and *Zaphrentis*, a fauna which indicates Mississippian (lower Carboniferous) age.

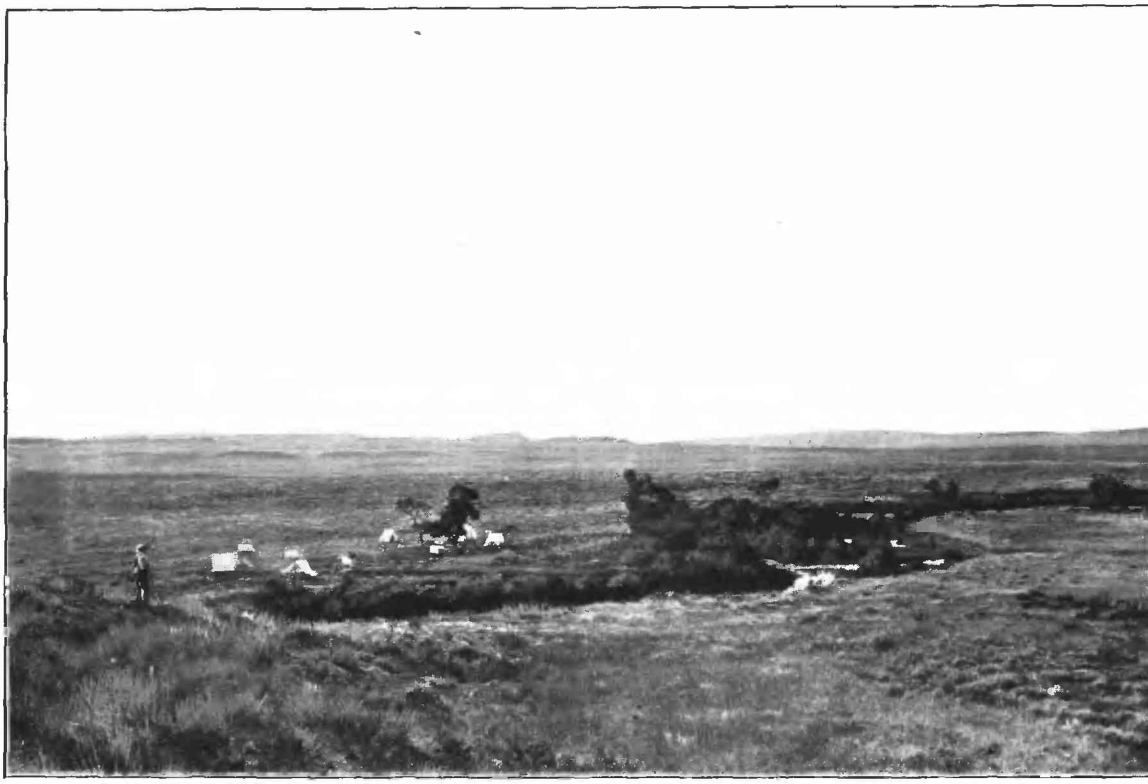
Minnelusa formation.—The Minnelusa formation is next to the Pahasapa limestone in order of prominence among the Black Hills formations, extending around the uplift in a broad zone of conspicuous outcrops. It varies in components, but consists mainly of thick masses of buff and reddish sandstones, which are striking features in the walls of the many canyons by which the formation is traversed. The sandstones are mostly fine grained, massively bedded, and in their unweathered condition contain a considerable proportion of carbonate of lime. Thin sheets of limestone occur in places, and, less frequently, sandy shales of red or gray color. Some layers are cherty. Although the formation probably was deposited at

A. TYPICAL VIEW ON THE HIGH PLAINS OF WESTERN KANSAS.

Level floor of Ogalalla formation. Photograph by G. K. Gilbert

B. TYPICAL VIEW OF THE GREAT PLAINS WEST OF PIERRE, S. DAK.

The great brown prairie of Pierre shale, one of the finest grazing regions in the world. Photograph by E. H. Barbour.

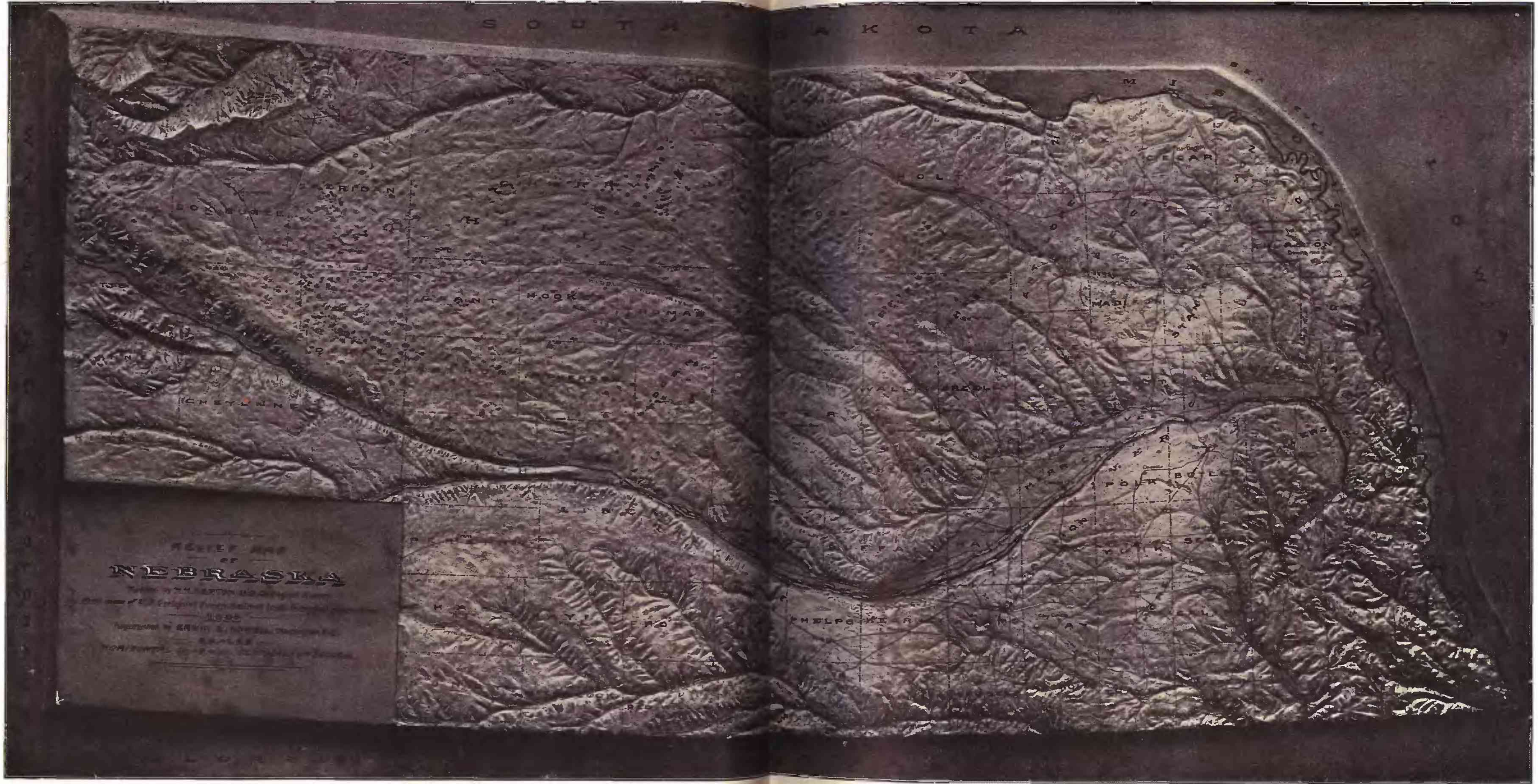


A TYPICAL VIEW ON THE GREAT PLAINS, NORTH OF CHEYENNE, WYO.

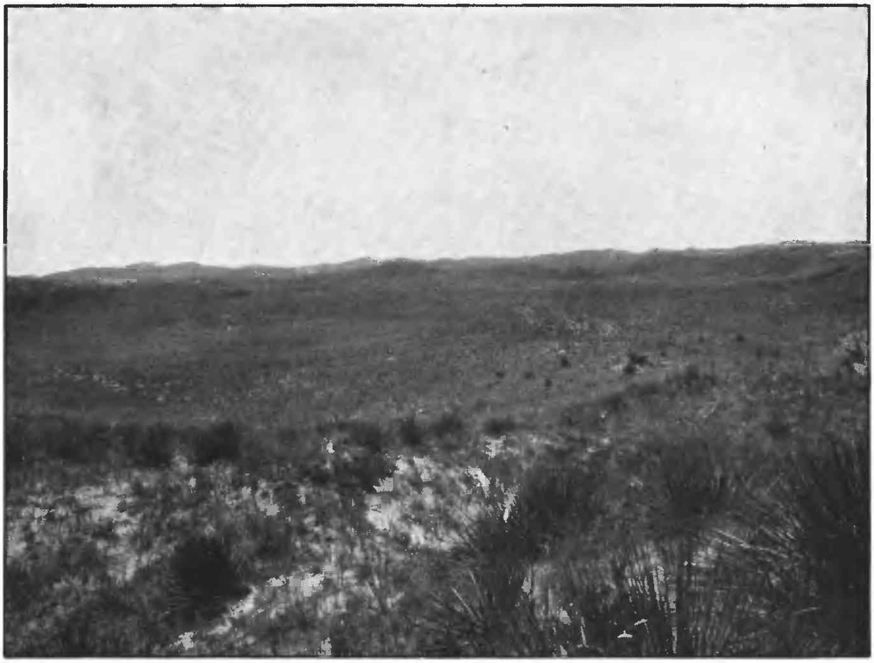
Buttes of Arikaree formation in distance. Looking southeast. Photograph by W. H. Jackson.

B. PINE RIDGE ESCARPMENT AT THE NEBRASKA-WYOMING STATE LINE.

High cliffs of Arikaree sandstone; lowlands of Brule clay. Looking west.



RELIEF MAP OF NEBRASKA.



A

B

SAND HILLS OF WESTERN NEBRASKA.

A Leeward side of dunes. Looking west. *B*. Windward side of dunes, with blow-outs. Looking southeast.

the same time as the Coal Measures, which contain extensive beds of coal in Mississippi Valley, it is barren of coal in the Black Hills, except in the occasional occurrence of very thin beds of impure coal in gray shales. The formation is thickest on the western side, where it is fully 600 feet thick. It thins gradually to the south and east, being about 420 feet thick west of Hot Springs, and less than 400 feet thick on Spring Creek.

Although the Minnelusa formation has wide areas of exposure, it does not give rise to very marked topographic features, generally occupying elevated slopes surmounted by low hills and ridges due to its harder layers. Its inner boundary is usually not marked by an escarpment such as is seen at the inner margin of the Pahasapa limestone, and there is no noticeable topographic break in passing from one formation to the other. On slopes of the two formations the soil becomes sandy on the Minnelusa beds. In the many canyons which are cut through that formation the Pahasapa limestone is usually exposed beneath it without presenting any change of features except in color. The lower members of the Minnelusa formation are generally buff slabby sandstones, often having a thickness of 100 feet, and a thin bed of red shale.

Breccias, which occur in the middle beds, are a distinctive feature throughout the southern Black Hills. The brecciated material is usually somewhat more calcareous than the matrix, but it is all of local origin. In the region west of Hermosa and thence northward the Minnelusa beds consist of a thick mass of coffee-colored sandstone at the top, reddish-buff sandstone with some thin interbedded limestone layers next below, and a basal member of gray sandstone. On the western side of the Black Hills the formation consists of the members given in the record of the boring at Cambria (p. 371). In its outcrops there are exhibited a top series of light-colored massive sandstones, a thick medial member of red and buff sandstones, and a basal member of gray calcareous sandstone with reddish shale partings and considerable chert. At its base there is usually a red shaly bed of slight thickness, containing oval concretions of hard silica from 6 inches to 2 feet in diameter. The total thickness is about 600 feet. A chemical examination of the borings from the Cambria well shows that nearly all the rocks contain considerable carbonate of lime underground, but in the outcrops the lime has been mostly leached out and porous sandstones remain.

The age of the formation has not been satisfactorily ascertained, for fossils are rare. A few impressions found in the upper beds west of Hot Springs appeared to be *Productus semireticulatus* and *Athyris subtilita*, which indicate upper Carboniferous (Pennsylvanian) age for these beds. Mississippian *Leperditia* have been found in the concretions in the red shale at the base of the formation. If the formation represents the Hartville formation of the Hartville region, as it probably

does, its lower portion is Mississippian and its upper beds Pennsylvanian in age. There is some suggestion also that its lower beds represent the upper portion of the Guernsey formation of the Hartville region, which would indicate a still lower extension into the Mississippian.

Opeche formation.—This series of red beds, lying between the Minnelusa formation and the Minnekahta limestone, extends continuously around the Black Hills. Its exposures are almost always confined to the slopes below the escarpments of Minnekahta limestone. Its thickness averages slightly less than 100 feet. The materials are soft red sandstone, mainly thin bedded and containing variable amounts of clay admixture. At the top of the formation, for the first few feet below the Minnekahta limestone, there are shales which are invariably of deep purple color. The basal beds of the formation are usually red sandstones, the beds varying in thickness from 4 to 15 inches. A few thin local beds of gypsum are sometimes observed in the formation, attaining in Gillette Canyon a thickness of several inches.

On Spring Creek, Battle Creek, and French Creek the formation averages about 100 feet in thickness; in Beaver Canyon it attains its maximum thickness of 150 feet; on Cold Brook, 4 miles northwest of Hot Springs, its thickness is 115 feet, with purple clay at the top, 50 feet of red sandy clay below, and 60 feet of red sandstone at the bottom in beds 1 to 4 feet thick, with red clay partings; farther down Cold Brook, at a point 1½ miles from Hot Springs, a thickness of 135 feet is exhibited. Along the southwest side of the Black Hills the thickness averages from 90 to 100 feet, and on the northern slopes is about 75 feet. In the well at Cambria the following section was obtained:

Section at Cambria, Wyo.

	Feet.
Purplish shales	4
Dark-purple shales	4
Red clay (sandy)	62
Dark red-brown sandstone	2½
Light-red sandy shale lying on a light-pinkish sandstone at a depth of 1,096 feet, which is supposed to be the top of the Minnelusa formation	1½
Total	74

The age of the formation has not been definitely determined, for so far it has yielded no fossils. From the facts that the overlying Minnekahta limestone is of Permo-Carboniferous age and that the deposition of gypsiferous red beds in other regions began in Permo-Carboniferous time, the formation is provisionally assigned to that division.

Minnekahta limestone.—This formation, long known as the "purple limestone," is a prominent member in the Black Hills region. Though thin, averaging less than

50 feet in thickness, it is hard and flexible and covers moderately extensive areas on the outer slopes of the Minnelusa formation. The prominence of the Minnekahta limestone outcrops is due largely to the fact that the overlying formation is soft, red shale, which has been deeply eroded, leaving the underlying limestone bare on slopes up which the red shale originally extended. The underlying formation, the Opeche, also being soft, the limestone nearly everywhere presents an escarpment, and the many canyons which are cut through it have vertical walls of the limestone. (See Pls. XV and XVI.)

The formation is uniform in character throughout, being a thin-bedded light-colored limestone containing magnesia and more or less clay. Its thin bedding is a characteristic feature, although the thin layers are so cemented together that the outcropping ledges present a massive appearance. On weathering, however, it breaks into slabs usually 2 to 3 inches in thickness. On the western side of the Black Hills, notably in the region from east of Clifton northward, its coloring is slightly darker, varying from dove color to lead gray, and some of its beds present a seminodular structure. An increased admixture of clay is also observed in some layers. The general appearance of the formation is always slightly pinkish, with a tinge of purple, from which the term "purple limestone" originated. The Minnekahta limestone occasionally contains fossils which are believed to be Permian forms.

TRIASSIC (?).

Spearfish formation.—The Spearfish formation is the conspicuous series of gypsiferous red beds encircling the Black Hills and in most places giving rise to the wide Red Valley, which, in the northern Black Hills, the Indians have designated the "race course." Red Valley is treeless, and usually presents wide areas of bare red slopes and red buttes, with frequent outcrops of gypsum.

The formation consists of from 350 to 695 feet of red sandy clays, with intercalated beds of gypsum sometimes 30 feet thick. The bright red of the shales and the snowy whiteness of the gypsum are striking features; in Pl. XVII an attempt has been made to show the red color of these shales.

Were it not for the beds of gypsum the formation would present no noticeable features of stratigraphy. The sedimentary material is almost entirely a red shale containing varying amounts of sand admixture, and is generally thin-bedded. The gypsum occurs in beds at various horizons, some of the larger beds extending continuously over wide areas. There is also throughout the formation more or less gypsum of secondary deposition in very small veins.

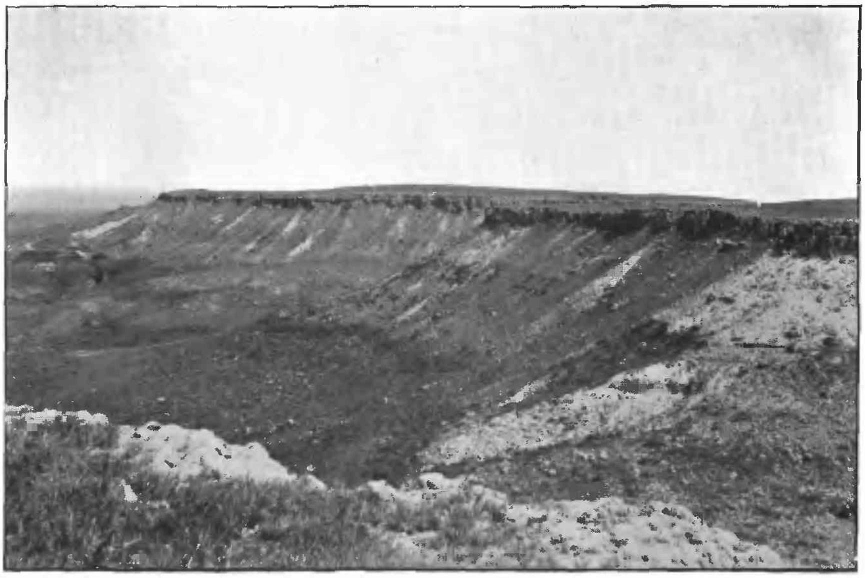
The continuity of the outcrops of the red beds is considerably broken in the region west of Fairburn and Hermosa by overlaps of the Tertiary formations, which in some cases completely fill Red Valley. The width of the outcrop varies

from 1 to 3 miles, attaining its maximum in the region west of Buffalo Gap and in the broad belt extending from east of Minnekahta station nearly to the north end of Elk Mountain. Owing to the local steep dip of the formation, the outcrop is very narrow for 5 miles north from Cascade Springs and in a portion of the valley of Stockade Beaver Creek east of Newcastle. The Belle Fourche cuts into the formation for some distance above and below the Devils Tower.

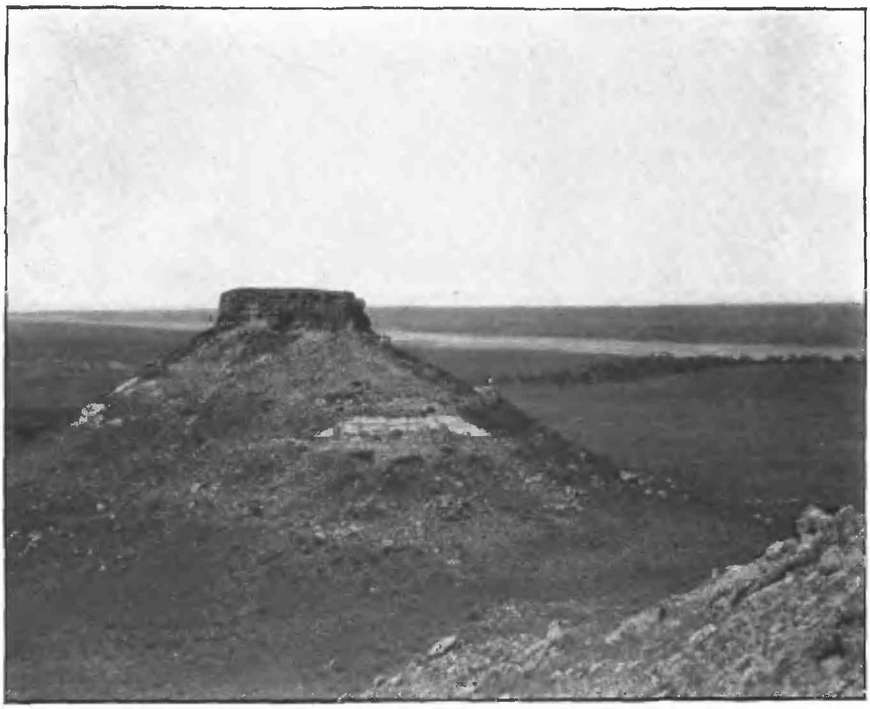
The thickness of the Spearfish formation can seldom be determined with any degree of accuracy, owing to the softness of its materials and the frequent variations in its dip. Along the east side of the Black Hills it appears to have a thickness of between 350 and 400 feet, so far as can be estimated from very indefinite dip observations. In this region the principal bed of gypsum occurs considerably below the center of the formation. West of Hermosa this gypsum bed has a thickness of about 15 feet, but southward, in the region west of Fairburn, it thins out and may at some points be absent. West of Buffalo Gap the gypsum deposits increase in thickness and attain their maximum prominence at Hot Springs, where the principal beds have a thickness of 33½ feet, with a 10-foot parting of red shale between them. In the wide part of Red Valley, extending south from Hot Springs to Sheps Canyon, gypsum beds are a conspicuous feature, but they gradually diminish in thickness in that direction.

At Cascade Springs and thence north on the west side of the anticline the dips are very steep and the outcrop of the Spearfish formation becomes so narrow that Red Valley is only a few rods in width from the springs north nearly to the railroad. Here a relatively accurate measurement of the beds was made from the steep slopes of the Minnekahta limestone to the basal sandstone beds of the Sundance formation. At the base of the Spearfish there are 150 feet of red sandy shales, then a bed of gypsum, in places 20 feet in thickness, overlain by 250 feet of red sandy shales with a few thin layers of gypsum, the formation here having a total thickness of 420 feet. Just west of Fanny Peak a measurement was made showing 450 feet, or possibly slightly more, of red sandy shales, including two thick beds of gypsum near the middle. Northeast of Cambria there are exhibited 25 feet of gypsum at the top of the formation, several thick beds in its center, and a local thin bed of gypsum lying directly on the Minnekahta limestone at its base. In the boring at Cambria the Spearfish red beds were plainly recognized, having a thickness of 492 feet, with the members described on page 371. In the deep well at Fort Meade the formation is 695 feet thick.

Throughout the Black Hills the formation is distinctly separated from the underlying Minnekahta limestone and the overlying shales and red sandstone of the Sundance formation.



A



B

MORTAR-BED TOPOGRAPHY AT MARGIN OF THE HIGH PLAINS IN CENTRAL KANSAS.

Photographs by C. Willard Johnson.

It has been regarded as Triassic in age, because it lies unconformably beneath marine Jurassic deposits and is underlain by the Minnekahta limestone, which is known to be of Permo-Carboniferous age. No fossils have yet been discovered in the formation except a small fragment of a fish, which was not sufficiently distinct for determination. It is possible that at least the lower portion of the formation is Permo-Carboniferous, but there is no evidence on this point one way or the other.

JURASSIC.

Sundance formation.—This member of the Jurassic extends continuously around the Black Hills uplift, and throughout its course presents characteristics by which it can easily be recognized. It outcrops mainly along the outer side of Red Valley, on the lower inner slopes of Hogback Range, and in Belle Fourche Valley. It carries abundant marine fossils throughout. The formation comprises about 350 feet of shales and sandstones, in a series which varies but little in sequence in different portions of the region. The shales are mainly dark green and the sandstones pale buff, but there is an intermediate member of sandy shales and sandstones of reddish color and often a local basal member of massive red sandstone. The shales usually include thin layers of limestone, which are always highly fossiliferous. Fossils also occur in the sandstone. Molluscan fossils predominate, together with *Pentacrinites asteriscus* and bone fragments.

Certain members of the formation are of general occurrence, while others are less persistent. The usual succession is 60 feet of lower dark shale, 30 feet of massive, buff, ripple-marked sandstone next above, a reddish, sandy shale above this, and at the top about 200 feet of green shale with thin fossiliferous limestone layers. At the base of the formation there is often a massive red or buff sandstone occurring in extended lenses and frequently attaining a thickness of 25 feet. Some characteristic features of the formation are shown in Pls. XVII, XVIII, *A*, and XIX, *B*.

Unkpapa sandstone.—This formation takes its name from one of the tribes of Dakota Indians which at one time dwelt about the southeastern portion of the Black Hills. It is always clearly separable both from the Sundance shales below and the Morrison shales or the Lakota sandstone above. It consists of a very massive fine-grained sandstone, varying in color from white to purple and buff. Its greatest development is in the foothill ridges or hogbacks east of Hot Springs. Its first outcrops southward are observed about Cascade Springs, and it extends continuously from that region, past Hot Springs, all along the eastern side of the Black Hills to the Belle Fourche. North of Buffalo Gap its thickness diminishes rapidly to less than 50 feet in most places, but north of Rapid it increases locally to 150 feet. It is thickest in Sheps Canyon, southeast of Hot Springs, where 225 feet were measured.

Some of the exposures east of Hot Springs are very striking in their colorings of brilliant pink, purple, and pure white. In three of the canyons between Fall River and Buffalo Gap the rock has been quarried to some extent for building stone. Portions of the rock are beautifully banded with various colors, in part along the stratification planes, but often diagonal to them. In the quarry west of Buffalo Gap these banded beds exhibit minute faulting in a most instructive manner, affording fine illustrations of block-fault phenomena. The sandstone is characterized in general by its fine grain and very massive but uniform texture. (See Pl. XIX.) Contacts with the overlying buff sandstones of the Lakota formation are frequently exposed, and they are seen to be marked by considerable unconformity due to erosion. One of them is shown in Pl. XIX, *A*.

CRETACEOUS.

Morrison shale.—This formation has been designated the Atlantosaurus beds by Marsh and others, and for a while it was known as the Beulah shale. It appears northwest of Hermosa, lying between the Unkpapa sandstone and the Lakota formation, thickens rapidly to an average of about 150 feet, and passes around the northern and western sides of the Black Hills as a prominent member of the series. Beyond the edge of the Unkpapa sandstone it lies conformably upon the Sundance formation, and, owing to the similarity of materials, might not be readily separated if the relations had not been determined on the eastern side of the uplift. It finally thins out northeast of Edgemont. The formation is mainly composed of a "joint clay" or massive shale, somewhat darker and more fissile to the east than to the north and west. The predominating color is a very pale greenish gray merging into chocolate and maroon. Thin beds of fine-grained, white or light-gray sandstone and some thin local layers of impure limestone are included. A few fresh-water shells were observed, and there is an almost general occurrence of saurian bones, believed to be of Cretaceous age, although some paleontologists regard them as latest Jurassic.

Lakota sandstone.—This formation, which consists mainly of sandstone, gives rise to the crest and upper slopes of the hogback ranges that form the outer encircling rim of the Black Hills. Its sandstones are hard, coarse grained, cross-bedded, and massive, with partings of shale of no great thickness. Locally the formation includes beds of coal, which about Cambria and on Hay Creek are mined to some extent. In the central and southern Black Hills its thickness is usually from 200 to 300 feet, with local variations; to the north it averages about 100 feet thick. Throughout its course it lies unconformably on the Morrison shale to the north and west and on the Unkpapa sandstone to the east and south.

A. CHEYENNE RIVER AT MOUTH OF LANCE CREEK, WYOMING.

A typical stream of the arid regions, nearly dry in midsummer. View upstream.

B. NORTH PLATTE RIVER AT THE NEBRASKA-WYOMING STATE LINE.

View showing shrunken midsummer condition. Looking east.

The amount of unconformity is not known, and the period of uplift it represents was not one of flexing of sufficient amount to give rise to any material discordance in dip. A typical exposure of the unconformity is represented in Pl. XIX, *A*.

Although the Lakota formation presents the predominant features above described, there are frequent local variations in the thickness of the beds and in the occurrence of intercalated fine-grained members. In the canyon of Fall River the formation has a thickness varying from 225 to 250 feet. (See Pl. XX.) The beds of sandstone are very massive, but they are separated by greenish-gray shales 15 to 20 feet thick at several horizons. The uppermost member, a dull-yellow sandstone, is immediately overlain by the Minnewaste limestone in the region east of Hot Springs. Some conglomeratic layers occur, especially in the lower members.

Excepting petrified wood, which is abundant, fossils are rarely found in the Lakota formation. A few bones of a stegosaur were obtained near Buffalo Gap, and occasional bone fragments were observed at various localities. Plants of lower Cretaceous age occur east of Hot Springs and in the Hay Creek region, and pine needles are abundant in some of the coaly layers. Cycads are found in places, notably in the slopes southwest of Minnekahta and near Blackhawk, and recently Professor O'Harra has observed one northwest of Aladdin. This geologist also discovered the following fossils 3 miles north of Piedmont, which were determined by Dr. T. W. Stanton: An isopod crustacean, probably of family Ægidæ; an *Estheria;* a scale of a gar (*Lepidosteus*), and a crocodile tooth—all fresh-water forms.

Minnewaste limestone.—This formation overlies the Lakota sandstone from the vicinity of Cascade Springs northward to Buffalo Gap. For the greater part of its course it has a thickness of only 25 feet, but is conspicuous on the hogback ranges east of Hot Springs, extending far up the slopes on some of the higher divides. One of the most extensive exposures is at the falls of Cheyenne River. These falls are due to this formation, the water falling over a ledge of it about 20 feet high. Widespread outcrops may be seen in the anticline 2 miles east of Hot Springs, where, with a steep dip to the west, they appear on the western slope of the anticlinal ridge.

The rock is a nearly pure light-gray limestone, presenting a uniform character throughout. An extended search has failed to detect any fossils in it, but it is of lower Cretaceous age, since it lies below the Fuson formation. It thins out rapidly north of Buffalo Gap and appears to be entirely absent in the canyon of Fuson Creek. It is thin at Cascade Springs and disappears a short distance to the west.

Fuson formation.—This is a series of fine-grained deposits lying between the Dakota and the Lakōta sandstones and encircling the Black Hills. Its thickness averages about 50 feet, but varies considerably and is greatest in the northern hills. Its material consists of a mixture of clay and fine sand, usually massively bedded. Some beds of coarser sandstone are locally included, and other portions are nearly pure shale. The predominant color is white or gray, but buff, purple, and maroon tints are often conspicuous.

As the formation is relatively soft compared with adjoining sandstones, it usually gives rise to a depression between a low crest of Dakota sandstone on the one hand and the higher summits of the Lakota sandstone on the other. One of the most extensive exposures is at the falls of Cheyenne River, where the section is as follows:

Section at falls of Cheyenne River, South Dakota.

	Feet.
Dakota sandstone.	
Dark sandy shale	4
Soft, gray, slabby sandstone; plants	6
Compact white mudstone	8
Dark-green clay	1
Dark-gray compact mudstone	25
Very compact white mudstone	2½
Gray mudstone	6
Harder white mudstone	9
Purplish shale	1
White fine-grained sandstone	5 to 12
Purple shale	6 to 8
Light-buff massive sandstone	25
Dark-buff coarser sandstone, much honeycombed by weathering	25
Minnewaste limestone.	

Outcrops of the formation are considerably obscured by talus along the canyon of Fall River, but there are extensive exposures in the vicinity, notably in the canyon on the steep side of the anticline 2 miles due east of Hot Springs, where much of the material is bright purple and strongly resembles a shale that has been subjected to alteration by igneous matter. Fuson Canyon affords some striking exposures of a portion of the formation in cliffs capped by Dakota sandstone. The uppermost bed is a moderately hard sandstone underlain in sequence by 10 feet of purplish-gray shales, 10 feet of white mudstone, and 20 feet of bright-purple shale. On Dry Creek the formation is represented by 50 feet of white massive shale. On Squaw Creek the Lakota sandstone is overlain by about 50 feet of buff and purple shale, grading upward to the Dakota sandstone through several feet of shale and thin sandstone. Northwest of Hermosa shales of bright color prevail, much of the material being purple. Near Rapid it

is 100 feet thick, and near Sturgis 65 feet. On the southern and western sides of the hills the formation is often mixed with considerable sand and sandstone, and north of Elk Mountain for some distance it becomes thinner and sometimes so sandy that it is difficult to distinguish it from the Dakota sandstone. In the northern hills its thickness varies from 60 to over 100 feet, but it is often covered by talus from the sandstone cliffs above. In the Hay Creek region it has yielded large numbers of fossil plants of lower Cretaceous age, described by L. F. Ward[a] as occurring in the upper part of "Division No. 2."

Dakota sandstone.—This formation is the uppermost member of the series formerly designated "Dakota sandstone" in the Black Hills region. Being rarely over 100 feet thick, it constitutes only a small part of the mass of the hogback range, but is, nevertheless, conspicuous, because the foothills to which it usually gives rise ascend steeply out of the adjoining valley or level plain underlain by the Graneros shales. It generally consists of a brown sandstone, hard and massive below, but thinner bedded above. It appears to extend continuously around the Black Hills. The fossil plants which have been obtained from it are impressions of dicotyledonous leaves occurring in the upper portion of the formation.

Some aspects of the Dakota sandstone are shown in Pls. XX and XXI, in which the more massive variety of the rock is shown in the cliffs at the top.

Benton group.—The Graneros shale, which is the lowest member of the Benton group, extends entirely around the Black Hills uplift, with a course marked by lowlands and valleys. It is believed to be the precise equivalent of the Graneros shale of southeast Colorado, for it lies between the Dakota sandstone and the very characteristic Greenhorn limestone which in both regions is filled with impressions of *Inoceramus labiatus*.

In some areas the formation contains, toward its base, a thin layer of hard sandstone, which often rises in a ridge of considerable prominence. It occurs locally, but apparently always at the same horizon, a short distance beneath a typical series of hard shales and thin-bedded sandstones, which weathers to a light-gray color and contains large numbers of fish scales. The sandstone member is a noticeable feature in the vicinity of Newcastle, where it contains petroleum and has been explored as an oil sand. It there attains a thickness of 30 feet and lies 205 feet above the Dakota sandstone. To the north, in the vicinity of Pedro, it thins to less than a foot, and to the south near Clifton, it disappears. In the Newcastle region it is overlain by 800 feet of black shales, constituting the remainder of the formation, which here, consequently, has a total thickness of 1,085 feet.

The Graneros formation thins toward Edgemont, and thence for many miles to the northeast its thickness is about 900 feet, so far as could be ascertained from

[a] Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, pp. 521-946

numerous cross-section measurements, with rather uncertain dip determinations. West of Hermosa a sandstone again comes in about 200 feet above the base of the formation and attains a thickness of 15 feet; it is traceable for 4 to 5 miles, and then thins out again. At a point 2 miles north of Hermosa it contains abundant impressions of fossil leaves. This sandstone again appears on the Belle Fourche north of Aladdin and on the Little Missouri west of the Devils Tower.

One of the most prominent features in the plains immediately adjoining the Black Hills is a low but distinct escarpment due to a hard limestone bed in the middle of the Benton group. It usually lies from 1 to 4 miles distant from the hog-back ridge of the Dakota sandstone and presents its face toward the hills. It is thin, but persistent, and is characterized by large numbers of impressions of *Inoceramus labiatus*, a fossil of infrequent occurrence in the adjoining formations. It is believed to represent the Greenhorn limestone of Arkansas Valley.

The Greenhorn limestone contains a considerable amount of clay and fine sand. It appears to gain hardness on weathering, breaking into hard, thin, pale-buff slabs covered with impressions of the distinctive fossil. (See Pl. XXIV.) Its thickness averages about 50 feet. At its base it is usually distinctly separated from the dark shales of the Graneros formation, as shown in Pl. XXII, and in its upper portion appears to grade into shales of the Carlile formation through 6 or 8 feet of passage beds.

The most extensive exposures of the Greenhorn limestone are in the prominent escarpments west and northwest of Edgemont, which rise high above the slopes extending along either side of Cheyenne River, as shown in Pl. XXIII, *B*. Owing to the low dip in this vicinity the limestone is spread out in plateaus extending back for some distance from the edge of the escarpment. In Weston County, Wyo., where the dip soon increases in amount, the escarpment ceases, giving place to a small but very persistent ridge of nearly vertical beds, which continues for many miles to the north. (See Pl. XXIII, *A*.) In the ridge south of Newcastle there is a local diminution of dip in which the outcrop widens into a narrow sloping plateau for a few miles. In the region about Fairburn the formation is traversed by a syncline which spreads it out into a bifurcated ridge south of the town. On the adjoining divides, notably in those between French Creek and Battle Creek, and between Battle Creek and Spring Creek, the formation is buried beneath the overlapping White River deposits. It is well exposed in the banks of Battle Creek, 1½ miles below Hermosa, where, in its only slightly weathered condition in the fresh stream cut, it is seen to be a hard, calcareous, light-gray shale filled with *Inocerami*. In the northern Black Hills it is a less conspicuous feature, but is distinctly traceable throughout.

SCOTTS BLUFF, FROM THE NORTH SIDE OF NORTH PLATTE RIVER.

View showing terrace at foot of bluffs, into which the badlands are cut, and the broad river bottom; Dome Rock on the left. Arikaree and Gering formations on Brule clay. A typical butte of Tertiary formations.

The Carlile formation, which is the uppermost member of the Benton group, is a series of shales, with thin sandstone and impure limestone layers, lying between the Greenhorn limestone and the Niobrara chalk. It is similar in character and relations to the deposits occupying the same position in southeastern Colorado. The formation consists mainly of shales, with two thin, hard beds of sandstone, the upper one calcareous; at the top the shales contain numerous oval concretions, always yielding occasional *Prionotropis prionocyclas*. The thickness varies from 500 to slightly over 700 feet, the larger amount being in the region about Newcastle. Some typical sections are as follows:

Section of Carlile formation near Buffalo Gap, S. Dak.

	Feet.
Niobrara chalk.	
Shales, with large buff concretions	150
Hard slabby sandstone	2
Gray shale	130
Thin, coarse sandstone	4
Gray shale	75
Concretions in gray shale	2
Gray shale	40
Calcareous beds with *Ostrea*, etc	4
Shale and talus	180
Greenhorn limestone.	

Section of Carlile formation, 1½ miles southeast of the falls of Cheyenne River, South Dakota.

	Feet.
Niobrara chalk.	
Gray shale, with large buff concretions	50
Gray shale	70
Light-gray sandstone	4
Dark-gray shale, with thin sandy layers	160
Sandstone	2
Gray shales	150
Greenhorn limestone.	

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

	Feet.
Niobrara chalk.	
Dark shales, with light-colored concretions	130
Dark shales	200
Calcareous concretions	3
Sandy shales, with thin sandstones	170
Brown sandstone	4
Dark shales	200
Greenhorn limestone.	

GEOLOGIC SECTIONS ACROSS THE CENTRAL GREAT PLAINS
ALONG THE LINES 1, 2, 3, 4, AND 5, PLATES XXXV AND LXIX
BY
N. H. DARTON

Section of Carlile formation north of Pedro, S. Dak.

	Feet.
Niobrara chalk.	
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 thickening of the sandstones in this last section is due mainly to intercalations of sandy shales.

Niobrara formation.—The calcareous deposits of the Niobrara formation completely encircle the Black Hills, presenting distinctive features throughout, but to a less degree to the north and northeast than to the south. The material is a soft shaly limestone or impure chalk, containing greater or less admixture of clay and fine sand. In unweathered exposures it is usually light gray, while its weathered outcrops have a bright-yellow color which usually renders them conspicuous, although, owing to the softness of the materials, they rarely give rise to noticeable ridges. The thickness of the formation is about 225 feet in the central and southern Black Hills and about 100 feet on the northern slopes. Thin layers of hard limestone are often included, consisting of an aggregation of shells of *Ostrea congesta*, a fossil distinctive of the formation when it occurs in this manner (see Pl. XXIV).

Pierre shale.—Many thousand square miles of the country adjoining the Black Hills are occupied by Pierre shale. It is a thick mass of dark-colored shale, weathering light brown, and is relatively uniform in composition throughout. It gives rise to a dreary monotony of low rounded hills, sparsely covered with grass and not very useful for agriculture. The thickness of the formation is about 1,200 feet, so far as can be ascertained, but it is only rarely that it can be measured. Where it dips gently away from the hills it is almost impossible to measure the rate of the dip of the shale. Fortunately it has been found that the formation includes, at a horizon about 1,000 feet above its base, scattered lenses of limestone usually containing numerous shells of *Lucina occidentalis*. The greater number of these lenses occur at the definite horizon just mentioned, and, in some places, where they occupy the surface over a wide area, they throw light on the attitude of the formation. It is from evidence of this sort that we have made some of the determinations of structure which afford an important part of the data for ascertaining the depth of the Dakota sandstone in the region adjoining the Black Hills.

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GEOLOGIC SECTIONS ACROSS THE CENTRAL GREAT PLAINS
ALONG THE LINES 6, 7, 8, 9, AND 10, PLATES XXV AND LXIX

BY

N. H. DARTON

1904

The limestone concretions with *Lucina* vary in size from 2 or 3 cubic feet to masses 20 feet in diameter and 6 or 8 feet thick, usually of irregular lens shape. Owing to their hardness these lenses, when uncovered by erosion, give rise to low conical buttes resembling in form very squat tepees, and accordingly have been designated "tepee buttes," a term used for similar occurrences in the Pierre shale of southeastern Colorado. They occur in large numbers in the vicinity of Oelrichs and west and southwest of Newcastle, varying in height from 10 to 150 feet above the surrounding slopes. Horizontally the lenses occur at irregular intervals, so that the buttes are scattered very erratically and are sometimes separated by many miles. Their occurrence in some of the steeply tilted sections in Converse and Weston counties, particularly near Oldwoman Creek, has afforded opportunity for determining the distance of the horizon above the base of the Pierre shales.

Numerous concretions occur in the Pierre shales at various horizons and usually contain large numbers of very distinctive fossils, of which the more abundant are the following: *Baculites compressus*, *Inoceramus sagensis*, *Nautilus dekayi*, *Placenticeras placenta*, *Heteroceras nebrascensis*, and an occasional *Lucina occidentalis*. The most fossiliferous horizon is in the upper part of the formation. The concretions are generally of small size, of a calcareous nature, and break into small pyramidal fragments, which are scattered more or less thickly all over the Pierre surfaces.

At the base of the formation overlying the Niobrara chalk there is always a very distinctive series of black, splintery, fissile shales, containing three beds of concretions. These shales have been included in the Pierre, although they have not yet been found to contain distinctive fossils. They are about 150 feet thick in the southern Black Hills, where they give rise to a steep slope, often rising conspicuously above the lowlands eroded in the Niobrara chalk. The concretions exhibit a curious sequence. The lower ones are biscuit-shaped, hard, and siliceous; those in the layers next above are similar in shape and composition, but are traversed in every direction by deep cracks filled with calcite and sometimes scattered crystals of barite; and those in the uppermost layers are large, lens-shaped, highly calcareous, and of a light-straw color, consisting mainly of well-developed cone-in-cone.

Fox Hills and Laramie formations.—These formations occupy a vast area of the plains adjoining the Black Hills in all directions, except to the east and southeast. They approach nearest to the hills in the eastern portion of Weston and Converse counties, Wyo., where they occupy several hundred square miles of the central Great Plains area. It is from the Laramie formation in this district that Hatcher and Marsh obtained the large collection of remains of Ceratopsidæ in deposits which

have been designated locally[a] the Ceratops beds. These Ceratops beds extend northward from Buck and Lance creeks into Weston County. They have been described by Hatcher,[b] and by Stanton and Knowlton,[c] who have shown from faunal, floral, and stratigraphic evidence that they are of Laramie age. The underlying Fox Hills formation is fully characterized by its distinctive marine fauna, and the overlying beds are found by Knowlton to contain a typical Fort Union flora. The precise boundary between the Ceratops beds, or Laramie formation, and the Fox Hills has not yet been ascertained, but it is usually placed at the top of the deposits which have yielded a marine fauna. The base of the Laramie formation, thus defined, consists of a series of sandstones and shales of no great thickness, in which no fossils have been discovered, but which appear more closely allied to the well-defined Ceratops beds above than to the Fox Hills below.

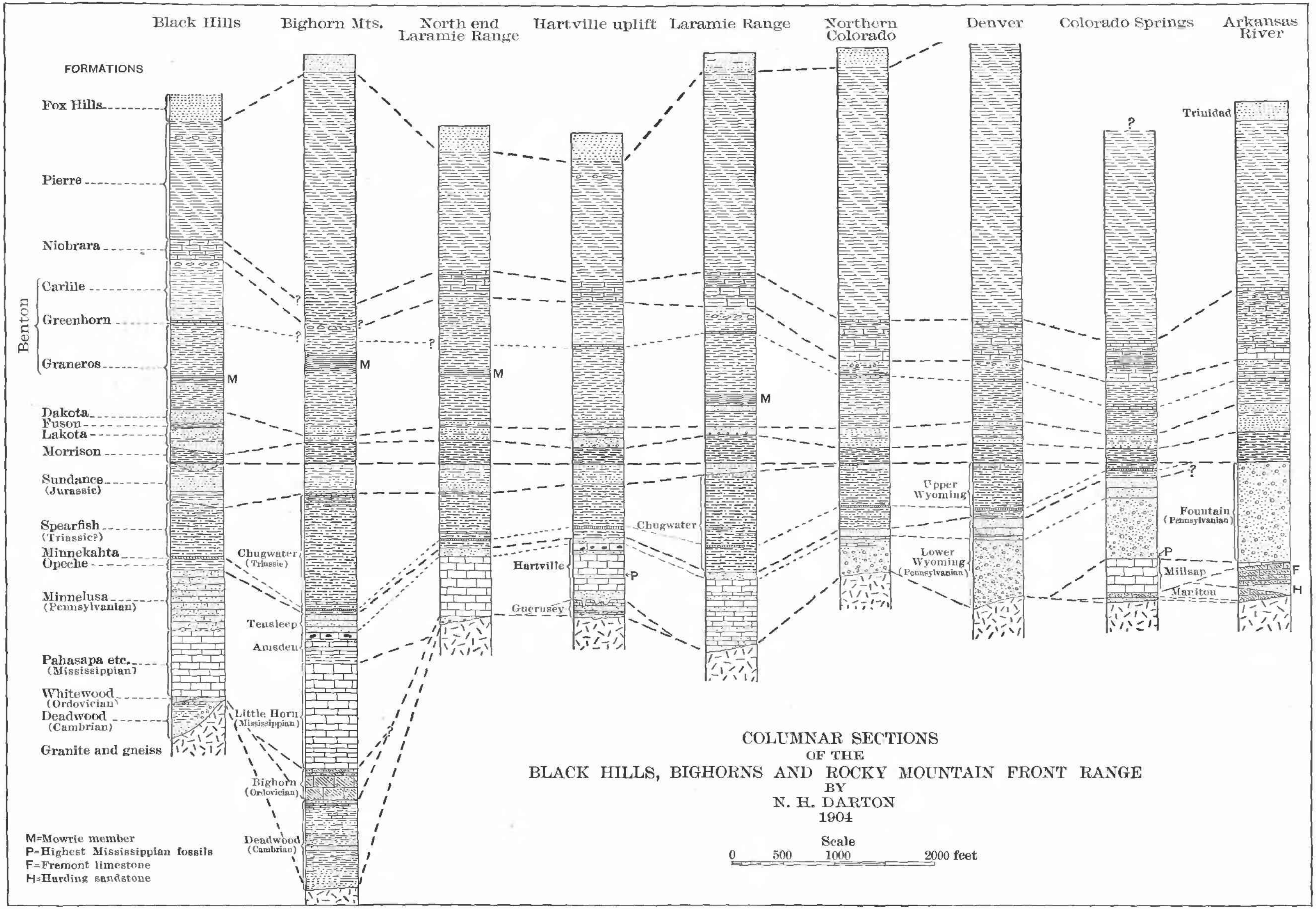
The Fox Hills formation in Converse and Weston counties, Wyo., presents an alternation of slabby sandstones and sandy shales, apparently in conformable succession to the Pierre shale. The sandstones give rise to an escarpment which faces eastward, overlooking the lower lands of the Pierre, Niobrara, and Benton formations. It is about 15 miles distant from the foothills of the Black Hills, at Newcastle and throughout Weston County, but lies much farther west in Converse County, as the Hogback Range bears to the southeast. The escarpment has a height of from 150 to 200 feet in greater part, comprising lower slopes of Pierre shale, a gray-sandstone or sandy-shale series in the middle slopes, and a capping of three thin but hard beds of slabby sandstone intercalated in sandy shales. The sandstones or sandy shales next above the Pierre shale usually contain large faintly defined concretions, due to local increase of lithification, and they carry abundant fossils, mainly *Veniella*. Their thickness is from 250 to 500 feet.

Next above the sandstones of the Fox Hills escarpment and ridge are slopes of sandy shales, surmounted by high hills composed of the succession of sandstones and shales constituting the Ceratops beds. These deposits alternate through a series several thousand feet thick, with the component beds varying greatly in thickness and extent. No stratigraphic order of beds has yet been detected and none of the strata is continuous for any great distance. Sandstones predominate, consisting mainly of fine-grained, loosely cemented beds of light-buff color, often having a thickness of 40 feet. They contain very characteristic concretions of gray color and of great variety of shapes. The material is simply the sand of the soft sandstone, locally lithified to increased hardness and slightly darkened. The sizes vary from a few inches to many feet. The forms are usually elongated, with rounded outlines,

[a] Marsh, O. C., The skull of the gigantic Ceratopsidæ: Am. Jour. Sci., 3d ser., vol. 38, 1889, pp. 501-606, Pl. XII.

[b] Hatcher, J. B., The Ceratops beds of Converse County, Wyo.: Am. Jour. Sci., 3d ser., vol. 45, 1893, pp. 135-144. Some localities for Laramie mammals and horned dinosaurs. Am. Naturalist, vol. 30, 1896, pp. 112-120, and map.

[c] Stanton, T. W., and Knowlton, F. H., Stratigraphy and paleontology of the Laramie and related formations in Wyoming: Bull. Geol. Soc. America, vol. 8, 1897, pp. 127-156.



COLUMNAR SECTIONS
OF THE
BLACK HILLS, BIGHORNS AND ROCKY MOUNTAIN FRONT RANGE
BY
N. H. DARTON
1904

but spherical and lens-shaped concretions abound. (See Pl. XVIII, *B*.) Shales occur interbedded among the sandstones of the Laramie formation and are often 30 to 50 feet thick. They are usually of dark-gray color and in places lignitic. Coal was not observed in this formation near the Black Hills, but is found extensively to the north and west.

TERTIARY DEPOSITS.

The earliest deposits of Tertiary age—those of the Eocene epoch—are not found in the region adjoining the Black Hills, and there are many reasons for believing that the principal epoch of the uplift in the Black Hills region was in early Tertiary time. Early Eocene deposits may have been laid down and removed by erosion in consequence of uplift in later Eocene time, but it is much more probable that the entire area was subjected to vigorous erosion throughout the portion of Eocene time prior to the Oligocene. During the Oligocene epoch there was widespread deposition in the Central Plains region, and adjoining the Black Hills there was laid down a thick mantle of the sands and clays, which will be described below. The Arikaree[a] formation, of Miocene age, which caps Pine Ridge, has not been found on the Black Hills, and nothing is known as to its former extension in that direction. According to Prof. J. E. Todd, a representative of the formation occurs north of the hills in the high buttes beyond Belle Fourche River, in the northwest corner of South Dakota.

White River group.—The well-known formations of the Big Badlands lying between Cheyenne and White rivers in western South Dakota and underlying Pine Ridge, have been found to extend to the Black Hills and high up on their flanks in a portion of the region. About Fairburn and Hermosa wide areas of the highlands are occupied by the Chadron and Brule formations, which often give rise to miniature badlands of considerable extent. The deposits comprise both fine-grained and coarse-grained materials, the latter marking the course of the more vigorous streams of the period. There are large areas of fuller's earth, sand, limestone, calcareous grit, and channels filled with conglomerate, in some places silicified and in others cemented by carbonate of lime.

The principal areas now remaining are on the high divides between Lame Johnny and Rapid creeks, but there are also extensive masses in the broad part of Red Valley behind the Hogback Range, and there are narrow valleys filled with the deposits, which extend several miles back over the Carboniferous and Cambrian onto the Algonkian crystalline rocks. Some details of their distribution are shown on the geologic map (Pl. XXXV). To the southwest there are scattered areas at a number of points between Edgemont and Pringle, notably on the Minnelusa formation west of Argyle, in Red Valley north and west of Minnekahta, and on the Dakota sand-

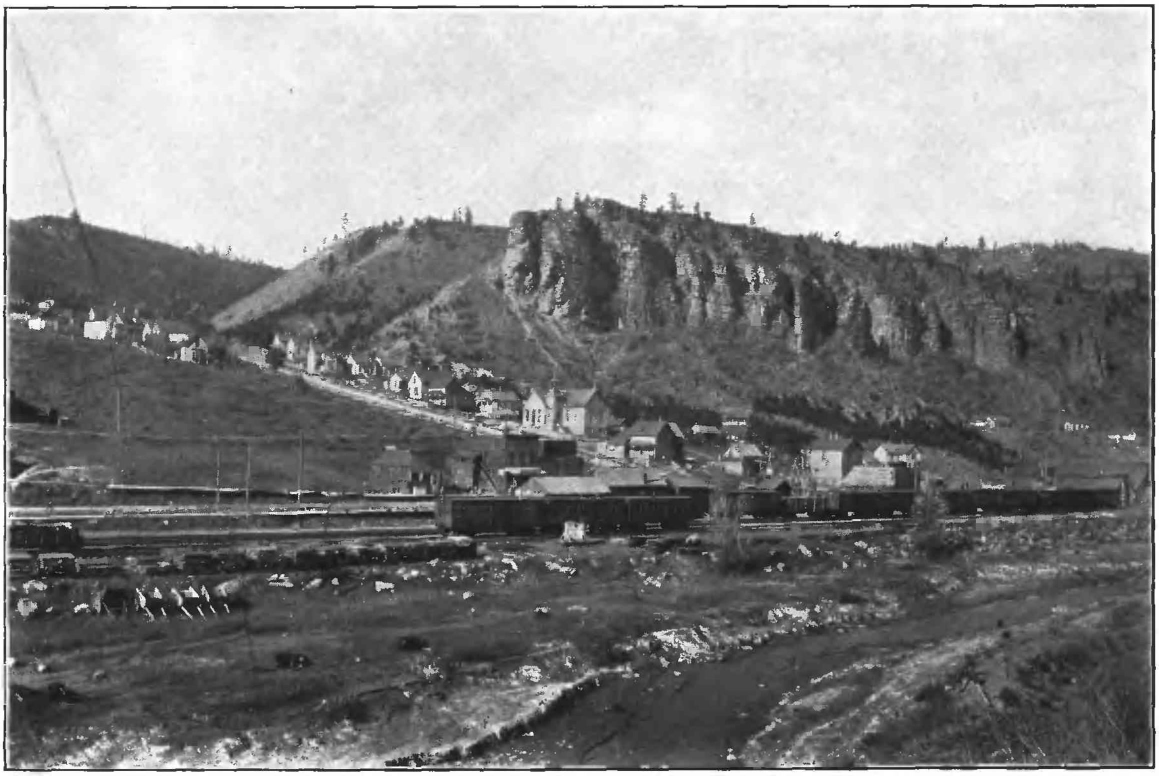
[a] Darton, N. H., Report on Nebraska west of the one hundred and third meridian: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1898, p. 735.

stone not far north of Edgemont. South of Oelrichs there is a narrow basin which has been preserved in a syncline extending toward the Big Badlands. In Converse County, Wyo., the formation extends from the foot of Pine Ridge over a portion of the anticline rising along the east side of Oldwoman Creek.

The deposits of the White River group exhibit considerable diversity of composition. The principal material is a porous crumbling clay, pale-flesh color when dry, but light brown when damp. Some portions of it are pale green when dry and olive when wet. It is a hydrosilicate of alumina with some admixture of sand and clay, being in reality fuller's earth, and differing from ordinary clay in being much less plastic. In the lower beds of the group it merges into sand on the one hand and into clay on the other. It is often associated with or gives place to coarse materials occupying channels or broad sheets. In the vicinity of Hermosa the principal material is coarse sandstone and conglomerate, mainly of dark-brown color, which mantles extensive plateaus. On the high level ridge north of Spring Creek there are coarse conglomerates, which extend entirely across the Hogback Range. About Fairburn, and to the west, there are long channels filled with conglomerate consisting of limestone pebbles and a calcareous matrix. These extend up several of the depressions through the Hogback Range, either displacing the fuller's earth deposits or being intercalated among them. The limestone pebbles appear to have been derived from Tertiary limestones, for they do not represent any of the Mesozoic or Paleozoic rocks of the hills. On the higher lands of Red Valley, between Hermosa and Rockerville, there is an extensive deposit of nearly pure limestone, giving rise to a high plateau of considerable extent. The total thickness of the beds is about 30 feet at some places, the limestone being underlain by fuller's earth. A characteristic outcrop is shown in Pl. XXV, *A*.

Limestones of various degrees of purity are abundantly intercalated in the fuller's earth deposits in the region west and southwest of Fairburn, lying in depressions on the older rocks. Their most southerly occurrence is on the ridge a short distance northwest of the western entrance of Fuson Canyon and on the high divide just north of Lame Johnny Creek, a short distance west of the Fremont, Elkhorn, and Missouri Valley Railroad. These limestones usually contain fresh-water fossils, mainly gastropods, often in great abundance.

There are extensive exposures of coarse materials of White River age in the railroad cuts through this divide south of Fairburn (shown in Pl. XXV, *B*), where the materials are mainly cross-bedded coarse sands with a large proportion of gravel, largely derived from the crystalline rocks of the hills. The thickness of the White River deposits on the flanks of the Black Hills varies from a thin remnant to 200 feet or more. In the divide just south of Lame Johnny Creek, in Red Valley, at a point 10 miles southwest of Fairburn, over 200 feet were measured, consisting mainly of pale flesh-colored sandy clay and fuller's earth.



A. DEADWOOD FORMATION IN NORTHERN PART OF DEADWOOD, S. DAK.

View showing thick mass of regularly bedded sandstone in middle of formation. Looking northeast.

B. DEADWOOD SANDSTONE LYING ON ALGONKIAN SCHISTS IN DEADWOOD, S. DAK.

Shows slight channeling.

East of the Hills the White River deposits are usually divisible into two formations—the Titanotherium beds or Chadron formation below and the Oreodon beds or Brule clay above. The Chadron formation consists of fuller's earth of light-gray, drab, pale-green, or pinkish tints, traversed by channels filled with gray sandstone, and usually has at its base a bed of coarse gravel composed of rocks derived from the Black Hills. The Brule clay consists of massively bedded sandy clay of pale-flesh and drab colors. These formations are most extensively exhibited in the large area of badlands lying southeast of Cheyenne River. Some of their typical features are illustrated in Pls. XLV and XLVI.

All of the White River beds have yielded fossil bones of various kinds which are typical of the Oligocene epoch. The following, which were determined by Prof. F. A. Lucas, were obtained in beds high up on the flanks of the Black Hills west of Fairburn: *Oreodon culbertsonii*, *Pœbrotherium wilsoni*, *Stylemys nebrascensis*, and *Hyracodon nebrascensis*.

The White River deposits southwest of Argyle consist mainly of fuller's earth. A few turtle bones were found in them, but no extensive search was made for fossils. North and west of Minnekahta the material is a mixture of fine sand and clay. The outlier northwest of Edgemont caps an area of Graneros shale high on the slope of the Dakota sandstone. It consists mainly of gray conglomeratic sandstone. In the vicinity of Lead small areas of White River beds have been found at an altitude of about 5,000 feet, and on the slopes of Bearlodge Mountains deposits supposed to be of this age occur at an altitude of more than 6,000 feet.

During White River time in the Black Hills and adjoining regions there was deposition of a considerable volume of volcanic ash. The period appears to have been one of volcanic activity in the region west, and the ashes were borne on the winds and dropped into the waters so as to be spread over a wide area of country adjoining the Black Hills. There is more or less volcanic ash throughout the White River deposits as an admixture with the clay and sand. Accumulations of the pure material are often found at various horizons from the lower Chadron beds to the highest formation in Pine Ridge.

GEOLOGY OF A PORTION OF THE BIGHORN MOUNTAINS.

GENERAL RELATIONS.

The Bighorn Mountains are due to a great anticline of many thousand feet uplift rising in south-central Montana and extending southeast and south about 125 miles into central Wyoming. It elevates a thick series of Paleozoic and Mesozoic formations high above the plains, and, owing to the deep erosion of its crest, presents a central nucleus of pre-Cambrian granites from which the sedimentary rocks dip at varying angles on either side. The most elevated portion of the uplift is near latitude 44° 30′, where one of the granite summits, Cloud Peak, has an altitude of

13,165 feet, a rise of about 9,000 feet above the adjoining plains. (See Pl. XXVI, *A*.) The uplift diminishes in amount to the north and finally dies out in Montana; to the south it becomes lower, but continues for many miles, finally curving around to the west and extending into the Rattlesnake and the Owl mountains. On the flanks of the uplift there is exposed a series of Paleozoic and Mesozoic rocks, the former giving rise to a high monoclinal range, shown in Pl. XXVIII, while a parallel lower hogback marks the outcrop of the harder members of the Mesozoic rocks. The general structure is illustrated in sections 1, 2, and 3 on Pl. X.

STRATIGRAPHY.

During 1901 and 1902 a detailed study was made of the stratigraphy of the formations on a portion of the eastern side of the Bighorn uplift, and the general features were determined as indicated in the following table:

Table of formations on east side of Bighorn Mountains, in Wyoming.

Age.	Formation.	Principal character.	General thickness.
			Feet.
Cretaceous	Laramie	Sandstones and shales with local coal beds; lenses of conglomerate near base.	2,000±
	Fox Hills	Soft buff sandstone	200
	Pierre	Dark-gray shales	2,700
	Niobrara	Gray shales	200±
	Benton	Dark shales, sandy shale with thin, rusty sandstone layers at base.	1,150
	Cloverly	Gray to purple clay (Fuson)	30
		Coarse sandstone (Lakota)	30
	Morrison	Massive shales and sandstones	150–250
Jurassic	Sundance	Buff sandstones and green shales	300
Triassic (?) or Permian	Chugwater	Red sandstone and shales with gypsum (Spearfish).	1,200
		Purple to gray limestone (Minnekahta ?)	5
		Red shales (Opeche ?)	30
Carboniferous	Tensleep	White sandstone	50–200
	Amsden	Red shales, white limestone, sandstone, and cherty limestone.	300
	Little Horn	Limestones of light color	1,000
Ordovician	Bighorn	Limestone, in greater part very hard and massive.	250
Cambrian	Deadwood	Sandstone, shale, conglomerate, and limestones.	1,000
Algonkian or Archean		Granite	

DEADWOOD SANDSTONE LYING ON ALGONKIAN SCHISTS, ON SQUAW CREEK, BELOW OTIS, S. DAK.

Typical flat-bottomed valley of Black Hill parks; sandstone about 30 feet thick, marked by line of cliffs to right. Looking north.

CAMBRIAN.

Deadwood formation.—The lowest member of the sedimentary series in the Bighorn Mountains consists of middle Cambrian beds, so closely resembling the Deadwood formation of the northern Black Hills that this name may be employed in both regions. The rocks comprise sandstones, shales, limestones, and conglomerates, averaging from 900 to 1,000 feet in thickness for the most part. At the base there is usually at least from 10 to 30 feet of brown sandstone lying on granite and often conglomeratic near the contact. Some typical features are shown in Pl. XXVI, *B*. Next above are gray and greenish-gray shales, usually with thin sandstone or sandy shale intercalations. Ordinarily these shales have a thickness of 250 to 300 feet. They are succeeded by a bed of coarse gray sandstone, averaging from 25 to 40 feet thick, and apparently of wide extent. This sandstone is overlain by several hundred feet of gray shales and thin-bedded sandstones, containing considerable glauconite at most localities and a few thin layers of limestone. This series merges upward into an alternation of impure limestones and very characteristic conglomerates of flat limestone pebbles, often green on the surface, but from gray to pale pink inside. This limy series has a thickness of about 200 feet and is succeeded abruptly by a bed of white sandstone about 25 feet thick, which is regarded as the top of the Deadwood formation. The pre-Cambrian surface on which the Deadwood formation lies is in general remarkably smooth, but has in it occasional local irregularities consisting of shallow channels or low cliffs.

The formation does not present much local variation in character, the principal changes being in the basal sandstones, which, in some portions of the area, attain a thickness of 300 feet.

Fossils from the upper limestone series have been found to be *Dicellomus politus* (of middle Cambrian age), which also occurs in great abundance in the thin limestone layers in the underlying shales and at intervals to the base of the formation, the small, white shells being conspicuous in the gray and buff sandstone. In the lower sandstones *Ptychoparia oweni* occurs often in great abundance.

ORDOVICIAN.

Bighorn limestone.—This limestone is one of the most prominent members of the sedimentary series in the Bighorn Mountains, rising in high cliffs along the inner face of the limestone front range, as shown in Pls. XXVI and XXVIII. Its principal member is a hard, massive, impure limestone of light-gray or light-buff color, with reticulating masses of silica, which give the weathered rock a very coarse, irregularly pitted, or honeycombed surface. The thickness ranges from 200 to 300 feet for the most part, and the bedding planes are mostly from 10 to 20 feet apart. The very few fossils it has yielded are of Ordovician age and are regarded by E. O.

Ulrich as lower Galena-Trenton in equivalency. In its upper portion the rock becomes less massive, and the top member of the formation includes some thin-bedded, impure limestones which, at one locality northwest of Buffalo, contain large numbers of fossils representing the Richmond fauna of the upper Ordovician. This upper series is not well exposed, and apparently it is not continuous.

In some localities the massive member of the Bighorn limestone is succeeded by fine-grained, light-colored limestones containing numerous corals, among which were recognized *Halysites catenulata* and other forms. This overlying series is included in the Bighorn limestone because of its Ordovician age.

CARBONIFEROUS.

Little Horn limestone.—This limestone comprises about 1,000 feet of beds, and constitutes the greater part of the high front range of the Bighorn Mountains. Its thickness diminishes greatly to the southwest. The rocks are mainly of light color and are massively bedded. At the top there is a series of pure limestones 100 feet or more in thickness, but of soft texture, which weathers in typical castellated forms, one of which is shown in Pl. XXVII. Many of the lower beds contain much sand admixture and are usually darker. Fossils of typical lower Carboniferous forms occur at several horizons. The thickness of the formation diminishes to about 250 feet in the southeast portion of the uplift. The Little Horn limestone is equivalent in the main to the Madison limestone of Montana and the Pahasapa limestone of the Black Hills; but as the stratigraphic limits of the formation are somewhat indefinite, a local name is applied, derived from the canyon of Little Horn River, where there are extensive exposures.

Although there is no marked evidence of unconformity at the base of the Little Horn limestone, and the lowest beds are not fossiliferous, it is probable that the Silurian and the Devonian are absent.

Amsden formation.—The uppermost limestone member of the Bighorn front range has been separated as the Amsden formation, named from a branch of Tongue River west of Dayton. It consists of a somewhat variable succession of red shales, limestones, cherty limestones, and sandy members outcropping along the higher outer slopes of the range. Its thickness is about 150 feet near the Montana line, but increases gradually to the south and amounts to 350 feet west of Sheridan and Buffalo. Throughout its course the basal member is a red sandy shale or fine-grained red sandstone from 50 to 100 feet thick, the amount gradually increasing to the south, lying on the massive bluish-gray limestone of the Little Horn formation with no apparent unconformity. Next above is a somewhat variable series including very compact, pure, white limestones, several thin beds of gray sandstone, occasional thin

WESTERN SLOPE OF BLACK HILLS ON EAST SIDE OF STOCKADE BEAVER VALLEY, SOUTHEAST OF NEWCASTLE, WYO.

Steep-dipping beds from Minnelusa to Minnekahta limestone, the latter spreading out in a characteristic plateau at the foot of the slope. Looking southeast.

bodies of red shale, and, in the greater part of the region, several thick beds of very cherty limestone which contain fossils. Only a very few fragmentary specimens have been found in the lower beds, so that the age of these is uncertain.

Tensleep sandstone.—The outer slope of the Front Range is flanked to a varying height with a sheet of sandstone which is continuous throughout. It is a massive, white sandstone, locally of buff color, with an average thickness of about 200 feet west and southwest of Buffalo, but thinning gradually to the north to about 50 feet near the Montana line. Some limy and cherty layers occur in its middle and upper parts. Its white ledges are conspicuous features on the mountain slopes rising abruptly out of the red shale valley (see Pl. XXVIII). The sandstone is mostly massive, there is much cross bedding, and the material is fine grained and moderately hard at most points. Fossils found in chert nodules in the medial beds of the formation are of Pennsylvanian age. Its name is derived from extensive typical exposures in the walls of the lower canyon of Tensleep Creek.

TRIASSIC (?) OR PERMIAN.

Chugwater formation.—There extends along the foot of the Bighorn Range a thick series of red beds apparently equivalent to the Red Beds of the Black Hills, but not so plainly divisible into three members.

The Minnekahta limestone, which is the lowest of the trio in the Black Hills, appears to have an attenuated representative in the Bighorn uplift, but as its identity can not be proved it has been thought best not to attempt to subdivide, but to comprise all under the one designation of the Chugwater formation, a name derived from Chugwater Creek, on which the formation is extensively exhibited in the vicinity of Iron Mountain.

The formation averages 1,250 feet in thickness, and consists mainly of bright-red sandstones and sandy shales containing deposits of gypsum with thin beds of limestone near the top and the bottom. The lowest limestone, which occurs about 20 feet above the Tensleep sandstone and has an average thickness of less than 5 feet, consists of thinly laminated, pinkish, dolomitic limestone strongly suggestive in appearance and relations of the Minnekahta limestone of the Black Hills; it has yielded no fossils. About 80 feet higher in the formation there occurs another bed of limestone averaging about 3 feet in thickness, of impure character and honeycombed structure, which is a prominent member along the east side of the Bighorn basin. A series of several thin beds, having in all a thickness of from 120 to 250 feet, appears near the top of the formation intercalated among red sandy shales. Their individual thicknesses vary from 2 to 10 feet. They contain fossils at a number of localities, but unfortunately the forms are so lacking in characteristics that

it has not been possible to ascertain whether they are of the latest Paleozoic or the earliest Mesozoic age. One prominent exposure standing vertical is shown in Pl. XXIX, *B*. As in other regions, the gypsum occurs mainly in the lower 200 feet of the formation.

JURASSIC.

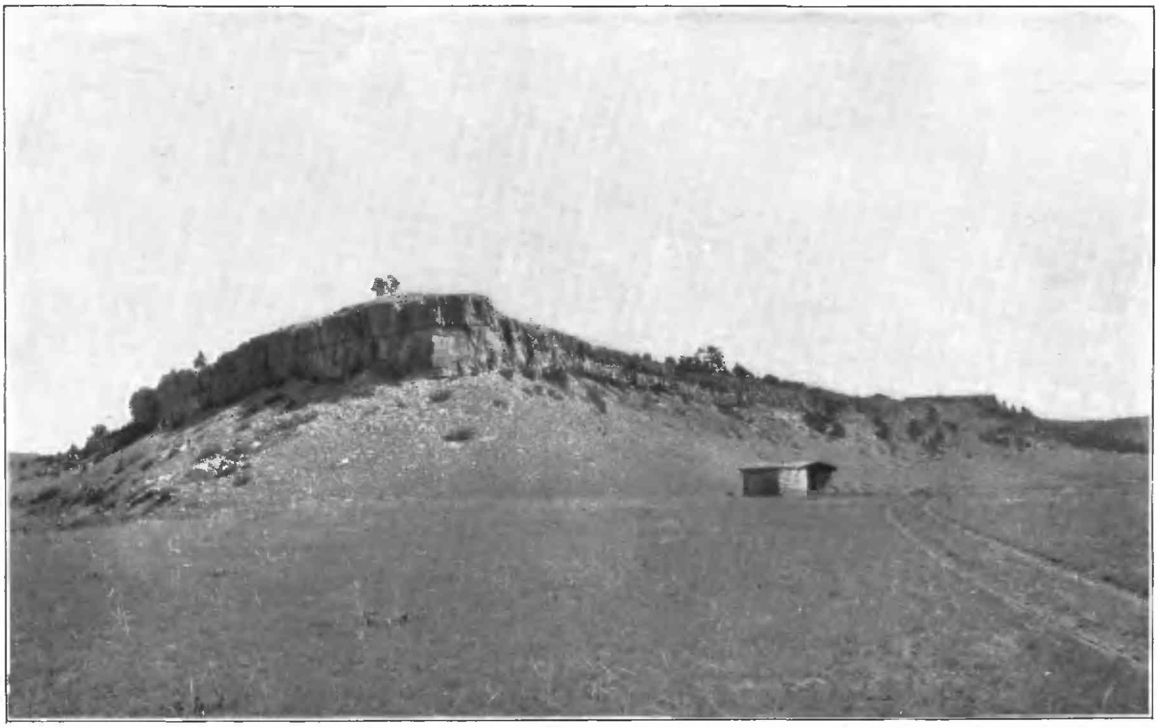
Sundance formation.—Typical marine Jurassic deposits, with abundant fauna, are well represented in the Bighorn Mountain section. Owing to the steep dip of the beds along the foot of the Front Range the outcrop zone is narrow, but it continues throughout, except at a few points where the beds are cut out by faults. The beds present the usual succession of a sandy series below and a considerable thickness of greenish fossiliferous shales above. The thickness averages about 300 feet, with local variations of small amounts. At or near the base there is usually a hard fossiliferous limestone having a thickness of from 3 to 5 feet, increasing locally to 25 feet. Next above are soft sandy beds often containing large numbers of *Gryphæa calceola*, var. *nebrascencis*. The greenish shales next above contain thin layers of highly fossiliferous limestone and a few thin sandy layers containing many *Belemnites densus*.

CRETACEOUS.

Morrison formation.—This formation outcrops along a narrow zone in the foothills at the base of the mountains. It consists mainly of shales or hard clay of a pale-greenish or maroon color, with a darker clay at its summit, all having a peculiar chalky appearance and massive or joint-clay structure. It includes several beds of light-gray or buff sandstone, varying in thickness from 2 to 20 feet, usually soft, with thin, irregular bedding planes, which generally have a peculiar wavy surface suggestive of incipient cross bedding. The thickness is about 150 feet to the north and 250 feet to the south. Remains of dinosaurs are abundant, but no other fossils were observed.

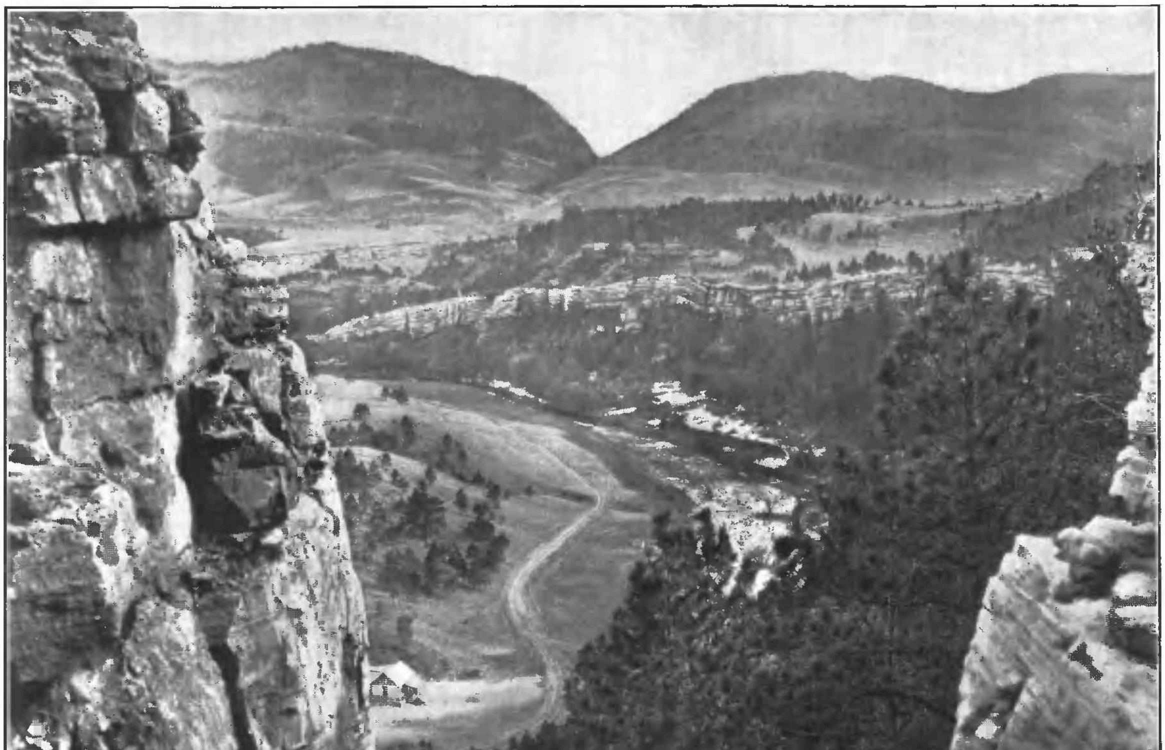
Cloverly formation.—Overlying the Morrison shales there is a thin bed of sandstone which, from its stratigraphic relations and character, is believed to represent the Lakota of the Black Hills, overlain by and merging into clays resembling the Fuson formation. Owing, however, to the lack of any definite evidence as to the equivalency of these beds, and especially in consideration of the apparent absence of deposits representing the Dakota sandstone above the clay, it has been thought best to give this series a separate designation, and the word "Cloverly" is proposed, a name derived from the post-office on the eastern side of the Bighorn basin.

The sandstone member of the Cloverly formation usually gives rise to a line of knobs or low ridges on the divides along the eastern slope of the Bighorn uplift, one



A. TYPICAL CANYON WALLS OF MINNEKAHTA LIMESTONE LYING ON SLOPE OF OPECHE RED BEDS, GILLETTE CANYON, SOUTHEAST OF NEWCASTLE. WYO.

View showing massive appearance of this thin bedded rock.



B. MINNEKAHTA LIMESTONE AND OVERLYING RED BEDS, ETC, SIOUX PASS, BLACK HILLS, SOUTH DAKOTA.

Hogback of Dakota-Lakota sandstone in distance.

of which is shown in Pl. XXIX, *A*. Ordinarily it is a coarse-grained, buff or dirty-gray, cross-bedded, massive sandstone, averaging 30 feet in thickness, but varying from 10 to 60 feet. The overlying clay is rarely exposed, but in a few outcrops is seen to be a reddish to ash-colored clay, locally of darker gray color and with a thickness of from 30 to 40 feet. Near the base of the sandstones there occur some very thin deposits of coal, or coaly shale, which sometimes contain remains of numerous flattened pine needles, as do the coal deposits of the lower portion of the Lakota of the Black Hills.

Benton formation.—The lower portion of the great mass of shales underlying the plains along the foot of the Bighorn Mountains, with an average thickness of about 1,300 feet, belongs in the Benton formation. The subdivisions recognized in the Black Hills and in Colorado are not apparent in the Bighorn region, mainly owing to the absence of the Greenhorn limestone, but the hard shales which weather to a light-gray color are present nearly a thousand feet above the base of the formation, which indicates a great expansion of the lower third of the Graneros shales.

The basal member of the Benton consists of dark-gray shales, in part sandy and of rusty-brown color, with occasional thin beds of brown sandstone, which locally expand into beds of moderate thickness. It is possible that this portion of the formation represents the Dakota sandstone of other regions, but there is no direct evidence, and even if the few indistinct plant remains which it contains should prove to belong to the Dakota flora, that would be no more than we should expect in any shallow-water deposits at the beginning of Benton times. A zone of shales carrying globular concretions averaging for the most part from three-fourths of an inch to 2 inches in diameter, with radiated crystalline structure and dark-gray color, occurs in the upper part of this lower series all along both sides of the Bighorn uplift. It consists mostly of phosphate of lime, and appears to have the structure of marcasite and to be a replacement of that mineral.

Next above this lower member there are several hundred feet of dark shales, mostly fissile, which contain thin beds of sandstone and iron and lime concretions of typical lower Graneros character.

These are overlain by a very characteristic series, about 150 feet thick, of hard, lighter gray shales and thin-bedded sandstones, which weather very light colored and form bare ridges of considerable prominence, notably Columbus Peak, southwest of Parkman. Most of its beds contain large numbers of fish scales and occasionally fish teeth and bones. By some observers this member was supposed to be Niobrara, but it lies below beds containing distinctive Benton fossils, and in other portions of eastern Wyoming is exposed with relations that indicate that its position is below the middle of the Graneros division of the Benton formation, or several

hundred feet below the Greenhorn limestone horizon. This series will be designated the Mowrie beds, from Mowrie Creek, northwest of Buffalo.

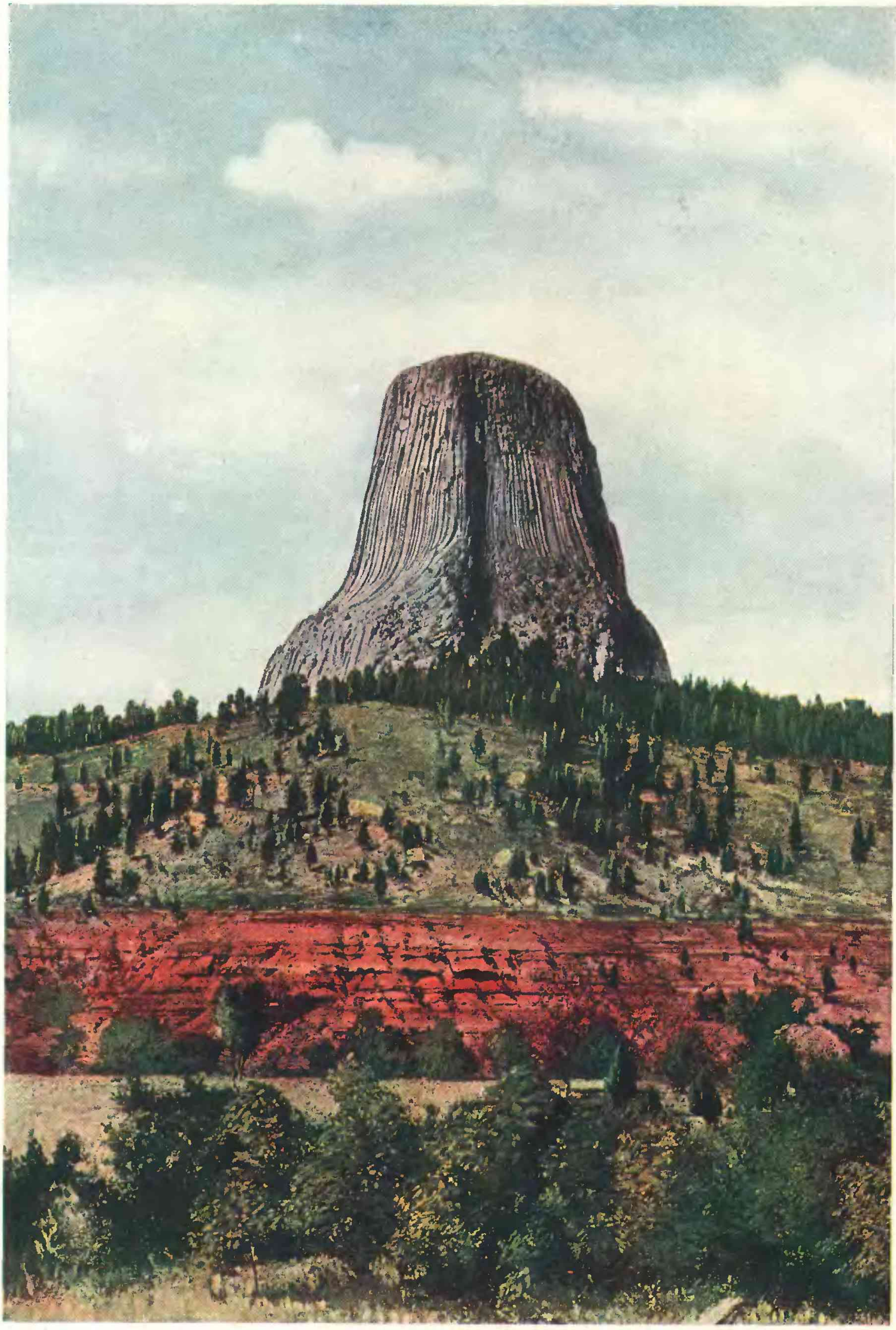
The top member of the Benton formation in this region comprises 200 feet or more of dark shales, with occasional fossiliferous layers containing Benton forms, having at their top a series from 20 to 30 feet thick containing lens-shaped lime concretions, 2 to 4 feet in diameter for the most part, of buff color when weathered, and carrying occasional remains of *Prionotropis woolgari* and *Prionocyclas wyomingensis*, species characteristic of the upper part of the Benton (Carlile) beds about the Black Hills and elsewhere.

Niobrara shale.—This series of limy deposits, which is so conspicuous along the Rocky Mountain front and in the vicinity of the Black Hills, is not clearly defined in the vicinity of the Bighorn Mountains. It appears to be represented by about 200 feet of light-gray shales lying between the *Prionotropis* shales above referred to and the fossiliferous beds of the Pierre shales. A few of the characteristic *Ostrea congesta* were found at this horizon far south in the range, but none were observed in the district northward.

Pierre shale.—The Pierre shale outcrops along the eastern base of the Bighorn Range, presenting its usual features of dark-gray shales or clays containing occasional concretions filled with characteristic fossils. In the northern part of the region occur a few thin beds of sandstone, which develop to the south. The thickness of the formation varies from 2,000 to 3,000 feet, but it is possible that this apparent unusual thickness is due partly to crumpling of the beds in the steeper slopes of the uplift. The usual assemblage of Pierre fossils occurs in the formation, but not in as great abundance as in other regions.

Fox Hills sandstone.—The Pierre shales give place rapidly to the Fox Hills sandstones, which have a thickness of 200 feet or more and consist mainly of fine-grained light-buff rock, with numerous marine fossils. The bedding is massive in greater part, and the lithification of the sandstone is irregular, some portions being hard and others so soft that they can be dug with a shovel. Hard concretions occur, mainly in elongated rounded forms of dark-gray color. These concretions are similar to those which sometimes occur in the soft sandstones of the lower part of the Laramie formation, especially in the region west of the Black Hills. The following fossils, obtained from the Fox Hills sandstone near the Bighorn Mountains, were determined by Mr. T. W. Stanton:

Cardium speciosum, M. & H.; *Avicula linguiformis*, Ev. & Sh.; *A. nebrascensis*, Ev. & Sh.; *Ostrea glabra*, M. & H.; *Liopistha* (*Cymella*) *undata*, M. & H.; *Leptosolen*, n. sp.; *Cylichna* (?), sp.; *Baculites*, sp.; *Modiola*, sp.: *Prima lakesi* (?), White; *Leda*, n. sp. (?); *Thracia subgracilis*, Whitfield; *T. subtortuosa*, M. & H.;



IVES THREE-COLOR PROCESS PHOTOGRAPH BY N. H. DARTON

DEVILS TOWER, ON WEST BANK OF
BELLE FOURCHE RIVER, SOUTH OF HULETT, WYO.

Lunatia subcrassa, M. & H.; *Sphærilla* (?) *cordata*, M. & H.; *Tellina equilateralis*, M. & H.

Laramie formation.—The wide expanse of plains lying between the foothills of the Bighorn Mountains and the Black Hills is occupied by the Laramie and overlying formations, as shown in sections 1, 2, and 3, Pl. X. The formation lies in a broad, flat-bottomed basin, with steep dips on the west side on the slope of the Bighorn uplift. The thickness of beds lying in this basin is not definitely ascertained, but appears to be several thousand feet. The lower members are undoubtedly Laramie, but the upper ones probably extend to the "Fort Union" formation.

The Laramie rocks are sandstones, sandy shales, and shales, with numerous thin beds of lignite. At the base there is usually a very characteristic member consisting of alternating shales and thin-bedded rusty sandstone. This, in the northern portion of the region, is succeeded by a conglomerate containing pebbles of limestones and of the characteristic flat-pebble conglomerate of the Deadwood formation derived from the mountains westward, indicating that there was an uplift in the region in early Laramie times. This conglomerate begins west of Sheridan and extends southward to Crazy Woman Creek. Pl. XXX shows an outcrop in the area of its greatest development. It is succeeded by sandstones and shales with lignite beds at various horizons.

GEOLOGY OF THE NORTH END OF THE LARAMIE RANGE.

GENERAL RELATIONS.

Under this heading will be described the results of some recent examinations which I have made of Casper Mountain and of the ridges in the southeast corner of Converse County, Wyo., which lie at the north end of the Laramie Range. In these ridges the Paleozoic and Mesozoic formations are exposed, lying on the granites and schists and in greater part trending east and west, at right angles to the strike of the Laramie Front Range. This district was examined by Hayden many years ago, but only some of the general features were mentioned, and the important fault was not recognized.

STRUCTURE.

Casper Mountain may be regarded as the northwestern extremity of the Laramie Range, although an anticline of moderate prominence extends farther west to the Rattlesnake ridges. The mountain is an anticline, with due east-west trend, broken by a profound fault which extends parallel to the strike along the north front of the ridge. The older formations south of this fault rise in a high escarpment

surmounting a slope extending to North Platte River, which at Casper is 6 miles from the top of the ridge. Only the eastern half of the mountain was examined, and it was found to present the general structural features shown in the following sketch sections:

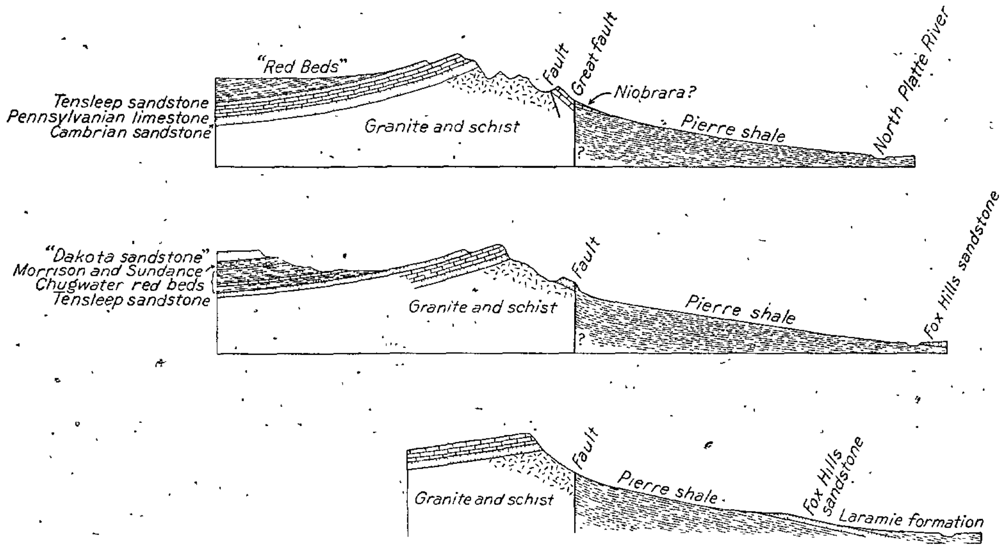


FIG. 2.—Cross sections of Casper Mountain, looking west. The first of these sections is somewhat west of south of Casper; the second is nearly due south, and the third is southeast

At the east end of the mountain the anticline pitches downward and the succession of outcrops curves around to the south into the syncline with beautiful distinctness; some features of this are shown in Pl. XXXII. On the south side of the syncline the Cambrian and Carboniferous beds rise again on the slopes of a

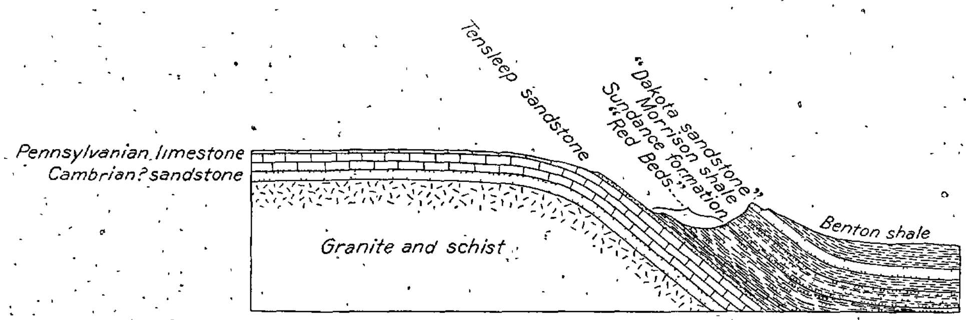
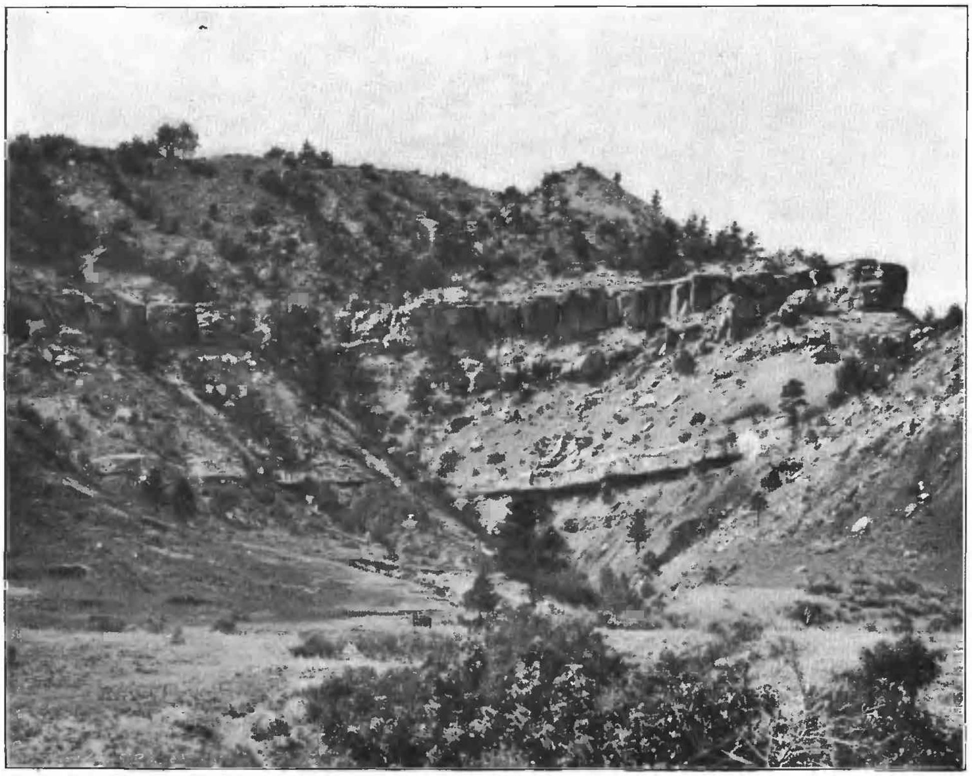


FIG. 3.—Longitudinal section of Casper Mountain, looking north.

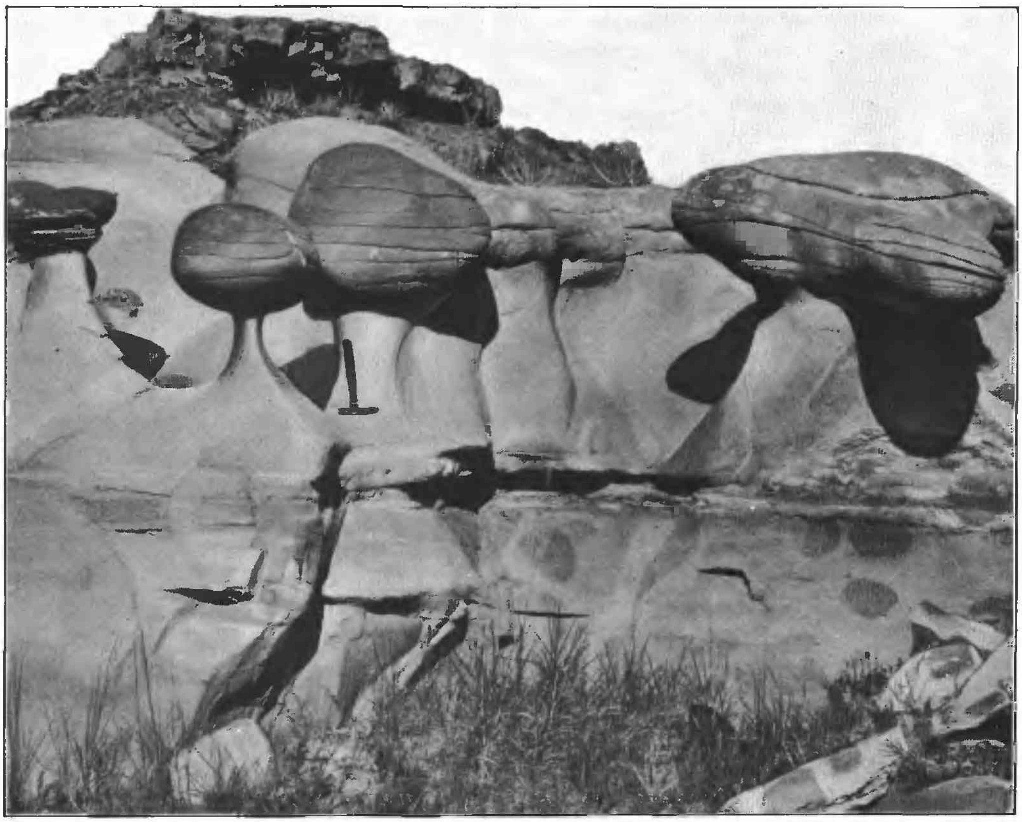
high ridge of granite and schists in a northwest-dipping monocline which extends to the eastward extension of the fault mentioned above, and thence along the south side of the fault to beyond La Prele Creek.

Along the front of this eastern ridge, from Deer Creek to La Prele Creek,



A. WEST SLOPE OF STOCKADE BEAVER VALLEY, EAST OF NEWCASTLE, WYO.

View showing Spearfish red beds below with gypsum on top; middle slopes of Sundance shales and massive sandstone; upper slopes of Sundance and Morrison shales, with Lakota outlier on knob.



B. CONCRETIONS IN LARAMIE SANDSTONE, SOUTHWEST OF NEWCASTLE, WYO.

Prominence due to erosion.

the fault parallels the monocline and Laramie and Carboniferous beds are in contact. To the east the monocline develops into an anticline with granites and schists in its center, and this flexure develops into complex corrugations toward Wagonhound Creek. On La Bonte Creek and in the big bend of North Platte River there is an extensive series of Mesozoic and Paleozoic formations which soon pass beneath White River deposits to the east. The anticlinal structure is well exhibited on La Prele Creek, above the natural bridge, in a high arch of the limestone, south of which there is a synclinal valley occupied by Chugwater red beds, mostly overlain by White River deposits. East of La Prele Creek the main anticlinal ridge curves to the southeast and passes beneath Chugwater and overlying formations in the big bend of North Platte River. To the south there are several corrugations exhibiting Chugwater and overlying formations to the Niobrara, ending in a monocline in which the Carboniferous limestones rise on the slopes of the older granites and schists.

STRATIGRAPHY.

The rocks exhibited in the uplift at the north end of the Laramie Range, from Casper Mountain eastward, are as follows:

Table of sedimentary formations at the north end of Laramie Range.

Age.	Formation.	Principal character.	Thickness.
			Feet.
	Laramie	Sandstones with coal and shales	500 or more.
	Fox Hills	Sandstones	200±
	Pierre	Dark shales	1,000 or more.
	Niobrara	Calcareous shales	100±
Cretaceous	Benton	Dark shales and sandstones	800±
	Dakota-Lakota	Buff massive sandstone and conglomerate, with shale intercalations.	200±
	Morrison	Light-colored massive shale and gray sandstone.	
Jurassic	Sundance	Greenish shales and buff sandstones, local gypsum bed.	475
Triassic (?) or Permian	Spearfish	Red shales and sandstone, with gypsum and limestone.	450
	Minnekahta (Chugwater.)	Thin-bedded limestone	20 to 25.
Carboniferous	Opeche	Red shale	80
	Tensleep	Gray massive sandstone	60
	——	Gray massive limestone	200+
Cambrian		Coarse, hard, massive, gray, conglomeratic sandstone.	100 or less.
Archean or Algonkian		Granites and schists	

CAMBRIAN (?).

The sandstones underlying the Carboniferous limestones in Casper Mountain and in some of the ridges eastward are supposed to be of Cambrian age, but no fossils were observed. It is possible that they are shore deposits of Carboniferous age. The rocks are gray and brown sandstones, conglomeratic at the base, but of varying degrees of coarseness above. They lie on a smooth erosion plain of granites and schists. Their thickness averages about 100 feet, but they thin out to the east, and in some of the slopes west and south of Douglas disappear, the Carboniferous limestones lying directly on the old schists.

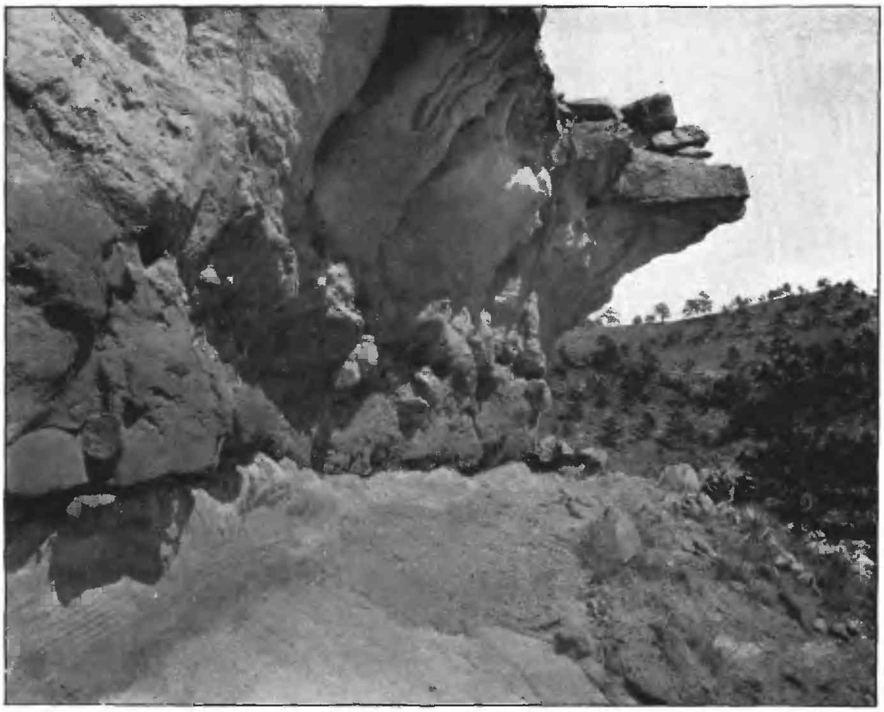
CARBONIFEROUS.

The summit of Casper Range and the slopes of the ridges at the north end of the Laramie Range consist of a series of limestones and sandstones of Carboniferous age. The thickness varies considerably, but averages about 250 feet in most portions of the area.

The usual succession is a series of gray massive limestones, lying on Cambrian sandstone and in some cases overlapping on the old granites and schists, capped by an upper member of gray massive sandstone 60 feet thick, which is correlated with the Tensleep sandstone of the Bighorn and Rocky Mountain ranges. On Casper Mountain, as shown in cross sections (fig. 2), this series dips gently southward from the fault scarp on the north face of the mountain, under a basin occupied by a considerable thickness of Mesozoic rocks. On the south side of this basin the limestone again appears and rises on the slopes of the ridges which constitute the north end of the main Laramie Range. To the east there are exposures in many small canyons which head in the mountain, and especially in the canyons of Boxelder and La Prele creeks. In the syncline west of Douglas the limestones are mostly covered by the Chadron formation of the White River group, but are conspicuous again about the head of La Bonte Creek. They disappear to the east, being concealed by the Tertiary deposits which abut against the old granites and schists in the northwest corner of Laramie County.

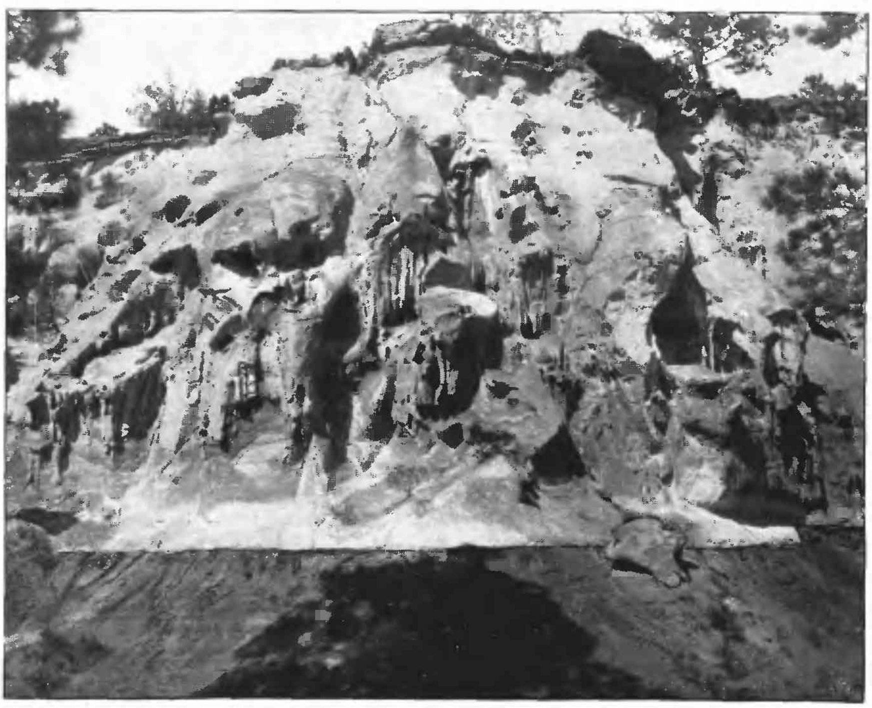
Hayden[a] has referred to some features of this region, describing the limestone on Boxelder Creek as having irregular bedding in greater part and being colored from light-yellow to deep rusty, with some brick-red layers. *Athyris subtilita* is reported from some cherty beds. In the blue limestone on La Prele Creek, Hayden found the fossils *Hemipronites crassus*, *Productus nodosus*, *Myarina perattenuata*, and states: "The underlying limestone is very cherty."

[a] Fourth Ann. Rept. U. S. Geol. and Geog. Survey Terr., pt. 1, 1871, pp. 23-25.



A. LAKOTA SANDSTONE, LYING UNCONFORMABLY ON UNKPAPA SANDSTONE, IN NORTH WALL OF SHEPS CANYON, SOUTH OF HOT SPRINGS, S. DAK.

View shows channeling at contact.



B. SUNDANCE FORMATION LYING UNCONFORMABLY ON SPEARFISH RED SHALES, 7 MILES SOUTH OF HOT SPRINGS, S. DAK.

Tensleep sandstone.—The Tensleep sandstone is continuous throughout, consisting of a massive, coarse-grained, porous sandstone, usually of light-gray color, but in some of the ridges west of Douglas dark-gray to brown, especially on weathered surfaces. Its thickness appears to be over 50 feet. Its outcrop on the east end of Casper Mountain is shown in Pl. XXXII, *A* and *B*. It is in this formation that the natural bridge on La Prele Creek has been eroded, as shown in Pl. XXXI.

TRIASSIC (?).

Chugwater formation.—Throughout this region the red beds, comprising the Chugwater formation, consist of the usual succession of Opeche red shale, Minnekahta limestone, and Spearfish red sandy shales, with gypsum deposits, as in the Black Hills. The Opeche shale averages 80 feet in thickness; the Minnekahta limestone is 20 to 25 feet thick; and the Spearfish red beds are upward of 450 feet thick. These formations are cut off by the fault south of Casper, but they appear again on Muddy Creek and its branches in the syncline south of Casper Mountain. There are excellent exposures in a gorge at the east end of Casper Mountain and southwestward, where the beds dip steeply to the southeast.

The Minnekahta limestone is mostly thin-bedded and of purplish tint, a characteristic aspect which it has in the Black Hills. It is overlain by about 80 feet of red shales, extending to a 15-foot layer of cherty limestone (a feature often seen in the Bighorn section), followed by about 350 feet of typical red shales and sandstones, the whole capped by a 20-foot limestone layer which marks the top of the formation and probably represents the alternation of limestones and red shales at the top of the red beds in the Bighorn region. No gypsum is present in this section. In a portion of the area, at the east end of Casper Mountain, the top limestone gives rise to a prominent wall, in which the beds stand vertical.

The red beds extend along the slopes south of Muddy Creek Valley, but are cut off by the fault southwest of Glen Rock. Their next appearance is on Spring Creek, 2 miles west of La Prele Creek, just below the natural bridge, where the fault bends slightly northward and passes between the red beds and the Laramie sandstone. In this section about 15 feet of Minnekahta limestone is exposed, above about 80 feet of Opeche red shales, which lie on typical Tensleep white sandstone. On La Prele Creek, just below the natural bridge, the fault is in the Spearfish red beds. A short distance south of this the Minnekahta limestone appears, 20 feet thick, above about 80 feet of typical Opeche red sandy shales (with the characteristic purple shales at the top, as in the Black Hills region), which is underlain by 80 feet or more of the Tensleep white sandstone that crosses the creek at the natural bridge. A short distance east, the White River beds extend to the Carboniferous

limestone slopes and for some distance the red beds are concealed. They appear again south of Douglas and extend up the valleys of Wagonhound and La Bonte creeks, where the Spearfish red beds are seen to contain considerable gypsum.

One of the most extensive exposures in this region is on North Platte River in the big bend 7 miles due south of Douglas. At this point the river cuts through an anticline, exposing a small area of Minnekahta limestone and about 50 feet of Opeche red shale. In the exposure the Minnekahta limestone is massive in general appearance, but is very thin bedded and weathers out in thin slabs. Its upper portion is mottled dark gray, but at the top there are 5 feet of more massive limestone of light color, which is rather an unusual feature. The Opeche formation, 80 feet thick, is seen again in a gorge of Wagonhound Creek 9 miles south-southwest of Douglas, lying on the Tensleep sandstone, here very dark.

JURASSIC.

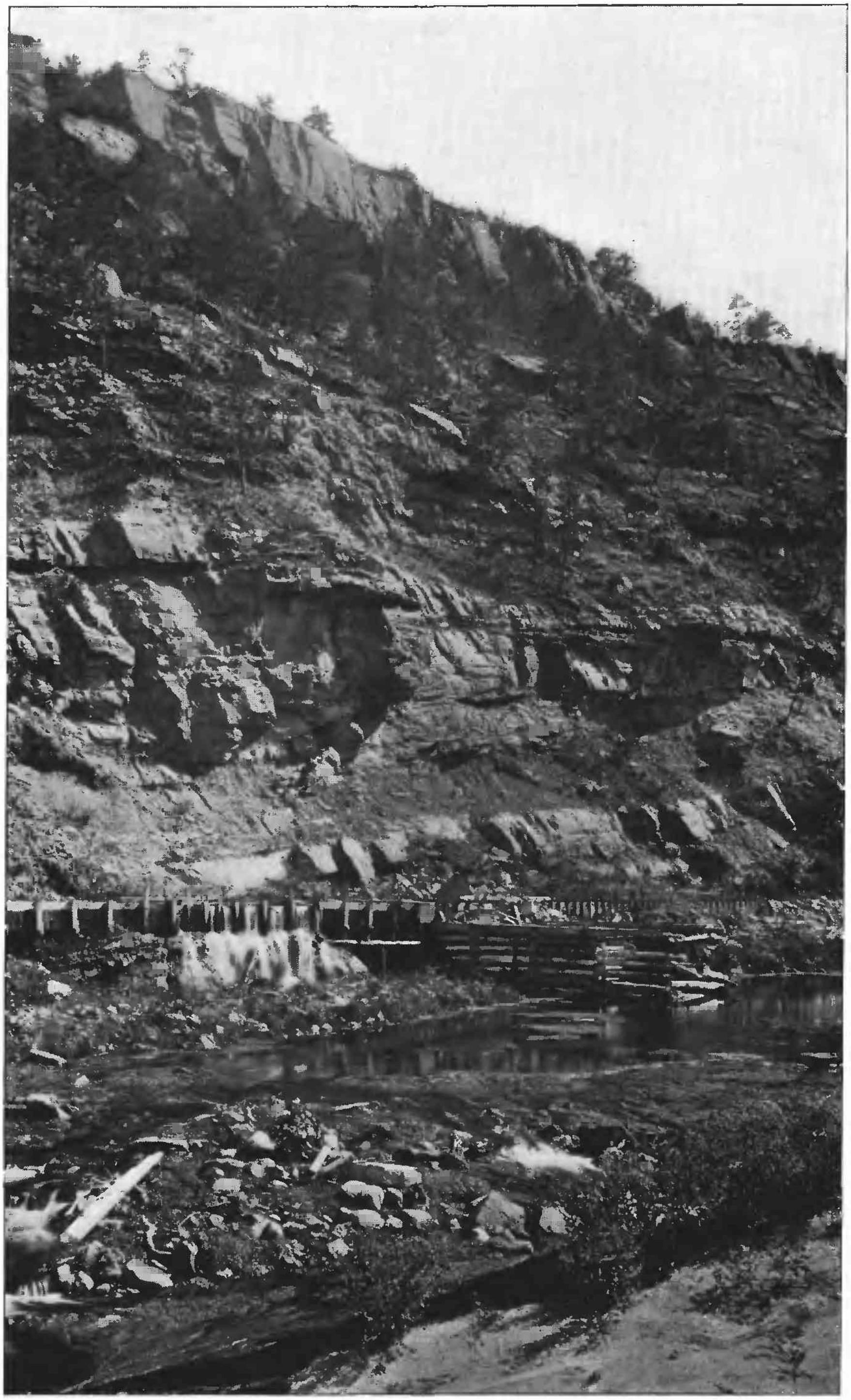
Sundance formation.—Typical marine Jurassic is exposed on both sides of the syncline south and southeast of Casper Mountain, but it is cut off by the fault along the north side of Casper Mountain and eastward for some distance. It appears again on Wagonhound Creek and North Platte River south of Douglas.

The section at the east end of Casper Mountain presents most of the usual features of the formation, which here has a thickness of about 350 feet. At the base, overlying the limestone which is supposed to represent the top of the Spearfish red beds, there are 20 feet or more of white to red sandstones, then a few feet of buff sandstones and shales, with an 8-foot bed of gypsum, which may belong in the Spearfish formation. The principal rocks are dark shales, with limestone layers and concretions filled with characteristic fossils, including many *Belemnites densus.*

There are extensive exposures of the formation along Platte River in the big bend south of Douglas and just west on Wagonhound Creek. The succession here is seen to be 30 feet or more of massive gray sandstone at the bottom, overlain by pale-greenish sandy shales 30 feet thick, succeeded by 5 feet of soft, greenish, massive sandstone, 40 feet of bright-reddish sandy beds, and 15 feet of massive buff sandstone, and topped by about 200 feet of green shales, with a few thin beds of sandstone and limestone containing many later Jurassic fossils.

CRETACEOUS.

Morrison formation.—This characteristic member of the sedimentary series outcrops extensively on both sides of the syncline of the Muddy Creek basin and along the inner slopes of the Hogback Range south of Douglas. It presents its usual characteristics of a "joint clay" or massive shale, mostly of greenish-gray



DAKOTA SANDSTONE, FUSON FORMATION, MINNEWASTE LIMESTONE, AND LAKOTA FORMATION, NEAR EVANS QUARRY, SOUTH WALL OF FALL RIVER CANYON, 4 MILES BELOW HOT SPRINGS, S. DAK.

Capping rock of Dakota sandstone in typical massive beds; lower outcrops are Lakota sandstone, showing nearly entire thickness of that formation.

color, with some portions of maroon tint. Some thin beds of light-colored sand stones are included. The thickness is about 100 feet.

Dakota-Lakota formations.—The sandstone series which has usually been designated the Dakota is well characterized in the region at the north end of the Laramie Range, on the southern side of Casper Mountain, in Muddy Creek Valley, and in the basin south of Douglas. It is cut off by a fault on the north side of Casper Mountain and along the ridge south of Glenrock. At the east end of Casper Mountain sandstones appear in the outlying ridge (shown in Pl. XXXII, *B*), from which they extend to the southwest in a prominent ridge, rising like a wall for some distance where the beds stand vertical. At the base of the series there is a brown conglomerate lying on the Morrison shales, 25 feet thick in places, with pebbles one-half inch to 1 inch in diameter, partly of jasper. This rock merges upward into a coarse buff sandstone, which doubtless represents the Lakota formation of the Black Hills region. Above this are dark shales, indistinctly exposed, which include, at a horizon about 50 feet above the conglomerate, a bright, purplish-red clay bed, all strongly suggestive of the Fuson formation. In the hogback (shown in Pl. XXXII, *B*) there are two sandstone beds above the basal conglomeratic member. These are separated by shales, and the upper, probably representing the Dakota sandstone, is immediately overlain by black shales of the Benton group. Its uppermost beds are thin bedded, rusty colored, and intercalated with very thin-bedded brown sandstones and shales. South of Douglas there are three sandstones, the basal one coarse grained and conglomeratic, as on Muddy Creek. Near Guthrie post-office the upper sandstone is prominent and is underlain by 20 feet or more of reddish clay, strongly suggestive of the Fuson formation. The series here forms a prominent ridge rising above Red Valley on the west and badlands of Benton formation on the east. Farther east is an overlap of White River deposits.

Benton group.—The Benton group is extensively exhibited in the valley of Muddy Creek southeast of Casper and on some branches of the La Bonte south of Douglas. The typical Mowrie beds of hard shales are included, lying 500 feet above the Dakota sandstone at the east end of Casper Mountain and appearing prominently on the south flank of the first anticline south of Douglas. The underlying rocks are dark shales with thin beds of rusty sandstone, typical of the lower portion of the Graneros formation.

The Mowrie beds comprise a total of 50 feet of hard sandy shales, which weather to a light-gray color and rise in low but sharp ridges bearing scattered pines and cedars, as in the Bighorn and Black Hills regions. Next above are about 500 feet of dark shales, extending to a very conspicuous sandstone layer 20 feet or more in thickness, partly massive and partly thin bedded, which is very

fossiliferous in Muddy Creek Valley. The following fossils obtained in this horizon were determined by Mr. T. W. Stanton: *Inoceramus fragilis*, M. & H., and *Cardium pauperculum*, Meek, which indicate a horizon in the upper part of the Benton. This sandstone is overlain by several hundred feet of dark shales, with some thin layers of sandstone and horizons of concretions, but the thickness of this upper series was not accurately measured.

Niobrara formation.—Some areas of this formation are exposed in the syncline southwest of Glenrock and 12 miles south of Douglas on La Bonte Creek. The material is a limy shale or impure chalk, some of the beds of which are moderately hard. It is characterized by the light straw color which it presents on weathered outcrops and by the occurrence of thin beds of limestone filled with *Ostrea congesta.* A small outcrop of beds supposed to belong to this formation appears southwest of Casper at the foot of Casper Mountain, lying on the north side of the fault under the upturned edge of the Pierre shale, but is too indistinct for conclusive identification.

Pierre shale.—The Pierre shale is extensively exposed about Casper, extending to the foot of Casper Mountain, where it is upturned somewhat and cut off abruptly by the great east–west fault. Its dips are mainly to the northeast, and east of Casper it soon passes under the Fox Hills sandstone. To the northwest it extends from Casper to the base of the Bighorn uplift in continuous outcrop. The material is dark-gray shale in which occur numerous concretions, mostly of small size, some of them containing distinctive Pierre fossils. The relations to the Fox Hills formation are somewhat obscure, for apparently to the north the upper Pierre beds contain sandstone intercalations which closely resemble Fox Hills beds.

Fox Hills and Laramie formations.—Between Casper and Douglas there are extensive exposures of the Laramie formation, underlain to the west by the Fox Hills sandstone, and traversed by the Casper Mountain fault, which brings them in contact with the series of older rocks lying to the south. On North Platte River and in the vicinity of Casper and Glen Rock the Pierre shale appears to be clearly separable from the Fox Hills, if the lowest series of light-colored sandstones is to be regarded as the base of the latter.

In this lower sandstone series, 2 miles south of Glenrock, the following fossils were obtained, according to determinations by Mr. T. W. Stanton: *Anomia* sp., *Avicula linguiformia*, E. & S.; *A. nebrascana*, E. & S.; *Modiola meeki*, E. & S.; *Lunatia occidentalis*, M. & H. (?); *Haminea occidentalis*, M. & H.; *Callista deweyi*, M. & H., and *Scaphites nodosus*. These sandstones are regarded as either high in the Pierre shale or as representing the lower portion of the Fox Hills. The latter is a more acceptable interpretation, for the sandstones lie not far below the base of the Laramie coal measures of the mines at Glen Rock, the dip being very gentle between the two places.

GEOLOGY OF THE HARTVILLE UPLIFT.

STRUCTURAL RELATIONS.

The Rocky Mountain Front Range and the Black Hills uplifts are connected by an anticline which would have considerable prominence were it not for the thick covering of Tertiary deposits. It branches from the main Laramie uplift north of Iron Mountain, is extensively bared by erosion along North Platte River and northward for some distance in the Hartville region, and is marked by the prominent peak of granite known as Rawhide Butte and by numerous minor outcrops of schists, limestone, and Cretaceous rocks in the eastern portion of Converse County. This anticline is separated from the main Black Hills uplift by a low, transverse syncline in which it is crossed by Cheyenne River.

As compared with the Laramie Mountains and the Black Hills this uplift is low and narrow, but has sufficient prominence to expose the pre-Cambrian rocks in places, and doubtless has raised in other places ridges of these rocks that are now concealed under Tertiary deposits. The syncline lying west of this uplift is deeply covered by these Tertiary deposits along the flank of the Laramie Range, but reveals an extensive area of Carboniferous limestones to the south, Morrison to Niobrara and probably younger formations in the northwest corner of Albany County, and Fox Hills and Laramie formations to the north, where it merges into the great syncline lying between the Black Hills and the Bighorn Mountains. On the east side the covering of White River and late Tertiary deposits is so heavy, especially in the high range of Pine Ridge and on the divide between North and South Platte rivers, that the relations are difficult to ascertain. In Goshen Hole, where the Tertiary formations have been removed, it is seen that there is a basin of Laramie shales and sandstones, undoubtedly the northern extension of the great area of this formation which underlies the northeastern portion of Colorado. To the north this basin rises so that there appear in succession the Pierre shale, Niobrara chalk, and the other Cretaceous and underlying formations on the flanks of the Black Hills uplift in the southwest corner of South Dakota.

The most extensive exposures of the Hartville uplift are along North Platte River, above Guernsey, and about Hartville and northeastward. Some of the general relations are shown in section 4, Pl. X. It will be seen from this section that the old granites and schists are exposed in a narrow zone, on the eastern side of which the overlying Carboniferous limestones dip eastward under a district heavily covered by Arikaree formation, but doubtless underlain by the regular succession of Paleozoic and Mesozoic rocks. West of the axis there is a broad plateau of Carboniferous limestones dipping very gently westward for some distance, then rising in a low arch with steep dips on its west side which carry it into a syncline containing upper

Carboniferous, Permian, and Cretaceous rocks up to Graneros shales. These formations are all clearly exposed in the deep gorge cut by North Platte River. To the south there is a great thickness of Arikaree formation extending to the base of Laramie range and far up its flanks. On Laramie River, some distance below the Colorado and Southern Railway crossing there are small exposures of granites and schists, which again outcrop in high ridges in Rawhide Butte, which rises prominently above the high plains south of the head of Niobrara River. Near Lusk, at the head of this river, the old schists again appear at a number of points in the vicinity, with overlying red quartzite and limestones aud a small exposure of Red Beds just east of Manline station. Along the northern face of Pine Ridge there is a continuous covering of Arikaree formation, but in some of the canyons at the head of Oldwoman Creek and its branches in the northern face of the great escarpment there are several exposures of the older rocks. On the east side of Oldwoman Creek there is exposed, by the removal of the White River beds, an anticlinal ridge of considerable prominence, consisting mainly of Dakota-Lakota sandstone, which pitches downward to the north and disappears in the plains south of Lance Creek. It has gentle dips on the east and nearly vertical dips on the west side.

STRATIGRAPHY.

The rocks of the Hartville uplift are given in the following table:

Generalized section of the rocks of the Hartville uplift.[a]

Age.	Formation.	Principal character.	Thickness.
			Feet.
Cretaceous	Pierre	Dark shales with limstone concretions	1,200
	Niobrara	Impure chalk and limy shales	250
	Carlile	Gray shales with concretions and thin sandstone layers.	425
	Greenhorn	Hard, impure, slabby limestone	50
	Graneros	Dark shales with local sandstone bed near base	‡800
	Dakota	Buff, gray, and reddish, massive, coarse-grained sandstone.	‡60
	Fuson	Gray, buff, and maroon shales and sandstone	60
	Minnewaste	Gray limestone	5
	Lakota	Coarse, buff, massive, cross-bedded sandstone	100
	Morrison	Pale-green, gray, purple, and black clay, with thin limestone.	100
Jurassic	Sundance	Buff sandstones and gray clays	200

[a] A detailed description of the geology of the Hartville region appears in folio No. 91 of the U. S. Geol. Survey, by W. S. Tangier Smith and N. H. Darton.

TYPICAL CLIFFS OF DAKOTA SANDSTONE, NORTHEAST SIDE OF SALT CREEK, 2 MILES SOUTH OF NEWCASTLE, WYO.

View showing massive bedding and large columnar structure. Looking southeast.

Generalized section of the rocks of the Hartville uplift—Continued.

Age.	Formation.	Principal character.	Thickness.
			Feet.
Triassic? or Permian.	Spearfish	Bright, reddish-brown, sandy shales and thin-bedded sandstone with gypsum.	450
	Minnekahta (Permian).	Thin-bedded gray limestone	20
Carboniferous	Opeche (Permian)	Bright-red thin-bedded sandstone, with red, sandy shale.	60
	Hartville (Pennsylvanian to Mississippian).	Massive gray limestone, in part cherty, some beds very sandy; also white, gray, buff, and red sandstone, red shale, and gray limestone near base, and, at base, red quartzite.	630
	Guernsey (Mississippian).	Conglomeratic quartzite, with overlying sandstone and massive gray limestone, lying on quartzite, schist, limestone, gneiss, and granite dikes.	150
Algonkian		Granites and schists.	

CARBONIFEROUS.

Guernsey formation.—The name Guernsey formation has been applied to the basal member of the Carboniferous in the Guernsey-Hartville region. It consists mainly of limestone, but has a thin series of alternating sandstones and limestones at its base, the lowermost member, a white to pinkish conglomeratic quartzite, lying unconformably on a planed-off surface of Algonkian schists and granites. Its thickness ranges from 75 feet to about 200 feet, the smaller amount being due to the removal of upper members by erosion prior to the deposition of the overlying formation. The following typical section was made by Dr. W. S. Tangier Smith, west of Guernsey, on North Platte River:

Geologic section of Guernsey formation west of Guernsey, Wyo.

	Feet.
Red quartzite of the Hartville formation, unconformity.	
Dark-gray fine-grained limestone bed	30
Light-gray fine-grained limestone bed	40
Fine-grained gray limestone, with purplish tinge, about	30
Yellow, fine-grained, massive limestone	18
Red fossiliferous sandstone	6
Fine-grained gray limestone	5
Moderately coarse-grained, limy sandstones, of dull-reddish or yellowish color	4
Nearly white conglomeratic quartzite lying on Algonkian schists	10

This formation probably is represented farther south on this uplift, near the junction of the Laramie Range, but it has not been differentiated in that portion of

the area. It extends to the northward for some distance and is believed to represent part of the Pahasapa limestone of the Black Hills. The following fossils were collected from the Guernsey formation in the Platte Canyon and determined by Dr. G. H. Girty:

Eumetria verneuiliana?.
Fish tooth.
Productus gallatinensis.
Productus lævicosta.
Productus semireticulatus?.
Pugnax sp.
Seminula subquadrata.
Spirifer cf. Keokuk.
Spirifer striatus var. madisonensis.
Zaphrentis sp.

These are Mississippian (lower Carboniferous) forms.

Hartville formation.—The Hartville formation consists of a thick mass of limestones having at the base a characteristic deposit of brownish-red quartzite from 50 to 100 feet thick lying on the irregularly eroded surface of the Guernsey formation. The erosion separating these two formations represents a portion of earlier Carboniferous times. The limestones contain sandy beds, some sandy mixture, and occasional thin layers of shale. The limestones are fine grained and compact, generally of light-gray color, and, at some horizons, contain thin sheets of chert and chert nodules. The sandstones are medium grained and occur mostly in beds less than 10 feet thick, although locally they are thicker. They appear to have calcareous cement and probably, where not weathered near the surface, are too compact to be water bearing.

The Hartville formation is extensively exposed in the region north of Guernsey, about Hartville, and westward, and especially in the deep canyon which has been cut by North Platte River above Guernsey. It gives rise also to an extensive plateau extending northward from Platte Canyon to the Elkhorn Railroad. The limestones about Lusk, with the basal red sandstone lying on the Algonkian schists, probably belong to the Hartville formation, which doubtless represents the Minnelusa formation of the Black Hills. The following fossils, obtained from between 300 and 500 feet above the base of the formation in the canyon of Platte River, were determined by Dr. G. H. Girty, by whom they are regarded as upper Carboniferous (Pennsylvanian division):

Ambocœlia? sp.
Archæocidaris spines.
Aviculopecten occidentalis.
Derbya crassa.
Euomphalus sp.
Fusilina cylindrica.
Marginifera splendens?.
Orthothetes (or Derbya).
Productus æquicostatus.
Productus cf. inflatus.
Productus prattenianus.
Productus punctatus.
Productus semireticulatus.
Seminula subtilita.
Spirifer rockymontanus.

GREENHORN LIMESTONE LYING ON GRANEROS SHALES, COTTONWOOD CREEK, SOUTHWEST OF EDGEMONT, S. DAK.

View showing characteristic thin bedding and shale intercalations in Greenhorn limestone, and the abrupt change from Graneros shale.

A. MONOCLINAL RIDGES OF GREENHORN LIMESTONE AND SANDSTONE IN CARLILE FORMATION, AT DAM OF CLIFTON RESERVOIR, SOUTH OF NEWCASTLE, WYO.

Dakota hogback in distance, to right. Looking north.

B. MESAS CAPPED BY GREENHORN LIMESTONE, SOUTH OF EDGEMONT, S. DAK.

Slopes of Graneros shale. Looking east.

From the lower portion of the formation there were obtained several of the lower Carboniferous (Mississippian) forms given on page 64.

A series of red shales in the lower portion of this formation and its basal red quartzite may represent the basal red shale member of the Minnelusa formation in the Black Hills region.

Opeche formation.—The chief exposures of the Opeche formation in this uplift are in the vicinity of North Platte River, on the west side of the uplift, 15 miles northwest of Guernsey, and in a few scattered outcrops to the north. Apparently it is also exposed near the beginning of the uplift north of Iron Mountain. It has a thickness of about 60 feet, and consists of thin-bedded, fine grained, bright-red sandstone. It rests conformably upon a massive white sandstone at the top of the Hartville formation, a relation similar to that which it presents throughout the Northwest.

Minnekahta limestone.—This limestone doubtless extends under the Arikaree formation along both flanks of the uplift from Laramie Range to the foot of Pine Ridge, but was observed only in one small area, together with the Opeche formation, northwest of Guernsey. The rock usually outcrops in a massive ledge, but is made up of thin layers, which, on weathering, break up into plates or thin slabs.

TRIASSIC (?).

Spearfish formation.—The Spearfish red beds are exposed in the small basin 15 miles northwest of Guernsey, at the head of South Fork of Sybylee Creek north of Iron Mountain, in the upper portion of Chugwater Valley, and near the railroad east of Manline station. The rocks are the typical red sandy shales, grading into soft thin-bedded sandstone, some layers of which are distinctly ripple marked. Some of the lower beds contain thin layers of white limestone from a few inches to several feet thick, and intercalations of thin beds of gypsum. The total thickness exposed northwest of Guernsey is estimated to be 450 feet.

JURASSIC.

Sundance formation.—In the basin northwest of Guernsey the Sundance formation is exposed in small areas, mainly in the banks of North Platte River and on some of the slopes north, and in the forks of Muddy Creek. Soft fine-grained sandstones of light-buff color predominate. A thickness of 200 feet is exhibited, of which the lower 140 feet are sandstones and the upper 60 feet interbedded slabby sandstones and clays. The rocks contain typical marine Jurassic fossils in moderate number. A section of the middle and upper beds of the

formation exposed near Muddy Creek has been reported by the late Prof. Wilbur Knight[a] as follows:

Geologic section of Sundance formation near Muddy Creek, Wyoming.

	Feet.
Variegated clays and marls with bands of sandstone	43½
Yellowish sandstone	8½
Dark shale beds with remains of *Baptanodon, Belemnites, Ostrea, Tancredia, Comptonectes,* and a few septaria	38½
Yellowish sandstone	2½
Gray sandstone	5½
Yellowish sandstone alternating with thin clay bands	6½
Thin-bedded gray sandstones with a few bands of clay	5½
Total thickness exposed	110½

A small exposure of the top of the formation occurs in a small side ravine in the anticline on the east side of Oldwoman Creek.

CRETACEOUS.

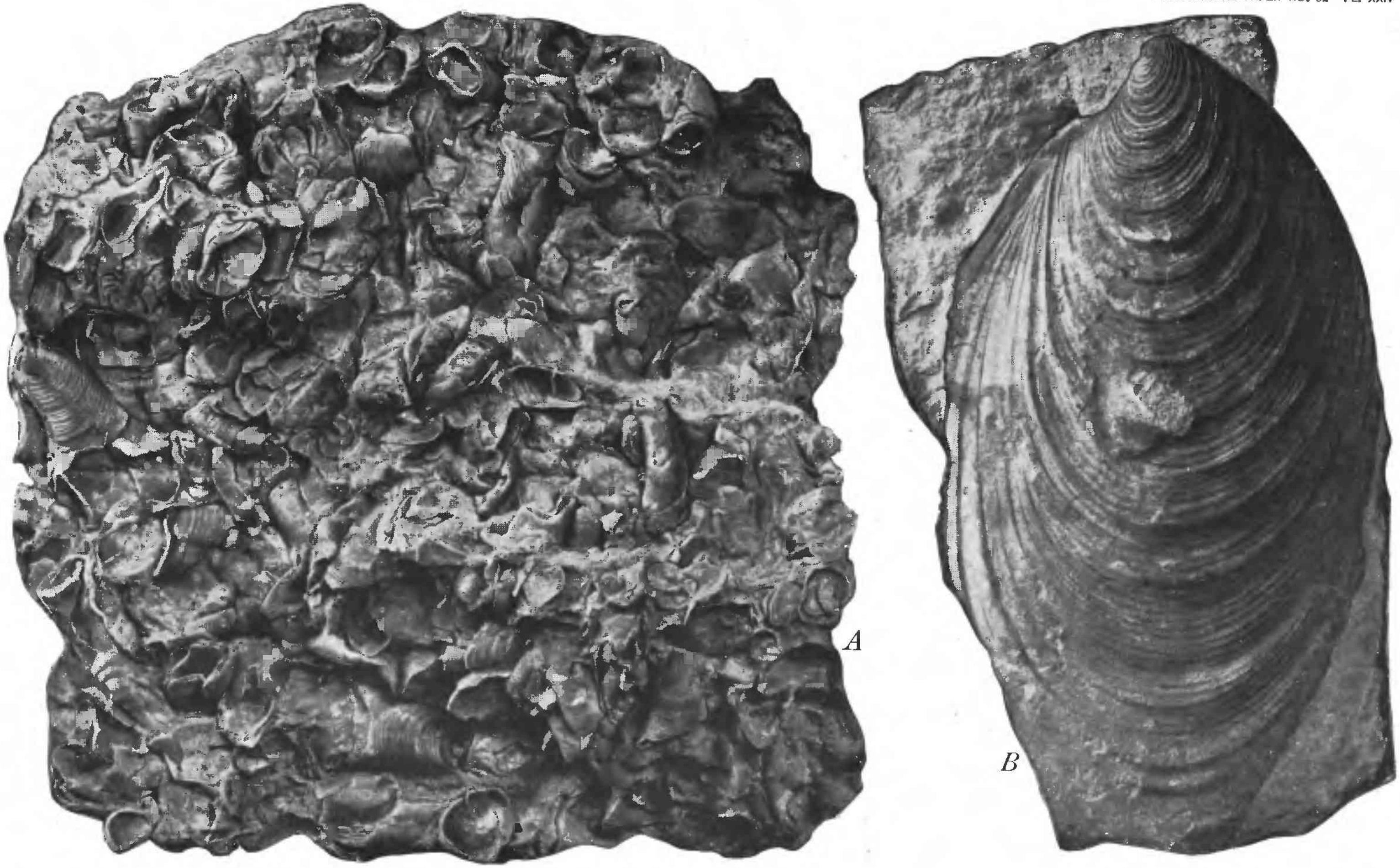
Morrison formation.—The Morrison formation appears in the banks of North Platte River and adjoining slopes, in the basin northwest of Guernsey, and in the draw in the anticline on the east side of Oldwoman Creek. It consists of "joint clays," or massive shales of various colors in which pale green predominates, but of which some portions are purplish, reddish, and black. Some thin beds of limestone are intercalated. The rocks in a section on Muddy Creek northwest of Guernsey are described by the late Prof. Wilbur Knight[b] as follows:

Geologic section of Morrison formation on Muddy Creek, Wyoming.

	Feet.
Dakota conglomerate and sandstone	
Variegated marls and clays shading from yellow to dark maroon, with dinosaurian remains	38½
Calcareous sandstone	2
Bluish and yellowish marls, containing *Brontosaurus* at top and *Morosaurus* at base	22½
Drab calcareous sandstone	1½
Light-colored clays and marls, with thin bands of sandstone	24
Clays and marls varying from light gray to brown	23½
Hard band of light-gray clay	4½
Drab and greenish clays	22½
Drab sandstone	2
Yellow, greenish, and light-brown marls shading into maroon in the upper portion	38½
Gray sandstones	3
Bluish gray clay	4
Bluish and drab clays interstratified with yellowish bands	38½
Total thickness	234½

[a] Bull. Geol. Soc. America, vol. 2, pp. 377-388.

[b] Loc. cit.



CHARACTERISTIC FOSSILS OF NIOBRARA CHALK (*A*) AND GREENHORN LIMESTONE (*B*), IMPORTANT GUIDES IN WELL BORING.

A. Ostrea congesta; *B*, Inoceramus labiatus.

Dakota-Lakota formations.—The sandstones of these formations are prominent features in the basin northwest of Guernsey, and constitute the higher part of the anticlinal range on the east side of Oldwoman Creek. The series is from 250 to 350 feet thick, comprising hard, massive, coarse-grained sandstones which to the north are separated by a succession of clays and thin-bedded sandstones, believed to belong to the Fuson formation of the Black Hills series. In the sandstones there are thin, conglomeratic streaks, general cross bedding, and colors predominately buff to dirty gray. In the uppermost sandstone there is usually more or less ironstone in thin layers and concretions. On the east side of Oldwoman Creek the Fuson formation is underlain by a thin bed of limestone, which probably represents the Minnewaste limestone of the southern Black Hills.

Benton group.—In the basin northwest of Guernsey only the Graneros member of this group is exposed to a thickness of about 120 feet, but the entire group is exhibited in the anticline on the east side of Oldwoman Creek, where the lower formation (the Graneros) consists of dark shales 800 feet thick at the greatest measurement, but apparently somewhat crushed and faulted in places, so that the full amount is not exhibited at all points. A thin bed of hard sandstone occurs about 100 feet above the base, a feature also seen northwest of Guernsey, where this sandstone is the uppermost member exposed. Above the sandstone there are dark shales with occasional thin sandstone layers, capped by the Greenhorn limestone, a member consisting of about 50 feet of thin-bedded impure limestone, weathering out in slabs of dirty buff color and usually containing large numbers of the characteristic fossil, *Inoceramus labiatus.* This member is succeeded by the uppermost member of the group, the Carlile, which has a thickness of about 425 feet, and consists of shales of gray color, with occasional thin beds of sandstone, and, toward the top, contains a characteristic horizon of biscuit-shaped concretions.

There are extensive exposures of the upper members of the Benton formation on the west side of the anticline on Oldwoman Creek, the beds dipping very steeply to the west.

Niobrara formation.—This formation is exposed along the Oldwoman Creek anticline. Its thickness is 250 feet, and the rocks consist of impure chalk and limy shale, which are of lead-gray color in fresh exposures, but weather to a bright, pale-straw color, a highly characteristic feature which renders the outcrops very conspicuous. The formation contains occasional thin layers of limestone filled with the characteristic fossil, *Ostrea congesta.*

Pierre shale.—This formation probably underlies the Arikaree formation along the east side of the uplift from Iron Mountain station northward, and doubtless also the western side of the uplift north of Orin Junction, but it is exposed only in the lowlands north of the foot of Pine Ridge. There it is

found on both sides of the anticline of Oldwoman Creek, extending to Cheyenne River and thence along the slopes of the Black Hills uplift. The beds dip steeply along the Oldwoman Creek Valley, where a cross-section measurement gave a thickness of 1,200 feet. The rocks consist of a monotonous series of dark-gray shales, with occasional thin concretions, and, 200 feet below the top, a zone of concretions of limestone filled with *Lucina occidentalis*. As in other regions, the limestone concretions of this upper zone weather out in characteristic tepee-shaped forms, which have been designated tepee buttes.

The Pierre shale is overlain by the Fox Hills and Laramie sandstones, which extend far to the north and west in the great basin lying between the Black Hills and the Bighorn Mountains.

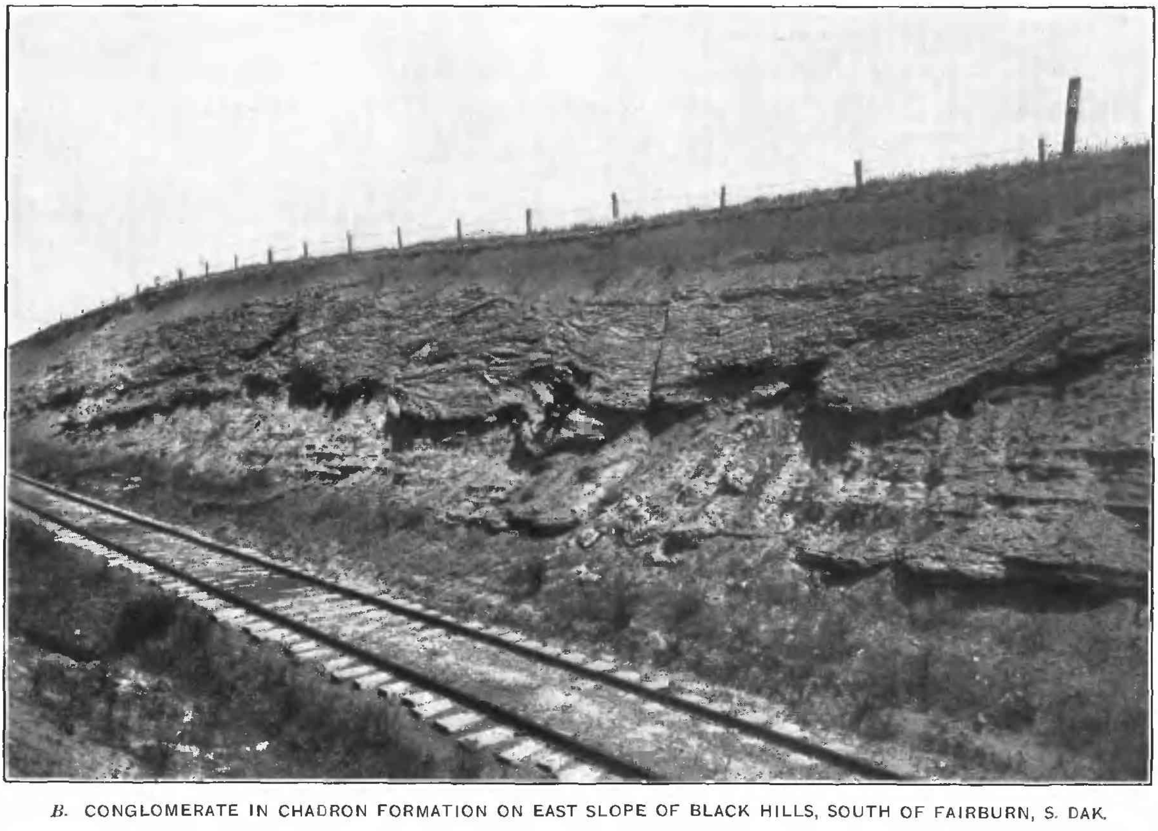
GEOLOGY OF THE LARAMIE FRONT RANGE.

GENERAL STRUCTURE.

The Laramie Front Range is composed chiefly of schists and granites of Algonkian and Archean age, against which lie the regular succession of upper Paleozoic and Mesozoic rocks. Originally the front of the range was entirely covered by the Arikaree formation, but now this formation has been removed by erosion in places along the range, allowing the older sedimentary strata to appear. There are still, however, wide areas to the north in which they are hidden. Hayden mentions a locality at the head of Cottonwood Creek where the limestone appears, and in the Report of the Fortieth Parallel Survey Mr. Arnold Hague describes the sedimentary rocks extending southward from the head of Sybylee Creek. Between this creek and Iron Mountain station a projection of the schists of the Laramie Range extends northeastward along the axis of the Hartville uplift. On the north side of this projection, in which the schists are exposed for about 10 miles northeast from the main mountain mass, lies Sybylee Valley, in which is a considerable area of Red Beds (Chugwater formation), overlying Carboniferous limestone to the west and apparently abutting against the schists to the east. Possibly the apparent overlap is due in part to faulting.

Near Iron Mountain station there are several flexures in which the Paleozoic and Mesozoic rocks are extensively exposed, the station itself being on an anticline which extends southward diagonally out of the mountain. To the west of this anticline there is a narrow synclinal basin, exposing all of the rocks up to the Benton. To the south for some distance there is an interval in which the Tertiary deposits abut against the schists in the mountain slopes, but at Horse Creek and thence southward to Lodgepole Creek there are extensive exposures of the older sedimentary rocks lying west of the railroad. On Horse Creek these rocks include all the formations up to and including the Fox Hills. Southwest of

A. LIMESTONES OF WHITE RIVER GROUP IN RED VALLEY, 8 MILES NORTHWEST OF HERMOSA, S. DAK.



B. CONGLOMERATE IN CHADRON FORMATION ON EAST SLOPE OF BLACK HILLS, SOUTH OF FAIRBURN, S. DAK.

View showing cross bedding.

Islay a small area of granite rises east of the small basin of Carboniferous limestones, but the succession east of the granite is covered by Tertiary deposits. On Crow Creek the granite is offset to the east for some distance, and in Granite Canyon, on the railroad, and thence southward to the Colorado line, the succession of sedimentary rocks is exposed, comprising at the State line all rocks from the Carboniferous limestone to the Dakota sandstone.

STRATIGRAPHY.

CARBONIFEROUS.

The following section was measured by Dr. W. S. Tangier Smith on the Chugwater at Iron Mountain station, Wyoming:

Geologic section at Iron Mountain station, Wyoming.

	Feet.
Limestone	5
Reddish sandstone	15
Limestone	40
Red sandstone	25
Massive limestone	135
Reddish quartzitic sandstone	12
Massive gray limestone	40
Quartzitic red sandstone conglomerate	25
Compact limestone	25
Red, rather coarse-grained sandstone and medium-grained conglomerate	25
Conglomeratic quartzite, light colored	10
Granite.	

The lower sedimentary members in this section may possibly be older than Carboniferous, but no evidence on this point is obtainable, and the upper series of 85 feet, consisting of red sandstones with included limestones, probably belongs in the Red Beds.

In Horse Creek Canyon, where the beds stand nearly vertical, a thickness of about 500 feet was measured. The basal bed is a sandy limestone lying directly on the granite. The rocks are mainly limestones, with several intercalated beds of brown sandstone, as in the Chugwater section.

At Table Mountain, between North Crow Creek and Lodgepole Creek, the following section is given by Mr. Hague:

Geologic section at Table Mountain, Wyoming.

	Feet.
Pink and cream-colored limestone, alternating with thin sandy beds	650
Bluish limestone, highly siliceous	650
Conglomerate (thin bed)	650
Gray and bluish sandy limestone	650
Red sandy limestone	50
Pink sandstone	50
Gray sandstone, fine grained, but with some conglomerate, very compact	100

At Granite Canyon, just north of the Union Pacific Railroad, Mr. Hague reports the following succession:

Succession of beds at Granite Canyon, Wyoming.

Light-gray limestone, with sandy beds.
Massive blue limestone
Bright red sandy limestone.
Reddish-gray sandstone, compact, fine pebbles.

East of Signal Peak, 3 or 4 miles south of the railroad, the following section was measured by Mr. Hague:

Geologic section east of Signal Peak, Wyoming.

	Feet.
Blue limestone	300
Fine conglomerate (thin bed)	300
Red sandy limestone	300
Bluish-gray limestone	400
Red sandstone, limy near top	100

The sandstones are all somewhat limy and the limestones carry more or less sand, and in the heavier bedded rocks there frequently occur thin intercalated sandstones and fine conglomerates. The lower sandstones vary from a hard rock to a loose friable conglomerate, and all have a reddish tint. The upper sandstones are generally coarse and of bright-red color. Many of the limestones are of dark bluish-gray color, with bands of various colored beds. The upper members are usually lighter in color, often pink and white. At Granite Canyon the lower limestone is dolomitic. The uppermost limestone and the bed immediately underlying the red beds at Horse Creek is a very fine-grained homogeneous rock of deep flesh-red color, and is a nearly pure dolomite. The red arenaceous limestone at the base of the limestone series appears to be a constant horizon. The fossils reported are as follows: *Productus semireticulatus*, *P. cora*, and *Seminula subtilita*, the first being the most abundant. These indicate that the beds are upper Carboniferous, or Pennsylvanian, doubtless representing part of the Minnelusa formation of the Black Hills or the Hartville limestone of the Hartville-Guernsey region.

TRIASSIC (?).

Chugwater formation.—The red-bed series on the Chugwater about Iron Mountain, as measured a short distance north of Iron Mountain station, has a thickness of between 700 and 800 feet in beds dipping from 43° to 78°. The rocks are mostly red sandy shales grading into soft red sandstones, which, in most of the beds, contain

A. CLOUD PEAK, THE CULMINATION OF THE BIGHORN MOUNTAINS.

View showing typical glacial erosion in granite. Cloud Peak and top of glacier slightly to right of center distance. Looking west.

B. EAST SLOPE OF BIGHORN MOUNTAINS, FROM ACROSS WOLF CREEK CANYON.

Granite on left, overlain by Deadwood shales and sandstone, Bighorn limestone (the most prominent ledge in distance), and Littlehorn limestone; beds all steeply arched to right of center in distance.

considerable clay. Their brilliant red color is their most striking feature. Near the middle of the formation are two thin layers of limestone, and at the base the following section:

Section just north of Iron Mountain station, Wyoming.

	Feet.
Typical red beds	Many.
Brownish-red soft sandstone, massive	10
Limestone, white, massive	5
Brownish-red sandstone, moderately soft, massive	40
Thin-bedded limestone	6
Reddish-brown sandstone	3
Limestone with Carboniferous fossils	Many.

The Minnekahta limestone, probably, is not represented in Chugwater Valley, a most unusual feature. The brownish-red sandstones with limestone layers in the basal series presumably represent the Tensleep sandstone. The top of the red beds on the Chugwater consists of a massive bed of pale-red sandstone, a characteristic member from there southward to and through Colorado. Gypsum does not occur in the section on the Chugwater, but appears farther south.

On Horse Creek the Chugwater formation is extensively exposed and the following section was measured across vertical strata:

Section on Horse Creek, Wyoming.

	Feet.
Pale reddish-brown, massive sandstone	40
Bright-red sandy shales and soft thin-bedded sandstones	700
White limestone, massive	5
Bright-red shale	100
Porous sandy limestone	4+
Bright-red shale	70
Limestone, sandy and massive above, thin-bedded and purplish below	20
Bright-red shales and sandstones	260
Pale-reddish, massive, soft sandstone	20
White, hard, massive limestone	5
Pale reddish-brown, massive, soft sandstone	40
Massive limestones, Carboniferous	Many.

The 20-foot limestone bed in this section gives rise to a conspicuous ragged wall rising 20 feet or more on the red-shale slopes. The whole strongly suggests Minnekahta limestone with red Opeche beds below. The basal sandstone bed, 60 feet thick with the included 5-foot limestone layer, is similar to the basal series on Chugwater Creek and probably represents the Tensleep sandstone.

JURASSIC.

Sundance formation.—This formation extends all along the foot of Laramie Range in Wyoming and is exposed on the Chugwater about Iron Mountain station, on Horse Creek and for some distance southward, and near the State line. Near Iron Mountain station it is well exhibited, consisting of an upper series, 30 feet thick, of soft slabby sandstone, gray at the base and buff toward the top, with ripple-marked layers and much intercalated shale, and of a lower series, 50 feet thick, mostly of green to gray shale, with layers of soft, thin-bedded, greenish-gray sandstones, lying on the red beds of the Chugwater formation.

In the vicinity of Horse Creek the exposures are not plain, but at the base are seen about 30 feet of greenish-gray sandy shales, overlain by 10 feet of bright, buff-colored sandstone, capped by the Morrison formation.

CRETACEOUS.

Morrison formation.—The Morrison beds are exposed extensively on the Chugwater, to some extent on Horse Creek at the head of the Lodgepole, and on head branches of Boxelder Creek near the State line. The rocks are mainly shales with several limestone layers, especially in the lower members. Much of the material is a "joint clay" or a massive shale of pale, greenish-gray tint, and some beds in the middle of the formation present bright maroon and chocolate colors. There are several limestone layers in the lower 50 feet of the formation, varying from a few inches to 3 feet thick. In one of these, near Iron Mountain station, as in other districts, many remains of fresh-water algæ were observed. The thickness on the Chugwater and near Horse Creek is 300 feet.

"*Dakota*" *sandstone.*—The Morrison formation is overlain by sandstone, which gives rise to distinct hogback ridges. The thickness of this sandstone varies from 100 to 150 feet in greater part, but is much less at some points. At the bottom there is usually more or less conglomerate, grading up into buff sandstones, massively bedded, and often more or less cross-bedded, a member which probably corresponds to the Lakota sandstone of the region north. It is overlain by clays with thin sandstones, capped by a series of hard, massive, buff sandstones of typical Dakota aspect, outcropping in prominent cliffs and containing more or less ironstone in streaks and concretions. Near Horse Creek the Dakota sandstone is less conspicuous than the sandstone in the Benton, owing partly to its diminished thickness and partly to its being less hard.

Benton group.—The Benton rocks are exposed to a moderate extent on the Chugwater near Iron Mountain station and on Horse and Lodgepole creeks. They consist of about 1,200 feet of dark clays, hard and fissile below, lighter colored and

CANYON OF TONGUE RIVER BIGHORN MOUNTAINS, WYOMING.

Showing Littlehorn limestone with characteristic castellated erosion forms and canyon walls. Looking west, upstream.

softer above, with a conspicuous bed of hard sandstone about 150 feet above their base. The group usually is separable into Graneros shales, Greenhorn limestone, and Carlile formation, but the Greenhorn limestone is very thin and not everywhere recognizable. The sandstone in the Graneros is well exposed north of Iron Mountain station, having a thickness of 25 feet and rising in a conspicuous minor hogback outside of the Dakota hogback. It lies on 140 feet of dark shale. Above it are 50 feet of dark shale, merging upward into the series of hard gray shales and thin-bedded sandstones, weathering light gray and filled with fish scales, that is so conspicuous along the Bighorn and Black Hills uplifts. The Carlile beds near Iron Mountain station contain thin sandstone beds and numerous concretions near their tops, which present the usual sandstone layers. Near Horse Creek station the concretions in the upper part of the Carlile beds, about 40 feet below the basal massive limestone of the Niobrara, contain *Prionotropis*, an occurrence of this characteristic form similar to that in other districts. The following section gives the succession of Benton rocks in the slopes west of Horse Creek station:

Geologic section of Benton beds west of Horse Creek station, Wyoming.

		Feet.
Niobrara	Limestone.	
Carlile	Black shale	10
	Sandstone and sandy shale	20
	Gray shales, with concretions containing *Prionotropis* near top	200
Greenhorn	Sandy limestone with *Inoceramus labiatus*	½
Graneros	Shales, dark and fissile below	450
	Hard shales and thin-bedded, hard sandstones, weathering light gray, with fish scales (Mowrie beds)	80
	Dark shale	30
	Hard coarse sandstone, massive	25
	Dark shales, fissile to soft	150
Dakota	Sandstone, buff, coarse, mostly soft	20+

Some of these measurements are uncertain, owing to talus or to crushing, for the beds stand nearly vertical. The 25-foot bed of hard sandstone in the Graneros formation rises in a sharp hogback, more conspicuous than the Dakota ridge, which is there very slightly marked, owing to the thinness and softness of the rock. The hard shale, weathering light gray, beginning 30 feet above the Graneros sandstone (Mowrie beds), is the characteristic horizon so conspicuous in regions farther north.

Niobrara formation.—This formation appears in the vicinity of Horse Creek and on the Chugwater northeast of Iron Mountain station. It consists of limestone and impure chalk, grading into limy shale and having all the typical features which it presents in Colorado. Its basal member is a soft, light-gray, massive limestone, filled with the typical *Inoceramus deformis*, and there are two

other beds of limestone above, separated by limy shales. At the top is the usual chalky bed, which weathers to a bright-straw or pale-ocher color, and contains thin limestone masses consisting of colonies of *Ostrea congesta.* The thickness of the formation is 375 feet on Horse Creek and somewhat less on the Chugwater.

Pierre shale.—The Pierre shale appears extensively for some distance on both slopes of the Horse Creek and Chugwater valleys, in a zone approaching a half mile in width in some places. As the beds dip nearly vertically, this indicates great thickness. All the material is dark shale, containing occasional calcareous concretions with typical fossils.

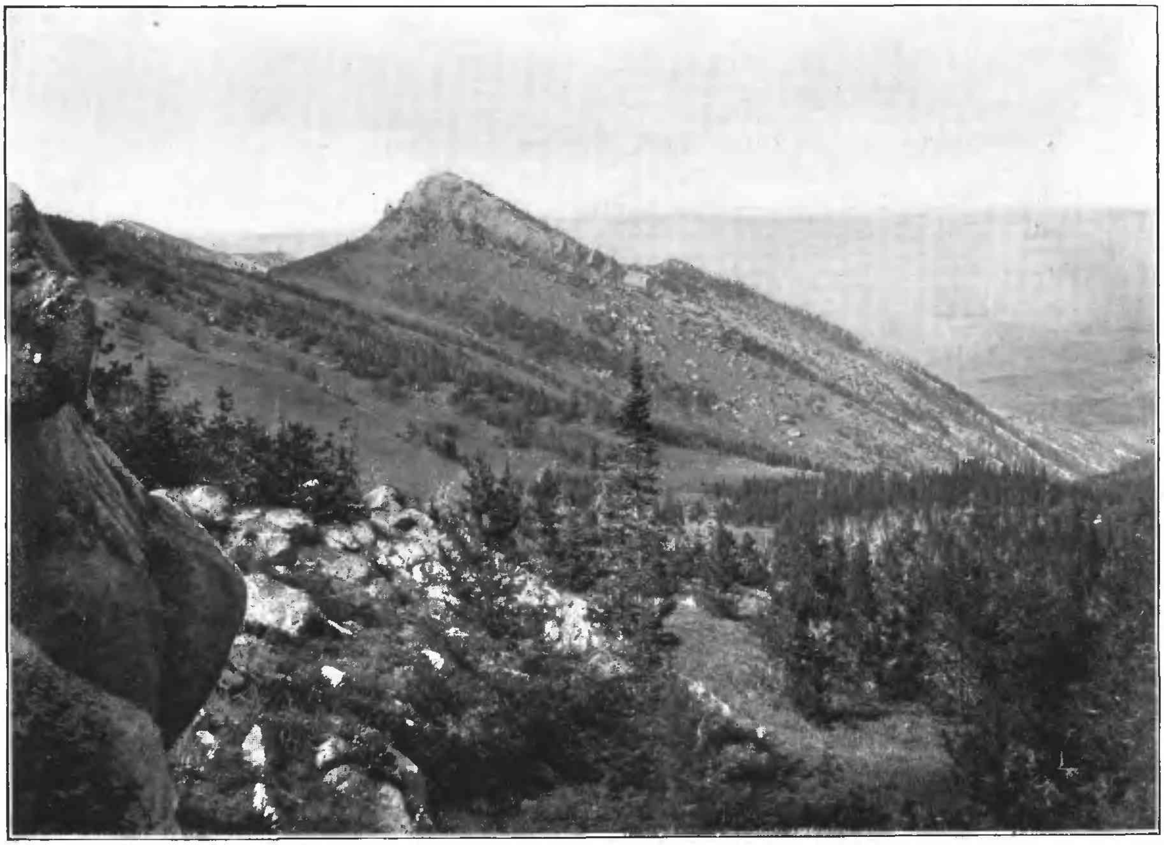
Fox Hills formation. The Fox Hills beds outcrop along the railroad just north of Horse Creek station and possibly at other points in the valleys. The formation consists of soft impure sandstones and sandy clays with an incipient concretionary structure. No fossils were observed and the beds are provisionally classified as Fox Hills because of their sandy character.

PALEOZOIC AND MESOZOIC GEOLOGY OF EASTERN COLORADO.

GENERAL RELATIONS.

The eastern half of Colorado is underlain by an extensive series of sedimentary formations from Cambrian to Tertiary in age. They are in widely extended sheets, which lie nearly level under the plains, but are upturned steeply against the front ranges of the Rocky Mountains. The largest surface areas are the later Cretaceous and Tertiary formations, the latter covering most of the region north. The general structure of the region is indicated in sections 6, 7, 8, and 9, Pl. XI. From these it will be seen that there is a general steep monoclinal dip along the mountain front into a basin east of which there is a low arch extending to and beyond the east line of the State. The broader structural features are shown in Pl. LVIII, which shows the contour of the Dakota sandstone. In the southeastern portion of the State the principal arch east of the main uplift is an anticline which extends southeastward from the Greenhorn and Wet Mountain ranges and passes under the Mesa de Maya. By this uplift the Dakota sandstone is brought to the surface over a wide area south of Arkansas River, especially in localities where there has been deep erosion by the transverse streams. The deep basin west of Trinidad passes diagonally to the northwest behind the Greenhorn Mountain range, and the Florence basin lies in a sharp depression between the southern prolongation of the anticline of the Pikes Peak range and that of Wet Mountain, which coalesce a short distance southwest of Pueblo.

It will be seen from these statements that the monocline of the Rocky Mountain front is by no means continuous throughout. North of Denver it presents some small offsets, of which a series of three en échelon are finely exposed west of

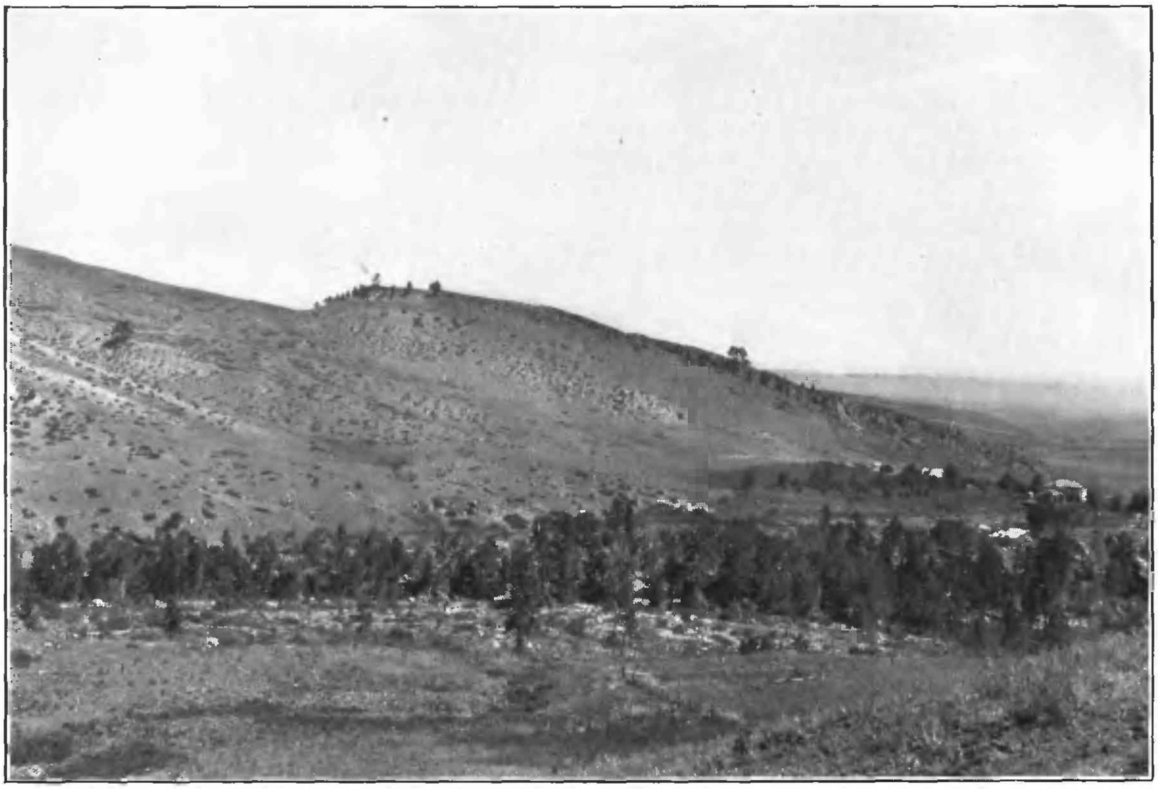


A. TYPICAL CROSS-SECTION VIEW OF EAST SLOPE OF FRONT RANGE OF BIGHORN MOUNTAINS, WEST OF SHERIDAN, WYO.

Granite to left, overlain by Deadwood beds; knob capped by Bighorn limestone; plains of Laramie formation in distance to right.

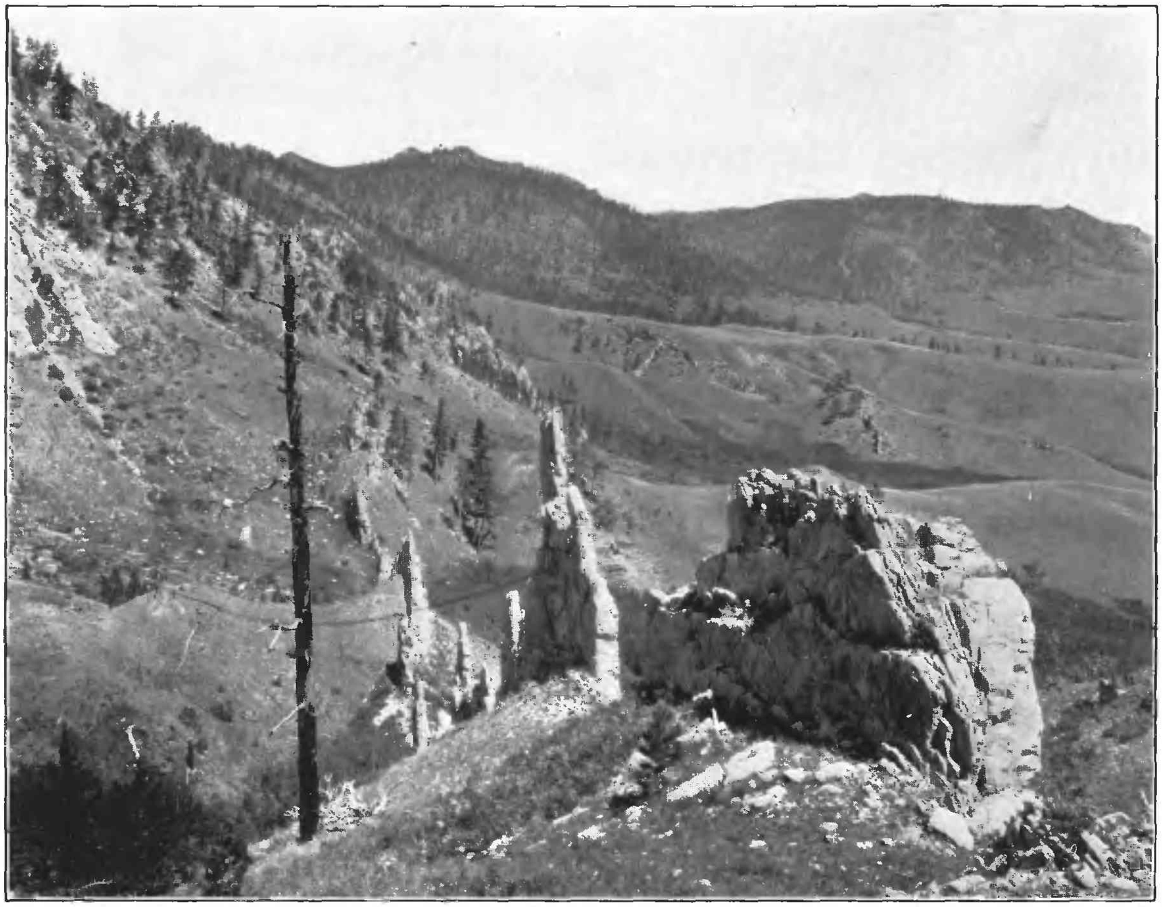
B. EAST SLOPE OF BIGHORN MOUNTAINS, WOLF CREEK, WEST OF SHERIDAN, WYO.

Showing granite in gap and Deadwood to Sundance formations, Tensleep sandstone on slope; Chugwater red beds in valley; cliffs to right capped by Sundance beds (over tents).



A. EAST SLOPE OF BIGHORN MOUNTAINS, ON NORTH SIDE OF WOLF CREEK, NORTHWEST OF SHERIDAN, WYO.

Hogback of Cloverly sandstone; slopes of Morrison formation to left.



B. EAST SLOPE OF BIGHORN MOUNTAINS, AT ROCK CREEK, NORTHWEST OF BUFFALO, WYO.

Limestone layer in Red Beds; dips nearly vertical; Tensleep sandstone to left; granite in distance, brought up by cross fault.

Greeley. These are insignificant compared with the great offsets due to the south-pitching anticlines at the southern end of the Pikes Peak and the Greenhorn Mountain ranges, which extend transversely to the southeast out into the plains.

STRATIGRAPHY.

The sedimentary formations in eastern Colorado maintain great uniformity throughout their course, but occasionally present certain regional variations which are of importance, particularly in the lower formations, some of which occur only in limited areas. The principal variations of this class are due to the fact that there are numerous embayments and protuberances in the floor of granites on which the sedimentary rocks lie, giving rise to overlaps of various kinds. Two of these protuberances west of Denver have been described by Eldridge,[a] who found that they not only cut off some of the lowermost formations, but also mark zones of movement on which uplift has taken place at various times, as indicated by the local absence of some of the formations at different horizons. W. T. Lee has found similar relations in the vicinity of Perry Park southward, and they exist in the great Manitou embayment west of Colorado Springs, where several hundred feet of the older formations are present in a local basin overlapped by later beds on either side. South of this embayment the granite mass of Cheyenne Mountain extends to the east for several miles diagonally across the edges of several thousand feet of nearly vertical beds, a relation which indicates a great fault, some features of which have been described by Prof. W. O. Crosby. This fault extends to the Pierre shale, which appears to lie against the granite for some distance south. In the deep embayment northwest of Pueblo all the formations again appear, from Cambrian to Laramie, with various overlaps and considerable faulting. It is stated that south of Florence the Laramie beds are faulted into contact with the granite. Southwest of Canyon the progressive overlap from Silurian to Morrison onto the granite is clearly exposed. There are numerous overlaps southwest of Wet Mountain, which indicate migrations of shore lines along relatively steep granite slopes at various geologic periods. Southwest of Denver there is also more or less overlap of the Laramie and overlying formations beyond the edges of lower strata, reaching the granite for some distance along the Arkansas divide. There appears to be a similar overlap on the west side of Wet Mountain range.

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[a] Eldridge, G. H., Mon. U. S. Geol. Survey, vol. 27, 1896.

Table of Paleozoic and Mesozoic formations of eastern Colorado.

Age.	Formations.	Principal character.	Thickness.
			Feet.
Tertiary	Denver	Conglomerates, sandstones, and clays.	1,450
	Arapahoe	Clay on thick basal series of conglomerates.	800
Cretaceous	Laramie	Clays, with sandstone layers and coal beds.	1,000
	Fox Hills	Sandy shales, with sandstone at top	100–1,000
	Pierre	Dark shales, with local sandstone layers.	1,500–7,500?
	Niobrara	Light-colored soft limestones and limy clays.	350–700
	Carlile	Dark shales, with sandstone at top	200
	Greenhorn	Slabby limestones	30
	Graneros	Dark shales, with local sandstone layers in lower part.	400–500
	"Dakota"	Gray sandstones, sometimes conglomeratic; fire clay in middle.	100–350
	Comanche series	Soft sandstone and sandy clay	20
	Morrison	Gray to maroon "joint clay," with limestone and sandstone layers.	200
Triassic (?) or Permian	Upper Wyoming (Chugwater).	Bright-red sandy shales, with thin limestone layers and gypsum; reddish sandstone at top.	400
Pennsylvanian	Lower Wyoming (Fountain).	Coarse red sandstones and conglomerates.	600–1,200
Lower Mississippian	Millsap	Gray and purplish limestone	30–200
Ordovician	Fremont	Gray to pinkish dolomite, uneven grain.	100
	Harding	Fine, even-grained, gray to pink sandstone; some shale.	100
	Manitou	Reddish dolomite	100–270
Cambrian		Reddish sandstone	40–100

CAMBRIAN.

Rocks of Cambrian age underlie the Ordovician limestones in the Manitou embayment west of Colorado Springs and in a small area north of Canyon. Elsewhere along the Front Range post-Cambrian rocks appear to lie directly on the old granites or schists, the most extensive development being found on Trout Creek, in Manitou Park, where Dr. A. C. Peale[a] gives two sections having the following succession:

[a] Hayden, F. V., Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873, p. 208.

Sections on Trout Creek, Manitou Park, Colo.

	I.	II.
	Feet.	*Feet.*
Pink limestones	54	60
Blood-red calcareous sandstones		
Green sandstone	4	3
Dark purplish-brown sandstone	16	13
Pinkish sandstone	73	65
Yellow sandstone		
Granite.		

Fossils found in the red sandstone near the top are *Lingulepis* and *Obolus*, and from the top limestone were reported *Orthis* cf. *desmopleura* and *Euomphalus*, *Asaphas*. (*Megalaspis*), *Conocoryphe*, *Lingula*, *Bathyurus*, and *Paradoxides* or *Olenus*, a mixture of Cambrian and Ordovician forms. Dr. C. W. Cross[a] visited this area and from East Branch of Trout Creek obtained fossils which were identified by Mr. C. D. Walcott, as follows: "From reddish-brown sandstone 45 feet above the granite, *Lingulepis* sp.?, an elongate form allied to *L. pinnæformis* of the Potsdam of Wisconsin."

From red calcareous sandstone, alternating with white limestone farther up, an Ordovician fauna was obtained. A similar basal sandstone series, which appears at Manitou and extends for some distance north along the west side of the Garden of the Gods to beyond Glen Eyrie contains upper Cambrian fossils. According to W. T. Lee, a quartzite, which is presumably of the same age, appears on Deadman Creek. The basal quartzites and immediately overlying cherty limestone of the Garden Park area are of Cambrian age, the cherty limestones having yielded an upper Cambrian trilobite, *Ptychoparia*. A section of basal beds west of Colorado Springs is given as follows:[b]

Geologic section west of Colorado Springs, Colo.

	Feet.
Brick-red sandstone, with green layers	20
Coarse gray sandstone	6
Coarse dark-green sandstone	4
Coarse grayish-white sandstone	26
Granite.	

This series yielded no fossils here, but it underlies Ordovician (Manitou) limestone, as in Manitou Park, and a few miles farther north yielded fossils of upper Cambrian age.

[a] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886, p. 62.
[b] Hayden. F. V., Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873, p. 201.

ORDOVICIAN.

The only Ordovician rocks which reach the surface on the eastern side of the Rocky Mountains are some limestones and sandstones that lie in the Manitou embayment, Trout Creek Valley, Perry Park, and in the district extending from Arkansas River north for some miles in the vicinity of Canyon.

In these localities the deposits, as above mentioned, usually lie on a thin mass of Cambrian sandstone or quartzite, but sometimes they overlap on the granite and schists. In the Canyon district the Ordovician is represented by the Manitou limestone, Harding sandstone, and Fremont limestone. These have been described in detail by Mr. C. D. Walcott,[a] mainly in connection with the occurrence of fish remains, and by Dr. W. C. Cross in describing the region northeast of Canyon in the Pikes Peak folio. The following members are described by Doctor Cross:

Manitou limestone.—This limestone is extensively exhibited in Oil Creek Valley, Garden Park, where it consists of fine-grained pink or reddish dolomite less than 100 feet thick. It occurs also in the Manitou region, where it contains *Ophileta*, *Camerella*, and other characteristic Ordovician fossils.

Harding sandstone.—This formation consists mainly of fine, even-grained, granular sandstone in alternating bands of light-gray and pinkish or variegated colors, with a few bands of dark-red or purplish sandy shale, having a maximum thickness of about 100 feet. The lower part is sometimes calcareous and develops laterally into a thin fine-grained dolomite. This formation contains fish remains at the Canyon locality. In Garden Park the sandstone rests with apparent conformity on the Manitou limestone, but to the southeast it overlaps on the basal sandstone and near Canyon on the gneiss. At Canyon the formation is 86 feet thick and consists of gray, reddish, and purplish-brown sandstone and shales with many fossils of early Trenton age. A small outlier of sandstone, apparently of this formation, is mapped by Gilbert, underlying the Millsap (Carboniferous) limestone in the slopes west of Beulah.

Fremont limestone.—Overlying "the Harding sandstone with apparent conformity, there occurs a bluish-gray or pinkish dolomite of uneven grain, sometimes arenaceous, which gives rise to very rough weathered surfaces." Its thickness in Garden Park is about 100 feet, but increases southward to a maximum of 270 feet near Canyon, partly through the development of an upper fossiliferous member. In Garden Park it is characterized especially by the coral *Halysites catenulatus*, and also contains a molluscan fauna like that of the upper Trenton in New York. It appears to be restricted to a small area in Garden Park and vicinity and a narrow outcrop extending southward past Canyon. These formations all end a short distance southwest of Canyon by overlap of later deposits.

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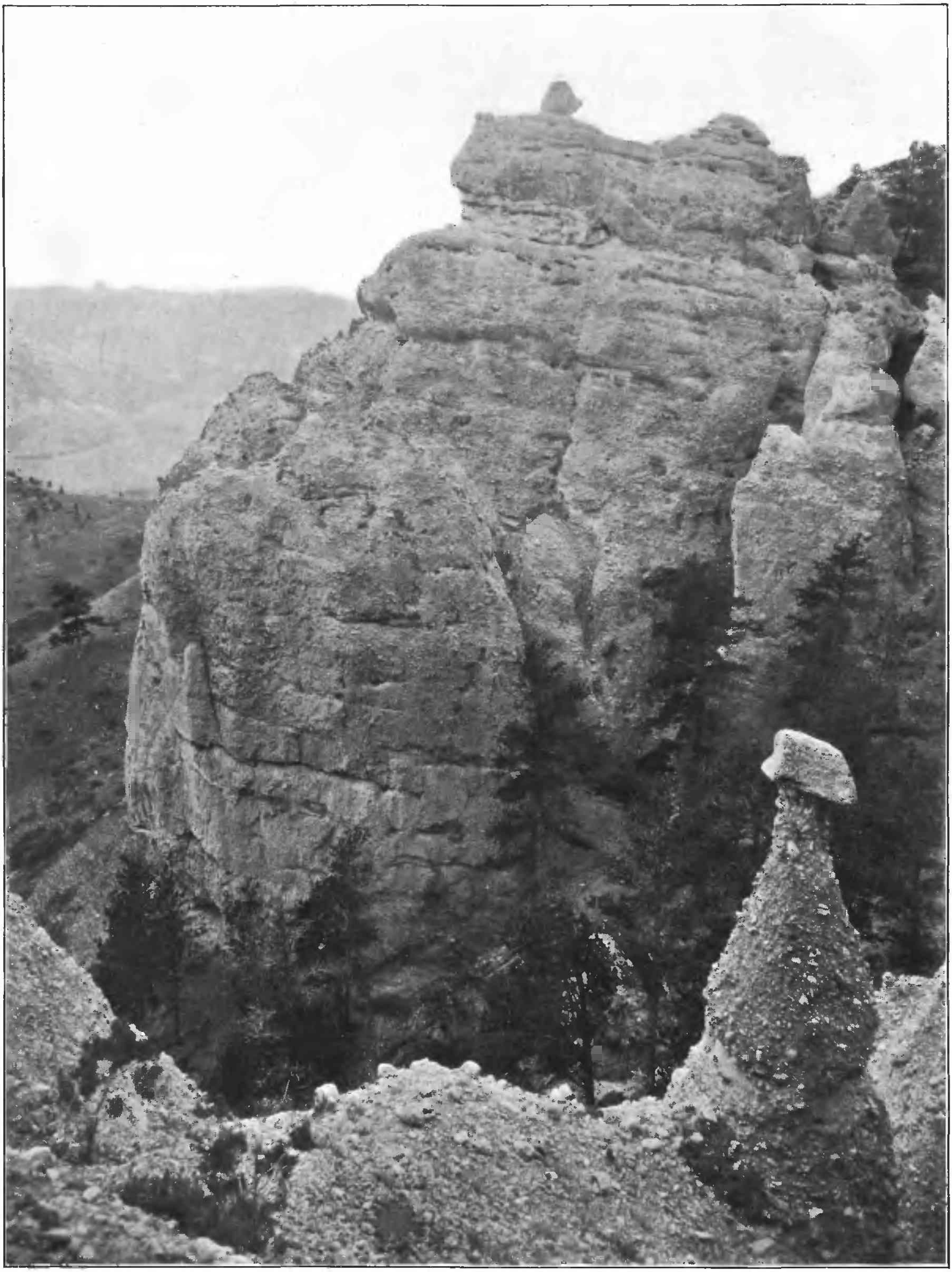
[a] Bull. Geol. Soc. America, vol. 3, pp. 153-167.



CONGLOMERATE IN LOWER PORTION OF LARAMIE FORMATION, NORTH SIDE OF ROCK CREEK, NORTHWEST OF BUFFALO, WYO.

Conglomerate, largely of Deadwood, Bighorn, and Littlehorn materials, limestone and granite in Bighorn Mountains in distance. Looking west.

At Manitou and for some distance northward and in Trout Creek Valley (Manitou Park) there are other areas of Manitou limestone underlying the red beds. On Trout Creek this limestone has yielded distinctive Ordovician fossils, as noted on page 77.

Doctor Peale gives the following section of the exposures of Manitou limestone and associated formations on Camp Creek, at Glen Eyrie:[a]

Geologic section of basal rocks near Glen Eyrie, Colo.

		Feet.
Carboniferous (?)	Gray, purplish, and yellow limestones	297
Ordovician	Red shaly limestones, with fragments of Ordovician fossils	4
	Limestones with interlaminated shales	7
	Red limestone with flint nodules	7
	Red limestone	2
	Red shaly limestone	1
	Red limestone	1
	Irregularly laminated limestone	3
	Red and greenish limestone	5
Cambrian	Brick-red sandstone with green layers	20
	Coarse gray sandstone	6
	Coarse dark-green sandstone	4
	Coarse grayish-white sandstone	20
	Granite.	

On Deadman Creek, 6 miles south of Perry Park, a small outlying area has been investigated by Mr. Willis T. Lee.[b] The rocks are cherty limestones in layers interstratified with red clay, overlying a few feet of deep-red quartzite of supposed Cambrian age. The fossils obtained were examined by Doctor Weller, who found the best preserved specimens to be *Dalmanella testudinaria* of Ordovician age. A second exposure of this limestone, similar to the first, occurs in the southern portion of the Perry Park area at the head of the easternmost prong of West Plum Creek, as noted by Doctor Peale of the Hayden Survey. Mr. Lee found no fossils at this locality.

Silurian and Devonian rocks appear to be entirely lacking in the Rocky Mountain Front Range, although possibly they were laid down in the region and afterwards removed by the vigorous erosion preceding the Carboniferous deposition.

CARBONIFEROUS-TRIASSIC.

Millsap limestone and Wyoming formation.—Along the Front Range in Colorado there are three series of deposits representing, respectively, the Carboniferous, probably the Permian, and possibly the Triassic. The lowest of these is a

[a] Loc. cit., p. 201.
[b] Lee, W. T., Geology of the Castle Rock region, Colorado: Am. Geologist, vol. 29, pp. 96-97.

limestone—the Millsap—containing a lower Carboniferous fauna, which outcrops in a few small areas and is separated from adjoining formations by an erosional unconformity. Next comes an extensive series of sandstones predominately of red color, which to the north and to the south in part merge into and in part overlie limestones with an upper Carboniferous fauna; this series comprises the lower Wyoming formation of Eldridge, which is the Fountain formation of Cross and Gilbert and the Badito formation of Hills. The third or uppermost member (the upper Wyoming of Eldridge) consists mostly of fine-grained red shales and sandy shales, with deposits of gypsum and thin beds of limestone, which are believed to represent the southern extension of the Spearfish and Opeche red beds and included Minnekahta limestone of the Black Hills and other regions.

The lower Carboniferous, or Millsap, limestone outcrops in detached basins in Perry Park, about Manitou, and in the district north of Canyon, and to a limited extent near Beulah, southwest of Pueblo; possibly there is a continuous sheet of it out under the Plains. It is everywhere distinctly separable from the overlying and overlapping red beds.

The Fountain, or lower Wyoming, formation extends for many miles along the Front Range, lying directly on the irregular surface of the crystalline rocks for the greater part of its course. The upper Wyoming, or gypsiferous red beds, appears not to extend quite to Arkansas River, although probably it reappears again farther south and southeast.

The upper Carboniferous limestone, which is found in the northern portion of the Front Range near the Wyoming State line and in the Culebra Range, appears to merge into the Fountain red beds, which I believe are precisely equivalent to the lower Wyoming of Eldridge and the Badito formation of Hills, and represent the Amsden formation and overlying Tensleep sandstone of the Bighorn Range and the Minnelusa formation of the Black Hills. The gray sandstone which generally marks the summit of these lower red beds appears to be the same as the Tensleep sandstone of the Bighorns and the sandstone which usually occurs at the same horizon (upper Minnelusa) in the Black Hills.

Upon this sandstone there lies the principal upper series of red beds, the upper Wyoming of Eldridge, a formation clearly separable in the Front Range zone in central and northern Colorado. This series has been found to contain, near its base, a persistent and characteristic layer of limestone, usually very thin in Colorado, which separates a thin series of fine-grained red beds below from a thick overlying mass of fine-grained gypsiferous beds above, presenting precisely the succession of Opeche and Spearfish red beds with intervening Minnekahta limestone found in the Black Hills and in eastern Wyoming. This

NATURAL BRIDGE IN TENSLEEP FORMATION, LA PRELE CREEK, SOUTHWEST OF DOUGLAS, WYO.

sequence is clear at Laporte, Lyons, Boulder, Morrison, Perry Park, and the Garden of the Gods, in Colorado, but, approaching Arkansas River, the region of the typical Fountain formation, this upper gypsiferous series appears to thin and end. Probably it is represented again farther eastward in the canyons of the Purgatory, Cimarron, Muddy, and other streams by the occurrence of gypsiferous beds between the Morrison formation and the coarser-grained red sandstones believed to represent the Fountain formation.

The age of this upper series of red beds is not definitely known. It has usually been regarded as Triassic for the reason that some known Triassic beds west of the Rocky Mountains consist of similar rocks. The Hayden Survey classified the lower Wyoming beds as Triassic and the upper Wyoming, together with the overlying Morrison, as Jurassic. From fossils found in the Minnekahta limestone in the Black Hills region, a horizon which appears to be continuous through the lower portion of the upper Wyoming beds in Colorado, it is believed that at least the lower third of these beds is Permian, but even if this be the case the upper portion may be Triassic and represent either all or a part of that period. At their top there is an unconformity which may represent Triassic time together with Jurassic, as Jurassic beds are absent to the south. Southward from Colorado Springs, where the upper Wyoming beds appear to be absent, this unconformity at the base of the Morrison comprises all Permian, Triassic, and Jurassic times.

Some features of the Carboniferous deposits and "red beds" in eastern Colorado are as follows:

In Boxelder Valley, in the foothills of the Rocky Mountains, at the Wyoming State line, there are exposures of limestones containing Pennsylvanian fossils, overlain by fine-grained gypsiferous red beds of the Chugwater formation, which in turn are capped unconformably by the Sundance formation, or marine Jurassic. These upper red beds continue far to the south, but the Pennsylvanian limestone rapidly gives place to coarse sandstones, mainly of red color, which extend for many miles south as the basal member of the sedimentary series. These coarse beds are always separated from the Chugwater formation by a sandstone which overlies the Pennsylvanian limestone in Wyoming, where I have designated it the Tensleep sandstone. This sandstone is mostly a fine-grained regularly bedded rock from 50 to 200 feet thick, varying in color from gray to red. I believe it to be an important horizon marker. The most northern exposures that I examined in Colorado were in Owl Canyon, which is a small branch of the Cache la Poudre

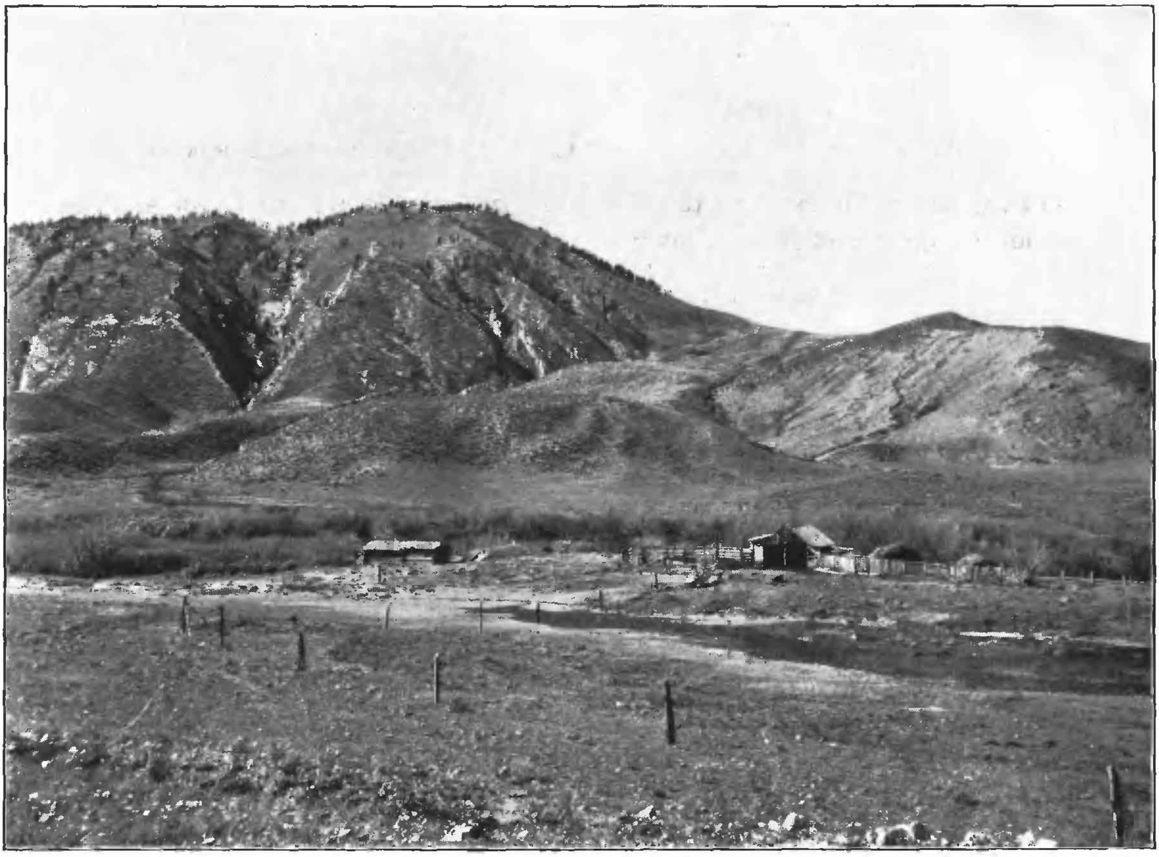
drainage that is followed by the old main road from Denver to Laramie. The section is approximately as follows:

Section of red beds at Owl Canyon, 17 miles northwest of Fort Collins, Colo.

	Feet.
Gray shale and buff sandstone with Jurassic fossils.	
Chugwater formation:	
Massive pale-red sandstone, partly cross-bedded	40+
Red sandy shales with gypsum at top and thin limestones near bottom	200+
Gray limestone, in part thin bedded	5
Red sandy shales with several beds of gypsum near bottom	120
Gray cross-bedded sandstone	15
Red sandy shales with two thin layers of limestone	150±
Pink sandstone, mostly fine grained, regular bedded (Tensleep)	50
Fine-grained light-gray limestone	20
Reddish sandstone	25
Fine-grained moderately light-gray limestone	15
Reddish to buff sandstone	30
Limestone	6
Coarse red sandstone with red shale	150+
Coarse reddish and gray conglomerate	100±
Granite.	

The massive reddish sandstone at the top of the Chugwater formation in this section is a feature which extends southward to beyond South Platte River. It is overlain uncomformably by the marine Jurassic at the north and by the Morrison at the south. The underlying series of gypsiferous red shales of the Chugwater formation contains a local bed of coarse sandstone, which is unusual, and a prominent limestone horizon, which is believed to represent the Minnekahta limestone of the region north. As above stated, the 50-foot bed of pinkish sandstone next below probably represents the Tensleep horizon. The underlying red beds contain the southern extension of the Pennsylvanian limestones, which were traced south to beyond Belleview, where they gradually thin out.

In another section measured a short distance northwest of Laporte I found the features to be very similar to those given in the above section. The supposed representative of the Tensleep horizon is prominent, overlain by about 150 feet of soft red shales, on which there is a series of limestones 30 feet thick. This series consists of a bed of massive limestone at the base, then red limestones and shales alternating, and at the top a 10-foot bed of limestone almost precisely similar in aspect and relations to the Minnekahta limestone of the Black Hills and at the north end of the Laramie Mountains. Above are several hundred feet of typical red sandy shales of the Chugwater red beds, surmounted by 60 feet of pinkish red sandstone, mostly massive, extending to the unconformity at the base of typical Morrison beds. Mid-



A. EAST END OF CASPER MOUNTAIN, SOUTHEAST OF CASPER, WYO.

Typical slopes of Tensleep sandstone to left; Red Beds come in to left over house; great fault above corral, where Pierre shale abuts against Tensleep sandstone. Looking west.

B. VALLEY OF MUDDY CREEK, AT EAST END OF CASPER MOUNTAIN, SOUTHEAST OF CASPER, WYO.

Slopes of Tensleep sandstone on right; hogback of Dakota and associated sandstones on left. Looking south, up creek.

way in the red shales below the limestone is a thin bed of gray sandstone, which continues south from the Owl Creek Canyon section described above.

The "red beds" in northern Colorado were first examined in detail by Mr. A. Marvine, of the Hayden Survey. He states[a] that their thickness is from 2,000 feet to possibly as little as 400 feet, and that they vary from coarse grits and moderately coarse sandstones, usually cross-bedded, to fine-grained and shaly layers; the latter are intercalated to some extent among the former and also constitute a separate upper portion of the series. Dark red is the prevalent color, although light-red and yellow layers are frequent. They lie on an irregular surface of granite and many of their variations in thickness are due to the absence of the lowermost members, for there is usually an overlap of the higher beds to the west and much lateral overlap and variation locally. On Little Thompson Creek the following section is given:

Section of Red Beds on Little Thompson Creek, Colorado.

	Feet.
Soft, rather massive, sandstone	100
Soft, red, shaly sandstone with cherty limestone near the base	250
Massive red sandstone constituting the top of the principal inner hogback	250
Soft, red, shaly sandstone	260
Soft, massive, red sandstone	110
Coarse granitic sandstones and conglomerates, white and red	125
Granites and schists.	

The upper 350 feet are placed by Marvine in the Jurassic and the lower portion in the Triassic. The top member is a pinkish and gray sandstone, a characteristic feature in the region west and north of Denver, everywhere unconformably overlain by Morrison beds. The next underlying series, consisting of soft, red, shaly sandstones, are also characteristic upper Wyoming beds, including the limestone layers near the base. This limestone was examined at several points in the region and found to resemble very closely the Minnekahta limestone, a horizon which it is believed to represent. The massive red sandstone in the middle of the section is strongly suggestive of the Tensleep sandstone of the Bighorn region, except that it is reddish. Generally it is parted into two or three prominent layers, with thin shaly strata. It abruptly gives place above to the soft red shales of the upper Wyoming beds. To the south the lower beds become heavier. Toward Lefthand Creek the series thickens slightly, the top member contains much yellow sandstone, the shales diminish in amount, and the lower beds are less conglomeratic, characteristics which continue to Boulder. It is reported that chert pebbles in the lower red beds contain lower Carboniferous fossils.[b]

There are extensive exposures of the red beds at Lyons, clearly illustrating the stratigraphy. At the base, lying on the granite, are several hundred feet of coarse,

[a] Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873.
[b] Girty, G. H., Carboniferous of Colorado: Prof. Paper U. S. Geol. Survey No. 16, 1903, p. 226.

arkosic, red sandstones with some gray mottlings and gray layers. These are capped by 80 feet or more of fine, even-grained, pale-reddish sandstone, in part thin bedded, which is extensively quarried. It weathers into ridges and is believed to represent the Tensleep sandstone of the Bighorn region. It is overlain by the usual soft, red, sandy shales of the typical upper Wyoming in the following succession:

Section of the Chugwater formation at Lyons, Colo.

	Feet.
Red and green "joint clays" (Morrison).	
Talus	25
Buff and yellowish-buff sandstone	30
Dirty red sandstone	30
Red sandy shales	200±
Limestone, thin-bedded (Minnekahta?)	15
Red shales or sandstone	80

The thin-bedded limestone, which is very similar to the Minnekahta limestone of the Black Hills and central-eastern Wyoming, yielded a few poorly preserved fossils, which unfortunately afforded no decisive evidence as to the age of the beds. They comprised a small gasteropod, supposed to be *Natica* or *Naticopsis*, and some small, indeterminate pelecypods, which may be either Triassic or Carboniferous.

In the steep-dipping beds west of Boulder a thin bed of similar limestone occurs 70 feet above the top sandstone (Tensleep) of the lower Wyoming series, from which it is separated by the usual series of bright-red sandy shales; it is overlain by gypsiferous red shales. The lower Wyoming ledges south of Boulder are shown in Pl. XXXIV, *A*, from a photograph by Mr. J. B. Walker, jr.

Marvine[a] gives the following section at Bear Canyon, 3 miles south of Boulder:

Section of Red Beds at Bear Canyon, Colorado.

		Feet.
Shales, limestone, and sandstone (Morrison).		
Soft, white, massive sandstone		30
Upper Wyoming	Soft, red, shaly sandstone	400
	Limestone (Minnekahta?)	25
	Red shaly sandstone (Opeche?)	200
Lower Wyoming	Yellow granular sandstone, rather soft (Tensleep?)	300
	Hard, massive, red sandstones, with intercalated shales and some conglomerates	800
Granite.		

At Ralston Creek the yellow siliceous sandstone (Tensleep) is stated by Marvine to be 125 feet thick, overlain by 100 feet of red sandy shales (Opeche?), 25 feet of cherty limestone (Minnekahta?), and this by 150 feet of red sandy shales (Spearfish?). On Bear Creek he reports a thickness of 900 feet for the basal

[a] Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873.

series, consisting of soft, red, massive sandstones, with some shales and conglomerates, 100 feet of yellow massive sandstone (Tensleep?), 150 feet of red sandy shales (Opeche?), 25 feet of limestone (Minnekahta?), and 300 feet of red sandy shales (Spearfish?). On South Platte River, at the mouth of Platte Canyon, the supposed Minnekahta limestone is reported near the base of the upper Wyoming red beds.

In the monograph on the geology of the Denver basin the red beds are described in their extension from the vicinity of Boulder to south of Deer Creek. They are termed the Wyoming formation and are divided into upper Wyoming and lower Wyoming, as mentioned above, the latter lying directly on the granite throughout, as in the region northward. The thickness is said to be exceedingly variable, ranging from 200 to 2,400 feet in the lower series and 400 to 600 feet in the upper, although the upper Wyoming disappears for a short distance near Boulder and Golden. The variations in thickness of the lower division are due mainly to the inequalities of the granite floor on which it lies, the thicker portions lying in deep basins and the thinner portions where there is overlap of the higher beds up the slopes of these basins. At the granite contact at all horizons there are usually hard coarse sandstones and conglomerates of moderately coarse material, extensively cross-bedded.

Succeeding the basal deposit there is a series of heavily bedded sandstones and grits, with small local bodies of sandy shale. The normal thickness of this series is about 1,200 feet, and its color varies from prevailing red to gray, the finer grained beds being, as a rule, the most highly colored. Cross-bedding is a marked feature from base to summit. Toward the upper part of the lower Wyoming there is a transitional zone of lighter red and more quartzose sandstones, which is terminated by a characteristic member of heavily bedded creamy-white sandstone from 200 to 400 feet thick (the supposed equivalent of the Tensleep sandstone). This member usually forms a well-marked ridge 50 to 100 feet high along the middle of the valley of the Red Beds. Its lower half is less compact and often is more or less tinged with red in the irregular patches. Two small bands of dark-brown quartzose limestone from 2 to 8 feet thick are present, one near the base and the other farther up. The intervening sandstone is heavily cross-bedded, and contains in some layers conglomeratic pebbles in a matrix consisting generally of quartz, occasionally of an arkosic nature, containing some brown or cherty limestone fragments.

Near the middle of the "creamy sandstone" there is usually a conglomeratic streak, but the materials become fine grained above and consist of quartz of great purity, which is extensively employed for silica in the pottery and fire-brick establishments at Golden. Toward the top some portions are conglomeratic and disintegrate easily.

The upper Wyoming formation consists mainly of fine-grained sediments of a bright-red color, the typical red sandy shales of the Red Beds of the Black Hills, Bighorn Mountains, and southeastern Wyoming. The lower half of this formation "consists of bright, brick-red, arenaceous shales and sandstones with intercalations of limestone. The limestone occurs within 75 feet of the base; usually 3 or 4 beds of it from 6 to 18 inches thick are in the lower 15 feet, and a bed 5 feet thick 50 feet higher up, with red sandy shale intervening. The upper bed is overlain by a bed of thin, wafer-like layers of white limestone and red mud, in all 5 or 10 feet; these present in cross-section a wavy structure with sharp contrast of color and texture. The surface weathers in delicate corrugations,"[a] this feature being also present in the limestone itself. Cherty concretions of purple color and small geodes of calcite also occur. The following analysis[b] of the upper Wyoming limestone by L. G. Eakins, of the United States Geological Survey, is given:

Analysis of upper Wyoming limestone from Morrison, Colo.

	Per cent.
Lime, CaO	48.73
Magnesia, MgO	2.95
Manganese oxide	.49
Alumina, Al_2O_3	.53
Iron sesquioxide, Fe_2O_3	.38
Phosphoric acid, P_2O_5	.03
Water	.11
Carbonic acid, CO_2	41.71
Insoluble	5.32
	100.25

The principal members above the limestones are red sandy shales, with the amount of sand increasing gradually in the higher beds. "About 60 feet up are a number of layers of fine-grained, compact, red sandstone, 2 to 6 inches thick, characteristically marked with white dots. A heavy-bedded fine-grained sandstone occasionally appears in this series, notably in the vicinity of Turkey Creek."[a] Higher up, or from 150 to 200 feet below the top of the formation, the strata become more clayey and present a variety of tints, gray, yellow, green, pink, and lilac, while gypsum and brown earthy limestones are common. The gypsum occurs in small lens-shaped deposits, mainly in connection with limestones. Near Morrison and Deer Creek, at this horizon, there is a thin band of sandstone carrying white and red grains of jasper-like material.

The top of the upper Wyoming beds is marked by a sandstone 15 to 25 feet thick, varying from compact and massive to thin bedded and friable, of which the lower 8 feet is usually brown, the middle 10 to 15 feet pink, and the upper 4 feet

[a] Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873, p. 54.

[b] Loc. cit., p. 55.

brown, all fine grained, delicately cross-bedded and ripple-marked. The stratum is very distinct, especially at its contact with the overlying Morrison, which "is somewhat undulating, apparently the line of an unconformity, or at least of interrupted deposition."[a] A typical section at Morrison is given as follows:[b]

Section of Wyoming formation at Morrison, Colo.

	Feet.
UPPER DIVISION.	
Sandstone, fine grained, often massive, pink and brown; persistent	15–25
Clays, bright colored, gray, yellow, green, pink, and lilac; gypsiferous and calcareous, especially at 40 feet below their summit	125–175
Clays, more arenaceous than above; transitional in color, from grays above, to prevailing brick reds below	150–200
Sandstone and shale, alternating; brick red to pink; white dots; sandstones prominent	50
Sandstones and shales	60
Shales, sandy and argillaceous, brick red, carrying narrow bands (3 to 6 feet thick) of white crystalline limestone	75
LOWER DIVISION.	
"Creamy" sandstone; quartzose; conglomeratic at base; two sandy limestone bands in lower part; round ferruginous concretions near top; forms prominent outcrop in valley between Archean and Dakota (average 250 feet)	200–400
Red Beds; conglomerates, sandstones, and shales, the last of minimum development; color, red; outcrops, lofty spires and pinnacles and towering masses of irregular shape	270–2,000

Some features of the Red Beds of the Morrison region are shown in Pl. XXXIII, which are reproduced from photographs by Mr. J. B. Walker, jr.

I visited the Morrison locality in 1901 in order to compare this section with those in the Black Hills and Bighorn Mountains. I found the "creamy sandstone" series strongly suggestive of the Tensleep sandstone of the Bighorn Mountains and of the top sandstones of the Minnelusa of the Black Hills. The overlying red shales begin abruptly, and they are very closely similar to the Opeche in aspect and relations. The limestone bands have the character of the Minnekahta limestone, especially the upper bed, which is 5 feet thick and lies, as stated by Eldridge, 70 feet above the "creamy limestone," a position similar to that of the Minnekahta limestone in the northern part of the Laramie Range in eastern Wyoming and elsewhere north and west. A careful search for fossils yielded a few indistinct forms similar in appearance to the *Bakewellia* of the Minnekahta limestones of the Black Hills. The overlying red sandy shales with gypsum are very like the

[a] Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873, p. 56.
[b] Loc. cit., p. 52.

Spearfish formation of the region north. The pinkish sandstone at the top, underlying the Morrison, is the same as the top member at other localities north.

Peale[a] and Marvine[b] have described some features of the red-bed exposures on South Platte River at the mouth of the canyon. The basal beds lying on the granite consist of coarse, white and red mottled sandstones, overlain by finer grained red sandstones, in all 1,500 to 2,000 feet thick, capped by 600 feet of white sandstone corresponding to the "creamy sandstone" of Eldridge (Tensleep sandstone). This member has reddish bands 4 to 6 feet thick separating the white portions into bands 20 to 30 feet thick, in part conglomeratic. The upper Wyoming red beds are not well exposed, but are reported to contain a layer of compact red limestone near their base and thin limestones and limy shales higher up. The beds dip east-northeast at an angle of 65°.

Doctor Peale has given a section similar to that on p. 87 for Willow Creek, and Eldridge[c] has supplied some details regarding the succession of limestones in the upper Wyoming beds in that vicinity. He says: "There are four distinct layers of limestone, one lying immediately on the 'creamy sandstones,' and the others 30, 60, and 70 feet above. All are white and crystalline. The lowest is 1½ feet thick, without banding, and has an angular fracture. The second is 2 feet thick, gray, faintly banded. The third is 2 to 4 feet thick, banded and cherty. The fourth is 10 feet above the third limestone, the two being united by intervening banded lime and shale beds. The upper layer is banded faint purple and white, and is overlain by strata of lime and red clay."

For Perry Park (formerly Pleasant Park) on Beaver Creek there are sections by Doctor Peale[d] and Mr. W. T. Lee.[e] Doctor Peale's section is as follows:

Section of red beds, etc., at Pleasant (Perry) Park, Colo.

	Feet.
Thin limestones (at base of Morrison probably).	
Gypsum	81
Slopes with few outcrops of thin limestone beds, four in all, averaging 4 feet thick (probably in red shales)	461
Mottled yellow and red sandstones, light colored above, mottled reddish below. Massive red sandstones. Slope apparently underlain by red sandstones	1,500
Coarse white sandstone, loosely cemented in upper part; bands of red sandstone varying from 1 to 3 feet thick	80
Small outcrop of limestone with chert pebbles and fossils (*Terebratula* and *Spiriferina*) overlain by purplish sandstone and gray sandstone	6
Irregular bed of limestone with pebbles of greenish chert and limestone	3
Red calcareous sandstone, very hard, and with cross-bedding thin layers	3

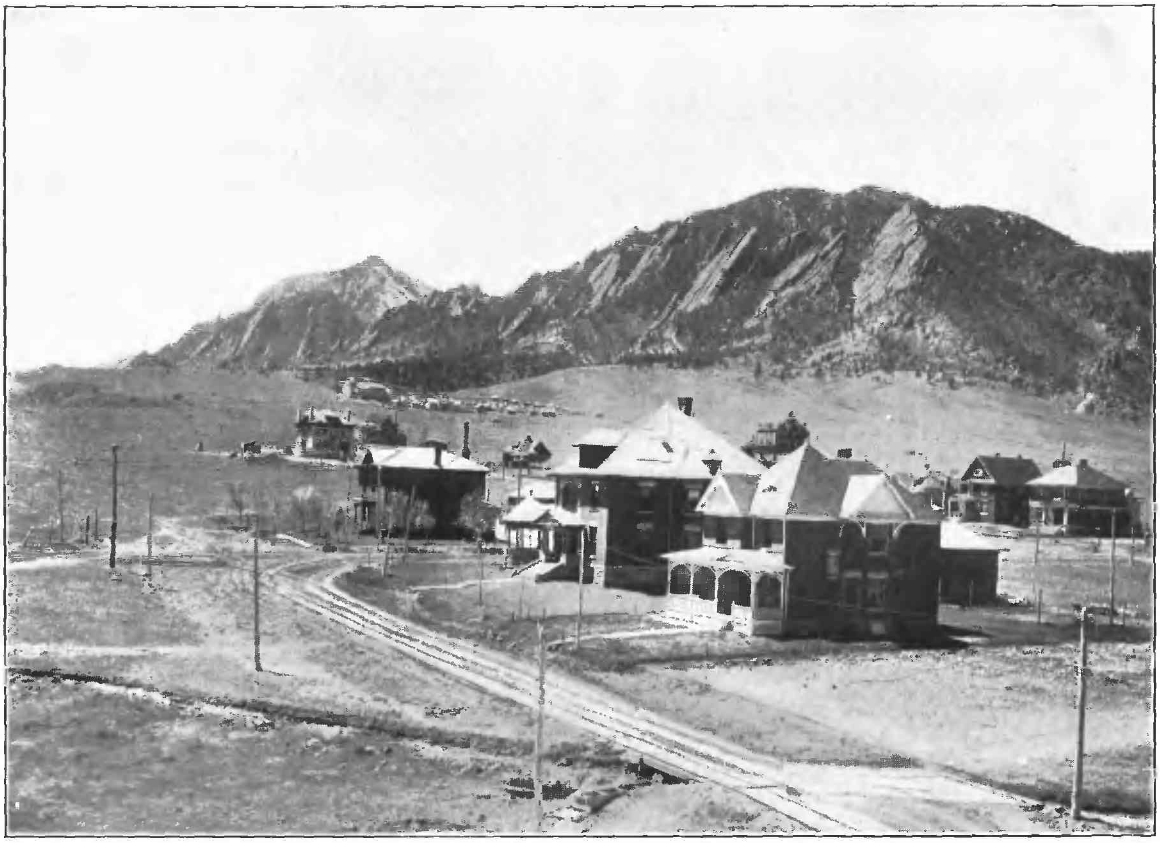
[a] Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr. for 1873, by F. V. Hayden, p. 195.
[b] Ibid., pl. opposite p. 93.
[c] Geology of the Denver basin in Colorado: Mon. U. S. Geol. Survey, vol. 27, 1896.
[d] Ibid., pp. 197-199, and Pl. II.
[e] Am. Geol., vol. 29, 1902, pp. 97-98.

A. RED VALLEY AT MORRISON, COLO.

Lower Wyoming red sandstones in foreground; valley of soft Chugwater red beds, with gypsum, in middle-ground; hogback of east-dipping Dakota sandstone, with Morrison-shale slopes, in center and left. Looking south. Photograph by J. B. Walker, jr.

B. LOWER WYOMING RED CONGLOMERATIC GRITS IN GATEWAY OF "GARDEN OF ANGELS," NEAR MORRISON, COLO.

Showing rock texture and massive bedding. Underlying granite in distance. Photograph by J. B. Walker, jr.



A. LOWER WYOMING RED BEDS LYING ON GRANITE IN FRONT RANGE OF ROCKY MOUNTAINS, JUST SOUTH OF BOULDER, COLO.

Showing steep dip and massive character of rocks Looking southwest. Photograph by J. B. Walker, jr.

B. GATEWAY TO PERRY PARK, COLORADO.

Nearly vertical lower Wyoming red grits; cliffs of "Dakota sandstone" surmounting slopes of Morrison formation in distance. Looking east.

	Feet.
Compact red sandstone in 1-foot layers veined with calcite	15
Dark-purplish cherty limestones	3
Red limy sandstone	4
Very coarse white sandstone lying on granite	80

The 80-foot bed of coarse, loose sandstone in this section is regarded as the same as the basal member in the Platte Canyon section, where the underlying 114 feet of beds of the Perry Park section are thought to be absent. The upper red beds, including the 81-foot bed of gypsum, are stated to have a thickness of 542 feet, an estimate which probably is too great. The lower limestone in this upper series strongly resembles the Minnekahta limestone and has the same stratigraphic relation in lying near the base of the upper Wyoming and in being separated from the gray sandstone at the top of the lower Wyoming (Tensleep apparently) by red shales corresponding to the Opeche. The heavy gypsum bed at the top of the formation extends for several miles, but varies greatly in thickness.

Mr. Willis T. Lee obtained fossils from the limestone near the base of the Perry Park section, as follows: *Orthothetes inequalis*, *Spirifer centronatus*, *Spirifer* sp., *Spiriferina solidirostris* (?), *Seminula subquadrata* (?), *Cranæna* n. sp., *Myarina arkansasana*, *Aviculopecten* sp.—a fauna regarded as lower Carboniferous and probably of its middle portion. This limestone is an outlier of the Millsap limestone of the region farther south. Mr. Lee describes, at the base of the formation, 40 feet of coarse-grained crumbling sandstone, conglomeratic in places, and mottled in varying shades of red and gray, a member which may be older than Carboniferous. Above this sandstone is a series 10 to 15 feet thick of deep-red to white, cherty limestone in layers alternating with red shale, and near the top is the layer yielding the fossils. Above are several hundred feet of coarse-grained sandstones and conglomerates in conformable succession. "They are colored irregularly in various shades of red and gray to an extent which gives the series a conspicuous mottled appearance."[a] Gray predominates toward the base and the amount of red color increases toward the upper portion of the formation.

In the extensive exposures which are to be seen in many places in the vicinity of the Garden of the Gods some of the stratigraphic features present considerable variation. The basal limestone, with Ordovician fossils, is succeeded by gray, purplish, and yellowish limestones from 200 to 300 feet thick, in the upper beds of which M. A. W. Grabau has found Carboniferous fossils, presumably Millsap. These limestones are conspicuous about Manitou, especially in Williams Canyon, and extend north to beyond the Garden of the Gods, where they appear to abut against the granite and are overlapped by the overlying lower Wyoming sandstones. Five miles north of the Garden of the Gods the lowest pink limestones, containing Ordovician fossils, are overlain by a massive gray limestone, which, in turn, is

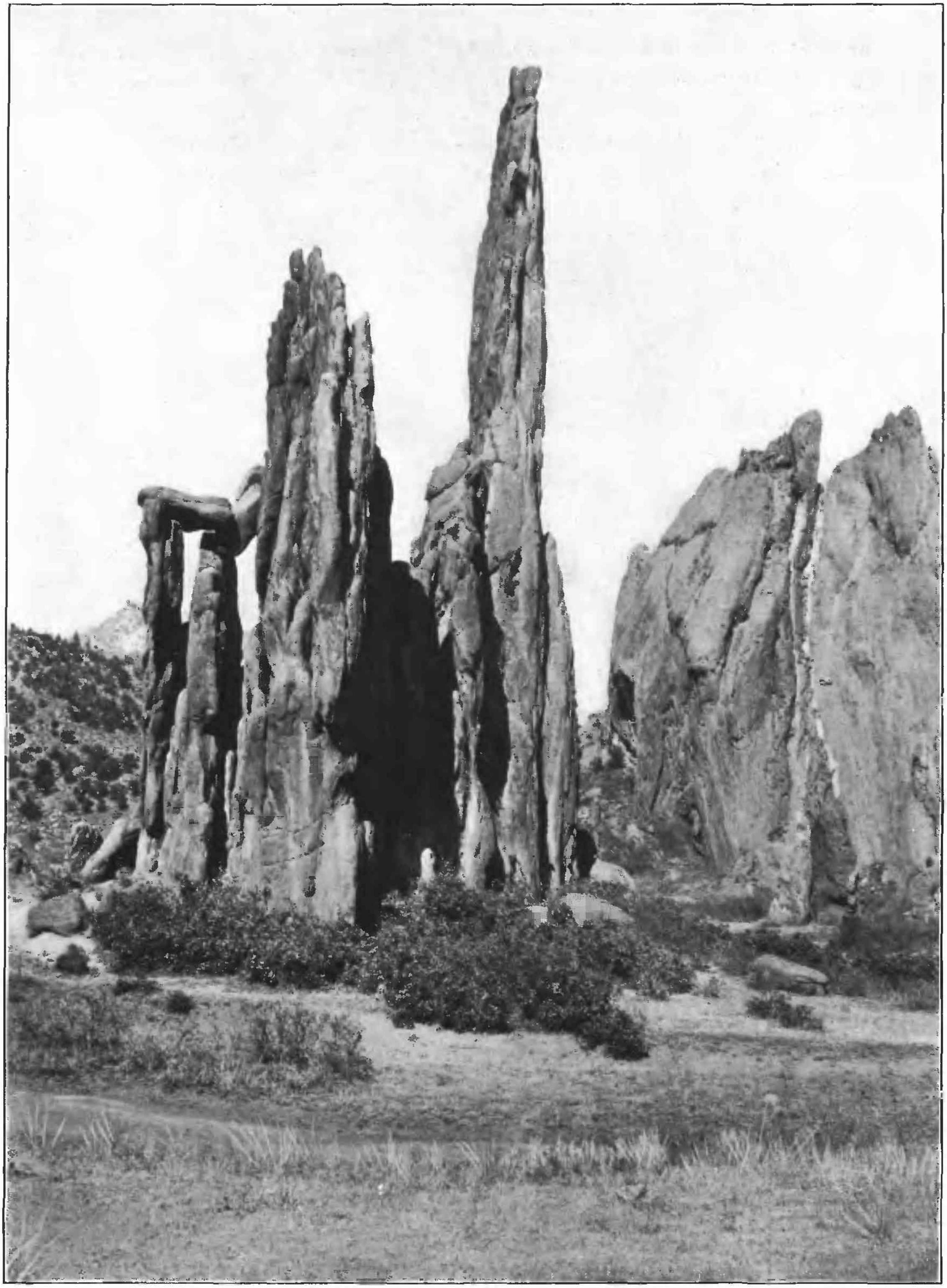
[a] Lee, W. T., The areal geology of Castle Rock region: Am. Geologist, vol. 29, p. 97.

succeeded by a limestone breccia strongly suggestive of unconformity. The lower Wyoming sandstones have a thickness of 1,000 feet or more, and are coarse grained, massive, often cross-bedded, and predominately red. They give rise to the picturesque features of the Garden of the Gods, the "Gateway," which is shown in Pl. I (p. 21), marking the outcrop of the uppermost, hard, red stratum. Next above there are some softer, striped-red sandstones about 100 feet thick, not well exposed at the Gateway, and then the white sandstone bed, which outcrops in the sharp low ridge in the middle-ground of the picture. This bed is about 100 feet thick, moderately fine grained, massive, and cross-bedded, and almost surely represents the "creamy sandstone" of Eldridge at the top of his lower Wyoming. As before explained, the occurrence of this lighter colored, finer grained sandstone at this horizon is general along the foothills of the Rocky Mountains from Manitou north and in the Laramie Range, Black Hills, and Bighorn Mountains, being the Tensleep sandstone in the Bighorn slopes. Near the Garden of the Gods it is similarly succeeded abruptly by soft red shales, including, near the base, thin limestones believed to represent the Minnekahta limestone and gypsum deposits above, and extending to typical Morrison shale. This upper series of red shales, limestone, and gypsum undoubtedly is equivalent to the upper Wyoming of Eldridge. At its base, overlying the white sandstone, are 55 feet of soft red shale, and red clayey sandstone (Opeche horizon), a series 25 feet thick of thin limestone layers with red shale intercalations (Minnekahta), and 30 feet of red shales surmounted by a 30-foot bed of gypsum overlain by Morrison shales. The following section was measured a short distance north of the Gateway to the Garden of the Gods:

Section of upper Red Beds between the Gateway of Garden of the Gods and Glen Eyrie, Colo.

			Feet.
	Shale and clay (Morrison).		
Upper Wyoming beds	Gypsum		30
	Red shales		30
	Limestone	(Minnekahta)	3
	Red shales with thin limestones	(Minnekahta)	22
	Limestone, purple, thin layers	(Minnekahta)	1
	Soft red shale and sandstone		55
	Top of lower Wyoming—massive, white sandstone (Tensleep).		

To the south the two series of Red Beds preserve the same general features to the foot of Cheyenne Mountain, but there are local variations. At the Gateway the 30-foot bed of gypsum is a conspicuous feature, as shown in the foreground in Pl. I; there is another thin bed a short distance below its base. Just below the Gateway these beds are offset and twisted, so that they are locally deflected to some distance west of the general line of strike. On the roadside south of the Gateway are very coarse cross-bedded materials in the upper part of the lower Wyoming formation, giving place abruptly to the fine-grained red sandstones and



CATHEDRAL SPIRES, GARDEN OF THE GODS, COLORADO.

Vertical strata of lower Wyoming red grits. Looking north.

red gypsiferous shales of the upper Wyoming, all vertical or dipping steeply eastward (Pl. XXXVI).

In a railroad cut at Colorado City the following section is exposed:

Partial section of Red Beds at Colorado City.

	Feet.
Sandy shales, etc. (Morrison).	
Talus and red beds	50
Impure gypsum	5
Red shales and soft sandstone with 3 feet of thin beds of gypsum near top	60
Soft, massive, red sandstone	55

The section consists of upper Wyoming red beds, except perhaps the basal member, which may possibly be the upper part of the lower Wyoming division.

When the Red Beds next appear, southwest of the village of Fountain, after the first one or two miles they are seen to consist almost entirely of coarse-grained materials without the uppermost gypsiferous red shales, and are overlain directly by Morrison beds. This coarse series, or the entire Red Bed succession of this region, was designated the Fountain formation by Cross, a name which has been employed by Gilbert in the region still farther south. It lies unconformably on Millsap limestone and overlaps widely on the granite and schist. The coarse red grits and sandstones in the Garden of the Gods region are precisely the same as the typical Fountain formation and, special investigation in the field affords no suggestion but that the Fountain and lower Wyoming formations represent the same period of deposition. They are alike in character, representing the same conditions as to origin; they are similarly underlain unconformably by remnants of Millsap limestone; and there is not the slightest evidence that they overlap.

The Fountain formation in the region extending from southwest of Fountain to Canyon consists mainly of coarse-grained, crumbling, arkosic sandstone in massive beds, usually cross-bedded. Many conglomeratic streaks occur, and a basal conglomerate often appears, notably on the road northwest of Canyon where it lies on an eroded surface of Millsap limestone. The beds are prominently reddish, but some are gray and others are mottled gray and red. Finer grained materials often occur, which are nearly all of a bright brownish red color. The thickness is estimated at 1,000 feet, but varies considerably. Nearly everywhere the formation is separated from the granites and gneiss by limestones of Ordovician age, but in places it overlaps the crystalline rocks, and in some localities the underlying limestones are faulted out. In the vicinity of Canyon, and at a small locality on Cripple Creek, at the head of Garden Park, the underlying Millsap limestone appears. It is a thinly bedded, variegated, dolomitic limestone, with a few thin sandstone layers, and in its upper portion there are chert nodules which carry *Spirifera rockymontana* and *Athyris subtilita*, lower Carboniferous (Mississippian)

forms. This limestone outcrops again on the slopes west of Beulah, 25 miles southwest of Pueblo, as described by Mr. Gilbert. In this locality its thickness is 200 feet, and it consists of gray and purplish limestones, with some shale in its lower part. *Spirifera rockymontana* occurs near its middle.

In the region southwest of Pueblo the Fountain formation, as measured by Mr. Gilbert, is 2,100 feet thick, but to the south it thins out and is absent for some distance along the foot of Greenhorn Mountain. At the south end of this mountain appears a similar series of rocks, which Mr. Hills has named the Badito formation. It comprises an upper member about 100 feet thick, generally massive or thick bedded, but sometimes shaly on the weathered surface, corresponding to a part of the Fountain formation. The lower member consists of about the same thickness of very coarse conglomerate of a brownish red color. To the south this series appears again in the Culebra Range, where it lies on the granites and gneisses and has a great thickness. The Carboniferous limestones appear again on this range about La Veta Pass and extend southward into New Mexico. This area was described in considerable detail by Mr. Endlich, of the Hayden Survey, who mapped the lower portion of the series as lower Carboniferous, and several thousand feet of overlying beds as upper Carboniferous.

In 1902, Mr. Willis T. Lee[a] collected fossils and made a section southwest of Spanish Peaks. These fossils, obtained mostly from the lower hundred feet of the series, were identified by Dr. Stuart Weller and found to be upper Carboniferous. The species were as follows:

Zaphrentis sp. undet.
Orbiculoidea convexa Shum.
Orbiculoidea missouriensis Shum.
Chonetes mesoloba N. & P.
Productus longispinus Sow.
Productus costatus Sow.
Productus cora D'Orb.
Spirifer cameratus Morton.
Spirifer rockymontana Marcou.
Reticularia perplexa McCh.
Seminula argentea Shep.
Aviculopecten carboniferus Stev.
Astartella concentrica McCh.
Nucula ventricosa H.
Nuculana bellistriata Stev.
Bellerophon percarinatus Con.
Bellerophon carbonarius Cox.
Bellerophon montfortianus N. & P.
Bellerophon sp. undet.
Rotella verrucelifera White.
Soleniscus brevis White
Soleniscus sp. undet.
Sphærodema texana Shum.
Sphærodema sp. undet.
Trachydomia wheeleri Swall. var.
Naticopsis altonensis McCh.
Naticopsis altonensis var. gigantea M. & W.
Pleurotomaria perizomata White.
Pleurotomaria (several species undet.).
Murchisonia copei White
Orthoceras sp. undet.
Syringopora sp.
Campophyllum torquium Owen.
Straparolus catilloides Con.

[a] Lee, Willis T., Note on the Carboniferous of the Sangre de Cristo Range, Colorado: Jour. Geol., vol. 10, 1902, pp. 393-396.

Several other fossils were found in loose fragments, which were—

Derbya crassa M. & H.	Bellerophon (large sp. undet.).
Hustedia mormoni Marcou.	Temnocheilus winslowi M. & W.
Allorisma subcuneata M. & H.	Phillipsia sp., large fish spine.
Schizodus wheeleri Swall.	

The following section is given by Mr. Lee:

Section at crest of Culebra Range, between Middle Fork and North Fork of Purgatory River, Colorado.

	Feet.
Hard quartzitic conglomerate	10
Dark shale	5
Limestone, fossiliferous	2
Red sandstone, with bands of red shale and irregular masses of limestone	12
Greenish argillaceous sandstone	4
Pink sandstone, argillaceous above, conglomeratic below	18
Fossiliferous limestone	4
Deep-red sandstone, conglomeratic at the base, shaly near the top	10
Limestone, arenaceous near the base	20
Massive light-colored grit, coarse and conglomeratic	13
Banded sandstone and limestone intimately commingled. The limestone is often in more or less rounded masses. Irregular beds of gravel occur in places	6
Nodular limestone	3
Massive limestone	8
Shale, with limestone nodules	3
Massive limestone	23
Coarse sandstone, conglomeratic in the lower half	20
Massive grit (local unconformity)	8
Calcareous shale, passing to black shale, with limestone nodules near the top	10
Fossiliferous limestone, with sandstone layers; cup corals abundant	15
Massive limestone	6
Shale	8
Coarse grit	2
Sandstone, with large nodules and irregular masses of limestone	10
Shale, with bands of sandstone and limestone	25
Banded limestone	4–12
Soft black shale, fossiliferous	28
Coarse grit	9
Black shale	6
Coarse grit, conglomeratic in places	2–20
Dark shale, with limestone nodules and thin seams of sandstone; runs to massive limestone in places; becomes red and arenaceous near the base	45
Coarse grit	7
Dark-red shale, with nodules and irregular masses of limestone	10
Limestone	4
Red to black micaceous shale, with bands of sandstone near the base and limestone nodules near the top	12
Coarse grit	10
Red grit and conglomerate	?
Crystalline rocks of the mountains.	

A small collection of fossils was also obtained from the western slope of La Veta Pass, 5 miles above Placer, in a succession consisting of sandstones, limestones, shales, and conglomerates similar to those above described. The following upper Carboniferous forms were found in this locality:

Zaphrentis sp.
Orbiculoidea sp.
Derbya crassa M. & H.
Chonetes granulifera Owen.
Chonetes mesoloba N. & P.
Productus nebrascensis Owen.
Productus costatus Sow.
Spirifer cameratus Morton.
Reticularia perplexa McCh.
Seminula argentea Shep.
Hustedia mormoni Marcou.
Aviculopecten occidentalis.
Astartella concentrica McCh.
Schizodus wheeleri, Swall.
Bellerophon percarinatus Con.
Bellerophon inspeciosus White (?).
Soleniscus sp.
Orthoceras sp.

Mr. Lee did not observe the Millsap and underlying limestones in the Culebra Range, although possibly there may be small outliers of them in portions of the range which he did not visit. The strata overlying the section given above consist of several thousand feet of red and gray sandstones, mostly coarse, extending to the base of the Morrison formation, and representing the Fountain series.

In the canyon of Cucharas River, near the north line of Huerfano County, the upper portion of the Red Beds is exposed, being here termed the Badito formation by R. C. Hills.[a] At Red Rocks in the canyon of the Purgatory, in the northern portion of Las Animas County, there are extensive exposures of the Red Beds and of an overlying bed of gypsum, which appears to belong with them. Several hundred feet are exposed, consisting at the top under the gypsum of a coarse, conglomeratic, massive, red sandstone, which merges downward into more regularly stratified red sandstones, with occasional layers of sandy red shales. In the uppermost sandstones I found a small bone fragment, apparently a portion of a shoulder blade of a bolodont, which suggests that the formation is of Triassic age.

Mr. W. T. Lee[b] has published also the following section:

Partial section of Red Beds in Plum Canyon, near Purgatory River, Las Animas County, Colo.

	Feet.
Two massive sandstones with clay between (Dakota)	140
Variegated shales with thin limestone layers (Morrison)	85
Dark shales with irregular masses of gypsum	15
Gypsum with streaks of clay	1½
Variegated shale with much gypsum in masses up to a foot in diameter	8
Gypsum in layers sometimes separated by layers of clay	25
Massive gypsum	5

[a] Walsenburg district: Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900.
[b] Morrison formation of Colorado: Jour. Geol., vol. 9, 1901, p. 346.

	Feet.
Red gypsiferous shales, soft and regularly bedded	30–40
Red calcareous sandstone, oolitic, cross-bedded, layers variable in thickness and character, shaly near top, grading into gypsiferous shales	60
Red sandstone, massive, cross-bedded	175–200
Red arenaceous shales	6
Red sandstone	1
Fine red shale	4
Even-bedded red sandstone	9
Red arenaceous shale	2
Red sandstone, cross-bedded	40
Loose red sandstone alternating with shale	15
Massive red sandstone	5
Soft red sandstone containing ripple-marked hard layers	30
White, hard, argillaceous limestone, thin layers, contorted	4
Red sandstone to river bottom	15

The correlation of these Red Beds with the Wyoming formation is reasonably certain when their character and relations are considered; apparently the upper gypsiferous series represents the upper Wyoming. They underlie a wide area in southeastern Colorado and have been penetrated by some of the wells. The well at La Junta reached them at 605 feet and continued in them to 1,150 feet. The well at Bloom penetrated them from 400 feet to 1,162 feet without reaching their bottom. They also appear in some of the deep canyons south of the west end of Mesa de Maya, but their character in that region was not ascertained.

The Red Beds are exposed in an area of about 3 square miles in the Two Buttes uplift on Butte Creek, in Prowers and Baca counties. They are described by Mr. G. K. Gilbert,[a] who estimates that over 600 feet are exhibited. The lowest beds are sandstones and shales, the latter predominating somewhat. Some of the beds are orange or yellowish. These are overlain by white limestone 5 to 10 feet thick, which I found to be very like the Minnekahta limestone in its thin-bedded character and general aspect in the outcrops. It is overlain by brick-red shales about 150 feet thick, becoming sandy at the top and merging into a massive red sandstone more than 300 feet thick, which forms prominent bluffs along the creek and caps the butte that was uplifted by the laccolitic intrusion of igneous rock. At one place this sandstone is parted by 40 to 50 feet of shale. Parts of the sandstone are buff, yellow, or gray, somewhat resembling Dakota sandstone, for which it has been mistaken here and elsewhere. It is, however, separated from the Dakota by typical Morrison shales and probably represents the Exeter sandstone of Mr. Willis T. Lee, which appears extensively along Cimarron River to the south. No fossils were discovered in any of the rocks.

[a] Gilbert, G. K., Laccolites in southeastern Colorado: Jour. Geol., vol. 4, 1896, pp. 816–825.

JURASSIC.

The Sundance formation extends only a few miles into Colorado from the northward, finally thinning out. Doctor Hayden[a] discovered fossils, "*Ostrea* and fragments of *Pentacrinus asteristicus* on Boxelder Creek in yellow sandstones and clays," with scattered layers or nodules of limestone. He suggested that the limestone sometimes found at the base of the Morrison may be a representative of the marine Jurassic, a suggestion based on its similarity in character and relations to a limestone on the Laramie plains which contains *Apiocrinites*. As these limestones characterize typical Morrison beds where the marine Jurassic is represented, I feel certain that those in the Front Range are all of Morrison age.

CRETACEOUS.

Morrison formation.—This formation extends along the entire Rocky Mountain front through Colorado, outcrops frequently, and presents very characteristic features. In a few localities it is cut off by faults or locally buried under overlaps of younger formations. It is also exposed in some of the canyons eastward, notably in the deeper ones of eastern Las Animas County and in the Two Buttes uplift. Its general character is nearly uniform throughout, being a series of light-colored massive clays, or "joint clays," with thin beds of limestone and sandstone of fresh-water origin, containing bones of saurians of the so-called Atlantosaurus fauna. Its thickness averages less than 200 feet in most cases. It presents frequent and rapid variations in the local succession of beds, but the predominance of joint clays of chalky aspect and the occurrence of maroon and purplish layers among them are characteristic features. The name Morrison was given by Eldridge, from the town of Morrison, where the formation is extensively developed.

South of the end of the marine Jurassic deposits (Sundance formation) the Morrison beds lie unconformably on the upper Wyoming or Chugwater formation for many miles, and, southwest of Colorado Springs, overlap the red grits of the Fountain and Badito formations. In eastern Las Animas County they lie on a bed of gypsum. Mr. W. T. Lee has traced them into western Oklahoma and found that they either merge into or are displaced by lower Cretaceous marine beds, containing fossils of Comanche age, an observation which I have found verified on Butte Creek, east of Two Buttes, in Prowers County, Colo.

The saurian remains which have been obtained so abundantly from the Morrison beds west of Denver and north of Canyon are regarded as latest Jurassic by some paleontologists and earliest Cretaceous by others; but, from the stratigraphic relations of the formation to the later Comanche, it is preferable to class them even later in the lower Cretaceous.

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[a] Hayden, F. V., Third Ann. Rept. U. S. Geol. and Geog. Surv. Terr. (for 1869), p. 119.

The Morrison beds in the foothills of the Rocky Mountains in northern Colorado were described by Marvine as a variable series, consisting of variegated shales, sandy shales, siliceous shales, and soft, white, massive sandstones, with several thin layers of limestone. The thickness indicated is less than 100 feet, and the beds were classed as Jurassic, together with the underlying gypsiferous red beds (upper Wyoming formation). The basal unconformity is one of widespread planation, with local shallow channeling, but no perceptible discordance of dips. In a section measured northwest of Laporte I found the following beds:

Geologic section of Morrison formation northwest of Laporte, Colo.

		Feet.
Dakota	Coarse sandstone, with conglomerate at base.	
Morrison	Gray massive shales, with thin limestone bed about 20 feet below top	80
	Limestone, gray, with algæ	6
	Sandy shale, reddish to buff, partly massive	20
	Pinkish and buff sandstones at top of Chugwater formation	60

The basal, reddish, sandy member of the Morrison at this place is an unusual feature in Colorado, and may possibly belong to the Chugwater formation; more likely, however, it consists partly of deposits derived from that formation, a feature occasionally observed along the southern portion of the Black Hills. The 6-foot limestone layer outcrops in a prominent ledge. The only fossils observed are many algæ in one of its lower layers. The basal sandstone somewhat suggests a bed often seen at the base of the Sundance in Wyoming. Along the creek and ditches east of Lyons there are excellent exposures of the entire series, having the very unusual thickness of about 420 feet and consisting of the following beds:

Geologic section of Morrison formation east of Lyons, Colo.

		Feet.
Dakota	Sandstone, hard, massive, buff.	
Morrison	Olive-green massive shale, with some sandstone layers	150
	Light grayish-green, massive shale	30
	Soft to hard gray sandstone, fine grained	15
	Red, maroon, and green massive shale	150
	Massive buff sandstone, moderately fine	10
	Grayish-green to maroon massive shale, with thin layers of fine-grained sandstone	40
	Covered	25
	Soft buff sandstone on Chugwater formation	30

The typical Morrison formation in the region west of Denver has been defined by Eldridge[a] as consisting of fresh-water marls, having an average thickness of 200 feet, the amount varying somewhat. Its upper limit is sharply defined by the Dakota sandstone, while the brown and pink sandstone, regarded as the top member

[a] Emmons Cross, and Eldridge, Geology of the Denver basin. Mon. U. S Geol. Survey, vol. 27, 1896, pp. 61-62.

of the upper Wyoming, clearly marks its lower limit. Mr. Eldridge's description of the formation is as follows:

"The marls are green, drab, or gray, and carry in the lower two-thirds numerous lenticular bodies of limestone of a characteristic drab color and a texture compact and even throughout. A small but persistent band of sandstone and limestone in thin alternating layers occurs about 20 feet above the base; in some places the arenaceous elements largely predominate, and near Mount Vernon, 3 miles north of Morrison and in the vicinity of Van Bibber Creek, there are at about this horizon from 10 to 15 feet of dull-gray or yellowish sandstones carrying small pebbles of flint of various colors. The clays of the lower two-thirds are remarkable for their reptilian remains.

"The upper one-third of the formation is generally a succession of sandstones and marls, of which the former predominate; locally, however, either may prevail to almost the entire exclusion of the other. The most important sandstone occurs just above the lower clays, is very persistent, and from contained saurian remains has been called the Saurian sandstone. It varies in thickness between 5 and 35 feet, and in its distance below the Dakota from 10 to 125 feet, although more generally it lies 50 to 80 feet below. The chief constitutent is quartz.

"The sandstone is everywhere marked with small rusty dots, round and sharply defined, one-sixteenth to one-fourth inch in diameter, the result of spherical stains of brown oxide of iron; occasionally the appearance is one of irregular mottling. The sandstone is locally divided into several layers by narrow intercalations of drab clay. In the vicinity of Turkey Creek these clays reach the unusual thickness of 20 to 30 feet; the sandstones aggregating about 20 feet. The bed may be locally calcareous, especially in the northern half of the field, the lime being uniformly distributed throughout the mass. At the base is generally a conglomerate having a maximum thickness of 8 feet, in which the pebbles so closely resemble those of the Dakota that but for a slight admixture of red jasper and the characteristic brown dots the two layers could with difficulty be distinguished from each other. The shales overlying this sandstone are similar to those comprising the bulk of the formation, but carry through them a number of minor sandstones and occasionally one or two strata of limestone.

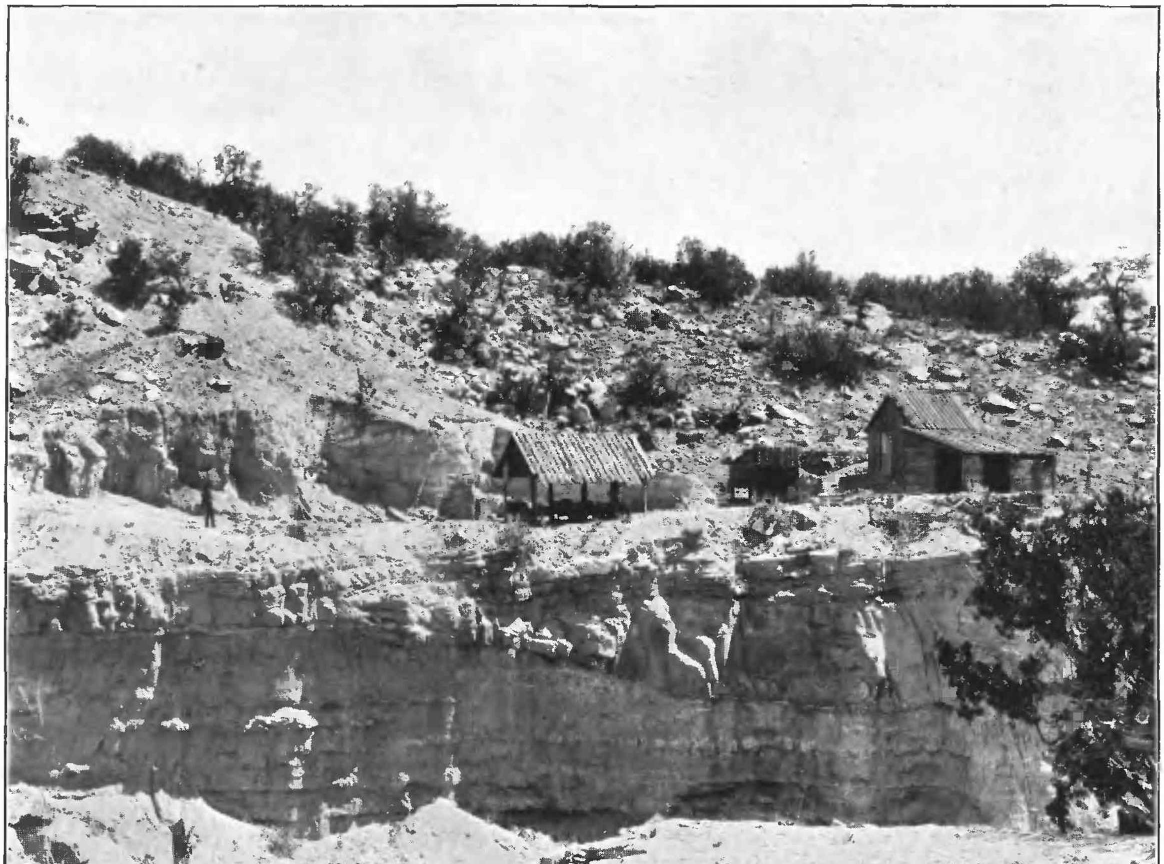
"A variation in the Saurian sandstone occurs in the vicinity of Van Bibber Creek, which, on account of its determinative value in connection with the structural features about Golden, is of considerable importance. The bed is essentially a sandstone, but is divided into minor layers by bands of hard white clay from 1½ to 2 feet thick. Occasionally the clay also is specked with rust spots, and upon becoming coarser grained is directly identifiable with the mottled or specked sandstone described above. It is also sometimes conglomeratic.

"The cause of the variation in the thickness of the upper half of the formation could not be determined from conditions existing in the Denver field, but an oft-suggested unconformity at the base of the Dakota may be the explanation."

Doctor Peale refers to some features of the Morrison formation in the district between South Platte River and Colorado City, and Mr. Lee mentions its occurrence in Perry Park. It is well exposed a short distance north of the gateway to the

A. TWO BUTTES, SOUTHWESTERN PROWERS COUNTY, COLO.

Exeter sandstone, uplifted by a laccolith; adjoining plain covered by later Tertiary deposits. Looking south.



B. BONE-BEARING SANDSTONE IN MIDDLE OF MORRISON FORMATION, IN GARDEN PARK, NORTH OF CANYON, COLO.

Photograph by I. C. Russell.

Garden of the Gods, where I found its thickness to be 130 feet. The basal beds here lie on the thick deposit of gypsum at the top of the Chugwater formation, and consist of ash-gray massive shales with several thin limestone layers and a few streaks of shales with clay pebbles. These grade up into typical, pale-greenish and maroon, massive clays with a few thin layers of fine-grained light-colored sandstone abruptly overlain by coarse-grained buff-colored Dakota sandstone.

At Colorado City the Morrison beds are exposed only in part in the railroad cut, the top and bottom members being covered by talus. The beds stand nearly or quite vertical. To the west are 55 feet of pale greenish-gray, sandy shale, mostly massive, with thin layers which are overlain (to the east) by a 15-foot bed of soft, pale greenish-gray sandstone.

The formation is cut off by the overlap and fault south of Colorado City, but reappears again in the embayment north and northeast of Canyon. In Garden Park, on Oil Creek, it has a thickness of about 350 feet, according to Cross,[a] and consists mainly of greenish, pinkish, or gray shales or marls with sandstone layers at various horizons. It usually lies on the Fountain formation, but overlaps locally onto the granite. It this region the formation has yielded large numbers of dinosaur remains. The late J. B. Hatcher[b] described the formation and its relations in the Garden Park area, and gave some details regarding the fossiliferous horizons. He estimated the thickness at 450 feet, placing the upper limit higher than Cross, so as to include some "Dakota" sandstones and shales with dinosaur remains. The bones have been obtained in largest number from a thick sandstone layer about 150 feet above the base of the formation shown in Pl. XXXVII, *B*, but some occur 30 feet below this stratum and others have been found at various horizons above, both in shale and sandstones. Just below the main bone-bearing sandstone bed there is a layer of clay with thin limestone beds containing numerous freshwater Gastropods, and at a somewhat lower horizon is a marly layer with abundant remains of Unios. These shell fossils have been described by C. A. White, who classes them as Jurassic, because they occur with supposed Jurassic dinosaurs, but states that otherwise they might be much younger, so that they throw no light on the age of the beds. Hatcher reported the discovery of an *Inoceramus* at the Garden Park locality.

South of Canyon these beds are faulted out or overlapped by younger strata, and they do not reappear again until in the vicinity of Beulah, southwest of Pueblo, where they extend for a few miles along the foot of the mountains. North of Beulah for several miles the Dakota sandstone lies directly on the Fountain formation, but probably the Morrison beds formerly covered the region and were removed by pre-Dakota erosion. South of Beulah, according to Mr. Gilbert,[c] the

[a] Cross, Whitman, Description of the Pikes Peak district: Geologic Atlas U. S., folio 7, U. S. Geol. Survey, 1894, p. 2.
[b] Hatcher, J. B., Annals of Carnegie Museum, vol. 1, 1901, pp. 327-341.
[c] Gilbert, G. K., Description of the Pueblo district: Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897.

Morrison beds consist chiefly of red shale with a few layers of hard red sandstone beds about 70 feet thick. They are faulted against the gneiss and also overlap that rock for a portion of their course. Near the contact they are paler in color, white and orange predominating, and no hard beds appear.

The formation comes up again for 5 miles at the south end of Greenhorn Mountain, lying partly on gneiss and partly on the Red Beds. Its thickness here, according to Hills,[a] is 270 feet, the lower portion consisting of about 60 feet of soft white sandstone, conglomeratic at base. The middle portion is a series of pinkish and greenish massive clays and the upper beds are variegated shales and clays alternating with bands of fine-grained limestone, often containing vermilion-colored cherts. Hills states that there is considerable doubt as to the true position of the formation in the time scale and assigns it to the Jurassic provisionally.

Mr. Willis T. Lee[b] has made a special study of the Morrison formation in the southern Colorado region, and his work has thrown much light on its distribution and components. He describes its continuation southward along the foot of the Rocky Mountains west of the Spanish Peaks into New Mexico, and its existence in the deep canyons of Las Animas County, Colo., and to the south. He has found that in this region it presents its usual characteristics of regular stratigraphic position and dinosaur remains. The first exposures east of the foot of the mountains are in Cuchara and Huerfano canyons in western Huerfano and southern Pueblo counties, where Hills reports the formation as 100 feet thick and consisting of variegated shales and clays alternating with layers of fine-grained limestone. In Apishapa Canyon, north of Thatcher, the typical Morrison is reported by Lee underlying the "Dakota" sandstone. There are extensive exposures in the Purgatory and adjacent canyons where the Red Beds are uplifted. Mr. Lee gives the following section in Plum Canyon near its mouth:

Geologic section of Morrison formation in Plum Canyon, Las Animas County, Colo.

		Feet.
Dakota	Massive sandstones	140
Morrison	Greenish clay shale, soft and fine grained	11
	Dull-red clay, soft and fine grained	12
	Brown to yellow shale	10
	Argillaceous limestone; fine, dark laminæ	½
	Buff-colored shale	1½
	Argillaceous limestone; fine, dark laminæ	½
	Variegated joint clay	18
	Argillaceous limestone, fine grained and hard, with contorted laminæ	2
	Variegated shales, very soft	30
Red Beds	Dark shale, with gypsum and gypsum beds on Red Beds.	

[a] Hills, R. C., Description of the Walsenburg district: Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900.
[b] Jour. Geol., vol. 9, 1901, pp. 343–352, and vol. 10, 1902, pp. 36–58.

In Red Rocks Canyon, a small side canyon of Purgatory River, Mr. Lee gives the following section:

Geologic section of Morrison beds in Red Rocks Canyon, Las Animas County, Colo.

		Feet.
Dakota	Massive sandstone.	
Morrison	Brick-red sandy shale, with bands of hard, fine-grained sandstone	25
	Reddish limestone; conchoidal fracture	3–5
	Soft, dark, clay shale	30
	Light-brown clay shale	11
	Argillaceous limestone	½
	Brown shale	7
	Concretionary limestone	1
	Variegated joint clay	7
	Yellow paper shale	3
	Argillaceous limestone; thin layers	½
	Fine shale	1½
	White limestone	1
	Variegated clay-shale	15
	Argillaceous limestone; thin layers	⅜
	Yellow shale	4
	Sandstone with agate masses	1
	Sandstone, soft, thin bedded	8
	Massive sandstone, soft	2
	Paper shale	2
	Massive sandstone, soft	7
Red Beds	Gypsum and clay on red sandstone	12–20

In Red Rocks Canyon the thickness of the formation is 132 feet; in Chaquaqua Canyon, 10 miles from the mouth of Plum Canyon, it is 175 feet (by barometer), the predominating material being a variegated clay shale popularly termed "joint clay." Lee says:

"A subordinate amount of sandstone occurs in places, but there seems to be no particular horizon at which this is likely to be found. In Red Rocks Canyon it occurs at the base; in Plum Canyon none is found; in a side gulch east of Plum Canyon a brecciated layer occurs near the top containing angular fragments one-quarter inch in diameter; in Chaquaqua Canyon, 4 miles from the mouth of Plum Creek, a coarse cross-bedded sandstone layer 15 feet in thickness occurs about 50 feet from the top; just across the canyon from this point, perhaps 2 miles distant and at the same horizon, about 30 feet of limestone is found in place of the sandstone. In many places the sandstones are friable and composed of nearly pure quartz. * * * The occurrence of the limestones, most of which are more or less argillaceous, is as erratic as that of the sandstones. The relative amount and position of sandstone, shale, and limestones vary locally."

Dinosaur bones were observed by Mr. Lee in the shales at nearly every horizon, but no invertebrates were found.

It is reported that the formation is sharply separated from adjoining formations, but without evidence of unconformity by erosion. The gypsiferous shales appear to be distinct and are regarded as a portion of the Red Beds series. The formation extends down the Purgatory to the west line of Bent County, where it passes beneath the Dakota sandstone. In Muddy Creek Valley, in the southern corner of Bent County and adjoining portion of Las Animas County, the Morrison formation is bared of Dakota sandstone over an area of several square miles, in which the same general features are presented as in Purgatory Valley. It again appears in Longs Canyon, and I found it exposed in the Two Buttes uplift on Butte Creek, where it is thin, but consists of gray and purplish clays with layers of light-colored sandstones and limestones overlying buff and red sandstones at the top of the Red Beds. In a paper presented to the Geological Society of America in December, 1902, Mr. Lee announced that he had traced the formation eastward down Cimarron Valley and found that it appeared to merge into sandstones representing the upper part of the Comanche series, a relation which I also found exhibited on Butte Creek, 5 miles east of Two Buttes, in Colorado.

Comanche series.—The only point at which this series is known to be exposed in Colorado is on Butte Creek, 5 miles east of Two Buttes. At this locality the creek crosses a low anticline in which the Dakota sandstone is underlain by 20 feet or more of sandy shales containing numerous *Gryphæa corrugata* Say, a fossil characteristic of the upper part of the Comanche series. The locality is just above Mechling's ranch, in bluffs along the south bank of the creek. Farther westward on the creek, and generally through southern Colorado, the Dakota sandstone is immediately underlain by typical Morrison deposits. Doubtless the upper Comanche beds underlie the greater part of Baca County, for they were found by Mr. Lee along the Cimarron near the New Mexico–Oklahoma line. Possibly they are exposed along Bear and Horse creeks, but these streams have not been examined for outcrops of beds underlying the Dakota sandstone.

"*Dakota*" *sandstone.*—Under this heading will be described the entire sandstone series overlying the Morrison formation, for this series always has been known as the Dakota sandstone or Dakota formation. It generally consists of two bodies of sandstone, each 100 feet or more in thickness, separated by a deposit of clay or shale 10 to 100 feet or more thick. This clay and the top sandstone have yielded abundant plant remains of the Dakota flora (upper Cretaceous), but there is no conclusive paleontologic evidence as to the age of the basal sandstone series. The tripartite succession strongly suggests the Dakota sandstone, Fuson clay, and Lakota sandstone of the Black Hills, and it is believed that probably these formations are represented.

The Dakota sandstone is remarkably uniform in character throughout eastern Colorado. The sandstones are mostly hard and massive, giving rise to a well-marked hogback range (shown in Pls. XXXIII, *A*, and XXXIV, *B*) along the foothills

and plateaus, with steep-walled canyons in the southeastern part of the State. The predominating color is light buff, but some portions are light gray or white, and darker tints are not infrequent, especially in the upper beds. Cross-bedding is almost general and conglomeratic streaks frequent, especially at or near the base of the lower sandstone. The contact with Morrison beds is abrupt and often presents evidence of unconformity by erosion. There is often a very rapid change to Benton deposits, but in most areas there are a few feet of transition beds consisting of an alternation of shales with thin-bedded brown sandstones. The lower sandstone series is thicker and often somewhat softer than the upper, and contains shale partings at some localities. The middle shale member appears to be present throughout, but is generally covered by talus.

In the region west of Denver the formation is described by Eldridge as having a thickness of 225 feet and as consisting of two or three nearly equal benches of massive sandstone separated by thin bodies of clay, a characteristic conglomerate at the base, and a zone of hard, white, slaty shales 10 to 30 feet thick at the top, transitional to the Benton. Fossil plants, mainly leaves of deciduous trees and enormous fucoids, occur from base to summit. The sandstones vary from cross-bedded to slabby and often some layers of them are ripple-marked. The basal conglomerate varies from almost nothing to 30 feet in thickness and is composed of well-rounded pebbles from the size of a pea to a diameter of one inch. They comprise a variety of materials, including quartzites, quartz, flints, jaspers, limestones, granites, and a few materials of Ordovician age identified by fossils. Thin local streaks of conglomerate sometimes occur at the base of the upper sandstone and also near its summit. There are generally two beds of clay, one midway in the formation and the other nearer the summit. The thickness varies from 2 to 8 feet and the material is in part a typical fire clay of blue or blue-gray color, fine, even grained, and very compact, but in places carrying intercalated sandy shales. The Dakota formation thins out and disappears for several miles in the vicinity of Golden.

Doctor Peale[a] gives the following section of the Dakota at the mouth of South Platte Canyon:

Geologic section of Dakota sandstone at mouth of South Platte Canyon, Colorado.

	Feet.
Gray and yellow sandstones	70
Shaly sandstones, fossiliferous	12
Fine-grained white sandstones	3
Rusty yellow sandstone	245

The total thickness of these members is 330 feet. The fossils referred to were determined by Professor Lesquereux and included a *Proteoides* very near *P. acuta*, H.

At Perry (Pleasant) Park Doctor Peale measured 213 feet of Dakota sandstone,

[a] Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873.

but found its upper and lower contacts obscured by talus. The sandstone appears again for several miles in the Garden of the Gods region, where Doctor Peale reports 257 feet of exposed beds, consisting of 200 feet of massive sandstones above, underlain by a finer grained sandstone, in part yellow, containing fragments of *Lingula* and a lignitic layer with vegetal fragments. My own measurement in vertical beds near the Gateway gave considerable less thickness, and I found the formation to consist of two massive beds of sandstone, apparently with a thin series of shales between.

The great fault cuts off the formation southwest of Colorado Springs, but it appears again in the Canyon region, where Cross describes it as having a thickness of 300 feet and as consisting mainly of pure-white or gray sandstone, usually friable, of uniform texture, with a thin basal conglomerate. Dark-shale layers are reported midway in the formation. Fossil leaves are stated to occur in thin shale layers at various horizons. Hatcher found saurian remains in the lower portion of the series in this region, and, on this account, was inclined to place that portion of it in the Morrison formation. This, however, gives too indefinite a stratigraphic limit to the formations.

Dakota sandstone is prominent at the foot of Wet Mountain, southwest of Pueblo, where it has been described by Mr. Gilbert.[a] Its greatest measured thickness is 650 feet near Beulah, where it consists almost entirely of sandstone; elsewhere in the area it contains beds of shale and is from 300 to 350 feet thick. The basal portion usually is conglomeratic, sharply separated from the Morrison clays and the Fountain formation, which it overlaps locally. At the top there is a transition into the Benton (Graneros) shales, through an alternation of shale and thin-bedded brown sandstones.

In the northern portion of Huerfano County and along the foot of the Greenhorn Mountain the formation is described by Hills as consisting of 350 feet or more of sandstone, of which the lower two-thirds is generally a yellowish-gray rock of coarse porous texture, with some layers of fine conglomerate, commonly cross-bedded, and is separated from the upper one-third by gray shales from 8 to 10 feet in thickness. The upper sandstones are from 100 to 150 feet in thickness, are light gray when fresh, fine grained, of close texture, and regularly bedded. The sandstone lies in part on the Morrison formation, but in places along the mountain front overlaps onto the granites and schists. In the canyons of Cuchara and Huerfano rivers it lies nearly level, and presents steep canyon walls surmounting slopes of Morrison clay. The Dakota sandstone is a prominent feature in the foothills, extending between the Spanish Peaks and Sangre de Cristo Range, giving rise for

[a] Pueblo folio: Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897.

many miles to a "stone wall," where the sandstone is vertical and rises prominently above the adjoining softer beds. In this district there are always two sandstone members separated by 20 feet or more of fire clay as in the region northward.

In the extensive exposures of Dakota sandstone in the eastern half of Las Animas County is presented a regular succession of the two massive sandstones with their intervening shale series. Referring to the formation in Purgatory Canyon, near longitude 104°, Hills[a] states the following facts: The thickness is about 375 feet. The lower two-thirds consists of massive, mostly cross-bedded sandstones with a few shale partings between the beds and more or less fine conglomerate. This basal member is overlain by a layer of fire clay, the position of which is marked by a narrow shelf, due to the projection of the underlying sandstone. The upper sandstone is grayish white, thinner bedded, with more numerous shale partings and generally finer grain and greater compactness than the lower more porous sandstone. These features prevail over the wide area of Dakota outcrop in southeastern Colorado, in Baca, Prowers, and Bent counties, but with many variations of thickness and local details of stratigraphy.

The thickness diminishes considerably in southern Prowers and Baca counties. In the vicinity of the Two Buttes uplift the sandstone has been extensively eroded. These buttes are capped by a thick massive sandstone (Exeter?), which is the upper member of the Red Beds, and is separated from the Dakota sandstone by distinct Morrison shales with limestones.

Benton group.—The formations of the Benton group extend across eastern Colorado, outcropping in a narrow zone lying next west of the Niobrara outcrop as far south as Arkansas Valley, down which they extend for some distance, presenting outcrops of greater or less size, mainly on the north side of the valley.

The thickness of the group is given as 600 feet at Platte Canyon, 590 feet at Deer Creek west of Denver, 500 feet on Turkey Creek, 580 feet at Morrison, 400 feet 1 mile north of Morrison, 440 feet at Ralston Creek, 348 feet at Bear Canyon 3½ miles south of the town of Boulder, and about 500 feet at Fourmile Canyon. It is about 640 feet east of Lyons. In the Arkansas Valley region it varies but little from 410 feet. The three formations, which Mr. G. K. Gilbert has differentiated as Graneros shale, Greenhorn limestone, and Carlile shale in Arkansas Valley, have been found to be easily traceable all along the Front Range northward through Colorado.

The Graneros shale is a fissile dark-colored shale usually uniform in composition. It contains lime concretions and a few thin limestone layers with shells;

[a] El Moro folio: Geologic Atlas U. S., folio 58, U. S. Geol. Survey, 1899.

the latter occurring more abundantly in Arkansas Valley than elsewhere. The Graneros shale is usually about 200 feet thick, though it increases considerably in the region west of Denver. In this region prominent zones of iron concretions occupy a thickness of from 40 to 50 feet at a horizon about 200 feet above the base of the formation. They are from 1 to 3 feet in diameter and contain a considerable proportion of iron oxide. East of Lyons, on Little Thompson Creek, the formation has a thickness of 525 feet or more, with the following components:

Section of Graneros formation on Little Thompson Creek, Colorado.

	Feet.
Shales, dark above, lighter below	125
Fossiliferous limestone	½
Dark shales	225
Sandstone, partly thin bedded	15
Dark shales, with a few thin beds of sandstone	160+

The widespread Greenhorn limestone consists of impure shaly limestones 25 to 40 feet thick, occurring in layers from 3 to 12 inches thick, separated by several inches of shale. The deposit is of light-gray color when fresh and is relatively soft when moist, but it usually hardens on weathering, becoming sufficiently hard to constitute a low but distinct ridge. The limestone is characterized by containing large numbers of *Inoceramus labiatus*, which may occasionally occur in other beds but are extremely abundant at this horizon. The formation outcrops in a wide area in Arkansas Valley in Colorado and Kansas. It is 20 to 75 feet thick and rises prominently in a ridge at the gateway to the Garden of the Gods and appears frequently in the Denver region and northward. East of Lyons it appears between the Dakota and Niobrara ridges with a thickness of 25 feet, consisting of limestone layers 4 to 10 inches thick, separated by a few inches of dark shales and filled with *Inoceramus labiatus*. West of Laporte it is 20 feet thick and presents its usual characteristics and fossils.

The Carlile shale, in its typical development about Pueblo and along Arkansas Valley, is from 175 to 200 feet thick. West of Colorado Springs it is 240 feet, and east of Lyons 125 feet. It consists mainly of shale of gray color, slightly darker below than above, with more or less sand, especially to the west along the Rocky Mountain front, where its upper member is usually a gray sandstone 6 to 15 feet thick. East of Pueblo, in Arkansas Valley, the sandstone is replaced by a purplish sandy limestone 2 to 3 feet thick, containing fossils, of which the most characteristic is the *Prionocyclas wyomingensis;* about 125 feet lower down there is usually a thin bed of impure limestone also containing fossils. Near the top of the formation the shales usually contain numerous

lens-shaped lime concretions, in greater part from 2 to 4 feet in diameter, containing *Prionotropis woolgari.*

Niobrara formation.—The Niobrara formation extends from north to south across central Colorado a short distance east of the foothill ranges of the Rocky Mountains. To the east it underlies the greater part of the State north of Arkansas River, but to the northeast is deeply buried beneath Tertiary and later Cretaceous deposits. It rises to the south and has extensive surface outcrops along Arkansas Valley in Pueblo, Otero, Bent, Prowers, and Kiowa counties. It contains much lime in the form of limestone and impure chalk, usually with considerable clay admixture, which increases in amount to the west. The upper members consist mostly of chalk and calcareous shale; at the base there is generally a bed of moderately pure hard limestone, or dolomite.

The thickness of the formation in the Pueblo region and for some distance down Arkansas Valley is 700 feet, but west of Denver and in Kansas it is about 400 feet, apparently diminishing gradually to the north and to the east. The upper portion of the Niobrara formation, consisting of calcareous shale, has a thickness of about 500 feet in the Pueblo region and half as much in the Denver region. The material is dark gray in color when fresh, but weathers to a distinctive bright-yellow tint. Occasional thin sandy beds occur; and nearly everywhere are thin beds of light-colored limestone containing large numbers of *Ostrea congesta*, as shown in Pl. XXIV.

In Arkansas Valley the formation contains concretions which are often of considerable size. In this valley there is also an intermediate member of light-gray shales and marls containing a large amount of lime, with occasional thin beds of limestone containing *Ostrea congesta*. This member is from 100 to 125 feet thick, grading downward into a persistent bed of hard limestone, which is the westward continuation of the Fort Hays limestone of Kansas, a rock extensively employed as a building stone at many localities. This last-named bed averages about 50 feet in thickness, and consists of beds for the most part from 8 inches to a foot thick, separated by thin layers of gray calcareous shale. It is of light-gray color, weathering nearly white on some of the surfaces, close textured and fine grained, containing sufficient magnesia to be classed as a dolomite. Its characteristic fossil is the *Inoceramus deformis*, but *Ostrea congesta* occasionally occurs also. Its upper 15 or 20 feet are usually thinner bedded, softer, and impure, owing to admixture with shale or fine sand. It is usually distinctly recognized in well borings by its hardness and purity, a thickness of from 25 to 40 feet generally being reported.

Pierre shale.—Nearly all of the Great Plains portion of Colorado north of Arkansas River is underlain by a sheet of this formation, which extends along

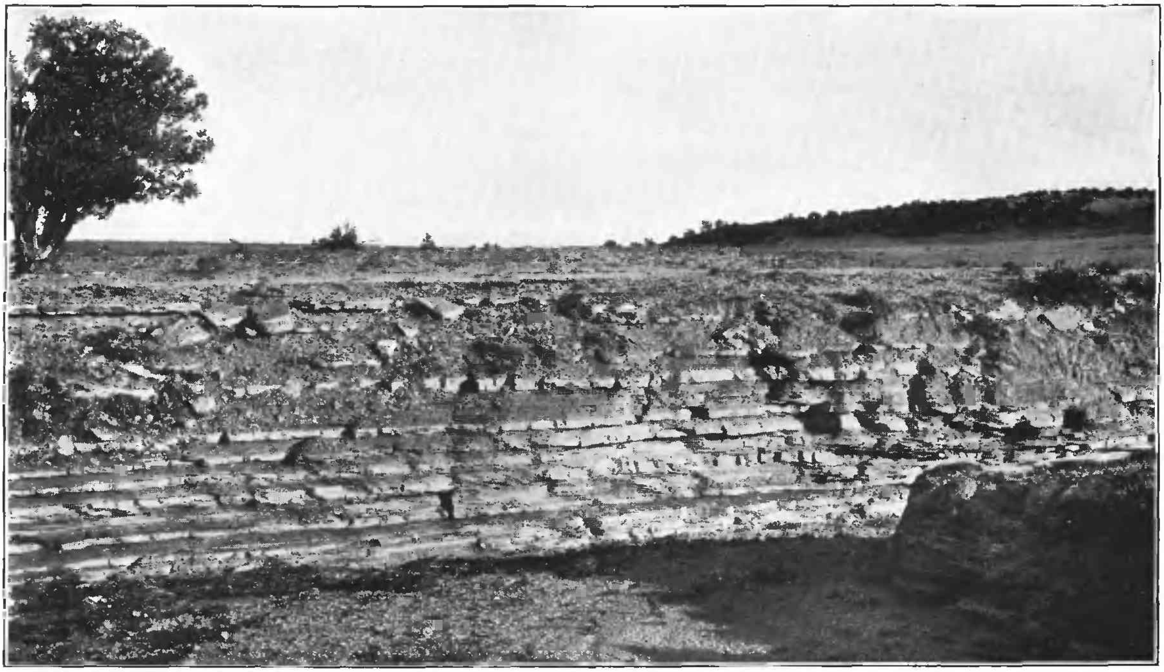
the flanks of the Rocky Mountains from Florence to Trinidad. Its thickness is great, ranging from 4,000 to over 7,000 feet adjoining the mountains to much less to the east. About Denver and to the south and north it is overlain by Laramie and still later formations, and in the high divides eastward, between Arkansas and Platte rivers, it is mantled to a greater or less depth by Tertiary deposits. In character it is a remarkably uniform dark-colored clay or shale, weathering into a brownish-buff gumbo; there are local slight variations in color and stratigraphic components, but these are subordinate to the general uniformity. Lime concretions of various sizes are of frequent occurrence. Some local beds of sandstone and sandy shale are included, which, in the vicinity of Boulder, yield petroleum in considerable amount.

The lime concretions begin to be abundant above the first 400 or 500 feet of basal members in the formation and continue to its top. The ordinary type consists of lens-shaped masses, with a coat of rusty material on the outside and dark-colored fine-grained limestone within. Often the concretions are traversed by cracks filled with calcite. They vary in size from a few inches to 5 or 6 feet in diameter, but most of them are less than 2 feet in diameter and from 4 to 8 inches thick. They weather into the angular fragments with rusty surfaces that are usually found scattered over the surface of Pierre outcrops.

In the Pueblo region these concretions, which are particularly abundant in a zone about 600 feet thick lying from 400 to 500 feet above the base of the formation, carry fossils typical of the Pierre shale. Above this zone the shale is paler in color and finer grained, and concretions are abundant, generally larger, and much more fossiliferous. The fossils are often well preserved, showing the actual shells with much of their original pearly luster. *Baculites compressus*, a conspicuous form, often several inches in diameter, and large *Inocerami sagensis* abound.

In the zone to the south there are found occasional large concretions which give rise to "tepee buttes." These masses consist of "coarse, gray, fossiliferous limestone, irregular or rudely cylindrical in form, and standing vertical within the shale mass. Ordinarily they are from 5 to 30 feet in horizontal diameter, and their vertical extent is greater. As the wash of the rain carries away the shale, these cores, being more resistant, are left projecting from the surface."[a] In a measure they protect the shale from erosion and so give rise to conical hills with shale slopes and a mass of the limestone at the top. On account of their form they have been called "tepee buttes." (See Pl. XXXVIII, *B*.) The characteristic fossil in the limestone is a small shell about an inch wide known as *Lucina occidentalis*.

[a] Gilbert, G. K., Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897.



A. GREENHORN LIMESTONE IN BENTON GROUP NEAR THATCHER, COLO.

View showing alternation of limestone and shale. Photograph by G. K. Gilbert.

B. TEPEE BUTTES IN PIERRE SHALE NORTH OF NEPESTA, COLO.

Photograph by G. K Gilbert.

Above the zone of shales containing the limestone lenses of tepee buttes there are several hundred feet of dark shales.

In the Florence oil-field basin the formation is 4,000 feet thick, and contains many thin beds of hard shale carrying the oil. According to R. C. Hills, it is from 1,200 to 1,300 feet thick to the south about Trinidad. West of Denver it has a thickness of 7,700 feet, greater than is observed anywhere else in the Great Plains region. There the formation contains thin local beds of limestone and a local bed of sandstone about 2,500 feet above its base, which varies from 100 to 350 feet in thickness. This sandstone is a soft, friable, yellowish-gray rock composed of quartz sand and more or less clay, intermixed and intercalated.

Fox Hills formation.—The Fox Hills formation, although of wide distribution beneath younger formations in the Denver region and through northeastern Colorado, generally outcrops in a narrow zone. This outcrop appears near the Wyoming State line not far east of the foothills, and extends continuously along the western margin of the Denver basin, dipping steeply to the east. It emerges from beneath the Tertiary for some distance in the vicinity of Colorado Springs, south of the Platte-Arkansas divide, and it occupies a small circular area in the syncline near Florence. In the syncline of the Spanish Peaks basin the supposed southern extension of its upper sandstone member, which has been separated as the Trinidad sandstone, forms a prominent escarpment bordering the Laramie outcrop.

The maximum thickness of the Fox Hills is from 800 to 1,000 feet in the Denver region, thinning locally to 500 feet at Golden, where, apparently, its lower member is absent for a short distance. In the Florence district the thickness is 430 feet and yet farther south its upper member (the Trinidad sandstone) ranges from 175 feet about Walsenburg to 150 feet at the type locality about Trinidad.

In the Denver basin the formation is made up of a series of arenaceous shales with occasional bands of clay, all of a yellowish color and surmounted by a persistent 50-foot bed of sandstone of greenish cast, weathering to light-gray color. In the Florence district the cap of yellowish sandstone, though persistent, varies from 10 to 50 feet in thickness. The Trinidad consists of two members—an upper one of massive, greenish-gray sandstone, weathering to gray, with prominent joint planes, 75 to 80 feet in thickness; and a lower one, 80 to 90 feet in thickness, made up of thin-bedded dark-gray sandstone in strata 2 to 4 inches in thickness, with thinner partings of shale.

Cone-in-cone structure is common in the Fox Hills beds, and a varying quantity of sandy, limestone concretions, resembling those of the Pierre shale, occur abundantly and are fossiliferous. Poorly preserved *Baculites* are found in many places in the shaly member, and the fucoid, *Halymenites major*, occurs everywhere in the

upper sandstone. In the Denver region this sandstone yields a rich invertebrate fauna, as follows:

- Mytilus subarcuatus.
- Nucula cancellata.
- Solemya subplicata.
- Veniella humilis.
- Callista (Dosinopsis) owenana.
- Tellina scitula.
- Liopistha (Cymella) undata.
- Pyrula bairdi.
- Pseudobuccinum nebrascense.
- Turritella sp.?
- Cylichna sp.?
- Crenella elegantula.
- Cardium (Ethmocardium) speciosum.
- Sphæriola cordata.
- Callista deweyi.
- Mactra alta.
- Tancredia americana.
- Fasciolaria cheyennensis.
- Fusus sp.?
- Anchura americana.
- Dentalium sp.?

Laramie formation.—The Laramie is the surface formation in wide areas on both sides of South Platte Valley, and, extending southward beneath the more recent formations which cap the Platte-Arkansas divide, reappears in extensive outcrops in the vicinity of Colorado Springs. A small outlying area of the Laramie, bordered by the Fox Hills, occurs in the Florence syncline. The Laramie and a thick series of overlying formations occupy the extensive syncline of the Spanish Peaks region south of Walsenburg.

In the Denver region the Laramie formation is from 600 to 1,200 feet in thickness, and, like the Fox Hills, consists of two members, one of sandstone and the other largely of shale; but, unlike the Fox Hills, the sandstone member is the lower one, lying immediately over the Fox Hills sandstone, and often forming an escarpment in connection with it. The two sandstones are easily distinguishable by the mixture of mica with the sand in the Fox Hills, while the lower Laramie sandstone is exclusively quartz. A horizon of marine fossils also occurs near the top of the Fox Hills.

The lower division of the Laramie comprises at the base two beds of white sandstone, each about 60 feet thick, separated by 2 to 4 feet of shale.. A third bed of sandstone, 8 or 10 feet thick, occurs 60 feet above the last mentioned, the intervening space being occupied by alternations of shale and beds of lignite, which are extensively worked. A distinctive feature of this middle sandstone is the occurrence of large concretionary forms, some as much as 30 or 40 feet long, of the same material as the surrounding rock, but extremely hard.

The upper division of the Laramie formation in the Denver basin varies from 400 to 1,000 feet in thickness, the smaller thickness being due to uneven denudation. It consists chiefly of clays, through which are distributed small lenticular bodies of sandstone, from 6 to 30 feet in diameter and from 1 to 6 feet in thickness, and

innumerable concretionary ironstones, from 2 to 4 feet in diameter, which invariably contain plant remains, often well preserved. The coal of this division is not important.

In the Florence basin the Laramie formation is composed of a succession of heavy bedded sandstones with intercalated shales, and, in its lower portions, of workable coal. The sandstones form an escarpment surrounding the mesa southwest of Florence and constitute one or two small outliers.

In the vicinity of Walsenburg the Laramie has a thickness of 1,000 feet, which increases to the south, due to thickening of the upper member and to less erosion at its top, until, at the State line south of Trinidad, its thickness is 2,500 feet. A massive bed of sandstone a hundred feet or so from the base of the formation is persistent, and overlies an alternation of arenaceous shale, clay shale, and coal. Above this massive sandstone the formation is predominantly sandstone, but the sandstones and clay partings vary greatly in thickness.

The fossil remains of the Laramie formation are limited to the characteristic *Ostrea glabra*, a unio, and a dinosaur of undetermined genus. Contrasted with this there is a rich subtropical flora, similar to the present-day flora of the Gulf States, consisting of figs (15 species), oaks, ferns, palms, poplars, willows, and tulip. In the region about Golden there are 83 species which are peculiar to the Laramie.

GEOLOGY OF EASTERN SOUTH DAKOTA.

GENERAL STRUCTURE.

The greater part of eastern South Dakota is heavily covered by glacial drift and outcrops of the underlying formations are rare. Fortunately, however, there are numerous deep wells, and from the records of these it has been possible to ascertain some of the broader features of structure and stratigraphy. The Missouri has cut a deep valley which affords extensive exposures of the older formations, but the prominent feature for many miles in this valley is a great succession of high banks of Pierre shale. Below the Great Bend Niobrara chalk exposures begin, and continue in the lower slopes as far as the mouth of James River. At this place the Benton shales and sandstones appear, and, approaching Sioux City, Iowa, the Dakota sandstone finally outrops in the extreme southeast corner of the State.

In the outcrops the rocks appear to lie horizontally, but when the relations are studied it is found that there are low dips in various directions. The principal feature is a general rise to the southeast, which, together with the diminishing height of the land, brings to view the lower formations in succession in

that direction. There is also a low anticline with its axis extending westward through Mitchell toward Chamberlain, which brings the Niobrara and Benton formations and the Sioux quartzite to the surface over an area of considerable extent in James River Valley. This uplift is coincident with an old ridge of Sioux quartzite which was a shore during the deposition of the Dakota sandstone and, to a less extent, during Benton time, but apparently was almost, if not entirely, covered by Niobrara waters. It was an outlying ridge completely separated from the main shore of granites and gneisses which rise in Minnesota Valley and northeastward.

STRATIGRAPHY.

ARCHEAN AND ALGONKIAN.

The pre-Cambrian crystalline rocks which underlie the Central Plains rise rapidly in the eastern part of South Dakota and finally reach the surface. One area of outcrop extends from James River Valley, near Mitchell, eastward to the vicinity of Pipestone, its appearance being mainly due to an anticlinal uplift; another is in Minnesota Valley, where the rocks rise on the slope of the great uplift of the Minnesota area. The configuration of the "bed-rock" surface, as it is termed in eastern South Dakota, is shown in Pl. XXXIX by contour lines determined partly by outcrops, but mainly from numerous wells which either have reached older rocks or failed to reach them, and thus, in a measure, have delimited its depth.

In addition to the general gradual rise of the "bed-rock" surface to the east, there is a conspicuously high underground ridge or promontory, which extends through Salem and Mitchell toward Chamberlain. This ridge, so buried beneath later sediments that it has no effect on the present topography, has steep slopes several hundred feet high, so that it would have considerable prominence topographically if the surrounding clays and sandstones were removed. The structure of the younger formations abutting against this underground ridge indicates that while it is partly due to anticlinal uplift it was also a ridge of considerable height at the time of the deposition of the Dakota sandstone. The rock of this ridge, known as "Sioux quartzite" throughout the area, outcrops extensively along Big Sioux River near Sioux Falls and at other points to the west and to the northeast. This quartzite consists mainly of rounded or subangular sand grains cemented by silica, and to a greater or less extent built into quartz crystals. It is usually very compact and intensely hard, so that steel of high temper is generally required for drilling it, though some portions are locally much softer. The predominating color is pale pink, but some portions are

MAP SHOWING CONTOUR AND ALTITUDE OF "BED-ROCK" SURFACE IN A PORTION OF SOUTH DAKOTA

BY N. H. DARTON, J. E. TODD, AND C. M. HALL, 1904

JULIUS BIEN & CO. LITH. N.Y.

gray, or buff. The bedding varies from slabby to massive. The thickness of the formation is not known, but a well at Sioux Falls 575 feet deep and one at Mitchell 225 feet deep were in typical quartzite throughout. In Hanson County the quartzite ridge rises steeply about 400 feet above an underground plain or valley, whose floor several of the wells have reached and found to be of granite, an occurrence which probably indicates that the present thickness of the quartzite rising to the south is less than 400 feet. As the surface of the quartzite was exposed to extensive erosion, especially during Glacial times, as shown by its being deeply scarred by glacial scratches, the original thickness doubtless was greater than it is at present.

To the northeastward, in the vicinity of Pipestone, the Sioux quartzite is overlain by or merges into a very compact red clay known as "catlinite," or "pipestone," a material which has been long employed by the Indians for the manufacture of pipes and other articles. A few impressions resembling Cambrian fossils were reported from these deposits by Prof. N. H. Winchell, but it is believed that the Sioux quartzite as a whole is Algonkian, from its similarity to quartzites farther to the northeast, which are known to underlie Cambrian rocks.

The Sioux quartzite is penetrated by dikes in the vicinity of The Dells, near Garretson, Minn., and an igneous mass has been found in well drillings in the southwest corner of Minnesota, and possibly also in sec. 25, T. 104, R. 58 in South Dakota. Outcrops of the Sioux quartzite occupy a considerable area at Sioux Falls and vicinity, and it rises in extensive and very picturesque walls, often 50 feet high, in The Dells, near Garretson, and on Split Rock Creek. The vertical cleavage which the rock presents in these two localities is a characteristic feature, and is the principal factor in the palisadal structure that it exhibits. To the west the rock outcrops in most of the deeper valleys between Sioux Falls and Mitchell, notably on Vermilion River southeast of Parker, along East Fork of Vermilion River below Montrose, West Fork of Vermilion River near Salem, south of Salem on Black Earth Creek, on Wolf Creek near Spencer and near Bridgewater, on Pierre Creek northeast and southeast of Alexandria, on Johnson Creek and its branches north and east of Fulton, on Rock Creek northwest of Fulton, on James River west of Alexandria, at Rockport, and on Enemy Creek near its mouth.

Beyond the area of outcrop the quartzite has been reported from numerous wells of moderate depth in Minnehaha, Moody, Turner, Lincoln, McCook, Hanson, Hutchinson, and adjoining counties. It has been reported in deep wells in Aurora and Beadle counties, and at Scotland and Tyndall, in Bonhomme County.

In the records of borings which are claimed to have reached bed rock the nature of the material has not always been ascertained, some of the drillers reporting "hard

rock," or "very hard rock," which gives no clue to its nature. In a few cases samples have been obtained and submitted to persons qualified to determine the nature, but more often there has been only the judgment of the well drillers. Ordinarily these persons have been able to recognize the typical Sioux quartzite without much doubt, but with other rocks their judgment is open to considerable question. It is asserted also that in several instances rocks collected on the prairie have been placed in the wells and afterwards churned up by the boring machine, either for mischief on the part of some foolish person, or by the driller for the purpose of giving the impression that he had reached "bed rock" and could abandon further boring. In the following list are given all the data so far obtained regarding the occurrence of "bed rock" in the borings in the eastern portion of the Dakotas and in the immediately adjoining portions of the adjacent States. In this list are not included the many shallow wells which have reached the Sioux quartzite where it is near the surface in the eastern portion of Hanson County, central McCook County, and in the counties to the east.

List of wells to or into bed rock, mainly in South Dakota.

Location.	Rock.	Depths.
		Feet.
Jamestown Asylum	Hard limestone	1,505–1,524
Aberdeen	Quartzite	1,221–1,267
	Granite	1,267–1,300
Budlong well, T. 114, R. 62, sec. 18	Quartzite	922–995
	Granite	995–998½
Glidden well, three-fourths of a mile west-northwest of Hitchcock	Quartzite	1,083–1,142
	Granite	1,142–1,150
Motley well, T. 115, R. 61, sec. 7	"Very hard rock"	1,050
Wolsey	do	928–930
Huron	Quartzite on granite	1,070–1,139
Bohri well, near Raymond	do	1,198–1,200
T. 102, R. 61, sec. 18	"Quartzite"	280
T. 102, R. 62, sec. 25	do	280
Brookings	Quartzite	556
White Lake	Sioux quartzite	900
Pierre [a]	"Granite"	1,250–1,256
Henneau's well, T. 103, R. 66, sec. 34	Sioux quartzite	842
T. 103, R. 61, sec. 17	"Quartzite"	312
Plankinton [b]	Sioux quartzite	745–830
T. 104, R. 58, sec. 24	Granite	512–518
T. 104, R. 58, SW. ¼ sec. 25	Diabase	506

[a] Another well nearby found no "bed rock" to a depth of 1,537 feet.
[b] Nettleton, E. S., Artesian and underflow investigation: Report to Secretary of Agriculture, pt. 2, 1892.

List of wells to or into bed rock, mainly in South Dakota—Continued.

Location.	Rock.	Depths.
		Feet.
T. 104, R. 58, sec. 36	Quartzite	480
T. 104, R. 60, sec. 29	do	228
T. 104, R. 57, sec. 13	"Hard rock"	204
T. 104, R. 57, NE. ¼ sec. 17	Gray granite	510
T. 104, R. 57, NW. ¼ sec. 19	do	557
Fulton	Quartizite	30
Ethan	"Hard rock"	320
T. 104, R. 60, sec. 25	do	115
Mitchell	Quartzite	540–765
Doxheimer well, T. 103, R. 57, sec. 11	"Jasper"	153
T. 103, R. 61, sec. 25	Dark-gray granite	500
T. 102, R. 60, sec. 20	"Quartzite"	195
Alexandria	Quartzite	40
	With sandstone and water below, and in one well hard rock from	490–496
T. 104, R. 59, sec. 29 (?)	Quartzite	100
Elm Springs	do	247–412
Spencer	"Jasper"	100
10 miles southeast of Salem	Quartzite	170
Salem	Sioux quartzite	220–247
West Point region	Quartzite	300
Humboldt region	do	140–153
Sioux Falls	do	0–575
County well, T. 100, R. 62, sec. 18	Granite	1,025
County well, T. 100, R. 64, sec. 26	Hard rock, "granite"	937
7 miles north of Parker	Quartzite	140
Parkston	Sioux Falls quartzite	510–522
Do	do	542
Menno	do	410–417
Well in center of Turner County	"Very hard rock"	510–513 or 556–559
Well 7 miles southeast of Canastota	Quartzite	140
Fort Randall[a]	"Hard rock"	576–610
Scotland[a]	Quartzite	535–587
Tyndall[a]	do	735
Yankton	"Granite"	898–942
5 miles north of Alcester	"Hard rock"	480
Verblen, Marshall County	Granite	860
Vermilion, University well	Quartzite	630

[a] Nettleton, E. S., Artesian and underflow investigation: Report to Secretary of Agriculture, pt. 2, 1892.

List of wells to or into bed rock, mainly in South Dakota—Continued.

Location.	Rock.	Depths.
		Feet.
Layson well, T. 94, R. 61, sec. 22 [a]	"Very hard rock"	1,074–1,075½
Elk Point	"Hard rock"	303
Do	do	367
Milbank [b]	Granite	280–303
Albee, Grant County	do	168
Whiterock, Roberts County, S. Dak	do	500
Brown Valley, Minn. [b]	Granite (?)	425–465
Canby, Minn	"Granite"	400
Moorehead, Minn. [c]	Granite	360–1,750
Marshall, Minn., 6 miles south-southwest	do	505–505½
Ponca, Nebr. [a]	Sandy shale and green clay	420–455
	Limestone	455–498
Sioux City, Iowa [d]	Limestone, chalky at top	335–1,255
	Sand, marl, etc	1,255–1,320
	Limestone and sandstone	
	Quartzite (?)	1,510–1,525
	Granite or gneiss	1,525–2,071

a Nettleton, E. S., Artesian and underflow investigation: Report to Secretary of Agriculture, pt. 2, 1892.
b Winchell, N. H., Notes on some deep wells in Minnesota: Fourteenth Report Geol. and Nat. Hist. Survey Minnesota, 1888, p. 14.
c Winchell, N. H., Natural gas in Minnesota: Bull. Nat. Hist. Survey Minnesota No. 5, pp. 27–31.
d Todd, J. E., Notes on geology of north-northwest Iowa: Proc. Iowa Acad. Sci., 1891.

These data, in the main, satisfactorily agree with one another and with the general structure. A few indicate rather unexpected details of configuration of the "bed-rock" surface, but, on the whole, the apparent distribution of the various rocks and the underground contour of the surface on which the water-bearing beds of Dakota sandstone lie are everywhere in reasonable accord (see Pl. XXXIX). The general form of all the larger features is indicated, at least approximately, by the experience of more than one well. It is undoubtedly the case that more complete data, or different interpretation of certain well records, might suggest modification of the contours shown, but it is thought that it would be in respect to minor details only.

The high quartzite ridge extending underground nearly due east and west through Minnehaha, McCook, and Hanson counties, and prolonged with diminished height to White Lake and beyond, is perhaps the most noteworthy feature shown. Its extent and altitude are deduced very obviously from the experience of a large number of borings which are fully in accord in nearly every respect. In several wells the Sioux quartzite, with its unmistakable texture and pink color, was penetrated for a number of feet, and between James River and Enemy

Creek, near Mitchell and the Minnesota line, are numerous exposures of the rock in the depressions which cross this buried ridge. As previously stated, at Sioux Falls the typical Sioux quartzite was penetrated by a boring to a depth of 575 feet without reaching its base, and at a number of other points as far west as White Lake it has been penetrated to a considerable depth.

I examined a sample of the material penetrated between 512 and 518 feet, from the boring in T. 104, R. 58, sec. 24, and found that it was a dark granite. This was at the base of the north side of the buried quartzite ridge above referred to, and would indicate that the quartzite is underlain by granite. In two county wells in the northern part of Douglas County granite was reported in a similar position on the opposite side of the quartzite ridge, but the identity of the rock is open to some question. The deep valley in the bed-rock surface lying north of the buried quartzite ridge is indicated by the fact that the Huron, Iroquois, Woonsocket, and Madison wells did not reach bed rock.

At Madison the boring penetrated to a point about 587 feet above sea level, and was discontinued in shale. The evidence of the line of borings from Brookings to Wolsey indicates some interesting features of underground topography in the bed-rock surface. In none of the borings is there definite evidence as to the nature of the rock penetrated. In the case of the De Smet well, it was at one time supposed that the quartzite had been reached in a hard rock at a depth of 1,456 feet; but at 1,470 feet the drill passed out into soft sandstone, presumably of Dakota age, which carried water. As no bed rock was reported in the 800-foot boring at Arlington, the bed-rock surface evidently slopes down gradually from 1,160 feet above sea level at Brookings to less than 200 feet above sea level at Iroquois, where no bed rock was reached. At Huron the occurrence of bed rock at slightly less than 200 feet above sea level indicates the position of the deeper portion of the basin, for the bed-rock surface appears to rise rapidly to Wolsey. Colonel Nettleton is authority for the reported occurrence of the rock in the Wolsey well at an altitude of 420 feet above sea level, as he states in his "log" of this well that at 928 feet the boring entered very hard rock, into which it penetrated 2 feet. This would indicate the presence of a ridge terminated on the west by a steep slope, as shown by the deep wells around Miller and St. Lawrence; on the south, as indicated by wells north of Wessington Springs; and on the east, as indicated by the deep wells southwest and southeast of Huron, none of which reported bed rock.

The presence and prolongation of this ridge to the north is fully borne out by the experience of three wells north and northeast of Hitchcock. In two of these, the Budlong and Glidden, quartzite was bored through and the granite entered for a short distance. In the third well, on the farm of Mr. Moxley, bed

rock is reported at about the same altitude above tide level as in the Budlong well, but it was not penetrated, and its nature was not stated. I examined borings from both the Glidden and Budlong wells, and there is no doubt as to the nature of both the quartzite and the granite as indicated in the logs and stated in the table given on pages 114–116. The middle portions of the quartzite in the Budlong boring were not so distinctive in character as the upper and lower beds, for they appear to be of a somewhat softer material. The borings from the granite contained unmistakable feldspar fragments of jagged outline and in very fresh condition, together with some scales of mica and a large amount of quartz, mainly showing sharp edges. Some of the quartz grains were rounded, possibly by water action, but just as likely by the churning of the drill. It is also possible that some or all of these rounded grains were of sedimentary origin, but in this case they were undoubtedly derived from the overlying quartzite. It should be borne in mind in making a judgment on material of this character that there is more or less detachment of the overlying materials by the drill in both its descent and ascent, below the bottom of the casing. As the process of drilling in such a hard rock as granite is relatively slow, there is much more chance for admixture of material detached from above than in the case of rapid progress through soft beds.

The precise course of this ridge, which passes north of Hitchcock, probably to Wolsey, and its relations to the adjacent slopes of the bed-rock floor eastward are not definitely known, but the experience of the Bohri well, near Raymond, and the absence of bed rock in the 1,200-foot boring at Clark indicate approximately the features shown in Pl. XXXIX. The Doland, Redfield, Ashton, Turton, Conde, Mellette, and Northville deep borings, which did not reach bed rock, indicate that it is not prolonged to the northward. The Bohri well penetrated supposed bed rock for 2 feet, but no report was given as to the nature of the rock except that it was very hard. The deepest boring at Aberdeen found the water-bearing beds and some underlying shales and sandstones underlain by 46 feet of quartzite lying on granite, which was penetrated 33 feet. This relation of the quartzite to the granite is in accord with the experience of the wells near Hitchcock. The position of bed rock in the Aberdeen well, in relation to that in the Hitchcock region, indicates a relatively gentle slope from the top of the Wolsey ridge to Aberdeen. To the east of Aberdeen there is but little evidence as to the nature and rate of the bed-rock slope, but the relations of the Groton, Andover, and other wells which did not reach it indicate that its rise is very gradual.

The boring at Milbank, in which the granite was penetrated for some distance, the surface outcrops of the formation in Minnesota Valley below Ortonville, and the presence of granite at a depth of 168 feet at Albee, all bear out the idea of regular slope. The Brown Valley well appears to have reached the granite on this slope and to have penetrated it for a short distance. The material is not stated to

be granite by Professor Winchell, but as part of the borings were "greenish, micaceous, kaolinic clay or shale," and "white, opaque, and wholly unwaterworn angular quartz grains," it seems exceedingly probable that the material represented granite in at least the lower 40 feet of the boring. The well at Jamestown Asylum in North Dakota is reported to have penetrated for 19 feet at its bottom into hard limestone, which probably was either the Carboniferous or the Silurian, both of which come to the surface in Manitoba. The underground contours from Jamestown to Moorehead are constructed on the assumption of a regular slope. The edge of the limestone does not extend to Moorehead, where the deep boring passed through drift and possibly Cretaceous beds far into the granite.

Returning to the southeast corner of South Dakota, it is reported that the quartzite was penetrated in a number of wells, including those at Parkston, Scotland, Tyndall, Menno, and a well southwest of Parker. At Yankton the granite was reached. At Fort Randall the nature of the hard rock, which was penetrated for 34 feet according to Colonel Nettleton, is not stated, but presumably it was quartzite. The nature of the hard rock found in two borings at Elk Point is not known. The Ponca and Sioux City borings found Carboniferous limestone underlying the Dakota water-bearing series, possibly with a thin intervening representative of some intermediate formation. The Sioux City boring passed through a great mass of the limestone, through some limestone and sandstone, through 15 feet of a hard, brown rock, which, according to Professor Todd, may be the Sioux quartzite, and then penetrated nearly 550 feet into hard, gray granite. The borings at Parkston, Menno, and southwest of Parker indicate that the buried quartzite ridge which is so prominent from near Mitchell to Sioux Falls sinks almost as rapidly to the south as it does to the north, and this slope is further delimited by the experience of borings near Parker and in central-western Turner County. The steep slope in the Canton region is indicated by the relation of the surface outcrops, the rapid increase of thickness of the Dakota and overlying Cretacous sediments, and the experience of one or two borings in the southern part of Lincoln County. To the south of the steep southern front of the buried quartzite ridge there appears to be a relatively gentle slope intersected by two valleys, one of which heads near Menno, as indicated by the failure to reach bed rock in a 747-foot well, and by the relations of the wells in eastern Douglas County.

The irregular contour of the bed-rock surface, as shown in Pl. XXXIX, is no doubt partly due to subaerial erosion prior to the deposition of the Dakota sandstone. It has been suggested that the quartzite ridge which extends through Mitchell is a portion of the Dakota sandstone locally lithified, but the evidence of overlap and many other relations appear to indicate that this can not possibly be the case.

PALEOZOIC.

While it is probable that the Paleozoic rocks extend some distance east from the Black Hills, south from Manitoba, and north from Nebraska, they are absent in the greater part of the area of South Dakota lying east of Missouri River. The deeper wells at Aberdeen and Pierre found materials, apparently all of Cretaceous age, lying directly on the old crystalline rocks. South and east of these localities the same conditions prevail, and on the underground ridge of the Mitchell region even the Dakota sandstone is absent in an area of considerable size. To the south of this ridge numerous wells, as far south as Yankton and apparently also at Elk Point, have found the Dakota sandstone underlain by quartzite and granite without suggestion of intervening rocks. At Ponca, however, the Dakota sandstone is underlain by a series of limestones and sandstones which undoubtedly represent the Carboniferous and possibly still older sedimentary rocks, and at Sioux City, Iowa, similar relations were found. These indicate that the Paleozoic rocks, especially the Carboniferous, which is so extensively developed in Iowa and Nebraska, extend at least to the southeast corner of South Dakota.

EARLY MESOZOIC.

The red beds and marine Jurassic formations probably do not underlie eastern South Dakota. It is possible, however, if not probable, that the formation there termed Dakota may include in its lower members the Morrison, Lakota, and Fuson formations of the Black Hills and of the Rocky Mountain region. There is, however, no direct evidence on the subject, and it is mentioned here as a suggestion merely.

LATER MESOZOIC.

Dakota sandstone.—The Dakota sandstone underlies the greater part of eastern South Dakota, rising to the surface in the extreme southeast corner of the State. The predominant material is soft sandstone, moderately fine grained and porous for the most part, and of light-gray color. There are intercalated beds of clay or shale, of greater or less extent, separating the sandstone layers. The sandstone lies directly on crystalline rocks—granite or quartzite—but is absent on the higher part of the underground ridge of quartzite in the Mitchell region eastward. Although it rises in approaching this quartzite ridge, due mainly to anticlinal uplift, it does not arch over, but appears to be terminated by a shore line, beyond which there is an overlap of the Benton formation.

The configuration of the base of the Dakota sandstone, or "bed rock," is represented in Pl. XXXIX, and that of the upper surface in the map, Pl. LVIII, in which it will be seen that the contour lines represent considerable difference in slope from that of the bed-rock surface, a difference indicating variations in thickness of the

formation. This is an important condition as affecting water resources, but there is great scarcity of precise data bearing on the subject. The formation thins rapidly on the slopes of the quartzite ridge in the Mitchell region, and apparently also about Kimball and Hitchcock, but in other portions of the region appears to average from 150 to 300 feet in thickness. In no two sections is there found the same succession of beds having any constant thickness. The deepest well at Aberdeen penetrates the formation to the underlying "bed rock," indicating a thickness of 301 feet, lying between 920 and 1,221 feet and presenting the following succession:

Geologic section of Dakota formation in well at Aberdeen, S. Dak.

	Feet.
Dark-gray sandstone, water	15
Brownish and gray sandstone, pebbly in part, some pyrites and shale	142
Fine gray sandstone	23
Fine, hard, brown, shaly sandstone	72
Fine white clay	15
Fine gray sand, no water	34
Quartzite.	

Another report gives 77 feet of clay as constituting the lower part of the 142-foot series and 37 feet of clay the lower part of the 72-foot series.

In Spink County many of the deep wells penetrate the sandstone for from 40 to 208 feet, traversing thick masses of sandstone with thin bodies of shale. The Frankfort well penetrates the formation from 800 to 1,008 feet, with the following succession:

Partial geologic section of Dakota formation in well at Frankfort, S. Dak.

	Feet.
Conglomerate, at 800 feet	3
Sandstone	122
Hard shale	20
Sandstone	40
Hard shale	15
Sandstone	8+

Near Hitchcock are two wells, the Glidden and the Budlong, penetrating to the granite of an underground ridge of the older rocks on which there is thinning and change of character of the Dakota beds. The succession is as follows, beginning at the first sandstone below a very thick mass of Benton shales:

Geologic section of Dakota formation in Glidden well, three-fourths mile west-northwest of Hitchcock, S. Dak.

	Feet.
Sandstone, at 881 feet	6
Shale and limy conglomerate	30
White "limestone"	20
Yellow sandy shale	34

	Feet.
White sand, main flow	3
Shale and limestone	62
Coarse sand	10
White shale and limestone	38
Quartzite.	

This record was furnished by P. J. Stacy, the borer, whose identification of materials is exceptionally reliable. The section presents some features unusual for the Dakota formation.

Geologic section of Dakota formation in Budlong well 5 miles northeast of Hitchcock, S. Dak.

	Feet.
Sandy shale, at 776 feet	10
Hard sandstone	3
Conglomerate	30
Sandstone, soft	5
Dark shale	10
Sandy shale	12
White shale	19
Conglomerate	25
Sandstone, dry	12
White shale	19
Quartzite.	

The Bohri well in Clark County, a short distance northeast of Raymond, entered water-bearing sandstone supposed to be Dakota at the depth of 1,005 feet and was bored to "hard rock," presumably quartzite or granite, at 1,200 feet. The following record is given, which, if accurate, shows a remarkably thick body of shale below the sandstone:

Geologic section of Dakota? formation in Bohri well near Raymond, S. Dak.

	Feet.
Sand rock and shale, at 1,005 feet	20
"Lime rock"	25
Sandstone	3
Shale	90
Green shale with rock layers	55
Hard rock ("quartzite"?).	

Two wells at Huron in Beadle County have bored through the Dakota sandstone into the underlying quartzite and granite; the following is the record in one of them:

Geologic section of Dakota formation in city wells Nos. 3 and 4 at Huron, S. Dak.

	Feet.
Sandstone, with strong flow, at 740 feet	5
Sandy shale	50
Hard sandstone	12

	Feet.
Sandstone; much water	65
Gray limestone	58
Shale	
Sandstone, thin	
Shale	
Sandstone	3
Black shale	125
Pebbly sand and water	9
Coarse sandstone on quartz rock or granite	30

At Wolsey, 12 miles west of Huron, is another well which is claimed to have gone to the base of the Dakota formation; the following strata are reported:

Geologic section of Dakota sandstone in well at Wolsey, S. Dak.

	Feet.
Sandstone, with flow, at 808 feet	30
"Limestone" (?)	20
Sandstone	20
Hard shale	15
Sandstone	10
"Limestone" (?)	25

At De Smet, on the highlands 30 miles east of Huron, a deep boring passed through a thick series of sandstone with shale intercalations, probably comprising the greater part of the Dakota formation and including in its upper beds the lower portion of the Benton formation.

Partial geologic section in lower part of boring at De Smet, S. Dak.

		Feet.
Benton (?)	Hard sandstone, at 840 feet	25
	Sandstone	120
	Shale	200
Dakota	Sandstone	271
	Hard sandstone	14
	Sandstone	140

In Sanborn County many wells have reached the Dakota sandstone; the well at the mill at Woonsocket penetrated a solid mass of it from 697 to 775 feet, but had no need to go to the base. A well 2 miles southwest of Letcher reports Dakota beds from 400 to 863 feet without reaching their base; the material is mainly clay, including several sandstone layers with flowing water. In the Ashmore well, southwest of Artesian, the Dakota appears to have been entered at a depth of 626 feet; its upper members are 6 feet of sandstone and 67 feet of shale, lying on sandstone, which was penetrated 2 feet.

In Davison County the thicknesses are variable and diminish rapidly to nothing in an irregular area on the higher slopes of the underground ridge of Sioux

quartzite, south and southwest of Mitchell. At Mitchell the Dakota formation appears to extend from a depth of 445 feet to the quartzite at 540 feet, comprising 39 feet of sandstone above and 11 feet of sandstone at base, separated by 50 feet of shale. In the Smith and Davison well, 4 miles southwest of Mitchell, in a valley in the buried quartzite ridge, the formation is represented by 40 feet of sandstone and 10 feet of shale lying on quartzite, the top of which lies at a depth of 475 feet. At Ethan only 8 feet of sandstone, which may be Benton, occur on the quartzite. In the Lowrie well, northwest of Ethan, the formation appears to be 92 feet thick, lying on quartzite at a depth of 477 feet and consisting of a top member of sandstone about 30 feet thick and a lower series of shales. The formation thickens rapidly to the west and south, and in the J. K. Johnson well, 3 miles due north of Mount Vernon, the section, without reaching the underlying bed rock, is as follows:

Partial geologic section of Dakota formation, north of Mount Vernon, S. Dak.

	Feet.
Sandstone, at 350 feet	70
Shale	50
Sandstone	36
Shale	95
Sandstone	44+

In Aurora County several wells penetrate the formation a hundred feet or more and find alternations of sandstone and shales. The well at Plankinton is said to have reached granite at 756 feet; the overlying Dakota, beginning at a depth of 538 feet, appears to comprise 218 feet of beds consisting largely of shale, with several thin sandstone bodies. At White Lake, beds from a depth of 790 to 850 feet are reported as sandstone and shales lying on supposed granite. The Storla well, in the northeast corner of the county, reports beds apparently Dakota from a depth of 457 to 760 feet, as follows:

Partial geologic section of Dakota formation in Storla well, Aurora County, S. Dak.

	Feet.
Sandstone, at 457 feet	13
Shale	60
Sandstone	5
Shale	30
Sandstone	10
Shale	45
Sandstone	10
Shale	110
Sandstone	20+

In the Dougan well, 4 miles northeast of the Storla well, there were 23 feet of sandstone on 60 feet of shale, lying on sandstone. In the Bartow well, 3 miles northeast of Plankinton, the following beds are reported:

Partial geologic section of Dakota formation in Bartow well, near Plankinton, S. Dak.

	Feet.
Sandstone, at 455 feet	61
Shale	104
Sandstone	Few.
Shale, etc	133
Sandstone	2+

In the Resley well, 4 miles southeast of Plankinton, the section is as follows:

Partial geologic section of Dakota formation in Resley well, near Plankinton, S. Dak.

	Feet.
Sandstone, at 477 feet	12
Shale	116
Sandstone	5
?	24
Shale	45
Sandstone	39+

The formation is absent in the central and southern portion of Hanson County, but in its northern and northeastern part has been penetrated by several deep wells and found to consist of from 20 to 53 feet of sandstone lying on granite or quartzite. Apparently it thickens rapidly to the north under the western part of Miner County and in the southeastern part of Sanborn County.

In the northern portion of Hutchinson County the formation thins out against the Sioux quartzite slopes, but is more than a hundred feet thick to the south and to the west. At Parkston it appears to have been entered at a depth of 460 feet and found to end at "very hard rock," probably quartzite, at 542 feet. Its upper member is a 12-foot bed of sandstone, below which there are alternations of shales and sandy shales. A later boring gives 35 feet of sandstone on 20 feet of shale, lying on the quartzite at a depth of 520 feet. At Tripp 110 feet of sandstone are reported, extending from 729 to 824 feet in depth without reaching the bottom of the formation. In the Morris well, 5 miles north by west of Tripp, the formation was penetrated from 505 to 595 feet without reaching its bottom. It consisted of sandstone with muddy layers below a 7-foot shale bed, with a very hard sandstone cap 28 feet thick at the top.

But little is known of the thickness or character of the formation in the southwest half of Turner County, which it underlies. A well at Hurley appears to have reached its top at a depth of 400 feet; 3 miles west of that town a well 513 feet deep

is reported to have passed through 93 feet of sandstone, with some pyrites and shale, and to have penetrated the underlying quartzite 3 feet.

In Clay County the Dakota sandstone is reached by many wells, but none of them appear to penetrate it for more than 30 to 40 feet.

In Yankton County several wells have been drilled 150 to 200 feet into the formation. At Yankton one of the later borings in the city has reached the underlying granite at a depth of 898 feet; in the Asylum well, 3 miles to the north, it is reported that Sioux quartzite was reached at 825 feet. These data indicate a thickness of 415 to nearly 500 feet for the Dakota formation. The following record[a] is given of the lower beds in the city deep well:

Geologic section of Dakota formation in well at Yankton, S. Dak.

		Feet.
Benton?..	Sand rock, at 353 feet	20
	Shale	37
Hard rock		3
Sand with water		15
Shale		17
Sand with water		30
Hard rock		4
Shale		27
Flint		2
Coal		1
Shale		26
Hard sandstone		10
Sand with water		15
Shale		20
Sandstone		29
Fine sand		196
Clay		2
Sand		62
Greenish clay		7
Tough green rock.		

In Bonhomme County the Dakota sandstone varies considerably in thickness and presents the usual variability in character. At Springfield it appears to have been penetrated to depths of from 440 to 592 feet without reaching its bottom, the upper part consisting of sandstone and shales and the lower 62 feet of a solid mass of very permeable sandstone containing a vast volume of water. In the Layson well on the highlands northwest the formation was entered at a depth of 810 and supposed bed rock found at 1,075½ feet; the beds consist of an upper member of 230 feet of sandstone with very little water and a lower series of sand, gravel,

[a] Todd, J. E., Bull. South Dakota Geol. Survey No. 2, 1898, p. 101.

and sandstone lying on 38 feet of black mud at the base of the formation. In the well at Scotland a depth of 680 feet was reached, passing about 80 feet into Sioux quartzite and obtaining only a moderate supply of water from the Dakota sandstone. The following record begins below a thick body of shales and a succession of limestone and shales and thin sandy layers which continue to a depth of 476 feet.

Partial geologic section in well at Scotland, S. Dak.

	Feet.
Sandstone and shale streaks with flowing water	34
Red shale and hard sandstone	8
Gray sandstone with flowing water	40
Pyrites	1
Pinkish sandstone	31
Limy pinkish sand rock on soft Sioux quartzite	12

Some of the wells in Charles Mix County have penetrated the Dakota formation for greater or less distances without reaching its bottom. The usual irregular alternations of sandstones and clays are reported, the sandstones often thickening to 70 feet, as in the Lake Andes well. In the Hammer well, west of Castalia, a hard rock with pyrites, supposed to be the top of the Dakota formation, is reported at from 725 to 755 feet. Next below are 30 feet of shales and 181 feet of water-bearing sandstone.

As most of the Brule County wells obtain abundant water supplies from the upper sandstone of the Dakota formation they do not penetrate it very deeply. At Chamberlain the formation has been explored for over a hundred feet; some drillers report it solely as sandstone, while others state that heavy masses of shale separate the sandstone layers. At Kimball sandstone was entered at 900 feet and owing to the upper beds not yielding as much water as desired the well was continued to over 1,200 feet, all in sandstone.

In Buffalo, Jerauld, Hand, and Hyde counties the Dakota sandstone has been drilled for water, but only its upper beds have been penetrated. In Faulk County many wells pass into the formation for from 150 to 200 feet and find sandstone predominating, with shale alternations in some areas. No well has reached the bottom of the formation. At Gettysburg, in Potter County, the formation appears to extend from 1,780 to 2,130 feet, and to be overlain by 310 feet of sandy shales with pyrites. The formation consists of sandstone at the top, then 20 feet of sandy shale, 40 feet of sandstone, and 90 feet of alternating sandstones and shales to the bottom of the well.

At Pierre, in Hughes County, two deep wells have recently been completed which throw light on the stratigraphy of the Dakota sandstone, one of them, it is claimed, having reached bed rock. The top of the formation lies 1,130 feet below the surface.

Geologic section of Dakota formation in wells at Pierre, S. Dak.

	Feet.
Sandstone, yellowish, at 1,130 feet	10
Sandstone and limestone	35
Sandstone, yellowish	10
Shale, limestone, and sandstone	30
White sand, soft	30
White shale and limestone	25
Granite (supposed), at 1,260 feet	260

In another well 900 feet west of this one a depth of 1,537 feet was attained without finding granite. Below 1,325 feet there were penetrated 125 feet of gray shale and 87 feet of highly carbonaceous shales with some pyrites and lignite. From these two borings a thickness of over 600 feet is indicated, but the lowermost formation may be older than Dakota.

In the well on the Rosebud Reservation the Dakota sandstone appears to have been entered at a depth of 2,240 feet and was found to continue to 2,500 feet, a thickness of 260 feet, without reaching its bottom. All the rock was fine-grained sandstone with a few thin layers of shale and some pyrites.

The Dakota sandstone contains abundant plant and molluscan remains in its out-crops along Missouri River near Sioux City, and in Nebraska and Kansas. An extensive flora is represented, constituting the typical "Dakota flora" of upper Cretaceous age. The mollusca are fresh-water forms, which occur in considerable variety, but are not very distinctive as to age. According to Professor Todd *Goniobasis*, a fresh-water mollusk, was found in considerable numbers at a depth of 785 feet in wells near Esmond. The form is one typical of the formation in the outcrop region south. Professor Todd also reports that plant impressions were found in a well near Hitchcock.

Benton group.—Nearly all of eastern South Dakota is underlain by the Carlile, Greenhorn, and Graneros formations, constituting the Benton group, the exception being on the higher portions of the underground ridge of Sioux quartzite extending eastward from Hanson County, and along Minnesota River. The group has a thickness of several hundred feet, consisting mainly of dark-colored shales or hard clays, with thin beds of sandstone, parted near its middle by the very characteristic Greenhorn limestone, presenting a succession of beds similar to that in the Black Hills, but of greatly decreased thickness. Over a considerable area a notable bed of water-bearing sandstone occurs at or near the top of the Carlile formation, being either immediately overlain by the Niobrara chalkstone or separated by a small amount of black shale.

Rocks of the Benton group outcrop extensively along the south bank of Missouri River below the mouth of James River and in the valley of the Big

Sioux below Canton. One of its most typical exposures is on the south side of the Missouri, opposite Vermilion, where the thickness is about 250 feet, and where there is exhibited in the lower medial portion a very characteristic bed of slabby limestone, 30 to 40 feet thick—the Greenhorn limestone of the Black Hills and Rocky Mountain region—filled with the typical fossil *Inoceramus labiatus.* (See Pl. XXIV.) The basal beds are dark shales, similar to the Graneros shales of the region west, 50 to 90 feet thick, and the upper beds are Carlile shales, about 160 feet thick, containing several thin sandstone layers and zones of concretions. The group is also exposed at intervals in the bluffs along the east side of the Big Sioux and southward to Sioux City, Iowa, where its included limestone has been mistaken for the Niobrara, possibly on account of a small amount of chalk associated with it. The formation also appears to be near the surface under the drift in Minnesota Valley, as indicated by the occurrence of *Prionotropis woolgari* in shallow wells about Milbank. Other outcrops, due to uplift and erosion, appear along James River and some of the tributary valleys in Davison, Hanson, and Hutchinson counties. The most extensive of these exposures are along Twelvemile, Enemy, and Firesteel creeks and on James River in the vicinity of the quartzite.

The principal material seen in these outcrops is a buff or brown massive sandstone, exposed for a thickness of 15 to 20 feet at the greatest. The sand is coarse, there is more or less cross-bedding, and often small pebbles are included—all very suggestive of the Dakota sandstone. Heretofore, in fact, these sandstones have been regarded as a part of the Dakota formation. In well borings near by, however, it is found that they are underlain by several hundred feet of shales of typical Benton character, in some cases containing distinctive marine fossils and underlain by typical Dakota sandstone. These sandstones contain some fragments of wood and occasional leaves, and undoubtedly are the products of shallow waters, which continued even as late as the beginning of Niobrara time along the shore afforded by the ridge of Sioux quartzite. Sharks' teeth are reported from the associated shales, also indicating marine conditions. Benton shales, associated with these sandstones, are exposed at a number of points along Enemy, Twelvemile, and Firesteel creeks and James River.

The formations of the Benton group, as shown by the records of the wells, present considerable variation in local character and thickness. Apparently they thicken considerably to the north and to the west, being thinnest in the area of outcrop in the southeast corner of the State. In the vicinity of the quartzite ridge, in Davison and the counties eastward, they appear to thin out and disappear, overlapping the edges of the Dakota formation considerably. Probably,

however, there are some small outlying areas under the drift on portions of the quartzite ridge.

In the northeastern portion of the State, unfortunately, the Niobrara deposits are not clearly recognized, so that the limits of the Benton group can not always be ascertained. In the wells at Aberdeen the formations appear to be 400 feet thick, if certain limestones that are given in the records really belong to the Niobrara, and, on the same basis, the formation is 480 feet thick in the Andover wells. In Spink County the amount is somewhat less, but it appears to be 310 feet in the Cavanaugh well near Hitchcock, and 380 feet in the Glidden well, measured downward from the bed of sandstone which appears to be the one that characterizes the summit of the Carlile formation of the Benton group in other portions of the region.

In Beadle and Kingsbury counties the thickness of the Benton group appears to vary from 400 to 500 feet, probably increasing to the west, although the limits of the formations are not defined in that region. In eastern Jerauld County the Benton beds are 540 feet thick in the Feistner well, 510 feet in the Beug well, and 471 feet in the Schmidt well.

In central and southern Sanborn County, where the formation is uplifted toward the surface, the thicknesses vary greatly, diminishing rapidly toward the south. In Davison County the relations are clearly ascertained by numerous well borings, in which the thicknesses are found to vary mostly from 200 to 300 feet, and the upper sandstone continues to be a characteristic feature. This sandstone thickens and thins locally from 20 to 85 feet in the southwestern portion of the county, and is usually directly overlain by the Niobrara-chalkstone, although in portions of the area there is an intervening mass of shale, which sometimes attains a thickness of 50 feet.

In the northern part of Hanson County, where the formations of the Benton group vary in thickness from 250 to 300 feet, the upper sandstone is a conspicuous feature. In the vicinity of Ethan, in Davison County, the formations are 190 to 200 feet thick, and at Ethan 182 feet thick from the chalk above to a basal sandstone 8 feet thick, which may be Dakota lying on the quartzite. The stratigraphy varies considerably in this region, there being at various horizons occasional thin layers of sandstone, some of which yield a flow of water under moderate pressure.

In Miner County the formations of the Benton group have been penetrated at Carthage, where the chalk was found to be underlain by 30 feet of the Carlile upper sandstone, and this by 250 feet of shale, with considerable pyrite in layers lying on typical Dakota sandstone.

In Hutchinson County the formations of the Benton group present their

characteristic features, but thin considerably on the slopes of the buried quartzite ridge in the northern portion of the county. At Tripp a thickness of 400 feet is reported, comprising 100 feet of sandstone immediately underlying the chalk; at Scotland a thickness of 285 feet, with 25 feet of the top sandstone; and at Vodnany, a thickness of 305 feet, with the top sandstone very thin. In Turner County the formations of the Benton group are 265 feet thick in two wells near Hurley, consisting entirely of dark shale. In Aurora County they average about 300 feet thick and usually have from 20 to 70 feet of sandstone at the summit immediately overlain by the Niobrara chalkstone. In Charles Mix County the Lake Andes well has the following record in formation of the Benton group:

Geologic section of Benton group in well at Lake Andes, South Dakota.

	Feet.
Black shale, at 237 feet	30
Yellow sandy shale	39
Dark shale	145
Blue shale, with limestone streaks	50
Shelly lime rock	25
Blue shale (on Dakota sandstone)	70

In Brule County the Benton group appears to be from 400 to 500 feet thick and includes sandstone layers at some localities. At the Crow Creek Well in Buffalo County it is 350 feet thick, with the usual thin bed of sandstone at the top just below the Niobrara chalk. In Bonhomme County the group varies considerably in thickness, being about 300 feet in the Springfield well and 420 feet in the Layson well on the highlands northwest of Springfield. In Douglas County 350 feet are indicated, including a top sandstone of general occurrence underlying the chalk and a great mass of shales below with a few thin layers of limestone. These thin layers of limestone are mentioned in many of the well records in the southern townships, and probably represent the characteristic Greenhorn limestone horizon. To the south this limestone includes some chalky deposits like those of the Niobrara, but of no great thickness. The top sandstone is from 38 to 60 feet thick in wells about Armour. In the wells about Yankton the group appears to be not over 300 feet thick, and apparently it thins considerably eastward to its outcrop area in Clay County.

In Grant County, as recently ascertained by Professor Todd, the upper portion of the Benton group—Carlile formation—appears to come to the surface beneath the drift, for in shallow wells about Milbank numerous *Prionotropis woolgari* occur. The outcrops of sandstones that are reported by the Minnesota geological survey in Lyon County and northwest along the eastern slope of the coteau appear to be the upper sandstone of the Carlile formation. One exposure, 2

miles northwest of Taunton, is a thin-bedded quartzitic rock. According to H. H. Adair, the following beds are penetrated in the vicinity of Marshall, Minn.:

Geologic section of wells about Marshall, Minn.

Feet.	
0– 70	blue clay, with sand streaks.
70–170	"soapstone," light colored.
170–270	"soapstone," dark colored.
270–295	"black sand," or sandy shale, with flow of soft water.
295–415	"soapstone."
415–425 +	sandstone, with hard water under high pressure.

The bed of light-colored rock from 70 to 170 feet may represent the Niobrara chalk rock, and the lowest sandstone appears to be Dakota.

The shale exposures on the east side of Bigstone Lake, a mile from its lower end, have been examined by Prof. J. E. Todd, who finds that they are lead-colored shales containing biscuit-shaped concretions, but no fossils. Probably they are of upper Carlile age.

At Whiterock, in the northeast corner of Roberts County, about 20 feet of white "chalk" is reported, extending from a depth of 280 to 300 feet, underlain by 200 feet of "soapstone" lying on granite. This white "chalk" probably represents the Greenhorn limestone of the Benton group.

In the outcrops of the formations of the Benton group fossils occur in considerable number. Along Missouri and Big Sioux rivers the Greenhorn limestone member contains vast numbers of *Inoceramus labiatus*, and the associated shales are often highly fossiliferous, notably in the bluffs of the Missouri opposite Vermilion. In the exposures of the upper sandstone in Davison County Professor Todd has found many sharks' teeth, and reports the occurrence of a fragment of *Prionotropis* taken out of the shale on the east side of James River 1½ miles north of Elm Springs. Fossils are reported from some of the wells, notably the Ashmore well southwest of Artesian, from near the bottom of which a *Mactra* and *Fasciolaria* were obtained. In the well at Farwell sharks' teeth were obtained at a depth of 400 feet. In the well 2 miles north of Woonsocket abundant fragments of fossiliferous limestone were thrown out from 580 feet below the surface, which, Mr. T. W. Stanton reports, contains a small *Nucula* with striated surface, which may be the young of *N. cancellata* M. & H., a young *Mactra*, and numerous *Lucinæ* of undetermined species. These were found 250 feet below the chalkstone and 100 feet above the main flow.

Niobrara formation.—The chalkstone of this formation is a prominent feature in the bluffs of Missouri River above Yankton, as shown in Pl. XLI, especially about the mouth of Niobrara River, and shows almost continuously as far as the Great Bend, where it passes beneath the Pierre shale at water level. It under-

lies the drift along James River Valley as far north as Letcher, and west to beyond Plankinton, and extends eastward to Big Sioux River in Hutchinson, Turner, Lincoln, Yankton, Clay, and Union counties, although probably, in the higher part of Turkey Ridge, it is overlain by a small outlying area of Pierre shale. In central Davison, northern Turner, and Lincoln counties it abuts against the quartzite of the underground quartzite ridge, on top of which it also lies in detached areas in portions of Hanson, McCook, Minnehaha, and Moody counties. It also appears to extend across the greater part of the northwesternmost counties of Iowa, and along the Iowa-Minnesota State line. The formation is cut through by the Missouri below the mouth of James River, by the Big Sioux below Canton, and by the James from north of Mitchell to the center of Hutchinson County. It appears to extend along the east slope of the coteau in the valley of the Minnesota in Grant County, but is there covered by drift.

The formation consists mainly of chalk in the southeast portion of the State, but portions of it grade into shale, which appears to replace the chalk to the north. It is owing to this change in character that very few well borings in the north-central counties report any chalk at all. The purer material is of white or gray color when dry, although often of a dull drab when freshly excavated. It weathers to a bright-straw color, or in some cases a bright buff, which is a conspicuous feature in its exposures. It is in greater part massively bedded, and is very fine grained and uniform in texture. It is extensively employed for building, being easily quarried and readily shaped by an ax or a saw into suitable building blocks. The chalk consists largely of tests of minute animals, foraminifera, and coccoliths similar to those of the chalk of Europe, mixed with varying amounts of clay and very fine sand. The material was deposited in moderately deep nearly clear water, without strong currents or other conditions which would bring much admixture of land waste.

In the bluffs along the Missouri, near the mouth of Niobrara River, the locality from which the formation was named, it rises in cliffs 50 to 80 feet high, of which the light-buff color is in striking contrast to the dark slopes of the Pierre and Benton shales. Exposures are frequent along the river from the mouth of the James nearly to the Great Bend. On James River and the lower portions of its larger branches the chalkstone is exposed at intervals from Scotland northward to Firesteel Creek in Davison County. There are numerous exposures on the Firesteel northwest of Mitchell, and on Enemy and on Twelvemile creeks southwest and south of Mitchell. It also appears on Wolf Creek, on Dawson Creek near Scotland, on James River below the mouth of Wolf Creek, and east of Mitchell. It is reported in extensive exposures on Clay Creek 12 miles northeast of Yankton, on Brule Creek northeast of Vermilion, to the northwest of Canton, and on the Split Rock 2 miles north of Brandon.

This formation has been included in or mistaken for the Greenhorn limestone bed of the Benton by some geologists, an error which has produced considerable confusion in the literature relating to the geology of the eastern portion of this region. The Niobrara formation is characterized by the occurrence of small oysters known as *Ostrea congesta* (see Pl. XXIV), which usually occur in colonies, and sometimes on the shells of large fossils, constituting an impure limestone. The Greenhorn limestone, as has been explained, is characterized by the occurrence of large numbers of *Inoceramus labiatus*, a form which occurs infrequently, if at all, in the Niobrara.

The thickness and structural relations of the Niobrara formation have been determined in part by well borings. The chalkstone is a prominent feature in the wells in Davison County and in the regions south, but to the north, as before stated, it appears to give place to shale, so that, though undoubtedly existing in the northeastern portion of the State, it is seldom recognized by the well borers. In Yankton County the wells begin in lower beds and soon pass into the underlying Benton deposits. In Bonhomme County the Layson well in the highlands northwest of Springfield appears to have entered the top of the formation at a depth of 90 feet and to have continued in it for 300 feet, including 20 feet of hard limestone at the base. In the town well at Scotland 120 feet of chalk are reported, but in that region some of the top of the formation has been removed by erosion. At Turkey Ridge, in the northeast corner of the county, in one well 215 feet of chalk was reported; at Hurley 100 feet were passed through, and in numerous wells in the central and southern portions of Turner County equal amounts of chalk were recorded.

In Hutchinson County the thickness is considerably diminished as the uplift is approached, but in the western portion of the county, where the Pierre shale overlaps, the full amount remains. In the well at Tripp 300 feet were reported, extending from 25 to 300 feet in depth, but probably there was included in this much of the yellow clay of the lower part of the drift. In Douglas County the formation appears to average nearly 100 feet. It is reported to extend from a depth of 190 to 300 feet in a well 4 miles north of Delmont, consisting of blue shaly chalk above and white chalk below, lying on Carlile sandstone. In Charles Mix County the formation is not very definitely reported by any of the well drillers, except in the Hammer well, west of Castalia, where it is claimed that chalk extends from the depth of 87 to 630 feet, surely a great exaggeration of its true extent. In Brule County the formation appears to average 200 feet in thickness. In Aurora County from 100 to 150 feet are reported, except in the northwestern portion of the county, where the formation has suffered considerable erosion, and only from 40 to 60 feet remain. In Davison County nearly the entire surface has been subjected

to erosion, for it lies next below the drift. It is usually entered at from 20 to 50 feet below the surface, and varies in thickness up to 260 feet, which is reported in wells in the southwest corner of the county. In Hanson County the formation is very thin, and is absent over the greater part of the summit of the buried quartzite ridge.

In Sanborn County the formation varies greatly in thickness. To the southeast it has been partly removed by erosion, and it appears to thin under the Pierre shale to the north. In the McCurdy well, at Letcher, it is reported to be 175 feet thick, and in the Ryan well near by only 70 feet. The latter estimate is probably nearer the truth, for the limits of the chalk are clearly indicated by the underlying characteristic sandstone of the Carlile formation. In the Woonsocket well the only chalk reported is a layer 24 feet thick, extending from a depth of 412 to 436 feet.

In Miner County the chalk appears to be well characterized, having a thickness of from 70 to 120 feet or more, lying under drift to the southwest and under the Pierre shale to the north. At Canova it is reported at a depth of 120 to 150 feet, lying under drift or a small thickness of shale and having a thickness of from 50 to 80 feet. In Kingsbury County the only reference to chalk in any of the records is in the Matthews well, 4 miles northeast of Carthage, where it is reported as extending to 493 feet, and in the Welch well, 3 miles northwest of Carthage, where its top is 420 feet deep. In Beadle County chalk is mentioned in a few of the records, but apparently it has given place mostly to shale which is not distinguished from the adjoining Pierre or Benton. In Spink County some limestone is reported at an average depth of about 450 feet, underlain by sandstone reported to be at the top of the Benton, and this may be the chalk horizon. In the wells at Aberdeen "limestone" from 515 to 530 feet, and in Andover from 575 to 590 feet, may possibly represent the Niobrara. In Missouri Valley above Chamberlain the chalk is not reported by the well borers, doubtless giving place rapidly to gray shales, as in the northern James River Valley region just described.

In the northeast corner of the State chalk rock, which appears to be Niobrara in age, is reported from some wells in southeast Grant County on slopes above shales yielding *Prionocyclas woolgari*. The wells in which this rock is found are from 10 to 12 miles south of Milbank.

Pierre shale.—This formation extends across the greater part of eastern South Dakota, appearing extensively in the slopes of Missouri Valley, but being mostly covered by drift deposits in the country eastward. Its maximum thickness is probably near the mouth of Cheyenne River, where it is overlain by Fox Hills sandstone. To the east its surface has been more or less deeply eroded, especially in the area of

uplift adjacent to the lower portions of James and Big Sioux valleys, where it has been entirely removed from a zone of considerable width.

The formation consists almost entirely of dark-gray clay, hardly sufficiently compact to be termed a shale, and presenting but little variation in its character from top to bottom. It contains occasional concretions, frequent masses of pyrites, thin streaks of sandstone, and some local chalky deposits to the south. Many of the deep wells pass through the formation for several hundred feet, the amount increasing gradually to the north and west of Davison County. In the slopes of Missouri Valley above the Great Bend 500 feet of the formation are to be seen, but below the Great Bend, as the underlying Niobrara chalk rises in the banks, the shale diminishes, and a short distance below the mouth of Niobrara River thins out and disappears. The many variations in its thickness are due mainly to erosion, the Pierre shale having been extensively and irregularly eroded previous to the deposition of the glacial drift by which it is now mostly covered.

It is several hundred feet thick in the ridge lying between James and Missouri rivers, in Charles Mix, Douglas, and Brule counties. At Armour there are probably 170 feet of the formation; at 10 miles north of Armour, 300 feet; in the western portion of Aurora County, 350 feet; in Brule County the amount diminishes somewhat, owing to the local uplift; in approaching the uplift in eastern Aurora County it thins out entirely; in the highlands of Jerauld County 300 feet are reported. The amount increases on the higher lands, and the increase continues northward in the highlands between Missouri and James rivers; but owing to the indefiniteness of the well records as to the limits of the Niobrara formation in that direction the precise thickness can not be stated; apparently it is over 1,000 feet.

In James River Valley about 500 feet are reported in the wells at Aberdeen and Andover and about 400 feet in Spink County; but owing to the uncertainty as to the position of the Niobrara formation the lower limit of the formation is not clearly recognized in the reports of the well borings. In Beadle County the amount is materially less and diminishes to the south until finally the formation ends in the center of Davison County, on the anticlinal uplift of the Mitchell region.

East of James River Valley, north of this uplift, the formation extends eastward to the margin of Minnesota Valley, underlying the high coteau, where it has a thickness of several hundred feet. In Kingsbury County it appears to have a thickness of about 100 feet in the highlands eastward, although its limits in the De Smet well are not indicated by the record. It appears to extend south through Lake County to the quartzite ridge, for it presents considerable thickness in the well at Madison. It also appears to extend east into Minnesota, for Pierre fossils have been found in the west slopes of Minnesota Valley; and although it has been

stated by Professor Todd that probably all of these fossils so far reported were found in the glacial drift, yet they have not traveled far. About Taunton, in Lyon County, the fossils are found below the level of the Benton group, and there, as about Milbank, they are inclosed in drift deposits.

Exposures of the formation are exceedingly rare east of the immediate slopes of Missouri Valley. In the region of thin drift about Ree Heights and southward the formation outcrops for some distance, and it appears again south of Swan Lake in Potter County, northeast of Gann Valley, and on Turtle Ridge, near Wessington Springs. Professor Todd informs me that shallow streams cut into it in western Brown County, northwest of Aberdeen, and on Willow Creek and its north branch northwest of Westport; in southeastern Brown County, 5 to 8 miles south of Groton; along James River northeast of Redfield; in northwestern Day County, 2 miles and 4 miles north of Pierpoint; and extensively north and south of Groton. Dark shale, probably of the Pierre, is reported in the northeast corner of Yankton County, where it lies on the Niobrara at an altitude of 1,510 feet, and is believed to extend thence under a considerable portion of Turkey Ridge, beneath the drift. At the cement works, 3 miles west of Yankton, it caps the Niobrara chalk rock, a relation which it presents in frequent exposures for many miles along the river.

Fox Hills formation.—There is no good evidence of the existence of Fox Hills sandstone east of the Missouri, south and east of Campbell County. It is suggested by Professor Todd that some sand on the high hills north of Forest City and the fine yellow sand along Swan Creek southwest of Bangor may be Fox Hills, and that remnants of them may be found in the Faulkton, Bowdle, and Koto hills.

TERTIARY DEPOSITS.

Evidence as to the existence of the Tertiary formations in eastern South Dakota is meager. On the summits of the Bijou Hills are caps of distinctive green quartzite of later Tertiary age lying on light-colored sands and sandy clays. Another area of the quartzite is found on the high ridge due east of Greenwood.

Fossil fish of supposed Oligocene age have been obtained from the high ridge southwest of Ree Heights, but the extent of the deposit in which they were found has not been determined. According to Professor Todd, the high ridge just west of Wessington Springs contains deposits of sandstone supposed to be older than the drift and probably of the same age as the quartzite on the Bijou Hills. It shows the same general structure, even to occasional beds of grit between the finer layers, and lies on lead-colored Pierre clay. Doubtless much of eastern South Dakota was covered by Tertiary deposits originally, but they were removed by the deep and widespread erosion of early Pleistocene times, although in some areas they may remain, mostly covered by the glacial drift.

QUATERNARY DEPOSITS.

The portion of South Dakota lying east of the Missouri is covered in greater part by a thick mantle of Pleistocene deposits, mainly of glacial origin. There are several lines of morainal ridges, a nearly continuous sheet of glacial till, extensive glacial lake deposits, and alluvial accumulations of Glacial and of more recent age. These formations have been described in detail by Prof. J. E. Todd, to whose publications the reader is referred. The greater part of the information is given in "The moraines of the Missouri Coteau and their attendant deposits," U. S. Geological Survey Bulletin No. 144, 1896; "The moraines of southeastern South Dakota and their attendant deposits," U. S. Geological Survey Bulletin No. 158, 1899; and "Geology and Water Resources of a portion of southeastern South Dakota," U. S. Geological Survey Water-Supply and Irrigation Paper No. 34, 1900.

GEOLOGY OF EASTERN NEBRASKA.

GENERAL RELATIONS.

Eastern Nebraska is underlain by Carboniferous and Cretaceous formations bearing a superficial mantle of Pleistocene deposits. The older formations have a gentle slope toward the west, and the overlying deposits are in general conformable to the easterly slope of the land. Along the Missouri, from Burt County south, Carboniferous rocks appear and, in the region south of Lincoln, extend west to Lancaster and Gage counties, whereas to the north they pass beneath the Dakota sandstone. They are frequently exposed in the valleys in the southeast corner of the State, but on the higher lands are deeply buried under the drift. Toward the west their gentle dip and the rapid rise of the land carry them far beneath the surface, not to appear again until the Black Hills and Rocky Mountains are reached. The series of Cretaceous formations which lie on the Carboniferous beds comprise the Dakota sandstone, the Benton group, the Niobrara limestone, and the Pierre shale. The lower member, the Dakota sandstone, reaches the surface to the east in a zone that passes near Lincoln and occupies Missouri Valley above Omaha. The Red Beds, the Jurassic, and the lower Cretaceous formations of the mountain regions are lacking in eastern Nebraska.

The greater part of the surface is occupied by a thick mantle of Pleistocene deposits, comprising glacial drift and a thick cover of loess. West of longitude 98° there intervenes, between the Pleistocene deposits and the Cretaceous formations, a series of later Tertiary, "Loup Fork" deposits, which gradually thickens toward the west. The glacial drift is thickest in Lancaster County, and thins rapidly toward the Missouri and to the west, its attenuated margins passing under a thick sheet of loess

in both directions. Toward the west the glacial drift presents an obscure morainal front along the eastern side of Seward County, from which a continuous thick mantle of loess extends far westward. Under this loess mantle there is a thin sheet of gravels and sands, apparently extending out from the front of the glacial drift to about longitude 102°. The position of the east margin of the late Tertiary deposits has not been definitely ascertained, owing to the cover of superficial materials, and its representation on the map, Pl. XXXV, may be several miles in error in some localities. The loess has a thickness, in greater part, of from 60 to 90 feet. The larger depressions which traverse the region contain deposits of alluvial formations, which are of great width along Platte River. In some portions of the area there are accumulations of dune sands, of greater or less extent, which, except for the sand banks in the river and the recent wash and talus, are the most recent formations of the region.

STRATIGRAPHY.

CARBONIFEROUS.

Carboniferous limestones, sandstones, and shales reach the surface in many of the valleys of southeastern Nebraska and along Missouri Valley as far north as the southern part of Omaha. The rocks consist of a variety of limestone beds, with intercalated shales, sandstones, and clays in a succession which appears to present a thickness of 1,500 feet or more. The structure and stratigraphic relations of the Carboniferous formations have not been ascertained as yet, except in a most general way. Doubtless the investigations now in progress by the State survey will result in a complete determination of their relations. It is not practicable here to review the several papers which touch on the geology of the Carboniferous of Nebraska, but they agree that the age of the beds exposed is Pennsylvanian and Permian, the latter appearing in Gage County. The Cottonwood limestone of the Kansas survey has been traced across a portion of the southeast corner of the State, and the associated succession of rocks appears to be constant for some distance from the Kansas line.

In a deep boring at Lincoln the Carboniferous beds are reported to have been entered at a depth of 269 feet, and distinctive fossils were obtained as low as 1,090 feet. Below this depth Magnesian limestones were reported to a depth of 1,813 feet, presumably in part at least of Mississippian age. They were underlain by rocks believed to represent the Trenton, St. Peter, lower Magnesian, and Potsdam to 2,192⅔ feet, where supposed Sioux quartzite was entered and continued to the bottom of the well at 2,463 feet.

CRETACEOUS.

Dakota sandstone.—The outcrop zone of this sandstone extends across eastern Nebraska on a nearly due north-south course, passing through Lincoln and up Missouri Valley into the southeast corner of South Dakota. It is mostly covered by glacial drift and loess, but appears to have a width of 10 to 20 miles underneath these superficial deposits. To the west the formation passes under the Benton shales along a line that has been only approximately determined, and underlies the region to the west at gradually increasing depths. It lies directly on Carboniferous limestones, the contact being exposed at a number of points, notably at Beatrice, at Roca, and at several points on South Platte River below Ashland. One of these localities is shown in Pl. XL, *B*.

The thickness of the formation probably varies considerably, but appears to average nearly 300 feet. In the well at Lincoln it is penetrated for 269 feet.

The contact line between the Dakota sandstone and the Carboniferous beds in eastern Nebraska presents many steep slopes, indicating an irregular shore line against which Dakota sediments were deposited. The sandstones are mainly of gray and brown colors and contain extensive bodies of intercalated clays of various light colors and local beds of conglomerate. Owing to their softness the clays are infrequently exposed, while the sandstones often give rise to prominent bluffs. Portions of the sandstone contain so much iron as to be frequently mistaken for iron ore. The coarser sandy members usually are cross-bedded. The texture varies irregularly from rock that is quite firm, to sand that is hardly consolidated; in most cases the material is so soft that it can be excavated easily with a pick. A bed of light-colored quartzitic sandstone 3 feet thick is reported on Whisky Run, about 5 miles northeast of Fairbury. Fossil leaves occur in considerable abundance at many localities, notably in the bluffs at Dakota City, the place from which the formation was named and where there were obtained the original extensive collections of upper Cretaceous plants of the characteristic Dakota flora described by Heer and Lesquereux. Two other notable localities for leaves are 5 miles south of Endicott, in Jefferson County, and near Decatur, in Burt County.

Outcrops of the Dakota sandstone are mostly small and widely scattered. Beginning at the south, there are exposures about Fairbury, about Jansen, and at Beatrice. "The largest single area is south from Little Blue River, near Endicott and Fairbury in Jefferson County, just beyond the line of glacial drift. The second largest is probably Iron Mountain, a few miles southeast of Beatrice."[a] Hayden[b] described the exposures along Little Blue River and gave the following section from the last exposure, which extended from 4 miles below the mouth of the Big Sandy to 2 miles south of the State line of Kansas.

[a] Gould, C. N., Am. Jour. Sci., vol. 9, 1900, p. 429.

[b] First Ann. Rept. U. S. Geol. Surv. Terr., 1867, p. 29.

A. PULPIT ROCK, KANSAS.

Dakota sandstone.

B. DAKOTA SANDSTONE IN BLUFFS ON WEST SIDE OF PLATTE RIVER, 1 MILE BELOW ASHLAND, NEBR.

Massive porous sandstone with coarse and fine beds and cross-bedding; Carboniferous limestone outcropping in weeds at base.

Geologic section at Little Blue River, Nebr.

	Feet.
Yellow and dark-brown rust-colored sandstones with a few leaves	50–100
Moderately coarse yellowish-white sand, irregularly bedded	50
Dark-colored laminated clays with particles and seams of carbonaceous matter and beds of carbonaceous clay in beds of 18 inches to 3 feet; much pyrite and wood	30–50
Variegated sandy clays; some seams of excellent potters' clay; probably	50–70
Dark-bluish shaly clay, Permian.	

Bones of extinct saurians are frequently found in these beds, and many leaves occur in the sandstones of the upper bed.

In the vicinity of Lincoln there are numerous small outcrops at intervals along the valley of Salt Creek and its branches; at Pleasantdale, in Seward County; and at Bennett, at the head of the Little Nemaha. The most extensive outcrops near Lincoln extend along the Burlington Railroad from Lincoln nearly to Roca. Some of the largest of these are about the penitentiary and in the vicinity of the Chicago, Rock Island and Pacific Railroad crossing. The brown sandstone appears on Antelope Creek in the southeastern corner of Lincoln County and at the "cave" in the southern margin of the city. Between Emerald and Pleasantdale the Dakota sandstone rises as a moderately high ridge under the drift and is exposed in railroad and stream cuts. The beds are extensively cross-bedded and in some of the exposures consist of highly ferruginous sandstones with complex concretionary structure. There are several exposures of the usual brown sandstone on both slopes of Haines Branch Valley and along the hollow beginning 2 miles southwest of Rokeby. At the brick and tile works a mile southwest of the insane asylum the formation is represented by clays mainly of mottled pink, brown, and gray, with streaks of sand and sandstone, lying on a bed of dark-gray clay containing a large amount of organic material; 30 feet are exposed. There is another excavation in a similar mass of clay in the southern edge of West Lincoln, just east of the lake. The exposures of Dakota sandstone north of Lincoln are along Little Salt Creek and some of its branches south and southwest of Davey, along Rock Creek north of Waverly, and in depressions along the head branches of Rock Creek northeast of Davey. In all of these exposures there is seen brown sandstone, excepting in the railroad cut northeast of Davey, where a mottled clay is exposed. The only exposures discovered east of Lincoln are in a small branch of Stevens Creek 6½ miles east of Lincoln post-office, at an old quarry in the north side of Stevens Creek a mile and a half above its mouth, and in the hollow just north of the railroad a mile west of Prairie Home.

The exposure of the Dakota sandstone just south of Bennett, at the head of Little Nemaha River, is very interesting. The formation consists of very regular

beds, 1 foot to 2 feet thick, of beautifully cross-bedded sands hardly sufficiently cemented to be classed as sandstone. The exposure is across a depression from a bluff of Carboniferous limestone. The relations indicate that probably there was a steep shore of the limestone here during the deposition of the Dakota sandstone, although possibly the two formations are separated by a fault.

The Dakota sandstone has been reported in many of the wells in Lancaster County, and in fact it is one of the principal sources of water supply in the deeper wells. Extensive springs flow out of it at many localities, notably at Case's and Price's, near Endicott; at Robinsons Spring, 4 miles south of Beatrice; and at Golden Spring, between Takamah and Decatur, which last runs a 6-inch stream.

In the boring made by the State near Lincoln in 1886 the lower portion of the Dakota formation was penetrated. According to Mr. B. P. Russell, the materials covering the Carboniferous limestone were as follows:

Geologic section of materials covering Carboniferous limestone near Lincoln, Nebr.

Feet.		
0 – 4	sandy loam.	
4 – 20	angular greenish sand.	
20 – $24\frac{2}{3}$	coarser whitish sand.	
$24\frac{2}{3}$ – $48\frac{1}{4}$	coarse gravel.	
$48\frac{1}{4}$ – 52	sand, whitish, even grained, in part rounded.	
52 – 57	coarse gravel.	
57 – 74	fine yellow sand.	
74 –100	lighter sand.	
100 –$112\frac{1}{2}$	coarser dark yellow sand; gravel and iron pebbles.	
$112\frac{1}{2}$ –$133\frac{3}{4}$	white sand and gravel, with brine at 119 feet.	
$133\frac{3}{4}$ –135	yellowish-white sand.	
135 –$147\frac{2}{3}$	yellow sand; small pebbles.	
$147\frac{2}{3}$ –$164\frac{1}{3}$	coarse yellow sand and gravel.	
$164\frac{1}{3}$ –$179\frac{2}{3}$	yellow sand.	
$179\frac{2}{3}$ –195	white sand; gravel.	
195 –202	very coarse gravel	Containing brine, 35°; strong flow.
202 –205	coarse gravel and conglomerates	
205 –$206\frac{1}{2}$	coarse conglomerate with chalky, flinty pebbles.	
$206\frac{1}{3}$ –$208\frac{2}{3}$	soft gray sandstone.	
$208\frac{2}{3}$ –$209\frac{1}{2}$	reddish clay.	
$209\frac{1}{3}$ –$214\frac{1}{5}$	light-drab clay.	
$214\frac{1}{5}$ –$244\frac{1}{2}$	fine-grained, gray, very soft sandstone.	
$244\frac{1}{2}$ –$247\frac{1}{4}$	greenish-drab clay.	
$247\frac{1}{4}$ –$267\frac{1}{12}$	fine-grained, reddish, very soft sandstone.	
$267\frac{1}{12}$–$269\frac{1}{12}$	sandy gray clay lying on chert, shale, and limestone.	

It is thought that the top of the Dakota formation was entered at a depth of $48\frac{1}{4}$ feet, but the evidence is by no means conclusive.

The Dakota formation outcrops at intervals along the bluffs of Platte River, from just below Ashland nearly to Plattsmouth, lying on an irregular surface of Pennsylvanian limestones and shales. The rocks consist of sandstones, clays, and gravels. Along the railroad cuts on the south side of the river between Ashland and South Bend there are high bluffs of the massive cross-bedded sandstone, at the base of which the older limestones often appear. Pl. XL, *B*, shows a typical portion of this exposure. On the opposite side of the river, at Santee Caves, 60 feet of sandstones are exposed. Below South Bend the Pennsylvanian rocks rise higher, and the Dakota clays, sandstones, and gravels are from 5 to 50 feet thick under the drift. Both contacts are extremely irregular, especially the lower one. Near Cedar Creek and Springfield there are extensive gravel beds, probably marking old stream courses in the Dakota deposition. Professor Gould[a] gives the following description of a typical exposure in the quarry a mile west of Cedar Creek: "The lower 15 or 20 feet consist of an extremely hard conglomerate, usually cross-bedded. The pebbles composing the conglomerate are smooth, waterworn, usually white or yellowish quartz. They vary from the size of a walnut to a very fine sand." Over this lie 30 to 40 feet of material of similar composition, but mostly very loosely cemented and containing smaller pebbles and some sand layers, which is extensively excavated for ballast on the railroads. The most westerly exposure of the sandstone in the Platte Valley is in the south bank of the river, near the bridge, 2 miles south of Fremont; this is probably near the top of the formation.

Along the right bank of the Missouri are frequent exposures from above Blair to Ponca, the formation sinking beneath the valley floor a short distance above the latter place. A mile north of Decatur, at Blackbird Hill and at the old Blackbird Mission, the river cuts into banks of Dakota sandstone. According to Hayden, 60 to 80 feet, consisting of soft sandstone with some very hard layers and considerable clay, are exposed near the Mission. At Tekamah the creek exposes 50 feet of the formation, consisting entirely of dark-brown sandstone. In a section 5 miles southeast of Homer Professor Condra reports 37 feet of Dakota beds, the upper half consisting of thin beds of sandstone and brown clay and the lower half of massive cross-bedded sandstones, varying in texture from sand to hard rock and presenting various tints of light gray, buff, and brown. In the quarry just northwest of Homer the following section is reported:

Partial geologic section of Dakota formation in quarry northwest of Homer, Nebr.

	Feet.
Clay of yellowish color	2
Sandstone, light colored, porous, massive, and not cross-bedded	7
Clay, light colored, concretionary	2

[a] First Ann. Rept. U. S. Geol. Surv. Terr., 1567, p. 431.

	Page.
Sandstone, light colored, porous, massive, and not cross-bedded	10
Clay, light colored, sandy, yellowish in places, with hard layers of iron concretions 1 to 12 inches thick	28
Clay, yellowish, with a few iron concretions	5
Sandstone, light gray to rust colored, massive, cross-bedded, with several layers of clay	20

The lower bed of sandstone in this section rises high in the bluffs some 6 or 7 miles southeast of Homer. Professor Condra gives the following section in the quarry at Jackson, Dakota County:

Partial geologic section of Dakota beds at Jackson, Nebr.

	Feet.
Glacial clay.	
Sandstone, rusty	½–1
Sandstone, light colored, loosely cemented	2
Sandstone, rusty to light color, soft beds 2 to 8 inches, with thin partings of light-colored clay	8
Clay, sandy, light color	½
Sandstone, soft, light colored	1½
Sandstone, clay or sand, color rusty to light	3

A thin bed of coal is reported 30 feet below the floor of the quarry.

The Dakota formation is reached by numerous wells in northeastern Nebraska, mainly in the northern portions of Cedar, Knox, and Holt counties and in Boyd County. Its top in some of these wells is at the following altitudes: Miller well at Aten, 840 feet; Santee, 750 feet; Niobrara, 700 feet; Lynch, 680 feet. This indicates a rise of 7 feet to the mile easterly from Niobrara to Ponca, where the top of the formation reaches the river at an altitude of 1,135 feet. Between Niobrara and Lynch the beds appear to be nearly horizontal, and west of Lynch they appear to rise slightly. By combining the thickness found in a well with the surface outcrops the thickness of the formation at Ponca appears to be 375 feet. At least 300 feet are found in the well and outcrops at Sioux City, Iowa.

Benton group.—The Benton group immediately underlies the drift in eastern Nebraska in a belt of considerable width, but owing to the softness of most of its materials and the heavy covering of superficial deposits, exposures are very rare and limited. South of Platte River there are only a few outcrops, and north of that river there are no exposures until the banks of the Missouri are reached, where for several miles the formation shows in occasional bluffs of considerable prominence.

The succession of beds is similar to that which is seen in the Rocky Mountains and in the Black Hills, but presents local modifications and greatly diminished thickness. At the base there are black fissile Graneros shales lying on the Dakota

sandstone and apparently averaging about 60 to 200 feet thick. These are capped by a thin but characteristic and persistent series of limestones filled with the casts of shells of *Inoceramus labiatus*, and therefore believed to be the precise equivalent of the Greenhorn limestone of the Black Hills and of southeastern Colorado. (See Pl. XXIV.) This limestone appears in the bluffs opposite Vermilion and at intervals south of Platte River, notably on Coon Creek at Milford, on Big Blue River below Milford, on West Blue River in the northern portion of Saline County, on Turkey Creek, on Little Blue River in Thayer County, and east of Powel and south of Rose Creek in Jefferson County. Overlying the limestones there are about 200 feet of dark shales, with a few thin sandstone layers, which appear to be exposed only along the Missouri; they present the characteristics of the Carlile formation of the region west, usually having at or near the top a distinct bed of sandstone sometimes separated from the Niobrara chalkstone by a small thickness of shale.

The relations of this series along the Missouri, in Dakota, in Dixon, and in Cedar counties, has recently been studied by Prof. G. E. Condra, who has furnished the following details: The Graneros formation in its outcrop zone is from 50 to 60 feet thick, but thickens to the west, showing 78 feet in the Niobrara well (at 442–520 feet), 98 feet in the Santee well (at 502 to 600 feet), and 90 feet in well at Lynch (at 610–700 feet). It consists mainly of very dark-gray to bluish-gray clay or soft shale somewhat harder in texture in its upper and in its lower portions. The Greenhorn limestone usually is from 18 to 20 feet thick, not including some shaly transition beds. Its rocks consist largely of carbonate of lime with admixture of clay and some sand. The upper beds are moderately hard, somewhat iron stained, weather to a dirty gray, and are filled with the impressions of the fossil everywhere so characteristic of this formation, *Inoceramus labiatus*. (See Pl. XXIV.) This member gives rise to local cliffs often of considerable prominence. The lower beds of the Greenhorn limestone are more massive, softer, and more chalky, some portions resembling the Niobrara chalk rock. Owing to this resemblance several geologists have confused this formation with the Niobrara. The Greenhorn ledge was found capping high hills in Dakota County, from which it gradually descends on a westerly dip and passes beneath the river level northeast of Newcastle. In a bluff three-fourths of a mile northwest of Ponca 19 feet of Greenhorn limestone is exposed over 50 feet of Graneros black shale. A similar exposure occurs in the river bank at the line between Dixon and Dakota counties. The Greenhorn limestone has been recognized by Condra in the wells at Niobrara at from 410 to 422 feet; at Santee, 445½ to 502 (?) feet, and at Lynch, 588 to 610 feet.

The Carlile formation appears in eastern Dixon County, overlying the Greenhorn limestone, and attains a thickness of about 170 feet where it passes under the Niobrara chalk rock. In the well at Niobrara it is 210 feet thick and in that at Lynch 288 feet, extending from 282 to 570 feet in depth. The materials are principally dark-gray and bluish-gray stratified clays with two zones of fossiliferous chalky shale. Sandstone beds of variable extent and character usually occur at different horizons, but generally near the top, as just west of Vermilion Ferry. Large calcareous concretions mark two horizons, respectively 50 and 60 feet below the top of the formation, the upper carrying numerous concretions from 2 to 8 feet long and a foot or more thick, and the lower others less numerous and smaller. These horizons pass beneath the river level between St. James and St. Helena. Considerable iron pyrites occur in the shales in thin layers and concretions. In a bluff at the "Ionia Volcano," near Ionia, 137 feet of the formation are exposed, lying on a few feet of Greenhorn limestone with 15 feet of bluish shaly passage beds. The top of the formation emerges from beneath the river level at a point about 4 miles above St. Helena, and rises gradually to 140 feet above the river a short distance west of Newcastle. The contact with the overlying Niobrara chalk is defined by a very abrupt change in the character of the materials from soft shale to compact chalk rock, a feature well exposed in the high bluff northeast of St. James. The Carlile beds contain numerous fossils at some localities, comprising *Prionocyclas*, *Ostrea*, *Inocerami*, and *Serpula*. Some further features of the formation in Missouri Valley are given in the well records on pages 277–278 and in the following general section by Prof. J. E. Todd:

Generalized geologic section of Benton group and associated formations along Missouri Valley from the mouth of Bow Creek to just below the mouth of Ayoway Creek, Nebraska.

Formation.	Materials.	Thickness.
		Feet.
Niobrara	Chalkstone, mostly pure, thick bedded; lower beds hard	40
Carlile	Blue shale with gypsum crystals	35
	Blue shale with zone of large lenticular concretions below and smaller concretions above.	10
	Blue shale with scattered concretions containing *Prionocyclas*, *Ostrea*, large *Inocerami*, *Serpula*, *Pinna*, etc., merging into	100+
Greenhorn	Blue chalky shale with few *Inoceramus labiatus*, merging into	4
	Hard slaty limestone and hard calcareous shale with many *Inoceramus labiatus*, merging into	12
	Blue chalky shale with some *Inoceramus labiatus*, merging into	12
Graneros	Bluish shale	29
	Dark carbonaceous shale	2
	Sandy dark shale	13
Dakota	Soft massive yellow sandstone	7+

A. PIERRE SHALE LYING ON NIOBRARA CHALK ROCK ON BANK OF MISSOURI RIVER, NORTHEAST OF LYNCH, NEBR.

The Niobrara is the more massive rock below; the illustration shows the abrupt change to Pierre shale. Photograph by G. E. Condra.

B. NIOBRARA CHALK ROCK LYING ON CARLILE SHALE ON BANK OF MISSOURI RIVER, NORTHEAST OF ST. JAMES, NEBR.

The contact is at the man's hand; the illustration shows the abrupt change from one formation to the other and the massive character of the chalk. Photograph by G. E. Condra.

In southern Nebraska the Benton series has not been examined, except at a few points. The outcrops of Greenhorn limestone have already been referred to.[a] The Graneros shales outcrop in a few areas in Jefferson and Thayer counties. In a well in the southwestern corner of Jefferson County 200 feet of dark shales, probably representing the Graneros formation, were penetrated, lying between the base of the Greenhorn limestone, at a depth of 50 feet, and the top of the Dakota sandstone, at a depth of 250 feet.

Niobrara formation.—This formation appears to extend across eastern Nebraska in a broad band under the Tertiary and later deposits. It is exposed for 125 miles along the valley of Republican River, from Indianola to Superior, but to the north is seen only in Loup Valley near Genoa until Missouri and Niobrara rivers are reached in Holt, Knox, Cedar, and Dixon counties, where there are extensive exposures.

The material is mainly a soft limestone, chalk rock, or limy clay, presenting considerable variation in composition from place to place. It appears to average about 200 feet thick so far as could be estimated, but data bearing on this point are few. The rocks weather to a very characteristic light-cream to straw color, which is conspicuous in the bluffs about the mouth of Niobrara River, where the formation received its name.

The principal fossil is a characteristic small oyster, *Ostrea congesta*, occurring in colonies, with the individuals so tightly packed together that they give rise to limestone layers. (See Pl. XXIV, *A*.) Some other shells also occur and large numbers of remains of fish and reptiles. The purer varieties of the chalk rock consist mainly of the tests of cocoliths and foraminifera similar to those which occur in the chalk of Europe.

The formation has recently been studied in detail in Missouri Valley by Prof. G. E. Condra, who has furnished the following data: The principal material is a lead-gray chalk rock, which weathers yellowish. There is a variable mixture of sand and clay, and thin local layers of hard limestone filled with *Ostrea congesta* abound in its upper beds. The base of the formation usually is a moderately firm sandy limestone. The purer chalk occurs in irregular bodies varying in thickness from 1 inch to 6 feet and merging laterally into mixed deposits. It has a fine texture, low specific gravity, and a characteristic hollow sound when struck with the hammer. The first exposures eastward are in the hills southwest of Vermilion Ferry, about 100 feet above the river.[b] Northwest of St. James a thickness of about 130 feet remains lying 70 feet above the river. There is a low westerly dip from this place to Niobrara, beyond which

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[a] In his report for 1867 Hayden refers to the limestone on hilltops in western Jefferson County composed of closely packed *Inoceramus problematicus*.

[b] The chalky rock capping hills in Dakota County, referred to as Niobrara by Meek and Hayden and others, proves to be Greenhorn limestone, as already explained.

the formation appears to lie level for some distance and then to rise gradually. At St. Helena the base of the Niobrara chalk rock is 30 feet above the river; a few miles above that place it passes beneath the river level. Its full thickness to the overlying Pierre shale in this district is about 200 feet, being 195 feet in the boring at Lynch and 205 feet in the well at Santee. In northern Cedar and Knox counties and westward up the river there are frequent high bluffs of the formation, the bright-yellow color of which is a conspicuous feature in the landscape. The formation passes below the surface to the southwest, its top being 105 feet deep at Lynch.

Pierre shale.—The eastern margin of the Pierre shales extends into eastern Nebraska, probably approximately to a line extending from Indianola, in Redwillow County, to the western margin of Cedar County, but, as it is overlain by Tertiary and later deposits in the interval, no details of this margin can be outlined. There are exposures along Republican Valley from near McCook westward and along the slopes of Missouri and Niobrara valleys in Knox, Holt, Boyd, Rock, and Brown counties. The principal material is a dark-colored shale or clay, presenting some local variations in character in its lower beds. Its surface has been extensively exposed to erosion in eastern Nebraska, and only a small thickness remains there, but as its base descends under the central and western portions of the State it attains a thickness of a thousand feet or more.

Along the Missouri, in Ponca and in Niobrara valleys, in Knox, Holt, and Cedar counties, there are numerous exposures, these valleys being largely excavated in the formation. In this region there is a lower member lying on the Niobrara chalkstone, consisting of very dark clays varying in thickness from 10 to 30 feet or more, to which Hayden has called attention. This is overlain by lighter-colored clays with thin seams of iron oxide averaging about 100 feet thick. Next above is an unusual feature in Pierre stratigraphy—a series of light-colored clays containing impure chalky beds weathering to buffish and reddish tints, about 100 feet thick, and in many outcrops somewhat resembling Niobrara formation.

TERTIARY DEPOSITS.

Very few facts have been obtained as to the extension of the Arikaree and other later Tertiary formations in eastern Nebraska. They are absent east of longitude 97, and to the west of this meridian there is such a deep covering of loess and sand that the underlying formations are rarely exposed. In Knox, in Boyd, and in northern Holt counties, on the slopes of Missouri and of Niobrara rivers, there appear sandstones, grits, and clays of various kinds, which probably represent the Arikaree formation. The most extensive exposures are in the Twin Buttes, west of Butte, and in hills south of that town.

The rock is a massively bedded, light-colored sandstone of very irregular structure cemented by carbonate of lime, underlain by a mixture of sand and clay of light-greenish, grayish, and pinkish tints. At some points a fine-grained dark-greenish-gray to olive-colored quartzite occurs in irregular masses, a rock similar to that reported on Minnechadusa Creek near Valentine. This green quartzite again appears at intervals south of Niobrara River, in the northeastern corner of Holt County, and on the high ridge east of Verdigre, and has been reported by Professor Todd[a] as capping a butte in the northeast corner of Knox County.

This peculiar rock, with its characteristic fine grain, green color, and conchoidal fracture, appears to be the same as that occurring on the Bijou Hills and on their west extension in South Dakota. It is stated that soft sandstones of supposed Arikaree age outcrop at Fullerton, and possibly the formation will be found at various points along the north side of the lower portion of Loup Valley.

In the vicinity of the ninety-eighth meridian, all the way across Nebraska, sands, which in most cases are doubtless of later Tertiary age, are reported in many of the well records, lying beneath the superficial formations. Their identity is not yet established.

QUATERNARY DEPOSITS.

The Quaternary deposits which cover the greater part of eastern Nebraska with a thick mantle have not been studied in detail. Prof. J. E. Todd, in a report on the moraines of southeastern South Dakota, gives much information regarding the contiguous portions of northeastern Nebraska, and to this publication the reader is referred.[b]

GEOLOGY OF CENTRAL AND WESTERN KANSAS.

GENERAL STRUCTURE.

The geology of Kansas has many features similar to those of Colorado and Nebraska, but several of the formations present important differences in structural relations and stratigraphic components, due to gradual change to the south and east. The eastern part of the State is crossed by a broad belt of Carboniferous limestones, shales, and sandstones from Mississippian to Permian in age, dipping gently to the west or slightly north of west under the younger formations. These latter comprise a series of upper Cretaceous members from Pierre shale to Dakota sandstone, which lie directly on the Permian beds, excepting locally, where they are separated by upper members of the Comanche series of the lower Cretaceous. In general they dip gently to the northwest, and, owing to this dip, together with the rise of land to the

[a] Todd, J. E., A green quartzite from Nebraska: Am. Geologist, vol. 3, p. 60.
[b] Todd, J. E., Bull. U. S. Geol. Survey No. 158, 1899.

west, the mass of formations thickens to the northwest. West of the ninety-eighth meridian nearly all the higher lands are covered by Tertiary and Pleistocene deposits to a thickness of from 150 to 250 feet.

STRATIGRAPHY.

The following list sets forth the order, age, and principal characteristics of the formations:

Table of geological formations in central and western Kansas.

Age.	Name.	Principal characteristics.
Quaternary	Sand hills	Sand, mainly in dunes due to wind action.
	Alluvium	Sand, loam, and gravel in valleys; talus on slopes.
	Loess	Fine sandy loam, of pale brownish-buff color.
	Equüs beds	Sands and sandy clays.
Pliocene	Ogalalla formation, comprising Tertiary grit, mortar beds, etc.	Calcareous grit, sandy clay, and sand.
Upper Cretaceous	Pierre shale	Dark-gray shale or clay.
	Niobrara formation	Chalk, soft limestone, and shales.
	Benton group	Shales, limestones, and sandstones.
	Dakota sandstone	Sandstones and shales.
Lower Cretaceous	Kiowa-Cheyenne (later Comanche) series.	Do.
Carboniferous	Cimarron series (Permian)	Red sandstones and shales.
	Permian	Shales and limestones.
	Cottonwood limestone	Limestone.
	Waubaunsee group	Limestones, shales, sandstones, and thin coal beds.

PERMO-CARBONIFEROUS.

Limestones and shales of this age extend in a wide belt across central eastern Kansas. There they are comprised in several formations, the uppermost of which are the Wellington shales and the Marion formation. The Wellington beds are mainly slate-colored shales which have a thickness of about 200 feet to the north and of 445 feet in the southern part of Sumner County. They pass beneath the Dakota sandstone north of Reno County and merge into the Red Beds southward. The Wellington shales are underlain by the Marion formation, which consists of light-colored limestones, shales, and marls, containing extensive deposits of salt and gypsum. The thickness of the formation is 300 to 400 feet. In some portions of its area a considerable proportion of its beds is salt.

Cimarron formation.—In the southern part of Kansas, from Sedgwick and Sumner counties westward, the Dakota sandstone and the Comanche series are underlain by Red Beds which thicken rapidly to the westward. They are the surface rock in Harper and in the greater part of Kingman, Barber, and Comanche counties, but pass under the younger formations to the north and the west. The material is mainly sandstone and shale of dark-red color, containing thick beds of gypsum. The total thickness in western Kansas is not known, but is probably at least 2,000 feet. The Comanche and Dakota formations lie unconformably upon the surface of the Red Beds. According to George I. Adams[a] these Red Beds merge into the Wellington shales and other Permian beds in Sedgwick and Sumner counties. How far they extend under the Dakota sandstone to the northwest is not known, well borings not having given decisive evidence in this regard much beyond Arkansas River.

CRETACEOUS.

Comanche series.—The upper formations of this series of lower Cretaceous rocks underlie the Dakota sandstone in a portion of central-southwest Kansas, outcropping under the edge of the Tertiary deposits in Clark, Comanche, Kiowa, and Barber counties. Another small area underlies the Dakota formation in the northwest corner of McPherson County. In southwestern Kansas there is an upper member, consisting mainly of shales, known as the Kiowa shales, which has a thickness of from 125 to 150 feet. The upper beds of this formation are yellowish-gray shales, with thin layers of fossiliferous limestone, which are either yellowish or pinkish in color. These beds are underlain by black and bluish-black to gray shales, having a thin hard stratum of sandy and calcareous matter at the bottom. The lower formation is the Cheyenne sandstone, which is composed mainly of coarse materials, usually of light color and of relatively soft texture. Its thickness varies from 40 to 60 feet. It is not unlike the Dakota sandstone in appearance and weathers with somewhat similar aspect, but usually is of lighter color. The lower Cretaceous in McPherson County consists of the Kiowa shales, which are calcareous and contain much shale or limestone; they lie on the Wellington shales without the intervening sandstone.

Dakota formation.—The Dakota formation underlies the western half of Kansas, outcropping in a zone 12 to 20 miles wide, extending from Washington County south and southwest to Arkansas River, in Rice and Barton counties, and thence up Arkansas Valley to Ford County, where it passes under the Tertiary deposits. It again appears in the valleys of Cimarron River and some of its branches near the Colorado

[a] Adams, George I., The Carboniferous and Permian age of the Red Beds of eastern Oklahoma, from stratigraphic evidence: Am. Jour. Sci., 4th ser., vol. 12, 1901, pp. 383-386.

State line. North of Arkansas River, in northwestern Kansas, it passes beneath the Benton, Niobrara, Pierre, and Tertiary formations, probably lying more than 2,000 feet below the surface in the northwest corner of the State. In north-central Kansas it lies on the dark shales and salt beds of the Wellington formation and to the south and southwest on the red beds of the Cimarron formation, in places with intervening masses of the lower Cretaceous (Kiowa and Cheyenne).

The Dakota formation consists mainly of sandstone, but there are also associated shales of considerable extent. The stratigraphy varies so that no very distinct subdivisions can be established. At the top of the formation, as defined by the Kansas geological survey, there is a thin bed of sandstone, usually not much more than a foot thick. Next below are shales containing so much gypsum in loose crystals and thin seams that this member has been called the "gypsiferous horizon." Its thickness varies from 10 to 20 feet. Next comes a series of shales containing much salt, which gives rise to many salt lakes and marshes and saline springs. The shales vary in thickness from 15 to 30 feet and are often underlain by a thin bed of lignite, which is sometimes 2 feet in thickness. The lignite is associated with shale, but often lies on or between sandstone. The characteristic member of the Dakota formation lies next below. It is a thick mass of sandstones with intercalated beds of clays of various kinds. The relations of the shale to the sandstone are exceedingly variable, but in the eastern part of the State well borings show first a series of sandstones, next a mass of shales of considerable thickness, often amounting to 100 feet, then a second sandstone, 50 or 60 feet in thickness, and then an alternation of sandstones and shales, amounting in all to 300 feet or possibly somewhat more.

The colors of the sandstones are usually gray or buff, but in places they are very red and sometimes portions are perfectly white. The material is quartz sand of varying degrees of fineness. The cementing material is calcareous and varies considerably in amount, portions of the stone being hard and resistant and other portions soft and crumbling. As a rule the rock is very porous and presents most favorable conditions for the storage of underground waters. Some outcrops of sandstone in the head of Medicine Lodge River, in the southeast corner of Kiowa County, are doubtfully referred to the Dakota; they lie directly upon upper members of the Comanche series.

Benton group.—The Benton group consists largely of alternations of shales, limestones, and sandstones, most of the shales being of dark color. The formation extends in a wide belt diagonally across the State from Republic County into Ford and Finney counties, where it passes under the Tertiary deposits, reappearing again along the valley of Arkansas River in Kearney and Hamilton counties. The thickness of the formation is probably somewhat variable, but averages about 400 feet.

The following table gives the components of the Benton group in Kansas, as described in the Kansas geological survey reports, with indications of the formational equivalents:

Table of members of Benton group.

Formations.	Local subdivisions.	Thickness.
		Feet.
Carlile shale	Victoria, or Blue Hill, shales	100
	Ostrea shales	150
Greenhorn limestone	Fence-post horizon	¾
	Inoceramus horizon	40
	Flag horizon	10
	Shales	....
	Lincoln marble	....
Graneros shale	Shales	45

The uppermost formation of the Benton group in Kansas consists almost entirely of shale. Two local divisions are recognized: The upper one, the Victoria, or Blue Hill, consists of loose shales of dark-bluish-gray color, characterized by the occurrence in their upper portion of numerous concretions, a feature which continues throughout the formation in Kansas as well as in adjoining States. These concretions are lens-shaped and vary in size up to 4 or 5 feet in diameter. They are dark colored and consist largely of carbonate of lime, some of them exhibiting cone-in-cone structure. Often they are hollow, or consist of geodes lined with calcite crystals, or are traversed by cracks filled with calcite or other minerals. They frequently contain fossils of typical late Benton forms, including several *Scaphites*, *Prionotropis woolgari*, and *Inocerami*. The upper division is underlain by another series of shales, termed the Ostrea shales in the Kansas reports. These consist of clay or soft shale of dark-blue-gray color, containing occasional thin beds of limestone, and have an average thickness of about 150 feet.

They are underlain by a series of limestones and shales, of which the upper bed is known as the "Fence-post" horizon. This is a sheet of limestone averaging 9 inches thick, which readily splits into masses suitable in size and shape for fence posts and flagstones.

Next beneath is the Inoceramus horizon, consisting of limy shales, including several thin beds of limestone separated by thin beds of shale. The limestone is filled with impressions of *Inoceramus labiatus* (shown in Pl. XXIV), a fossil which occurs also in other medial members of the Benton group, but characterizes the Inoceramus horizon by its great abundance.

The Inoceramos beds are underlain by the "Flagstone" horizon, a member consisting of several layers of limestone, separated by thin beds of shale, having in all a thickness of about 10 feet. The limestone is white or of light cream color, fine grained, and hard, and has been used extensively for flagstones at many places in central Kansas. It is underlain by the Lincoln marble, a more massive bluish-gray limestone about 15 feet thick, which, although hard and flinty, weathers easily.

Underlying the marble horizon there is a series of bituminous shales which have a thickness of 25 to 30 feet in central Kansas, but probably thicken considerably to the west. They are dark, moderately hard, break into thin flakes on weathering, and are regarded as the basal member of the Benton group.

Niobrara formation.—The Niobrara formation underlies a wide region in Kansas west of the ninety-eighth meridian and north of Arkansas River. Its eastern margin lies in a series of slopes rising above the rolling topography of the formations of the Benton group and trending southwest across the State from Jewell County to the northeast corner of Finney County. It is thickly overlain by Tertiary deposits to the west, but some of the larger valleys, notably that of Smoky Hill River, are so deeply cut that they afford extensive exposures of the Niobrara.

The formation consists of a lower series of limestones, which has been termed the "Fort Hays limestone," and an upper series of chalks, which has been designated as the "Pteranodon beds," or "Smoky Hill chalks." The total thickness of the formation is about 350 to 400 feet, of which the Pteranodon beds comprise between 300 and 350 feet. These beds immediately underlie the Pierre shale, but the two formations have not been observed in contact in Kansas owing to the overlap of Tertiary formations. The Pteranodon beds in unweathered condition appear as a massive light-bluish-gray clay, but on weathering usually become yellow or buff, and, in some cases, light red, a change due to the oxidation of the iron contained in the deposits. In well borings the material is a pale-blue chalky clay, not very sticky when wet.

Some rather pure chalk occurs in the formation, notably in the vicinity of Norton in the valley of Prairiedog Creek, where it has been quarried to some extent. The chalk beds present their best exposures in the valley of Smoky Hill River, where they give rise to many prominent buttes and castellated cliffs. A small exposure has been observed northwest of Horace, near the State line. The principal fossils of this series are the *Ostrea congesta*, shown in Pl. XXIV, and the *Inoceramus deformis*. Crystals of gypsum are not uncommon in the weathered beds, and a large amount of pyrites weathers out in nodules in many localities.

The Pteranodon beds are underlain by the Fort Hays limestone, which has an average thickness of 50 feet. It is a soft, massive, light-colored rock, which

weathers out in bluffs of moderate prominence. In well boring it is generally distinctly recognized by its increased hardness over the Pteranodon chalk. Its outcrop extends all along the margin of the Niobrara area from Jewell County to Finney County and up Smoky Hill Valley into Gove County. It is again seen in Hamilton County north of Coolidge and at some other points south of Arkansas River.

The Niobrara formation has been penetrated by numerous wells, which throw light on its position and thickness underground. At Horace, in Greeley County, the deep boring found the top of the formation a short distance below the surface and apparently about 650 feet thick, although a portion of its topmost beds has been removed by erosion.

Pierre shale.—In the northwest corner of Kansas the upper members of the Niobrara formation are overlain by Pierre shale, which is exposed at intervals in the valleys of Republican and Arikaree rivers and their branches in Cheyenne County, notably in the banks of Hackberry Creek, 15 miles south of St. Francis; on Beaver Creek, in Rawlins County; and on Prairiedog Creek, in Norton County. The shale is of dark-grayish-blue color, but weathers to a rusty yellowish-brown tint. The beds are soft and clayey. Lens-shaped concretions of various sizes occur in some of the beds and carry distinctive Pierre fossils.

TERTIARY AND LATER DEPOSITS.

For a discussion of Tertiary deposits see Ogalalla formation, page 178.

Loess.—The loess covers wide areas of the high plains between the valleys in northern Kansas. It is a smooth-surfaced thick mantle, lying on a somewhat irregular surface composed of Tertiary deposits and the several upper Cretaceous formations.

Alluvium.—There are in Kansas many wide valleys which are floored to a greater or less depth with deposits of alluvial materials brought by the streams at various stages of their development. The valley of Arkansas River is the most extensive of these, having a width of 6 to 10 miles and crossing the entire State. All the river and creek valleys contain more or less alluvial material of relatively recent origin, and most slopes are mantled with talus washed from above.

Sand hills.—Fine-blown sand is found mostly in central Kansas and in the valley of Arkansas River from Ford to Great Bend and on the adjoining slopes to the southeast. The sand constitutes hills and ridges of moderate height, with intervening irregular basins and flats. It has been derived from the alluvial flats along the river and blown out by the prevailing winds, of which the stronger are from the northwest.

RÉSUMÉ OF PALEOZOIC AND MESOZOIC GEOLOGY OF THE CENTRAL GREAT PLAINS REGION.

CAMBRIAN.

The Cambrian rocks appear to be the least extensive of the sedimentary formations uplifted along the western margin of the Great Plains, but probably they underlie a considerable area of the plains, especially to the northwest. The small outcrops of upper Cambrian in the Manitou and Canyon embayments in Colorado may be narrow extensions of a wider area to the east, but until some very deep wells are sunk in eastern Colorado and eastward we can have no knowledge on this point. The well at Lincoln, Nebr., is supposed to have penetrated St. Peter sandstone and, in eastern Kansas and western Iowa, upper Cambrian sandstones appear to have been reached. In eastern South Dakota there is no Cambrian, as the Dakota sandstone lies directly on the Sioux quartzite, which is believed to be of Algonkian age. Carboniferous beds lie directly on the old crystalline rocks along the Rocky Mountain front north of the Arkansas divide through Colorado and Wyoming to and possibly including the Casper Range and also in the Hartville uplift. In the Black Hills the Cambrian is thin to the south and gradually increases to 400 feet in the Deadwood region. The fossils are all middle Cambrian.

Deadwood formation.—In their thicker portion the rocks comprise a medial series of shales and thin-bedded limestones, with layers of a very peculiar flat-pebbled limestone conglomerate. This conglomerate is precisely similar to one extensively developed in the Bighorn Mountains and northwest, where it has similar associations and fossils. In the Bighorn uplift the Cambrian beds average about 900 feet in thickness, and comprise, successively, a basal sandstone series, green shales with sandstone layers, shales and limestones with the flat limestone-pebble conglomerate, and, locally, a thin sandstone series at the top; middle Cambrian fossils occur in most of the beds. The entire sequence has been designated the Deadwood formation, because of its resemblance to the Cambrian of the northern Black Hills region; probably it represents the Gallatin limestone and Flathead formation of south-central Montana, but the medial limestone marking the base of the former is absent or too thin to be noticeable.

ORDOVICIAN.

In the Bighorn Mountains, the northern Black Hills, and at a few detached localities along the Rocky Mountain front range the Ordovician rocks appear overlying the Cambrian sandstone. In the Bighorn Mountains they extend continuously around the uplift and are termed the Bighorn limestone. The lower

massive members, which are several hundred feet thick, have a fauna of Trenton age, and the thin, overlying, softer beds carry a Richmond fauna of upper Ordovician age. The upper limits are indefinite, for although there is no transition to the lower Carboniferous limestone, no marked evidence of unconformity has been observed so far. In the Black Hills the Ordovician, which has been designated the Whitewood limestone, appears in the northern portion of the uplift and to a limited extent in the Bear Lodge Range. It carries an upper Trenton fauna, and probably from this fact and from the close lithologic similarity is believed to be equivalent to the lower massive member of the Bighorn limestone. The few feet of green shales which lie above the Whitewood limestone are of undetermined age. No evidence of Ordovician could be detected in the Casper or Laramie ranges, in the Hartville uplift, or in the Rocky Mountain front ranges north of Denver. I feel confident that they are absent in the outcrop zone, although they may have been deposited and removed by pre-Pennsylvanian erosion. The Ordovician rocks which appear in the central portion of the Front Range in Colorado (the Manitou limestone, the Harding sandstone, and the Fremont limestone) contain a Trenton fauna, the Harding sandstone representing the lower Trenton and the Fremont limestone the upper Trenton.

SILURIAN AND DEVONIAN.

No deposits representing these two great periods of geologic time have been discovered in the area to which this report relates. They are certainly absent in the Front Range exposures in Colorado, but may possibly be represented in the green shale of the northern Black Hills and in the zone of apparently nonfossiliferous limestones lying between the Bighorn and Little Horn limestones of the Bighorn uplift. I think, however, that it is much more likely that they are entirely absent along the east side of the Rocky Mountain uplift, although they may underlie a portion of the Great Plains eastward.

LOWER CARBONIFEROUS.

The lower Carboniferous rocks are exposed principally in the Black Hills and in the Bighorn uplifts and in a few small areas that occur along the foot of the Front Range in Colorado. It is probable that they extend widely under the Great Plains, but have been reached by no borings except in east Kansas and southeast Nebraska.

In the Black Hills the Mississippian is represented by two limestone formations, the Englewood and the Pahasapa, each containing an abundance of characteristic fossils, those of the Englewood being equivalent to the lowest Mississippian (Chouteau or Kinderhook) and those of the Pahasapa equivalent to the Madison

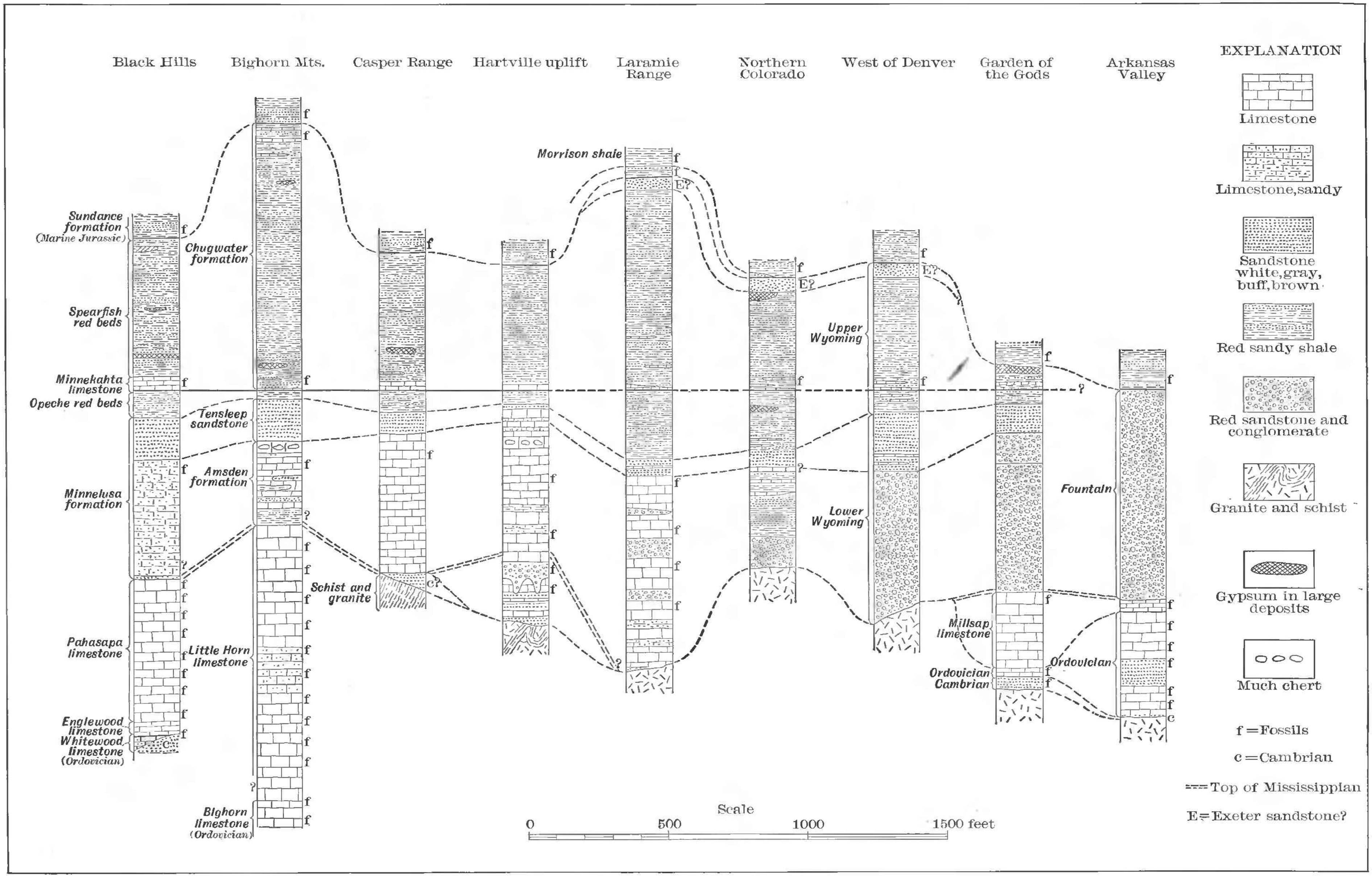
limestone of the Northwest. The *Leperditia* in the concretions in the red shale at the base of the Minnelusa are of a type characteristic of the Mississippian, especially at about the horizon of the St. Louis limestone, indicating that at least the lower part of the Minnelusa is also of Mississippian age; probably it is equivalent to the Hartville limestone. The great limestone series of the Bighorn uplift consists mainly of a representative of the Madison and Pahasapa limestones. Doubtless the Englewood is also included, but the upper limit of rocks of Mississippian age in the uplift has not as yet been ascertained.

Along the Laramie Range the apparent absence of lower Carboniferous is an interesting feature, indicating either nondeposition or removal by the very profound later Carboniferous erosion. A short distance eastward, in the Hartville uplift, the Mississippian comprises the Guernsey formation, which is 150 feet or more in thickness, and the lower members of the Hartville formation, the two being separated by strongly marked erosional unconformity. The basal sediments of the Hartville formation are red sands, and there is strong suggestion that these are of the same age as the red shale at the base of the Minnelusa formation of the Black Hills and at the base of the Amsden formation in the Bighorns. The representative of the lower Carboniferous in Colorado appears in small areas at Perry Park, about Manitou, about Canyon, and southwest of Pueblo, and is known as the Millsap limestone. It lies unconformably on the Cambrian, Ordovician, and pre-Cambrian, and is unconformably overlain by the Fountain formation, or lower Wyoming division, which overlaps directly on the granites and schists in most portions of the region. Its fauna is thought to be of moderately early Mississippian age.

UPPER CARBONIFEROUS AND RED BEDS.

The classification of the formations representing later Carboniferous to Triassic time in this region is one of its most interesting problems. Upper Carboniferous and Permian fossils occur at several localities, but some of the sediments have yielded either no organic remains or only fossils that do not afford satisfactory evidence as to age. The stratigraphy presents much diversity in different portions of the region, but by extended field work it has been found possible to correlate most of the rocks in the various uplifts.

More or less of the Red Beds, especially their upper members, have generally been classed in the Triassic, but there is no definite proof whether a representative of this period is present or not. The fossils which I discovered in 1901 in the upper limestones of the Red Beds on the east slope of the Bighorns are thought to be Permian, but may possibly be Triassic. The fossils of the upper Red Beds of southern Kansas and Oklahoma are regarded as Permian, but the precise relations of these



COLUMNAR SECTIONS OF CARBONIFEROUS AND "RED BEDS."

deposits to the Red Beds of Colorado is not determined. In 1901 I found at Red Rocks in Purgatory Canyon in southern Colorado a fragment of a shoulder bone, which Prof. F. A. Lucas regarded as a portion of a bolodont, an opinion sustained by Dr. E. Fraas. This genus is considered typical of the Triassic.

The lower Red Beds of the Rocky Mountain Front Range, which have yielded no fossils, undoubtedly merge into upper Carboniferous limestones both to the north and the south, and can be correlated with formations in the Bighorn Mountains and Black Hills. According to George I. Adams, whose evidence appears entirely satisfactory, the Red Beds of south-central Kansas and southward merge into the limestone and shales of the Permo-Carboniferous series. It is certain that the Red Beds represent a considerable interval of time, and that the discovery of fossils at one horizon does not settle the age of the whole series.

Throughout the Black Hills, the Bighorns, and much of the region south the upper Carboniferous and Red Bed series presents a general succession as follows, beginning at the top: A thick mass of gypsiferous, red, sandy shales; a thin mass of thin-bedded limestone; a thin mass of red sandy shales; a thick, hard, light-colored, fine-grained sandstone; and, at the base, limestones and sandstones giving place to sandstones and conglomerates, the basal series lying unconformably on Mississippian limestones, on Cambrian, or on old granites and schists. (See columnar sections in Pl. XLII.)

In the Bighorn and Black Hills uplift the assignment of formations to the upper Carboniferous or Pennsylvanian is somewhat provisional. A few fragmentary fossils were observed, but they were hardly determinative. The Minnelusa formation, which succeeds the Pahasapa (lower Carboniferous), is a strongly marked series, supposed from a few fossils that I obtained in its upper beds near Hot Springs to be, in part at least, Pennsylvanian. These fossils were *Productus semireticulatus* and *Seminula subtilita*(?). In the slopes of the Bighorn Mountains there is a series somewhat similar to the Minnelusa beds, which I have designated the Amsden formation and the Tensleep sandstone. The former contains a basal red-shale member, probably representing the thin one which occurs at the base of the Minnelusa formation of the Black Hills, and alternations of limestone and sandstone with much chert, suggesting the lower two-thirds of the Minnelusa formation, but with purer limestone deposits. The lower limestones have so far yielded only some fragmentary indeterminate fossils, but the higher cherty limestones contain Pennsylvanian forms. Next above is the Tensleep sandstone, very like the top sandstone of the Minnelusa in most portions of the Black Hills, and similarly overlain by a great body of Red Beds. It contains Pennsylvanian fossils.

In the Black Hills these Red Beds have three distinct subdivisions, the Opeche formation at the base, 60 to 120 feet thick; the Minnekahta, or "purple limestone," as it was termed by Newton, about 50 feet thick and of very characteristic aspect;

and at the top tne several hundred feet of red sandy shales that I have designated the Spearfish formation. This is succeeded unconformably by the marine Jurassic. In the Minnekahta limestone fossils occur at many localities, comprising forms which are regarded as Permian in age.

In the Bighorn uplift the Red Bed series is slightly thicker, but its character is nearly the same as in the Black Hills; it has been designated the Chugwater formation. The basal Opeche beds appear to be present in this formation, but only 20 feet thick, and succeeded by a few feet only of limestone, probably a representative of the Minnekahta, but unfortunately without fossils, so far as observed. This limestone is succeeded by a thousand feet or more of red sandy shales, believed to represent the Spearfish formation; they are unconformably overlain by marine Jurassic. These Red Beds similarly contain gypsum deposits, but differ from the Black Hills rocks in including several thin beds of limestone near their top. Fossils of several species are abundant in these limestones, but they do not indicate whether the age is Triassic or Permian.

Passing south in Wyoming toward the Laramie Range the lower members of the upper Carboniferous series change considerably, but the Red Beds present the features which characterize them in the Black Hills. The limestones on Casper Mountain and ranges southwest of Douglas are of upper Carboniferous age and seem to represent the Amsden formation of the Bighorn uplift. Locally they lie on a sandstone which is probably Cambrian, but may be younger, and they are separated from the Chugwater red beds by typical Tensleep sandstone. The tripartite subdivision of the Chugwater red beds is established by the occurrence of typical Minnekahta limestone, notably in the big bend of North Platte River 6 miles south of Douglas, and farther down the river in the basin northwest of Hartville. In the Hartville area the Opeche red shales are underlain by the Hartville limestone, which is Pennsylvanian in its upper part and Mississippian at base. The top beds are sandy, suggesting Tensleep sandstone, and the lower beds limestones with cherty and sandstone layers, doubtless representing the Amsden formation of the Bighorns and the Minnelusa of the Black Hills. No special search has been made yet for evidence of unconformity in the Hartville limestone at the top of the Pennsylvanian.

In the Front Range, northwest of Cheyenne, the stratigraphy is somewhat variable. The lower limestones lie directly on the granites and are apparently upper Carboniferous, although no fossils were observed in the lower 100 feet. It has been suggested that the nonfossiliferous basal beds may represent the lower Paleozoic series, but the overlap relations north and south do not sustain this, except that, if the limestones represent all of the Hartville formations of the Hartville region, the lower beds may possibly include rocks of later Mississippian age. The limestone series contains several red-sandstone members, but at the top gives place rapidly to the thick Chugwater red beds. The Tensleep sandstone appears to be represented,

containing thin layers of limestone in its middle, and on Chugwater Creek another layer near its top. Then succeed typical, soft, red sandy shales of the Chugwater formation, which, on Horse Creek, include a 20-foot bed of limestone apparently representing the Minnekahta horizon—a bed not found on Chugwater Creek.

Near the Colorado-Wyoming State line the upper Carboniferous limestones may be seen to merge into red sandstones, apparently by the expansion of included reddish sandy layers observed northwest of Cheyenne and a corresponding thinning of the limestones. A mass of red sandstones and conglomerates, which lies at the base of the limestone for some distance, is seen also to thicken gradually to the south. The product of this change is a great lower series of coarse red beds containing three thin limestone layers, which persist for several miles.

All through northern Colorado the supposed Tensleep sandstone horizon is well marked, and it was traced without difficulty southward to beyond the Garden of the Gods. It is the "creamy sandstone" at the summit of the lower Wyoming of Eldridge, as described in the Denver monograph, and I feel certain that the conspicuous white sandstone ledge lying immediately in front of the gateway to the Garden of the Gods is the upper part of the southern extension of the same bed, so that it is an important horizon marker. Throughout its course in Colorado it marks the transition from the coarse deposits of the lower coarse red beds (lower Wyoming) to the bright-red gypsiferous shales of the Chugwater formation (upper Wyoming), although it is quite sharply demarked from both. It is possible that in the Denver region it comprises more of the upper Carboniferous column than is included in the topmost sandstone northwest of Laporte, for the two thin beds of limestone which it contains west of Denver suggest that it comprises the extension of the thin limestones underlying the supposed Tensleep sandstone northwest of Laporte.

The thick mass of red-sandstone sediments of the lower Wyoming division is believed to represent upper Carboniferous only, but as it includes also an expansion of shore deposits lying beneath the limestones near the Colorado-Wyoming State line, it may possibly comprise older rocks, though this is very doubtful. These lower Wyoming beds, in their southern extension into Perry Park, lie unconformably on fossiliferous limestones of Mississippian age, and a similar relation exists in the region west of Colorado Springs and at intervals southward. The presence of the unconformity between the Guernsey and Hartville formations in the Hartville region and its possible extension in the Black Hills and the Bighorns suggest that the same unconformity may extend south to, and along, the Laramie and the Rocky Mountain fronts, especially at the top of the Millsap limestone. In this case the lower Wyoming red beds would comprise some sediments of late Mississippian age.

The name "Fountain formation" has been used to comprise all of the red beds in the region northeast of Canyon and southwest of Pueblo, and if, as I believe, the Chugwater (upper Wyoming) formation thins out a short distance south of the Garden of the Gods, the Fountain formation corresponds in the main to the lower Wyoming, and is the product of similar conditions at the same geologic epoch. I do not see the slightest reason for supposing that the two formations are not equivalent. The character of the beds northwest of Pueblo and in the Garden of the Gods region is precisely the same as in the district west and north of Denver, and although I made special search I could find no evidence of overlaps or unconformities of any kind within the great uniform mass of red grit deposits.

The upper and the lower Wyoming are very distinct from each other from the Garden of the Gods north to the State line, as recognized by the geologists of the Hayden survey and clearly set forth in the Denver monograph, where the terms "lower Wyoming" and "upper Wyoming" were introduced. The upper Wyoming consists mainly of fine-grained sediments extending from the "creamy sandstone," which I believe to be the equivalent of the Tensleep, to the base of the Morrison formation. It consists mainly of bright-red shales, always with a thin limestone layer or series toward its base, and from Platte Canyon northward with a massive pinkish sandstone at its top. The included limestone is believed to represent the Minnekahta horizon of the Black Hills and other regions, indicating a short but widespread interval of limestone deposition at this epoch in the West. The few fossils found in this limestone unfortunately do not settle its age, but there appears to be but little doubt that its representative in the Black Hills is Permian. The overlying red shales, with gypsum, in northern Colorado may be Permian or Triassic, for the fossils in the limestones which occur near the top of the extension of this series into the Bighorn uplift do not indicate whether the beds are Paleozoic or Mesozoic.

The Chugwater formation (upper Wyoming red beds) is only 140 feet thick at the Garden of the Gods and appears to thin out and disappear a few miles south, bringing the Fountain fromation into contact with the Morrison, a relation due either to nondeposition of the Chugwater beds or to their removal by erosion in pre-Morrison times. As it is, the hiatus probably represents part of the later Carboniferous, the Permian, the Triassic, and all of the Jurassic periods. South of Arkansas River some of the Chugwater beds probably appear again, although at present their identity is not established.

The Badito formation of Hills appears to be simply the Fountain formation of Cross and Gilbert. The Sangre de Cristo formation to which Hills refers in the Walsenburg folio appears to represent a great development of Fountain (or lower Wyoming) deposits. It is stated that remains of an upper Carboniferous fauna and

flora occur in this formation, which is added evidence as to the age of the lower Red Beds (Fountain-lower Wyoming) series. These beds overlie or merge into the basal limestone series on the eastern slopes of the Sangre de Cristo (Culebra) Range, in which Mr. Willis T. Lee has discovered an extensive upper Carboniferous (Pennsylvanian) fauna.

The Red Beds revealed in the canyons of southeastern Colorado can not be classified with certainty from the present evidence. On Purgatory River and Muddy Creek the principal body of Red Beds is separated from the Morrison formation by gypsum or gypsiferous shales, strongly suggestive of the Chugwater (upper Wyoming) formation. It was immediately under this gypsum in Purgatory Canyon that I found the shoulder bone of a supposed Bolodont. Mr. Willis T. Lee has traced the Red Beds farther south into northeast New Mexico, where the gypsiferous horizon gives place to a massive sandstone, termed the Exeter sandstone, constituting the summit of the Red Beds, a member which may represent the distinctive top sandstone of the Chugwater formation in northern Colorado and in southern Wyoming. This sandstone is prominent in the Two Buttes uplift, constituting the summit of the Red Beds, and is underlain by red shales, which contain a thin bed of limestone, noted by Mr. Gilbert, strikingly like the Minnekahta horizon. I have not made observations on the Red Beds in Kansas and do not feel that a comparison of the published statements with my observations in the region north and west would aid in the correlation.

JURASSIC.

Sundance formation.—The Jurassic appears to exist only in the northwest portion of the region to which this report relates, apparently owing to nondeposition in other portions of the region. In the Bighorn Mountains and in the Black Hills it is represented by 300 to 400 feet of deposits, but thins gradually to the south in the Laramie Range and disappears in the northern portion of Colorado. The thinning appears to be general and the upper beds probably disappear first, but this point has not been definitely determined, and it may be that the upper shales merge into sandy beds, which thin out gradually together with the underlying sandstones.

The formation is evidently of marine origin, as indicated by its numerous molluscan remains, and its age is regarded as late Jurassic. It has not been divided into subordinate members, but in its regular succession presents a general order of beds and faunas which are constant over a wide area, especially as to the sandstone near the base and the green shales above, containing numerous *Belemnites densus*. It is probable that the Sundance formation does not extend far east of the Black Hills nor southeast of the locality at which it disappears in surface outcrops in northern Colorado, but there is no direct evidence on this question.

Unkpapa sandstone.—This sandstone, which succeeds the Sundance along the eastern side of the Black Hills, is relatively a local feature of unknown age. It appears to represent a local shore deposit of late Jurassic times laid down prior to the deposition of the Morrison beds. The horizon may possibly be represented in portions of the uplift by the almost general occurrence of the yellowish sandy bed at the top of the Sundance formation, although where it appears to be absent there may be a small unconformity or hiatus. There is always a very abrupt change from the Sundance to the Morrison sediments, but no direct evidence of unconformity has ever been found.

CRETACEOUS.

Morrison formation.—As the western portion of the Great Plains is explored it is found that the Morrison formation is very extensive in its distribution. It outcrops nearly all the way around the Black Hills uplift, extends along both sides of the Bighorn Mountains, appears extensively in the Hartville uplift, and is traceable along Laramie Range into Colorado and far south into New Mexico. Mr. Willis T. Lee has found that it extends east in the canyons of southern Colorado and down Cimarron River, where, near the Oklahoma-New Mexico line, it either merges into the upper formations of the Comanche series or occupies the same horizon relative to the adjoining beds. I have recently found a similar relationship on the eastern side of the Two Butte uplift in the southeast corner of Colorado.

The character of the formation is strikingly uniform throughout, consisting mainly of a mixture of clay and fine sand having a massive structure like joint clay, mainly gray or pale-greenish-gray in color, with portions which are purple, maroon, or chocolate. Beds of fine-grained light-colored sandstones also occur, and in many districts, especially in the lower portion of the formation, thin beds of limestone appear, in which I have lately discovered remains of fresh-water algæ at various horizons. In both the clays and sandstones saurian remains occur, sometimes in large quantities. They have been collected extensively near Canyon and on the east side of the Black Hills. I have recently observed them along the eastern foothills of the Bighorn ranges and along both sides of the Bighorn basin as well.

The extent of the formation to the east and especially to the northeast is not known. Probably it would be found in deep borings for some distance east of the Black Hills, but not in the east part of South Dakota nor in Nebraska nor Kansas.

Comanche series.—I have made no special examination of the marine deposits representing the upper part of the Comanche series in the south Kansas region. In their western extension, as stated above, they are apparently represented in whole or part by the Morrison beds, which, to the north, end against the margin of a basin. If equivalent to the Morrison these upper Comanche beds are older than

the Lakota of the Black Hills and Bighorn uplifts, which is contrary to the opinion of some paleobotanists that the Fuson-Lakota flora is older than the flora that occurs in Texas in one of the medial members of the Comanche series. In this case, owing to the great difference in latitude and the consequent probable difference in climate, I think that the criteria of a few fossil plants are open to question.

Dakota-Lakota formations.—In 1893 Prof. Lester Ward discovered that the so-called Dakota sandstone of the Black Hills contained not only a Dakota flora, but in its lower beds an extensive flora of later Cretaceous age. As the Dakota sandstone in its type region is characterized by a distinct upper Cretaceous flora, it became necessary to restrict the term "Dakota" in the Black Hills to the upper sandstone carrying the upper Cretaceous plants. In investigating the stratigraphy of the uplift it was found that the upper sandstone is separated from the lower sandstone, which was designated the Lakota sandstones, by a persistent body of shale which has been designated the Fuson formation. In tracing these formations northward it was found that the principal plant-bearing horizon in the northern Black Hills was in the Fuson formation, which has yielded a large and beautiful flora of lower Cretaceous plants, which Professor Ward has described. The tripartite composition of the old "Dakota" group in the Black Hills is very distinct throughout the uplift and apparently is a widespread feature in adjoining regions.

Along the eastern base of the Bighorn Range there is a sandstone which appears to represent the Lakota overlain by typical clays of the Fuson, but the Dakota sandstone does not appear, unless it is represented by some sandy layers among the shales in the base of the next succeeding formation. This same relation is found on the west side of Bighorn Range and appears to extend far south in Wyoming.

In tracing the beds through southern Wyoming the outcrops of this horizon are so discontinuous, owing to the overlaps of Tertiary deposits, that the stratigraphic conditions could not be definitely ascertained. Southeast of Casper is found some suggestion of the regular succession of Lakota, Fuson, and Dakota, appearing at intervals to the south, although at some points there is only one sandstone, which, so far as its character goes, might belong to either member.

In Colorado there are usually two sandstones separated by a bed of fire clay, which strongly suggest the Dakota-Fuson-Lakota succession, but it has been supposed that all the rocks are of Dakota age. The intercalated fire-clay series extends far south through Colorado and east in the exposures of the Purgatory and other canyons.

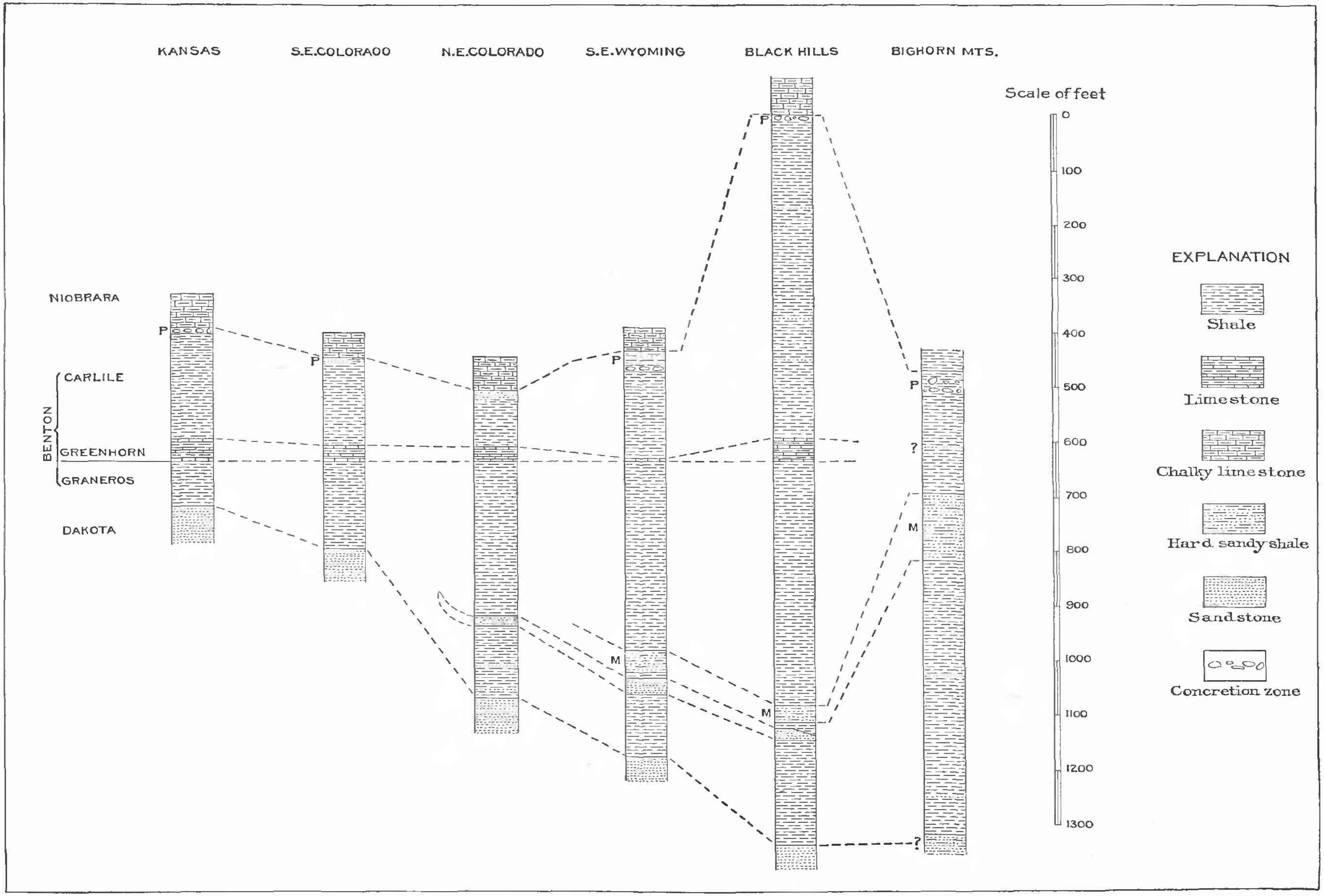
Throughout Colorado and eastern Wyoming, as in the region northward, the sandstones are underlain by the Morrison formation, excepting at a very few localities, and, although there is general unconformity, it is difficult to believe

that this represents Lakota and Fuson time. The Morrison materials are soft and, if they had been exposed to erosion for such a long period, would undoubtedly have suffered deep and widespread degradation. It is unlikely also that the Lakota and Fuson could have been deposited in regular order and then so completely and evenly removed as to leave the Morrison overlying sandstones in their present uniform stratigraphic relations. A discovery very significant in this connection has been made by J. B. Hatcher—that dinosaur remains of Morrison type occur in the lower members of the overlying "Dakota" sandstone beds north of Canyon, which indicates that there could have been no great time break at this horizon. For these reasons it is probable that the Lakota-Fuson-Dakota series extends south through Wyoming and Colorado, and that careful search in the medial fire clays and lower sandstones may yield lower Cretaceous plants.

Benton group.—The rocks of this group are the most widespread and constant in characteristics of all the sedimentary deposits of the Central Plains region, their salient feature being a thick succession of shales overlying the Dakota sandstone. They present, however, persistent subdivisions or horizons of variation. The thickness is variable, ranging from about 400 feet in the southeast to 1,600 feet in the Black Hills.

In nearly all the half-million square miles under consideration the group comprises three members—a basal, dark-shale series known as the Graneros shales, a medial limestone known as the Greenhorn limestone, and an upper shale series with sandy layers known as the Carlile formation. Toward its base the Graneros shale includes a horizon marked by local deposits of sandstone; the Greenhorn limestone always presents alternations of slabby limestone and shales; the Carlile formation generally has a sandstone bed at or near its top, not far below which concretions usually occur. The Greenhorn limestone is characterized by great colonies of *Inoceramus labiatus*, a species rarely found at all in other horizons; the upper portion of the Carlile contains *Prionotropis woolgari*, which appear to be restricted to that horizon and to characterize it throughout the region and even in the Bighorn basin. Throughout east Wyoming and the Black Hills region the middle part of the Graneros shales includes, not far above the local sandstone horizon, a series of hard gray shales and fine-grained thin-bedded sandstones filled with fish scales, which weather light gray and from their hardness often give rise to a ridge or cliff. These have been termed the Mowrie beds and are conspicuous along both sides of the Bighorn uplift, all around the Black Hills, and along the Laramie Front Range to the Colorado line.

In Pl. XLIII sections are given showing the principal stratigraphic features of the Benton group in different districts. As these sections are drawn on a large scale, the variations in thickness are very striking, especially between the 400 feet



SECTIONS ILLUSTRATING VARIATIONS IN STRATIGRAPHY OF BENTON GROUP.

in Kansas and the 1,300 feet which is the average thickness in the Black Hills region. The salient feature in the Kansas section is the Greenhorn limestone, comprising several layers having, in all, a thickness of 60 feet, 40 feet of which near the middle are characterized by large numbers of the typical *Inoceramus labiatus*. The Kansas geologists have included about 50 feet of the basal shales in the top of the Dakota, but the reasons for this inclusion are not convincing, and I should be inclined to regard these saliferous and gypsiferous shales as comprising the lower portion of the Graneros.

The three subdivisions are readily distinguishable throughout eastern Colorado, where the formation gradually increases in thickness, mainly by the expansion of the lower beds. In this region also there first appears near the base of the Graneros formation, a bed of sandstone which varies greatly in thickness from 50 to 15 feet, often giving rise to a conspicuous subordinate hogback ridge lying east of the main Dakota hogback, or on its slope.

In southeast Wyoming a further increase of thickness is exhibited, but the Greenhorn limestone finally becomes thin and discontinuous on approaching the end of the Laramie Range, and is not recognizable at all in the sections along the Bighorn uplift. It is, however, a conspicuous feature in the slopes adjoining the Black Hills, extending entirely around that uplift and often attaining a thickness of 50 feet. The sandstone in the lower portion of the Graneros seems to extend almost continuously through southeast Wyoming, and appears at intervals around the Black Hills, notably at Newcastle, Hermosa, and the north end of the uplift, but does not appear in the Bighorns unless possibly at one locality.

The Mowrie beds, consisting of hard shales and thin sandstones with fish scales, weathering light gray, appear first in southeast Wyoming, whence they are a conspicuous feature north at a horizon a short distance above that of the sandstone in the lower part of the Graneros, and attain their greatest prominence along the Bighorns and around the Black Hills.

The Carlile formation does not vary greatly in thickness through Colorado and southern Wyoming, but expands greatly in the Black Hills to over 500 feet in most parts of the uplift. It is not, however, characterized in the Bighorn uplift, though doubtless represented in the gray shales lying not far above the Mowrie beds. Owing to the absence of the Greenhorn limestone in this area, the lower limit of Carlile sediments is not indicated, but its upper portion is characterized by a zone of sandy concretions containing *Prionotropis* and *Prionocyclas*, a horizon characteristic of the proximity of the upper limit of the group throughout its course. The top of the Carlile formation is usually marked by sandy sediments, and a top sandstone is a prominent feature in eastern South Dakota, through Colorado, and in southeastern Wyoming. Around the Black Hills and in Kansas the place of this top sandstone

is taken by numerous concretions, which also occur under the sandstone in some other districts. In a portion of Arkansas Valley the upper sandstone of the Carlile formation is often replaced by a thin bed of purplish limestone carrying *Prionocyclus*.

The Benton group in eastern South Dakota comprises a thin mass of Graneros black shales, Greenhorn limestone apparently associated with some chalkstone, and a considerable thickness of Carlile shales containing, at or near the top, concretions and a nearly general bed of sandstone from 15 to 50 feet thick and in places considerably thicker. As elsewhere, *Prionotropis* occurs in the concretions.

Niobrara formation.—This deposit occupies a wide area in the central Great Plains region, succeeding the Carlile without suggestion of unconformity and, except in the vicinity of the Bighorn Mountains, consisting largely of carbonate of lime. Its thickness varies considerably from apparently less than 100 feet in some portions of eastern South Dakota to 700 feet in central-southeast Colorado.

At the type locality on Missouri River at the mouth of the Niobrara the formation is represented by a chalk rock having a thickness of about 200 feet. In southern Nebraska and Kansas, where it appears extensively, the amount is considerably greater, 350 feet being the estimate of the Kansas geologists. The formation usually presents purer and harder carbonate of lime deposits near its base, constituting the Fort Hays limestone in Kansas and the Timpas formation in Colorado. The characteristic fossil of this horizon is the *Inoceramus deformis*, which is a conspicuous feature in Colorado and for some distance north into Wyoming.

Along the foot of the Rocky Mountain and the Laramie Front Range the formation usually presents three limestone layers, a lower massive bed and two upper layers, separated by limy shales, the uppermost overlain by impure limestones, which weather to a bright-yellow color and always contain flat masses of limestone consisting of colonies of *Ostrea congesta*. The formation thins to the north in Colorado and Wyoming, becoming about 400 feet thick northwest of Cheyenne, and about 200 feet on the slopes of the Black Hills. The bright-yellow color of the weathered beds is a conspicuous feature. The point farthest west at which the formation was noted is southwest of Casper. It is not characterized along the slopes of the Bighorn Mountains, although doubtless it is there represented by some gray shales not distinguishable from those of the adjoining formations, for there is no suggestion of hiatus in the sedimentary series.

Pierre shale.—The great shale series of the Pierre formation occupies a vast area in the central Great Plains and was probably originally of even greater extent, for it appears to have been removed by erosion in the mountain uplifts, in eastern Nebraska, and in southern and eastern Kansas. No special investigation has been made of the Pierre stratigraphy, and, although the beds seem to be uniform in composition, probably a careful study of the distribution of its numerous fossils would

show widespread stages. One of these is the upper horizon of concretions with *Lucina occidentalis*, giving rise to "tepee buttes," which appears to extend from Arkansas Valley through Colorado to and all around the Black Hills. In places along the western margin of the area great variations in thickness are presented, the shales becoming thicker and local sandstone beds being included. West of Denver the formation appears to have a thickness of over 7,700 feet, and of considerably over 3,000 feet at Florence and near Boulder.

Fox Hills formation.—The Fox Hills formation appears to be present everywhere between the Pierre and the Laramie, merging into both formations and constituting beds of passage between them. In some districts the Fox Hills beds begin abruptly with a sudden change from the dark shales of the Pierre to sandstones or sandy shales of the Fox Hills containing some distinctive species. It is probable that this change does not take place at the same horizon throughout, and the Fox Hills fauna appears in connection with the sandy sediments.

Usually the Fox Hills deposits are less than 300 feet thick, but, in the Denver region, where they comprise a thick mass of sandy clays in their lower portion, they attain a thickness of a thousand feet. The top member in this region is a persistent, characteristic sandstone, 50 feet thick, which appears to be the same as the Trinidad sandstone in the Spanish Peaks district in south Colorado. The top of the Fox Hills formation is not always clearly definable, and, in most cases, can only be placed arbitrarily at the horizon where the first deposits of evident freshwater origin appear.

Laramie formation.—This great formation received no special study in the present investigation, and has been separated from the adjoining formations only in a few localities. The work of Cross in the Denver basin and of Hills in the Spanish Peaks region has shown that it is of less thickness than originally supposed, and that the great mass of coarse sediments overlying it are of early Tertiary age. The thickness of the formation, as thus delimited, averages about a thousand feet in the Denver region and nearly twice as much in southern Colorado.

LATER TERTIARY FORMATIONS OF THE CENTRAL GREAT PLAINS.

GENERAL RELATIONS.

A large portion of the central Great Plains is covered by deposits of Miocene and Pliocene ages, underlain to the west and northwest by formations of the White River group of Oligocene age. All these formations lie mainly on the Pierre shale, but overlap other formations to a greater or less extent. The average thickness is 200 to 300 feet in east Colorado and west Kansas, but increases to nearly a thousand feet in portions of west Nebraska and southeast Wyoming. It is probable that originally the entire region was covered with later Tertiary deposits that extended far up the flanks of the Rocky Mountains, the Bighorn

Mountains, and the Black Hills, as indicated by the occurrence of outliers at high altitudes, but a vast amount of the formations have been removed from the higher lands and in the region of glaciation eastward. The formations have not received systematic study as a whole, but they have been investigated at various localities and some of their general relations ascertained. On the geologic maps heretofore they have all been grouped together and their distribution shown in a most general way. On the map, Pl. XXXV, there is represented for the first time the distribution of the White River group, and, although many minor details of boundaries have not yet been accurately mapped, the outlines as shown are approximately correct. The most doubtful feature is as to the eastern margin of the later Tertiary area across eastern Nebraska, and data are not yet available for separating the Pliocene deposits from the Oligocene deposits in the Monument Creek area, south of Denver. The Miocene and Pliocene deposits comprise several formations, but as these have not been differentiated throughout the area they are not separately shown on the map.

White River group.—Early in the study of Great Plains geology the Tertiary formations were divided into the White River group below and the Loup Fork above. This distinction is a clearly recognizable one, although, as now well known, there were confused under the name of Loup Fork a number of separate formations ranging in age from Miocene to early Pleistocene.

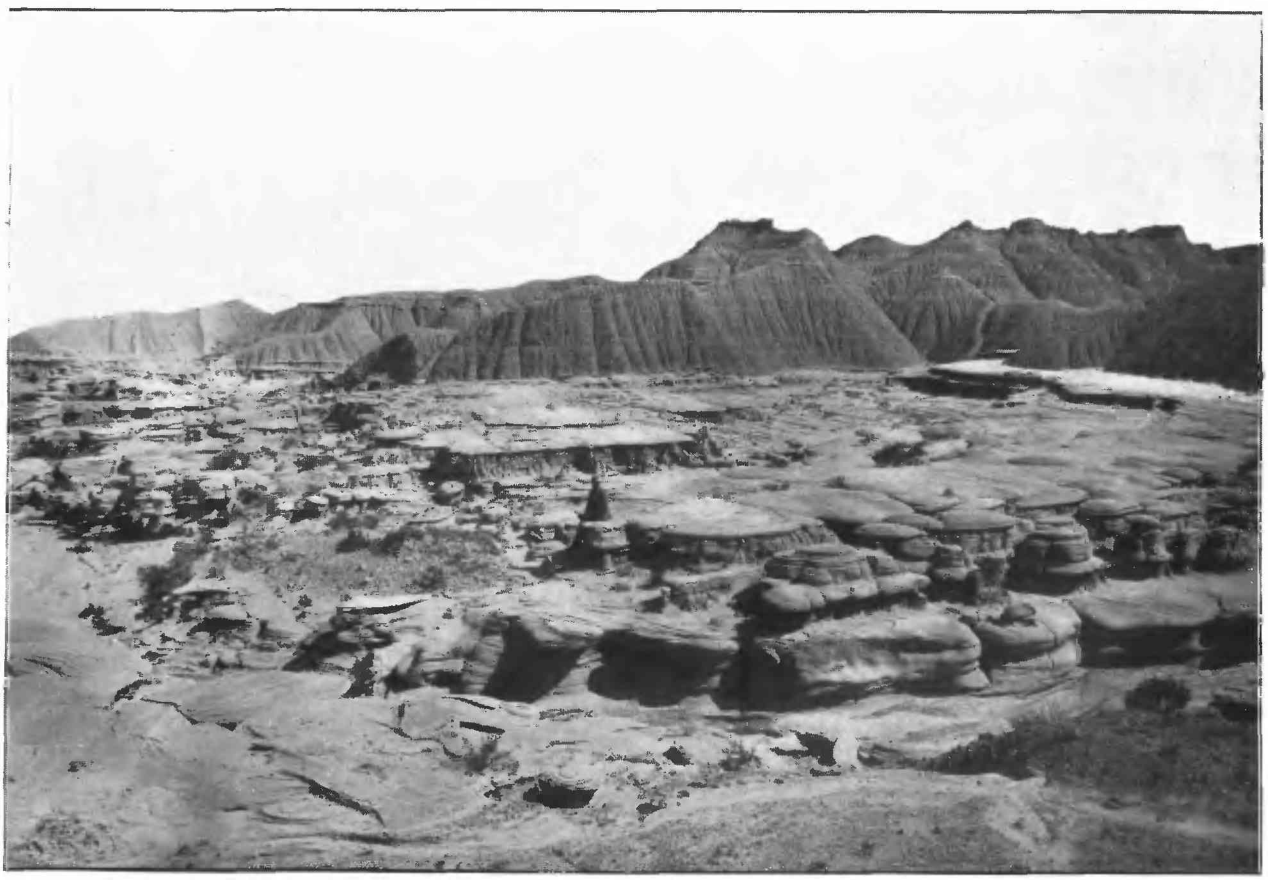
The White River group has been studied mainly in the Big Badlands, lying southeast of the Black Hills, where three principal subdivisions were defined, the the lower one as the Titanotherium beds, the middle as the Oreodon beds, and the upper as a series consisting of the Protoceras sandstone and some overlying clays. This classification is distinctly set forth by Doctor Wortman.[a] In the Oreodon clays there is often a marked sandstone horizon known as the Metamynodon beds.

In mapping the geology of western Nebraska, in 1897, I had need to subdivide the formations in the valley of Platte River and Pine Ridge, where I found that the White River group consisted of the usual basal series, the Titanotherium beds, which I designated the Chadron formation, and the usual overlying series of flesh-colored, sandy clays, the Oreodon beds, to which the name Brule clays was applied. These clays were locally overlain by sandstones which appear to belong to the Miocene rather than the Oligocene and are almost certainly higher stratigraphically than the Protoceras sandstone and overlying beds in the Big Badlands. A reconnaissance in the high region lying south of White River in the Pine Ridge Reservation brought out the fact that the Protoceras horizon was overlain by several hundred feet of clays and sandstones, which, when traced along the Pine Ridge front, appeared to

[a] Wortman, J. L., On the divisions of the White River or lower Miocene of Dakota: Bull. Am. Mus. Nat. Hist., vol. 5, 1893, pp. 95–105.

A. BIG BADLANDS, SOUTH DAKOTA. EAST OF FLOUR TRAIL.

Characteristic rounded forms of Chadron clays, overlain by Brule clay (Oredon beds) in distance; remnants of plateau out of which badlands were carved in foreground and in outlying buttes. Looking east.



B. "TOADSTOOL PARK," IN BADLANDS WEST OF ADELIA, NORTHERN SIOUX COUNTY, NEBR.

Sandstones overlain by Brule clays.

merge into the typical Brule clay. It may be, however, that to the south this upper horizon either never was deposited or has since been removed by erosion.

A typical section of the Oligocene deposits in Scotts Bluff is given in fig. 4, and another at Round Top, west of Adelia station, 75 miles north of Scotts Bluff, is given in fig. 5. In Pine Ridge and the divides southward to the valley of North Platte River the Oligocene deposits are deeply buried beneath the Arikaree forma-

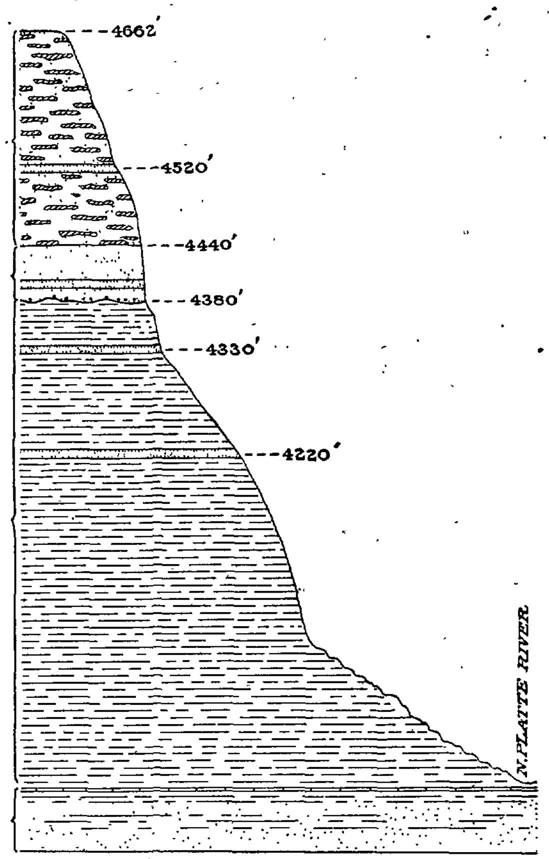


FIG. 4.—Columnar section of Oligocene and Miocene formations in Scotts Bluff and vicinity, Nebraska.

tion. North Platte River has removed this formation for many miles, and in this valley the Oligocene beds are exposed in their entire thickness near the Nebraska-Wyoming State line.

The Chadron formation appears extensively in Goshen Hole, where it is exposed lying on the Laramie sandstones, and extends down Platte Valley into Nebraska nearly to Scotts Bluff. The predominant materials are sandy clays and greenish-gray sandstones, mostly of soft texture, in which characteristic Titanotherium remains are of frequent occurrence. The upper limit to the formation is

placed arbitrarily just below some pink clays lying below a thin bed of limestone, which is believed to be at the same horizon as one in the Big Badlands, where it immediately overlies the last of the beds of Chadron character. The thickness of the formation appears to be about 200 feet at most, but, as it lies on a very uneven surface, the amount varies greatly. The sandstones, which occur at various horizons, appear to lie in narrow belts, doubtless indicating channels of deposition.

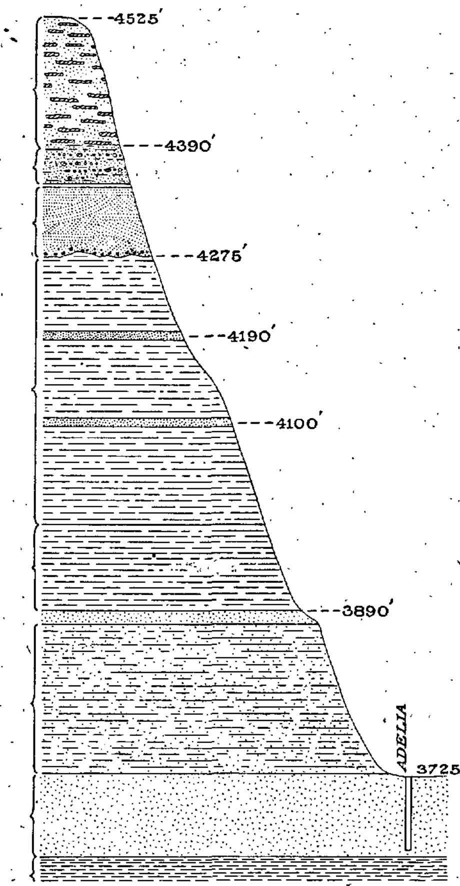
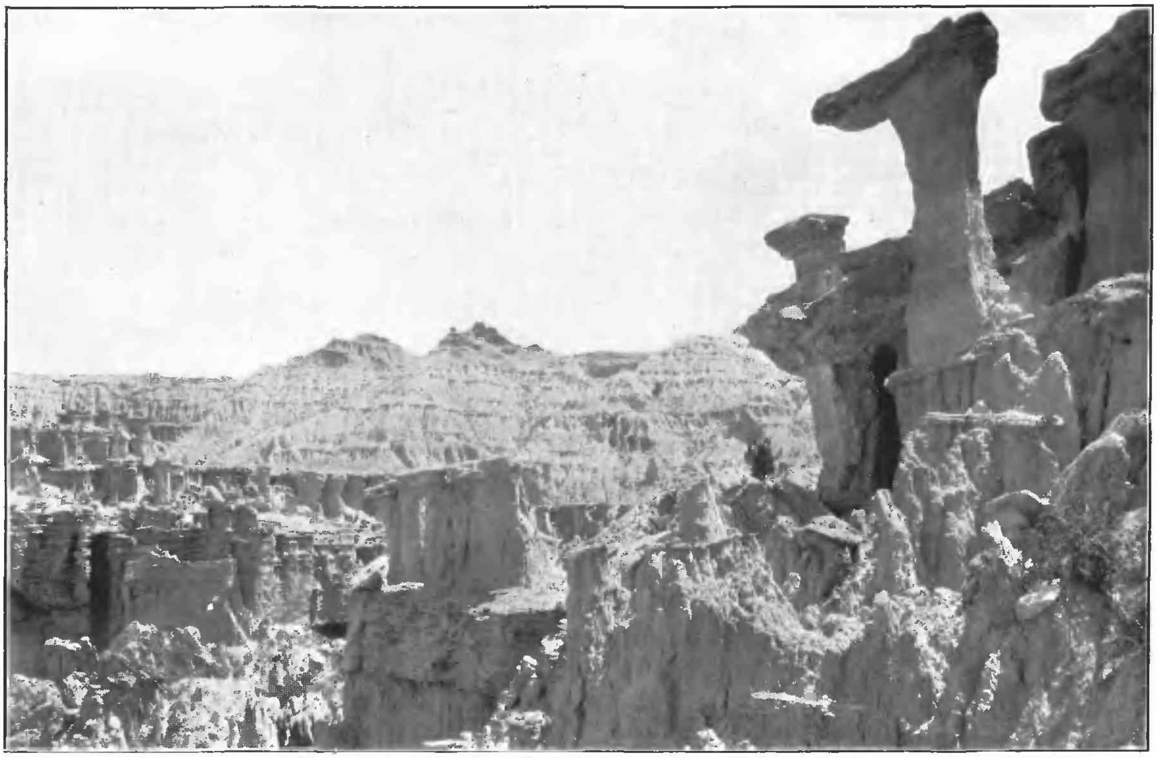


FIG. 5.—Columnar section of Oligocene and Miocene formations between Adelia and Round Top, Sioux County, Nebr.

The lineal character of some of these channels is very distinctly exposed in the western portion of Goshen Hole.

In Platte Valley the Brule clay consists mainly of a hard sandy clay of pale-pink color and massive structure, having near the base a thin layer of limestone. Locally some portions are sandy and contain beds of sandstone. Extensive exposures of Brule clay occur in the northern face of Scotts Bluff, where from the base of the overlying Gering beds to the surface of the river there is a vertical interval of 500 feet continuous outcrop. The formation also has a small



A

B

HEAD OF COTTONWOOD DRAW, IN CENTER OF BIG BADLANDS OF SOUTH DAKOTA.

A. Protoceras sandstone underlying Leptauchenia clays; showing alternations of sandstones and clays, extreme development of badlands and typical nodule-bearing clays in upper clay series. *B*. Protoceras sandstone overlying Oredon clay; layers of sandstone mark courses of currents interrupting clay deposition at irregular intervals.

additional thickness below the level of the river. The appearance of this exposure is shown in Pls. IX and XLVII. The badlands topography is a characteristic feature of most exposures of the Brule clay, and is extensively developed in the area at the foot of Scotts Bluff. The massive structure of the formation gives it the necessary solidity to preserve details of configuration, its softness permits ready carving by the rain and rivulets, and the slight variation in the hardness of its beds gives rise to unequal slopes. The basal portion of the formation generally includes a thin bed of limestone, and at various horizons there are occasional irregular lens-shaped masses of sandstone. The greatest development of the limestone is seen near Caldwell, near Sunflower, south of Gering, and northwest of Larissa. It is a very thin bed of compact cream-colored rock lying on a series of pinkish and greenish clays which are regarded as the base of the formation.

Beds of volcanic ash occur in the Brule clay, some of them of wide extent and apparently at constant horizons. One bed, conspicuous in many outcrops lies at 60 to 70 feet below the top of the formation in the district south and southeast of Gering. It is about 150 feet below the top at Scotts Bluff, a position which it holds for some distance to the west. Another higher bed often occurs. Fossil bones of various mammals and turtles characteristic of the Oreodon fauna of the Oligocene occur in the Brule clay. The principal forms collected in North Platte Valley in the Scotts Bluff region, as determined by Prof. F. A. Lucas, of the National Museum, and in part by Dr. W. B. Scott, are: *Oreodon gracilis*, *O. culbertsonii*, *Palæolagus haydeni*, *Cynodictus gregarius*, *Pœbrotherium wilsoni*, *Elotherium mortoni*, *Hyracodon nebrascensis*, *Leptomeryx evansi*, *Mesohippus bairdi*, *Aceratherium occidentale*, *Stylemys*, and *Testudo*.

As before stated, the top of the formation is 500 feet above the river at Scotts Bluff. Its surface drops gradually to the west and more rapidly to the east, and appears to sink beneath the bottom of the valley a short distance east of longitude 102°. The upper portion of the formation again appears in Lodgepole Valley from near the State line to its mouth.

Along the northern margin of Colorado the White River beds appear in the lower slopes of the high cliffs from a point south of Cheyenne nearly to Julesburg, presenting extensive exposures in the Chalk Cliffs and at intervals eastward, notably on the headwaters of Horsehead Creek, as shown in Pl. LIV. They lie on the Laramie sandstones throughout and are overlain by the Arikaree formation, which caps the high plains in the divide between the Platte and the Lodgepole. The usual succession is presented of Titanotherium beds (Chadron formation) at the base, and the flesh-colored, massive, sandy Brule clays above. These clays are constant in character throughout, but the Chadron formation varies greatly, in some places

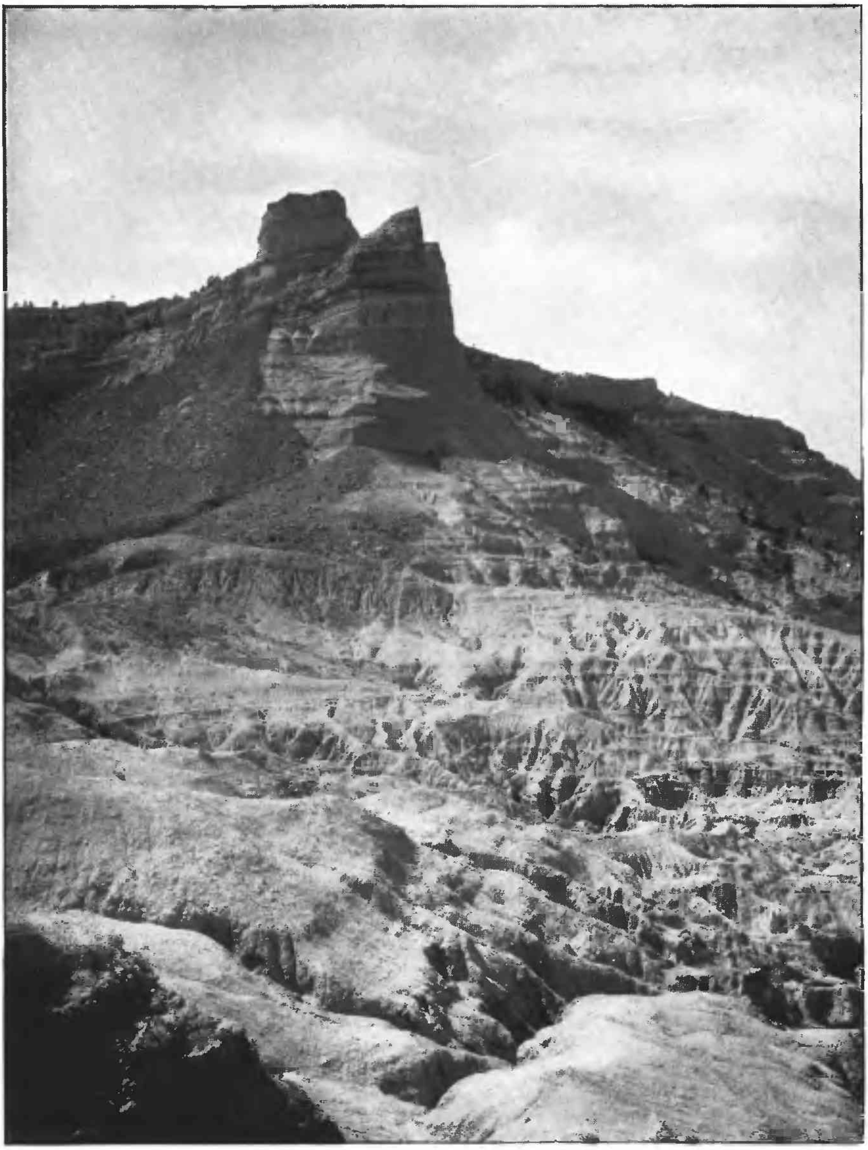
being a greenish-gray sandy clay and in others a very coarse hard sandstone, usually containing large numbers of fragments of Titanotherium bones and teeth. In Pl. LIV are shown two prominent exposures of typical Brule clays with characteristic erosion forms.

Mr. W. D. Matthew[a] has described the succession in the region north of the Pawnee Buttes. He writes: "The lower part of the White River formation, the Titanotherium beds, * * * consists of hard, white, or grayish-white clays with considerable horizontal cleavage and containing some layers of sandstones, apparently of limited extent." This formation he designates the Horsetail Creek beds. It is stated that the fauna is a scanty one, but several species of *Titanotherium* and also *Elotherium* were collected. The overlying beds, designated the "Cedar Creek and Martin Canyon beds," are described as fine, light-colored, pinkish or buff-colored clays, much softer than the Titanotherium beds "and becoming progressively softer toward the top of the formation. No horizontal cleavage or fine lamination is discernible in these beds, but from a distance the horizontal color bands are sometimes marked and very uniform. They do not, however, present any wide variations in color. The fauna is large and varied. The upper part of the formation is separated on account of the difference in fauna, but no stratigraphic demarcation can be made out, the beds becoming gradually finer and softer as we ascend, but retaining all their characters to the top." Some thin local layers of sandstone were noted lying unconformably on the clays and filling little erosion valleys cut by streams during the deposition of the formation. The total thickness of the White River beds in this area is stated to be 300 feet.

The Titanotherium beds (Chadron formation) and part of the overlying Brule clays occur under the Ogalalla beds on the south side of North Platte River and are traceable southward through Washington and part of Adams counties. Their precise southern termination was not located. There are extensive exposures about Fremont Butte just west of Akron, where sandstones in the Chadron formation contain abundant titanotherium and elotherium remains. As suggested by Cope many years ago, the Monument Creek formation appears to belong to the White River beds. Together with its beds of sandstone, it includes clays of characteristic Chadron and Brule character, from which have been obtained a few fragments of bones of Oligocene age.

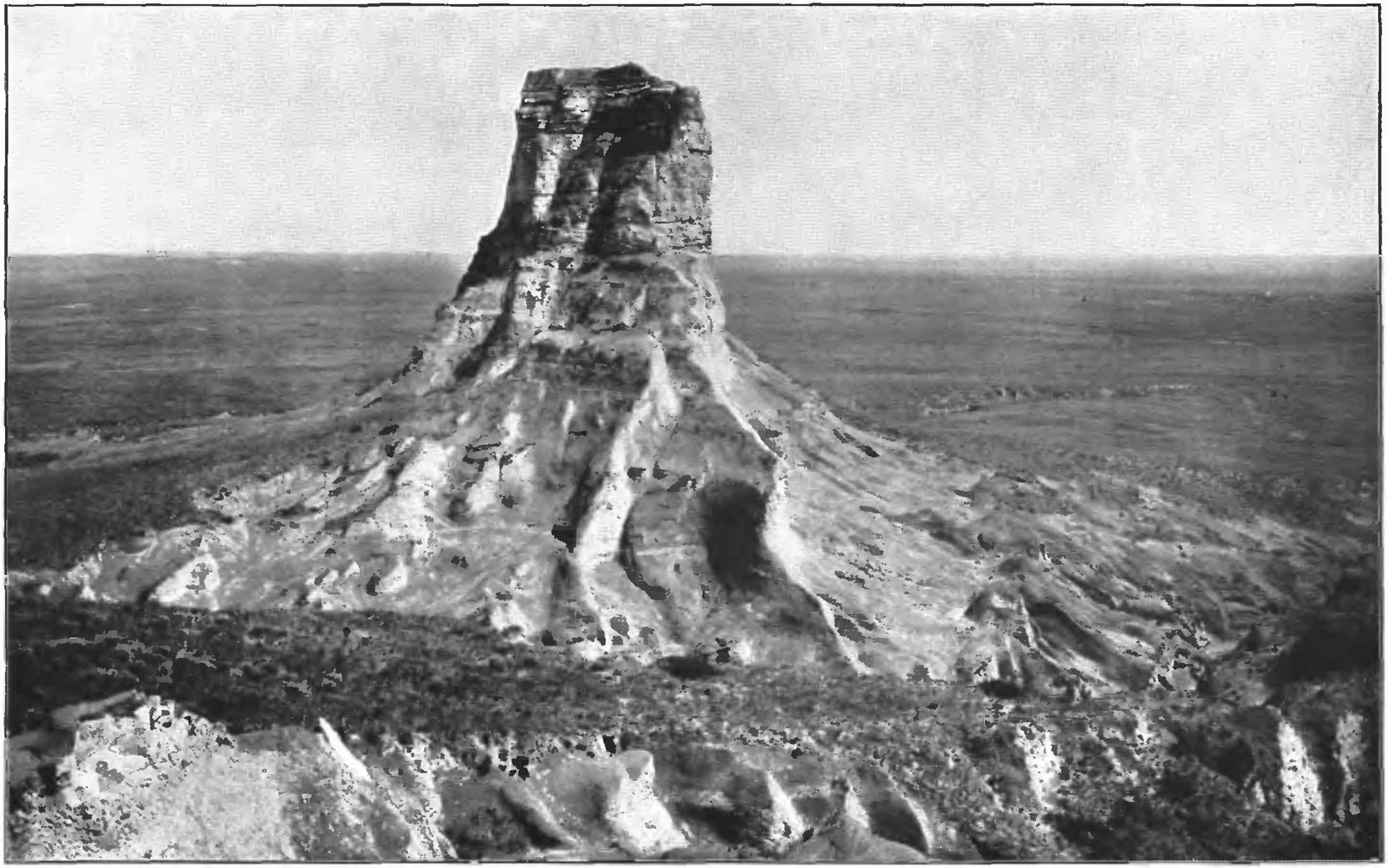
The White River outcrops extend along the foot of Pine Ridge through east Wyoming and end against slopes of Laramie sandstones north of Douglas. The Chadron and Brule clays are extensively exposed in the valley of North Platte River about Orin Junction and extend westward up among the ridges on La Bonte, Horseshoe, and La Prele creeks. To the east they extend through the

[a] Tertiary mammal of the Tertiary of northeastern Colorado: Mem. Am. Mus. Nat. Hist., vol. 1, pt. 7, 1901, 356.



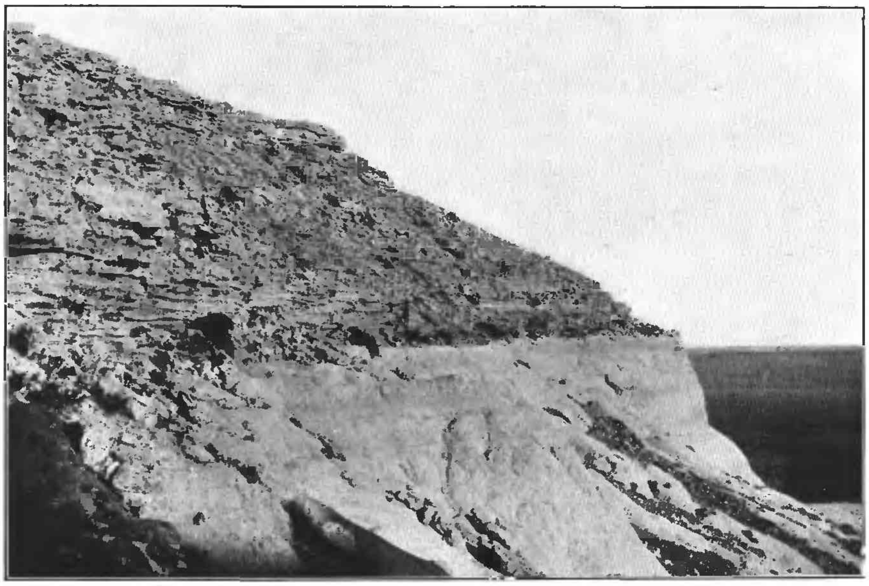
NORTH FACE OF SCOTTS BLUFF, NEAR PLATTE RIVER, WEST OF GERING, NEBR.

Upper cliffs of Arikaree formation; lower slopes and badlands of Brule clay. Typical erosion forms of Brule clay in western Nebraska.



JAIL ROCK.

Showing castellated form of weathering of Gering sandstone; slopes of Brule clay. Valley of North Platte in distance. View from Court-house Rock. Looking east.



A. ARIKAREE FORMATION ON BRULE CLAY, SOUTHWEST PART OF SIOUX COUNTY, NEBR.

Showing character of Brule clay and occurrence of concretions which characterize the Arikaree. Looking east.

B. GERING FORMATION ON BRULE CLAY, NORTHWEST OF REDINGTON, NEBR.

Unconformity at man's hand; bowlders of clay in base of Gering beds.

Rosebud Indian Reservation to the vicinity of longitude 100°, where they appear to thin out and disappear. There are extensive exposures of characteristic titanotherium beds overlain by Brule clays on Little White River a short distance below the Rosebud Agency. Hatcher has reported the discovery of titanotherium remains in the valley of Longpine Creek near Longpine, probably from a small outlier lying between the Arikaree sandstones and Pierre shale. Deposits of fuller's earth reported east of Valentine appear to indicate the occurrence of another outlier or southeast prolongation of the formation in Niobrara Valley.

White River formations occur on several of the divides west of Cheyenne River, as ascertained by Newton in the Black Hills survey, and have been found to extend far up the flanks of the Black Hills in the divides adjoining Spring, Battle, and French creeks, in some cases reaching the granites of the central area. Small outliers have been discovered at intervals along the western slope of the hills, notably at a locality 18 miles northwest of Hot Springs, where fuller's earth is mined. At Lead, at an altitude of over 5,000 feet, there occurs an outlier of the formation which has yielded numerous remains of *oreodon*, and a few miles northwest Doctor Jagger has mapped another similar deposit. In 1900 I found that there were Tertiary deposits extending up to altitudes of 6,000 feet about the Bearlodge Mountains, which are either of White River or Miocene age. In 1895 Prof. J. E. Todd made an expedition into the high divides lying between the headwaters of the Owl, the Grand, and the Little Missouri in the northwest corner of South Dakota, where he found outliers of White River formation lying on Laramie beds. During the past spring Prof. C. C. O'Harra has ascertained that there are similar outliers on the west side of Little Missouri River in the southeast corner of Montana.

Gering formation.—In studying the Tertiary deposits in North Platte Valley it was found that the Brule clay is overlain in some localities by sands and sandstones constituting a series sufficiently distinct to be separated as a formation. Accordingly it has been so represented in the Scotts Bluff and Camp Clarke folios of the Geologic Atlas of the United States and given the name "Gering formation." In several districts there seems to be an unconformity at the top of the Brule clays representing a considerable interval. The Gering formation consists of river deposits laid down in channels upon this old surface, probably at the beginning of Miocene times. Its most extensive development is seen in the ridge between the valleys of North Platte River and Pumpkinseed Creek, and at intervals along the northern face of Pine Ridge in Sioux County; it also appears in the valley of Lawrence Fork and in northeastern Colorado.

The formation attains a thickness of 200 feet near Chimney Rock, in North Platte Valley, but is usually much less than this. The principal material is soft

sandstone with pebbly layers and often with two or three members of sandstone with more or less conglomerate at the base of each. The formation lies on an irregularly eroded surface of Brule clay and includes pebbles of Brule materials. A contact of this sort is shown in Pl. XLIX, *A*.

In sec. 4, T 15, R 54, in the valley of Lawrence Fork, there is an exposure in which the Gering beds are seen to lie in a very irregular channel in the Brule clay and to consist almost entirely of conglomerate of local origin. Some features of the stratigraphy and relations of the formation are shown in figs. 4 to 8.

A small number of fossil bones were collected from Gering sands in North Platte Valley. According to determinations by Profs. W. B. Scott and F. A. Lucas the following forms occur: *Dienictis major*, *Merycochœrus rusticus*, *Leptauchenia decora*, *L. nitida*, *Aceratherium platycephalum*, and rhinoceros.

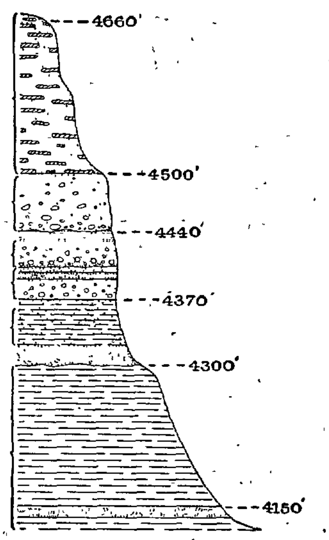


FIG. 6.—Columnar section of Gering and associated formations 6 miles south-southwest of Gering, Nebr.

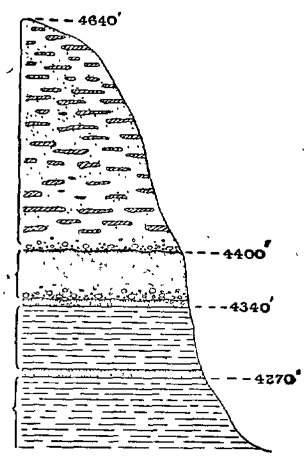
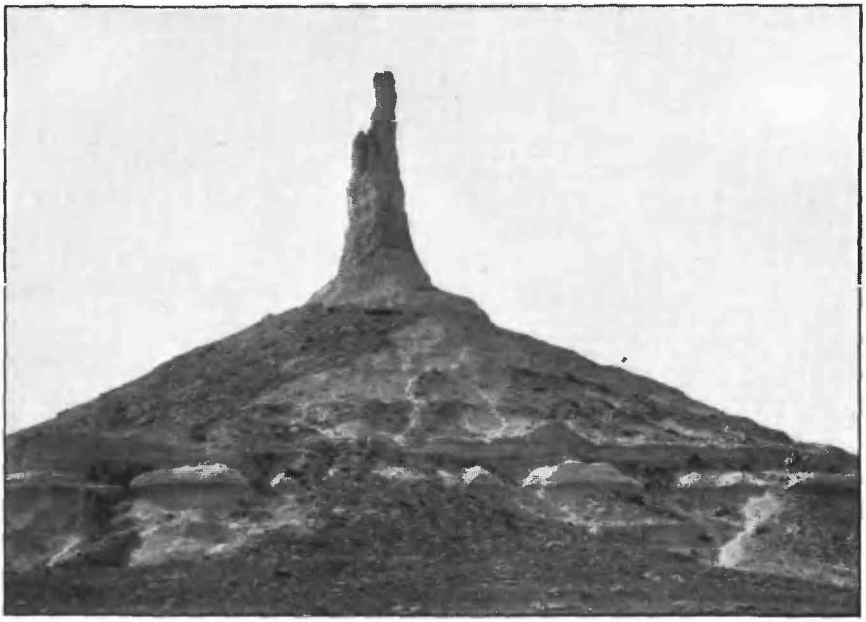


FIG. 7.—Columnar section of Gering and associated formations 7 miles due south of Gering, Nebr.

Arikaree formation.—A large portion of the higher lands of western Nebraska and southeast Wyoming extending south from Pine Ridge is capped by sands and soft sandstones which have been designated the "Arikaree formation." It is the principal component of the series formerly termed "Loup Fork." Generally it lies unconformably on the Brule clay but overlaps the margins of that formation in some portions of the area. It attains a thickness of over 800 feet in southeast Wyoming, and, judging from the occurrence of outliers, formerly extended far up the slopes of the mountains to the north and west.



A CHIMNEY ROCK, NORTH PLATTE VALLEY, NEBRASKA.

Gering sandstone on Brule clay; volcanic ash stratum under horse's feet. Looking west.

B. CONGLOMERATE IN ARIKAREE FORMATION, 3 MILES SOUTHEAST OF LARISSA, NEBR.

Showing irregularities in base of conglomerate.

The predominant material is sand loosely cemented into a soft sandstone. The colors vary from white to light gray. Characteristic, partly calcareous concretions occur throughout the formation and greatly predominate in its lower members. They are mostly of elongated cylindrical form, usually occurring in layers connected to a greater or less extent into irregular sheets. Their character is indicated with a fair degree of distinctness in Pl. LII, *B*. From observations by Professors Barbour and Fisher it has been found that these concretions are due to the growth of calcite crystals in certain portions and layers of the sandstone. It is owing to these hard concretions that the formation gives rise to prominent topographic features, notably such as the high escarpment along the northern face of Pine Ridge.

In portions of North Platte Valley in western Nebraska and along Pine Ridge the formation is underlain by Gering sands and sandstone, and, although in some cases the two formations are separated by unconformity, they usually so merge that it is believed that the Gering beds represent the first deposits of Arikaree times, separable only in areas where they consist of coarse material laid down in channels. The southern margin of the Arikaree formation appears in the high cliffs extending eastward from Chalk Bluff along the northern margin of eastern Colorado. To the east it appears to constitute the surface of the greater part of western and central Nebraska, while to the south it thins out and disappears under the Ogalalla formation from northeast Colorado to the southwest corner of Nebraska. The Arikaree is the formation which constitutes the northern portion of the High Plains, which are continued south by the overlapping Ogalalla formation.

According to Hatcher[a] the Arikaree formation in the western portion of Pine Ridge is divisible into three distinct horizons, comprising the Monroe Creek beds, which overlie the Gering sandstones north of Harrison, Nebr.; the Harrison beds, which constitute the surface of Pine Ridge in the vicinity of Harrison; and the Nebraska beds of Scott, which occur along Niobrara River south of Harrison. The Monroe Creek beds are stated to consist of 300 feet of very light-colored, fine-grained, not very hard, but firm and massive sandstones, which decrease in thickness rapidly to the east and increase to the west. They have yielded fossils, which appear to represent the upper "John Day" and lower "Deep River" faunas.

The Harrison beds are composed of about 200 feet of fine-grained, rather incoherent sandstones, with numerous siliceous tubes arranged vertically rather than horizontally, and large numbers of *Dæmonelix*. From these beds Hatcher reported

[a] Proc. Am. Philos. Soc., vol. 41, p. 113.

a large number of fossil mammals belonging to characteristic Miocene genera; believed to represent the hiatus between the lower and upper Deep River.

The Nebraska beds consist of buff-colored sandstone of varying degrees of hardness and undetermined thickness, with occasional layers of siliceous, not calcareous, grits, which protrude as hard, indurated, or shelving masses in the base of the cliffs. They contain large numbers of fossil bones, regarded as belonging to upper Deep River fauna.

Ogalalla formation.—In studying the geology of North Platte Valley in west Nebraska it was discovered that the Arikaree deposits were overlain unconformably by deposits of sand, gravel, and calcareous grits, which, on being traced south, were found to be the north extension of the Tertiary grit and mortar beds of the Kansas and east Colorado region. They were given the local designation Ogalalla formation, and in the Scotts Bluff and Camp Clarke folios of the Geologic Atlas of the United States their distribution and relations were set forth. The formation was found to overlap to the east and south on the Brule clay, and in southwest Nebraska, west Kansas, and east Colorado to lie directly on Pierre shale, Niobrara, Benton, and Laramie formations.

In the vicinity of North Platte River the formation is thin. To the north and northeast it apparently thins out entirely, but to the south it constitutes the surface of the High Plains over many thousand square miles, taking the place of the Arikaree formation, which has similar topographic relations to the north. Its distinctness from that formation was clearly ascertained both along the south side of North Platte Valley in west Nebraska and in exposures in northeast Colorado, where the Arikaree beds are well characterized and are seen to be unconformably overlain by the Ogalalla beds. Moreover, the overlying formation contains numerous bones of Pliocene age at many localities in Kansas and in adjoining regions.

The materials of the Ogalalla formation are mainly sands merging into gravels, and gravelly sands more or less cemented by carbonate of lime into a grit rock which often has the appearance of rough mortar, from which the name "mortar beds" is derived. Sometimes the lime rock contains but little sand, and usually it varies from grit to conglomerate or conglomeratic grit.

This rock outcrops extensively in west Kansas and southwest Nebraska. To the west in Colorado it usually contains less lime, while the high plains in that State are mostly mantled by a deposit of sand and gravel, which extends west to the foot of the Rocky Mountains on the Arkansas divide. In the region about Denver and northeast down the valley of the South Platte the formation has been removed over a wide area, but on the north side of that valley it again appears, capping the High Plains and probably extending to the foot of the mountains in the southeast

corner of Wyoming. It is extensively exposed in the High Plains divides in both sides of Lodgepole Valley all the way to its head, lying on typical Arikaree beds throughout. In the divide south of Arkansas River the Ogalalla formation extends on the High Plains surface to beyond longitude 103° and is found at intervals farther west on some of the higher summits in the "Nussbaum" formation of Gilbert. Near the south line of Colorado it is overlain, according to W. T. Lee, by lava flows of Mesa de Maya and other areas.

The southeast margin of the Ogalalla formation in Kansas is exceedingly irregular, extending far out on the divides and retreating far west up the valleys of Smoky Hill and Solomon rivers. In Arkansas Valley the formation descends to low levels from longitude 98° to 101° in a syncline, probably of post-Ogalalla age. The Ogalalla formation extends far eastward in southern Nebraska, but its north and east limits in this State are hidden by the great deposits of loess which extend across the central and eastern counties.

OUTLINE OF GEOLOGIC HISTORY.

The sedimentary rocks of the Great Plains region afford a record of physical geography from middle Cambrian time to the present, but owing to the lack of knowledge of the relations of some of the deeply buried rocks and to our imperfect interpretation of many features of different geologic epochs, only a general outline can be offered as to the general sequence of events. One significant feature is that most of the conditions were widespread, for there is remarkable uniformity in the resulting products. There were undoubtedly many marine submergences and several periods of emergence in which the surface was sculptured by running waters, especially in the later epochs.

CAMBRIAN SUBMERGENCE.

One of the great events in early North American history was the wide expansion of an interior sea over the west-central region. The submergence reached the Rocky Mountain province during middle Cambrian times, finding an irregular shore line about a great series of archipelagoes. From the ancient crystalline rocks of these shores waves and streams gathered and concentrated sands and pebbles, which were deposited as a widespread sheet of sandstone and conglomerate on sea beaches, partly in shallow waters offshore and partly in estuaries. We now find numerous exposures in which these sediments, containing much local material, may be seen abutting against the irregular surface of the crystalline rocks which formed these shores. The central portion of the Black Hills was probably an island in the earlier stages of this period, and, as Mr. Emmons has shown, the Laramie Range and the Rocky Mountain Front Range were highlands rising out of the Cambrian sea.

As middle Cambrian time progressed submergence increased, and in the region west and northwest of the central Black Hills, at least the thick mass of finer-grained muds now represented by the middle Cambrian shales and limestones in the region to the north was deposited. The conditions in later Cambrian times are much less clearly indicated, for there appear to be no sediments of this age in the region north, and the small areas of upper Cambrian rocks west of Colorado Springs throw but little light on the problem. Possibly the submergence to the north was so deep and the shores became so distant that the conditions for sedimentation were unfavorable, so that the upper Cambrian is represented by a very thin deep-sea deposit which we either have not recognized or which was removed before the deposition of the Ordovician sediments.

ORDOVICIAN.

Apparently in Ordovician times there was widespread submergence over the entire Great Plains region, and also deposition of a considerable mass of limy sediments to the west and limy and sandy sediments to the east. The rocks now exposed in the mountain uplifts northwestward appear not to represent the entire period, being older to the south and younger to the north, but the interpretation of this distribution is difficult, owing to our lack of knowledge of the relations and sequence of beds in the great deeply buried area away from the uplifts. The present Bighorn and northern Black Hills areas appear to have been completely submerged, but the Laramie range, Rocky Mountain front range, and the ridge now extending underground past Hartville to and including the southern Black Hills probably was a shore line. The Ordovician rocks now visible west of Colorado Springs appear to have been deposited in estuaries or embayments, which extended west beyond the general line of the Rocky Mountain front, and persisted through all or nearly all of Ordovician, and possibly into earliest Silurian, time. Of course it is possible that some of this area, in which there are now no Ordovician rocks, received deposits which were removed by erosion in Silurian, Devonian, or early Carboniferous times.

SILURIAN-DEVONIAN CONDITIONS.

From the close of Ordovician time to the early Carboniferous sea the uplifts along the western margin of the Great Plains region present no geologic record, the Silurian and Devonian being absent throughout. 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 generally throughout the region.

BUTTE CAPPED BY BED OF SANDSTONE IN ARIKAREE FORMATION, NORTHEAST OF BOXELDER SPRINGS, NEAR HARTVILLE, WYO.

CARBONIFEROUS SEA.

Under the marine conditions of the early Carboniferous there were laid down calcareous sediments, which are now represented by several hundred feet of nearly pure limestone, known as the Pahasapa and Englewood limestones in the Black Hills, the Little Horn limestone in the Bighorn Mountains, and the Guernsey and lower Hartville limestones in the Hartville uplift. As no coarse deposits occur it is probable that no crystalline rocks were exposed above water in the northern part of the region, but to the south, between latitude 41° and 42°, the limestone, or its stratigraphic equivalents, was deposited immediately upon them. In the southern Black Hills the limestone lies directly on a thin sheet of Cambrian sandstone, the thinness of which and the absence of Ordovician beds possibly being due to pre-Carboniferous erosion.

Along the Rocky Mountain front the lower Carboniferous beds appear only at a few points, apparently in estuaries which extended west of a general shore line now buried under the later Carboniferous sediments by the overlap of the latter on the crystalline rocks. In the later part of earlier Carboniferous time there appear to have been shallower waters with sediments of mixed limy and sandy nature in some portions of the region to the northwest, while in the Black Hills and Bighorn districts some red shales of nonmarine character appear to have been deposited in an area of wide extent, if the lower portion of the Minnelusa and Amsden formations are to be regarded as lower Carboniferous in age. In later Carboniferous times, prior to the Permian, the conditions presented considerable diversity, with limy and lime and sand deposition northwest and southeast and coarse red beds along the Rocky Mountain front, while in southern Colorado and southward there was an alternation of coarse red beds and limestones.

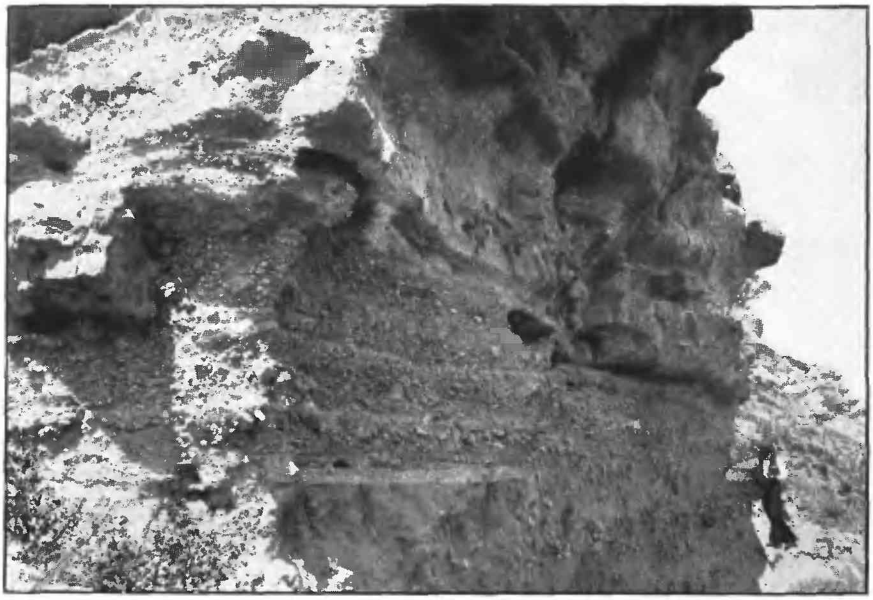
Assuming that the upper Red Beds are all of Permian age, there was in the earlier portion of this period still further emergence, resulting in a shallow basin, which extended across the western portion of the central Great Plains region and far northwest. In this basin were laid down the great mass of red shales of the Chugwater red beds, with their extensive interbedded deposits of gypsum, presumably products of an arid climate. The sandy clay of this formation accumulated in thin layers to a thickness of 500 to 1,000 feet, and there is such uniformity of the deep-red tint that this is undoubtedly the original color. This color is present not only throughout practically the entire outcrop of the formation, but also throughout its entire thickness, as is shown by deep borings. It is, therefore, not due to later or surface oxidation. This deposition of red mud was interrupted from time to time by chemical precipitation of comparatively pure gypsum in beds ranging in thickness from a few inches to 30 feet, and often free from mechanical sediment. It is apparent that these beds are the products of evaporation while mechanical sedimentation was temporarily suspended, a condition indicative of greatly diminished rainfall; other-

wise it is difficult to understand their nearly general purity. Most of the red deposits were laid down in shallow water, so that there must have been a subsidence which kept pace with deposition most of the time.

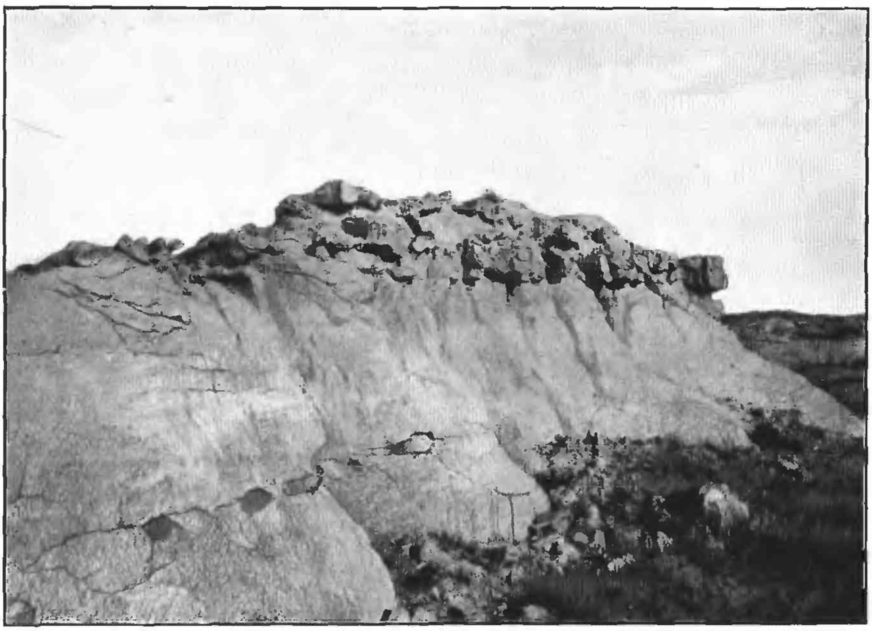
At an early stage of deposition of the gypsiferous Red Beds in the western portion of the region there was a widespread interruption of the shale sedimentation, and carbonate of lime was precipitated in the thin but wonderfully persistent bed now represented by the Minnekahta limestone. In the Bighorn region also there was an alternation of lime and red clay deposition toward the end of the epoch. To the southeast, in Kansas and Oklahoma, there was deposited simultaneously with the gypsiferous Red Beds a part at least of the dark shales into which they merge. These shales, which are of Permian age, contain thick deposits of salt and scattered deposits of gypsum at various horizons. Apparently, also, to the southeast, some of the lowest Red Bed deposits are represented by limestones of the lower members of the Permian, the products of deeper marine waters. Whether this deposition of the Red Beds extended into or through Triassic times in the central Great Plains region is not known, but evidently it was ended by the uplift which brought the region above the water. Probably this condition extended through the latter part if not all of the Triassic, and well into Jurassic time, during which there was no deposition and probably some slight erosion.

JURASSIC SEA.

In later Jurassic time a sea covered the region in which the Laramie and Bighorn mountains and the Black Hills now rise, and doubtless extended for some distance into northeast Colorado. The conditions varied somewhat from shallow to deep waters, but marine waters prevailed. The materials are nearly all fine-grained and indicate the absence of strong currents, except along some portions of the shores, where coarse sandstones were laid down, some of them of bright-red color, which probably derived their sediments from adjacent land surfaces of red beds. Generally, however, clay was the first sediment, and it was followed by ripple-marked sandstone, evidently laid down in shallow water and probably the product of a time when sedimentation was in excess of subsidence, if not during an arrest of subsidence. The red color in the medial part of the Jurassic deposits in some districts may represent a transient return to arid conditions similar to those under which the gypsiferous red beds were laid down, this condition being indicated by a local Jurassic gypsum deposit in Casper Range. The next series, a thick mass of shales with thin limestones filled with marine fossils, is indicative of deeper waters. After this stage there was widespread uplift, at least in the northern portion of the region, and the sands of the Unkpapa sandstone were deposited in the Black Hills region apparently in shallow fresh waters with moderate currents. There was no



A. CONGLOMERATE LYING ON ARIKAREE SANDSTONE, AT BASE OF OGALALLA FORMATION, 5 MILES SOUTH-SOUTHEAST OF REDINGTON, NEBR.



B. TYPICAL PIPY CONCRETIONS OF ARIKAREE FORMATION, SCOTTS BLUFF COUNTY, NEBR.

erosion of the surface of the marine Jurassic deposits at this stage in the region north, but if these deposits originally extended farther south in Colorado than we now find them they were eroded from that area at this time. Probably, however, the region along the eastern foot of the Rocky Mountain range was a land surface throughout Jurassic and earliest Cretaceous time, as shown by the general unconformity between the Morrison formation and the Red Beds in that region.

CRETACEOUS SEDIMENTATION.

On the assumption that the Morrison formation is equivalent to the upper members of the Comanche series, there is a long interval of earlier Cretaceous time not represented by deposits in the central Great Plains north of latitude 37°. Morrison sedimentation was in a long, relatively narrow trough extending along the Rocky Mountain region, as shown in Pl. XLIV. This trough was occupied by a shallow body of fresh water which deposited very fine-grained sediments, mixtures of clay and fine sand, with thin, irregular bodies of coarser sand deposited by streams or along shores, and with occasional thin beds of limy sediments. Huge saurians were abundant, as shown by the frequent occurrence of their remains in the deposits, although it is possible that this abundance is due mainly to increased mortality or more favorable conditions of preservation, or both.

Morrison time was succeeded abruptly by a change to conditions under which coarse-grained, cross-bedded, massive Dakota-Lakota sandstones were deposited. Although the deposits change abruptly and there was local channeling of the surface of the soft Morrison deposits, the erosion appears to be of remarkably small amount and no more than would be expected to result from the strong currents bearing coarse sands and pebbles.

It is believed that there was no great uplift-erosion interval following Morrison deposition, for if there had been the soft deposits would have been widely removed. As it is, the Dakota-Lakota sandstones lie on a uniform series of Morrison sediments from Montana to New Mexico and Oklahoma. It is a significant fact also in this connection that some of the saurians of the Morrison time continued into the next epoch. In southeast Colorado, west Kansas, and south, where Morrison deposits appear to be represented by upper Comanche sediments, marine conditions prevailed in the early Cretaceous time, and these gave place to an alternation of marine and fresh-water conditions—probably estuarine—of which the products are the lower members of the "Dakota series."

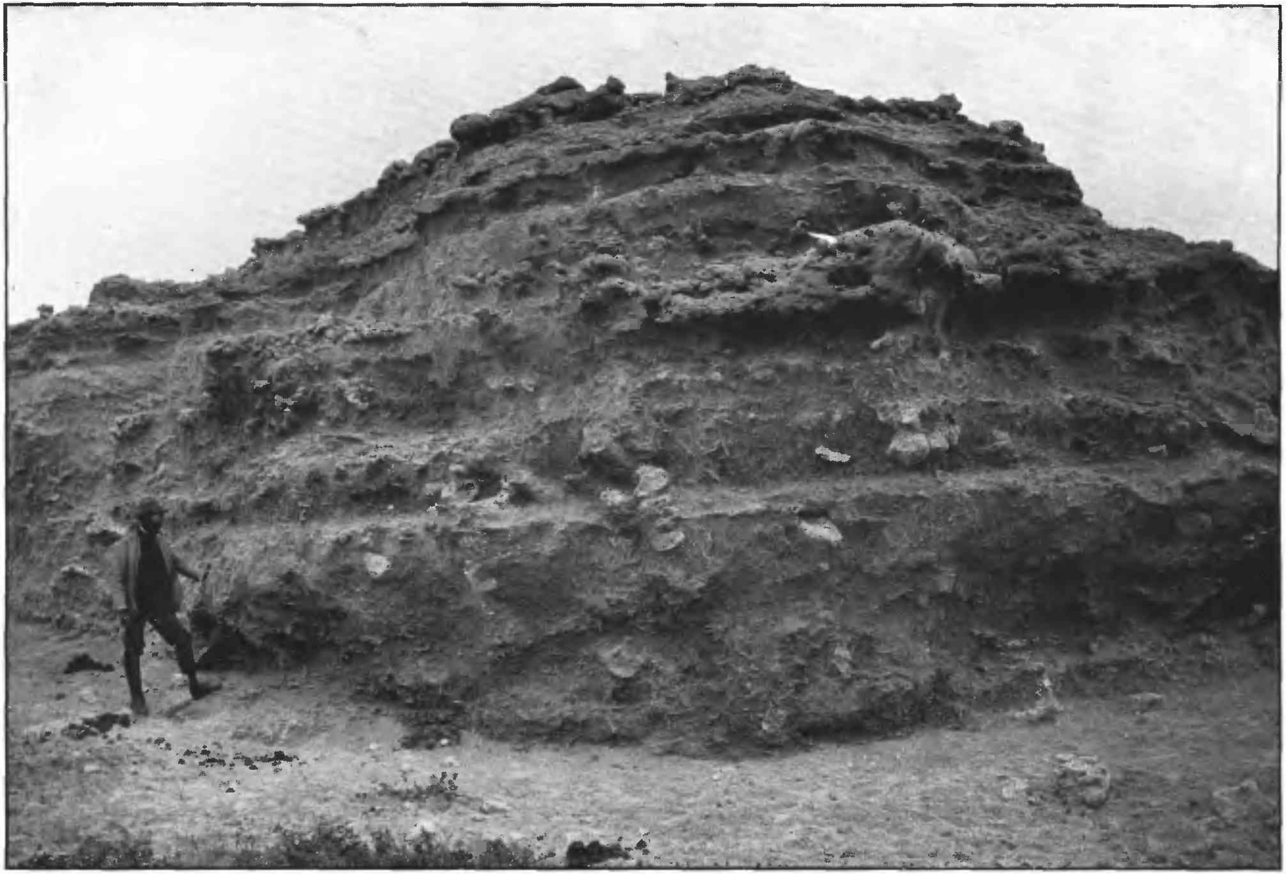
The Dakota-Lakota sands were derived from various sources not fully located and spread by strong currents in thick beds, with intervening shales in some areas. In the earlier stages local coal beds were accumulated in the Black Hills region.

Midway in the series a thin, widely extended clay body was laid down. Just prior to this, in the Black Hills region, a thin local bed of limestone was deposited. The extent of the Lakota as separated from the Dakota not having been ascertained, excepting that both are present in the Black Hills region and that the Lakota is surely absent in east Nebraska and east Kansas, their relative areas of deposition can not yet be indicated. The vast extent of this coarse-sandstone series is a wonderful feature, and it is difficult to picture the conditions under which it accumulated. I formerly thought that there might have been a shore line progressing gradually westward, with coarse deposits near shore and fine deposits in the deepening waters east, so that the Dakota sandstone in western Kansas, for instance, might be represented by shales in central Kansas, but since the Benton stratigraphy and the Dakota-Benton relations are so uniform over the entire area this hypothesis is untenable.

Following the deposition of this great sheet of sandy sediments there was a rapid change to clay deposition, of which the first representative is the Benton shale, a formation even more extensive than the underlying Dakota sandstone. This represents the later Cretaceous submergence, in which marine conditions prevailed, and it continued until several thousand feet of clays were deposited, during the Benton, the Niobrara, and the Pierre epochs. In Benton times there were occasional deposits of sand, and one thin but very widespread deposit of lime, the Greenhorn limestone, near the middle of the Benton sediments. The shale of the Benton is followed by several hundred feet of impure chalk, now constituting the Niobrara formation, and this in turn by many hundred feet of Pierre shale, which thickens rapidly to the west, attaining 1,200 feet or more in western South Dakota and over 7,000(?) feet adjacent to the Rocky Mountains in a limited area west of Denver.

The retreat of the Cretaceous sea, which corresponds with the Fox Hills epoch, resulted in extensive bodies of brackish waters, which spread sands over the clay beds; and then of fresh waters, which deposited the sands, clays, and marsh material of the Laramie. Apparently these last-mentioned formations were not laid down much east of longitude 101°, for they thin rapidly to the east, although, as we do not know the extent of post-Laramie erosion, their former limits can only be conjectured.

In the Bighorn Range, at least, there was an uplift of moderate prominence in early Laramie times, possibly consisting only of a fault of local extent. It was of sufficient magnitude, however, to afford erosion products from beds down to the Cambrian, some of the materials of which appear in a long lens of conglomerate extending for 40 miles along the east side of the range.



ARIKAREE SANDS FILLED WITH DÆMONELIX, AT HEAD OF LITTLE MONROE CANYON, SIOUX COUNTY, NEBR.

EARLY TERTIARY MOUNTAIN GROWTH.

There was extensive uplift in the Rocky Mountain province in early Tertiary time. This fact is clearly indicated in the Black Hills and the Laramie ranges, where the Oligocene deposits lie on an eroded surface having the general outlines of the present configuration, a relation which indicates that some of the mountain uplifts were truncated and the larger outlines of topography established in earlier Eocene time. It is probable that the main uplift of the Rocky Mountain Front Range and the Bighorns also occurred in this same epoch. Where the great mass of eroded material was carried is not known, for in the lower beds to the east and the south there are no early Eocene deposits nearer than those on the Gulf coast and the Mississippi embayment, excepting the relatively small areas of Denver and Arapahoe formations in the Denver basin and their possible representatives north through eastern Wyoming. The early Eocene erosion was effected by streams which had strong declivities due to the uplifts.

OLIGOCENE FRESH-WATER DEPOSITS.

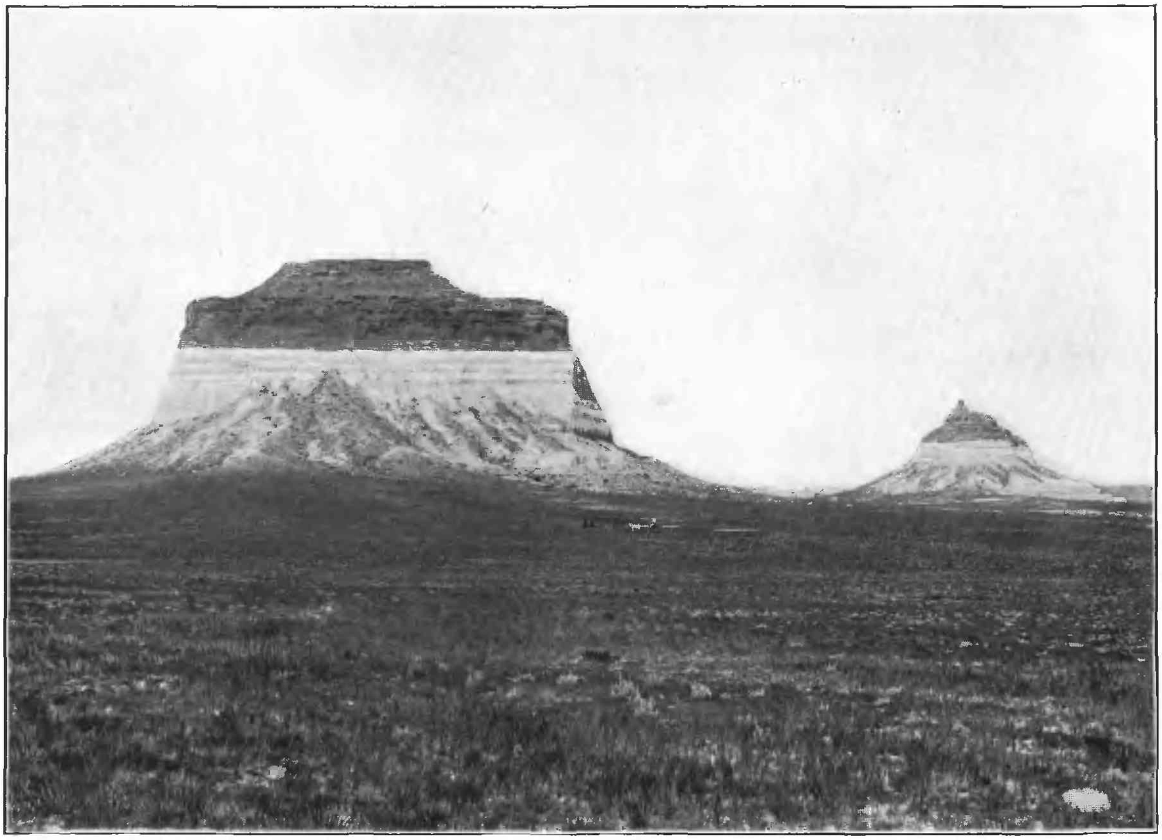
Later in Tertiary time, after the outlines of the great mountain ranges to the north and west had been carved, there was a long period in which streams of moderate declivity flowed across the central Great Plains region. These, with frequently varying channels and extensive local lakes due to damming and the sluggish flow of the waters, laid down the widespread mantle of the Oligocene or White River deposits. These began with the sands of the Chadron formation, which show clearly the course of old currents by channels filled with coarse sandstone, and areas of slack water and overflow in which fuller's earth and other clays were laid down. The area of deposition of this series extended across east Colorado and Wyoming and west Nebraska and South Dakota, and probably also farther north, for the deposits have been found in west Canada. Doubtless the original extent was much wider than the area in which we now find the formation, for much has been removed by erosion. The White River epoch was continued by the deposition of the Brule clays under conditions in which the currents were less strong and local lakes and slack-water overflows were more extensive. The Brule clay has about the same area as the the Chadron, and originally was much more extensive than it is at present.

At the beginning of Miocene time the general conditions had not changed materially, but doubtless for a while an extensive land surface existed in the central Great Plains area. In the stream channels extending across this surface the Gering formation was laid down, one channel extending across west Nebraska for some miles just south of North Platte River. Next came the deposition of a widespread sheet of sands derived from the mountains to the west, probably spread

over the entire central Great Plains region by streams, aided to a minor extent by winds. The streams of this time shifted their courses across the Plains, spreading the débris from the mountains in a sheet which in some parts of the area attained a thickness of 1,000 feet—a flat alluvial fan of wonderful extent. This is the Arikaree formation, which buried some of the lower ranges of the uplifts, as shown by the high altitudes to which it extends on the slopes of Rawhide Butte and along the front of the Laramie Range. It has been so widely eroded since its deposition that we do not know its original extent, but doubtless, as suggested on Pl. XLIV, it covered most of the central Great Plains far to the east. It was followed by uplift and erosion—erosion which removed the Arikaree and parts of underlying formations from the south and the east, leaving the thickest mass of the deposit in west Nebraska and east Wyoming. Probably, however, it never was thick nor widespread to the south, erosion predominating in that part of the area during deposition to the north. Next came the epoch in which the streams began depositing the thin mantles of sands of the Ogalalla and other late Pliocene formations, especially in south Colorado, in south Nebraska, in Kansas, and in regions farther south. The deposition at this time appears to have been mainly in the southern region above described, erosion probably predominating in the district lying farther north.

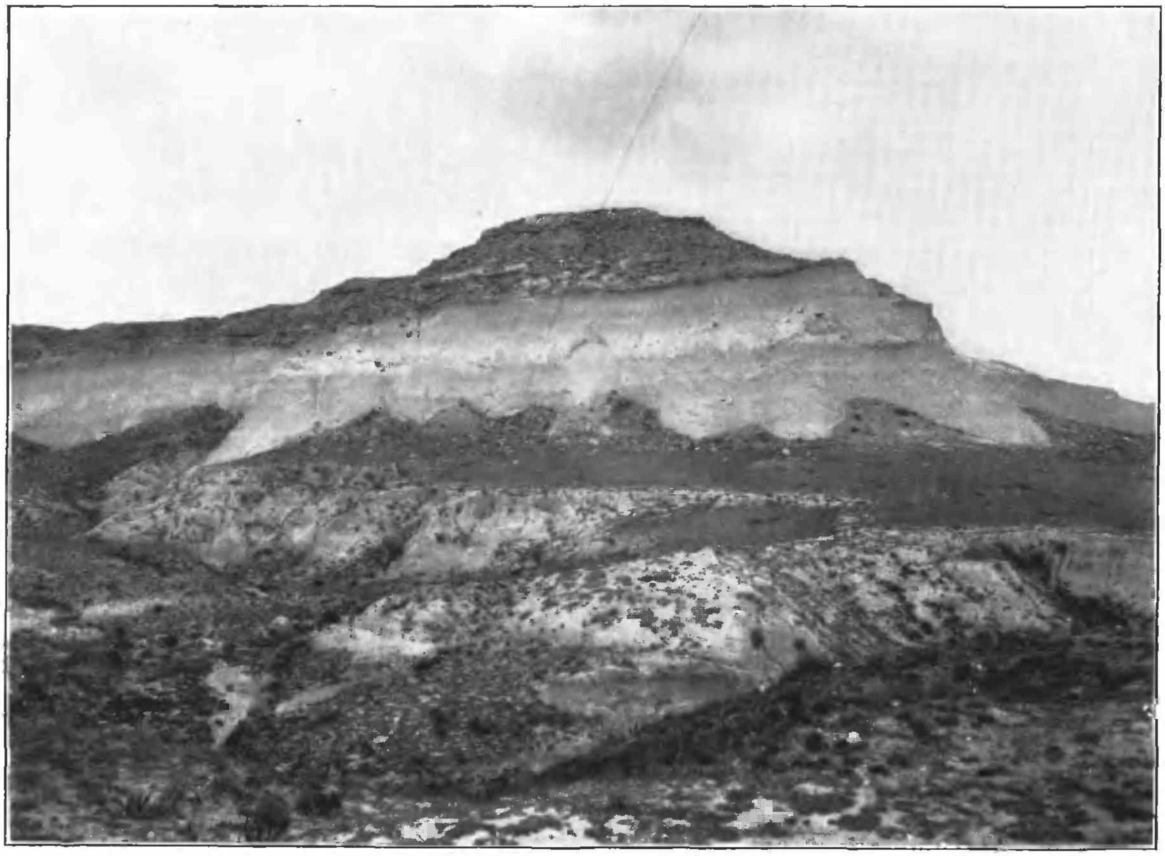
These alternating conditions of later Tertiary deposition and erosion, first in the north and next in the south, were undoubtedly determined by differential uplift, the uplifted region suffering erosion and the depressed or stationary region receiving deposits from streams which did not have sufficient declivity to carry off their loads. This condition also is a feature of the semiarid climate of the Plains, the mountain torrents and resulting vigorous erosion furnishing large amounts of débris, which the streams of low declivity and constantly diminishing volume on the Plains were unable to carry to the sea. Even if such a region is traversed by valleys cut during a time of uplift or increased rainfall, when cutting ceases these valleys are soon filled by sediments, and when they are full the streams at times of freshet, and to a less extent in the dry portion of the year, shift their courses so as finally to spread a wide mantle of deposits over the entire area in which there is sluggish drainage.

During the early portion of the Pleistocene there was uplift and floods from increased precipitation, which resulted in widespread denudation of the preceding deposits, so that the later ones were entirely removed in the eastern portion of the area, where there were glacial floods, and widely and deeply trenched in the west portion. To the west there extended to the foot of the mountains a great high plain of wonderful smoothness, mantled mostly by the Arikaree to the north



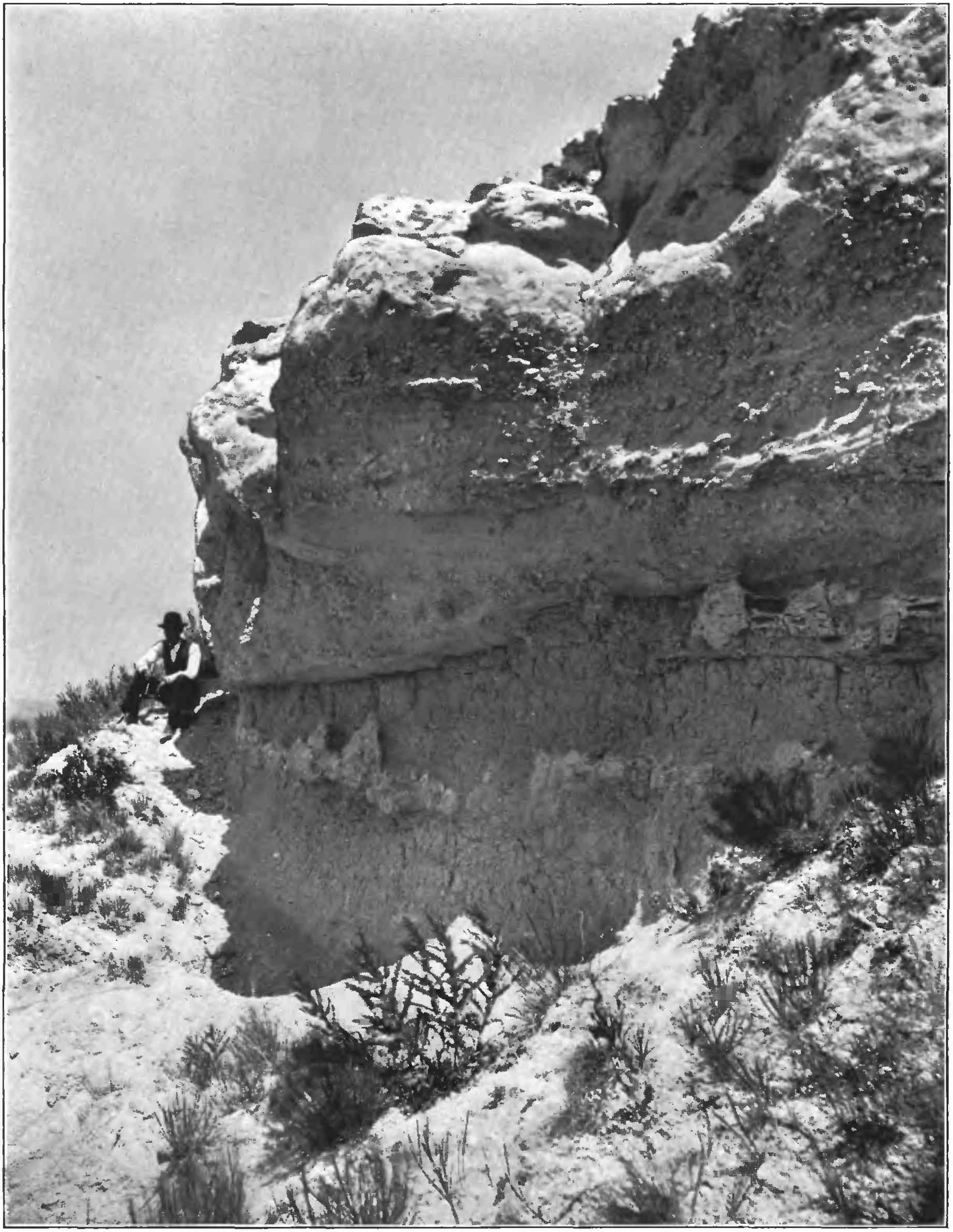
A. ARIKAREE SANDSTONE ON BRULE CLAY, IN PAWNEE BUTTES, WELD COUNTY, COLO.

Strong unconformity due to erosion, typical beds of concretions in Arikaree formation.



B. ARIKAREE SANDSTONE ON BRULE CLAY, 18 MILES NORTH OF STERLING, COLO.

Strong evidence of erosion between, and typical features of, both formations



OGALALLA CONGLOMERATE ON BRULE CLAY, AT MOUTH OF ASH CREEK, DEUEL COUNTY, NEBR.

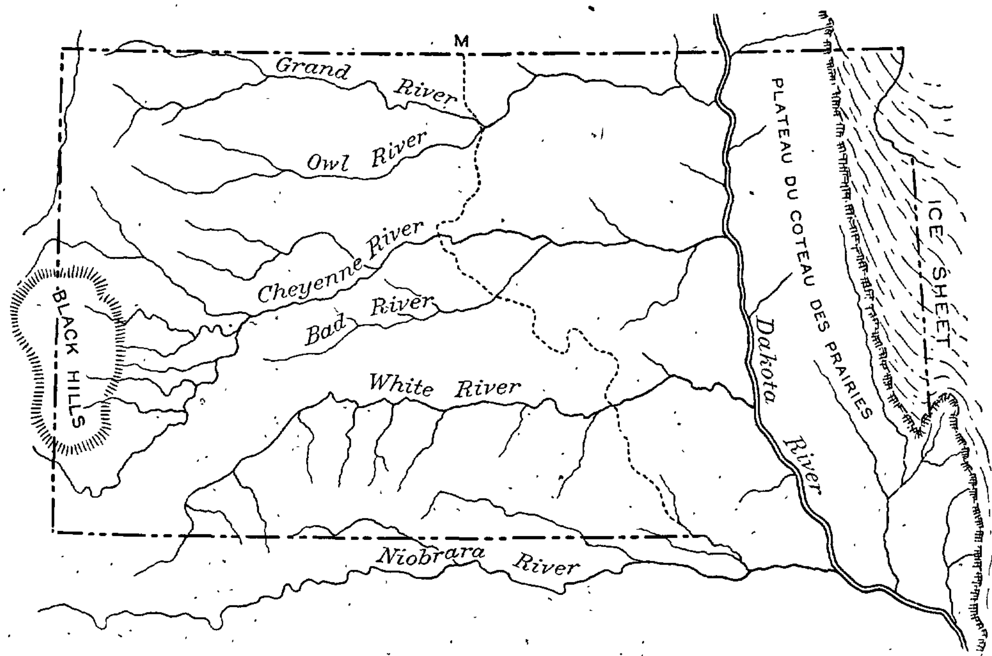


FIG. 8.—Outlines of the drainage of South Dakota during the earlier portion of the Glacial epoch, by J. E. Todd. The dotted line shows approximately the present course of Missouri River.

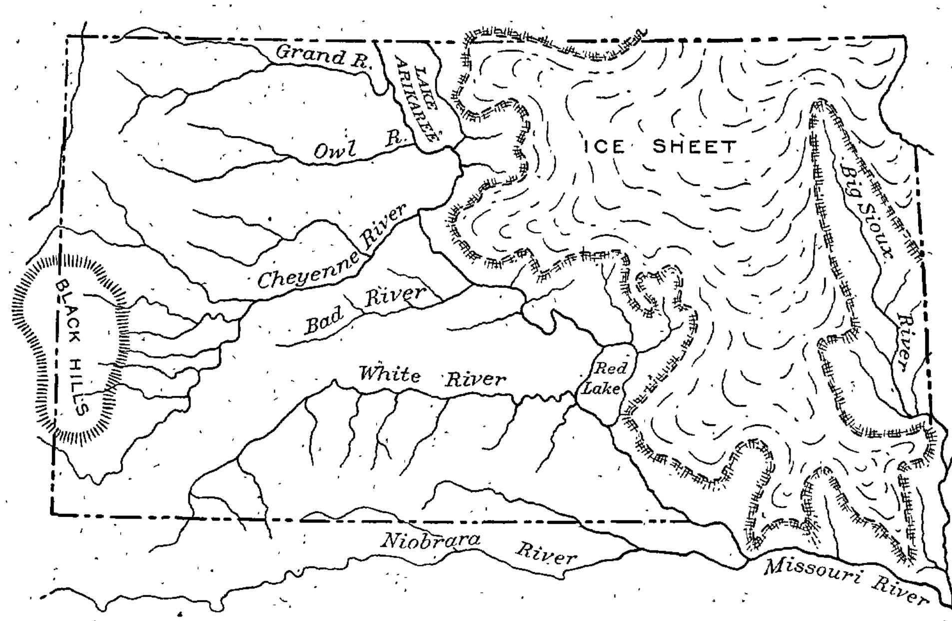


FIG. 9.—Outlines of drainage of South Dakota during the period of maximum advance of the ice sheet of the later Glacial epoch, by J. E. Todd.

and by the Ogalalla and possibly some later deposits to the south, the product of later Tertiary deposition. As the Black Hills dome rose somewhat higher than the general uplift, there was deep erosion around it, so that the High Plains, whatever their extent may have been in that region, were largely removed, and their northern edge left, as at present, in the great escarpment of Pine Ridge facing toward the Black Hills uplift. Farther south, across Nebraska, Colorado, Kansas, and Texas, the High Plains still present wide areas of tabular surface, though the streams of Pleistocene time cut into them deeply and removed them widely. Numerous changes in stream courses took place in Pleistocene times, some of the valleys still presenting relations which clearly illustrate their history.

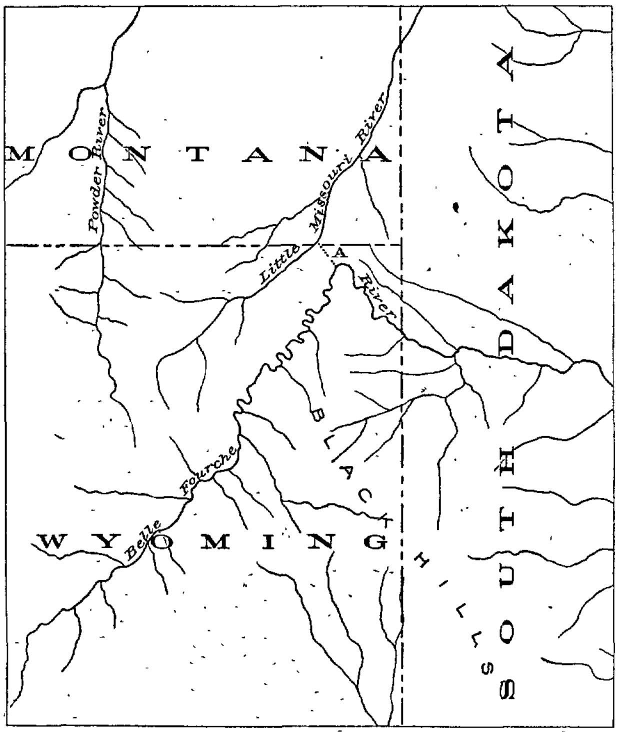


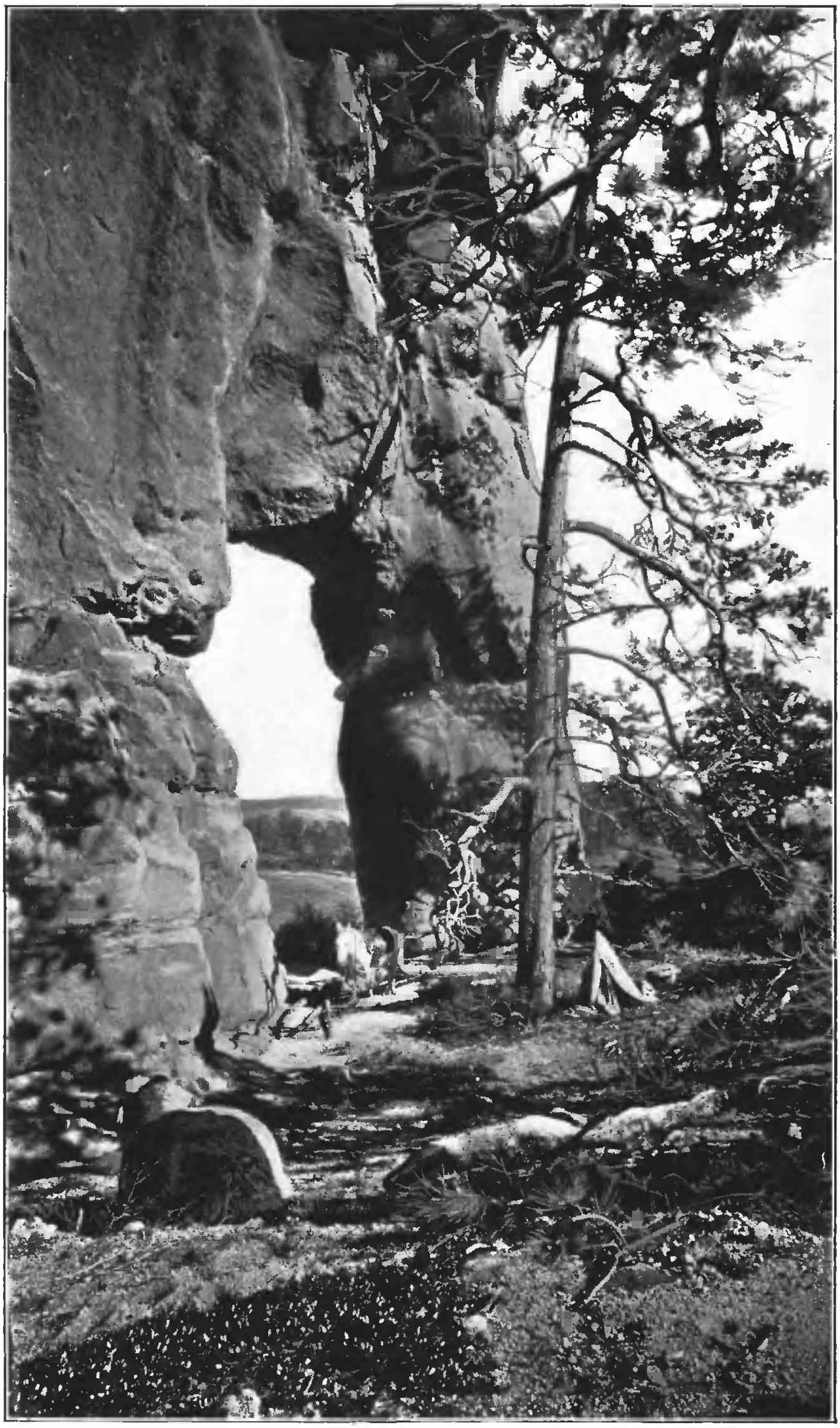
FIG. 10.—Outline map showing relations of upper Belle Fourche and Little Missouri drainages.

One of the most important causes of changes in drainage was the presence of the great ice sheet during the Glacial epoch, especially in eastern South Dakota. As shown by Prof. J. E. Todd,[a] the Missouri originally flowed down the wide valley now occupied by the James; the Grand, Cheyenne, White, and others, were then at a higher level, flowing across the region now occupied by the divide between the James and the Missouri. The original drainage relations, according to this idea, are shown in fig. 8.

Later in the Glacial epoch the margin of the ice sheet advanced to the west, filling up James River Valley, shortening the branch streams from the west, and giving rise to a new river having the course of the present Missouri, which at once began to cut a deep valley in the soft Pierre shales. The relations at this period are shown in fig. 9.

When the ice sheet retreated the new valley had been cut so deeply that the old course could not be resumed, and the new one has persisted until the present time.

[a] Todd, J. E., Hydrographic history of South Dakota: Bull. Geol. Soc. America, vol. 13, 1902, pp. 27-40, pl. 3.



ARCHWAY ERODED IN MONUMENT CREEK SANDSTONE, AT "ELEPHANT ROCK," NEAR MONUMENT, COLO.

Showing massive character of sandstone.

Along the east side of the Black Hills many of the streams are cutting new valleys, some of which have tapped the heads of former valleys, causing considerable complexity in the topographic relations and affording many striking examples of stream robbery. One of the most extensive stream diversions in the Black Hills has been that of the upper waters of the Belle Fourche into the Cheyenne River drainage at the peculiar sharp bend at the north end of the Black Hills uplift. Originally this stream above the bend was the main head branch of Little Missouri River, the connection with the present Little Missouri Valley being at *A* in fig. 10.

At this locality, A, there is a wide, flat-bottomed valley, which to the north merges into Little Missouri Valley, as shown north of S in fig. 11.

FIG. 11.—Sketch showing abandoned valley through which the Belle Fourche formerly joined Little Missouri River. S, Stoneville Flat; M, Little Missouri River; B, Belle Fourche River.

At the bend in the Belle Fourche the stream now occupies a new canyon, cut about 50 feet below the floor of the older valley. This robbery was due to a small branch of Cheyenne River, which had steep declivity and was in greater part cutting along the strike of soft shales, so that it had greatly the advantage of the original headwater branch of Little Missouri River, and finally tapped it. The water now flows to Missouri Valley in central South Dakota by a course 300 miles shorter than the roundabout one that it formerly followed down the Little Missouri far to the north and then back to the southeast through central South Dakota.

In most portions of the central Great Plains erosion is still in progress, especially in the smaller streams, where the water has sufficient declivity to carry away its load; but in some of the larger streams the valleys are building up, as in the later Tertiary periods, through the volume of water not being adequate to carry away the waste from the adjoining slopes. Without further uplift the valleys will in this way in time be filled, the streams will again wander over the divides, and the Great Plains receive a new mantle similar to those of Tertiary time.

UNDERGROUND WATERS OF THE GREAT PLAINS.

GENERAL CONDITIONS.

The thick succession of sedimentary formations underlying the Great Plains includes porous strata containing large volumes of water. These water-bearing deposits comprise widespread sheets of sandstones or sand, from Cambrian to Tertiary in age, the alluvial sands in the bottoms of valleys, and the sands of the sand hills. The sandstones of the older formations are in sheets often several hundred feet thick, alternating with bodies of relatively impermeable shales or limestones, so that they present favorable conditions as water bearers. To the west they are upturned by the great uplifts and outcrop along the high mountain slopes; to the east most of them rise gradually to the surface, while in the central and northern regions they lie at great depth under the heavy mantle of younger deposits. Although most of these general relations are shown in the ten cross sections of Pls. X and XI, the simplified section in fig. 12 will show more plainly the problem of the artesian waters.

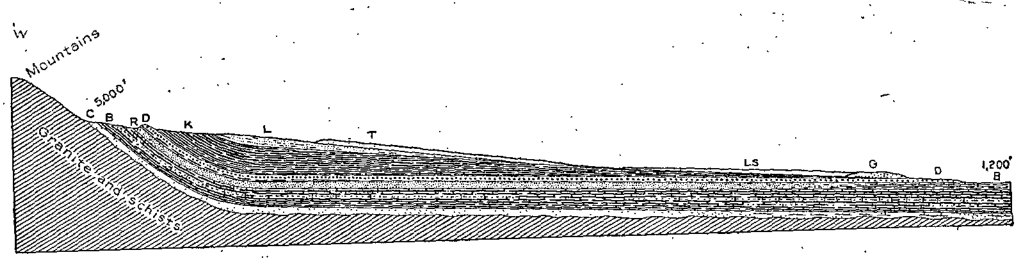
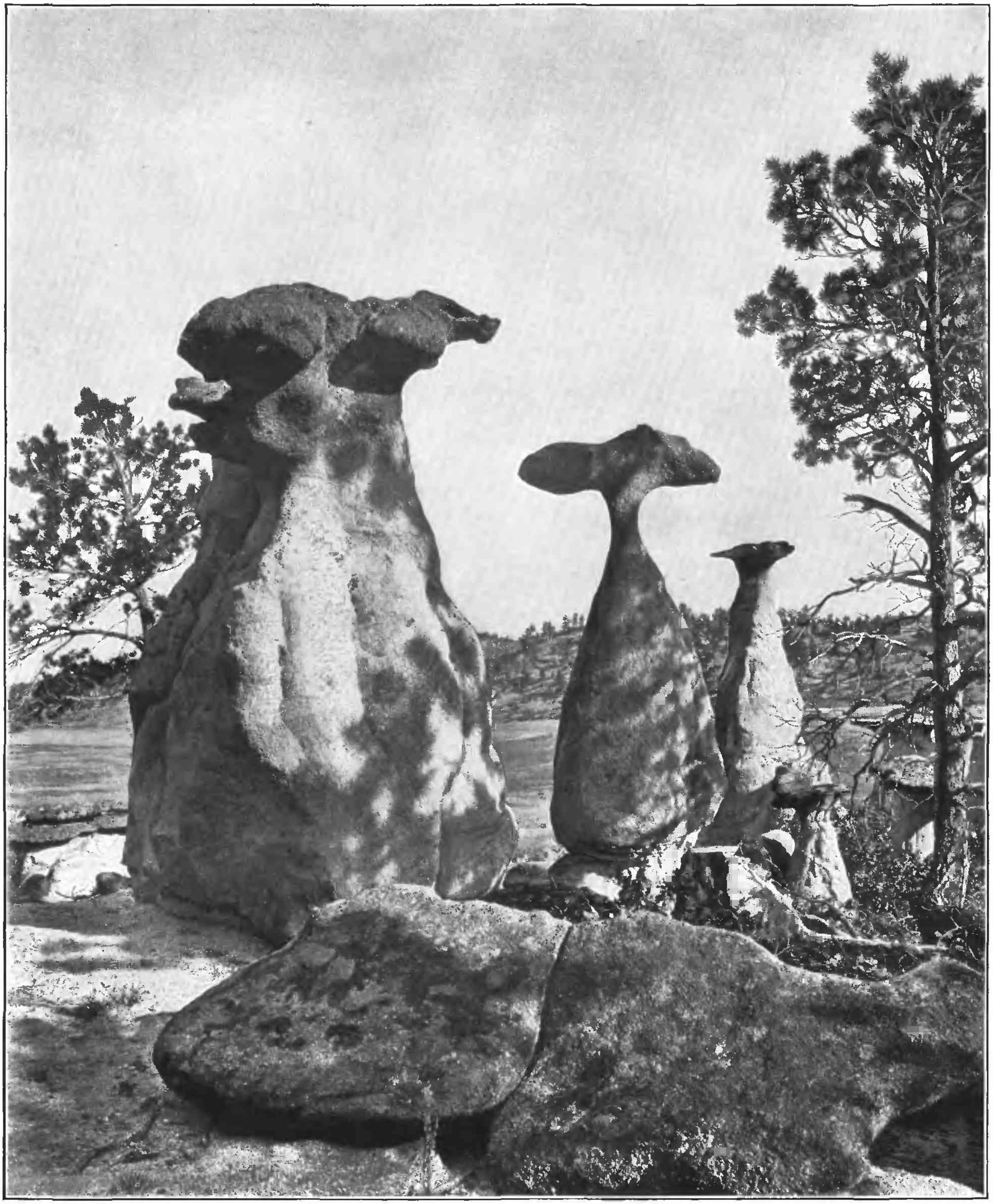


FIG. 12.—Cross section of the Great Plains, showing general structural relations of the water-bearing strata; C, Cambrian sandstones; B, Carboniferous and Ordovician limestones with local sandstone beds; R, Red Beds; D, Dakota-Lakota sandstones; K, Benton, Niobrara, and Pierre formations, mostly shale; L, Laramie and Fox Hills formations, largely sandstones; T, Tertiary deposits, in part sandstones; L, Loess underlain by gravel; G, Glacial drift.

Part of the surface water passes into the sandstones in their elevated outcrop zones along the foot of the western mountains and flows east through the permeable rocks, in most cases finally escaping in springs in the low-level areas of outcrop eastward and southward. In such water-bearing strata as the Dakota and underlying beds, which are overlain by a thick mass of impermeable deposits, the waters are under great pressure, for the intake zone has an altitude of from 4,000 to 6,000 feet and the region of outflow is only from 1,000 to 1,200 feet above sea level. The existence of this pressure, as found in many wells in eastern South Dakota, is the strongest evidence we possess that the waters flow underground for many hundreds of miles. Several wells show surface pressures over 175 pounds to the square inch and two are slightly over 200 pounds, the latter indicating a pressure of 780 pounds at the bottom of the well. Such pressures can only be explained



ERODED SANDSTONES, MONUMENT PARK, COLORADO.

Photograph by W. H. Jackson.

by the hydrostatic influence of a column of water extending to a high altitude west. If it were not for the outflow of the water to the east and south the initial head which the waters derive from the highlands of the intake zone would continue under the entire region, but owing to this leakage the head is not maintained, and there is a gradual diminution to the east known as "hydrostatic grade," a slope sustained by the friction of the water in its passage through the strata. In fig. 13 there is shown a simple apparatus which illustrates the general conditions.

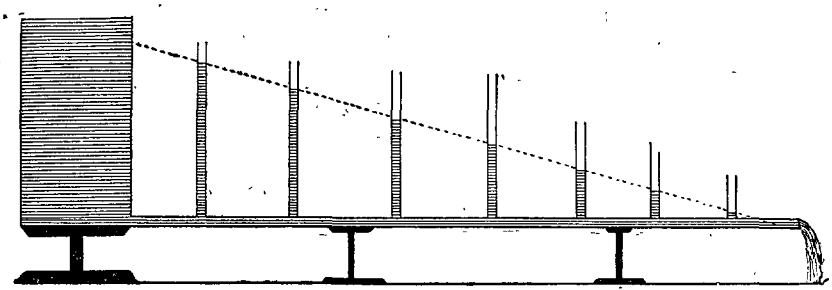


FIG. 13.—Diagram of apparatus for illustrating the declivity of head of liquids flowing from a reservoir. The shaded portions are water.

Another factor which undoubtedly somewhat influences the hydrostatic grade in the Great Plains region is a certain but unknown amount of general leakage through the so-called impermeable strata, all of which permit the passage of an appreciable proportion of water, especially when under great pressure. The conditions shown in fig. 13 are closely similar to those found in the Dakota sandstone, which is the principal water-bearing stratum underlying the Great Plains. From the altitudes of outcrops of this sandstone and pressures observed in many wells the lines in Pl. LIX have been constructed to indicate the observed and probable head of the artesian waters. In areas of flow the pressure in pounds at any point may be ascertained by subtracting the altitude of the land from the altitude of head and dividing by 2.3 (the height in feet of a column of water 1 inch square, weighing 1 pound). In areas too high for flow the depth to the point to which the water may be expected to rise may be found by subtracting the altitude of head from the altitude of the land.

WATER HORIZONS.

CAMBRIAN.

The basal sediments in the Great Plains region consist mainly of sandstones, which probably underlie nearly the entire area and contain water. They outcrop extensively in the uplifts of the Bighorn Mountains and the Black Hills and have been reached by some of the deep wells in the lower Missouri Valley, but, owing

to the great depth at which they lie in the central region, nothing is known of their relations or capabilities. In a few districts immediately adjoining the Black Hills the sandstones of the Deadwood formation may be reached by wells, but as, in most portions of the area, the depth would be considerably over 2,000 feet and as there are excellent prospects for water at a less depth, it is not likely that these sandstones will be tested except possibly at a few points in Red Valley. The deep boring at Minnekahta appears to have failed to reach them at a depth of 1,348 feet. At Lincoln, Nebr., a red sandstone 71½ feet thick, lying on supposed Sioux quartzite, was found at a depth of 2,121 feet, which may possibly be of Cambrian age. It yielded no water supply.

ORDOVICIAN.

The Ordovician rocks in the Bighorn Mountains, northern Black Hills, and west of Colorado Springs are mostly limestones not likely to contain water, and their steep dips soon carry them far beneath the surface. In Mississippi Valley the important water-bearing St. Peter sandstone is the source of water in numerous deep wells, but how far to the west this water-bearing horizon extends is not known, for under the central Great Plains it lies too deep for ordinary deep wells. At Lincoln a sandstone 60½ feet thick, supposed to represent the St. Peter, was entered at a depth of 1,947 feet, but apparently yielded no water.

CARBONIFEROUS.

Excepting in the greater portion of east South Dakota the Great Plains are probably underlain by rocks of Carboniferous age, although in much of this district these rocks lie too deep for wells. In the vicinity of the Black Hills uplift, in portions of southeast Colorado, in Kansas, and in east Nebraska they are at moderate distances beneath the surface. The rocks consist mainly of limestones, but water-bearing sandstones also are included. In the vicinity of the Black Hills the sandstones of the Minnelusa formation probably will prove to be a source of supply for deep wells in Red Valley, although these sandstones failed to yield water at Minnekahta and at Cambria. At the base of the Minnelusa formation more or less water usually occurs, and from a horizon within the Pahasapa limestone there is obtained a large supply of excellent water tapped by the wells at Cambria. Along the Rocky Mountain front and east in Colorado some deep wells have been sunk into the red sandstones in the upper portion of the Carboniferous, but, although in several cases a water supply has been found, the water has been too saline for use. Such also has been the experience

of numerous wells in east Kansas and in the deep wells at Lincoln and other points in east Nebraska.

JURASSIC.

Along the slopes of the Black Hills and in parts of southeastern Wyoming the sandstone bed in the lower part of the Sundance formation contains water of some importance. Several wells in Hay Creek Valley west of Belle Fourche flow from this horizon.

CRETACEOUS.

Dakota-Lakota formations.—The Dakota water horizon is the most widely extended and most useful in the Great Plains region. The sandstones appear to extend under the entire area in a sheet generally from 150 to 300 feet thick, underlain by Red Beds or Carboniferous limestones and shales, or by the Sioux quartzite in east South Dakota, and overlain by the great mass of clays and shales of the Benton, Niobrara, and Pierre formations. The sandstones outcrop extensively along the uplifts of the Black Hills, the Bighorns, and the Rocky Mountain front ranges, and in the Arkansas Valley in southern Colorado, where they receive large volumes of water, not only directly from the rainfall, but by the sinking of water from streams. In some portions of the central Great Plains the Dakota water horizon lies too deep to be reached by ordinary deep wells, but in the greater part of the area in which this condition is found there is, owing to the height of the lands, no prospect for a flow. In the map, Pl. LXIX, there is shown the depth at which this water horizon lies, as determined by all available data, and in the following portions of this chapter there will be described the experience of wells and the prospects for obtaining water in the various localities. It will be seen that the most important prospects for waters from the Dakota-Lakota sandstones, so far undeveloped, are in the central and western portions of South Dakota and in the region north of the Black Hills.

Fox Hills-Laramie formations.—The Fox Hills sandstone and the various sandstone beds in the Laramie contain considerable water, although artesian flows are obtainable only in restricted areas. In the Denver basin there is a mass of sandstone at the top of the Fox Hills and the base of the Laramie formation which undoubtedly contains a large volume of water, but it has not yet been drawn upon to any considerable extent, although eventually it may be the source of large artesian flows. The sandstones of the Laramie formation furnish considerable water along the line of the Burlington and Missouri River Railroad in northeast Wyoming, but do not give prospects of flows.

TERTIARY DEPOSITS.

Arapahoe formation.—The conglomerates and coarse sandstones at the base of this formation in the Denver basin afford the greater part of the very large underground water supply from deep wells in the city of Denver and its vicinity. Formerly the waters flowed with considerable pressure, but now the wells are so large and numerous that in most cases the waters have to be pumped.

White River group.—Most of the deposits of the White River group are too fine grained to yield water, but in some areas the base of the lower member (Chadron formation) is a coarse sand which yields water to pump wells of moderate depths in portions of west South Dakota, in Nebraska, and in the Goshen Hole in Wyoming.

Arikaree-Ogalalla formations.—These great sand deposits, constituting the surface of the High Plains, contain a large volume of excellent water, which usually accumulates in the lower beds, where it is available for pump wells, generally at depths of about 200 to 300 feet. Such wells are numerous in the upland region of west Kansas, west Nebraska, and east Colorado, where they are the principal sources of supply. Ordinarily these waters rise for some distance in the wells and in central Nebraska afford flows in a few districts. They also flow in a small area west of Cheyenne.

QUATERNARY DEPOSITS.

More or less water is contained in the alluvial deposits along the streams, in the gravel deposits underlying the loess in central and east Nebraska, in the glacial deposits of east South Dakota and east Nebraska, and in the various sand-hill districts. The waters in the alluvial deposits afford the principal water supplies of the Great Plains regions, for most wells are in the valleys. These obtain water at depths from 5 to 50 feet in most cases, drawing supplies either from the underflow of a surface stream or from a sunken watercourse, or from sheet water in the alluvium. In the more arid regions west these waters often contain alkali in greater or less proportion. The waters in the gravel beds beneath the loess are available under many thousand square miles in central Nebraska, mostly at depths of from 30 to 50 feet, and afford very satisfactory supplies. The waters of the glacial drift occur mainly at the base of the till, at depths varying from 100 to 300 feet in greater part, and these waters are the principal sources of supply for tubular wells in portions of east South Dakota and to a considerable extent in east Nebraska. In the sand-hill districts nearly all of the water that falls sinks into the ground and, at many localities, especially in central Nebraska, is found available in large amounts in wells from 5 to 100 feet in depth.

DEEP WELLS AND WELL PROSPECTS IN SOUTH DAKOTA.

GENERAL CONDITIONS.

In its wide extent under this State the Dakota sandstone carries a large volume of water which has been extensively utilized by artesian wells. This water is under pressure so great that in the eastern portion of the State flows are obtainable in all but the very highest lands, except in the southeast corner, near the zone where the head is lost by the sandstone reaching the surface. Over a thousand deep wells have been sunk east of Missouri River, most of which are from 500 to 1,000 feet in depth and generally yield a large supply of flowing water, much of which is used for irrigation. The aggregate flow from these wells is estimated to be about 7,000,000 gallons a day.

It is believed by some persons that owing to this great draft upon the resources the available supply is diminishing, but there is as yet no valid evidence that this is the case, excepting locally where there are numerous wells. Individual wells often diminish in efficiency owing to leakage, clogging, and other causes, but ordinarily new wells in the same vicinity show the same pressure and flow as were found in the older ones. But it is probable that if this large flow is permitted to continue, the available volume of artesian supply will eventually be greatly diminished.

The source of water is believed to be in the Black Hills and in the Rocky Mountains, for the sandstone appears to be a continuous stratum or a series of strata, permeable throughout and containing water which to the east has much of the initial head or pressure due to the high altitude of the zone of intake on the mountain slopes. There are extensive areas in central South Dakota in which the underground waters have not yet been developed. Apparently in these areas the Dakota sandstone lies deep, but not at an impracticable depth for well boring. Probably further drilling will show that flowing waters may be obtained all the way up Cheyenne Valley and its two branches to the Black Hills, and up the valleys of White, Bad, and Owl rivers nearly to longitude 102°.

AURORA COUNTY.

Aurora County lies mainly on the divide between the valleys of James and Missouri rivers. Its surface is largely covered by glacial deposits, which lie on Niobrara chalkstone to the east and on Pierre shale to the north, west, and south. The Dakota sandstone underlies the entire area and contains a large volume of water under pressure sufficient to afford artesian flows, except possibly in the highest hills in the extreme northwest townships and a small area in the south-central part of the county. The sandstone dips gently to the south in the southern portion of the county and to the north in the northern part, arching over a gentle

anticline which rises over the underground ridge of Sioux quartzite that extends westward from the Alexandria and Mitchell region.

The depths to the sandstone vary from 400 feet near the center of the eastern margin of the county to 550 feet at Plankinton, 800 feet or more in the central, north-central, and southern portions of the county, and somewhat over 1,000 feet in the northwest corner. The Dakota sandstone contains several flows of water, the lowest ones having the largest volume and highest pressure. The volume varies considerably and appears to be less over the underground quartzite ridge which extends east and west in the center of the county. The following is a list of the principal wells, with statements as to their depths and other features:

List of representative artesian wells in Aurora County, S. Dak.

Location.	Depth.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Inches.*	*Gallons.*	
J. Asmuss, T. 101, R. 64, NW. ¼ sec. 1	630			
Peter Mathig, T. 101, R. 66, SW. ¼ sec. 17	960	2	60	
Anton Hettinger, T. 101, R. 66, NE. ¼ sec. 3	800	2	50	
James Dunbar, T. 101, R. 66, SW. ¼ sec. 6	730	2	30	
T. 102, R. 63, sec. 1	300			
T. 102, R. 63, sec. 10	536			
J. W. Ryan, T. 102, R. 63, NE. ¼ sec. 10	613	2	3	
T. 102, R. 63, sec. 11	460			
Crystal Lake Township, SE. ¼, sec. 17	850	4½	600	Pressure, 55 pounds.
Sam Edelman, T. 102, R. 64, NW. ¼ sec. 19	800	3–2	40	Pressure, 78 pounds.
Do	800	3–2	40	
John Scales, T. 102, R. 64, SE. ¼ sec. 29	600	2	8	
Wm. Edelman, T. 102, R. 65, sec. 25	795	2	10	Pressure, 40+ pounds
Geo. Severance, T. 102, R. 66, SW. ¼ sec. 7	800	2	120	
Mike Galles, T. 102, R. 66, sec. 17	835	4½	400	
Philip Eyer, T. 103, R. 63, 5 miles southeast of Plankinton	705	3	200	
Evon Raesley, T. 103, R. 63, sec. 28	716	3	200	
George Saville (?), T. 103, R. 63	530	2	30	
Sam Swenson, T. 103, R. 63, sec. 13	420	2	30	
J. D. Barton, T. 103, R. 63, SW. ¼ sec. 8	755	3	100	Pressure, 80 pounds.
J. R. Mabbot, T. 103, R. 63, sec. 26	530	2	10	
L. Mabbot, T. 103, R. 63, sec. 26	490	2	10	
Leonard Scott, T. 103, R. 63, sec. 35	484	4–3		
C. R. Cook, T. 103, R. 63, sec. 32	623	3–2	15	
T. 103, R. 63, sec. 4	500			
T. 103, R. 63, sec. 8	755			
T. 103, R. 63, sec. 9	470			

List of representative artesian wells in Aurora County, S. Dak.—Continued.

Location.	Depth.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Inches.*	*Gallons.*	
T. 103, R. 63, sec. 10	900	2	4+	
Do	425			
T. 103, R. 63, sec. 11	440			
T. 103, R. 63, sec. 12	390			
T. 103, R. 63, sec. 13	380			
T. 103, R. 63, sec. 24	425			
Do	378			
T. 103, R. 63, sec. 25	420			
T 103, R. 63, sec 35	507			
City of Plankinton, T. 103, R. 64, sec. 22	795	4½		
Plankinton Township well, T. 103, R. 64, sec. 22	775	4½	200	Pressure, 55 pounds.
Plankinton	830	4½–3	225	Pressure, 91 pounds.
Thos. Mullivan, T. 103, R. 64, NW. ¼ sec. 29	715		1,200	
O. R. Auld, in Plankinton	745	4	60	
T. 103, R. 64, sec. 27	765			
Hans Hanson, T. 103, R. 65, SW. ¼ sec. 31	830	2	40	
A. H. Henneaus, T. 103, R. 66, sec. 34	842	6		
White Lake, T. 103, R. 66	863	4	150	Pressure, 35 pounds.
White Lake, T. 103, R. 66, sec. 10	900	2	4	Pressure, 12+ pounds; city well No. 2.
White Lake, T. 103, R. 66, sec. 11	830	2	4	Pressure, 10± pounds; city well No. 3.
James Ryan, T. 104, R. 63, sec. 22	525	4½–3	168	
O. Scott, T. 104, R. 63, sec. 1	470	2	4	
A. D. Dougan, T. 104, R. 63, sec. 21	523	4½	150	Pressure, 45 pounds.
B. H. Sullivan, T. 104, R. 63, sec. 21	525	4½	150	
T. 104, R. 63, sec. 2	740			
T. 104, R. 63, sec. 3	508			
T. 104, R. 63, sec. 10	440			
T. 104, R. 63, sec. 15	465			
T. 104, R. 63, sec. 17	540			
T. 104, R. 63, sec. 20	530			
T. 104, R. 63, sec. 21	575			
T. 104, R. 63, sec. 23	364			
T. 104, R. 63, sec. 26	426			
T. 104, R. 63, sec. 35	400			
Do	450			
T. 104, R. 64, sec. 34	590			
Do	545	2	2½	
H. Koemen, jr., T. 104, R. 65, sec. 26	728	2	84	
A. W. Closson, T. 104, R. 66, sec. 3	922	2	75	

List of representative artesian wells in Aurora County, S. Dak.—Continued.

Location.	Depth.	Diameter.	Yield per minute.	Remarks.
	Feet.	*Inches.*	*Gallons.*	
S. H. Bullock, T. 104, R. 66, sec. 2	844	2	150	
T. 105, R. 63, sec. 24	487	2	32	
George Scott, T. 105, R. 63, sec. —	475	2	5	
T. 105, R. 63, sec. 2	400			
T. 105, R. 63, sec. 7	580			
T. 105, R. 63, sec. 24	500			
T. 105, R. 63, sec. 26	490			
Do	475			
T. 105, R. 63, sec. 28	508			
Do	560			
T. 105, R. 63, sec. 35	620			
T. 105, R. 64, sec. 2	640			
T. 105, R. 64, sec. 22	563			
M. E. Lewis, T. 105, R. 66, sec. 32	1,222	3	Few.	On high land; barely flows.
Mullen Bros., T. 105, R. 66, sec. 24	953	2	60	

Some representative deep well records in Aurora County are as follows:

Record of well of J. W. Ryan, NE. ¼ sec. 10, T. 102, R. 63.

Feet.	
0– 80	drift.
80–104	shale (Pierre?)
104–214	chalk rock (Niobrara).
214–324	sand rock and sand, soft water.
324–536	shale.
536–566	sandstone.
566–576	shale.
576–580	sandstone with large flow of water.
580–614	shale.

The sand rock from 214 to 324 feet is at the top of the Carlile formation of the Benton group, which extends to the probable top of the Dakota sandstone at 536 feet.

Record of well of Mr. Raesley in SW. ¼ sec. 28, T. 103, R. 63.

Feet.	
0– 90	drift.
90–230	chalk rock (Niobrara).
230–260	sand rock, with soft water.

Feet.		
260–308	blue shale.	
308–328	hard layers (probably Greenhorn limestone).	
328–477	shale	(Graneros.)
477–489	hard sandstone, first flow of water.	(Graneros.)
489–605	blue sandy shale	(Graneros.)
605–610	sand rock with second flow of 100 gallons	(Dakota.)
610–675	shale, with hard layers	(Dakota.)
675–705	sandstone, third flow, of 100 gallons	(Dakota.)
705–716	gray shale.	

In this record the sandstone at the top of the Carlile formation at 230 feet is only 30 feet thick, and its amount is found to be very variable in other wells in the vicinity.

Record of well of J. Asmuss, NW. ¼ sec. 1, T. 101, R. 64.

Feet.	
0–250	drift and clay.
250–398	chalk rock (Niobrara).
398–430	sandstone, with soft water.
430–630	shale.
630–632	sandstone and flow.

It is not certain that this well reaches the top of the Dakota sandstone, and it may flow from a first-flow sandstone low in the Graneros formation.

Record of well at Plankinton.

Feet.	
0–145	drift and clay.
145–256	chalk rock (Niobrara).
256–266	sand and soft water.
266–538	shale; some sandy layers.
538–543	sandstone, with flow.
543–763	shale, probably with a flow at 646 feet.
763–793	sandstone, with main flow.
793–795	quartzite (Sioux quartzite probably).

It is believed that the top of the Dakota is at a depth of 538 feet in this well. Quartzite is reported at a depth of 850 at White Lake, with the top of Dakota sandstone at a depth of 790 feet.

The deepest well in the county, so far reported, is on the ranch of M. E. Lewis, SW. ¼ sec. 32, T. 105, R. 66, having a depth of 1,222 feet, but only a light flow, probably owing to the height of the land on which it is situated. Samples of borings at 1,218, 1,220, 1,221, and 1,222 feet were found to be hard sandstone with iron-oxide cement, undoubtedly Dakota sandstone.

BEADLE COUNTY.

Beadle County lies mainly in James River Valley, but its southwest corner extends up the slopes of the higher lands lying to the west. The surface is covered by glacial deposits varying in thickness from 50 to 300 feet, lying on Pierre clay. This clay is several hundred feet thick and is underlain by the usual succession of Niobrara formation, Benton shales and sandstone, and Dakota sandstone lying on granite and quartzite. The Niobrara formation becomes so shaly in this county that ordinarily it is not recognized by the well borers as distinct from the adjoining formations. The Benton formation comprises a bed of sandstone at its top and other thin beds of sandstone lower down, which contain water supplies, the upper sandstone yielding water for pump wells and the lower sandstone yielding small first flows in the deep wells.

The Dakota sandstone contains a great volume of water under high pressure and affords a supply for a number of wells in all portions of the county. The sandstone lies nearly level, and, as the country is relatively flat, the variations in depth are not great. The depths of the majority of wells range from 750 to 1,100 feet, the deeper ones extending into the lower beds of the formation, where the flows usually have somewhat greater volume and higher pressure than those in the upper sandstone layers.

The following is a list of the artesian wells in Beadle county:

List of artesian wells, by townships, in Beadle County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
109	62	785–916	35–250	Pressure, 125 pounds.
109	63	806–856	Many.	
109	64	830, 910	45	
		850	45	
110	59	857	50	
110	60	930	930	Pressure, 100 pounds.
		790	111	
		770	35	
110	61	879	150–200	Pressure, 60 to 100 pounds.
		900	500	Pressure, 125 pounds.
110	62	784–1,139	350–2,250	Pressure, 120 to 165 pounds. Huron town wells.
110	63	840	....	
110	64	847	100	
110	65	870	50	
111	59	940	20	

List of artesian wells, by townships, in Beadle County, S. Dak.—Continued.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
111	59	925	50	
111	61	792	200	
		836	360	
111	62	744–788	300	
111	63	780–918	45–114	
111	64	784–870	43–100	
		930	330	Pressure, 137 pounds. Wolsey well.
111	65	1,000	80	
112	59	913, 933	33, 36	
112	60	779	400–600	Pressure, 120 pounds.
112	61	778–917	35	
		777	600	Pressure, 125 (?) pounds.
112	62	793–817	40–240	Pressure in one well, 50 pounds.
112	63	601–870	16–200	In one well the pressure is from 60 to 90 pounds, and in another 20 pounds.
112	64	900	45	
113	60	810	200	Pressure, 115 pounds.
113	61	750–810	60–125	
113	62	815	120	
113	63	890	300	Pressure, 100 (?) pounds.
113	63	900–912	50	
		953	1,260	Pressure, 150 pounds. Hitchcock well.
113	64	980–1,118	20–1,435	Pressure in one well, 175 pounds.
114	59	1,038	8	

BONHOMME COUNTY.

Bonhomme County extends northward from Missouri River into a region of plains and ridges. The greater part of the county is heavily drift covered, but there are extensive exposures of the underlying Niobrara chalkstone in the bluffs along Missouri River. The higher lands of the ridges east of Choteau Creek are underlain by Pierre shale. The county lies in the Dakota artesian area, but the higher lands in its western portion are too high for flowing wells. In the valleys and on the broad plain in the central and eastern portion of the county there are numerous flowing wells, which obtain large supplies of water at moderate depths. There is considerable variation in the volume of water, a well at Springfield yielding 3,000 gallons a minute (see Pl. LX), while at Scotland the flow is small, owing to local conditions of diminished thickness and porosity of the sandstone. The following list

gives the principal features of the deeper wells in this county from which reports have been received.

List of artesian wells, by townships, in Bonhomme County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
92	60	885, 920	....	Pressure in 885-foot well, 30 pounds.
93	58	630–665	95–100	Pressure, 42 to 45 pounds.
93	59	530–855	15–252	Pressure, 40 to 66 pounds.
93	60	620	700	Springfield city well.
93	60	592	3,292	Pressure, 86 pounds. In Springfield mill.
93	60	828	72	Pressure, 86 pounds. City well.
93	61	735–1,000	25–70	Pressure, 12 to 14 pounds.
93	62	862(?), 897	1,400–1,600	Pressure, 62 and 58 pounds.
94	58	576–645	11–100	Pressure, 40 pounds.
94	59	552–752	13–150	Pressure, 40 pounds in 752-foot well.
94	59	857	1,000	Pressure, 30 pounds. City of Tyndall.
94	61	1,074⅔	⅓	Pressure, 2½ pounds.
95	59	730–828	26–97	
96	58	590–680	9	Scotland wells.
96	59	590–700	Few.	

The well at Springfield is a phenomenal one, with its flow of 3,292 gallons per minute, although its closed pressure is not so great as that of many other wells in the State. It furnishes power for a 60-barrel flour mill by day and for an electric-light plant by night. For a while it threw sand, and when this finally ceased the flow was thought to have slightly decreased. The city well when finished was for some time allowed to run at full head, and it was then observed that the flow of the mill well was noticeably weakened for the time being.

The well at the mill at Tyndall became clogged some time ago, but it was recently cleaned out and the former flow and pressure regained.

The first well at Scotland was sunk to a depth of 582 feet, of which the last 52 feet were in "quartzite." The water supply, found in sand on the surface of this quartzite was so small that the well was regarded as a practical failure. Not far from the old well another was recently sunk through a hard sandstone bed into clear white sand at 590 feet, but obtained no increase in flow. The Layson well was sunk on the high ridge between Emanuel and Choteau creeks to a depth of 1,074 feet. Only a feeble flow was found, and the pressure was sufficient to raise the water only about 7 feet above the surface. The wells at Tyndall, those in the southeast corner

A. ARTESIAN WELL AT SPRINGFIELD, S. DAK.

Well flows more than 3,000 gallons of water per minute.

B. ARTESIAN WELL AT WOONSOCKET, S. DAK.

Well throws a 3-inch stream to a height of 97 feet.

of the county, and those in the Missouri bottom near the mouth of Choteau Creek yield more satisfactory supplies.

The artesian waters in Bonhomme County, excepting those at Scotland, Layson, and the mouth of Choteau Creek, all appear to come from approximately the same horizon. At Scotland the waters appear to be largely cut off by a ridge of the quartzite bed rock. The Layson well appears to have been sunk to a horizon considerably below that of the group of successful wells to the east and south. The low pressure in this well is due to the height of the land on which the well is sunk, while the small volume of water is no doubt due to some variation in texture, such as occasionally occurs in the Dakota beds. The wells at the mouth of Choteau Creek appear to draw their waters from a horizon somewhat lower than that at Springfield and Tyndall. Probably it is the same horizon as that which furnishes the small flow at the Layson well on the ridge to the northeast, but here the sandstone is of such porous character as to furnish a larger volume of water.

The head of the waters in Bonhomme County is considerably less than it is farther north, for the amount decreases rapidly to the south and east in this region. It appears, however, to be sufficient to bring the water to the surface over all of the county with the probable exception of the high ridge between Emanuel Creek and Choteau Creek.

The records of wells in Bonhomme County show much diversity in the underground geology. After passing through the drift they enter the chalk rock, which, having an irregular surface and thickness, varies considerably in amount. It is usually underlain by upper Carlile sandstone, sometimes separated from the chalk by clay, which yields considerable water to some of the deeper pump wells in the county. The underlying Benton shales include beds of limestone and sandstone, the latter sometimes yielding small first flows. The thickness of this formation and of the underlying Dakota appears to vary considerably. Under Scotland the Dakota sandstone is very thin. At Springfield it is penetrated for 50 feet, and in the Layson well, on the high ridge west of Springfield, a continuous bed of sandstone is reported from 810 to 1,043 feet, containing but little water, and separated from a very hard rock, presumably granite or quartzite, by a small mass of shale. The record of the Scotland well, kindly furnished by Mr. A. E. Swan, is as follows:

Record of well at Scotland, Bonhomme County, S. Dak.

Feet.	
0- 15	yellow clay.
15- 20	hardpan.
20- 42	blue clay.
42- 75	gray clay.
75- 90	black clay, gravelly.

Feet.	
90–130	chalk rock.
130–155	yellow sandstone, hard.
155–195	blue shale.
195–350	gray shale.
350–380	yellow lime rock.
380–415	shale and lime.
415–445	sand and shale.
445–451	lime rock.
451–456	sandy mud.
456–476	lime rock, shale, and marl.
476–510	sand rock, with shale streaks.
510–518	red shale and quartzite.
518–558	gray sand rock; 80-gallon flow; one-foot layer of pyrites at base.
558–589	sand rock, pinkish.
589–601	calcareous sand rock, pink.
601–674	quartzite, pink, with calcareous beds.
674–680	Sioux quartzite.

This record is probably more accurate than some others which have been published in indicating a thickness of 120 feet of chalk under the drift.

BROOKINGS COUNTY.

Brookings County is in the drainage basin of Big Sioux River, on the east coteau, and varies in altitude from about 1,600 to 1,800 feet. The region is heavily mantled by glacial drift and underlain by a considerable thickness of Pierre shale. To the south and east the Sioux quartzite appears to rise rapidly, and probably the Dakota sandstone is cut off by it in all of the area east of Volga and south of White. In the area underlain by the Dakota sandstone the altitude of the land is too high for the water to flow.

At Brookings a boring was made several years ago which is said to have reached the quartzite at a depth of about 556 feet. It obtained a small amount of water in overlying sandy beds, probably in the Benton formation, but the pressure was not sufficient to afford a flow. A well at Elkston is 230 feet deep, with the last 30 feet in sandstone, which is probably at the top of the Benton group.

BROWN COUNTY.

Brown County lies in James River Valley and consists almost entirely of a level plain traversed by a few shallow depressions carrying the drainage. It is covered with glacial deposits, but, from numerous well borings, these are known to be underlain by a thick mass of Pierre shale and underlying Niobrara, Benton,

and Dakota beds, the latter lying on quartzite and granite. The strata lie very nearly level and the average depth to the top of the Dakota sandstone is between 850 and 1,000 feet. The sandstone contains a large volume of water, yielding large flows and having in most cases a pressure considerably over 100 pounds to the square inch, the amount varying somewhat in different portions of the county. In the summer of 1903 it was estimated that there were 170 artesian wells in active operation in the county. The depth and other data of these wells are given in the following table:

List of artesian wells, by townships, in southern half of Brown County, S. Dak.

Township.	Range.	Depth.	Yield per minute.	Remarks.
		Feet.	*Gallons.*	
121	60	940	57	
121	61	900, 940	14, 43	Pressure, 168 pounds.
121	62	930, 960	106, 306	
121	63	898–980	33–96	
121	64	1,000	96	Warner town well.
121	64	903–1,015	35, 96	Pressure, 20–60 pounds.
121	65	1,070	46	
122	60	940–1,000	15–76	Town of Ferney.
122	61	900–960	39–70	Pressure, 125 pounds.
122	63	920–940	25–34	Pressure, 120 pounds.
122	64	1,000	30	
122	65	1,080	37	
123	60	920–977	10–105	Pressure, 80 pounds.
123	60	922, 960	830	Pressure, 135 pounds. (Groton town wells Nos. 1 and 2.)
123	61	920–935	15–123	
123	62	900	95	
123	63	....	31–96	
123	64	918–1,117	250–1,060	Pressures, 40 to 138 pounds. Town wells (Aberdeen). The 1,117-foot well is in T. 123, R. 63.
123	64	1,300	1,350	Aberdeen, city well No. 3.
123	64	1,300	1,000	Aberdeen, city well No. 4.
123	65	1,070–1,167	25–53	
124	60	942	150	Pressure, 137 pounds.
124	62	900	25	
124	63	945	123	
124	64	975	31	
124	65	....	....	

These wells passed through a great thickness of gray and blue clays, representing the Pierre, Niobrara, and Benton formations. In the latter there was generally found a thin bed of sandstone yielding a small amount of first-flow water. The Dakota

sandstone is usually overlain by hard cap rock, and consists of a succession of soft sandstone layers, with bodies of shale and sandy shale varying in thickness from a few feet to 50 or 60 feet in some cases. All the sandstones contain water, but the volume and pressure usually increase in the lower beds. In the city well No. 4, at Aberdeen, the base of the formation was found to consist of 49 feet of sand without much water, underlain by quartzite and granite, the top of the latter being entered at a depth of about 1,267 feet.

BRULE COUNTY.

Brule County extends eastward from Missouri River and is in greater part an elevated plateau, or region of gently rolling plains, from 300 to 400 feet higher than the river. In the southern portion the Bijou Hills rise still higher, their altitude probably being something over 2,000 feet. All of the highlands are covered by glacial drift lying on Pierre shale. The Bijou Hills are capped by Tertiary sands and green quartzite. Missouri River cuts through the Pierre shale and exposes the Niobrara chalkstone in the lower valley slopes.

The artesian waters of this county have been extensively developed, for over 60 wells are reported, most of them between 800 and 1,000 feet in depth. They nearly all furnish large flows of excellent water, which is used mainly for irrigation. One of the wells near Chamberlain is reported to have a flow of 3,000 gallons per minute. The average flow of a 6-inch well is about 500 gallons, and of a 2-inch well, of which here are many, from 50 to 150 gallons per minute. On the higher lands the pressures are moderate, but in some cases rise above 50 pounds per square inch. Wells on the lower lands have greater pressure, one of the city wells in Chamberlain having over 100 pounds and developing 10 horsepower.

The greater part of the water is obtained in the upper part of the Dakota sandstone, but, in a region extending through Kimball, the upper beds are too compact to yield much water and it is necessary to sink to a looser sandstone below. Artesian waters appear to be available throughout this county, except on the higher portions of the Bijou Hills. The following is a list of wells in Brule County, arranged by townships:

List of artesian wells, by townships, in Brule County, S. Dak.

Township.	Range.	Depth.	Yield per minute.	Remarks.
		Feet.	*Gallons.*	
101	67	750– 950	18– 60	Pressure 20 to 40 pounds.
101	68	815– 962	20–1,098	Pressure 12 to 25 pounds.
102	67	750– 880	18– 100	Pressure 40 pounds in some wells.
102	68	800–1,050	9–1,000	In one well pressure is 10 pounds.
102	69	900	50– 800	Pressure varies from 5 to 40 pounds.

List of artesian wells, by townships, in Brule County, S. Dak.—Continued.

Township.	Range.	Depth.	Yield per minute.	Remarks.
		Feet.	*Gallons.*	
102	70	1,027–1,230	400– 900	Pressure 2 to 40 pounds.
102	71	1,230–1,270	45– 605	
103	67	840– 956	40– 90	
103	68	900–1,210	60– 750	
		1,254	185	Kimball city wells. Original pressure 7 to 20 pounds.
103	69	983–1,210	12– 60	Pressure 40 pounds.
103	71	1,063, 1,100	25–1,000	
104	68	960	128	
104	69	940–1,200	60– 70	
104	70	927	1,385	Flows at 890 and 903 feet.
104	71	600–1,186	3– 300	
		645, 670	4,500	Chamberlain Electric Light Co.'s wells Nos. 1 and 2; supply and pressure diminished.
		540– 600	1,450–5,000	Quarnberg's 4 wells. Flow decreasing.
		815, 960	537, 700	Chamberlain city wells Nos. 1 and 2; supply greatly diminished.
105	67	940	80	
105	68	930– 987	300– 815	Pressure from 5 to 75 pounds.
105	69	1,075	30	Flows at 990 and 1,060 feet. Pressure 16 pounds.

Two representative well sections in this county are as follows:

Record of well on Carpenter farm, near Pukwana, S. Dak.

Feet.	
0– 60	black loam.
60– 72	yellow sand.
72–196	blue clay.
196–435	chalk rock.
435–536	black clay.
536–559	first sand.
559–749	blue-black clay.
749–771	second sand.
771–845	light chalky clay.
845–907	third sand (Dakota sandstone).

This well is on high land and the chalk rock is overlain by over 100 feet of Pierre clay.

Record of power well in Chamberlain, S. Dak.

Feet.	
0– 22	sand and gravel.
22– 42	blue clay.
42–132	chalk rock.

Feet.	
132–498	blue clay, tough and dark below.
498–507	sand.
507–555	tough dark clay.
555–584	sand and clay with flow.
584–612	find dark sand, very fine below.
612–619	hard sand rock.
619–633	compact sandstone.
633–689	sandstone under capstone yielding a flow of 4,350 gallons per minute from an 8-inch pipe.

The chalk rock in this section is in the lower portion of the Niobrara, and the Benton shales appear to extend from 132 feet to 555 feet in depth.

In its lower part the deep boring at Kimball penetrated very hard dry sandstones, which, it was thought, might possibly be Sioux quartzite. Samples forwarded by the driller from 1,157, 1,175, 1,190, 1,210, 1,225, 1,240, and 1,246 feet represented hard buff sandstone with considerable oxide of iron in their cement, especially in the 1,246-foot sample. Irony sandstones were also penetrated from 1,130 to 1,138 feet and 1,140 to 1,150 feet; hard sandy clay from 1,150 to 1,155 feet; buff sandstone at 1,143 feet; and buff clay from 1,153 to 1,170 feet.

BUFFALO COUNTY.

Including part of Crow Creek Indian Reservation.

In this county the geologic conditions are similar to those in Brule County, but the depth to the Dakota sandstone is slightly greater, the strata dipping gently to the northwest and the land rising slightly as the river is ascended. It is probable that the depth to the sandstone is about 900 feet at the northwest end of the county in Missouri Valley, and 1,100 to 1,200 feet in the higher lands.

Judging from the pressure observed in wells in this county and in the surrounding counties artesian flows may be expected throughout the area, except possibly on the very highest summits northwest of Gann. Several wells are reported; one at Crow Creek Agency, another in sec. 1, T. 108, R. 70, and a third on the south branch of Crow Creek below Vega. The latter has a depth of 875 feet and a flow of 135 gallons per minute of hard water, with a pressure estimated at 75 pounds. It is a 2-inch well, and the first flow was reported at 800 feet. The well in T. 108, R. 70, is in the southwest quarter of section 1. It is said to be 1,450 feet deep, 2 inches in diameter, and has a flow of 27 gallons per minute. The water rises 20 feet or more above the ground.

Crow Creek Agency.—The well at this agency was sunk in 1896 by the United States Indian Bureau. It has a depth of about 780 feet and is 6 inches in diameter. The flow is very large, and it is stated that the column of water rises 5

feet above the surface when the well is wide open. The closed pressure exceeded 180 pounds, the total registering capacity of the gage. With a $1\frac{5}{8}$-inch nozzle outlet the remaining pressure is 85 pounds; with a $1\frac{7}{8}$-inch nozzle outlet, 70 pounds; and with a 2-inch nozzle, 65 pounds. The temperature of the water is 72°, and its specific gravity 1.004. The well at first threw out white sand, but this discontinued after a while, and its subsequent behavior has been entirely satisfactory. The first flow was found at 409 feet, but its head was barely sufficient to bring the water above the surface. The final flow was reached at 760 feet, and the water-bearing sand was penetrated to a depth of 20 feet. The following record is based on a few samples, with explanatory notes by the agent:

Record of artesian well at Crow Creek Agency, on Missouri River, Buffalo County, S. Dak.

Feet.	
40- 78	gravelly beds, some clay.
78- 88	gray clay on thin bed of small gravel.
88-242	gray shale.
242-252	gray limestone.
252-409	gray chalk, etc., with first flow at 409 feet.
409-435	pyrites.
435-700	shale (?) on 3-foot layer of pyrites.
700-760	shale, with pyrites.
760-780	sandstone, main flow.

BUTTE COUNTY.

This county occupies the northwest corner of the State, with an area of over 8,500 square miles, lying mainly on the Great Plains. Its southwest corner is crossed by the Black Hills uplift, exposing formations from the Spearfish red beds upward. The north, central, and east portions of the county are occupied by a considerable thickness of Laramie and associated formations, the Dakota sandstone lying more than 2,500 feet below the surface in the lowest valleys. The Laramie sandstones contain local water supplies which may be available in deep wells, but their capabilities in this respect have not yet been tested.

The greater part of the region lying between Indian Creek and Owl River is underlain by Pierre shales, and the Dakota sandstone appears to be within reach of deep borings; but judging from the pressures exhibited in the wells at Belle Fourche the country is too high for artesian flows. Between Indian Creek and the hogbacks of Dakota sandstone south of Belle Fourche there is a district extending northwest and southeast in which the Dakota sandstone waters are available at depths ranging from slightly over 300 feet just south of Belle Fourche to about 2,000 feet on Indian Creek, the rate increasing as the formation descends in its dip to the northeast.

Belle Fourche.—There are several excellent wells at Belle Fourche and in the adjoining region which obtain water under considerable pressure from the Dakota and underlying sandstones. The first well at Belle Fourche was sunk in 1894, and is reported to be 525½ feet deep. Its original flow was 60 gallons per minute. Its head raises it into a tank (see Pl. LX, *A*) 72 feet above a small knoll just south of the railroad station, and it is claimed is sufficient to raise it very much higher. Owing to some unknown cause its flow is now much diminished; probably it is partly choked or its casing leaks. The materials penetrated were shales, 207 feet; sand, 100 feet, yielding a small flow at 245 feet; soft clay, 118 feet, containing a thin layer of sand of 23 feet, yielding a small second flow; and sandstone to the bottom, containing water at various horizons, with gradually increasing volume and head, the maximum flow being at about 510 feet. A second well, on somewhat lower land near the center of town, had the following record:

Record of well at Belle Fourche, S. Dak.

Feet.	
0–300	shale.
300–330	hard sandstone, small flow.
330–410	soft sandstone, with flow at 410 feet.
410–435	red, white, and mottled clay (Fuson formation).
435–470	gray sandy clay and sand with lignite fragments.

A third well was bored, in 1903, to a depth of 881 feet, which found water-bearing strata at intervals from 297 to 560 feet. The well is 4 inches in diameter and has a flow of 30 gallons per minute. Several small wells in the vicinity and up Hay Creek to the west obtain flows at depths of 300–380 feet. On Belle Fourche River, 3 miles below Belle Fourche, Mr. F. M. Fuller has a well, completed in 1901, which has a depth of 736 feet and obtains a water supply from 726 feet, flowing 60 gallons per minute from a 3-inch hole. The pressure is said to be sufficient to raise the water 40 feet and apparently considerably more. On the Barbour ranch on the Belle Fourche, 6 miles above the village, there is a well with a large flow from a depth of about 350 feet. At Minnesela, in Redwater Valley, a well finished in 1904 has a depth of 381 feet, obtaining a 10-gallon flow from sandy Dakota beds, which extend from 360 to 381 feet.

In Hay Creek Valley, near the Wyoming State line, there are several wells about 350 feet deep, which obtain satisfactory flows from the sandstone near the base of the Sundance formation.

CHARLES MIX COUNTY.

Charles Mix County extends along the east bank of Missouri River for 75 miles or more and onto the High Plains to the northeast. These plains are elevated about 300 feet above the river and have some ridges upon them which rise considerably higher. The high lands are covered by drift, but along the river banks

and in some of the valleys the Niobrara chalkstone appears overlain by Pierre shale. The Dakota sandstone underlies the county and is the source of water in numerous wells. Artesian flows are available in all but the very highest lands, there being one small nonflowing area west of Geddes and another on the morainal hills south of Wagner; possibly there are a few other localities too high for flows. Wells are most numerous on the plains in the northern townships; others are sunk at intervals along the river bottom and in some of the southeast townships. The following nearly complete list includes all wells from which returns have been received:

List of artesian wells, by townships, in Charles Mix County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
94	64	651	3,000	Pressure, 119 pounds.
95	63	795	....	
95	64	1,020	....	Sec. 15. No flow.
95	65	730	16	Pressure, 40 pounds.
96	62	150	....	
96	63	151	8–15	
96	64	144	7½	
96	65	775½, 802	1,500	Pressure, 70 pounds.
96	67	266	....	Pressure, 10+ pounds.
96	68	810	37	
97	63	150	....	
97	66	800–905	4–20	
97	67	700–900	5–150	Pressure, 5 pounds.
98	64	772	200	Pressure, 52 pounds.
98	65	920, 940	6, 11	Pressure, 2 to 8 pounds.
98	66	820–950	50–65	Pressure, 24–30 pounds.
98	67	800–991	6–65	Various pressures are reported, the greatest being 63 pounds.
98	68	800–1,110	10–150	Pressure, 3 to 80 pounds.
98	68	1,220	....	Sec. 14. No flow.
98	69	250, 644	50	Pressure, 24+ pounds.
99	66	840	20	Do.
99	67	730–950	4–50	The greatest pressure reported is 50 pounds.
99	68	720–1,006	2–78	The greatest pressure reported is 40 pounds.
99	69	944, 966	60	Pressure, 50 pounds.
99	70	840–1,000	10–30	Pressures, 20 to 26 pounds.
100	67	734–875	20–120	The greatest pressure reported is 87 pounds.
100	68	720–930	7–31½	The greatest pressure reported is 13 pounds.
100	69	856–1,030	15–125	In one well the pressure is 15 pounds.
100	70	890, 900	16	Pressure, 30 pounds.
100	71	688–868	500–2,352	

The materials penetrated in wells in Charles Mix County vary considerably. On the higher lands they consist of more or less drift and Pierre shale, underlain by chalk rock, and this in turn by the Benton formation, with layers of sandstone and limestone. The Dakota sandstone is usually entered for some distance to obtain a sufficient large volume of water, and on the higher lands for increased pressure. The following record is given of well No. 2, sunk by the Government at Lake Andes:

Record of well No. 2, Lake Andes, Charles Mix County, S. Dak.

Feet.		
0– 20	yellow gravelly clay.	
20– 45	blue clay and hardpan.	
45– 55	sand and gravel.	
55–130	blue bowlder clay.	
130–163	sand and gravel.	
163–180	black shale (Pierre?).	
180–265	blue shales, with lime	Chalk?
265–280	lime rock	
280–335	yellow sandy shale.	
335–475	gray shale.	
475–520	blue shale, with lime.	
520–550	shelly lime rock.	
550–615	blue shale.	
615–623	sandstone, light color.	
623–725	blue shale, with sand and pyrites.	
725–773	sandstone, light color.	
773–775½	soapstone.	

The sandy beds that lie a short distance below the supposed chalk probably represent the sandstone member, which is persistent under a wide area in southeast South Dakota. The layers of lime rock, which extend from 520 to 550 feet, may represent the Greenhorn limestone horizon in the Benton formation. The precise boundary between the Benton and Dakota is difficult to discern in the record as given, but probably it is at a depth of 725 feet, the sandstone extending from this depth to 773 feet and yielding a 1,500-gallon flow of water.

The following record is given for the well at the Yankton Agency:

Record of well at Yankton Agency, Greenwood, Charles Mix County, S. Dak.

Feet.	
0– 1	soil.
1– 25	yellow sandy clay.
25– 44	gray shale.
44– 75	blue shale.
75– 91	blue shale, with chalk and gravel.
91–114	yellow sand and gravel.
114–117	gray rock.

Feet.
117–123........gray shale.
123–144........gray limestone and pyrites.
144–178........sandy shale and sand.
144–150........much water, which rises to —65 feet.
178–199........blue shale.
199–275........black shale, with pyrites and shells.
275–380........blue shale, tough.
380–420........black shale, with pyrites and shells.
420–421........sand, with flow of 10 gallons per hour; temperature, 56°.
421–448........brown shale, with streaks of sand and lime rock.
448–497........black shale, with thin sandy streak; flow, 7 gallons per minute at 482–495 feet; soft water.
497–500........gray shale.
500–531........black shale, with lime and pyrite streaks.
531–552........gray shale.
552–556........sandstone; third flow, 15 gallons per minute.
556–577........gray shale.
577–579........sandstone; fourth flow, 30 gallons per minute; soft water.
579–641........gray shale full of lime and pyrite streaks 2 to 12 inches thick.
641–651........sandstone, very soft; 3,000-gallon flow, hard water; temperature, 70°.

CHEYENNE INDIAN RESERVATION.

This reservation is in north-central South Dakota, lying north of Cheyenne River, between Missouri River and longitude 102°. It comprises the deep valleys of Cheyenne, Missouri, and Owl rivers, together with Fox Ridge and the range of high hills north of Owl River, a region having considerable diversity of topography and a range of over a thousand feet in altitude. The high ridges are capped by the Fox Hills sandstone and to the west by the Laramie formation, while the valleys are excavated deeply in the Pierre shale. This shale has a thickness of about 1,000 feet, as nearly as could be ascertained, and is underlain by a regular succession of Niobrara and Benton shales and Dakota sandstone. The latter has been reached at the Cheyenne Agency at a depth of 1,317 feet and found to contain a large volume of water—500 gallons per minute under a pressure of 205 pounds to the square inch. As the mouth of the well is at an altitude of about 1,500 feet above sea level, the pressure indicates a head of 1,970 feet—one sufficiently great to afford a flow far up the slopes of the high ridges in the central and northern part of the reservation and throughout the valleys. As the hydraulic gradient rises to the west toward the Black Hills, the altitude at which flows are obtainable and the pressures in the lowlands, both gradually increase also in that direction.

Owing to the slight westerly dip of the formations and the rise in the land the Dakota sandstone doubtless lies much deeper in the western portion of the

county than at Cheyenne Agency. On Cheyenne River, at the west border of the county, its depth is probably nearly 2,000 feet. On Owl River, which is in a somewhat higher valley, it is estimated to be at a depth of at least 2,200 feet.

Cheyenne Agency.—The well at Cheyenne Agency is in Missouri Valley, on a terrace about 40 feet above the river. The flow was found at a depth of 1,317 feet, under a cap rock 1 foot thick. The pressure when the well was first closed was 187 pounds, but the amount increased to a maximum of 205 pounds in four days. The well contains 530 feet of 8-inch casing, 1,015 feet of 6-inch casing, and 1,337 feet of 4-inch casing. The water has a temperature of 79° or 80°, is similar in salinity to that at Pierre, and also contains much illuminating gas, which was encountered by the 8-inch casing and amounts to about 2,400 cubic feet per day. The log of the boring, kindly furnished by Mr. A. E. Swan, is as follow

Record of artesian well at Cheyenne Agency, Cheyenne Indian Reservation, S. Dak.

Feet.	
0– 21	yellowish gravelly clay.
21– 26	sand, bowlders, and shale fragments.
26– 40	shale, hard.
40– 280	blue shale, firm.
280– 390	blue shale, soft.
390– 485	black shale.
485– 500	sandy shale.
500– 515	gray shale.
515– 575	hard shale.
575– 700	dark-gray shale; gas at 650 feet.
700–1,050	black shale, with occasional beds of hard sandstone.
1,050–1,200	blue shale.
1,200–1,311	dark-gray shale; gas.
1,311–1,317	yellow lime rock, soft.
1,317–1,323	white sandstone; flow.
1,323–1,337	brownish shale.

Although the water of this well is somewhat saline, the boring is to be regarded as a great success. The pressure is phenomenal and could, if necessary, be utilized for running extensive machinery.

CLARK COUNTY.

Clark County extends from the east margin of the James River plain far up the western slope of the east couteau, having a range in altitude from about 1,400 feet to 1,800 feet.

Raymond.—The first flowing well bored in the county was on the farm of Bohri brothers, in SE. ¼ sec. 22, T. 117, R. 59, about 1½ miles northeast of Raymond, at an

altitude of about 1,490 feet above sea level. The total depth of the boring was 1,200 feet, but the casing extended only to 1,075 feet. The diameter was 6 inches, and the lower 40 feet were perforated. Flows were found in sands from 1,005 to 1,025 feet and from 1,050 to 1,053 feet. The well was finished in the spring of 1892, and the water continued to flow with a closed pressure of 80 pounds until the winter of 1893, when the casing became clogged up and the flow diminished to a small drip. The log of the boring is as follows:

Record of well 1½ miles northeast of Raymond, S. Dak.

Feet.	
0– 37	yellow clay.
37– 66	blue clay.
66– 80	sand, gravel, and clay.
80– 100	sand and clay, sand and gravel.
100– 126	hardpan.
126– 184	gray shale.
184– 194	blue shale.
194– 199	slate.
199– 279	blue shale.
279– 344	gray shale.
344– 434	blue shale.
434– 524	dark-brown shale.
524–1,005	blue shale, with thin layer of sand, rock, and shale.
1,005–1,025	sand rock, with flow.
1,025–1,053	lime rock, with thin layer of sand containing small flow.
1,053–1,143	shale.
1,143–1,198	green shale (rock layers).
1,200	hard rock.

The water-bearing horizon is in the top of the Dakota sandstone, and probably is the same as the one which supplies the Doland, Andover, Conde, Groton, Turton, and many other wells. This water and a smaller flow are obtainable all along the western margin of the county up to altitudes of 1,600 feet.

Several wells near Raymond obtain flows at 1,013 to 1,075 feet, and several in the southwest corner of the county averaging from 1,000 to 1,040 feet deep have moderately large flows under considerable pressure.

Clark.—Two attempts have been made to obtain the deep-seated waters at the village of Clark, but in both cases the tools were lost at a depth of about 1,200 feet and the borings abandoned. The water-bearing beds probably lie at a depth of about 1,300 feet at Clark, but the head is not sufficient for a surface flow at that locality. No doubt a well to this depth would obtain a large volume of water, which would rise to within about 110 feet of the surface and afford very satisfactory force-pump wells.

CLAY COUNTY.

Clay County lies in the valleys of James and Missouri rivers near the southeast corner of South Dakota. Its surface is mostly covered by glacial and alluvial deposits, but the underlying formations—chalkstone in the higher lands and Benton shales in the lower valleys southward—occasionally appear. The Dakota sandstone lies at a moderate depth below the surface, 600 feet in the northwest corner of the county and about 200 feet in its southeast corner, the beds rising gradually to the southeast.

The sandstone contains water throughout the county, but, owing to the diminution of head to the southeast, flows are obtainable only in the lower lands. The flow area comprises the southwest quarter of the county, the valley of Vermilion River and its larger branches, and the lowest lands of Missouri Valley below the mouth of Vermilion River. In this area there are many flowing wells, mostly from 250 to 500 feet in depth, which yield large supplies of excellent water. Most of the wells are small and many obtain their waters from the top of the Dakota sandstone. Some first flows are also obtained from sandstone near the bottom of the Benton formation. The following is a list of the wells in Clay County:

List of artesian wells, by townships, in Clay County, S. Dak.

Township.	Range.	Depth.	Yield per minute.	Remarks.
		Feet.	*Gallons.*	
91	51	210–280	6–20	
92	51	300–400	6–90	Water usually rises a few feet above the surface.
92	52	289–507	2–200	Water rises to +20 feet in some cases.
92	53	205–367	2–25	Some chalk penetrated. One 35-pound and one 20-pound pressure reported.
93	51	312–410	1–20	In one well the pressure is 4 pounds.
93	52	243–400	4–20	Pressure 15 pounds.
93	53	240–367	1½–150	Pressure 6 to 40 pounds. One well contains alkaline water.
94	52	400	1¼	
		402	5	
94	53	260–500	Few.	Some irony water.
95	52	260–507	1–3	Alkaline water in one well. Pressure 8 pounds.

CODINGTON COUNTY.

Codington County is on the summit of the east coteau, at an elevation varying from 1,700 to over 1,900 feet. At the surface is a thick mass of glacial drift lying on many hundred feet of Pierre shale. The county is underlain by Dakota sandstone, which is doubtless water bearing, but has a head only sufficient to cause the water to rise to about 1,650 feet above sea level, so that no flows are

to be expected. The sandstone lies at a depth of about 1,100 feet at Watertown and correspondingly deeper in the highlands of the surrounding hills; as it slopes downward to the west, it lies deeper in that direction also.

CUSTER COUNTY.

All the rocks from the Algonkian granites and schists to the Pierre shale and White River formation outcrop within Custer County, which extends across the greater part of the Black Hills uplift and east to Cheyenne River. There are many running streams in the higher lands within its borders, but in the lower regions to the east and southwest increased water supplies are greatly needed. On the east side of the crystalline-rock area the formations dip steeply to the east and pass beneath the surface in rapid succession, the Dakota and associated sandstones reaching a depth of 2,600 feet under the higher lands in the eastern part of the county. The top of the Dakota sandstone reaches a depth of 500 feet within about a mile from the foot of Hogback Range and keeps descending at about the same rate for the next 5 miles. Then the dip gradually diminishes, until in the extreme eastern part of the county the beds lie nearly level. At Hermosa the depth to the top of the sandstone is probably not over 600 feet; at Fairburn, about 900 feet. Along the lower portions of Spring, Battle, and French creeks the Dakota sandstone probably lies from about 2,300 feet to 2,500 feet below the surface, and correspondingly deeper in the higher lands of the intervening divides. Along Cheyenne River the depth probably averages from 2,200 to 2,400 feet. These calculations are based on the measurements of the thickness of the Benton formation, about 1,300 feet, and the Niobrara formation, about 200 feet, and from the occurrence of the Tepee zone in the Pierre shale, apparently at a horizon of about 1,000 feet above the base of that formation. It is probable that flowing water could be obtained throughout the lower lands east of the Hogback Range, but not on the divides. In the southwest corner of the county there is a small area underlain by Dakota sandstone which may be expected to yield flowing wells, as indicated by the experience of the 550-foot flowing well at Argentine, in the adjoining county to the south.

It is possible that underground waters may be found under Red Valley in this county in the Minnelusa formation or in the underlying Pahasapa limestone and Deadwood sandstone. These horizons have not yet been explored for water in this district, but may prove to be sources of supply, as in the case of the Pahasapa limestone at Cambria, a short distance northwest. The unsatisfactory results of the boring at Minnekahta junction are discouraging as to the prospects for water in these horizons to the southeast, although that boring did not test the question conclusively, as it apparently did not reach the Deadwood sandstone. It is thought

that this sandstone lies at a depth of about 1,000 feet along the center of Red Valley, the amount increasing slightly toward the Hogback Range and decreasing toward the Minnekahta limestone outcrop.

Buffalo Gap.—At this place two attempts were made to reach the Dakota sandstone. Both borings were slightly over 700 feet in depth, entirely in the Benton formation. One was on the crest of a low ridge in the western part of the town, and the other was on the lower land on the main street. As the latter began in the middle of the Carlile beds, it would probably have reached the Dakota sandstone within the next 500 feet, and have obtained a flow, although the altitude is just about at the limit to which the water should be expected to rise in that vicinity.

DAVISON COUNTY.

This county lies entirely in James River Valley, near the eastern margin of the Dakota artesian basin. Owing to uplift of the formations the water-bearing beds are near the surface in a portion of the county, and the waters have been extensively developed by many wells, mostly of moderate depth. In the region south of Mitchell the underground ridge of Sioux quartzite has considerable prominence, its slopes intercepting the Dakota sandstone, so that in several townships the waters from the latter are not available. This is the case south and southwest of Mitchell for several miles, although in a portion of the area sandstones in the Benton formation overlap the quartzite and yield flowing wells, in which, however, the pressure is sufficient to afford flows only in the lower lands. Several wells in this district have been bored to the "bed rock," and, although in some cases obtaining water, have not had sufficient head to afford a flow. In the north, west, and south portions of the county there are wells in nearly every section, most of which find water supplies at less than 500 feet below the surface. Some obtain flows from the sandstones underlying the chalk, others from sandstones low in the Benton group, but most of them have penetrated to the top of the Dakota sandstone. In the southwest corner of the county the land rises considerably and the sandstone dips toward the southeast, so that the depth to the Dakota water rapidly increases. In the extreme southwest portion of the county the depth is between 750 and 800 feet below the surface, and in the valley of Enemy Creek between 350 and 450 feet. About Mount Vernon many wells obtain water, apparently from Dakota sandstone, at depths from 300 to 420 feet in greater part, in most cases also finding upper flows in sandstones of the Benton formation. Halfway between Mount Vernon and Mitchell there is an area of considerable size in which the Dakota sandstone reaches its maximum uplift and affords flows in wells from 250 to 300 feet deep. On Firesteel Creek and along James River the sandstone is also reached by wells from 200 to 300 feet in depth.

In the northern portion of the county the Dakota sandstone dips to the north and the depths increase, but only to 460 feet in the extreme northwest corner. The following is a list of the principal borings in the different townships of Davison County:

List of artesian wells, by townships, in Davison County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
101	60	315–525	10–45	Deepest wells are in southwest corner of township.
101	61	350–640	....	Depths increase regularly from northeast to southwest in this township.
101	62	480–775	60	
102	60	195, 360	No flow.	Flowing water only in southwest corner of township.
102	61	250–500	....	
		250, 375	....	To "bed rock." No flow in western part of township.
102	62	350–535	....	Depth increases gradually southwest of Enemy Creek. A 280-foot well reached bed rock in southeast corner of township (no flow).
103	60	330–550	....	
103	60	765	....	In Mitchell flows at 285, 376, 445, and 540 feet. Quartzite at 540–765 feet.
103	60	433–586	20–600	In Mitchell and vicinity; pressures, 13–28 pounds.
103	60	294	....	Southwest of Mitchell. Quartzite; no flow.
103	61	250–375	....	
		300, 425	....	Wells to bed rock in southeast corner of township. No flow.
103	62	315–495	....	Depths gradually increase to southwest.
		646	700	Flows at 350, 470, 620 feet.
104	60	237–507	10–100	Water beds rise to the east. Some water also in Benton sandstone.
104	61	260–415	....	Most wells have also first flow from Benton sandstone.
		585–653	Many.	Deep into Dakota sandstone. Several flows (235, 480, and 585 feet.
104	62	300–601	....	Depths increase northwestward. Many wells have also first flow from Benton sandstone.

DAY COUNTY.

This county lies mainly on the high coteau, but, to the west, extends to the plain of James River Valley. The coteau consists of a high ridge of glacial deposits underlain by a great thickness of Pierre shale. The Dakota sandstone underlies the entire county, having a depth of about a thousand feet at Andover, but being very much deeper under the high lands east. It appears to dip gently

to the west, judging from its difference in altitude in the well at Milbank and at other places in James River Valley. The formation is undoubtedly water bearing throughout, but as the maximum head of the water is only about 1,680 feet and the land on the summit of the coteau has an elevation of from 1,750 to 1,900 feet, flowing wells are not obtainable far east of Andover. There are several successful wells in the vicinity of Pierpoint and at Andover; but on the coteau at Webster, although the Dakota sandstone appears to have been reached, the altitude is too great to afford a flow.

Andover.—This well has a flow of 300 gallons per minute, a pressure of 90 pounds to the square inch, and a bore of 6½ inches. Its log is as follows:

Record of well at Andover, S. Dak.

Feet.	
0– 50	soil, sand, and clay.
50– 75	blue clay.
75– 575	blue shale.
575– 590	limestone.
590–1,070	shale with streaks of limestone.
1,070–1,075	sandstone with water.

The water contained 150 grains per gallon of saline ingredients, of which 20 grains are chloride of sodium.

Pierpoint.—The Potter well, 2 miles west of Pierpoint, has a depth of 970 feet, a diameter of 1¼ inches, a flow of 35 gallons per minute, and a pressure of 90 pounds to the square inch. The Lemmon well, a short distance east of the village, has a depth of 1,200 feet, a diameter of 1¼ inches, and a 15-gallon flow under 93 pounds pressure. The first flow is at 1,070 feet.

Webster.—In the boring at Webster, it is claimed that a depth of 1,550 feet was reached, but by some it is asserted that only 1,400 feet was attained. By some also it is claimed that a small flow was found at 1,100 feet in 1896. It is improbable that this flow is derived from the Dakota sandstone, for that would indicate a head of 1,840 feet, an amount very much greater than the head in the wells in James River Valley to the west and at Milbank to the east. It is reported that the principal formation underlying the drift was shale, with some beds of pyrites, limestone, and sandstone, and it is also stated that sand supposed to be Dakota sandstone was penetrated, which yielded a large amount of water that did not rise to the surface. Some samples of borings submitted were mainly fine sand, but, as they are evidently washings from the drillings and there is no statement furnished as to their thicknesses, they throw no light on the stratigraphy.

List of artesian wells in Day County, S. Dak.

Location.	Depth.	Diameter.	Average yield per minute.	Remarks.
	Feet.	*Inches.*	*Gallons.*	
Webster	1,550	2		Unsuccessful.
Jno. Marso, T. 122, R. 59	1,080	1½	40	Pressure, 85 pounds.
Pierpont station, T. 123, R. 58	1,240	3		
T. 124, R. 58, northeast of Pierpont	1,240			Water just flows.
J. C. McConnell, T. 124, R. 58, sec. 6	930	1¼	28	Pressure, 70 pounds.
T. P. & W. H. Lemmon, T. 124, R. 58	1,200	1¼	15	Pressure, 40 pounds.
Thos. Burridge, T. 124, R. 59, sec. 2	930	1¼	40	Pressure, 75 pounds.
V. R. Potter, T. 124, R. 59, sec. 36	970	1½	35	Pressure, 90 pounds.

DEUEL COUNTY.

Deuel County lies on the east side of the east coteau, embracing the ridge which lies between Sioux and Minnesota rivers. The altitudes are about 1,600 feet in the southeast corner, 1,800 feet in the center, and 1,300 feet in the northeast corner. The high lands are thickly mantled by glacial drift lying on a thick mass of Pierre shale. Dakota sandstone underlies the entire county at depths from 1,200 to 500 feet, being nearest the surface in the lowest land in the northeast corner of the county. The formation probably contains water having a head from 1,400 to 1,500 feet, which would yield a flow in the extreme northeast corner of the county. So far as known, no wells have been sunk to test the conditions of the deeper seated underground waters.

DOUGLAS COUNTY.

Douglas County is on the high lands between the valleys of James and Missouri rivers. It is covered thickly by drift, which is underlain by several hundred feet of Pierre shale. This formation is penetrated by wells which also pass through the Niobrara chalkstone and the Benton shales and sandstone to reach the Dakota sandstone. This sandstone lies nearly level, or has a slight dip to the southeast, but, owing to the irregular topography, varies considerably in depth below the surface.

Most of the wells are between 750 and 1,000 feet in depth and obtain abundant supplies of excellent water, under pressure sufficiently great to indicate that flows are obtainable in all parts of the county, unless possibly on some of the very highest points in northwest and northeast townships. In the following list are given facts relating to all of the wells in this county from which returns have been received:

List of artesian wells in Douglas County, S. Dak.

Location.	Depth.	Diameter.	Average yield per minute.	Remarks.
	Feet.	*Inches.*	*Gallons.*	
Delmont	821	2	60	
City of Armour	757	6	1,500	Pressure, 55 pounds.
O. H. Bush, T. 98, R. 63, sec. 20	722	1¼	Many.	Pressure, 64 pounds.
Armour Mill Company	800	8	1,500	
L. W. Wheelock, T. 98, R. 64, sec. 2	901	8–6	1,200	
Jno. J. Walsh, T. 98, R. 64, sec. 24	736	2	20+	
C. O. Knapp, T. 98, R. 65, sec. 2	860	6	900	
J. A. Wilson, T. 99, R. 63, sec. 35	703½	8–6	2,100.	Pressure, 75 pounds.
County well, T. 99, R. 65, sec. 14	925	4	600–700	
F. E. Van Zee, T. 99, R. 65	1,010	6	1,000	
Ernest Bertram, T. 100, R. 62, sec. 16	600	2	Many.	
County well, T. 100, R. 62, sec. 18	1,025	....	1,025	
Flensburg	611	2	60	
Flensburg, ½ mile west	651	2	....	
Flensburg, ¾ mile west	775	2	65–70	
County well, T. 100, R. 63, sec. 15	750	4	600–700	
County well, T. 100, R. 64, sec. 26	937	6	900	Pressure, 40 pounds.
County well, T. 100, R. 64, sec. 26	975	4	1,000	
J. Markin, T. 100, R. 65, sec. 9	80	12	Few.	

The wells appear to draw their supplies from the upper portion of the Dakota sandstone in most cases, but others go deeply into it so as to gain additional pressure and volume. The sandstone appears to be 150 feet or more in thickness, lying mostly in one body, but locally there are intercalated masses of shale. At the county well in sec. 26, T. 100, R. 64, it is reported that the sand rock was entered at 800 feet and was found to be underlain by granite at 937 feet. For the first 60 to 140 feet the wells pass through drift deposits, then through 100 to 200 feet of Pierre shale, and 50 to 80 feet of chalk rock, into a bed of upper Carlile sandstone which persists over a wide area and yields water to several pump wells 300 to 450 feet deep. The Benton shales beneath this sandstone contain a layer of lime rock in their lower portion, and occasional layers of sandstone, which at some localities yield slight flows.

EDMUNDS COUNTY.

Edmunds County extends from the summit of the Bowdle Hills eastward into James River Valley, comprising lands in altitude from 1,400 to slightly over 2,000 feet. Under a mantle of glacial drift there is a thick mass of Pierre shale and the underlying formations, including several hundred feet of Dakota sandstone. The

first deep boring in the county was at Ipswich, where a large volume of water was found at a depth of 1,265 feet under a pressure claimed to have been 120 pounds. In 1891 a pressure of 106 pounds was measured, indicating a head sufficient to raise it to 1,775 feet above sea level. This is somewhat greater than is found in the wells at Aberdeen just east and 140 feet less than in the well at Shelby. The head is sufficient, however, to afford artesian flows in all the east part of the county, and probably, from the indication of the Shelby well, as far west as the base of the Bowdle Hills, some distance west of Roscoe, where there are altitudes of from 1,900 to over 2,000 feet. The first well at Ipswich did not prove satisfactory and another one, sunk in 1902, obtains a 150-gallon flow from a depth of 1,245 feet. In the summer of 1903 it was reported that there were 83 deep artesian wells in the county, mostly of medium size but furnishing an abundance of excellent water for farm and stock purposes. Some data of these wells are given in the following table, grouped by townships:

List of artesian wells in Edmunds County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
121	66	987–1,100	12–35	
121	67	1,025–1,155	20–50	
121	68	1,155–1,250	40–50	
121	69	1,240	25	
121	70	1,300–1,370	35	
121	71	1,500–1,569	20	
122	66	1,000–1,087	15–70	
122	67	1,000–1,140	5–35	
122	68	1,145–1,170	20–35	
122	69	1,305–1,360	35–70	
122	71	1,526	2	
123	66	1,075–1,115	25	
123	67	1,160	35	
123	68	1,195–1,245	97–150	
123	69	1,370–1,420	30	
123	70	1,498	3½	
124	66	1,125–1,148	40–41	
124	67	1,150–1,175	35–120	
124	68	1,225–1,350	25–45	
124	69	1,356	60	

FALL RIVER COUNTY.

This county lies on the south slope of the Black Hills uplift, with Dakota sandstone and underlying formations outcropping to the west. Cheyenne River cuts a deep valley across the uplift, but is deflected by it considerably to the south. The land presents much variety of configuration, having wide areas of undulating plains to the south and hogbacks of Dakota sandstone to the north. There is great diversity of geologic structure and distribution of the formations, there being to the south broad areas of Pierre shale, from under which the regular succession of Niobrara, Benton, Dakota, and underlying formations rises to the north. The general rise is to the north, but there is a main anticline which extends up Hat Creek Valley and pitches beneath Pine Ridge to the south. Another steeper but less extensive arch lies east of Maitland, and two smaller arches extend, respectively, southeast

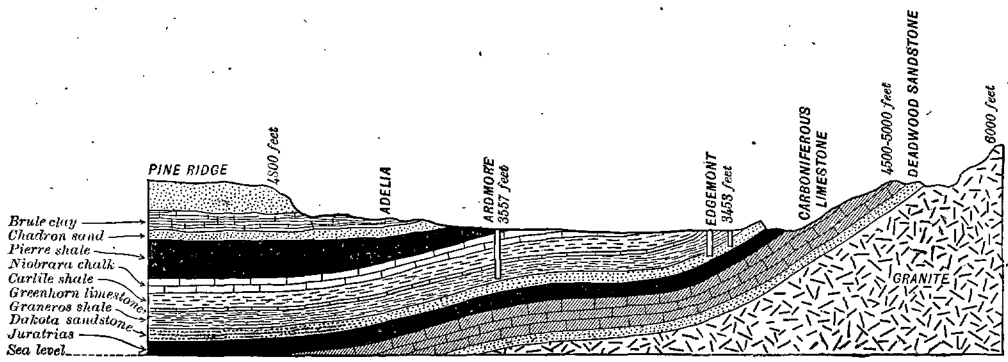


FIG. 14.—Section from the Black Hills to Pine Ridge, across Fall River County, showing relations of the water-bearing Dakota and associated sandstones; looking west.

from Edgemont, and into the southeast corner of the county from Pine Ridge Reservation. Between these anticlines are synclines, or basins, which in the vicinity of Oelrichs and southward hold fully 1,200 feet of Pierre shale, with Dakota sandstone more than 2,500 feet beneath the surface. The basin west of Hat Creek is much shallower, the greatest depth to the Dakota sandstone probably not being much over 2,000 feet on the highlands west of Ardmore. In fig. 14 is given a north and south section across the county.

A number of wells have been sunk in Fall River County, some of which have reached Dakota sandstone, while others have failed to do so. At Argentine a well in Dakota sandstone yields a flow, and at Edgemont wells obtain a water supply which has not sufficient head to reach the surface. At Minnekahta a deep boring begun in the Red Beds penetrated deep into the underlying formations, but was unsuccessful. It is probable from the results in these wells that in all of the county underlain by Dakota sandstone water supplies may be obtained, though flows

can be had only in the extreme northwestern portion, and on the slopes between the hogback and Cheyenne River in the northeastern portion.

Edgemont.—In this city and its vicinity a number of wells were sunk several years ago for water from the Dakota sandstone. Nearly all obtained supplies for pumping, but owing to the low level of the outcrops of the Dakota sandstone a short distance east the water does not have sufficient head to flow. The water did not prove satisfactory for use in locomotives, and all but the deeper well at the railroad roundhouse have been abandoned. This well at the roundhouse, of which the record is given below, had a depth of 1,125 feet, but is now filled to the depth of 700 feet.

Record of deep well at Edgemont, S. Dak.

Feet.	
0– 295	shale.
295– 325	sand, white; water.
325– 350	soft white bed.
350– 430	Fuson shale.
430– 455	sand, white, with 10-foot soft white bed at base.
455– 497	shale, light colored.
497– 509	limestone.
509– 604	sand, white; water.
604– 612	sand, dark.
612– 652	sand, white above, red below.
652– 705	shale, with 7-foot layer of limestone at base.
705– 752	shale, light colored.
752– 802	soft white bed.
802– 957	Sundance, upper dark shale.
957– 977	sandstone, red.
977–1,012	sandstone; bad water.
1,012–1,125	Sundance, lower shale.

Water of bad quality was found in the white sand at 295 feet and in the sandstone at 977 feet. Fairly good water, rising to within 60 feet of the surface, is now obtained from the sandstone that begins at a depth of 509 feet. It contains 239 grains of solid matter per gallon, of which 9.33 grains are lime. The log appears a fairly reliable one, indicating the Dakota sandstone from 295 to 350 feet; the Fuson formation, from 350 to 430 feet; the Lakota formation, from 430 to about 652 feet; the Morrison shales, 652 to 802; the characteristic red series in the Sundance formation, 957 to 977 feet; the bed of buff Sundance sandstone, 977 to 1,012 feet; and the basal dark Sundance shales, 1,012 to 1,125 feet, probably not far above the red beds of the Spearfish formation. The well at the north end of the Y across the river from Edgemont has a depth of 960 feet, and probably ends in Sundance shales, but the record appears not to be reliable in its details. Some water was found in the white sand at 230 feet and in sandstones at 290 and 430 feet.

At 578 feet a sandstone begins which yields a good supply of water, rising to within 30 feet of the surface. A thin sand rock at 700 feet also yields water, but its volume is small.

Record of deep boring at the Y, near Edgemont, S. Dak.

Feet.	
0– 30	sand and gravel.
30–230	shale.
230–260	white sand water.
260–300	shale, with 10-foot sandstone layer at base.
300–430	shale.
430–460	sandstone, etc.
460–485	sand and shale.
485–505	sand.
505–578	shale.
578–618	sand, white, with 5-foot layer of shale.
618–643	sandstone; water.
643–703	shale, with 5-foot layer of sandstone.
703–960	shale.

Minnekahta.—Several years ago the Burlington and Missouri River Railroad Company made a deep boring at Minnekahta station to obtain a water supply for locomotives. A depth of 1,348 feet is said to have been attained, but no promising amount of water was reported. The record, which is given below, is clearly an unreliable one and very unsatisfactory for the identification of the geologic formations. No clue is given as to the location of the Minnekahta formation, which should be expected to begin at about 300 feet below the surface at Minnekahta station. The red sands, from 743 to 908 feet, are doubtless in the Minnelusa formation, and possibly the red shale at 1,105 feet is the one at its base. At a depth of 1,348 feet the boring should be near the granite or schist bed rock, for the thickness of the formations from the lower half of the Spearfish through the Deadwood is not much more than this in the surface exposures in the region to the north. The references to gypsum at various depths in the boring are mistakes as to the identity of the material, except possibly those near the top. It is to be deeply regretted that the record is not more accurate, for it could have thrown important light on the stratigraphy.

Record of deep boring at Minnekahta, S. Dak.

Feet.	
0– 12	soil and gravel.
12– 47	gypsum (?).
47– 62	sandstone.
62– 107	gypsum (? ?).
107– 173	red gypsum (?).
173– 308	white gypsum (? ?).
308– 378	red sand.
378– 388	flint.

Feet.	
388– 428	red rock.
428– 443	white gypsum.
443– 523	red sands.
523– 538	quartzite (?).
538– 558	red sand.
558– 581	limestone (?).
581– 611	blue sand and rock.
611– 643	limestone (?).
643– 663	sand rock.
663– 743	gypsum (?).
743– 908	red sands.
908– 990	gypsum (?).
990–1,022	white sand.
1,022–1,082	marble.
1,082–1,105	gypsum.
1,105–1,190	red shale.
1,190–1,232	pebble rock, with layer of pyrites, 8 feet (?).
1,232–1,284	black gypsum (?).
1,284–1,307	crystalline gypsum.
1,307–1,325	red sand.
1,325–1,348	white sand.

Ardmore.—At Ardmore, on the Burlington and Missouri River Railroad, 26 miles south of Edgemont, the railroad company has made a boring to a depth of 1,500 feet without obtaining water. The hole is entirely in shale, except about 40 feet of white sand containing thin partings of black shale. This boring begins about at the surface of the Niobrara formation, and apparently penetrates very nearly to the Dakota sandstone, the sandstone bed reported probably being in the Graneros shales. As Ardmore is at the altitude of 3,557 feet, and the water-bearing Dakota sandstone outcrops about Edgemont are at an altitude of 3,400 feet, there is no possibility of a flow at the former place, but probably a supply of water for pumping could be obtained by deepening the boring into the Dakota sandstone. The estimated altitude to which the water would rise in such a well is about 3,450 feet. (See fig. 14, p. 224.)

Argentine.—This station is a water-tank siding on the Burlington and Missouri River Railroad, 17 miles northwest of Edgemont. The well is on the south side of Pass Creek, a short distance west. It is a flowing well, 550 feet deep, yielding a fairly large volume of water, but of a quality not satisfactory for locomotives, as the following analysis will show:

Analysis of artesian water at Argentine, S. Dak.

	Grains per gallon.
Sodium sulphate	39.90
Potassium sulphate	.90
Lime sulphate	4.20

	Grains per gallon.
Lime carbonate	6.00
Magnesia carbonate	4.00
Alumina and iron oxide	.05
Silica	.19
Total solids	56.60
Organic matter	.55

This analysis was kindly furnished by the railroad company. The log of the boring was not obtainable. The well begins in Graneros shales and undoubtedly obtains its water supply from the Lakota sandstone, which outcrops in the high ridge to the east.

Hot Springs.—At the Soldiers' Home, a short distance west of the town, a well was sunk some time ago to a depth of 223 feet. It began just above the top of the Minnekahta limestone, and obtains a moderate water supply from the sandstones in the Minnelusa formation.

FAULK COUNTY.

The geologic relations in Faulk County are almost precisely similar to those in Edmunds County. To the west it lies high on the slopes of the morainal hills of the Bowdle Range, and to the east extends far out on the low level lands of James River Valley. Many wells bored in the county within the last few years indicate that the Dakota sandstone is water bearing throughout and that waters are under sufficient head to afford flows, except possibly at one or two very high points in the extreme southwest corner. As the strata lie nearly level, dipping very gently toward the west from near Faulkton, the depths of the wells increase mainly with the rise of the land, which swells slightly toward the center of the county. There appears to be considerable variability in the horizon of the principal flow, many of the wells having had to be sunk considerably below the top of the sandstone to obtain water in satisfactory volume. The only reports of pressure which have been received are from the old well at Faulkton, which indicated 25 to 34 pounds per square inch at a time when it was partly clogged up. The old well 4 miles north of east from Orient is reported to have had a pressure of 130 pounds to the square inch before it was clogged, which would indicate a water head of about 1,865 feet above sea level. It had a depth of about 1,215 feet, a flow of 950 gallons, and a diameter of 6 to 5¼ inches. Flows were reported in a thin bed of lime rock at 394 feet, at 1,070, and at 1,165 feet, where the principal supply was obtained. The materials penetrated are reported to have been as follows:

Record of well in T. 117, R. 68, sec. 18, near Orient, Faulk County, S. Dak.

Feet.
0– 20......yellow clay.
20– 47......blue clay.
47– 394......shales, black, blue, and gray, with thin layer of lime rock at base furnishing small flow.
394–1,070......shales, gray, blue, and black.
1,070–1,110......hard sandstone.
1,110–1,165......sand, lime, pyrites, and shale.
1,165–1,215......sandstone; 950-gallon flow.

List of artesian wells, by townships, in Faulk County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
117	66	913–1,054	45–65	
117	68	1,095–1,156	90	
117	69	1,232	60	
118	67	1,016–1,075	60–75	First flow at 850 feet.
118	69	1,220–1,466	25–40	Pressure, 60 pounds in one well.
118	70	1,183–1,608	45–100	
119	67	1,030–1,117	20-	
119	68	1,165	150	
119	69	1,206–1,456	25–100	
119	70	1,367–1,402	100–185	
119	71	1,545	45	
120	67	1,039–1,060	50–150	
120	68	1,025	25	Pressure, 85 pounds (?).
120	69	1,197–1,287	10–125	
120	70	1,342–1,512	12–100	
120	71	1,505–1,570	27–35	
120	72	1,580–1,650	30–70	

GRANT COUNTY.

Grant County lies on the eastern slope of the east coteau, extending from an altitude of over 2,000 feet near Summit to less than 1,000 feet at the foot of Bigstone Lake, in Minnesota Valley. To the east there is a thick mass of glacial drift constituting the coteau, underlain by the Pierre shale, which extends nearly to the old granites exposed in the vicinity of Bigstone. Dakota sandstone underlies the greater part of the county and appears to abut against the granite floor as this old rock surface rises to the northeast, but the position of its margin is not known. A boring at Milbank is said to have reached a depth of 303 feet,

the lower 20 feet of which was in granite. A thin deposit of water-bearing gravel is reported lying on this rock, containing fossils, and overlain by 200 feet of shale capped by 75 feet of blue clay doubtless of Pleistocene age. It has been supposed that the basal bed is Dakota sandstone, but possibly it is in the Benton. A number of other wells in the valley bottom to the west and south obtain satisfactory flows at various depths, but the pressure is too low to afford a flow on the upper slopes and summit of the coteau.

List of artesian wells in Grant County, S. Dak.

Location.	Depth.	Diameter.	Average yield per minute.	Remarks.
	Feet.	*Inches.*	*Gallons.*	
Mrs. Johanna Schultz, T. 118, R. 47 SW. ¼ sec. 30.	155	2	65	Water rises to +25 feet.
Ed. Redman, T. 118, R. 48 SW. ¼ sec. 14	57	1, 2	40	"
Milbank	303	....	Several.	20 feet into granite.
Will Marquette, T. 118, R. 48 NE. ¼ sec. 9	206	3	3	Water rises to +4 feet.
W. H. Koepke, T. 120, R. 48 NE. ¼ sec. 22	407	2	2	Water rises to +36 feet.
J. W. Newenburg, T. 120, R. 49 SE. ¼ sec. 18.	422	2	10	Water rises to +17 feet.
W. B. Saunderson, T. 120, R. 49 NW. ¼ sec. 7.	510	2	30	Water rises to +32 feet.
Mehegan & Fairchild, T. 120, R. 49 NE. ¼ sec. 11.	379	2	½	Water rises to +2 feet.
Julius Runge, T. 120, R. 49 NE. ¼ sec. 13	459	2	45	Water rises to +38 feet.

GREGORY COUNTY.

Gregory County lies in the southwest corner of the portion of the State west of Missouri River. It extends along the west side of the river for about 50 miles, and comprises the high plateaus extending southwest to Ponca Creek and beyond. On the river banks and on some of the slopes westward the Niobrara chalk is exposed, overlain in the highlands by Pierre shale, which is capped to the south by Tertiary and Pleistocene deposits.

The thickness of the Niobrara formation appears to be about 200 feet. It is underlain by 400 feet or more of Benton shales lying on Dakota sandstone. This sandstone contains artesian waters which have been tapped by a number of wells on Whetstone Creek and by the old well at Fort Randall. The pressure in these wells indicates that the head of the waters along the river is about 1,800 feet to the north and slightly over 1,500 feet to the south and probably increases to 1,850 feet in the southwest corner. This head is only sufficient to afford flows along Missouri and Whetstone valleys and in the lower and middle slopes rising from them to the plateau. It is insufficient to give a flow at Bonesteel, at Fairfax, or in Ponca Valley.

The depth to the Dakota sandstone averages from 700 to 800 feet along Missouri River, 1,200 feet on the east portion of the plateau, and somewhat over 1,500 feet in the higher lands in the central, west, and southwest townships The wells in Whetstone Valley are from 714 to 890 feet deep and yield large flows of good water.

Fort Randall.—The well at Fort Randall, sunk by the Government many years ago, has a depth of 610 feet and is reported to have the following record:

Record of well at Fort Randall, Gregory County, S. Dak.

Feet.	
0–100	gumbo and clay.
100–460	soft stone.
460–520	sandstone; 600-gallon flow.
520–576	blue clay.
576–610	very hard rock.

This record is probably a very inaccurate one, but it appears to indicate that the Dakota sandstone was entered at a depth of 460 feet, or very much nearer the surface than would be expected from the experience of wells on the other side of the river. Possibly the flow is from a sandstone in the Benton group, but the large volume of water is difficult to account for on this supposition. It is claimed that the hard rock in the bottom of the well was granite or quartzite, but this also is very uncertain.

HAMLIN COUNTY.

This county is on the summit of the east coteau, between James and Minnesota River valleys. Its surface consists of a great thickness of glacial drift lying on Pierre shale. Apparently it is underlain also by Dakota sandstone at a depth averaging but little more than 1,000 feet throughout. As the altitude of the land is from 1,650 to about 1,900 feet, it is too high for an artesian flow, the probable head of the water in the Dakota sandstone being about 1,600 feet. So far as known no endeavors have been made to reach the formation.

HAND COUNTY.

Hand County lies partly on highlands of drift and on the lowlands of James River Valley, the former rising to an altitude of somewhat over 2,000 feet in Ree Heights, and the latter having an average elevation of 1,400 feet. The surface is entirely covered by glacial materials, but these are underlain by a thick mass of Pierre shale and by the usual succession of Niobrara and Benton shales and Dakota sandstone. The latter has been reached by numerous wells, which afford flows in the central, northern, and eastern portions of the county. The head of the water averages slightly over 1,850 feet about Miller and due north, increasing

somewhat to the west and decreasing to 1,700 feet in the northeast corner of the county. In the highlands of the southern half of the county the elevation is considerably too great to afford flowing wells, but the precise extent of the nonflowing area has not been ascertained. A well 1,611 feet deep, in NW. ¼ of sec. 21, T. 110, R. 68, is in this area, and although it penetrated the Dakota sandstone the water failed to reach the surface by 80 feet. The water-bearing sandstones in the Dakota formations occur at several horizons, and the principal flows are found at some distance below the top bed of the formation. Different wells in the region vary somewhat as to the horizon of the principal flow. The strata lie nearly level or undulate very gently. A faint anticline appears to extend north and south through Miller, but it is a very low uplift.

Record of town well in Miller, Hand County, S. Dak.

Feet.	
0– 220	soil, clay, and gravel.
220– 930	blue shale.
930– 975	hard sandstone and pyrites.
975–1,105	shale (cap rock at 1,105 feet).
1,105–1,145	sandstone, 460-gallon flow.

The following is a list of the artesian wells of the county:

List of artesian wells in Hand County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Average yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
L. L. Eiles, T. 110, R. 68, NW. ¼ sec. 21.	1,611	....	2	....	Water rises to −80 feet.
Peter Myers, T. 110, R. 68, NE. ¼ sec. 28.	838	....	1¼	50	
C. Rowen, T. 111, R. 66, NE. ¼ sec. 8	....	....	1¼	....	
H. D. Ellis, T. 112, R. 66, NW. ¼ sec. 30.	1,269	....	2 –1¼	40	
M. N. Strickling, T. 112, R. 67, SW. ¼ sec. 26	1,246	....	....	40	
St. Lawrence, T. 112, R. 67, sec. 7	1,272	1,070 1,272	....	Few.	Pressure, 40 pounds.
R. T. Sedam, T. 112, R. 67, sec. 18	1,343	1,315	3	350	Pressure, 125 pounds.
John Baldwin, T. 112, R. 67, sec. 33	1,375	1,343	3	1,350	Pressure, 119 pounds.
J. McCullam, T. 112, R. 68, SW. ¼ sec. 2.	1,158	....	1¼	135	
Township well, T. 112, R. 68, sec. 7	1,200	....	4	50	
W. H. Smith, T. 112, R. 68, sec. 10	1,140	1,110	3½	....	
Miller, T. 112, R. 68, sec. 10	1,139	1,112	6¼–4½	360	Pressure, 120 pounds.
Miller, Lost Creek Ranch Co	1,142	1,142	3 –2	40	
Joseph Koeck, T. 112, R. 69, sec. 11	1,207	1,030 1,100 1,207	2	100	Pressure, 60 pounds.
N. Noble, T. 113, R. 66, SW. ¼ sec. 20	1,058	....	1¼	35	

List of artesian wells in Hand County, S. Dak.—Continued.

Location, etc.	Depth.	Depth to water.	Diameter.	Average yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
A. B. Holmes, T. 113, R. 66, sec. 11	980		2	100?	Water rises to +20 feet
Ick Brown, T. 113, R. 66, sec. 24	980		1¼	35	
Will. F. Pantsah, T. 113, R. 66, SW. ¼ sec. 15	967		1¼		
D. Conkey, T. 113, R. 67, SE. ¼ sec. 14	1,155		2½		
A. S. Piper, T. 113, R. 67, SE. ¼ sec. 15	800		2		
Township well, T. 113, R. 67, sec. 25	1,137	1,087 1,127			
W. W. Cotton, T. 113, R. 67, SE. ¼ sec. 25	1,140	1,100 1,112 1,129	3	400	Pressure, 128 pounds.
Mr. Escher, T. 113, R. 68, SW. ¼ sec. 29	1,125	1,105	3		
Gus Merion, T. 113, R. 69, SE. ¼ sec. 33	1,214		1¼	60	
Chas. Fuller, T. 113, R. 69. NE. ¼ sec. 13	1,162		2	100	
Mr. Wyland, T. 113, R. 69, NW. ¼ sec. 14	1,215	1,190	2		
Township well, T. 113, R. 69	1,200				
Sam Bushong, T. 114, R. 66, sec. 11	1,070		1¼	35	
Frank Yodes, T. 114, R. 66, W. ½ sec. 35	1,010		1¼	35	
Thomas Jones, T. 114, R. 68, SE. ¼ sec. 27	1,272				
A. Gilmore, T. 114, R. 68, NE. ¼ sec. 12	1,050		1¼	40	
Thos. E. Eaton, T. 114, R. 68, SW. ¼ sec. 9	1,185	1,185	1¼	30	
J. C. Harris?, T. 114, R. 69, SE. ¼ sec. 14	1,197		2		
Oliver McGee, T. 114, R. 70, sec. 15	1,303		3 -1¼	15 or 25	
Jno. J. Stornif			3		In progress, 1903.
H. Schoefers, T. 115, R. 69, SE. ¼ sec. 10			2		
Nabor Bros., T. 115, R. 69, NW. ¼ sec. 24	1,242			16	
J. B. Carl, T. 115, R. 70, SW. ¼ sec. 28	1,300		2	100	
D. Countryman, T. 116, R. 67, sec. 26	853		1¼		

HANSON COUNTY.

Hanson County is in James River Valley, its northern portion extending into the artesian basin. As the greater part of the county lies on the summit of the old buried ridge of Sioux quartzite, the Dakota sandstone is mostly absent. In the part of this area northeast of Mitchell, northwest of Spencer, east of Ethan, and on James River about Elm Springs, overlapping sandstones in the Benton formation are sources of small artesian supplies. Small flows are also obtained from the base of the drift, probably due to leakage from the Benton horizon. East of Mitchell the upper beds of Dakota sandstone appear to lie in a valley in the quartzite ridge

for some distance, and to contain water which affords flows on the lower lands along James River and on the slopes and upland just north of the mouth of Rock Creek.

In the northwest corner of the county there is an area of about 30 square miles in which excellent flows are obtained from the Benton sandstone in wells 80 to 200 feet deep, and from the base of the drift in shallower wells. These conditions continue to the east at intervals through the northern tier of townships, especially in the district north of Spencer.

List of artesian wells in Hanson County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
101	58	412	....	
103	56	112, 150	Several.	Flows from base of drift north of Spencer only.
		165, 260	Several.	Flows from upper sandstone of Benton north of Spencer only.
103	57	127	Several.	Flows from base of drift in section 11 only.
103	57	155–290	5–40	Flows from upper sandstone of Benton in northeastern sections only.
103	57	400	Many.	In section 4, from sandstone in Benton group.
103	58	140	Several.	
103	59	135–176	Several.	Flows from base of drift.
103	59	400–470	Many.	Flows in northwestern sections only.
103	59	410	None.	Insufficient head for flow in section 18.
104	56	80–145	Several.	Flows from base of drift in western sections.
104	56	167–260	Several.	Flows from upper sandstone of Benton in western sections.
104	57	152–170	Several.	Flows from base of drift.
104	57	170–365	½–5	Flows from sandstones of Benton.
104	57	508–600	4–50	
104	58	90	Several.	Flows from base of drift.
104	58	175–365	Several.	Flows from sandstones of Benton.
104	58	440–555	30–150	No flows in sections 30, 31, 32, and 33.

The main artesian basin extends under the greater part of townships 104, ranges 57 and 58, in the northeast and north-central part of the county, where there are numerous wells 400 to 589 feet deep. They furnish large flows and usually have first flows also from Benton sandstone, which is the source of small flows in numerous wells 200 to 300 feet deep.

A typical deep-well section in Hanson County is as follows:

Log of Knapp well, in sec. 13, T. 104, R. 58, Hanson County, S. Dak.

Feet.		
0- 20	yellow clay	Drift.
20-123	blue clay	
123-188	coarse sand with small flow	Benton.
188-208	black shale	
208-218	coarse sand with water	
218-230	blue shale	
230-235	sand	
235-535	shale, dark above, lighter below	
535-550	soft sandstone, with 150-gallon flow from 2-inch pipe (Dakota).	

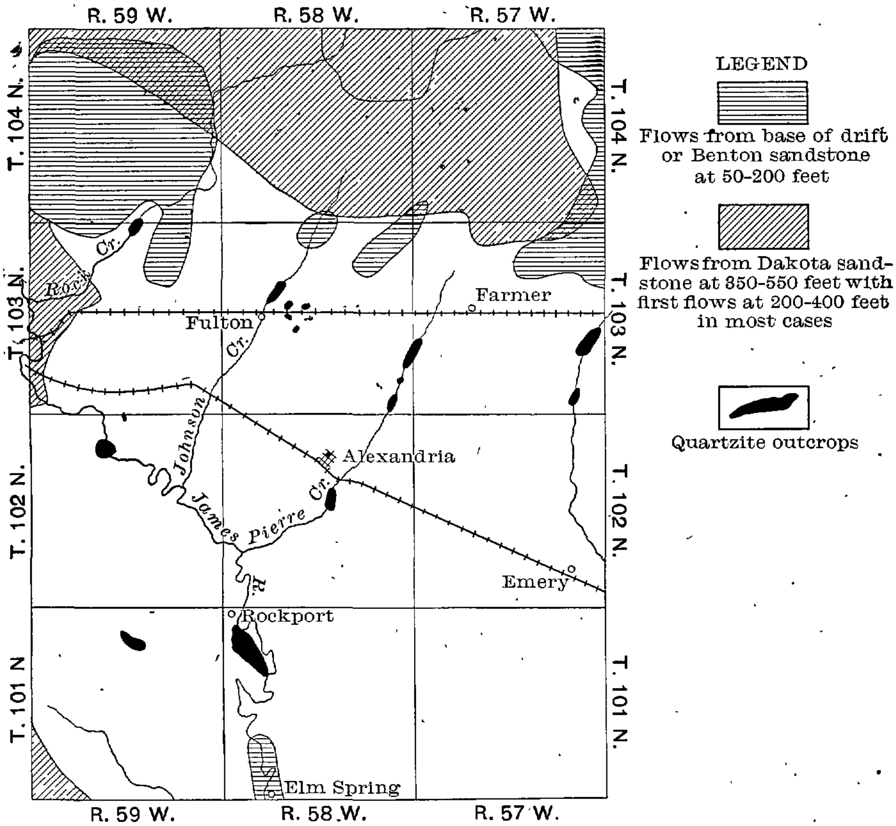


FIG. 15.—Map of Hanson County, showing artesian conditions, etc., by the late C. M. Hall.

HUGHES COUNTY.

Hughes County extends from Missouri Valley eastward onto the highlands. Most of the surface is covered with glacial deposits which are underlain by several hundred feet of Pierre shale. Under this is the usual succession of Niobrara formation, here mostly shale, Benton shales and sandstones, and Dakota sandstone lying on

granite or quartzite. The sandstone is water bearing, and the water appears to be under sufficient head to afford flows throughout the county. Its depth varies from 1,000 feet in Missouri Valley at the south margin of the county to about 1,600 feet in the highest lands in the northwest portion. The beds dip gently to the northwest.

There are several wells at Pierre and vicinity, one at Harrold, and another just north in Sully County. The three wells at Pierre are 1,160, 1,256, and 1,537 feet deep, respectively, the two latter having, it is asserted, passed through the sandstone to granite. The greatest pressure reported is 210 pounds to the square inch, sufficient to raise the water to an altitude of 1,920 feet above sea level. The Pierre wells yield large flows of water, with considerable gas, which has been found useful. The following record is reported by Mr. Swan, the driller:[a]

Record of well at Pierre, Hughes County, S. Dak.

Feet.	
0– 62	sand and gravel.
62– 87	gray shale.
87– 275	black shale.
275– 325	blue shale.
325– 425	light-gray shale.
425– 476	dark-gray shale.
476– 479	lime rock, hard.
479– 530	blue shale.
530– 533	lime rock, hard.
533– 650	blue shale, soft above, with gas.
650– 654	hard sandstone.
654–1,085	blue shale. Small first flows at 870 and 890 feet.
1,085–1,130	streaks of lime and shale.
1,130–1,140	sand rock, yellowish. Flows of water and gas.
1,140–1,175	streaks of lime and sand.
1,175–1,185	sand rock, yellowish. Flows of water and gas.
1,185–1,215	streaks of shale, lime, and sand.
1,215–1,245	white sand, soft. Main flow, 210 pounds pressure. Temperature, 89°.
1,245–1,250	streaks of white shale and lime.
1,250–1,256	granite.

Professor Todd reports that there is no question as to the identity of the granite claimed to have been penetrated 6 feet at the bottom of the well. Another well sunk recently a short distance west found the granite at a depth of 1,537 feet, a discrepancy difficult to account for.

The well at Harrold is at the altitude of 1,801 feet, and the water is under

[a] Bull. South Dakota Geol. Survey No. 2, 1898, pp. 93-94.

sufficient pressure to rise 62 feet higher, yielding a flow of 84 gallons per minute from a 4-inch pipe. The well is 1,453 feet deep and has the following record:

Record of well at Harrold, Hughes County, S. Dak.

Feet.	
0- 125	glacial deposits.
125- 280	blue shale.
280- 282	limestone.
282- 450	blue shale.
450- 550	gray shale, with limestone layers.
550-1,435	gray shale, with limestone layers in its lower portion.
1,435-1,451	sandstone.
1,451-1,453	brown shale.

HUTCHINSON COUNTY.

Hutchinson County is partly in James River Valley and extends up the slopes of the adjoining high lands to the east and to the west. The surface is mostly covered by glacial drift, but in some of the valleys there are outcrops of Niobrara chalkstone and the sandstone at the top of the Benton formation. The Dakota sandstone underlies the greater part of the county, but to the north abuts against the Sioux quartzite and ends, the overlying formations extending beyond, up the slopes of an underground ridge. The formations all dip gently toward the southwest along the slope of this ridge.

The depth to the Dakota sandstone is slightly less than 300 feet along James River, gradually increasing in the higher lands to the west and to the east. In the southwest corner of the county the sandstone lies nearly 800 feet beneath the surface, and in the southeast corner 700 feet. It contains large volumes of water under considerable pressure, which is sufficient to afford flows in the lower lands but not in the higher areas in the east and extreme southwest portions of the county. There are several horizons of flow in the region, beginning with sandstones in the Benton shales and comprising two or three thick sandstone layers in the Dakota. These are tapped by numerous wells in the northwest, central, and south portions of the county. Some of the wells obtain their waters from the top of the sandstone, and others penetrate to lower horizons to obtain increased volume and pressure.

In the east portion of the county are several wells which have been sunk to the quartzite without obtaining water or only finding supplies in the Benton sandstones that lacked sufficient head to flow. Flows are obtained from the Benton sandstones at Elm Springs and at some other points in the area in which the Dakota sandstone is absent, and from this source several wells in the region to the west have obtained first flows of moderate volume. The principal features of the representative wells in this county are set forth in the following table:

List of artesian wells, by townships, in Hutchinson County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
97	56	445–480	....	No flow.
		122	27–60	Flows from base of drift.
97	57	65–154	3–10	Flows only in valleys, from base of drift.
		417	Few.	Low pressure. Menno town well.
		406–630	Many.	Pressure 25 pounds.
		747	6	
97	59	480–620	30–50	Pressure 25 to 35 pounds; several flows.
		300	Few.	Flows from Benton sandstone.
		500	1	Sec. 26.
97	60	540–614	40–50	
		648–760	50–100	Pressure 35 to 60 pounds.
		842	700	Pressure 9 pounds. Tripp town well.
97	61	30–62	6	Flows from base of drift.
		945	....	
98	56	53–54	4–9	Do.
98	57	55–65	1–3	Do.
98	58	420	....	
98	59	40–200	Several.	Flows from base of drift and upper Benton sandstone.
		370–450	1–15	
98	60	470–580	16–120	
		120–189	Several.	Do.
98	61	482–560	13–60	
		64–130	6–10	Flows from base of drift.
99	56	54–95	10–12	Do.
99	57	150	....	Wolf Creek.
99	58	270–335	1–10	
		280	....	No flows in northern sections.
99	59	365–490	Many.	
		118	Many.	Flows from base of drift.
99	60	470–540	5–150	
		100–130	Many.	Do.
		360–440	....	First flows from lower Benton sandstones.
		542	30	Pressure 20 pounds. Parkston town well.
99	61	515–535	10–50	Pressure 13 pounds and over.
		140	....	Flows from base of drift.
		490–572	8–50	
100	59	180–220	....	First flows from lower Benton sandstones.
		240–345	....	No flow.
100	60	560	10	
		370–462	3–10	First flows from lower Benton sandstones.
		296–340	Many.	Flows from upper Benton sandstone.
100	61	419–585	1–90	

Record of well at Tripp, Hutchinson County, S. Dak.

Feet.	
0– 25	drift.
25–325	chalkstone (probably a portion of these 300 feet comprises light-colored clays in the lower part of the drift deposits).
325–425	sandstone (top of the Benton).
425–525	shale.
525–529	sandstone.
529–729	shale.
729–764	sandstone and shale.
764–824	sandstone with flowing water.

Record of well at Parkston, Hutchinson County, S. Dak.

Feet.	
0– 40	yellow clay.
40–225	sand with water.
225–434	blue shale.
434–444	gray shale with water.
444–460	gray shale.
460–472	fine sandstone.
472–542	shales, with hard layers above and sand layers below, with flow.
542	very hard rock.

HYDE COUNTY.

This county extends north and south along the summit of the high divide between Missouri and James river valleys, the higher portions of which attain an altitude of over 2,000 feet above sea level. The surface is thickly covered with glacial drift, with underlying Pierre, Niobrara, and Benton shales over 1,400 feet thick, lying on Dakota sandstone. Two borings have been reported—one at Highmore, with a depth of 1,552 feet, and another at the Mitchell ranch, 8 miles northeast, with a depth of 1,397 feet. Both obtain flows from the Dakota sandstone. The pressure in the Highmore well is stated to be 12 to 15 pounds to the square inch, indicating a head of 1,920 feet above sea level, a pressure insufficient to afford flows on the high summits south of Highmore and on the high ridges northwest.

Highmore.—The well at Highmore is at an altitude of 1,890 feet; its depth is 1,552 feet, diameter 6 inches, and flow about 9 gallons per minute. The principal flow was obtained from a depth of 1,537 feet. Nonflowing water was found in a bed of sandstone, probably in the Benton formation, extending from 1,430 to 1,442 feet. The following is the log of this well:

Record of town well at Highmore, Hyde County, S. Dak.

Feet.	
0– 240	soil, clay, and gravel.
240– 740	blue shale.
740– 815	hard gray shale, pyrites.

Feet.	
815–1,086	blue shale.
1,086–1,310	gray shale mixed with sand.
1,310–1,314	shale and pyrites.
1,314–1,430	blue shale.
1,430–1,442	sandstone; no flow.
1,442–1,537	sandy shale on bed of hard sand.
1,537–1,552	soft sandstone.

JERAULD COUNTY.

Jerauld County extends from the western part of James River Valley onto the high drift ridges westward. The surface is covered with drift lying on Pierre shale. Under this shale there is the usual succession of Niobrara chalkstone, Benton shales and sandstone, and Dakota sandstone lying on granite and quartzite, the beds dipping gently to the north.

The Dakota sandstone contains water under pressure sufficient to afford flows except on the highlands in the central portion of the county. There are numerous wells with large flows in the eastern third of the county, which average for the most part from 715 to 850 feet in depth and furnish large volumes of water under pressures of 90 to 132 pounds, indicating that flows may be expected in all portions of the area having an altitude of less than 1,700 feet. The following is a list of the wells which have been reported:

List of artesian wells in Jerauld County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
106	63	715–760	200–280	Pressures, 110–132 pounds.
106	64	735–880	5–280	Pressure, 114 pounds.
107	64	860	35	
107	65	1,200	1	
108	63	785	500	Water, irony.
108	64	799½	2	
		865, 840	45	
108	65	1,057	200	Pressure, 90 pounds.

Records of some typical wells in Jerauld County are as follows:

Record of well of S. H. Abert, T. 108, R. 65, sec. 5, Jerauld County, S. Dak.

Feet.	
0–47	drift.
47–400	shale, with pyrites layers, and with a layer with many shells at 290 feet.
400–415	chalkstone.
415–460	shale (top of Benton).

Feet.	
460– 490	sandstone; contains water.
490– 586	shales, with sandstone layers.
586– 705	shale.
705– 725	hard rock.
725– 899	shale, with thin limestone at 801 and thin sandstone at 845 feet.
899– 914	sandstone; small flow.
914–1,003	compact shale.
1,003–1,043	hard sandstone (top of Dakota).
1,043–1,057	sandstone, with 200-gallon flow.

In the well of P. Schultz, T. 106, R. 64, sec. 9, the first water was found under chalk at 290 feet below the surface, and Dakota sandstone was reached at 836 feet and yielded a 280-gallon flow at 880 feet.

Record of well of E. Schmidt, T. 108, R. 64, sec. 14, Jerauld County, S. Dak.

Feet.	
0–100	drift.
100–104	limestone.
104–254	shale (Pierre).
254–349	chalk.
349–369	chalk or sandstone, with water.
369–649	shale.
649–654	sandstone, with flow.
654–840	shale.
840–841	sandstone, with main flow.

Record of well of L. Feistner, NW. ¼ sec. 2, T. 106, R. 63, Jerauld County, S. Dak.

Feet.	
0– 40	drift.
40–100	shale.
100–160	chalkstone.
160–170	sandstone at top of Benton.
170–500	shale.
500–501	sandstone with flow.
501–701	shale.
701–721	top sandstone of Dakota, with main flow.

KINGSBURY COUNTY.

The artesian conditions in this county present considerable variety, the lower lands in the west portion of the county lying sufficiently low to be within the reach of flowing water, while to the east, in the higher coteau country, the land is too elevated for flows from the Dakota sandstone horizon. The entire country is underlain by Pierre shale overlain by Pleistocene deposits, which have considerable thickness in the coteau region eastward. Many wells, most of which yield large

flows, have been bored in the western part. The first one sunk was at Iroquois, where, at a depth of 1,115 feet, 1,000 gallons per minute were obtained. The well penetrated shales of the Pierre, Niobrara, and Benton formations. Small flows were found in thin sandstone layers at 400 and 600 feet, and the main flow in the Dakota sandstone, which was entered at 847 feet. The pressure was reported to be 67 pounds per square inch in 1890, but a determination in 1899 gave 71 pounds. Other wells have since been sunk, mostly in the western portion of the county, which have depths from 815 to 1,120 feet and yield from 20 to 100 gallons a minute, with surface pressures of from 8 to 50 pounds to the square inch. Several wells in various places obtain water supplies from a sandstone horizon just below the first great body of shales, probably at the top of the Benton group, but these have to be pumped to the surface. The surface of the Dakota sandstone slopes gently northwest, with slight local undulations. East of a line passing north and south near Manchester the land rises rapidly to the northeast from an average altitude of 1,500 feet to over 1,800 feet on the summit of the coteau. As the head of the water in the Dakota sandstone is from 1,550 to 1,615 feet on the west and 1,680 at De Smet, it is evident that no flows are obtainable in the wide coteau area.

The following is a list of the deep borings so far reported in the county:

List of deep borings in Kingsbury County, S. Dak.

Location.	Depth.	Average yield per minute.	Remarks.
	Feet.	*Gallons.*	
S. E. Matthews, T. 109, R. 57, sec. 30	925	80	Pressure, over 20 pounds.
K. Singerson, T. 109, R. 58, sec. 8	815	90	
Esmond	870	75	
F. H. Horton, T. 109, R. 58, sec. 29	840	Many.	
——, T. 109, R. 58, sec. 29	845	100	
H. H. Welch, T. 109, R. 58, sec. 35	906	50	Pressure, about 20 pounds.
——, T. 109, R. 58	600, 640	....	Water nearly to surface.
——, T. 109, R. 58	400–500	....	Several wells; water level, —30 to —50 feet.
Arlington	786	....	No flow.
E. Gulbransere, T. 110, R. 57, sec. 18	970	20	Pressure, 8 pounds.
Spear well, T. 110, R. 57, sec. 19	940	60	Pressure, 27 pounds.
Iroquois	1,115	1,000	Pressure, 67 pounds. Main flow from 850 to 900 feet.
A. N. Waters, T. 110, R. 58, sec. 28	850	35	
Desmet	1,610	....	Water to —20 and —40 feet from several strata.
——, T. 111, R. 56, sec. 32	500	Many.	No flow.
——, T. 111, R. 57, sec. 5	600	Many.	Do.
——, T. 111, R. 57, sec. 28	1,090	....	
——, T. 111, R. 57, sec. 31	970	30	

List of deep borings in Kingsbury County, S. Dak.—Continued.

Location.	Depth.	Average yield per minute.	Remarks.
	Feet.	*Gallons.*	
De Smet, T. 111, R. 58, sec. 22	943	Many.	Pressure, 50 pounds.
J. Burcheding, T. 111, R. 58, sec. 24	1,010	18	
C. G. Swefford, T. 111, R. 58, sec. 34	850	50	
Hetland, T. 112, R. 53, sec. 19	710	None.	Dry hole.
——, T. 112, R. 56	375, 600	Many.	Water level, —100 feet.
Wm. Rusche, T. 112, R. 57, sec. 7	1,120	4	Pressure, 15 pounds.
W. Solcey, T. 112, R. 58, sec. 3	1,000	40	Pressure, 40 pounds.
Andrew Mears, T. 112, R. 58, sec. 14	1,030	20	Pressure, 30 pounds.
Brooks's well, T. 112, R. 58, sec. 21	1,045	Many.	
S. Mann, T. 112, R. 58, sec. 30	947	10	
R. C. Purington, T. 112, R. 58, sec. 35	1,040	45	

The following records show the principal geologic features in some representative wells in Kingsbury County:

Record of artesian well at Iroquois, S. Dak.

Feet.	
0– 45	clay.
45– 400	shale.
400– 402	sand, with water.
402– 600	shale.
600– 602	sand, with water.
602– 847	shale.
847– 900	sandstone, with 1,000-gallon flow.
900–1,100	shale.

The shale from 45 to 400 feet is probably comprised in the Pierre and Niobrara formations, the latter here consisting of materials not sufficiently calcareous to be reported as chalkstone, a deposit which characterizes the formation farther south in the State. In this well the formations of the Benton group extend from 400 to 847 feet, where the top of the Dakota sandstone was entered.

Another well 4 miles northeast of Iroquois, on land 100 feet higher than the Iroquois well, obtains a large flow from a depth of 916 feet with a pressure of 50 pounds.

Record of Brooks's well, T. 112, R. 58, east side, sec. 21, Kingsbury County, S. Dak.

Feet.	
0– 113	yellow and blue clay.
113– 400	shale.
400– 450	sandstone, with water.
450–1,030	shale.
1,030–1,045	sandstone, with large artesian flow.

This record is very similar to that of the Iroquois well, 9 miles southwest. The sandstone extending from 400 to 450 feet probably represents the sandstone bed which usually characterizes the top or upper portion of the Benton group in eastern South Dakota, and furnishes water for many deep pump wells in portions of Kingsbury County and elsewhere.

Record of Spear artesian well, T. 110, R. 57, NE. ¼ of sec. 19, Kingsbury County, S. Dak.

Feet.	
0– 36	yellow clay.
36–140	blue clay and sand.
140–390	black shale.
390–485	gray shale.
485–505	sandstone; water to —111 feet.
505–862	gray shale.
862–863±	sand; some water.
863–932	shale.
932–937	sandstone; 60-gallon flow.
937–940	hard rock.

The black shale from 140 to 390 feet is undoubtedly Pierre, and apparently the gray shale below represents the Niobrara. The water-bearing sandstone extending from 485 to 505 feet is the usual feature at or near the top of the Benton group, and the sandstone entered at 932 feet is the Dakota, with a large volume of water showing a surface pressure of 27 pounds.

Record of deep boring at De Smet, S. Dak.

Feet.	
0– 44	clay.
44– 104	sand.
104– 840	shale.
840– 865	hard rock.
865– 985	sandstone, with water to —40 feet.
985–1,185	shale, or "soapstone," with fish teeth at 1,145 feet.
1,185–1,456	sandstone, with water to —40 feet.
1,456–1,470	hard rock.
1,470–1,610	sandstone, with water to —20 feet.

This boring was sunk with the hope of finding an artesian flow, but was unsuccessful, owing to the height of the land. Large volumes of water, it is claimed, were found, but failed to reach the surface by 20 to 40 feet. The first 104 feet in the boring are in drift, and from 104 to 1,185 feet in Pierre, Niobrara, and Benton clays. In one log the first water-bearing sands were reported from 763 to 793 feet, and in another from 865 to 985 feet; probably both were in the top of the Benton group. The hard rock from 840 to 865 feet may be a limestone such as sometimes occurs in the lower part of the Niobrara formation in

some regions. A stratum, said to be 1 foot thick, largely composed of fish teeth, was reported at a depth of 1,148 feet, apparently in the lower formation of the Benton group. The Dakota sandstone appears to have been penetrated from 1,185 to 1,610 feet, a thickness of 425 feet, without reaching its base. This boring probably shows that no flows are obtainable on the coteau.

A well at Arlington is reported to have reached a depth of 786 feet without obtaining a flow. It is almost certain that it did not reach the Dakota sandstone, which probably lies at a depth of 1,100 feet. As the altitude of the town is 1,846 feet and the head of the water in the Dakota sandstone is probably less than 1,700 feet, a flow could not be expected.

The following record of the Arlington boring has been reported:

Record of deep boring at Arlington, S. Dak.

Feet.	
0- 10	loam and clay.
10- 50	dark-yellow clay.
50-210	blue clay.
210-370	grayish clay.
370-785	blue shale.
785-786	sandstone.

Another similar deep boring was sunk at Hetland, in sec. 19, T. 112, R. 53, but was entirely dry.

Record of deep boring at Hetland, S. Dak.

Feet.	
0- 2	black loam.
2- 50	yellow clay.
50-285	blue clay.
285-310	soft yellow clay.
310-360	shell rock.
360-420	yellow clay.
420-710	blue shale.

Record of deep boring in T. 109, R. 58, SW. ¼ sec. 35, Kingsbury County, S. Dak.

Feet.	
0- 80	yellow and blue clay.
80-420	shale.
420- ?	chalk rock.
-760	soapstone and shale and hard layers.
at 760	first flow.
760-836	sandstone, shale.
836-883	cap rock.
883-893	water-bearing sandstone.
893-906	no more water.

Record of deep boring in T. 109, R. 57, SE. ¼ sec. 30, Kingsbury County, S. Dak.

Feet.	
0– 40	yellow till.
40– 60	blue clay.
60–282	black shale.
282–493	"soapstone" and chalkstone.
493–593	shales with hard streaks.
593–746	gray shale.
746–770	sandstone.
770–907	soapstone, sandstone, and shale.
907–915	cap rock.
915–928	sandstone.

LAKE COUNTY.

A buried valley in the quartzite and granite which extends north and south through the center of this county apparently contains the Dakota sandstone, but the altitudes of the land are too great for the formation to afford a flow.

Madison.—At Madison a boring was sunk to a depth of 1,082 feet, which appears to have been mainly in shale and to have obtained no water supply. Lime rock, which was reported from 490 to 570 feet, resting on sandstone, suggests the Niobrara chalk, but aside from this there is no evidence as to the geology of the boring. As the bed-rock surface is known to rise rapidly to the west, south, and east, it is evident that there is a deep trough at Madison, probably opening to the north, as shown in Pl. XXXIX. Whether this trough contains Dakota sandstone or not remains to be demonstrated, but if it does it is not to be expected that its water will have sufficient head to reach the surface, which at Madison is 1,669 feet above sea level.

LAWRENCE COUNTY.

This county is on the northeast slope of the Black Hills uplift, extending far into the region of crystalline rocks to the south and out on the plains of Benton shale to the northeast. In the northern half of the county the rocks dip mainly to the north and northeast and pass underground in regular succession from the old crystalline schists to the Benton shale. In the extreme northeast corner of the county the Dakota sandstone lies about 1,000 feet below the surface in a shallow syncline which pitches north. Probably its greatest depth in the county is 900 feet, in the ridges northeast of St. Onge.

Doubtless the sandstone would yield flowing water in the lower lands, as indicated by the experience of wells at Belle Fourche, a short distance north. It is probable that in Red Valley in this county underground waters could be obtained by sinking into the sandstone of the Minnelusa formation, and possibly also in the

underlying Pahasapa limestone and Deadwood sandstone. The depth from the middle of the Spearfish red beds to the top of the Minnelusa sandstone is about 500 feet, the Pahasapa limestone lying 500 feet deeper and having a thickness of 500 feet to the top of the Deadwood sandstone. No deep wells are reported in this county.

LINCOLN COUNTY.

Apparently only the extreme southwest corner of this county is underlain by the Dakota sandstone, and it is believed that the water of that formation does not have sufficient head to reach the surface in flowing wells. The Sioux quartzite rises to the surface in the northeast portion of the county and slopes gently to the southwest, where it is overlain by a greater or less thickness of Benton shale and Niobrara chalk.

LOWER BRULE INDIAN RESERVATION.

(See Lyman and Stanley counties.)

LYMAN COUNTY.

Including Southern Portion of Lower Brule Indian Reservation.

This county extends from Missouri River 85 miles west over the plains lying between Bad and White rivers. It is underlain almost entirely by Pierre shale, except along Missouri River and in its vicinity, where the underlying Niobrara chalkstone is exposed. A few of the higher points are capped by remnants of Tertiary deposits, notably at White Clay and Medicine buttes. Under the Pierre clay there is the usual succession of Niobrara chalkstone, Benton shale, and Dakota sandstone, the latter lying on the granite or quartzite to the east, but possibly overlapping rocks of Paleozoic and early Mesozoic age in the western portion of the county.

The Dakota sandstone contains water in large volume and under sufficient pressure to afford a flow in all the valleys and probably for some distance up the slopes. Owing to our lack of knowledge of the topography of the county and the precise head of the waters in its western part, the nonflowing areas can not be accurately delimited. The waters have been developed by several wells in Missouri Valley opposite Chamberlain, and in the McClure well on Cedar Creek, 18 miles south-southeast of Pierre. The wells opposite Chamberlain are of moderate depth. One on the farm of G. S. Grant, in T. 104, R. 72, sec. 14, has a depth of 563 feet and a diameter of 2 inches. The first flow was reported at 360 feet, the second flow at 460 feet, and the main flow at the top of the Dakota sandstone at 560 feet. Another well, on the farm of E. A. Barlow, on a bench a mile back from the river in the southern part of T. 104, R. 71, has a depth of 600 feet and a diameter of

2 inches. Its flow is small. The Adams-Brinkehoff well, on the NW. ¼ of sec. 7, T. 104, R. 71, has a 2-inch bore, is 737 feet deep, and flows several hundred gallons per minute. The pressure of the water in these wells is not given, but, judging from the wells at Chamberlain, it is probably sufficient to raise the water to 1,800 feet above sea level.

The Dakota sandstone in this county appears to dip gently west and its depth increases to the west by the gradual rise of the land in that direction. The wells on Missouri River reach it at a depth of about 550 feet, the amount increasing somewhat both up and down the river and rapidly in the highlands to the west. In the divide between Medicine Creek and White River it lies at least 1,400 feet below the surface to the east and at White Clay Butte somewhat over 2,000 feet. On White River, at the western border of the county, probably the depth is nearly 2,000 feet and on Bad River 1,600 to 1,700 feet.

The McClure well is in sec. 31 or 32, R. 78, T. 108, and has a depth of 1,653 feet. The inner tube is 1¼ inches in diameter and is reported to yield a flow of 40 gallons per minute with a pressure of 20 pounds. A special line of levels was run to this well, and it was found to be at an altitude of 1,917 feet, so that the pressure of 20 pounds indicates that the water at this place has sufficient head to rise to 1,963 feet above sea level, which, with the probable slight increase to the west, is sufficient to afford flows in portions of the county not on the higher divides. The record of the McClure well is reported as follows:

Record of McClure well, sec. 31 or 32, T. 108, R. 78, Lyman County, S. Dak.

Feet.	
0– 20	yellow shale.
20– 820	blue shale.
820–1,090	black shale.
1,090–1,094	hard shale.
1,094–1,294	black slate with layers of hard limestone.
1,294–1,320	sandy shale.
1,320–1,470	black shale with sandy streaks.
1,470–1,510	muddy sandstone, black shale, and shelly limestone.
1,510–1,550	gray shale and fine sandstone mixed.
1,550–1,552	very hard rock.
1,552–1,555	shale.
1,555–1,585	sandstone.
1,585–1,623	sandy shale.

There is some uncertainty in this record as to whether the Dakota sandstone was reached at 1,470 feet or 1,555 feet.

McCOOK COUNTY.

The area of artesian flows in this county appears to be restricted to the west half of the northwesternmost townships, where, in an area of about 35 square miles, there are several small flowing wells. These derive their waters either from the basal drift gravels, or from the chalk below in an extension of the shallow artesian region of Sanborn County. To the east and south the quartzite rises nearly to the surface and cuts off the source of supply.

The following list comprises all the flowing wells in McCook County from which returns were received:

List of artesian wells in McCook County, S. Dak.

Location, etc.	Depth.	Average yield per minute.	Remarks.
	Feet.	*Gallons.*	
J. N. Dickens, T. 104, R. 56, sec. 8	123	30	In chalk rock.
J. F. Gurney, T. 104, R. 56, sec. 17	86	150	
N. G. Hall, T. 104, R. 56, sec. 21	175	$\frac{1}{10}$	
John Madkins, T. 104, R. 56, sec. 30	172	25	
F. J. Butler, T. 104, R. 56, sec. 6	95	40	Do.
John D. Hoafer, Bridgewater	113	....	
Jacob Wahl, Bridgewater	160	$1\frac{1}{2}$	No flow.
Robert Glen, Bridgewater	196	....	Do.

These wells, which are all 2-inch bore, usually supply hard waters. The yield of those that flow is reported to be decreasing.

The quartzite lies at only 100 to 154 feet below the surface about Spencer, and at various depths from 150 to 500 feet or more in the region south and east. At Salem, according to Colonel Nettleton, it was found at a depth of 222 feet and was penetrated 25 feet. Water which rose to within 75 feet of the surface was found in this boring in sand at a depth of 215 to 220 feet. At Bridgewater a similar water horizon was found at a depth of 224 feet, but the bottom of the boring at the depth of 229 feet did not reach the quartzite.

MEADE COUNTY.

Meade County extends northeast from the flanks of the Black Hills to the divide between the Owl and Sulphur Creek. To the east it extends for some distance along the west side of Cheyenne River, and it comprises the lower portion of Belle Fourche Valley. A wide range of formations is included within its limits, extending from the granites and schists in the Black Hills uplift to Laramie sandstones and shales in the highlands north of the Belle Fourche.

On the slopes of the Black Hills the older rocks are exposed, dipping so steeply to the northeast that they are soon carried to a considerable depth. The dip diminishes away from the hills and thence, to the northeast, the strata lie nearly horizontal.

The Dakota sandstone is exposed in the hogbacks on the flanks of the Black Hills; it passes beneath the surface and, along the Belle Fourche, lies at a depth of 1,900 to 2,000 feet or more in the lowlands and of more than 2,500 feet on the divides. Probably it lies still deeper in the northeastern portion of the county. This sandstone contains artesian water, which enters it at a high altitude, and, as indicated by the flowing well 6 miles north of Sturgis, has sufficient head to afford artesian flows in the lower lands eastward.

Fort Meade.—Several years ago a well, which was sunk by the quartermaster's department at Fort Meade, just east of the Dakota Hogback Range, developed a 12-gallon flow of excellent water at a depth of 322 feet. With the expectation of finding additional supplies it was continued deeper and penetrated the Spearfish red shales to the Minnekahta limestone, where, unfortunately, it was discontinued without testing the prospects of obtaining water in the upper sandstones of the Minnelusa formation. The record of this boring, based mainly on samples furnished by the quartermaster, is as follows:

Record of boring at Fort Meade, Meade County, S. Dak.

Feet.	
0– 25	sandstone and gravel.
25– 50	buff sandstone, fine grained.
50– 75	buff sandstone, coarser.
75– 100	buff sandstone, medium grained.
100– 125	gray shale.
125– 153	yellow sandstone, fine grained.
153– 185	gray shale.
185– 200	coarse sandstone, dark colored.
200– 225	gray sandstone; some shale.
225– 250	light-gray shale.
250– 288	dark shale with pyrite.
288– 322	sandstone, fine-grained basal Lakota, with shale layers.
At 322	water of good quality, which rose 2 feet above the surface, and flowed 10 to 12 gallons per minute.
322– 600	light-greenish-gray shale.
600– 603	very dark shale.
603– 745	blue shale.
745– 770	red shale.
770– 771	blue shale.
771–1,440	red shale with gypsum at 890 feet, and some gray shale at 850 and 940 feet; gypsum, 910 to 930 feet.
1,440–1,450	limestone (Minnekahta).

It is probable that in Red Valley, in the western part of this county, the sandstones of the Minnelusa formation would be reached at moderate depths and would furnish water supplies, and it is possible also that waters under considerable pressure might be obtained from the underlying formations, the Pahasapa limestone and Deadwood sandstones.

Sturgis.—In a well completed in February, 1904, an excellent supply of flowing water was obtained 6 miles north of Sturgis, in the south-central portion of sec. 8, T. 6 N., R. 5 E., from a depth of 600 feet. The boring has a diameter of 3¾ inches, was sunk to a depth of 750 feet, and obtains its water from an 85-foot bed of white sand of the Lakota formation. The flow is said to run in large volume and have sufficient pressure to rise to a height of 35 feet or more above the surface. The following record was furnished:

Record of well 6 miles north by west of Sturgis, S. Dak.

Feet.	
0–275	dark shales.
275–435	light shales and sand.
435–505	red clay.
505–585	"rocks."
585–670	soft sandstone with large flow of water at about 600 feet.
At 670	coal, 1 inch thick.
670–685	dry sand.
685–705	black shales, with 2 inches of coal.
705–755	green shales, with thin limestone layers.

A small flow was found at 440 feet.

This boring was begun in the Graneros shales, passed through 70 feet of the Fuson formation from 435 to 505, then through 180 feet of Lakota sandstone, and penetrated 70 feet into the Morrison. The altitude of this boring is 3,225 feet, and the occurrence of flowing water indicates that flows are obtainable over a wide area of the lowlands adjoining the east slope of the Black Hills.

MINER COUNTY.

Miner County lies on the east side of James River Valley and extends up the slopes of the coteau eastward, its western half lying in the Dakota artesian basin. The surface of the county is covered by glacial deposits, which lie on Pierre clay in the central and northern parts and on Niobrara chalkstone in the south part. There is the usual succession underground of Niobrara and Benton formations underlain by Dakota sandstone, except in the east-central and southeast portions of the county, where this sandstone abuts against an underground ridge of Sioux quartzite, on which the overlying formations overlap eastward. In the western half of the county the formations dip gently to the northwest away from the quartzite ridge.

The depth to the Dakota sandstone is 375 feet in the southwest corner of the county; it increases gradually to the east and then to the north to from 750 to 800 feet along the north margin. The sandstone contains water throughout its extent under sufficient head to afford vigorous flows in the lower lands comprising the western half of the county. There is an 884-foot well at Carthage which obtains a flow from a depth of 768 feet, and there are numerous deep wells in the southwestern townships which obtain flows from the Dakota sandstone at depths of from 380 to 550 feet. In the two southwest townships flows are also obtained at depths of from 150 to 250 feet from sandstones in the Benton shales, and also at depths of from 50 to 140 feet from the base of the drift deposits. These shallow wells are numerous in the southwest corner of the county, and afford excellent water supplies for local use. Ordinarily the deeper wells are sunk only when the shallower horizons do not afford sufficient supplies. In the central-west portion of the county there are numerous wells about 400 or more feet deep which obtain water from the sandstone underlying the Niobrara chalkstone; it has, however, to be pumped to the surface. The following is a list of the wells in this county:

List of representative artesian wells in Miner County, S. Dak.

Township.	Range.	Average depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
105	56	73–146	5– 75	Flows from base of drift.
		225–320	100	Flows from Benton upper sandstone.
105	57	55–150	2– 50	Flows from base of drift.
		175–490	2–100	Flows from sandstones in Benton group.
105	58	100–140	10– 60	Flows from base of drift.
		170–396	15–150	Flows from sandstones in Benton group.
106	56	80, 126	50– 90	Flows from base of drift.
		450, 465	....	Nonflowing wells at Howard and Vilas.
106	57	66–120	3–100	Flows from base of drift.
		145–176	5– 50	Water from upper Benton sandstone.
106	58	84–100	Many	Flows from base of drift.
107	56	450, 580	Many	No flow; good pump supply; soft water.
107	58	60	Many	Flow from base of drift in section 31 only.
108	57	884	60	Carthage city well.
		408–450	Many	No flow; good pump supply; soft water.
108	58	405–430	Many	Do.

MINNEHAHA COUNTY.

The Dakota sandstone appears not to extend into this county at all, unless possibly under a small area in its northwest corner. The Sioux quartzite has been reached by numerous borings at no great depth, and in many places is overlain by a greater or less thickness of Benton shale and Niobrara chalk. The quartzite outcrops extensively along Sioux River and some of its branches. In some places wells in this quartzite obtain a small amount of water from crevices, but a boring 575 feet deep at Sioux Falls failed to obtain any useful amount of water and was in quartzite throughout. It was found that the formation varied somewhat in hardness.

MOODY COUNTY.

The Dakota sandstone appears to be entirely absent in Moody County. The formations, comprising the Pierre, Niobrara, and Benton shales lie on the Sioux quartzite, which outcrops in the southern portion of the county and has been reached by numerous wells to the north. Some of the sandy beds in the Benton yield small amounts of water, but without sufficient head to flow at the surface. Seven miles southeast of Flandreau the pipestone of the Sioux quartzite series was penetrated for from 230 to 236 feet under sand, shale, and sandy shale. Five miles west and 1 mile south of the same town a well 455 feet deep found water in sand, and water is obtained at Flandreau in sand at a depth of 126 feet. Sioux quartzite is reported at a depth of 100 feet north of Flandreau and at about the same depth 10 miles northeast of that place.

A well about 2 miles east of Trent is reported to have the following record:

Record of well in sec. 8, R. 48, T. 105, near Trent, S. Dak.

Feet.	
0–180	yellow clay and blue clay.
180–192	sand; no water.
192–220	sandy clay.
220–230	sand; with some water.
230–360	clay, with thin bed of sand at 300 feet.
360–363	sand, with main water supply.

PENNINGTON COUNTY.

The geologic relations in this county are very similar to those in Custer County, except that the dips on the east side of the Black Hills uplift average somewhat less. They are sufficient, however, to carry the Dakota and associated sandstones rapidly beneath the surface, so that at a distance of 10 miles east of the Hogback Range their top is at a depth of 2,000 feet. In the valley of Rapid Creek, in the east portion of the county, the sandstone is believed to lie at a depth of about 2,400 feet, and along Cheyenne River, at depths of from 2,100 to 2,300 feet, as

nearly as can be estimated from a determination of the structure of the Pierre shale based on the distribution of the "tepee" zone. Several borings of moderate depth have been made east of Rapid, but they have not been sufficiently deep to reach the Dakota sandstone. It is stated that in one boring a half mile southeast of Rapid a sandstone, probably a sandy layer in the Benton formation, was penetrated at a depth of 400 feet and yielded a small flow. It is probable that the Dakota sandstone would yield flows throughout the portion of this county east of the Hogback Range, except on the higher divides. The prospects for underground waters in the Red Valley are the same as in Custer County.

PINE RIDGE INDIAN RESERVATION.

This large reservation extends from the valleys of Cheyenne and White rivers onto the high table land of Pine Ridge, comprising broad valleys, extensive badlands districts, and wide areas of high plains. The altitudes range from about 2,100 feet in White River Valley in the extreme northwest corner of the reservation, to 3,800 feet or more in the high ridges east of the agency. The high plains are heavily mantled by soft Arikaree sandstone, and the lower slopes are mostly of the underlying White River formations exposed by erosion and giving rise to extensive badlands. In the northeast and the west portions of the reservation the Pierre shales are cut into by White and Cheyenne rivers, and in the extreme southwest corner the Niobrara and the Benton formations appear. The geologic structure probably is relatively simple, the strata in the eastern portion of the area dipping gently to the west and those in the western section dipping gently to the east on the slope of the Black Hills uplift.

Along White River, in the southwest corner of the reservation, a sharp local uplift exists by which the Niobrara and the Benton formations are exposed. The depth to the Dakota sandstone varies considerably in the reservation, owing largely to variations in the altitude of the land. As the thickness of the overlying Benton, Niobrara, and Pierre beds has not been very accurately ascertained, the depth to Dakota sandstone, as indicated on the map, Pl. LXIX, can be given only approximately, and for the south-central part of the reservation, where the Arikaree formation hides the underlying strata, no estimates can be made. The thickness of the Pierre shale doubtless reaches a thousand feet in the northwest corner of the reservation, but the amount diminishes gradually to the east. The Benton group, which has a thickness of somewhat over 1,300 feet on the southeast slopes of the Black Hills, undoubtedly thins rapidly to the east, for it has less than half of that amount on Missouri River. The Niobrara chalk and associated deposits probably preserve a thickness of about 200 feet throughout. The White River beds lie on a somewhat uneven surface of Pierre shale, eroded so that its thick-

ness varies considerably. From these factors it is believed that the Dakota sandstone lies at a depth of about 1,800 feet along White River in the extreme northeast portion of the reservation, and that the amount gradually increases west to 2,300 feet near Interior, a thickness which probably is uniform nearly to the mouth of White Clay Creek. Thence to the south the uplift brings the Dakota sandstone very much nearer the surface, so that, near the State line on White River, it is probably not more than 1,100 or 1,200 feet deep in the center of the anticline. At the Pine Ridge Agency the sandstone will probably be found at a depth of 1,400 to 1,500 feet. In the divide between White and Cheyenne rivers, and in the bad-lands slopes south of White River east of the mouth of Wounded Knee Creek, the Dakota sandstone lies 2,500 feet or more below the surface.

Judging from the general slope of the head of the water in the Dakota sandstones between the Black Hills and Missouri Valley and eastward, it is probable that flowing water may be expected on the Pine Ridge Reservation in the valleys of Cheyenne and White rivers, up to an altitude of 3,000 feet in the northwest corner, 2,600 feet in the north-central portion, and 2,200 feet in the eastern portion. This comprises all of the bottom lands, a moderate proportion of the slopes, and the lower portions of the valleys of the side streams of Cheyenne River and White River valleys below Interior post-office. According to the best estimates the Pine Ridge Agency is at an altitude of 3,300 feet, so that there is no probability of obtaining a flow in White Clay Valley at that place.

POTTER COUNTY.

This county extends east from Missouri River, comprising a narrow area of lowlands in the valley, with a rapid rise east to an elevated undulating district of drift hills. Along the river the altitude is in the neighborhood of 1,500 feet; in the highlands it is mostly at about 1,800 feet, though in portions of them it is considerably above 2,000 feet. The region is underlain by a thick mass of Pierre shale mantled by glacial deposits and underlain by Benton and Niobrara shales and by Dakota sandstone. The latter contains a large volume of water under great pressure, as demonstrated by the experience of the well at the Cheyenne Agency on the opposite side of Missouri River and the well at Gettysburg. The agency well, having a pressure of 205 pounds to the square inch, indicates a head sufficient to raise the water to an altitude of 1,970 feet. The Gettysburg well, which is on land having an altitude of 2,082 feet, has a water level 108 feet below the surface, indicating a head of 1,974 feet. In the adjoining county to the east, the head is less, indicating a rise to the west. Two wells on the highlands just east of Missouri River obtain satisfactory flows—one east of Forest City at 1,604 feet, and the other south of Forest City at 1,761 feet.

From these features it is seen that artesian waters would be available in Potter County in all but the very highest lands, which comprise the elevation on which Gettysburg is situated and the Bowdle Hills along the eastern margin of the county.

Gettysburg.—The Gettysburg well has a depth of 2,130 feet. It is 3 inches in diameter and yields soft water, the principal supply being found at a depth of 1,780 feet. The following record has been furnished by Mr. C. L. Nicholson, the driller:

Record of well at Gettysburg, S. Dak.

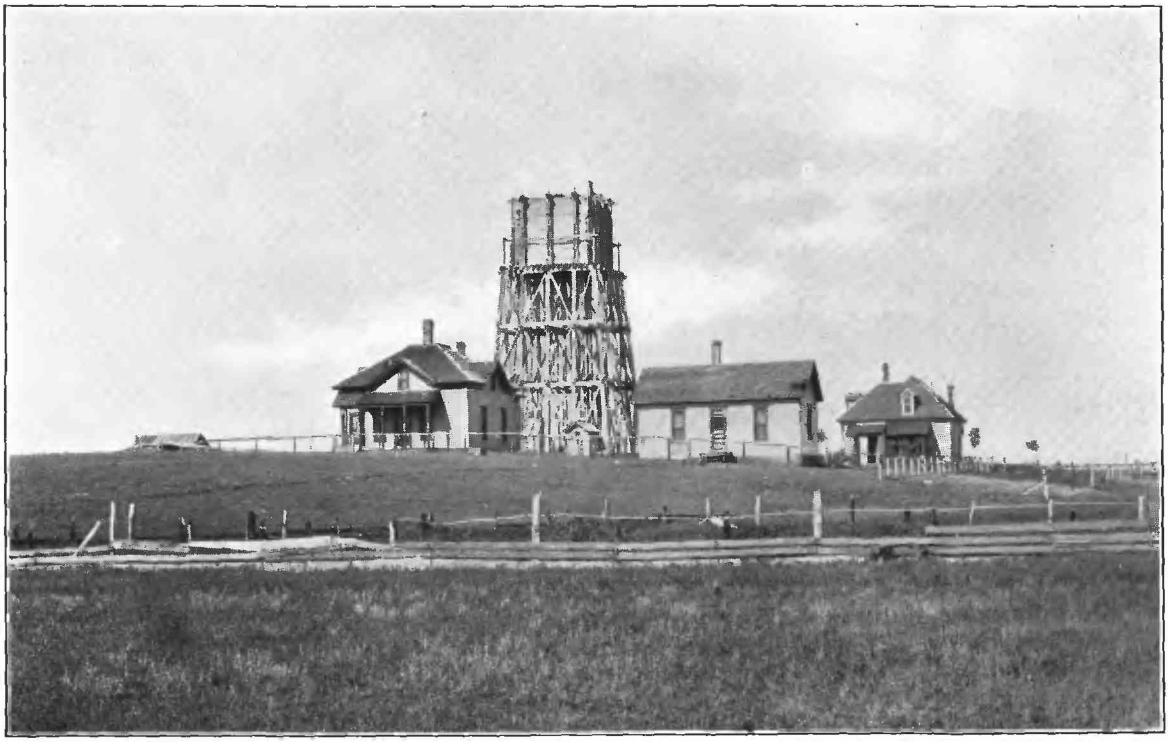
Feet	
0– 2	black soil.
2– 30	yellow clay.
30– 180	blue clay.
180–1,430	blue shale.
1,430–1,470	very hard rock.
1,470–1,780	sandy shale with much pyrites.
1,780–1,980	sand rock with water.
1,980–2,000	sandy shale.
2,000–2,040	sand rock.
2,040–2,130	sandstone and shale alternating.

ROSEBUD INDIAN RESERVATION.

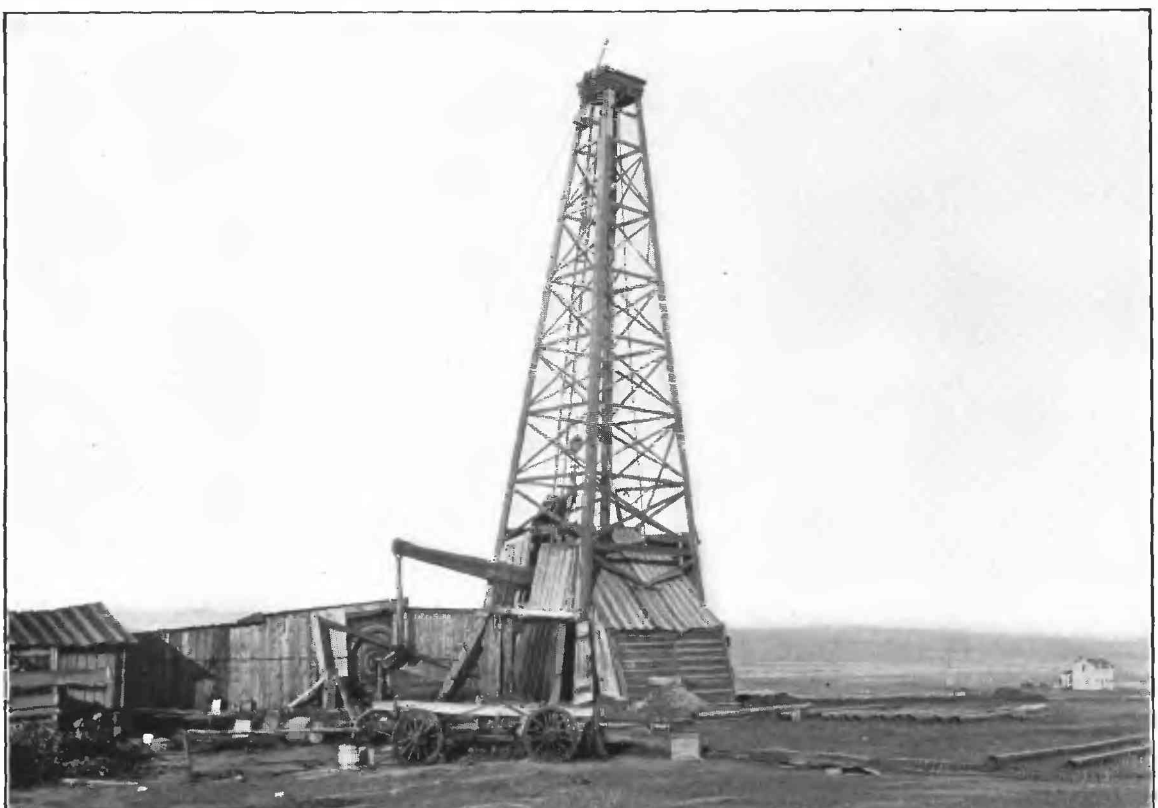
This reservation comprises about 5,000 square miles of the plains lying south of White River in the south-central portion of South Dakota. The greater part of the surface is rolling, with numerous deep valleys draining into White River to the north or Missouri River to the east. It also contains the headwaters of Ponca Creek and Keyapaha River. The altitudes range from somewhat less than 1,200 feet on Missouri River to 3,000 feet in the southwest corner of the reservation.

The predominating formation of the region is the Pierre shale, overlain in the higher lands of the south by White River and Arikaree deposits, and cut through by the Missouri, which exposes the underlying Niobrara chalkstone along the east side of the reservation. The beds lie nearly horizontal, dipping very slightly to the west. Beneath the Pierre shale there is the usual succession of Niobrara chalkstone, Benton shales, and Dakota sandstone. In the lower lands to the east this sandstone is less than a thousand feet below the surface, but lies deeper to the west, and, in the higher lands southwest of the Rosebud Agency, is at least 2,500 feet deep. On White River, in the northwest corner of the reservation, the depth is probably about 1,900 feet.

Only one boring has been sunk in the area. It is located on the high lands at the head of Oak Creek, on the divide between the White River and Keyapaha drainages. It was sunk by the Indian Bureau with the expectation of obtaining a flow that would fill some of the creeks with water, but this project was not



A. WATER TANK AT BELLEFOURCHE, S. DAK., FILLED BY DIRECT FLOW OF 500-FOOT ARTESIAN WELL.



B. TYPICAL DEEP-WELL RIG AT DEEP BORING, ROSEBUD RESERVATION, S. DAK., 25 MILES NORTHEAST OF AGENCY.

realized. A depth of 2,500 feet was attained and the Dakota sandstone penetrated for several hundred feet, finding water in moderate volume, which rose to within 500 or 600 feet of the surface. The ground at the well has been found by recent leveling to have an altitude of 2,626 feet, so that the water level at the well is between 2,026 and 2,126 feet above sea level. This head indicates that flows might be expected all along White River Valley and for some distance up the adjoining valleys and slopes, probably to the western margin of the reservation. This altitude of head probably increases slightly to the west, approaching the Black Hills, and decreases to the east, as shown by the experience of wells along Missouri Valley. Adjacent to this valley there is sufficient head to afford flows far up the slopes, but not on the wide areas of high plains in the eastern portion of the reservation. (See Pl. LXI, *B*.)

Rosebud well.—This boring was made in 1895, 1896, and 1897, and, while a costly experiment, has thrown very important light on underground-water conditions over a wide area of south-central South Dakota. The depth of the boring is 2,500 feet. It was cased with 8-inch casing to 2,145 feet, then with 6-inch casing. The following record is given, based on samples kindly furnished by Mr. Wright and Dr. McChesney, the Indian agents:

Record of the "Rosebud well," Rosebud Indian Reservation, S. Dak.

Feet.	
0- 350	Tertiary sands and clays.
350-1,390	dark-gray shales.
at 1,390	water which rose to -1,140 feet.
1,390-1,550	light-gray shales, with water at 1,490 feet.
1,550-1,730	light-gray limy shales.
1,730-1,860	dark shales.
1,860-1,880	sandstone and limestone.
1,880-1,885	hard sandstone, with water to -600 feet.
1,885-1,920	shale, darker below.
1,920-1,950	hard sandstone.
1,950-2,075	soft shales, with thin limestone bed at 2,060 feet.
2,075-2,100	(unknown).
2,100-2,140	gray sandstone, hard at top.
2,140-2,150	soft shale.
2,150-2,175	porous sandrock, with considerable water which rose to within 500 (?) feet of the surface.
2,175-2,210	(unknown).
2,210-2,240	shale.
2,240-2,290	sandstone.
2,290-2,292	gray shale.
2,292-2,500	fine-grained sandstone with some shale and pyrites, with water mainly at 2,295 feet.

The uppermost beds belong to the Arikaree and White River formations. The Pierre shale underlies these formations to a depth of about 1,550 feet, a thickness of 1,200 feet, to the Niobrara chalkstone, which appears to begin at a hard limestone layer and to comprise nearly the next 200 feet of limy clays to 1,730 feet. The underlying shales with thin beds of sandstone and limestone belong in the Benton formation, which extends to at least 2,100 feet, where thick beds of sandstone begin and continue thence to the bottom, probably representing the Dakota sandstone for the lower 200 feet at least. The volume of water in the sandstone in this well was not thoroughly tested, but it was the idea of the drillers that it was moderate, which is surprising when the large flows in some of the wells to the north and east are considered. The sandstones in the well are very fine grained and on this account much less permeable than in some other localities. It is unfortunate that this boring was not continued through the Dakota sandstone to test the water pressure in the lowermost beds, and to explore underlying formations in which waters might be expected to have still greater head.

It is possible that this region is underlain by the eastern extension of some of the sedimentary formations older than Dakota sandstone, which are so prominent in the Black Hills.

SANBORN COUNTY.

Sanborn County lies in James River Valley and comprises a very important portion of the Dakota artesian basin. It is underlain by Pierre shale, Niobrara chalk, Benton shales and sandstone, and Dakota sandstone, lying on a floor of quartzite and granite, all dipping gently to the north. The surface is deeply covered by drift and superficial deposits and there are no outcrops of the underlying rocks, all knowledge of them being derived entirely from well records. The Pierre shale underlies the northern portion of the county only, the drift in the southern portion of the county being underlain by the Niobrara chalk.

The depth to artesian water increases nearly regularly from north to south, except that in James River Valley, which is excavated to a depth of about 100 feet below the surrounding plains, the depths are correspondingly less. Dakota sandstone, usually near its top, is the principal source of water supply, though sandstones at various horizons in the Benton formation also afford flows of moderate volume. In the east-central portion of the county about Artesian there is an area of considerable extent in which flowing waters are obtained from the base of the drift at depths mostly from 50 to 110 feet, the water probably having its source through leakage from the upper sandstone of the Benton formation. This sandstone is a persistent member throughout the greater part of the region and is reached by many wells of moderate depth, especially in the district about Letcher.

The depths of wells to the Dakota sandstone averages from 340 to 450 feet along the southern margin of the county, increasing to 475 feet in the higher lands to the west and diminishing to less than 300 feet in the valley of James River. To the north the increase in depth is regular; along the northern margin of the county it is about 750 feet on the higher lands and 700 feet in the trough of James River Valley. The waters have considerable head, the altitude of which is about 1,400 feet in the southern part of the county, 1,500 feet in the central and eastern portion, 1,600 feet about Woonsocket and northward, and about 1,550 feet in the northeast corner. This head is indicated by a pressure of 130 pounds to the square inch at Woonsocket, and 90–130 pounds to the square inch in the vicinity of Letcher. A view of the Woonsocket well is given in Pl. LX, *B*, which clearly shows that the water is under high pressure, for it is being jetted to a height of over 100 feet above the surface of the ground. The volume of the water varies considerably, but, in general, increases to the north. At Woonsocket a flow of 1,150 gallons per minute is reported from a well 6 inches in diameter. The following is a list of the principal wells in Sanborn County:

List of artesian wells, by townships, in Sanborn County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
105	59	312	....	Flow from sandstones in Benton formation.
		380–476	....	Flow from Dakota sandstones.
105	60	75–100	....	Flow from Pleistocene deposits.
		400	....	Flow from Benton formation.
		360–630	15–165	Flow from Dakota sandstones. One well has a 35-pound pressure.
105	61	250–420	....	Flow from Benton formation.
		348–670	4–125	Flow from Dakota sandstone. One well, 80 pounds pressure.
	Letcher.	585	80	90-pound pressure.
105	62	300–410	....	Small flows from Benton formation.
		400–490	....	Small flows from Dakota sandstone.
106	59	80–201	....	Flow from Pleistocene deposits.
		625–701	....	Flow from Dakota sandstone.
	Artesian.	708	120	Do.
106	60	60–118	....	Flow from Pleistocene deposits.
		580–686	....	Flow from Dakota sandstone.
106	61	68–72	....	Flow from Pleistocene deposits.
		350–373	....	Flow from Benton formation.
		560–576	....	Flow from Dakota sandstone.

List of artesian wells, by townships, in Sanborn County, S. Dak.—Continued.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
107	59	47–110	....	Flow from Pleistocene deposits.
107	60	70–125	....	Do.
107	62	689–750	....	Flow from Dakota sandstone.
	Woonsocket.	725	1,150	Flow from Dakota sandstone; 130-pound pressure.
	Woonsocket.	775	Many.	Pressure 125 pounds (mill well).
108	60	74–80	....	Flow from Pleistocene deposits. One 40-gallon flow.
		530	....	Flow from Benton formation.
108	62	792	23	Flow from Dakota sandstone.

Records of some representative wells are as follows:

Record of mill well at Woonsocket, S. Dak.

Feet.
0– 25..........................yellow clay and blue clay.
25– 45..........................sand.
45– 58..........................blue clay.
58– 65..........................hardpan.
65– 95..........................sand.
95–165..........................hardpan and gravel.
165–412..........................shale with pyrites on top, "soapstone" below.
412–436..........................hard sandstone on brown sandstone.
436–637..........................soapstone and shale with pyrites.
637–645..........................hard lime rock.
645–690..........................shale.
690–697..........................hard rock on shale.
697–775..........................sandstone with water.

Record of well on farm of H. K. and E. O. Ashmore, near Artesian, S. Dak.

Feet.
0–130..drift.
130–140..chalk rock.
140–190..shale.
190–235..sandstone; no water.
235–690..shale, with first flow at 530 feet, layer of sand rock with water at 630 feet, rock, not very hard at 690 feet.

Record of well in northwest quarter sec. 18, T. 106, R. 59.

Feet.
0–130 .... glacial deposits.
130–140 .... chalk. ⎫
140–200 .... shale ⎪
200–262 .... sandstone ⎪
262–525 .... shale. At 525 feet, sandstone with first flow. ⎬ Benton.
525–626 .... shale ⎪
626–630 .... sandstone with second flow ⎪
630–699 .... shale ⎭
699–701 .... sandstone.

Apparently the first two flows in this well are from the thin sandstones in the Benton formation, and, in fact, characteristic Benton fossils were obtained near its bottom.

Record of the Ryan well at Letcher, S. Dak.

Feet.
1–100 .... (?).
100–170 .... chalk.
170–200 .... sandstone.
200–300 .... shale.
300–314 .... sandstone with first flow.
314–513 .... shale.
513–521 .... hard sandstone.
521–561 .... sandstone, with 125-gallon flow.

In this well the Dakota sandstone evidently begins at a depth of 513 feet, and the usual first flow is found in the second sandstone in the Benton formation, at 300 feet.

Record of city well at Artesian, S. Dak.

Feet.
0–63 .... drift deposits.
63–123 .... dark shale.
123–250 .... dark shale with lime rock and pyrites, thin bed of sandstone at base.
250–675 .... dark shale.
675–680 .... sandstone, with 50-gallon flow.
680–684 .... hard sandstone (?).
684–708 .... sandstone, with 120-gallon flow.

SPINK COUNTY.

Spink County is in James River Valley and consists mostly of a level plain with an average altitude of about 1,300 feet, traversed by the shallow valleys of the river and the creeks. The surface is mantled with drift deposits, mostly stratified, but presenting a few morainal hills. The underlying formations are Pierre shale, below which there is the usual succession of Niobrara, Benton, and Dakota formations lying on granite and possibly quartzite in some places. The Niobrara appears to be represented by shale, or by chalk so mixed with clay that its distinctive

features are not recognized by the well borers. The entire county lies within the Dakota artesian basin and its waters are tapped by numerous wells, there being probably nearly 75 in all. They average about 900 feet in depth, in most cases obtaining their water from the upper portion of the Dakota sandstone, though a few of the deeper ones reach lower strata. The beds lie nearly horizontal, but rise slightly to the southeast, owing to an underground ridge of quartzite and granite which extends across the southeast corner of the county. Some of the wells in the vicinity of this ridge which have not obtained satisfactory water supplies have been sunk to the granite in the hope of obtaining greater volume. The waters have high pressure, averaging over 100 pounds to the square inch throughout the county, rising to 165 pounds at Mellette and to 177 pounds at Redfield, and diminishing to 50 pounds in the Glidden well, a short distance northwest of Hitchcock, where granite was reached. The principal features of the wells in Spink County are given in the following list:

List of artesian wells, by townships, in Spink County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
114	62	890–1,000	30–1,000	Pressures of 125 and 150 pounds.
114	63	909 and 1,150	550 and 1,200	Pressure, 50 pounds.
114	64	921	35	
114	65	940	35	
115	61	1,050	75	Pressure, 87 pounds.
116	61	940	....	
116	62	910–920	35–40	
		895	600	Blaine well. } Frankfort.
		1,008	....	Town well. } Frankfort.
116	63	880–923	25–80	
116	64	960–1,060	....	Redfield city wells, Nos. 2 and 3.
116	64	956	300	Institution for feeble-minded.
116	64	858–965	45–175	
		964	1,260	Pressure, 177 pounds (Redfield town well).
		1,025	1,900	Well of Hassell & Myers in Redfield.
117	60	897 and 957	370 and 600	Pressure, 122 and 112 pounds (Doland town wells).
117	61	952	110	
117	62	950	350	
117	63	908–1,052	21–45	
117	64	957–987	....	
117	65	890–955	35–65	
118	60	850–986	25–35	
		920	1,300	Turton town well.
118	61	873–988	35–40	
118	62	863–1,012	25–120	

List of artesian wells, by townships, in Spink County, S. Dak.—Continued.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
118	63	870–882	10–200	
118	64	870–1,021	40–160	
		925, 1,003	100 and 2,000	Pressures, 60 pounds and 150 pounds. C., M. and St. P. R. R. well, and mill well at Ashton.
118	65	932, 960	36	Pressure, 150 pounds.
119	60	891–925	30–150	Pressure, 130 pounds.
119	61	825–970	2–60	
119	62	910–975	26–45	
119	63	920–958	60–894	Pressures, 141 pounds and 153 pounds.
119	64	920–1,065	467–1,320	Pressures from 156 to 165 pounds (Mellette town wells).
119	64	980, 1,020	1,900 and 150	Northville wells.
120	60	960	....	Well in Conde.
120	62	950–1,170	20–30	
120	63	920	180	
120	64	900–948	12–84	Pressure, 120 pounds.
120	65	918	278	

The records of borings in Spink County are very uniform. There are 800 feet or more of shales representing the Pierre, Niobrara, and Benton formations, the latter usually containing some thin beds of sandstone and limestone, with small flows. The Dakota sandstone has not been penetrated deeply in the northern portion of the county. At its top there is usually a thick mass of sandstone and sometimes bodies of shale. In the southern part of the county, where the crystalline rock has been reached, the sandstone was found to be of variable thickness, being about 200 feet in the Glidden well a short distance northwest of Hitchcock, and only 150 feet in the Budlong well 5 miles northeast of Hitchcock. In both of these places the sandstone was in thin layers separated by considerable shale, mostly of light color, in marked contrast to the conditions in other wells not far distant, in which thick masses of sandstone were found, as, for instance, in the boring at Frankfort, in which 200 feet in one nearly continuous mass was penetrated.

STANLEY COUNTY,

Including northern part of Lower Brule Indian Reservation.

This county comprises an area of nearly 5,000 square miles in the central part of South Dakota, extending west from Missouri River Valley south of Cheyenne River, and in its southwestern portion reaching White River. Very nearly all of its area is underlain by the Pierre shale, except in small areas of overlying Fox Hills sandstone west of Grindstone Buttes, and along the eastern margin of the White River badlands formations in the southwest corner. Under the Pierre shale

there is the usual succession of Niobrara chalk, Benton shale, and Dakota sandstone, underlain to the east by granite or quartzite and probably overlapping to the west onto the eastern extension of some of the earlier Mesozoic and Paleozoic rocks that extend underground from the Black Hills region. The beds appear to lie nearly level under the greater part of this county, or to dip gently to the west.

The depth to the Dakota sandstone at Pierre is about 1,150 feet and gradually increases as the land rises westward. In the northeast corner of the county, at the mouth of Cheyenne River, the depth is probably about 1,250 feet. On this river, in the northwest corner of the county, the depth is probably nearly 2,000 feet, or possibly more, if there is any unusual thickness of the formations in this direction. In the southwest corner of the county, on White River, the depth probably is somewhat greater and reaches very nearly 2,500 feet, and on the head of Bad River this amount must be considerably exceeded. On the high divide between the rivers the depths are from 300 to 500 feet greater than in the valleys.

Judging by the pressure of the waters in the wells at Pierre and the probable increase in head to the west, flowing waters may be expected in the large valleys and part of the way up the slopes all across the county, but it is exceedingly important that a well be sunk in some portion of this outlying region to ascertain the head of the artesian waters in the country midway between Pierre and the Black Hills.

SULLY COUNTY.

Sully County extends eastward from Missouri River part way across the high ridges lying between Okobojo and Medicine Knoll creeks. The highlands are covered more or less thickly by glacial drift and the entire region is underlain by a thick mass of Pierre shale. The Dakota sandstone lies deep, even in Missouri Valley, but has been reached by a number of wells and found to contain large volumes of water having sufficient head to afford a flow throughout the area. The following list indicates the principal conditions under which the waters are obtained:

List of artesian wells in Sully County, S. Dak.

Location, etc.	Depth.	Depth to water.	Diameter.	Average yield per minute.	Remarks.
	Feet.	*Feet.*	*Inches.*	*Gallons.*	
Mr. Wadleigh, T. 113, R. 79, SE. ¼ sec. 32.	1,565	1,565	3–2	200	Water saline.
Oneida, town well, T. 114, R. 77, NW. ¼ sec. 11.	1,717	1,560 1,630	2	85	Pressure 21 pounds; hard, no gas.
Pearl Township "No. 2," T. 115, R. 79, SE. ¼ sec. 3.	1,645	1,640	2	20	Water soft, warm, gassy.
Pearl Township "No. 1," T. 115, R. 79, NW. ¼ of NE. ¼ sec. 28.	1,781	1,600	2	65	Pressure 25 pounds; soft, gassy.
A. Hallam, T. 116, R. 78, sec. 19	1,595	1,595	2	85	Pressure 65 pounds; soft, gassy.

The following records of Sully County wells have been furnished:

Record of deep well in T. 113, R. 79, SE. ¼ sec. 32, Sully County, S. Dak.

Feet.	
0– 2	black soil and gravel.
2– 30	yellow clay, gravelly.
30– 190	blue clay (part till).
190– 610	blue shale, with slabs.
610– 680	black shale, with occasional slabs.
680– 720	coarse gravel.
720– 783	shale (?).
783– 785	very hard sandstone, with gas.
785–1,000	blue shale, with "shells" of limestone.
1,000–1,060	gray shale.
1,060–1,400	blue shale, with some limestone and slate.
1,400–1,402	hard stone.
1,402–1,510	shale and sandy streaks, with first flow at 1,402 feet.
1,510–1,565	fine sand rock, with hard shells; second flow, gas.

Record of deep well in T. 114, R. 77, NW. ¼ sec. 11, the town of Onida, S. Dak.

Feet.	
0– 3	black soil.
3– 34	yellow clay.
34– 170	blue clay and gravel pockets.
170– 950	blue shale, with hard shells.
950–1,200	black shale, with slate.
1,200–1,260	gray shale.
1,260–1,400	blue shale.
1,400–1,560	shale, sandy in streaks.
1,560–1,630	sandstone, with a few hard "shells," first flow.
1,630–1,717	sand rock, second flow.

Record of well No. 1, Pearl Township, Sully County, S. Dak.

Feet.	
0– 3	black soil.
3– 34	yellow clay.
34– 210	blue clay.
210– 968	blue shale, with slabs 2 to 20 feet thick.
968– 970	shaly limestone.
970–1,020	shale.
1,020–1,028	limestone.
1,028–1,080	shale.
1,080–1,585	blue shale, streaks of gray shale, and limestone.
1,585–1,780	sandstone; water; flows not definite.
1,780–1,781	very hard rock.

Record of deep well No. 2, Pearl Township, Sully County, S. Dak.

Feet.	
0 - 1½	..black soil.
1½- 32	..yellow clay.
32 - 200	..blue clay (till and Pierre ?).
200 - 210	..sand.
210 -1,240	..shale, with hard layers.
1,240 -1,265	.."many hard layers of limestone."
1,265 -1,295	..hard cap rock.
1,295 -1,525	..shale, with few "shells" (i. e., hard streaks, some gray below, blue and black above).
1,525 -1,531	..sandstone and water; no flow.
1,531 -1,600	..alternating shale and sand rock, 5 to 10-foot layers; water.
1,600 -1,645	..sandstone and flow of water, with gas.
1,645 -1,646	..very hard stone; probably granite.

TURNER COUNTY.

Turner County comprises a portion of Vermilion River Valley and the adjoining prairies to the summit of Turkey Ridge. Its surface is mostly covered with glacial drift which lies in thick masses on the higher lands. The Sioux quartzite rises in the north and northeast portions of the county, where it is exposed at a number of points and reached by numerous wells of moderate depth. To the south the drift is underlain by the Niobrara chalkstone and probably by more or less Pierre shale in Turkey Ridge. The Benton formation and Dakota sandstone underlie the central and south portions of the county, and abut against the slope of Sioux quartzite, the edge of the younger formation probably extending for several miles northwest beyond the margin of the older one.

Owing to the diminished pressure of water in the Dakota sandstone, artesian flows from this source are available in this county only in the southeast corner of Vermilion River Valley. There are, however, at numerous localities, small flows from the base of the drift at depths mostly of from 50 to 100 feet. A number of deep wells, which have been sunk in Turner County, have found in the Dakota sandstone water which rises several hundred feet, but not sufficiently to flow. One well 4 miles west by south of Hurley has a depth of 513 feet, passing through drift, 80 feet; chalkstone from 80 to 150 feet; Benton shales, 150 to 417 feet; and Dakota sandstone to the bottom, which apparently is in Sioux quartzite. At Hurley, a well passes through 35 feet of drift, 100 feet of chalk rock, and 265 feet of Benton shale to the top of the Dakota sandstone. North of this are a number of moderately deep wells which apparently obtain water supplies from sandstone at the base of the chalk rock, which is underlain at no great depth by Sioux quartzite.

UNION COUNTY.

The Dakota sandstone appears to underlie all of Union County, outcropping to the southeast in the bluffs on the Iowa side, near the mouth of Big Sioux River. The sandstone has been reached by a number of wells of moderate depth in the western portion of the county, but the head of the artesian water is so low that there are no surface flows.

WALWORTH COUNTY.

This county extends east from Missouri River, and, except for a narrow strip of bottom land, consists of highlands, with altitudes from 1,800 feet to slightly over 2,000 feet. The altitude of the river bottom is in the neighborhood of 1,500 feet, being 1,552 feet at Evarts. The county is underlain by Dakota sandstone, which has an altitude above sea level of about 300 feet in the eastern part and 150 feet in the western part.

Selby.—A well recently sunk at Selby reached the Dakota sandstone at a depth of 1,747 feet, penetrated it to a depth of 1,897 feet, and obtained a flow of 17 gallons per minute, under sufficient pressure to rise about 38 feet above the surface, or to 1,915 feet above sea level. The first 90 feet in the well are glacial drift, below which are 1,662 feet of shales, comprising the Pierre, Niobrara, and Benton formations. The diameter of the well is 1¼ inches inside. The water is alkaline and tepid, and contains sufficient gas to afford a constant flame several feet high. The principal flow was from a depth of 1,880 feet. This well indicates that artesian waters are available in Walworth County up to altitudes slightly above 1,900 feet in the vicinity of Selby, with the head diminishing somewhat to the east, as indicated by the lower pressure at Ipswich, and increasing to the south, as shown by the head of 1,974 feet in the Gettysburg well, in the adjoining county. These facts would indicate that about half of the county is sufficiently low for a flow, while the ridge north of Swan Creek, between Selby and Byron, together with some smaller areas, are too high for flowing wells.

YANKTON COUNTY.

Yankton County extends northward from Missouri River onto a region of rolling plains traversed by the valley of James River. The higher lands are covered by glacial drift and the underlying formations appear only in bluffs along Missouri River. Nearly all of the area is underlain by Niobrara chalkstone, but this formation is cut through by the Missouri, below the mouth of the James, revealing the underlying Carlile shales of the Benton series. The entire county is underlain by Dakota sandstone, containing a large volume of water, under pressure sufficiently great to afford flowing wells in all the townships, except on the divide between

James River and Clay Creek and in the northeast corner of the county. Along the bottom lands of Missouri and James rivers these waters have been developed by numerous wells which obtain flows at moderate depths. There is considerable variation in the volume of water, one well in Yankton 493 feet deep having at one time produced 3,000 gallons per minute from an 8-inch casing, while others in other portions of the district produce very much less, owing to locally increased compactness of the water-bearing rock and diminution of pressure. The decrease of pressure is gradual and regular from west to east across this county, owing to the fall of hydrostatic head toward the zone of leakage in the area in which the Dakota sandstone is at, or near, the surface in Union County and southward. The following list gives the principal features of the deeper wells in this county from which reports have been received:

List of artesian wells, by townships, in Yankton County, S. Dak.

Township.	Range.	Depth.	Average yield per minute.	Remarks.
		Feet.	*Gallons.*	
93	54	250–450	6–120	Pressure, 10 to 60 pounds.
93	55	212–483	36–140	Pressure, 15–30 pounds.
		520, 521	95, 350	Pressures, 45 and 49 pounds; several flows.
93	55–56	493	3,000	Excelsior Mill, Yankton; 8-inch; several flows; pressure, 52 pounds.
		600	1,450	Fountain Roller Mill, Yankton; 6-inch; pressure, 48 pounds.
		615	880	City well, Yankton; 6-inch; pressure, 18 pounds.
		942	....	City well, deepened; no additional flow.
		672	165	Asylum well near Yankton.
		524	2,600	College Hill, Yankton; 2-inch well.
		500	1,300	Cement company's well, near Yankton; 5 flows; 5-inch well; pressure, 50 pounds.
		521	350	Whiting nursery, Yankton; 3-inch well; pressure, 49 pounds.
		400–475	6–95	Small wells.
93	57	530, 585	Many.	Pressures of 30 pounds or more.
94	54	268–510	5–150	Numerous small wells; pressure, 12 to 60 pounds.
94	55	435–648	3–100	
95	54	545, 580	8	Three flows; pressure, 6 pounds.
95	55	535, 554	Many.	Several flows.
		266	90	First flow well.
95	56	544–640	43–80	Pressure, 15 pounds.
96	55	145, 590	Several.	
96	56	700	Many.	No flow.
96	57	505	5	Two flow.

One of the most noticeable features in this table is the great variation in the volume of water in wells in the vicinity of Yankton. This is particularly the case in the relatively small volume afforded by the city well at Yankton. In order to obtain a larger supply, this well was deepened some years ago from 625 to 942 feet, but no material increase of flow was obtained. It is stated that the last 44 feet were in crystalline "bed rock." In all of the deeper wells, several flows are found in sandstone beds occurring at intervals in alternation with clay beds in the Dakota formation. The thickness and position of these sandstone strata appear to be very variable. In general the deeper-seated waters are more uniform in volume and furnish large supplies, mainly in Yankton and its vicinity. Higher horizons furnish water for local use in many small wells, which are sunk only sufficiently deep to reach a moderate supply.

In Yankton the waters are used to a considerable extent for power in mills, in some cases developing a pressure of 50 pounds to the square inch. The wells on the higher lands are considerably over 600 feet in depth, while those on the low lands near the river are of correspondingly less depth. The pressure varies, partly on account of differences of altitudes of the wells, but gradually decreases to the east, as above explained. It is claimed that the pressure in the wells is diminishing, and, as a very large amount of water has been flowing from them for many years; doubtless this is the case in portions of the area where wells are numerous. At one of the mills in Yankton the original pressure was 45 pounds, but after the water had been flowing freely for two years it was found to be losing pressure. The practice was then begun of shutting off the flow when the mill was not running, since when the pressure has remained constant at 37 pounds. In many cases the apparent diminution of pressure in the wells is due to the caving in of the lower portion, which cuts off the lower and stronger flows, and in some cases also to the fact that the pipes are corroded and permit the water to escape underground into strata where the pressure is less.

The geologic conditions in the wells of Yankton County are very similar to those of Bon Homme County, most of the borings beginning in the Niobrara chalk rock, passing into the Benton series at a depth of from 50 to 200 feet, and thence, through 300 feet of this series, to the Dakota sandstone. Some typical sections are as follows:

Record of city well at Yankton, S. Dak.

Feet.	
0– 25	yellow clay.
25– 55	blue clay.
55–115	chalk.
115–415	Benton clays.
415–615	alternations of sandstone and clay, the latter predominating.
615–625	principal water-bearing horizon.
625–898	alternations of sandstone and clay.
898–942	"granite."

In the asylum well, 3 miles north of the city, a very similar record was observed, with a large body of water-bearing sand extending from 609 to 672 feet. It is stated that in another well at the asylum the Sioux quartzite was reached at a depth of 825 feet. At the mill well, in Yankton, a somewhat different series of beds was reported, as the following record shows:

Record of mill well, Yankton, S. Dak.

Feet.	
0– 38	soil, sand, and gravel.
38–100	chalk.
100–126	shale.
126–130	hard rock.
130–164	sand.
164–229	shale.
229–254	sand.
254–389	shale.
389–489	sand and clay in alternating strata.
489–595	water-bearing sandstone yielding a flow of 1,450 gallons per minute through a 6-inch casing; with a surface pressure of 48 pounds to the square inch.

It is probable that the sand beds reported between 130 and 254 feet occur in the other wells in this vicinity, but were not reported. The upper sand stratum is probably the one that usually occurs a short distance below the Niobrara chalkstone, and the hard rock stratum doubtless a concretion such as characterizes the upper portion of the Carlile formation.

At the Yankton cement works, west of Yankton, the top of the Dakota formation appears to have been reached at a depth of 450 feet and penetrated 50 feet, yielding a flow of 1,300 gallons per minute through a 5-inch casing.

DEEP WELLS AND WELL PROSPECTS IN NEBRASKA.

WESTERN NEBRASKA.

Under this head will be presented statements regarding the underground water conditions in the portion of the State which lies west of longitude 102°. The region is in greater part covered by thick mantles of sands and clays of later Tertiary age, which have a thickness of several hundred feet and so hide the underlying formations that the geologic structure of the older water-bearing formations can not be ascertained, except in a general way. Although North Platte River has cut a deep valley in the younger formations, it does not expose the underlying rocks, except in the extreme western portion of the State, where the Laramie sandstones are bared. In Colorado, not far south of the State line, South Platte River cuts through to the Laramie formation which it exposes as far eastward as longitude 102° 30′.

These exposures indicate that Kimball, Banner, Scotts Bluff, and the greater parts of Cheyenne and Deuel counties are underlain by the Laramie formation lying in a shallow synclinal trough.

As the Laramie consists of sandstones which rise to a considerable altitude to the west, the area which they underlie may yield artesian waters. A well sunk some years ago at Harrisburg, in the central portion of Banner County, to a depth of 700 feet, appears to have passed 500 feet or more into this formation, and although it found water, the head was not sufficient to afford a surface flow. At Gering, a well was sunk to a depth of 300 feet or more, which it is claimed afforded a vigorous flow of water for a short time, but was soon choked up with sand. The source of this water was undoubtedly a sandstone in the Laramie formation and its discovery is a most encouraging circumstance. As Gering is 600 feet lower than Harrisburg it is much more likely that flowing waters would be found there.

The thickness of the Laramie beds is not known, but probably they thin rapidly to the north. They are underlain by the Fox Hills sandstone and the Pierre shale, which last may be expected to be about 1,200 feet thick, and the usual succession of Niobrara chalk, 200 feet, and Benton shales, 500 feet or more, lying on the Dakota sandstone. It is almost certain that this sandstone lies at a very great depth in the region south of Niobrara River and under Pine Ridge to the north, but in the lowlands north of Pine Ridge where the Pierre shale is exposed it may be expected at a moderate depth. In northern Sioux County, along the valleys, the Dakota sandstone is probably not over 1,600 feet below the surface, but the land is probably too high for the sandstone to afford flowing wells. The well at Ardmore, a short distance north of the State line, reached a depth of 1,500 feet, and was discontinued apparently only a short distance above the top of the Dakota sandstone. (See fig. 14, p. 224.) In the northern portion of Dawes County there is a synclinal basin to the west and an anticlinal arch to the east, the Dakota sandstone lying more than 2,500 feet deep in the former and probably rising to within 1,100 feet of the surface in the highest part of the latter on White River, 10 miles northeast of Chadron.

It is very unlikely that the head of the water in the Dakota sandstone is sufficiently great to afford a flow in White River Valley north of Chadron, but there is considerable uncertainty as to the precise height to which the water should be expected to rise in this region. A boring was made a short distance north of Chadron to a depth of 1,800 feet, but was discontinued in the Benton shale and sandstone, probably 200 feet or more above the top of the Dakota sandstone, so that it was not successful.

In the lower portion of the Arikaree formation, which underlies all of the high divides of western Nebraska from Pine Ridge south, there is a supply of excellent

water which is available for pump wells from 200 to 500 feet deep. It is reached by numerous wells and affords an important source of water supply for cattle, and, in some cases, for the irrigation of small garden patches. In the underlying Brule clays of the White River group, water is almost entirely absent, although a small quantity is usually available in the basal Chadron sands which lie on the Pierre shales to the north and on the Laramie formation to the south.

A well at Gordon, bored by the Northwestern Railroad, found considerable water at various depths from 25 to 182 feet, but from 182 feet to the bottom at 580 feet no further supplies were obtained. Apparently the base of the White River group was not reached, so that the basal Chadron beds were not tested.

Record of deep boring at Gordon, Nebr.

Feet.
0- 12..firm gray clay.
12- 15..fine yellow sand.
15- 40..hard sandy clay.
40-180..sandy clay, with some water.
180-182..white sand, considerable water.
182-580..sand and clay, the former predominating; in alternate layers. Colors, white, yellow, and gray, with limestone concretions.

CENTRAL NEBRASKA,

Comprising Blaine, Brown, Buffalo, Cherry, Custer, Dawson, Grant, Garfield, Hooker, Keith, Lincoln, Logan, Loup, McPherson, Sherman, Perkins, Thomas, and Valley counties.

Central Nebraska is so widely covered by Quaternary and Tertiary deposits that the geology of the Cretaceous formations and the relations of the deeper underground waters are not known. No wells have yet been sunk sufficiently deep to throw light on the prospects for obtaining water from the Dakota formation, but the greater part of the district is too high for flowing wells from this formation, which probably lies so deeply buried that a boring sufficiently deep to reach it would not repay its cost. There is considerable water in the Tertiary formations, which affords satisfactory supplies for many pump wells and in certain areas for artesian wells of moderate depth, for stock and domestic use, so that there is no great need for the development of further resources by deep wells.

Apparently the entire area is underlain by Pierre shale at no great depth, and this, in turn, is underlain by the usual succession of Niobrara chalk and Benton shales, lying on the Dakota sandstone. In the vicinity of longitude 99°, from Platte River to the Northwestern Railroad, this sandstone probably lies at a depth of about 1,500 feet below the surface. Probably it goes no deeper to the northwest, because, apparently, there is a widespread local uplift covered by the Tertiary deposits under the region, in which the strata dip gently northeast into a very shallow basin.

Very few attempts have been made to reach the deep-seated waters in central Nebraska. It is claimed that at Kearney a well was sunk 2,600 feet, entirely in shale except for about 100 feet of superficial materials, but it is believed that the depth has been greatly exaggerated. It is probable that the top of the Dakota sandstone would be reached at a depth of 1,250 to 1,500 feet at Kearney; moreover, it is asserted that the apparatus at Kearney when the well was being sunk was not suitable for boring to any such depth. If the Dakota sandstone lies at a greater depth than 2,600 feet at Kearney, there must be in that vicinity a sudden downward pitch of the beds which should not be expected, considering the structure in Republican Valley and east Nebraska.

There are several wells of moderate depth north of Hyannis, from which there are abundant flows of soft water. The Abbott well, 10 miles northeast, is 475 feet deep, and has a 12-gallon flow under sufficient head to rise 11 feet above the surface. The Plumer well, 12 miles north of Hyannis, is 480 feet deep, with about the same conditions as the Abbott well. The Gentry well, 14 miles north of Hyannis, is 500 feet deep, and has a 10-gallon flow under several pounds' pressure. The Bartlett-Richards well is 300 feet deep, and has a 10-gallon flow which will rise over 10 feet above the surface. All these wells are 1½ inches in diameter. They appear to draw their waters from lower beds of the Arikaree formation, but possibly reach a lower horizon. A typical record is as follows:

Record of well of A. J. Abbott, 10 miles northeast of Hyannis, Nebr.

Feet.	
0– 32	sand.
32–200	blue clay.
200–250	sandstone.
250–300	quicksand.
300– ?	sandstone.
at 460	very coarse red sand.

In 1896 a deep boring was made at Marsland, on the banks of Niobrara River, with the expectation of obtaining artesian water or finding some other product of value. It reached a depth of 927 feet and found nothing except a water supply of moderate volume, which rose to within 50 feet of the surface and is now pumped by a windmill. The following record has been furnished by the driller:

Record of boring at Marsland, Nebr.

Feet.	
0– 5	clay.
5– 45	gravel, clay, and sand.
45– 51	hard rock.
51–151	"butte" rock.
151–171	slate.
171–250	rock and slate alternating.

Feet.	
at 250	6 inches of coal.
250–280	slate.
280–450	rock.
450–470	slate.
at 470	6 inches of coal.
470–620	rock.
at 750	6 inches of coal.
750–780	slate.
780–800	very hard sandstone, reddish.
800–900	softer sandstone.
900–927	harder sandstone.

It is reported that the slate was of a very light-blue color and that the sand rock varied from brown to deep red, gradually becoming harder and redder as the drilling continued. The coal at 250 feet and at 750 feet appeared to be hard and of unmistakable coaly nature. It is very difficult to interpret this well record, for the materials described below 151 feet strongly suggest the presence of the Laramie formation, and are very unlike anything that we might expect to find in the lower part of the Arikaree, Gering, Brule, or Chadron formations. If the beds are Laramie, this formation extends under the Tertiary formations from North Platte Valley near the State line, where its summit has an altitude of 4,000 feet, northeast with the same altitude, to Marsland. From here north, however, the floor of the Tertiary formations must drop rapidly, for it has an altitude of only about 3,600 feet at Crawford.

NORTHEASTERN NEBRASKA.

Under this heading will be comprised the region lying north of Platte and Loup rivers as far west as longitude 99°. In this portion of Nebraska there is a thick mantle of Pleistocene deposits, but occasional outcrops of the underlying rocks indicate that the structure is relatively simple, a regular succession of Pierre, Niobrara, Benton, and Dakota formations rising gradually to the east, the Dakota sandstone reaching the surface along Missouri River Valley from west of Omaha to the mouth of Big Sioux River. The depth to this formation increases gradually to the west with the dip of the strata and the gradual rise of the land, but, for a wide area, the formation is usually within reach of deep well borings. Owing to the relatively low head of the water to the southeast conditions favorable for flowing wells are found only in the lowlands along Missouri River above Ionia, in Niobrara and Ponca valleys, and possibly in Platte Valley from Fremont to Central City.

The waters of the Dakota sandstone have been explored in this region by a number of deep borings in Cedar, Knox, and Boyd counties, where, on the lowlands, they afford flowing wells of excellent water in large volume. At O'Neil

they appear to have been reached by the deep boring made some years ago, but the land was too high for them to flow. At Norfolk a boring was sunk to 472 feet, which is claimed to have passed through the chalk and shales for 60 to 70 feet and into sandstone; in this, although water was found, it would not rise nearer the surface than 100 feet. It is probable that the well did not reach the Dakota sandstone, though possibly there is a local uplift in this region that brings this sandstone nearer the surface than would be expected. At Tilden a large amount of water which rises to within 90 feet of the surface is obtained from a well "more than 400 feet deep." Judging from the pressures in the wells to the north, it is probable that the head of the water in the Dakota sandstone is not sufficient to afford a flow in Elkhorn Valley, at least not as far west as Norfolk. In the region where the Dakota sandstone is at or near the surface many wells have been sunk which usually obtain large volumes of water, and the water-bearing character of the formation is further shown by the occurrence of frequent springs, some of which are of great volume. It is the escape of the water in the outcrop of the formation eastward that so greatly diminishes the head that it has farther west. This is illustrated very clearly in Missouri Valley, from Yankton to Ionia, where the pressure decreases rapidly as the outcrop of the sandstone is approached. The last of the flowing wells are some distance west of Ionia, where the pressure is scarcely sufficient to lift the water above the level of the river.

The artesian area extends west for many miles up Missouri River Valley and for some distance up Niobrara and Ponca valleys. It is not ascertained just how far up these valleys artesian flows are obtainable, but apparently they may be expected in Niobrara Valley nearly as far west as Rock County, in Ponca Valley nearly to the State line, and in Keyapaha Valley possibly for a few miles above the confluence of that valley with the Niobrara.

List of artesian and deep wells in Knox County, Nebr.

Location.	Depth.	Diameter.	Average yield per minute.	Pressure to square inch.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Pounds.*	
T. 31, R. 6, sec. 29	770	2	14	34	Pressure diminished to 11 pounds.
T. 32, R. 6, sec. 12	548	2	240	82	Largest flow at 520 feet.
Niobrara, mill	656	8	1,900	95	Pressure 120 pounds in 1896.
——, packing house	600	2	280	107	Pressure lower than 107 pounds now, owing to leak.
T. 32, R. 7, sec. 21	500	2	....	....	In progress. No flows expected.
T. 33, R. 2, sec. 13	700	2	Many.	No flow.	200 feet above Missouri River.

List of artesian and deep wells in Knox County, Nebr.—Continued.

Location.	Depth.	Diameter.	Average yield per acre.	Pressure to square inch.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Pounds.*	
T. 33, R. 2, sec. 15	405, 425	2	9	14	Two wells; considerable leakage.
T. 33, R. 2, sec. 16	395, 400	1–2	3–9	11	Two wells, one with lower pressure.
T. 33, R. 2, sec. 17	400	2	3	25	Leaks.
T. 33, R. 2, sec. 19	550	2	10	....	
T. 33, R. 2, sec. 20	650	4½	30	64	Leaks. Present pressure low.
T. 33, R. 3, sec. 13	504	2	2	Few.	On high land.
T. 33, R. 3, sec. 15	400	2	....	Few.	
T. 33, R. 3, sec. 16	400	2	8	Few.	Leaks.
Santee Agency	600±	6	....	Few.	Do.
Santee Agency school	604	3	....	Few.	143 feet above Missouri River.
Do	740	8	1,699	55	105 feet above Missouri River. Pressure now 27 pounds and yield 800 gallons.
T. 33, R. 8, sec. 18	700	2	420	75	Pressure now 11 pounds owing to leakage. 3 flows.

List of artesian and deep wells in Cedar County, Nebr.

Location.	Depth.	Diameter.	Average yield per minute.	Pressure to square inch.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Pounds.*	
T. 32, R. 1 E	535	3	2	....	For watering cattle.
T. 32, R. 2 E	241	2	....	Few.	For stock and irrigation of garden. Temperature 60°.
Do	300–400	2	2–60	....	Temperature about 59°.
Do	400–500	2	Few.	Few.	Temperature about 60°.
Do	500–600	2	Few.	Few.	In several cases temperature about 60°.
T. 32, R. 3 E	40	2	....	5–16	For stock and domestic purposes.
Do	245–300	2	Few.	4–16	Temperature about 58°.
Do	300–400	2	1½–31½	Few.	Temperature 58° to 60°. Water used for stock and domestic purposes.
Do	530–600	2	Few.	....	600-foot well ceased flowing. Temperature 59°.
T. 33, R. 1 E	360–630	1½–2	5–25	....	Pressure is variable. Temperature about 60°. Used for stock and domestic purposes.
T. 33, R. 1 W	365–648	1¼–3½	7–44	8–15	Temperature 58° to 60°. Used for stock and domestic purposes.
St. Helena	466	....	Many.	....	Water at 400 feet.

List of artesian wells in Dixon County, Nebr.

Location.	Depth.	Diameter.	Average yield per minute.	Pressure to square inch.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Pounds.*	
T. 31, R. 6, sec. 20	484	3	Few.	....	Flowed 3 weeks, now–3 feet.
T. 32, R. 4, sec. 19	300	2–1½	2	Few.	Two wells.
T. 32, R. 4, sec. 28	177	2	Few.	Few.	
Do	277–290	2	Few.	5½–8	Do.
T. 32, R. 4, sec. 29	280	2	1	8	Pressure 2 pounds now.
T. 32, R. 4, sec. 34	300	2	1	Low.	Leaks.
T. 32, R. 5, sec. 28	265	2	....	10	First flow at 160 feet.
T. 32, R. 5, sec. 32	265	2	3	8	Pressure 2 pounds now.
Do	400	2	3	12½	Flowed 50 gallons originally.

Record of artesian well at St. Helena, Cedar County, Nebr.

Feet.
0– 25..........chalky limestone.
25– 59..........shale.
59–329..........dark-blue clay.
329–369..........shale.
369–418..........black shale with hard layers and beds of lignite 6 inches thick at 399 feet and at 418 feet.
418–466..........sand with flow, underlain by clay. Principal flow is from 420 feet.

Record of artesian well at Santee Agency, Knox County, Nebr.

Feet.
0– 23..............................soil.
23–240..............................Niobrara chalk rock, some blue clay.
240–445..............................Carlile blue shale with thin layers of pyrites.
445–502..............................Greenhorn limestone.
502–600..............................sandstone with large flow of water.

This well is 143 feet above Missouri River.

Record of artesian well at packing house, Niobrara. Nebr.

Feet.
0– 70....................soil and sand.
70–200....................Niobrara chalk rock.
200–410....................Carlile shales with thin layers of pyrites.
410–442....................Greenhorn limestone.
442–520....................Graneros dark shale.
520–600....................Dakota sandstone with 1,900-gallon flow in 8-inch well.

This well is reported to have a pressure of 95 pounds to the square inch. Another report gives 120 pounds and a depth of 645 feet, but probably these relate to another well. It is 40 feet above the river and furnishes power for a flour mill.

Record of well on ranch of John Lytle, 2 miles east of Herrick, Knox County, Nebr.

Feet.	
0– 6	soil.
6– 88	Niobrara chalk rock.
88–380	Carlile shales with some sandstone layers.
380–400	Greenhorn limestone.
400–490	Graneros dark shale.
490–530	Dakota sandstone and clay.

Record of new artesian well at Lynch, Nebr.

Feet.	
0– 18	sand and gravel.
18–105	Pierre clay.
105–300	Niobrara chalk rock, sandy and hard below.
300–588	Carlile shale with beds of pyrites.
588–610	Greenhorn limestone.
610–700	Graneros shales.
700–923	Dakota sandstone and clay alternating; four or five different flows.

This well has a flow of 3,100 gallons a minute from an 8-inch casing, with a pressure of 85 pounds to the square inch. A first flow was found at 740 feet and a second at 875 feet.

The first well at Lynch was 797 feet deep, 4½-inch bore, and produced 465 gallons with 52 pounds pressure. The power has been utilized in running a flouring mill. The well is shown in Pl. LXVII. The pressure is sufficient to raise water to an altitude of 1,590 feet above sea level, which indicates that flowing water is available from deep wells up Ponca Valley to Spencer and up Niobrara Valley nearly to Badger. If the pressure increases west in the same ratio as it does from the east, about 5 feet per mile, the artesian area should be expected to continue farther west than these points.

Record of deep boring at Dannebrog, Howard County, Nebr.

Feet.	
0– 8	clay.
8– 12	sand.
12– 26	sandy clay.
26– 41	red clay.
41– 56	sand and gravel.
56– 94	clay, yellow and darker.
94–104	sand and gravel.
104–118	soft sandy lime rock.
118–132	soft red sandstone.
132–135	sand.
135–161	shale, yellow, sticky.
161–211	shale, blue.
211–401	shale, black.

Feet.	
401- 426	sandy shale, gray; small flow at 426 feet.
426- 626	shale, blue.
626- 776	shale, light blue.
776-1,001	shale, soft, sticky, black.
1,001-1,011	shale, harder.

Record of boring at Norfolk, Madison County, Nebr.

Feet.	
0- 20	soil and clay.
20- 35	quicksand with water.
35- 95	chalk rock with water to —7 feet.
95-395	blue shale.
395-398	sandstone with water to —20 feet.
398-402	shale.
402-472	sandstone with water to —100 feet.

At Monroe, on Loup River, a 4-inch boring has been made for artesian water to a depth of 580 feet without obtaining water below the supply which lies near the surface. Shale was entered under 90 feet of sand, gravel, and clay, and found thence to be the prevailing material. Some hard layers of sandstone and pyritiferous white rock were encountered, and the boring was abandoned, owing to the drill getting fast in one of them. Doubtless this boring had penetrated the Niobrara formation and the greater part of the Benton group, so that it would have reached the Dakota sandstone at no great distance. As shown on Pl. LIX, it is estimated that the head of the water in the Dakota sandstone at Monroe is somewhat over 1,500 feet, and, as the boring is at an elevation of about 1,525 feet, there is possibility that an artesian flow would have been obtained. It is unfornate that the sandstone was not reached, so as fully to test its capabilities in this region.

A deep boring at Albion attained a depth of 827 feet, when it was discontinued by accident to the drill. It is stated that the entire distance was in shale; which represented a portion of the Pierre, probably all of the Niobrara, and part of the formations of the Benton group.

At Ericson a boring about 750 feet deep was all in shale, and found no water.

Many years ago a deep boring was made at Ponca in exploring for coal, oil, gas, and water. It began in the Dakota sandstone and reached a depth of 498 feet. Only a few facts have been supplied as to its record. From 420 to 450 feet it is reported to have passed through sandy shale and green clay, and from 455 to 498 through limestone, probably all of the Pennsylvania division of the Carboniferous. Nothing of value was obtained and the boring was abandoned.

In the vicinity of Omaha a number of deep wells in the Carboniferous limestones have found a supply of water of excellent quality, having sufficient head to afford surface flows over a wide area. The depths vary from 664 to 1,845 feet, there being several flows which vary considerably in head and distribution. The following is a list of the principal wells:

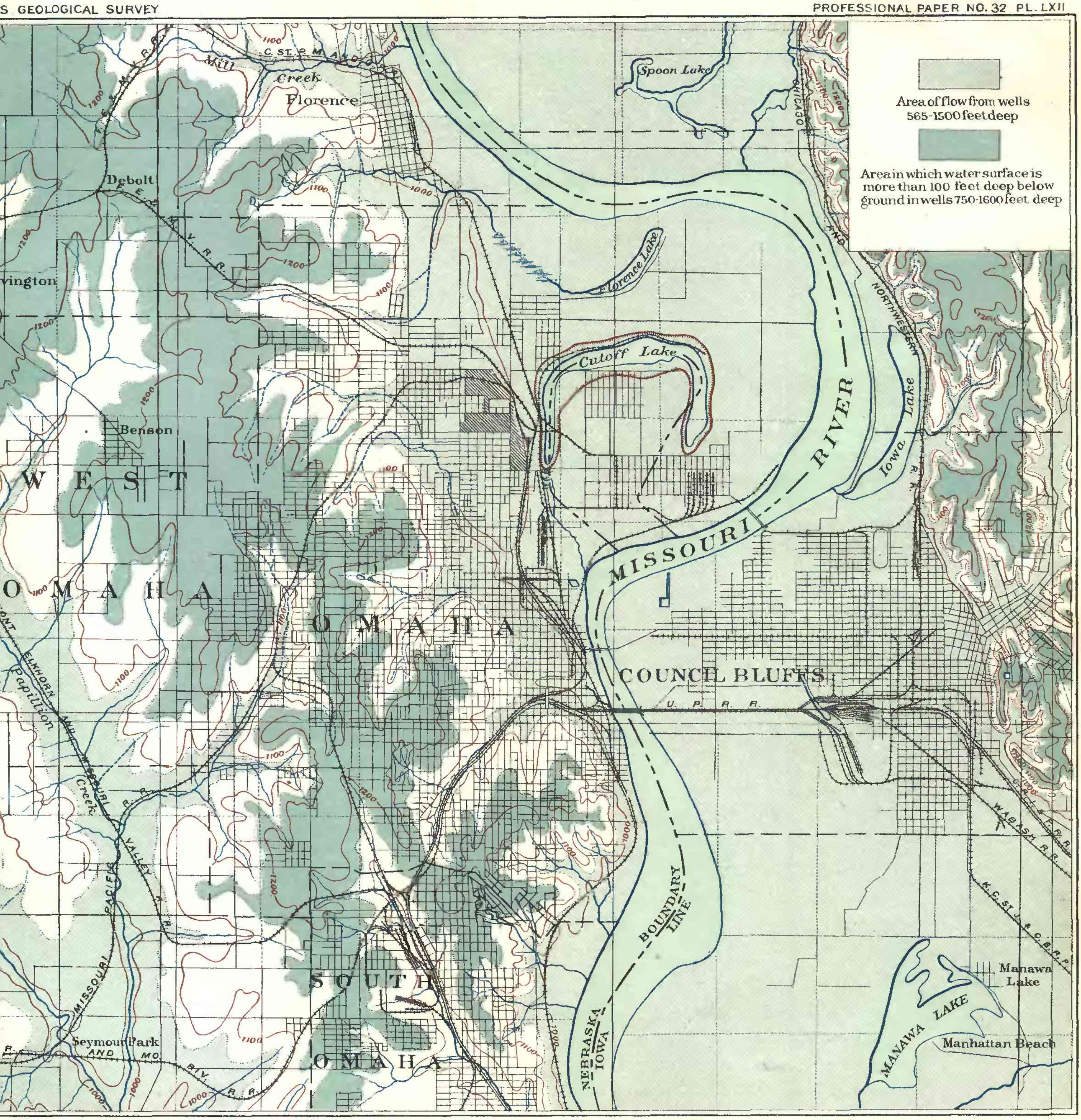
List of artesian wells in Omaha, Nebr.

Location.	Depth.	Diameter.	Average yield per minute.	Height of water.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Clark and Sixteenth streets	664		125	+ 52	Temperature 58°.
Grant smelter	1,044	10–6	800	+ 65	Flows at 650 and 800 feet also; temperature 55°.
Thirty-second and O streets	1,800		Many.	— 70	
Elmwood Park	1,845			— 50	
Hanscom Park	1,120		Many.	— 138	
Riverview Park	1,065		600		Temperature 62°.
Willow Spring	1,700		Many.	+ 100	
Exposition grounds	1,115		Many.	Flows.	First water at 700 feet; temperature 60°.
Seymour Park	1,303		500	+ 35	
Pickards	1,383		70	Flows.	Temperature 62°; abandoned.
Krug brewery	1,310		Many.	— 142	
Power house, Nineteenth street.	840				
Cortland Beach	998	6–5		+40(?)	

Pl. LXII shows the area near Omaha in which artesian waters will afford flows and gives some further information regarding them. Some of the wells on the higher lands have reached water, but do not flow on account of the insufficiency of the head to carry the water more than about 1,150 feet above sea level. One of the most remarkable wells in the area, located on the property of Doctor Miller at Deerfield, 7 miles west of Omaha, is 1,430 feet deep, 10 inches in diameter, has a pressure of 15 pounds, and is said to flow over a million gallons a day.

SOUTHEASTERN NEBRASKA.

Under this heading is comprised the portion of the State lying south of Platte River and east of the ninety-ninth meridian. This region consists of two distinct geologic provinces, having on the west of Blue River a wide area of smooth plains with a few wide shallow valleys, and on the east a country of rolling hills separated by numerous valleys. The plain to the west is covered by loess lying on Cretaceous clays. The hilly region to the east is mantled by glacial drift lying mostly on Dakota sandstone to the west and Carboniferous limestone to the east.



CONTOUR MAP OF OMAHA AND VICINITY SHOWING RELATIONS OF ARTESIAN WATER

BY N. H. DARTON 1904

SCALE

1 ½ 0 1 2 3 4 miles

JULIUS BIEN & CO. LITH. N.Y.

WELLS TO DAKOTA SANDSTONE.

The entire region is relatively well watered above ground and has numerous shallow wells drawing waters from coarse beds at the base of loess or drift. In the belt of country in which Dakota sandstone immediately underlies the drift exceptionally good water supplies are obtained from the sandstone in wells mostly from 60 to 150 feet deep. The Dakota sandstone, with its great store of underground waters, descends to the west, passing under Benton and other Cretaceous shales, and lies over a thousand feet below the plains surface in Adams County. West of the ninety-seventh meridian its water supplies have not been developed, partly on account of their depth, and because they do not have sufficient head to afford surface flows. The formation probably was reached in the 1,145-foot well at Hastings, but its capabilities were not tested, as abundant supplies are obtained in the gravels nearer the surface. The following record of the boring has been given:[a]

Record of deep boring at Hastings, Nebr.

Feet.	
0– 100	soil and loess.
100– 160	gravel and sand, full of water.
160– 164	clay, with boulders, very compact.
164– 224	gravel and sand, full of water.
224– 230	yellow clay.
230– 940	blue shale, gray near top.
at 940	strong salt water to — 300 feet.
940–1,144	blue shale.
1,144–1,145	fine round sand; water probable.

According to another authority the total depth was 1,346½ feet, the lower 370 feet being reported as "soft shale limestone with sand and gravel containing seashells at 1,300 feet." Hard limestone 1½ feet thick was reported at 775 feet, soft limestone and shale from 776 to 801½ feet, and light shale and lime rock from 930½ to 976½ feet. The great body of shale above was stated to be hard from 250 to 500 feet, and soft from 500 to 775 feet. Both of these records indicate a steep inclination of the beds north from Republican Valley, as well as west from Lancaster County.

Some years ago a boring 610 feet deep was made at Seward, without success, in the hope of obtaining an artesian flow. The following is its record:

Record of boring at Seward, Nebr.

Feet.	
0– 4	soil.
4– 56	blue clay.
56– 60	sand.

[a] Water-Sup. and Irr. Paper No. 12, U. S. Geol. Survey, 1898, p. 38.

Feet.	
60–385	blue clay.
385–392	sand and gravel.
392–492	blue clay.
492–610	"red ocher."

Probably the red material from 492 to 610 feet is red sandstone of the Dakota formation, here too fine grained to yield a water supply. It is unfortunate that the boring was not deepened to lower beds in which there are better prospects for water.

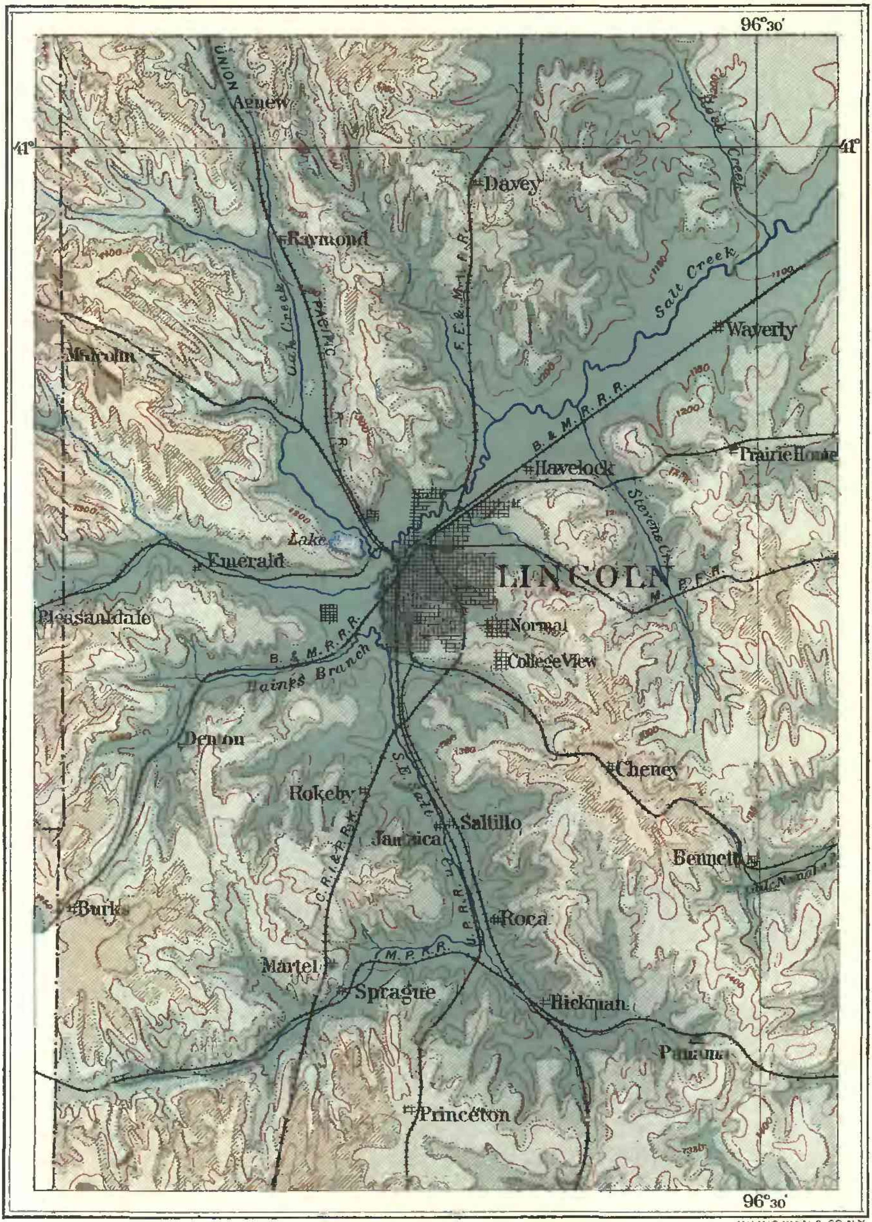
About ten years ago a boring was made at the Russian mill just south of York, and at a depth of 530 feet a flow was found which it is claimed spouted 2 feet above the top of a tube extending 14 feet out of the ground. A small flow was found at 290 (or 390?) feet. A somewhat uncertain record reports clay or fine sand to 93 feet, sand and gravel 93 to 100 feet, shale for some distance from 199 feet down, and at the bottom a sandstone which presumably is Dakota sandstone.

At Beaver Crossing, in the southwest portion of Seward County, artesian waters are found in West Blue Valley, from 6 miles below the town to about the same distance above. The wells are 90 to 140 feet in depth, nearly every farmer having one or more. The water may be derived from the Dakota sandstone by leakage from a considerable depth, and possibly the formation may be uplifted somewhat, but more likely the water is from the younger formations. In Jefferson, Gage, Saunders, and western Cass counties the Dakota sandstone is reached at many points by wells varying in depth upward to 300 feet. In some cases formations of the overlying Benton group are penetrated, and in others the drift or loess deposits. In nearly all localities an abundant water supply of excellent quality is obtainable. Owing to the low level of the outcrops of the formation in these counties the water does not reach the surface, but generally it rises considerably above the level at which it is found. In Pl. LXIII there is shown the depth to the top of the Dakota sandstone in Lancaster County, based on a detailed canvass, made by J. E. Macfarland in 1896, of all the wells within its borders.

The city water supply for Lincoln is obtained from pumping stations in the city limits, which draw from wells from 50 to 140 feet deep sunk in the Dakota sandstone. In the western portion of the city the waters are somewhat salty, but in the east, whence the present supply is drawn, the quality is satisfactory.

WELLS IN CARBONIFEROUS AND OLDER ROCKS.

In southeast Nebraska the Carboniferous rocks which underlie the Dakota sandstone rise to the surface. These older rocks have been bored into at several points for water and other minerals, with varying results. The best known borings are at Lincoln, where salt water was obtained in several wells. The deepest boring was sunk by the State, at the edge of the salt lake on the



JULIUS BIEN & CO. N.Y.

MAP OF LANCASTER COUNTY, NEBR.

SHOWING DEPTHS TO DAKOTA SANDSTONE, WHICH USUALLY YIELDS ABUNDANT WATER SUPPLIES

Scale of miles

0 1 2 3 4 5 10 15

LEGEND

0 to 50 feet	150 to 200 feet.
50 " 100 "	200 " 250 "
100 " 150 "	250 " 300 "

Waters also are found in satisfactory supplies in the overlying glacial drift but their occurrence is too irregular for representation on a map.

1904

western side of the city. The following record is given, mainly on authority of Mr. B. P. Russell,[a] who examined the borings and deposited them in the Museum of the State University.

Record of boring 1 mile west of the post-office, Lincoln, Nebr.

Feet.		
0- 25	soil, sand, and gravel.	
25- 269	sandstones, sands and clays, with brine 21° at 119 feet and 35° at 195 feet.	
269-1,099	limestones and shales with occasional beds of sandstone. Brine, 12° at 600, and 16° at 828 feet.	
1,099-1,813	magnesian limestones, probably in greater part of Mississippian age, 15 feet of sandstone, 1,218 to 1,233 feet, and 13 feet of red shale, 1,427 to 1,440 feet.	
1,813-1,847	very fine blue limestone	Trenton ?
1,847-1,867	heavy dark magnesian limestone	
1,867-1,947	very fine blue limestone	
1,947-2,008	sandstone (St. Peter ?).	
2,008-2,121	magnesian limestone.	
2,121-2,192	red sandstone (Potsdam ?).	
2,192-2,463	quartzite and metamorphosed shale, with quartz veins. Color, dark-red to flesh (Sioux quartzite ?).	

The principal flow of water, which is very saline, is from a reddish sandstone in the Carboniferous limestone at 600 feet. A similar flow is obtained at a depth of 570 feet at the Sanitarium in Lincoln, and at 560 feet in the 1,050-foot well in the post-office square. In the State well at the salt lake, another saline flow was obtained at a depth of 828 feet. The pressure of water at the sanitarium is 1.5 pounds to the square inch.

A number of borings have been sunk in the Carboniferous formations in the region south and southeast of Lincoln. One of these, at Beatrice, having a depth of 1,200 feet, yields a small flow; two others on farms in the vicinity of that city, found small supplies of water at depths of about 1,240 feet. At Nebraska City there are several wells, which yield mineral waters from 448 to 570 feet in depth. One well 448 feet deep, 4 inches in diameter, yields a flow of 20 gallons an hour, rising 6 feet or more above the surface. Another similar well is 5 miles north of the town of Loyds.

The water of the mineral well at Nebraska City is reported to contain 400 grains of solid matter per gallon, of which nearly half is sulphate of soda and 174 grains is common salt, with small amounts of magnesia, lime, potash, and lithia. At Tecumseh, in Johnson County, a diamond-drill boring 520 feet in depth, for coal, was unsuccessful, and no water was reported. Samples of the formations

[a] Sixth Bien. Rept. Com. Public Lands and Buildings to Governor of Nebr., 1888, pp. 57-84.

traversed are preserved in the court-house. There were similar experiences at Dubois, in Pawnee County, with a 562-foot boring; at Falls City, in Richardson County, with a 1,300-foot boring; and 2 miles west of Rulo, in Richardson County, with a 1,370-foot boring. A 725-foot boring, at Hubbell, in Thayer County, is said to obtain some water but no flow. At Brownville a test boring for coal was sunk to a depth of 1,001 feet, in which the rocks penetrated were shales, limestones, and sandstones. A coal bed 8 inches thick was found at a depth of 93 feet, one of 14 inches at 242 feet, one of 10 inches at 376 feet, and one of 30 inches at 820 feet. Flows of salty water were found with the coal at 242 feet, and in magnesian limestone at depths of 599 and 820 feet.

In 1891 a 4-inch diamond-drill boring was sunk 500 feet in the northeast corner of sec. 4, T. 2 N., R. 2, 3 miles northeast of Fairbury, to explore for coal. The following materials are reported:

Record of boring near Fairbury, Nebr.

Feet.	
0– 25	soil and sandstone.
25- 65	fire clay.
65–125	mixed clay, red, white, and yellow; micaceous.
125–225	dark clay with 4 or 5-foot bed of impure lignite near middle.
225–233	dark-gray soft sandstone.
233–238	sandstone with salt water, 30 per cent.
238–475	limestone.
475–500	flinty rock with salt water.

The salt water at 500 feet flows from the 4-inch casing in a stream rising 6 inches above the top of the hole and sometimes much higher. This boring began in the Dakota formation, which apparently continued to a depth of 235 feet.

In the boring at Dubois in Pawnee County it is reported[a] that the formations to 532 feet were an alternation of red and black shales and magnesian limestone. At 552 feet a crystalline rock was found which was penetrated to 562 feet. Much of it is flesh-red color and it has a hardness of about 6 on the mineral scale. Its chief ingredient is feldspar with particles of hornblende or pyroxene, and hematite. Probably it is an intrusive rock in the Carboniferous, although possibly part of the pre-Cambrian "bed rock." There is some doubt whether the sample really came from the boring.

SOUTHERN NEBRASKA.

Under this heading there is presented a description of the underground water conditions in Republican Valley, from Nuckolls County westward to Chase and Dundy counties. This region is extensively covered by Pliocene and Quaternary deposits, which form a mantle often 100 feet thick in the valleys and over the high-

[a] F. W. Russell, Am. Geologist, vol. 1, pp. 130-131.

lands. The underlying formations are Pierre shale to the west, from under which there rise in succession to the east the Niobrara and the Benton formations. Under the Benton lies the Dakota sandstone, which undoubtedly continues to the western margin of the State, where it lies at a depth of over 2,500 feet. In Nuckolls and Webster counties the formations appear to dip gently to the north and, as the land rises to the west, the top of the Dakota sandstone gradually sinks to a depth of about 1,000 feet in the northwest corner of Webster County, and 500 feet on Republican River east of Riverton. West of this place the formations rise, at about the same rate as the rise of the land, toward an anticline crossing the valley near Cambridge, which extends from Kansas across the south portion of Nebraska and probably far to the north. West of Indianola the strata sink again at a rate of about 16 feet to the mile near McCook and probably at a somewhat less rate west of Culbertson. On the eastern slope and crest of the anticline, from Cambridge to Bloomington, the Dakota sandstone lies about 500 feet below the surface in Republican Valley and correspondingly deeper on the adjoining highlands. A short distance west of Indianola the sandstone is probably about 1,000 feet below the surface; at Culbertson 1,500 feet; and at Benkelman 2,250 feet, as nearly as can be estimated from the data obtained.

Whether the sandstone will yield flowing wells in Republican Valley remains to be determined. Undoubtedly the water will come near to the surface throughout, but, judging from the low head in the wells in northwest Kansas, flows can not be definitely predicted for Republican Valley. The only deep well so far reported is one at McCook, having a depth of only 400 feet—800 feet less than the estimated depth to the Dakota sandstone. The materials overlying the Dakota sandstone of Republican Valley are the limy shales and the limestone of the Niobrara formation and the dark shales, with thin sandstones and limestones, of the formations of the Benton group. West of Indianola, the Niobrara is overlain by Pierre shale, which gradually thickens to at least 1,000 feet at the Colorado State line. These materials are all difficult to penetrate in well boring and, in order to attain a depth of 1,000 feet or more, it is usually found necessary to begin with casing of large diameter, 10 inches at least, and to use several strings of casing down to 4-inch.

DEEP WELLS AND WELL PROSPECTS IN CENTRAL AND WESTERN KANSAS.

GENERAL CONDITIONS.

The greater part of Kansas is underlain by nearly level sedimentary rocks, several members of which are water bearing. The central, northern, and western portions of the State are underlain by the Dakota sandstone, which appears to contain water throughout its course. It has been developed to a moderate extent in

areas in which it lies not far below the surface, but in the northwest corner of the State, where there is great need for water, no wells have yet been sunk sufficiently deep fully to ascertain its resources. During the last year drilling operations have been begun in this section to explore for oil and gas and may go sufficiently deep to test thoroughly the underground-water problem. Probably the greatest depth to the Dakota sandstone will be found to be not over 2,500 feet in the northwest counties; in an extensive area of the central-northwestern counties the depth is between 1,000 and 1,500 feet. Owing to the low altitudes of outcrops to the east and south the Dakota waters have but little head, and flows should be expected only in the lowest valleys.

The Red Beds which underlie the Dakota sandstone in the greater part of central and western Kansas contain much rock salt and gypsum, so that the waters which they yield in most localities are too highly mineralized to be useful, a condition found also in the shales into which these Red Beds merge in central and north-central Kansas. In the underlying limestones to the east, water supplies are scarce and in most cases unsatisfactory, as shown by the results of numerous deep borings for oil and gas.

BORINGS IN CENTRAL AND WESTERN KANSAS.

The following list comprises all borings in Kansas west of the ninety-seventh meridian that appear to throw light on the deeper seated underground waters, especially those in the Dakota sandstone. The list is thought to be nearly complete, for it is the product of an extended canvass of the region.

List of deep borings in Kansas west of the ninety-sixth meridian.

Location.		Depth.	Formations penetrated.	Results, etc.
Town.	County.			
		Feet.		
Abilene	Dickinson	1,260	Permian, etc	Mineral flow.
Alma	Wabaunsee	2,000	Permian and Carboniferous.	Salt water and gas.
Do	do	1,912	do	Do.
Anthony	Harper	2,335	Red beds and Carboniferous.	Salt well.
Arlington	Reno	1,000	Permian	Salt.
Asherville	Mitchell	638	Dakota to Permian	Salt water.
Banner (near)	Trego	438	Niobrara and Benton.	No water supply.
Bison	Rush	1,403	Graneros to Permian.	Flow of salt water.
Cactus (6 miles south).	Phillips	480	Niobrara and Benton.	Some water to —50 feet.
Caldwell	Sumner	800	Permian, etc	Salt well with some salt water.

List of deep borings in Kansas west of the ninety-sixth meridian—Continued.

Location.		Depth.	Formations penetrated.	Results, etc.
Town.	County.			
		Feet.		
Canton (5 miles northeast).	McPherson	500	Dakota and Permian	
Cawker City (2 miles northeast).	Mitchell	468	Benton and Dakota	Salt water and fresh water to —227 feet.
Cawker City (10 miles north).	Jewell	416	do	
Cedarville (near)	Smith	400+	Niobrara and Benton	No water supply.
Coolidge	Hamilton	225–300	Benton and Dakota	Flowing wells.
Danby (6 miles southwest).	Ness	385	do	Water to —110 feet.
Dodge City (1½ miles east).	Ford	800	Dakota and Permian	No water below Dakota.
Elkador	Logan	408	Niobrara and Benton	No water supply.
Elkador (7 miles south).	Scott	500	do	Do.
Ellsworth	Ellsworth	1,300	Permian	Salt water.
Emporia	Lyon	2,005	Permian and Carboniferous.	
Eureka	Greenwood	503	do	
Do	do	1,100+	do	
Fall River	do	986	do	
Do	do	1,480	do	
Garden City (½ mile northwest).	Finney	1,000+	Benton to Permian	Unsatisfactory.
Garden City (8 miles south).	do	1,250	Tertiary to Red Beds	Not reported.
Goodwater	Gove	501	Tertiary to Benton	Little water.
Great Bend (4 miles northeast).	Barton	1,365	Dakota? to Permian	Salty flow.
Harper	Harper	1,000		
Hays (14 miles south).	Ellis	1,177	Benton to Permian	Water in Dakota; artesian flow of salt water in Permian.
Hill City (3 miles from).	Graham	400	Niobrara and Benton	No water.
Horace	Greeley	1,350	Niobrara to Red Beds	Water to —700 feet; from Dakota sandstone.
Howard	Elk	{1,000–1,410}	Permian and Carboniferous.	
Hutchison	Reno	800+	Permian	Salt wells.
Ionia	Jewell	432	Benton	Salt water.
Jennings	Decatur	1,050	Pierre to Dakota	Water to —400 feet.
Jerome	Gove	400	Benton	Not reported.

List of deep borings in Kansas west of the ninety-sixth meridian—Continued.

Location.		Depth.	Formations penetrated.	Results, etc.
Town.	County.			
		Feet.		
Jetmore	Hodgman	700–1,000?	Benton to Red Beds	Good water in Dakota; salty water in Red Beds.
Jewell	Jewell	337	Benton	Salt water to —25 feet.
Johnson	Stanton	420	Late Tertiary to Dakota.	Good water to —150 feet.
Kalvesta	Finney	355	Benton	No water.
Kanona	Decatur	1,620	Pierre to Dakota	Water to —600 feet.
Kanopolis	Ellsworth	881	Permian	Salt well.
Kendall	Hamilton	537	Benton to Red Beds	Water in Dakota for pumping.
Kingman	Kingman	800+	Permian	Salt shafts.
Kingman (1½ miles north).	do	1,410	do	Salt
Kirwin	Phillips	430 or 514	Niobrara and Benton	Flows mineral water.
La Crosse	Rush	444	Benton and Dakota	Water to —204 feet.
Larned	Pawnee	743	Dakota to Permian	Mineral water flows.
Lexington	Clark	300	Red Beds	Salt water only.
Liberal	Seward	485	Neocene	Water for pumping.
Little River	Rice	1,000	Permian, etc	Water to —400 feet; then salt and shale.
Long Island (4½ miles northeast).	Phillips	650	Niobrara and Benton.	No water.
Lovewell (3½ miles northwest).	Jewell	300–400	Benton	Salt water only.
Lyons (Bemis Salt Co.).	Rice	1,625	Dakota to Permian, etc.	Good water at 45 feet; salt below.
Madison	Greenwood	1,896½	Permian and Carboniferous.	For gas; nnsuccessful.
Mankato	Jewell	500	Niobrara and Benton	Salt water to —50 feet.
Marysville	Marshall	1,360	Permian, etc	Strong flow salt water.
Marysville (near)	do	1,100	do	Not reported.
Marion	Marion	1,800	do	For coal; no success.
Marquette	McPherson	400	Permian	Salt water to —70 feet; rock salt, 368–400 feet.
Meade	Meade	800	Late Tertiary and Red Beds.	Red Beds at 200 feet; salt below.
Ness City (8 miles southwest).	Ness	450	Benton and Dakota	Water; no flow.
Ness City (12 miles west-southwest).		437	do	Do.
Newton	Harvey	910–1,076	Permian, etc	Several borings; unsuccessful.
Oakley	Logan	725	Late Tertiary to Benton.	Water near top.
Oberlin	Decatur	800–1,000	Pierre to Benton	Flow of mineral water.
Osborne	Osborne	301	Benton	Salty water to —30 feet.

List of deep borings in Kansas west of the ninety-sixth meridian—Continued.

Location.		Depth.	Formations penetrated.	Results, etc.
Town.	County.			
		Feet		
Osborne (9 miles south by east).	Osborne	360	Benton	Salty water to —45 feet.
Palacky	Ellsworth	336	Benton and Dakota	Water to —176 feet.
Peru	Chautauqua	1,240–1,700		
Peru (near)	do	1,190		
Phillipsburg (northwest of).	Phillips	430	Niobrara and Benton.	No water.
Portis (6 miles northwest).	Smith	546	Benton and Dakota	Salty water.
Portis (8 miles northwest).	do	543	do	Salty water to —200 feet.
Pratt	Pratt	800±	Dakota to Permian	Salt below 600 feet.
Ransom	Ness	653	Niobrara to Dakota	Water to —60 feet.
Randolph	Riley	400	Permian	Not reported.
Ravanna (north)	Finney	400+	Late Tertiary to Benton.	Water to —200 feet; abandoned.
Richfield	Morton	600–701	Late Tertiary to Red Beds.	Flow of salty water.
Russell	Russell	997	Benton to Permian	Good water at 360 feet. Salt below.
St. Marys	Pottawatomie	1,123		Flow of salt water.
Santa Fe	Haskell	1,300±	Late Tertiary to Red Beds.	No flow.
Scandia	Republic	1,110	Permian, etc	Good water at 1,000 feet to —16 feet.
Sedan	Chautauqua	1,700	Carboniferous	
Shields (3 miles north).	Lane	400	Niobrara to Benton	Small amount of water.
Smith Center	Smith	600	Niobrara and Benton.	Salty water at 590 feet.
Smith Center (12 miles southeast).	do	540	do	Salty water to —140 feet.
Sterling	Rice	916, 946	Permian, etc	Salt well.
Stockton (9 miles south).	Rooks	460	Niobrara and Benton to Dakota.	Much good water to —60 feet.
Syracuse	Hamilton	1,000	Benton to Red Beds	No water supply below Dakota.
Sun (southwest)	Barber	600	Red Beds	For coal; no success.
Tribune	Greeley	500	Niobrara	No water.
Wallace (vicinity).	Wallace	400, 448, 800	Pierre to Benton?	No water supply.
Wakeeney (12 miles west-southwest).	Trego	438	Niobrara and Benton.	Small water supply for pump.
Wamego	Pottawatomie	1,000		
Washington	Washington	2,200	Dakota to Permian, etc.	Salt water only.

List of deep borings in Kansas west of the ninety-sixth meridian—Continued.

Location.		Depth.	Formations penetrated.	Results, etc.
Town.	County.			
		Feet.		
Wichita	Sedgwick	1,605	Permian, etc	Salt water in large amount at 500 feet which rises to —70 feet.
Do	do	1,025	do	
Wilson	Ellsworth	1,375	do	Salt.
Winfield	Cowley	900,-1,200	Permian	Salt-water flow.
Winona	Logan	1,356	Pierre to Graneros	Dry hole.
Vulcan Iron Works.	Kingman	1,000	Permian, etc	Salt shafts.

BARTON COUNTY.

The south half of this county is underlain by the Dakota sandstone and the north half by the Benton shale. Along Arkansas Valley the Dakota sandstone is covered by a considerable thickness of alluvial materials, and also by large deposits of dune sands on the south side of the river. The sandstone is penetrated by numerous wells, to which, in most cases, it furnishes satisfactory supplies of water. Some of these wells begin in the sandstone and are bored or dug into its lower beds. The wells in the highlands in the north part of the county pass through a greater or less thickness of Benton shale and thence into the sandstone. A well 245 feet deep, 8 miles north and 2 miles west of Hoisington, penetrates 222 feet of shale before reaching the sand rock, where it obtains a large supply of water, which rises to within 212 feet of the surface. Southwest of Galatia the shale is 260 feet thick and the underlying sandstone furnishes a good supply of water, rising to within 236 feet of the surface. At Olmitz a well of 202 feet passes through the Benton shales into the sandstone and obtains a supply of very soft water, which rises to within 142 feet of the surface. A well 3 miles north of Verbeck has a depth of 244 feet, and the water rises to within 144 feet of the surface. These representative wells indicate that satisfactory supplies of water are obtainable from the Dakota sandstone through most of the north portion of the county, but that there are no prospects for flows. Several wells about Roberts, from 175 to 300 feet deep, in most cases obtain only salty or brackish water, of which the source is probably the transition salty series at the base of the Benton shales. In the south portion of the county the wells are shallower and mostly successful. The only unsuccessful well which has been reported is one in sec. 17, T. 18, R. 12,

which penetrated the Dakota sandstone 200 feet without obtaining a water supply. Four miles northeast of Great Bend a deep well was sunk some years ago to a depth of 1,365 feet to test the water supplies of the formations underlying the Dakota sandstone. Flowing water was obtained at 344 feet and at somewhat over 700 feet. The first water is still flowing at the rate of 10 gallons per minute, but it is too salty to be of any use. From 1,202 to 1,365 feet a large amount of rock salt was penetrated, and some of the overlying beds were highly gypsiferous. The following record is given:

Record of deep well 4 miles northeast of Great Bend, Barton County, Kans.

Feet.	
0– 60	surface materials.
60– 75	red sandstone.
75– 140	red shale.
140– 155	blue shale.
155– 255	sandstone, brown near top, hard near bottom.
255– 258	shale.
258– 275	hard sandstone.
275– 310	conglomerate, water.
310– 360	gray sandstone; artesian flow of salt water.
360– 400	gray sand and shales; salt water.
400– 420	red shale.
420– 425	blue shale.
425– 475	sandstone.
475–1,110	red shale with some sandstone.
1,110–1,240	blue shale.
1,240–1,365	salt and shale.

This well was mainly in the Permian rocks, and it is doubtful if the red sandstone from 60 to 75 feet belongs in the Dakota.

An analysis of this water by E. H. S. Bailey[a] is, in round numbers, as follows:

Analysis of mineral water from well at Great Bend, Kans.

	Grains per gallon.
Chloride of sodium	3,186
Sulphate of sodium	175
Sulphate of lime	131
Sulphate of magnesia	86
Bicarbonate of magnesia	142
Silica	2
Total	3,722

[a] Kans. Univ. Geol. Survey Rept., vol. 7, p. 197.

CHEYENNE COUNTY.

This county occupies a region of high plains traversed by Republican River, which has cut a valley about 200 feet below the general plain surface. The highlands are occupied by Tertiary grit, which is underlain by the Pierre shale, as revealed in Republican and Arikaree valleys. The Niobrara chalk and limestone lie at a depth of a thousand feet or more, but their precise position has not been ascertained. The thickness of this formation and the underlying Benton shales is about 900 feet in northwest Kansas, and the depth to the Dakota sandstone probably over 2,300 feet in Cheyenne County. Undoubtedly this sandstone contains water under sufficient pressure to rise several hundred feet in a well but not enough to afford a flow even in the deeper valleys. Apparently the beds lie nearly level or dip slightly to the west. So far as is known, there have been no borings in the county sufficiently deep to reach the chalk. On the high plains good water supplies for pump wells are usually obtained by sinking deeply into the "mortar beds," or Tertiary grit, and in the valleys the alluvial deposits usually yield considerable water.

CLARK COUNTY.

Clark County extends from the High Plains on the divide south of Arkansas River into Cimarron Valley. The plains are capped by Tertiary deposits underlain to the north by Dakota sandstone and to the south by lower Cretaceous sandstones and shales. To the south the underlying Red Beds are exposed over a wide area. To the north water for pump wells is obtained from the basal portion of the Tertiary deposits and from the underlying sandstones. In the Red Beds area the alluvial deposits in the valleys are the only sources of supply. Some years ago an attempt was made near Lexington to obtain water in the Red Beds by a boring 300 feet deep, but only salt water was obtained. No artesian fresh waters are to be expected in this county from the Red Beds, and, as this formation is probably very thick, the outlook is discouraging.

CLOUD COUNTY.

In this county the divide between Solomon and Republican rivers is capped by Benton shales and the lower lands are excavated in Dakota sandstone. This sandstone yields water to many shallow wells, both in the area of its outcrop and in borings on the divide, which pass through from 25 to 150 feet of Benton shales. There are no prospects for artesian waters, for the conditions are unfavorable for sustaining a head. The Dakota sandstone is underlain by shale, sandstone, and limestone of the Permian, which are probably several hundred feet thick. Although these usually contain water under considerable pressure, it is generally too salty for domestic use.

COMANCHE COUNTY.

The conditions in this county are precisely similar to those in the adjoining county of Clark on the west.

DECATUR COUNTY.

This county is an undulating region of high plains intersected by the valleys, 200 to 300 feet deep, of Beaver, Sappa, and Prairiedog creeks. The entire area appears to be mantled by the Tertiary "mortar beds" and other deposits, although possibly these have been cut through in the deeper portions of some of the valleys. The county is underlain by Pierre shale, which is thin to the east but thickens rapidly to the west. The underlying Niobrara chalk and the Benton group have a thickness of about 900 feet, and dip gently to the west. From these statements it may be seen that the Dakota sandstone probably lies at a depth of about 1,000 feet in the east portion of the county and considerably deeper on the higher lands in the west. Three deep wells have been bored in the county, at Jennings, Kanona, and Oberlin, which throw considerable light on the underground geology.

Jennings.—This boring was sunk to a depth of 1,050 feet, in 1903, in hopes of finding oil, but, owing to difficulties in continuing it farther, the first boring was abandoned and another of larger diameter is now in progress. The following record is given by the drillers:

Record of boring at Jennings, Kans.

Feet.		
0– 28	sand and gravel.	
28– 203	black shale (Pierre).	
203– 209	yellow limestone	Niobrara.
209– 289	chalkstone	
289– 439	light-gray shale	
439– 519	dark shale	
519– 579	chalkstone	
579– 594	gray sandstone with water	Benton.
594– 734	black shale	
734– 754	hard shale with rock layers	
754– 960	brown shale	
960–1,050	soft sandstone with water, Dakota.	

A large volume of water, rising to within about 400 feet of the surface, was found in the lower sandstone, which is probably the Dakota. Many Benton fossils were obtained from a depth of about 735 feet in this well, which were reported by Dr. T. W. Stanton to comprise *Inoceramus labiatus* and *Prionotropis woolgari*, but, owing to the immature condition of the specimens, the specific identification is not absolutely positive. A sample of water from a depth of 1,050 feet was examined in the laboratory of the United States Geological Survey, and found to contain 280 grains

per gallon of soluble constituents, consisting mainly of chloride of sodium, together with some lime and magnesia salts and chloride of potassium.

Kanona.—At this place a deep boring was in progress in 1903 with the expectation of finding oil or gas. The following record was supplied by the drillers:

Record of boring at Kanona, Kans.

Feet.	
0– 200	loam, clay, and sand; water at base.
200– 800	shales, dark in upper part.
800– 940	limestone.
940– 990	dark shales.
990–1,000	white limestone.
1,000–1,100	light-colored shale, with water nearly to surface.
1,100–1,150	black shale.
1,150–1,400	light-colored shale.
1,400–1,415	sand, with water in small amount.
1,415–1,450	black shale.
1,450–1,550	sand (Dakota).
1,550–1,595	shale.
1,595–1,610	brown sandstone.
1,610–1,620	brown sandstone, with soft fresh water.

The sand, extending from 1,450 to 1,550 feet, contains water in considerable amount, rising to within about 450 feet of the surface. The limestones from 800 to 940 feet and from 990 to 1,000 feet undoubtedly represent the Niobrara beds; according to one report limestone extends also from 480 to 600 feet. It is probable that the Niobrara formation extends from 480 to 1,000 feet, indicating a thickness of 520 feet. The Benton extends from 1,000 to 1,450 feet. The shales from 200 to 480 feet are Pierre.

These borings prove that the Dakota sandstone extends west in Kansas and contains a water supply, but, unfortunately, has too low a head to afford prospects for flowing wells, even on the lowest lands.

Oberlin.—This well is said to have a depth of about 1,000 feet, through chalk rock and shale, to a bed of sandstone. It yields a small flow of water so highly mineralized that it is not suitable for domestic use. It is thought this well is not deep enough to penetrate the Dakota sandstone, and that it obtains its supply from saliferous shales at the base of the Benton, a water horizon not reported in the boring at Kanona. The top of the Dakota sandstone lies 1,400 feet below the surface at Kanona, which is at an altitude of 2,726 feet, so that at Oberlin, only 200 feet lower, it would be at a depth of 1,200 feet if the beds were level. Owing, however, to the westerly dip of the formation, they are probably at least 100 feet deeper.

EDWARDS COUNTY.

Edwards County lies in Arkansas Valley, and is mainly underlain by Dakota sandstone. On the bottom lands the sandstone is largely covered by alluvium while the highlands are mantled by Tertiary deposits. In the extreme north portion of the county there is a small area of Benton shale.

The principal water supplies are derived from the lower portion of the alluvial and the Tertiary deposits, though some of the wells penetrate the Dakota sandstone and obtain good waters at moderate depths. So far as known, no attempts have been made to sink deeper wells, and, as the Red Beds lie at no great distance below the surface, are of great thickness, and yield only saline waters, there is no encouragement for deep boring in this county.

ELLIS COUNTY.

Ellis County is underlain mainly by the Benton formation, but the high divides to the west are capped by the Niobrara formation and some Tertiary deposits. The Dakota sandstone lies at a moderate depth, averaging from 300 to 400 feet through the greater part of the county, but increasing to over 500 feet in the highest lands to the west and diminishing to less than 200 feet in the deeper valleys to the east and south. The rocks dip gently to the north. A number of wells have been sunk to the Dakota sandstone, but no reports have yet been obtained as to their results.

In 1903 a deep boring was sunk on Smoky River, 15 miles due southwest of Hays, on the south half of sec. 10, T. 15, R. 20. A depth of 1,777 feet was reached, passing through the Benton shales and Dakota sandstone into the Red Beds, which were reached at a depth of 628 feet. Considerable water, which rose to within 70 feet of the surface, was found at the top of a thick bed of sandstone, presumably Dakota, at a depth of 215 feet. Near the bottom of this sandstone, at a depth of 500 feet, there was a strong artesian flow of fresh water, which is still flowing vigorously and under sufficient pressure to rise 15 inches above the top of the casing. Artesian salt water was found a short distance below and at intervals to a depth of 993 feet. The following record has been furnished by Mr. S. Motz:

Record of boring on Smoky River, Ellis County, Kans.

Feet.	
0 - 30	sandy soil, lime-rock fragments.
30 - 215	shale (Graneros).
215 - 505	sand rock, with water (Dakota).
505 - 545	black shale.
545 - 556	light-colored sand rock, with artesian salt water.
556 - 597	blue shale.

Feet.	
597 – 600	hard sandstone, white.
600 – 628	blue shale.
628 – 634	red shale.
634 – 638	white sand rock; artesian flow of salt water.
638 – 663	red shale, hard.
663 – 669	white sand rock; soft, strong flow of mineral water.
669 – 672	reddish shale.
672 – 673½	white sand rock.
673½ – 703	soft red shale.
703 – 993	soft red sand rock, with strong flow of salt water.
993 – 1,177	reddish sandstone "full of shells" (?).

ELLSWORTH COUNTY.

The Dakota sandstone is at or near the surface throughout this county, except in the deeper portion of Smoky Hill Valley to the southeast, where the underlying Permian rocks are cut into. The sandstone affords a water supply, in most cases of satisfactory quality, for many wells of various depths. On some of the lower lands between Ellsworth and Black Wolf the water flows in small volume in wells which reach the lower sandstone of the Dakota formation.

At Palacky, which is on the Benton shale, a well 336 feet deep obtains a large supply of slightly salty water, which rises to within 176 feet of the surface. The following record, which apparently is not reliable, was furnished:

Record of well at Palacky, Ellsworth County, Kans.

Feet.	
0–33	limestone.
33–165	blue shale.
165–175	"soapstone."
175–335	red, yellow, and white clay and sand, probably Dakota formation.

In the northeast corner of T. 14, R. 9, which is also on the Benton shale, a well 384 feet deep obtains a small supply of fine water, which does not rise materially in the well, at a depth of 170 feet. The following record is furnished:

Record of well in T. 14, R. 9, Ellsworth County, Kans.

Feet.	
0–40	limestone.
40–170	black shale.
170–316	gray sandy clay and sand, Dakota.
316–346	reddish and yellowish clay.
346–384	red shale.

A number of borings in this county have penetrated deeply into the Permian rocks underlying the Dakota sandstone and found only salt water, so that probably there are no prospects for fresh artesian waters. Just north of Ellsworth

a shaft 250 feet deep encountered a heavy flow of salt water, which rose to within 30 feet of the surface. From 730 to 880 feet a solid bed of salt was penetrated, at 1,100 feet a gas-bearing horizon with no water, and at 1,300 feet a large volume of water, of which the quality is not stated; it was presumably salty. At Kanopolis a well 881 feet, with the following record, is reported:

Record of well at Kanopolis, Ellsworth County, Kans.

Feet.	
0– 30	sand.
30– 40	sand and gravel, with a small amount of water.
40– 45	yellow clay.
45–645	shale of yellowish colors.
645–881	salt.

This boring was apparently entirely in the Permian rocks.

At Wilson, on the south side of the village, a boring of 1,375 feet has the following record:

Record of deep well at Wilson, Ellsworth County, Kans.

Feet.	
0– 65	sand, with water at 52 feet.
65– 465	blue shales, with flowing salt water near base.
465– 865	Red Beds.
865–1,165	rock salt.
1,165–1,275	blue shale.
1,275–1,375	rock (?).

FINNEY COUNTY.

There are comprised in this county a region of high planes to the north, a portion of Arkansas Valley across the center, and an extensive district of plains and sand hills to the south. The only running water is Arkansas River and some small streams in the headwaters of Pawnee Creek. Springs are very rare. Shallow wells obtain variable supplies from Tertiary deposits, valley alluvium, and dune sands. Some deeper wells reach the Dakota sandstone, which underlies the county at a depth of 200 feet in the southern portion, 400 feet at Garden, and 1,000 feet or more in the northern and northwestern portions. In the northeast corner the Dakota sandstone has been reached by several wells about 400 feet deep and a large supply of water found. The quality, however, has been somewhat variable and at some localities is too salty for use. It rises considerably, but does not reach the surface. A well at Kalvesta, 355 feet deep, failed to reach the top of the Dakota sandstone. In a boring half a mile northwest of Garden it is claimed that a depth of over a thousand feet was attained without obtaining a satisfactory supply. The following record was taken from the Garden City Sentinel:

Record of boring at Garden, Kans.

Feet.	
0- 12	soil.
12-311	quicksand.
311-461	black shale.
411-466	sandstone.
466-476	white slate.
476-481	dark sands.
481-550	soapstone.

This record is somewhat difficult to interpret, but apparently the boring entered the Dakota sandstone at a depth of 460 feet and probably continued in it for 250 or 300 feet It is reported that another well was sunk 8 miles south of Garden to a depth of 1,250 feet, passing into the Red Beds, but nothing has been learned of the result.

Two wells, 400 feet or more in depth, are reported north of Ravenna, in the northeast corner of the county. They found water in shales, but its quality was unsatisfactory.

FORD COUNTY.

Dakota sandstone underlies the southeast half of this county, and Benton shales the northwest half. Both formations are extensively covered by Tertiary deposits on the higher lands, and by alluvium and dune sands along the Arkansas. Shallow wells obtain water supplies from the younger formations, and, in some cases in the eastern part of the county, reach the Dakota sandstone and find water. No artesian flows are promised in this county, unless possibly from the Red Beds which underlie the Dakota sandstone, and the waters of these rocks are invariably salty. The formations below the Red Beds might present different conditions, but probably lie too deep for ordinary well borings. It is said that in 1886 a boring for coal, 1,000 feet deep, was made at Dodge, but it found neither coal nor water, and undoubtedly ended in the Red Beds.

GOVE COUNTY.

Gove County extends from Smoky Hill Valley north to the south side of Saline Valley, a region of high plains intersected by several branches of Smoky Hill River and the head of Big Creek. The highlands are covered by Tertiary deposits, but the valleys have cut through this mantle and have widely exposed the underlying Niobrara chalk. The depth to Dakota sandstone ranges from about 600 feet in the southeast corner of the county to slightly over 1,100 feet in the northwest corner, as nearly as can be calculated on the assumption of a thickness of 400 feet of Niobrara formation and 450 feet of Benton formation. A few wells have been sunk in the county, which attempted to penetrate the shale, but they were not successful. One well in the southwest corner, 3 miles south of Smoky Hill River,

reached a depth of 400 feet, 48 feet of which were reported as surface materials and the remainder as chalk, of which the lower 52 feet were white. At the depth of 400 feet a supply of fine water, reported to amount to 20 barrels per day, was obtained. In the vicinity of Catalpa a well of 400 feet had about the same result. Near Goodwater a well of 501 feet deep penetrated 70 feet of surface materials, 398 feet of blue shale, and 33 feet of light-colored chalk, from which, at a depth of 501 feet, a small amount of water was obtained. These borings, of course, were all too shallow to reach the Dakota sandstone. It is probable that in the lower lands of this county this sandstone would yield flowing water of moderate volume and of satisfactory quality.

GRAHAM COUNTY.

The High Plains of Graham County are thickly mantled by Tertiary deposits, which are cut through in the valleys of South Fork of Solomon River, of Bow Creek, and of Saline River, which lies a short distance south. The Niobrara chalk presents a thickness of considerably over 100 feet in the highlands and is underlain by about 400 feet of Benton shales lying on the Dakota sandstone. This sandstone is not over 500 feet below the surface in the southeast corner of the county, but, with the northeasterly dip of the beds and the rise of the land to the west, is about 1,000 feet deep in the highest ridges between Bow Creek and North Fork of Solomon River.

The only deep well that has been reported is 3 miles from Hill and a mile south of South Fork of Solomon River. It passed through the Niobrara formation, reached Benton shales at a depth of 165 feet, passed through these shales for 300 feet more or less, and was discontinued at a depth of about 465 feet, 100 feet or more above the surface of the Dakota sandstone, without obtaining water. Probably all of this county is too high for an artesian flow from the Dakota sandstone, unless possibly in the lowest part of Solomon Valley.

GRANT COUNTY.

This county extends from the valley of the Cimarron up the divide between that river and the Arkansas. The surface is covered by Tertiary deposits, which are known to be underlain by the Dakota sandstone at no great depth; in the northeastern part of the county, the sandstone is overlain by 100 feet or more of Benton shales. The only deep boring reported is the State well, 6 miles south by east of Ulysses. A depth of 231 feet was reached and an excellent water supply obtained, rising to within 123 feet of the surface. The following record is given:

Record of well 6 miles south by east of Ulysses, Grant County, Kans.

Feet.	
0 - 2	top soil.
2 - 8	clay and gypsum.
8 - 16	ashy material.
16 - 21	red sand, hard.

Feet.	
21 – 35	gypsum, very hard.
35 – 70	red sand.
70 – 79	clay and gypsum, very hard.
79 – 91	red sand, hard.
91 – 93	gray sand, soft.
93 –100	red sand, hard.
100 –109	red sand, soft.
109 –120	sandy clay, hard.
120 –124	clay.
124 –144	joint clay, water bearing.
144 –148	hard red clay, dry.
148 –153	red sand, water bearing.
153 –154	hard red clay, dry.
154 –157	gypsum, hard, dry.
157 –165	sand, water-bearing.
165 –170	joint clay, water-bearing.
170 –172½	coarse sand, water-bearing.
172½–185	red clay, dry.
185 –199	sand, water-bearing.
199 –202	joint clay, water-bearing.
202 –212	sand, water-bearing.
212 –220	rock, dry.
220 –231	blue shale, dry.

This section is difficult to reconcile with our knowledge of the succession of beds in the Dakota sandstone, but, if the gypsum is present and the sand and clays are bright red in color, the Red Beds have been entered and are the source of good water—a very unusual condition.

GRAY COUNTY.

Gray County lies mainly in Cimarron Valley, but extends southward to the head of Crooked Creek. The entire area is thickly covered by Tertiary and younger formations, but is known to be underlain by the Dakota sandstone, covered by a greater or less thickness of Benton shale, which is exposed southeast of Montezuma. The depth to the sandstone is not known precisely, but is not great in any portion of the county. Apparently some of the deeper wells in the county have reached it, but no satisfactory records have been obtainable. No flowing water is to be expected, unless possibly from the underlying Red Beds, the water from which would probably be too salty for use.

GREELEY COUNTY.

Greeley County, on the High Plains of western Kansas, slopes eastward from an altitude of about 4,000 feet above sea level on the State line, to 3,500 feet on its eastern margin. The surface is covered more or less deeply by Tertiary deposits,

but the Niobrara chalk appears to lie at no great depth throughout the area, although possibly near the extreme north margin of the county there may be an overlap of Pierre shale. The dip is gently to the northeast. The Niobrara formation probably is from 600 to 700 feet thick, and is separated from the Dakota sandstone by 400 feet of Benton shales. In the southeast part of the county this sandstone lies from 800 to 1,100 feet deep, the depth increasing gradually from southeast to northwest until it is about 1,400 feet in the northwest corner of the county. In a well recently bored at Horace, Kans., the Dakota sandstone was reached at a depth of 1,050 feet and was found to have a thickness of 300 feet. Layers of clay were intercalated in the sandstone. The well was continued to 1,350 feet, where the Red Beds were found. The water rises to within 700 feet of the surface and pumps 40 gallons per minute. This well throws most important light on the position and capabilities of the Dakota sandstone in western Kansas. The thickness of the overlying beds is shown and the head of the water is ascertained.

An attempt to obtain water was made some years ago at Tribune, and it is stated that a depth of 500 feet was attained, all in chalk and shale. The top of the chalk was found at 44 feet below the surface. The low head of water in the Horace well indicates that there are no prospects for flowing water in the higher lands of western Kansas.

HAMILTON COUNTY.

Hamilton County is in Arkansas Valley, in the extreme western portion of the State. It is underlain by Dakota sandstone, Benton shale, and Niobrara formation, all dipping gently to the northeast; the higher lands have a thick cover of Tertiary deposits. The Dakota sandstone is exposed in the southwest corner of the county, and the Benton shales appear in Arkansas Valley and at some isolated points south. The northern third of the county is underlain by Niobrara formation, which is exposed in some of the depressions north of Coolidge and Syracuse.

The Dakota sandstone furnishes water to a number of wells in Arkansas Valley, some of which flow in the eastern margin of the Arkansas Valley artesian area, which extends into the center of this county. At Coolidge there is a group of flowing wells, varying in depth from 226 to 300 feet, which furnish flows of from 27 to over 100 gallons per minute under slight pressure. Farther down the valley there are a number of wells, especially near Syracuse, where the water rises to within 30 feet of the surface. Several wells have been sunk in portions of the county away from Arkansas Valley, but have not reached the Dakota sandstone. Even at Coolidge flowing water is obtainable only in the lower part of the valley. The state well, 6 miles due north of Kendall, reaches a depth of 196 feet and obtains a water supply from Tertiary gravel and fine sand at 180 to 192 feet, lying on the surface

of Niobrara chalk. A number of wells in various parts of the county obtained supplies for pumping from this horizon, which is the principal source, the shales below rarely containing any water.

At Coolidge two of the wells have the following record:

Records of two wells at Coolidge, Kans.

Feet.	
0– 38	superficial materials; hard water.
38–200	shale (Benton).
200–300	Dakota sandstone, with 20-gallon flow at 268 feet.

At Kendall there is a well 537 feet deep, which does not flow, but yields 70 gallons a minute to pumps. It passes through the Dakota sandstone and some underlying shales of unknown age into the Red Beds. The following record is given:

Record of well at Kendall, Kans.

Feet.	
0– 53	superficial materials.
53–109	sandstone.
109–111	lignite.
111–114	clay.
114–152	gray sandstone; soft water.
152–154	very hard clay.
154–167	gray sandstone.
167–215	shale, very hard in center.
215–268	gray sandstone; soft water.
268–291	shale.
291–297	sandstone.
297–332	shale.
332–334	black sandstone.
334–348	shale.
348–367	gray sandstone; soft water.
367–425	light to gray shale.
425–430	brown sand.
430–453	clay, brown below.
453–476	sandy clay.
476–493	light-gray sandstone.
493–496	fire clay.
496–530	red clay.
530–533	hard layer.
533–537	red shale.

Record of well at Syracuse, Hamilton County, Kans.

Feet.	
0– 21	superficial materials.
21–185	shale, with bad water at 45 and 115 feet.
185–193	joint clay.

Feet.	
193–197	sandstone; soft water.
197–225	shale.
225	thin limestone streak.
225–240	shale.
240–250	white clay.
250–279	sandstone; soft water.
279–284	shale.

It is reported that a boring was sunk 1,000 feet at this place several years ago, but yielded no satisfactory result. Doubtless it passed deep into the Red Beds.

HASKELL COUNTY.

This county, which is situated on the High Plains between Arkansas and Cimarron rivers, has its entire surface covered by a mantle of Tertiary deposits from 20 to 100 feet or more in thickness, underlain in greater part by Benton shales. It is probable that in the southern portion of the county the underlying Dakota sandstone is not far below the surface. This sandstone is reached by several wells, in which the water rises somewhat but gives no promise of a flow. At Santa Fe a well was bored 1,300 feet or more through Tertiary deposits, Benton shale, Dakota sandstone, and far into the Red Beds, but no flowing water was obtained. A representative well to Dakota sandstone has the following record:

Record of well 10 miles northwest of Santa Fe., Kans.

Feet.	
0– 3	soil.
3– 45	Tertiary grit.
45–305	blue clay (Benton).
305–325	hard blue rock.
325–330	sand with much water rising to —210 feet.

HODGEMAN COUNTY.

The greater part of this county is underlain by the Benton shales, but the higher divides are capped by Tertiary deposits, and Pawnee Valley, in the eastern portion, cuts into the Dakota sandstone. Wells are numerous, some of them penetrating Dakota sandstone and obtaining satisfactory supplies of water; this is especially the case in Pawnee Valley below Jetmore. In the extreme northwest corner of the county the Dakota sandstone lies about 400 feet below the surface; in the extreme southwest portion, about 200 to 250 feet, so that throughout the county the sandstone is within reach of wells of moderate depth. In a well 2 miles northwest of Jetmore, Dakota sandstone was entered at a depth of 186 feet and penetrated to a depth of 227 feet, yielding a large supply of water which

rises considerably in the well. It was sunk by the State as a test well, and the following record is given:

Record of well 2 miles northwest of Jetmore, Hodgeman County, Kans.

Feet.	
0– 26	soil and "magnesia."
26– 44	limestone, dry.
44– 55	black shale, dry.
55– 99	gray shale, dry.
99–104	"soapstone," dry.
104–126	sand rock, dry.
126–129	gray shale, dry.
129–186	black shale, dry.
186–210	Dakota sand rock, water bearing.
210–218	white clay.
218–223	red clay.
223–243	white clay.
243–250	sand rock, water bearing.
250–264	white clay.
264–275	sand rock; strong flow of water.
275–277	blue clay, depth unknown.

Six miles west of Jetmore a well 325 feet deep has the following record:

Record of well 6 miles west of Jetmore, Hodgeman County, Kans.

Feet.	
0– 40	soil.
40–240	Benton clays.
240–260	joint clay.
260–263	sandstone.
263–283	"soapstone" (base of Benton).
283–303	compact sandstone with water to —112 feet.

At Jetmore a boring was sunk to a depth variously reported as 700, 800, and 1,000 feet, to ascertain the water resources of the formations underlying the Dakota sandstone. Good water was found in the Dakota sandstone and some salt water in the underlying beds. No record is obtainable. Doubtless the rocks penetrated beneath the Dakota were Red Beds, and the boring was not sufficiently deep to reach the bottom of these. Their thickness in this region is not known, but probably is considerable. Whether the underlying formations would yield water or not has never been ascertained.

JEWELL COUNTY.

Jewell County is situated on the high divide between Solomon and Republican rivers. The high ridges in its northwestern portion are capped by Tertiary grit The central, northern, and western portions are underlain by Niobrara chalk, and,

in the lower lands to the south and east, the Benton shales reach the surface. The Dakota sandstone, which outcrops in Republican and Solomon valleys, underlies the entire county, lying nearly level or dipping gently to the northwest. In the east and south portions of the county it lies but a short distance below the surface, but the depth increases gradually as higher lands are ascended to the north and west, so that probably it lies 700 or 800 feet deep in the northwest portion of the county.

Apparently the main body of the sandstone has not been reached by deep wells in this county, although several borings from 300 to 500 feet deep have been sunk to a water-bearing horizon underlying the Benton shales. This is the stratum which contains considerable salt in this region and has yielded salty waters which have not been useful. One well near Jewell, 337 feet deep, found salt water which rose to within 25 feet of the surface. At Ionia a well 432 feet deep has a similar condition. At Mankato a well 500 feet deep found an abundance of salt water which rose to within 50 feet of the surface. Three and one-half miles northwest of Lovewell borings 380 and 400 feet deep found salt water, and there are a number of other similar borings in the county.

It is unfortunate that these borings were not made sufficiently deep to test the water conditions in the Dakota sandstone, for, although it is not likely that they would obtain a flow, except possibly on the lowest lands, the water may be expected to be of good quality.

KEARNY COUNTY.

This county is in Arkansas Valley and has similar geologic relations to those in Hamilton County, but the formations are mostly obscured by a heavy covering of Tertiary and alluvial deposits. The county is underlain by the Dakota sandstone, which lies at a depth of about 300 feet along Arkansas Valley, and is deeper in the northern portion, owing to the northeasterly dip of the beds and the rise of the land. No deep wells are reported, but abundant water supplies are obtainable from the Dakota sandstone at moderate depths in Arkansas Valley, though without prospects for flows. The underlying Red Beds may yield flowing water, but probably it would be too salty for use.

KIOWA COUNTY.

Kiowa County extends from Arkansas Valley southeast across the divide to the Medicine Lodge. Its surface is covered with younger formations, alluvium, and sand hills in the northwest corner, and Tertiary deposits on the higher lands to the south and east. The Dakota sandstone is at no great distance beneath the surface, and is exposed on the opposite side of Arkansas River and in the southeast corner of the county. The formation thins rapidly to the southeast, owing mainly

to the erosion of its surface, and in Medicine Lodge Valley the underlying lower Cretaceous sandstones and Red Beds are exposed.

Most of the wells in the county obtain a water supply from the basal portion of the Tertiary deposits, but some have been bored into the underlying Dakota sandstone and obtain their supplies there. One well 9 miles southwest of Greensburg has a depth of 202 feet, and the water supply rises to −112 feet. There are no prospects for flowing waters in this county, not even from the Red Beds which underlie the Dakota and lower Cretaceous sandstones. Possibly these Red Beds contain water, but it would be too salty for use.

LANE COUNTY.

This county is mantled by Tertiary deposits lying on several hundred feet of Niobrara chalk, which is exposed in some of the deeper depressions to the north and east. The Dakota sandstone lies at a depth which gradually increases from about 500 feet in the southeast corner of the county to 700 feet in the northwest corner, the beds dipping very gently to the north and the land rising very gradually to the west.

Apparently no attempts have been made in this county to reach the Dakota sandstone. A well 3 miles north of Shields, having a depth of 400 feet, obtains a very limited supply of water from a thin sandstone bed, probably in the upper part of the Benton formation. This county lies too high for an artesian flow, but the Dakota sandstone may be expected to yield water that would rise to within 300 or 400 feet of the surface and yield an abundant supply to pump wells.

LINCOLN COUNTY.

Lincoln County includes a portion of the valley of Saline River and th adjoining slopes. In the river valley and along the east side of the county the Dakota sandstone is exposed and the higher lands are capped by a few hundred feet of Benton shales. There are numerous wells, most of them obtaining their water from the Dakota sandstone, in some cases from a depth as great as 280 feet. The water rises nearly to the surface and has considerable volume.

LOGAN COUNTY.

Logan County includes a portion of Smoky Hill Valley and adjoining high plains. The Tertiary deposits have been extensively removed by the river, which has cut a wide valley into the underlying Pierre formation to the west and into the Niobrara chalk to the east. The west and north portions of the county are underlain by the Pierre shale, and the southeast portion by the Niobrara formation. The Dakota sandstone underlies the county at a depth of 800 to 1,000 feet in the

southeast part of the county, and 1,000 to 1,500 feet in the higher lands in the north and west portions of the county, the dip of the beds being gently to the north. It is probable that the head of water in the Dakota sandstone is sufficient to raise it to an elevation of about 3,000 feet, so that it should be expected to yield a flow in wells in the valleys of Smoky Hill River and Twin Butte Creek.

Several attempts have been made to reach the deeper-seated waters in this county, the deepest boring being one recently sunk by the Union Pacific Railroad Company at Winona. The depth of the Winona boring is 1,356 feet, all below 160 feet being in shales, and it is reported as a dry hole. White shale was penetrated from 1,100 to 1,175 feet, probably representing a portion of the Niobrara formation. This hole undoubtedly would have reached the Dakota sandstone within a short distance and found a water supply which would have risen to within 300 or 400 feet below the surface. It is to be regretted that the boring was not continued to the Dakota horizon. Two deep borings on Hell Creek, in the extreme southeast corner of the county, reached a depth of 500 feet, all in the Niobrara formation and the top shales of the Benton, without obtaining any water supply, and a 408-foot boring at Elkador had a similiar result. A boring at Oakley is said to have reached a depth of 700 feet and obtained a small amount of water which rose to within 30 feet of the surface. It is reported that some water was found at 90 feet and at intervals down to 350 feet in alternating sands and clays in part of the Tertiary deposits. The underlying shales extend to the bottom, which lacks about 450 feet of reaching the Dakota sandstone. Oakley is slightly too high for a flow.

MEADE COUNTY.

In Crooked Creek Valley from Meade to Milburn numerous flowing wells 50 to 250 feet deep obtain water from Tertiary and Quaternary deposits. The water is much used for irrigation, but its pressure is slight. The northwest corner of the county is underlain by Dakota sandstone, which yields water to wells of moderate depth. Underlying the entire county and appearing in the valleys to the southeast are Red Beds which offer no prospects for a deep-seated water supply. One boring at Meade a little over 800 feet deep passed through 250 feet or more of Tertiary clay and sands and then Red Beds and gypsum to the bottom. No good water was obtained.

MITCHELL COUNTY.

Mitchell County includes a portion of Solomon and Salt Creek valleys. The greater part of its area is occupied by the Benton shales, but to the east Solomon River has cut through these into the Dakota sandstone. Various wells reach this sandstone and obtain satisfactory supplies, but do not flow. At Asherville (?) a well sunk 638 feet obtained abundant very salty water, which rose to 26 feet below

the surface. It penetrated 49 feet of sand and clay, 3 feet of sand (Dakota?), and thence to the bottom blue clay and sandstone.

A well near Bluehill is reported to have a depth of 308 feet, passing through Benton shales into Dakota sandstone. Good water was found, which at first rose to the top of the well and then settled down again. A boring made 2 miles northeast of Cawker is reported to have a depth of 467½ feet. It was sunk for coal, and has the following record:

Record of well 2 miles northeast of Cawker, Kans.

Feet.	
0 – 38	surface.
38 –213	dark-green shale, compact for lower 15 feet.
213 –215½	sandstone with strong brine.
215½–400	sand, shale, and red and yellow clay alternating.
400 –427	very hard red rock.
427 –467½	coarse sandy shale.

Fresh water was reported at 460 feet, but it mixed with the salty water from the higher horizon, so that it was not utilized. The water rose to within 227 feet of the surface. The salty water was undoubtedly from the saliferous shales which usually occur immediately under the Benton shales, while the lower water was doubtless derived from the Dakota sandstone.

MORTON COUNTY.

Morton County lies in the extreme southwest corner of Kansas, along the valley of Cimarron River. The entire county appears to be underlain by Dakota sandstone, which is deeply covered by the later Tertiary deposits on the higher lands. Along the Cimarron River bottoms, south and southwest of Richfield, this sandstone yields flowing water in wells 90 to 105 feet in depth, but the pressure is very slight and no flow is obtainable on the higher lands. Two attempts, 50 feet apart, have been made at Richfield to obtain flowing water by boring to the depths of 651 and 701 feet, but although a flow was obtained, it was from the Red Beds, and the water was of unsatisfactory quality. It is stated that the pressure was sufficient to raise the water 125 feet above the surface. The following record is given:

Record of well at Richfield, Kans.

Feet.	
1– 40	soil and Tertiary grit (reported as gypsum).
40– 52	yellow clay and sand.
52– 71	sand.
71– 72	blue joint clay.
72–202	Dakota sandstone with great quantities of water which does not rise much.
202–251	blue shale.
251–701	red sandstone with a flow of 6.3 gallons per minute at about 637 feet.

NESS COUNTY.

The central, southern, and eastern portions of this county are underlain by Benton shales, which, to the north and west, pass beneath the edge of the Niobrara formation, overlain on the higher ridges by Tertiary grit. Probably the Dakota sandstone is at the surface, or a very short distance below, on Pawnee Fork in the southeast portion of the county, and it underlies a region northward at depths which gradually increase to slightly over 500 feet on the divide between the head of Walnut Creek and Smoky Hill River. The town of Ransom, on this ridge, has a well 653 feet deep which passes into Dakota sandstone at 580 feet, and obtains a plentiful supply of soft water rising to within 60 feet of the surface. The rock is described as a soft porous sandstone, of brown color, overlain by several hundred feet of the blue shale of the Benton formation.

Ten miles southwest of Ness (northwest corner of T. 20, R. 24) a well 450 feet deep reached Dakota sandstone and obtained a satisfactory supply of soft water. The following record is reported:

Record of well in northwest corner T. 20, R. 24, Ness County, Kans.

Feet.	
0– 40	clay.
40–190	blue shale.
190–240	blue joint clay with hard blue gritty layers.
240–270	white clay.
270–310	sand rock with water (Dakota sandstone).
310–445	red clay and red sandy clay.
445–450	coarse sand; no water.

Twelve miles west-southwest of Ness (southwest corner of T. 19, R. 25) a well 437 feet deep passed through shale and clay into the Dakota sandstone at 370 feet, obtaining a satisfactory water supply. At Riverside, 12 miles southeast of Ness, a well 350 feet deep obtains a supply from the Dakota sandstone. A well 6 miles southwest of Danby is 385 feet deep and passes through 330 feet of shale into sand rock, which yields water rising to within 110 feet of the surface. A well 10 miles south-southwest of Ness (T. 20, R. 24, sec. 11) has a depth of 300 feet, with record as follows:

Record of well in sec. 11, T. 20, R. 24, Ness County, Kans

Feet.	
0– 40	surface materials.
40–210	black shale.
210–250	joint clay.
250–290	sandstone of the Dakota formation, containing a water supply.
290–295	red clay.
295–300	sandstone.

These representative wells indicate the general relations of the Dakota sandstone part of this county. The occurrence of the water is general and its quality good, but no flows are obtainable. The underlying Red Beds appear not to have been reached, and although the water which they contain may be expected to be under considerable pressure, its quality usually is bad.

NORTON COUNTY.

Norton County comprises portions of the valleys of Sappa and Prairiedog creeks and of the North Fork of Solomon River and the intervening divides. Apparently the entire county is underlain by the Niobrara chalk (which appears in the deeper wells), the intervening divides being covered by Tertiary deposits. The formations all appear to rise gradually to the west on a low anticline of which the summit extends north and south along the western line of the county. In the eastern portion of the county the Dakota sandstone probably is about 750 feet below the surface in the valleys and 150 feet deeper on the divides. In the valleys in the western portion of the county it lies about 900 feet deep and on the divides 200 feet deeper.

No deep borings have been reported from this county, but from the experience of the deep boring at Jennings and Kanona, in the next county west, the Dakota sandstone contains a large volume of water under moderate head which may possibly afford a flow in the deeper valleys.

OSBORNE COUNTY.

Osborne County lies mainly on the Benton shale, which passes under the Niobrara chalk to the west, the beds dipping very gently to the north. The Dakota sandstone lies at a moderate depth throughout the county, at a very few feet in its southeast corner, gradually increasing to about 500 feet on the divides in the extreme western and northwest portions. A number of borings have been made, of which some appear to have reached the Dakota sandstone and to have found satisfactory water supplies, while a number of others have not been quite deep enough and have been discontinued on encountering salt water, apparently in the shales underlying the Benton. A well of this character at Osborne had a depth of 301 feet and found very salty water, which rose to within 30 feet of the surface. The well passed entirely through shale, and no sandstone is reported. A well 9 miles south by east from Osborne (NW. ¼ sec. 33, T. 8, R. 12), with a depth of 360 feet, found a large volume of salty water, which rises to within 45 feet of the surface. On Solomon River, 6 miles northeast of Osborne (NE. ¼, sec. 14, T. 6, R. 12), a well 315 feet deep passed through blue shale and obtained a large volume of salty water which comes to the surface, and, it is claimed, rose several feet above it when the well was first opened.

These wells indicate the existence of an extensive stratum of water-bearing material at the base of the Benton shale, yielding water too salty for use. Doubtless wells bored through this horizon into the deeper beds of the Dakota sandstone would obtain satisfactory water supplies for pump wells.

OTTAWA COUNTY.

This county comprises a portion of the lower valley of Solomon River. It is underlain mostly by Dakota sandstone, but, in the deeper valleys in the southern portion of the county, the underlying Permian shales are exposed.

There are numerous wells which penetrate the sandstone to various depths, usually from 20 to 150 feet, and generally obtain satisfactory water supplies. Deeper wells would penetrate the salt-bearing shales which underlie the Dakota sandstone, in which there is no prospect of finding good water. The thickness of these shales has not been ascertained, and it is possible that good water supplies might be obtained in the limestones and sandstones by which they are underlain. Judging by wells in the country east and south, it would be necessary to bore over 1,500 feet, and possibly over 2,000 feet, to reach these limestones.

PAWNEE COUNTY.

Pawnee County embraces a portion of the valleys of Arkansas River and Pawnee Fork. All of the lower lands are underlain by the Dakota sandstone, but the high ridge in the northern portion of the county is capped by a thin mass of Benton shales. Along the river there are extensive alluvial deposits, and to the south sand dunes and Tertiary beds. Numerous shallow wells obtain water supplies from the Dakota sandstone, which rises to within a few feet of the surface in most cases. An exploration for deeper waters has been made at Larned, in a well 743 feet deep, from which there is a flow of 250 gallons per minute of very saline water. It is reported that fresh water was found in the Dakota sandstone near the surface, a slightly saline flow at 430 feet, and a strong brine under a pressure of 23½ pounds at 743 feet. The following analysis of this water by Professor Church is given:

Analysis of water from deep well at Larned, Kans.

	Grains per gallon.
Sodium chloride	3,373.61
Sodium sulphate	332.92
Sodium bicarbonate	146.93
Magnesium bicarbonate	25.52
Lime bicarbonate	127.23
Iron and alumina oxides	.21
Silica	.12
Organic matter	.09
Total	4,006.63

PHILLIPS COUNTY.

Phillips County lies near the eastern margin of the High Plains, extending from the valley of Prairiedog Creek southward to and beyond North Fork of Solomon River. It is underlain by the Niobrara formation, which is extensively exposed in the deeper valleys, the higher lands being covered by the late Tertiary sands and grits of the High Plains. The Niobrara is from 50 to 200 feet thick in this county and is underlain by the Benton formation, 400 feet thick, which, in turn, is underlain by the Dakota sandstone. The formations dip gently to the northeast, the Dakota sandstone varying in depth from 500 feet in Solomon Valley at the eastern margin of the county to from 700 to 850 feet in the higher lands to the north and west. The sandstone appears to have been reached at Kirwin, at a depth of 430 feet, by a well which affords a flow, but as the water is from the uppermost beds, or the beds at the base of the Benton, it is too highly mineralized to be of use. A well in Beaver township, 6 miles south of Cactus, was bored to a depth of 480 feet and found in blue shale a small supply of water, which rises to within 50 feet of the surface. A few miles northwest of Phillipsburg, a similar well is 430 feet deep, and a well in section 21, near Stuttgart, is 398 feet deep. These three wells were, of course, not sufficiently deep to reach the Dakota sandstone.

In 1903 a deep boring was in progress 4½ miles northeast of Long Island, in search of oil or gas. At a depth of 650 feet the top of a stratum reported as "hard rock," which is probably the Dakota sandstone, was reached. From 50 to 650 feet the boring was in "shale" of the Niobrara and Benton formations, the chalk rock and limestone not being specially recognized. As the altitude of this boring is about 2,050 feet, the altitude of the top of the supposed Dakota sandstone is 1,400 feet.

PRATT COUNTY.

Pratt County is situated in south-central Kansas, on the High Plains between Cimarron and Arkansas rivers. Its surface is covered by Tertiary deposits from 50 to 200 feet thick, and its principal water supplies are obtained from the coarser sands and gravels at their base. The next underlying formation is the Dakota sandstone, which thins out to the south and gives place to Red Beds, which lie at no great depth in the southeast corner of the county.

The only deep well reported in this county is at Pratt, where 800 feet was attained. Salt was found from 600 feet down, and some water, met with in the salt-bearing beds, rose to within 15 feet of the surface. Judging from the experience of the deep well at Anthony, in the adjoining county, the salt-bearing beds are very thick, and there are no prospects for reaching the underlying limestones at a depth of less than 2,500 feet, and perhaps of much more. There is also no certainty that these limestones would yield satisfactory water supplies.

RAWLINS COUNTY.

This county lies on the High Plains and is traversed by the valleys of Beaver and Sappa creeks. The entire area appears to be covered by Tertiary beds, excepting in the bottom of some valleys where the underlying Pierre shale is revealed. This formation has a thickness of several hundred feet, the State well at McDonald having penetrated it for 213 feet without reaching its base. The underlying Niobrara formation and the Benton group have a thickness of about 900 feet. The Dakota sandstone is at an altitude of from 850 to 1,150 feet above sea level, its surface dipping gently to the northwest. Accordingly it should be expected at a depth of 1,600 feet in the southeast corner of the county and at 2,400 feet on the higher lands of the western tier of townships. Judging from the experience of the wells in the adjoining county, Decatur, the formation contains water, but not under sufficient head to yield a flow even in the deeper valleys.

REPUBLIC COUNTY.

Republic County comprises a portion of Republican Valley and the highlands eastward. It lies mainly on the eastern edge of the Benton shales, with the Dakota sandstone exposed in Republican Valley. The formations lie nearly level, or dip very gently to the northwest.

A number of wells have been bored through the Benton shales into the Dakota sandstone, and others are sunk in the sandstone itself, obtaining satisfactory supplies in most cases. At Belleville a city supply is obtained from wells 155 feet deep, sunk through Benton shales into Dakota sandstone. They yield 25 gallons per minute. The only deep boring reported in the county is at Scandia, where a depth of 1,110 feet was reached. It passed through the Dakota sandstone and into Permian rocks, excellent water being found at a depth of 1,000 feet, which rose to within 16 feet of the surface. The following partial record was furnished:

Record of well at Scandia, Republic County, Kans.

Feet.	
0- 340	(not given.)
340- 410	fire clay.
410- 460	(not reported.)
460- 640	terra-cotta clay.
640-1,110	sandstone.

The materials reported in this record are difficult to place geologically, but probably they represent shales, sandstones, and limestones of the Permian.

RICE COUNTY.

Rice County includes a small portion of Arkansas Valley below the Great Bend and extends north onto the low divide toward Smoky Hill Valley. The

greater part of the county is underlain by Dakota sandstone, but the underlying Permian beds appear to the southeast.

Numerous shallow wells obtain water from the Dakota sandstone. There are a number of salt wells and shafts in the county, one boring in Lyons having reached a depth of 1,625 feet. In the Bemis salt shaft at Lyons the following formations were penetrated:

Record of Bemis salt well at Lyons, Kans.

Feet.	
0– 30	surface.
30– 45	sandy loam.
45– 55	Dakota sandstone, yielding 25 gallons per minute of good water.
55– 67	variegated clays.
67– 80	blue clay.
80– 110	black clay.
110– 120	gray sandstone, with small supply of water.
120– 272	Red Beds.
272–1,083½	limestone, shale, gypsum, and salt.

In Sterling there are deep brine wells, having depths of 916 and 946 feet, and at Little River a salt well 1,000 feet deep was reported. The thickness of the salt-bearing formations and the nature of the rocks by which they are underlain have not been determined.

ROOKS COUNTY.

Rooks County comprises a portion of Solomon River Valley and the adjoining ridges of high plains. The whole county appears to be underlain by the Niobrara formation, overlain on the higher lands by Tertiary deposits. The county is underlain by the Dakota sandstone, which, in greater part, lies more than 500 feet below the surface on the highest lands and somewhat less than this in the valleys, especially above North Fork of Solomon River, below Stockton. The strata dip gently to the north.

It is not to be expected that the waters of the Dakota sandstone will afford surface flows in this county, except possibly in the bottoms of some of the deeper valleys. The deepest well reported has a depth of 490 feet, passing through the lower beds of the Niobrara and the Benton formations to the Dakota sandstone. It is situated on the slopes, 9 miles south of Stockton, on the road to Plainville, and yields a large supply of excellent water, which rises to within 60 feet of the surface.

RUSH COUNTY.

The formation underlying this county is mainly Benton shale, but the Dakota sandstone is said to appear in its southeast corner. The beds sink gradually to the north, so that along the northern border of the county the depths to the

sandstone are from 200 to 500 feet, the latter being the elevation of the highest land in the divide south of Smoky Hill River. The sandstone has been reached by a number of wells which usually yield satisfactory supplies of excellent water. At La Crosse and in its vicinity there are numerous wells from 300 to 400 feet deep. At Otis a depth of 260 feet is reported. In the higher lands northeast of La Crosse a plentiful supply of soft water, which rises to within 240 feet of the surface, is found in the sandstone at a depth of 444 feet. In the township south of La Crosse some wells find the Dakota sandstone waters slightly too saline to be agreeable for domestic use. In other portions of the county salty waters are found in some wells which stop in the first sandstone layers under the Benton shale, a horizon which usually yields unsatisfactory waters. By deepening these wells a few feet the Dakota sandstone should be penetrated and probably more satisfactory water obtained. No reports have been received of deeper wells into the formations underlying the Dakota sandstone. It is to be expected that such wells, unless very deep, would find nothing but the salty water of the Red Beds.

RUSSELL COUNTY.

Russell County comprises portions of the valleys of Smoky Hill and Saline rivers and adjoining divides. The greater part of the county lies on the Benton shales, Dakota sandstone being exposed to the east in the valleys of the two rivers. The dip of the formations is very gently to the north.

The depth to the Dakota sandstone is less than 500 feet throughout, the amount being least along the river bottoms in the east, central, and south portions of the county. Many wells reach this sandstone and obtain water supplies, usually of good quality and in considerable volume. One well in Saline River bottom, northwest of Russell, has a depth of 125 feet and obtains a flow of moderately hard water from the Dakota sandstone, which is said to have sufficient pressure to rise 40 feet above the mouth of the well. Some of the wells obtain their water from the top sandstone of the Dakota, and others go deeper into the formation to obtain better supplies. A well at Russell is reported to have the following record:

Record of well at Russell, Russell County, Kans.

Feet.	
0- 3	soil.
3- 35	clay and limestone.
35-115	black shale, with thin rock layers.
115-155	blue clay.
155-190	sandstone.
190-210	blue clay.
210-270	red clay.
270-325	blue and red clay and sandy layers.

Apparently this well did not reach the Dakota sandstone.

At this place another well has been sunk to a depth of 997 feet, obtaining water, which rose to within 300 feet of the surface, but was too salty for use. A flow of fresh water was reported at 360 feet, apparently from Dakota sandstone, and it is claimed that rock salt was penetrated. This well was mainly in the Permian shales.

SCOTT COUNTY.

Scott County lies on the High Plains between Smoky Hill and Arkansas rivers. Its surface is covered with a mantle of Tertiary deposits, which are underlain at from 50 to 200 feet in depth by Niobrara chalk. Under this chalk, which probably averages from 150 to 300 feet thick in this region, increasing gradually to the northwest, there are about 400 feet of Benton shales underlain by Dakota sandstone. The beds all dip gently to the northeast. The depth of the sandstone is about 700 feet in the southeast corner of the county, gradually increasing to the northwest.

So far as known no attempts have been made to reach this sandstone, and, although it doubtless contains water supplies, the land is too high for surface flows.

SEWARD COUNTY.

Seward County comprises a portion of Cimarron Valley in southwest Kansas. The greater portion of its surface is covered by Tertiary deposits, which are known to be underlain by Dakota sandstone to the north and by Red Beds to the south.

Water is usually obtained from the coarse materials at the base of the Tertiary grit, and to the north by some of the wells from the Dakota sandstone. A State well 176 feet deep, sunk just northwest of Liberal, obtains a moderate amount of water from Tertiary grit beds. A well 485 feet deep, in Liberal, bored by the Rock Island Railroad Company, is reported to have found sandy clay with layers of sand rock all the way down, so that apparently it did not reach the Red Beds. A moderate supply of water was found, which rises to within 125 feet of the surface. A similar well at Arkalon has a depth of 300 feet.

No reports have been received of any attempts to penetrate the Red Beds for water supplies, but wells in other portions of the region show that the waters from the Red Beds are usually too much mineralized to be of use.

Record of well at Liberal, Kans.

Feet.	
0– 6	hard clay.
6– 41	sand.
41– 63	soft sandstone.
63– 75	coarse sandstone.

Feet.	
75–85	sand.
85–185	soft sandstone.
185–265	sand with clay, mixed.
265–270	hard drift sandstone.
270–315	coarse sand, gravel, and quicksand.
315–445	sand and drift sandstone.
445–485	coarse sand and gravel.

SHERIDAN COUNTY.

This county is a typical region of the High Plains, thickly covered by "mortar beds" or Tertiary grit. The underlying formation is, in part, Niobrara chalk, which is exposed in the valley of Saline River in the southeast corner of the county, and, in part, Pierre shale, which probably occupies the higher portion of the region to the northwest. The depth to Dakota sandstone is probably about 800 feet in the southeast part of the county and 1,250 feet in the northwest part, the beds dipping gently to the north.

SHERMAN COUNTY.

This county, which lies on the High Plains, mostly on the divide between Republican and Arkansas valleys, is thickly mantled by Tertiary deposits lying on Pierre shale. One of the State test wells, located 3 miles northeast of Goodland, reached a depth of 166 feet, all in Tertiary deposits, and obtained a large supply of water for pumping, probably from the basal beds. The thickness of Pierre shale is doubtless nearly 1,000 feet in this vicinity, with underlying Niobrara and Benton formations 950 feet thick, as in the region to the east and south. These beds dip gently to the north. The Dakota sandstone should be expected at about 1,500 feet below the surface in the southeast part of the county, and at a depth of at least 2,500 feet in the northwest part. All of the land is too high for flowing water from the Dakota sandstone although undoubtedly the water-bearing beds of this formation extend under the county and would yield water supplies for deep pump wells.

SMITH COUNTY.

Smith County extends north from North Fork of Solomon River, in the north-central portion of the State. The north half of the county is covered by Tertiary deposits, under which the Niobrara formations appear to the south, Benton shales being exposed in the southeast corner of the county. The formations dip gently to the north. The depth to the Dakota sandstone is from 300 to 500 feet in the southeast portion of the county, and the amount gradually increases north to 800 feet in the highest lands of the northwest corner of the county.

The principal water supplies are obtained from wells of moderate depth in the Tertiary and in alluvial deposits. Some deeper wells obtain small amounts of water in the Niobrara and Benton formations, but usually in these the waters are of bad quality or scanty supply. Several deep borings have been sunk. One at Smith Center, 600 feet deep, was all in shale, not being quite deep enough to reach the Dakota sandstone. Considerable water was found at a depth of 590 feet, which rose to within 390 feet of the surface, but was too salty to be of use. Apparently it was derived from the salty sandstones and shales which usually occur under the Benton shales. Twelve miles southeast of Smith Center, T. 5, R. 12, sec. 5, a well 540 feet deep passed through a thick body of dark shales into 5 feet of sandstone containing a large volume of water, which rose to within 140 feet of the surface, but is reported as being too salty for use. Near Cedarville a well 400 feet or more in depth failed to reach the bottom of the shale. It is unfortunate that no well has been sunk sufficiently deep to test thoroughly the Dakota sandstone waters in this county, for although they would not afford a flow, doubtless they would prove to be of better quality in the lower portion of the formation, and, having a large volume and considerable head, would prove an important source of supply for deep pump wells.

STEVENS COUNTY.

Stevens County lies in the big bend of Cimarron River near the southwest corner of the State. Its surface is heavily covered by Tertiary deposits which, to the north, lie on Dakota sandstone, and, to the south, on the Red Beds. The location of the line of division between the two underlying formations is not definitely ascertained.

Most of the water supplies in this county are obtained from wells of moderate depth in Tertiary sands and gravels; possibly, in some cases, the Dakota sandstone has been reached, but nothing is known of its precise depth and relations. Apparently it lies from 200 to 300 feet below the surface, the amount probably being less in Cimarron Valley. Probably, in the underlying Red Beds, the same horizon that yields the saline water in the wells at Richfield, in Morton County, might be found, but no deep wells have yet been sunk.

STANTON COUNTY.

The surface of Stanton County is almost entirely covered by the Tertiary deposits of the High Plains. Along some of the deeper valleys in the western portion of the county the Dakota sandstone is exposed, and it is known to underlie the Tertiary deposits in the region to the east and the south. It has been reached by a 420-foot well at Johnson and by other wells in the vicinity. The water of these

wells is of satisfactory quality and good volume, but its head is sufficient to bring it only to within 150 to 180 feet from the surface. The sandstone is underlain by Red Beds, but these have not been penetrated in this county; doubtless they would be found to contain water and might possibly afford a flow, as at Richfield, Morton County.

STAFFORD COUNTY.

Stafford County lies on the south side of the Great Bend of Arkansas Valley and is mostly a region of high plains. Its entire area is covered by Tertiary and later deposits, but these are underlain by the Dakota sandstone throughout.

Most of the wells in the county are from 20 to 70 feet deep, and obtain their water supplies from the Tertiary or later deposits. Doubtless deeper wells into the Dakota sandstone would yield additional supplies if they were required. The Dakota sandstone is underlain at a moderate depth by the Red Beds, which contain saline waters, and are probably very thick.

THOMAS COUNTY.

In this county the conditions are essentially the same as in Sherman County, but, owing to the slightly diminished altitude of the High Plains and the slight rise to the south of the underlying formations, the Dakota sandstone is probably nearer the surface, its depth being about 1,600 feet in the center of the county, 1,250 feet in the southeast corner, and 2,000 feet in the northwest corner. The deepest well in the county, of which there has been any report, is one which reached a depth of 200 feet at Colby, and obtained from the Tertiary "mortar beds" a satisfactory supply for pumping.

TREGO COUNTY.

Trego County is situated in west-central Kansas and comprises a portion of Smoky Hill Valley. On the higher lands there is a thick layer of Tertiary deposits, and in the valleys there are exposures of the Niobrara formation, which underlies the entire county. This formation attains a thickness of from 200 to 300 feet in the west portion of the county, but thins gradually to the east, owing to the erosion of its upper surface. It is underlain by about 400 feet of Benton formation, which in turn is underlain by the Dakota sandstone, the beds all dipping gently to the north. The sandstone lies about 400 feet below the surface in Smoky Hill Valley, 500 feet below in the lower lands along the east margin of the county, and about 900 feet below in the northwest townships.

No wells that have reached the sandstone are reported, although several have penetrated the overlying formations for several hundred feet. One of these, 3 miles

north of Smoky Hill River, near the west border of the county, is reported to have the following record:

Record of well north of Smoky Hill River, near western border of Trego County, Kans.

Feet.	
0– 40	clay.
40–150	blue shale.
150–190	white chalk, with small water supply.
190–446	blue shale.

A similar well, 3 miles south of the river, has about the same record. In a well 12 miles south-southwest of Wakeeney (T. 14, R. 24, sec. 12), a well 438 feet deep obtains 50 gallons a day of satisfactory water at a depth of 150 feet below the chalk. It is 438 feet deep and stops in black shale of the Benton formation. Many wells in the higher lands in the central portion of the county obtain satisfactory water supplies in the gravels and sands of the Tertiary deposits, but usually fail to find any water in the underlying shale. There is considerable water in the alluvial formations along the bottoms of Smoky Hill and Saline rivers and some other streams.

WALLACE COUNTY.

In Wallace County the High Plains are deeply trenched by the headwaters of branches of Smoky Hill River, the differences in altitude presented in the county being from 3,000 feet in the valley east of Wallace to slightly over 4,000 feet in the higher lands along the State line. The plains are occupied by Tertiary deposits, but in Smoky Hill Valley the underlying Pierre shales are exposed. These shales are probably not over 300 feet thick in the valley east of Wallace, but they thicken to the northwest. It is probable that the combined thickness of the Benton and Niobrara formations in this county is about 1,000 feet, for the Niobrara beds are known to thicken to the west. On this basis, the Dakota sandstone lies at a depth of about 1,100 feet in Smoky Hill Valley, at the eastern margin of the county; 1,500 feet at Sharon Springs; and probably about 2,000 feet in the northwest corner of the county. From the experience of the well at Horace, in the next county south, it is certain that the Dakota sandstone contains a large volume of water. Its head, however, is sufficient to take it only to an altitude of 2,938 feet, and although this increases somewhat to the north, it is still insufficient to afford flows except probably for a few miles in Smoky Hill Valley south and east of Wallace.

The principal water supplies are obtained from the lower portion of the Tertiary deposits and from the alluvial sands and gravels in the larger valleys. A number of attempts have been made to obtain water from the underlying shales; near the town of Wallace wells have been sunk to 400 and to 448 feet, all in shale below the Tertiary deposits, without obtaining much water. A short distance northwest of Wallace a boring 800 feet deep failed to reach the Dakota sandstone.

WASHINGTON COUNTY.

Washington County lies between Republican and Little Blue valleys in the north-central portion of the State. It is in greater part underlain by Dakota sandstone, but in Little Blue Valley, in the southeast corner, the underlying Permian beds appear.

Many of the wells of moderate depth obtain water supplies from the Dakota sandstone. A deep boring in the village of Washington was sunk to a depth of 2,200 feet and obtained no water supply of any consequence, an indication that the Permian shales, limestones, and sandstones, underlying the Dakota sandstone in this region, do not contain water and that there are no prospects for flowing wells.

WICHITA COUNTY.

Wichita County is in west-central Kansas, on the High Plains between Arkansas and Smoky Hill valleys. The surface is heavily covered by Tertiary deposits, probably underlain throughout by the Niobrara formation, and possibly, in the northwest corner of the county, by a small amount of Pierre shale. There are from 300 feet to 400 feet of Niobrara formation and about 400 feet of Benton shale lying on Dakota sandstone, the formations all dipping gently to the northeast. The Dakota sandstone lies from 800 to 1,100 feet below the surface, its depth increasing gradually from southeast to northwest. It contains water, but, as shown by the well at Horace in the adjoining county (Greeley), the head of this water is sufficient to bring it only to within 700 feet of the surface, so that it does not promise to have economic value.

The principal water supplies in the county are obtained from the coarse beds in the lower portions of the Tertiary deposits, at depths of from 100 to 300 feet. In some cases the wells have been bored into the underlying shales, but these yield no water of any consequence.

DEEP WELLS IN EAST AND SOUTH-CENTRAL KANSAS.

Including Clay County.

While there are several deep borings in the portion of Kansas lying east and south of the Dakota sandstone outcrop, between longitudes 96° and 99°, they yield only salt or salt water. The district is underlain by shales, sandstones, and limestones, which to the west, in Sumner, Kingman, and Harper counties, merge into the Red Beds. The principal formations contain vast deposits of salt, which at several localities are extensively worked for the market. The principal source of water supply for the large population in the district is from shallow wells in the alluvial deposits along the valleys. No deep water wells have been reported. A list of deep borings in the region is given on the table, page 286. Logs of deep borings at Anthony, 2,335 feet; Kingman, 1,410 feet; South Hutchinson, 1,307 feet; Lyons, 1,005 feet; Kanopolis, 880 feet; Little River, 964 feet; Sterling, 980 feet; and Wilson, 1,385 feet, are given in Mineral Resources of Kansas for 1898, published by the University geological survey of Kansas in 1899, pages 90–97.

DEEP WELLS AND WELL PROSPECTS IN EASTERN COLORADO.

That portion of Colorado lying east of the Rocky Mountain front is underlain by sedimentary rocks which include several horizons of sandstones that contain water. Nearly all of these descend very rapidly along the Rocky Mountain front on the steep easterly dips, but rise again to the southeast in an anticlinal axis of considerable prominence. It is due to this uplift that the Dakota sandstone, one of the principal water-bearing horizons, is brought within the reach of the well driller in Arkansas Valley, where it affords excellent flows for a number of wells from La Junta to Coolidge. North of Colorado Springs is a very deep basin which appears to reach its culmination near Denver, where it holds a great thickness of sandstones and other rocks of the Laramie and overlying formations. These sandstones are water bearing, and, in South Platte Valley from Denver to Greeley, have, at many localities, yielded artesian waters, which, until they were too vigorously pumped, flowed in moderate volume. A large proportion of the water of Denver is obtained from this source, but now, owing to the large number of wells, most of it has to be pumped to the surface.

ADAMS COUNTY.

This county extends eastward from the north part of Denver into the ridges lying south of Platte Valley. It is underlain by Laramie, Denver, and Arapahoe formations, and, far below, by Dakota sandstone and associated formations.

The sandstones of the Laramie and Fox Hills and Arapahoe formations are water bearing and are the source of supply in the artesian basin in the west portion of the county north of Denver. Apparently the artesian waters in this basin are obtainable only in Platte Valley, although possibly flows may be obtained in some of the valleys to the east. There are numerous deep wells at intervals along the valley from Denver to Brighton, some of which are flowing in satisfactory volume. Other wells near the city have not obtained flows, or have ceased to flow, owing to the general diminution of head, caused by the heavy draft on the waters in the Denver region. Most of the wells obtain their waters, at depths of from 400 to 800 feet, from the coarse sandstones at the base of the Arapahoe formation; the relations of these are shown in Pl. LXIV. A well recently bored at Utah Junction in Argo, 700 feet deep, is reported to have obtained a flow of 100 gallons a minute. The first flow was found at 400 feet, another at 500, and a third at 600, but the large supply is from the bottom. The water is of fine quality.

The sandstones at the top of the Fox Hills and the base of the Laramie formations lie considerably deeper, as shown in Pl. LXV, and this horizon may be expected to

yield flows of larger volume and greater head, for its supplies have not yet been drawn upon to any great extent. The depths average 1,200 to 1,400 feet along the lower valley lands in which flows are obtainable.

ARAPAHOE COUNTY.

This county is a new one, extending east from the southern part of Denver. It is underlain throughout by Laramie and overlying formations. In the sandstones of the Laramie there are waters which, in portions of the district, afford surface flows. Along South Platte Valley about Denver there is a narrow area in which the land is sufficiently low for flowing wells, many of which exist. In the immediate vicinity of Denver there is but little flow, as the waters have been pumped down and their head lost, but farther south, toward Littleton, an abundance of good flowing water is usually available at depths of from 500 to 1,000 feet.

Byers.—In T. 4, R. 61, sec. 20, a few miles south of Byers, there is a well 450 feet deep which has a flow of soft water from a depth of 435 feet. The diameter of the pipe is 1 inch, and the yield is estimated at 2,000 gallons a day. Whether flowing wells can be obtained in other valleys in the eastern part of the county has not been ascertained.

In 1902, at Peoria siding, 6 miles east by south of Byers, a deep boring was made in the Laramie formation for oil or gas without success. A depth of 800 feet was attained through materials reported as follows:

Record of well at Peoria siding, Colo.

Feet.	
80	gravel.
80–420	soft shale.
420	water to 80 feet.
420–500	soft shale.
500–505	hard bed.
505	quicksand, with much water to –10 feet.
505–800	"formation about the same as from 80 to 505. No more water."

BACA COUNTY.

The Dakota sandstone occupies the surface in the greater part of this county, being overlain to the east by the late Tertiary sands and gravels, and to the north in Butte Valley, from Atlanta to beyond Brookfield, by a small thickness of Benton formation. The sandstone contains considerable water which has yielded satisfactory supplies to numerous wells, but the conditions are not favorable for an artesian flow, except possibly in Butte Valley, where there is a shallow trough, in the lower

part of which wells 300 feet deep might be successful, as they are under somewhat similar conditions in the central portion of Prowers County. Only one deep well has been reported in this county, a boring 720 feet deep, east of Corrizo, made by J. A. Stinson, of Springfield, which penetrated deeply into the Red Beds and succeeded in obtaining a moderate volume of mineral water, which rose to within 20 feet of the surface. The entire county is underlain by the Red Beds which probably have a thickness of many hundred feet, and possibly may be found to be underlain by sandstones or limestones of the Carboniferous, which may yield flowing waters of good quality. A favorable place for trying an experiment would be in Cimarron Valley, where probably the Dakota sandstone is nearly, if not quite, cut through to the underlying Morrison shales.

BENT COUNTY.

Bent County is in Arkansas Valley, in southeast Colorado. Its lower lands along the river are at an altitude of 3,700 to 4,000 feet; the upper ones are about 400 feet higher to the north and about 800 feet higher to the south. The southern slopes are deeply incised by the valleys of Purgatory River and of a number of creeks, all cut more or less deeply into the Dakota sandstone, which extends along the river as far west as the town of Las Animas. The ridges to the south are occupied by the Benton formation, and the extreme southeast corner of the county by a small area of the lower beds of the Niobrara. To the north, the northerly dip of the formations and the rise of land carry the Dakota sandstone beneath the surface, which is occupied first by the overlying Benton shales and then by the limestones of the Niobrara.

In Arkansas Valley and northward artesian waters are available and have been developed by a number of deep borings, some of which afford flows of moderate volume and of good quality, which have proved to be of great service for domestic and railroad use. To the south there are waters in springs issuing from the Dakota sandstone, and in a number of shallow wells dug into that formation. To the north the water has insufficient head to afford flowing wells at any great distance up the valley slopes. Nothing is known as to the thickness of the Red Beds, which also underlie the county, separated from the Dakota sandstone by the Morrison shales, nor of the prospects for water in the formations which underlie them. The Red Beds are exposed in considerable area in the southwest corner of the county, owing to local uplift and deep erosion of the streams.

Las Animas.—The railroad well at Las Animas is relatively shallow, obtaining a 20-gallon flow of excellent water from the second sandstone in the Dakota formation at a depth of 330 feet. The following record is reported:

Record of artesian well at Las Animas, Colo.

Feet.	
0– 36	surface materials.
36– 90	shale.
90–195	sandstone.
195–240	shale.
240–333	sandstone; flow at 330 feet.
333–360	shale.

This well begins in the lower part of the Benton shale and reaches the Dakota sandstone at a depth of 90 feet, as the latter formation rises rapidly east of La Junta. The second bed of sandstone in the Dakota formation begins at 230 feet, with the usual intervening mass of shale. (See Pl. LXX.) Other wells in Las Animas have depths of 250 and 267 feet, and flows of 17 and 5 gallons, respectively.

Fort Lyon.—Twelve miles northeast of Las Animas is the well sunk in 1881 by the Government under direction of the Department of Agriculture. It was known as well No. 1, and was located 7 miles northeast of Fort Lyon. It had a depth of 815 feet, but obtained from a depth of 430 feet only a small amount of water, which flowed out at the surface at a rate reported by some authorities as 2 gallons a minute and by others as only 3 gallons an hour. The head was stated to be sufficient to raise the water just 10 feet above the surface of the ground. This boring cost $18,353. Its record is as follows:

Record of boring at Fort Lyon, Colo.

Feet.	
0– 74	sand, gravel, and quicksand.
74– 80	soft blue clay.
80– 86	blue shale.
86–116	gray sandstone.
116–120	dark shales.
120–140	streaked sandstone.
140–150	gray clean grit.
150–180	black sandy shale.
180–190	mottled-gray sandstone.
190–200	mica sandstone.
200–225	mixed sandy shale, light, very soft.
225–250	mixed sandy shale, dark, very soft.
250–275	black variegated shale, very soft.
275–300	mottled-purple shale, soft.
300–320	gray shale, soft.
320–340	mottled shales, soft.
340–344	black shales, soft.
344–355	gray sandstone.
355–368	coarse sandstone.
368–382	gray sandstone.

Feet.	
382–386	greenish clay.
386–396	marl.
396–439	green and red sandstone, soft.
439–445	dark-red shale.
445–450	rusty-gray sandstone.
450–460	green shale.
460–500	green and red shale, soft.
500–520	gray sandstone.
520–550	compact gray shale.
550–570	hard shales.
570–590	fine red sandstone.
590–630	coarse red sandstone.
630–650	hard red sandstone; some gypsum.
650–662	spotted sandstone.
662–703	mixed sandstones.
703–751	red sandstone, massive.
751–783	soft red sandstone.
783–815	spotted red sandstone.

The boring begins low down in the Graneros shale of the Benton group and passes through various members of the Dakota sandstone series into the Red Beds. It was located on the axis of the anticline extending from the south. It is difficult to understand why a large supply of water was not obtained from the various sandstones which were reported.

A well sunk in 1903, 6 miles west of the Government well (sec. 36, T. 21, R. 52), has a depth of 720 feet. A satisfactory supply of water was found in sandstone extending from 452 to 474 feet, but as it only rose to within 300 feet of the surface the well is regarded as a failure. The following record was furnished by the owner, O. G. Scott:

Record of well 8 miles NNE. of Las Animas, Colo.

Feet.	
0– 25	loam and sandstone.
25–452	dark shale.
452–475	Dakota sandstone; water to —300 feet.
474–596	dry sandstone.
596–656	dark shale.
656–700	gray shale with "bowlders" (?).
700–710	"talc."
710–720	gray shale lying on red shale.

The well began in the Niobrara formation and passed through the formations of the Benton group to the top of the Dakota sandstone at 452 feet. The sandstone is reported to be 144 feet thick, underlain by 124 feet of Morrison shales to the top of the Red Beds at 720 feet.

Caddoa.—At Caddoa, a station of the Atchison, Topeka and Santa Fe Railway, on the river bank, a well has been bored to a depth of 582 feet. The upper bed of the Dakota sandstone outcrops extensively in this vicinity and the well reaches the lower part of the lower sandstone of the formation. It is 10 miles southeast of the Government well just described. The water obtained at 285 feet was hard, so that wells now in use obtain their supply from the upper bed at a depth of 70 feet, where the water is relatively soft. The following record is given:

Record of well at Caddoa, Colo.

Feet.	
0– 29	surface materials.
29– 33	yellow clay.
33– 66	sandstone; soft water at 50 feet.
66–175	shale.
175–285	sandstone; hard water.
285–300	variegated shale; water to —75.
300–345	sandstone; water to —60.
345–384	shale.
384–425	white sandstone.
425–492	red shale and sand.
492–582	white slate.

BOULDER COUNTY.

The western portion of this county is in the high ridges of the Rocky Mountain Front Range; the eastern half comprises foothills and plains underlain by sedimentary rocks from Carboniferous to Fox Hills. All the lower formations in the foothills dip steeply to the east, but the dip rapidly diminishes away from the mountains, and in the eastern portion of the county is almost horizontal with some local undulations. The steep dips, however, rapidly carry the Dakota sandstone to a great depth, so that it is beyond the reach of practicable well boring in the eastern portion of the county. The overlying Pierre shale is 2,500 feet thick, and under this are 1,000 feet of Niobrara and Benton deposits.

In the oil field east and northeast of the town of Boulder numerous wells, which have been sunk deep into the Pierre shale in order to obtain oil from the sandstones in that formation, obtain considerable water from the same source. It is claimed that a well bored about ten years ago, at Boulder, passed through more than 1,000 feet of hard sandstones and obtained water, which flowed over the top of the pipe 20 feet above the surface. It contained a large amount of sulphate of soda.

A well at Hygiene is reputed to have the following record:

Record of well at Hygiene, Colo.

Feet.	
0– 17	surface and soapstone.
17– 50	coarse sandstone.
50–130	slate.

Feet.	
130–160	fine white sandstone.
160–190	shale.
190–198	sandstone.
198–200	fire clay.
200–204	coal (supposed).
204–284	sandstone, oil-bearing.
284–416	shale.
416–442	sandstone.
442–444	fire clay.
444–524	sandstone and coal.
524–589	sandstone.
589–591	fire clay.
591–605	coal.
605–905	sandstone, bearing oil.

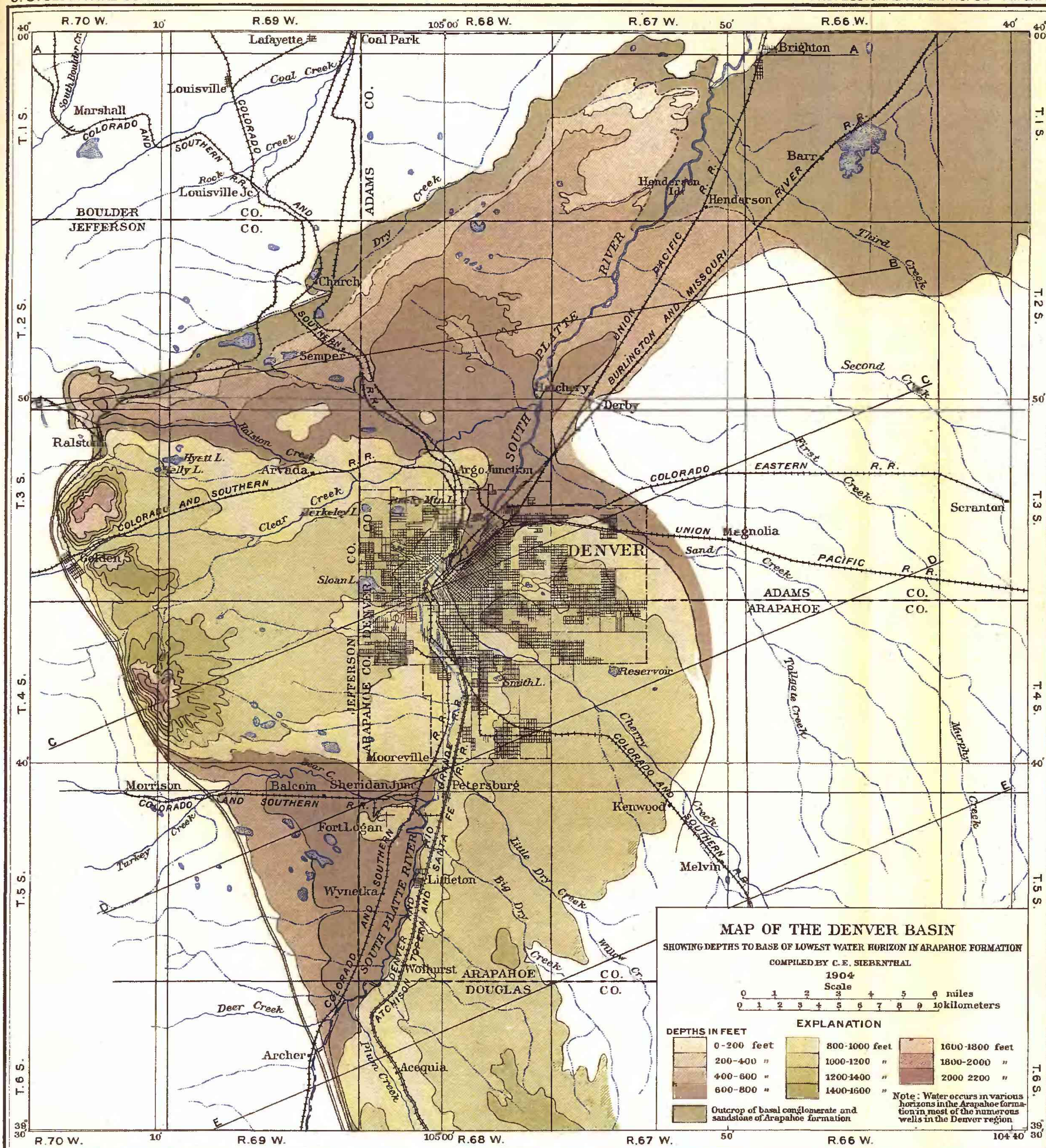
Water flowed at 675 feet, but soon ceased.

CHEYENNE COUNTY.

This county comprises a portion of the basin of Big Sandy and of the high plains at the head of Smoky Hill River. All of the higher lands are capped by late Tertiary deposits, which, in the larger depressions, are seen to be underlain by Pierre shale to the north and west and by Niobrara formation to the southeast. The region is underlain by Dakota sandstone at moderately great depth, 1,200 to 1,500 feet in the southern portion of the county, increasing gradually north, owing to the gentle northerly dip of the beds to probably 2,300 feet or more near the northern margin.

As shown by wells within the county and in adjoining districts, flowing waters are not to be expected from the Dakota sandstone in Cheyenne County. Two deep borings have been made.

Cheyenne Wells.—The well at Cheyenne was bored under the direction of the Department of Agriculture over twenty years ago, with an appropriation provided by a special act of Congress. No official data have been obtained regarding its depth, record, and results, except the statement that it was unsuccessful. As considerable gas was encountered in its lower portion a local company was organized to develop a gas supply by a second boring, which reached a depth of 1,700 feet and was then abandoned, because the gas was found to be of insufficient quantity. Through the kindness of Mr. McLane, of Cheyenne Wells, the following record was obtained:


MAP OF THE DENVER BASIN
SHOWING DEPTHS TO BASE OF LOWEST WATER HORIZON IN ARAPAHOE FORMATION
COMPILED BY C. E. SIEBENTHAL
1904
Scale
0 1 2 3 4 5 6 miles
0 1 2 3 4 5 6 7 8 9 10 kilometers
EXPLANATION
DEPTHS IN FEET
0-200 feet
200-400 "
400-600 "
600-800 "
800-1000 feet
1000-1200 "
1200-1400 "
1400-1600 "
1600-1800 feet
1800-2000 "
2000-2200 "
Outcrop of basal conglomerate and sandstone of Arapahoe formation
Note: Water occurs in various horizons in the Arapahoe formation in most of the numerous wells in the Denver region.
R.70 W.
R.69 W.
R.68 W.
R.67 W.
R.66 W.
T.1 S.
T.2 S.
T.3 S.
T.4 S.
T.5 S.
T.6 S.
40° 00'
50'
40'
39° 30'
10'
105° 00'
104° 40'
Lafayette
Coal Park
Brighton
Louisville
Marshall
Louisville Jc.
Coal Creek
South Boulder Cr.
COLORADO AND SOUTHERN
BOULDER CO.
JEFFERSON CO.
ADAMS CO.
Dry Creek
Barr
Henderson
Henderson Id.
Third Creek
Church
Semper
SOUTH PLATTE RIVER
UNION PACIFIC
BURLINGTON AND MISSOURI RIVER R.R.
Second Creek
Derby
Ralston
Ralston Creek
Hyatt L.
Kelly L.
Arvada
Argo Junction
First Creek
COLORADO EASTERN R.R.
Scranton
Golden
Clear Creek
Berkeley L.
Rocky Mtn. L.
DENVER
UNION PACIFIC R.R.
Magnolia
Sand Creek
Sloan L.
DENVER CO.
ADAMS CO.
ARAPAHOE CO.
Reservoir
Smith L.
Toll Gate Creek
Cherry Creek
Murphy Creek
Mooreville
Petersburg
Morrison
Balcom
Sheridan Junc.
Bear C.
Turkey Creek
Fort Logan
Kenwood
Melvin
Littleton
Wynetka
Little Dry Creek
Big Dry Creek
Willow Cr.
Wolhurst
ARAPAHOE CO.
DOUGLAS CO.
Deer Creek
Archer
Acequia
Plum Creek
ATCHISON TOPEKA AND SANTA FE
DENVER AND RIO GRANDE R.R.
A
B
C
D
E

Record of boring at Cheyenne Wells, Colo.

Feet.	
0- 30	clay.
30- 60	magnesia, chalk, rock.
60- 110	sandy gravelly clay.
110- 130	white sandy clay.
130- 145	soft white sand.
145- 185	white sandy clay.
185- 215	soft white sand.
215- 534	soft, black shale; at 257 feet, good water.
534-1, 260	white sandy shale with gas.
1, 260-1, 330	chalk rock with brackish water.
1, 330-1, 360	fine sand.
1, 360-1, 460	soft black shale.
1, 460-1, 510	soft white sand or limestone.
1, 510-1, 700	black shale.
1, 700-1, 770	(not given, but thought to be shale.)

In this boring a large supply of excellent water was obtained at a depth of 257 feet at the base of the Tertiary formations, but did not rise far in the casing. The record appears to indicate that the Tertiary formations extend to 215 feet, but probably they really extend to 257 or 260 feet, where the black shale begins in the two shallow wells now in use at the railroad tank. The upper shales are undoubtedly Pierre and the chalk rock from 1,260 to 1,330 is a portion of the Niobrara. The supposed limestone extending from 1,460 to 1,510 feet is probably the limestone at the base of the Niobrara, and, if this is the case, the boring stopped in the top of the shales about 150 feet above the Dakota sandstone. It was intended that the Government boring should be continued to 2,000 feet, but with the small-sized casing used in its lower portion the bit could not progress below about 1,770 feet. It is unfortunate that the boring was not sunk to the depth intended, as it had excellent prospects for reaching the Dakota sandstone and obtaining water for a pump well. It would thus have thrown most important light on the head of the water and the prospects in adjoining regions.

Kit Carson.—A well bored at Kit Carson in 1870 by the Kansas Pacific Railroad, which attained a depth stated by various authorities as 1,300, 1,460, and 1,500 feet, was also unsuccessful. Doubtless it penetrated practically the same beds as those below 300 feet in the Cheyenne Wells boring.

DENVER COUNTY.

The city and county of Denver are underlain by the Denver formation, which is overlain along Platte Valley by alluvial deposits. The Arapahoe and Laramie

formations lie at no great depth, and their sandstones contain a large volume of water which has been drawn on extensively by many establishments in the city. Formerly there were numerous flowing wells, the area of flow comprising all the lower lands extending to a moderate width on either side of South Platte River, but owing to the large number of wells and the vigorous pumping the head has been lowered so that now flows are obtainable only in the outskirts of the city. The underground water conditions in Denver have been described in detail by Eldridge,[a] and the following statements are, for the most part, condensed from his report:

The first deep boring in Denver was a well on the highlands east of the town sunk to a depth of 795 feet, in 1871 or 1874, but although water was found the well did not prove satisfactory. In 1883 a boring for coal near St. Luke's Hospital, in North Denver, encountered a large flow of water of fine quality, a discovery which led to active development of the underground waters. Several hundred wells have since been sunk in the city, mostly to depths from 400 to 1,100 feet. The water horizons are as follows:

(1) The upper sandstones of the Fox Hills formation, which appear not to have been reached even by the deepest wells. These sandstones are mostly fine grained, have a thickness of several hundred feet, and, as they are underlain by several thousand feet of clay and shale, are the lowest available water horizon in the Denver basin.

(2) The sandstones in the Laramie formation, which are coarser grained and more open in texture than the Fox Hills sandstones, occur in thick beds, mostly in the lower portion of the series. The lowest Laramie and top Fox Hills sandstones together have a thickness of about 200 feet and contain the largest volume of water. The top of this horizon is probably reached by several of the deepest wells, at depths of from 1,350 to 1,500 feet, but the water is much mineralized. The depth to this horizon is shown in Pl. LXV. There are other higher sandstones, which contain more or less water, in the lower part of the Laramie formation, within the next 50 feet above the basal bed.

(3) The Arapahoe formation, which supplies the greater part of the water in the basin. There is a heavy bed of conglomerate and sandstone at the base of the formation, varying in thickness from 25 to 200 feet or more, which appears to be continuous under a wide area. This member is coarse grained and very pervious, and furnishes water to many wells from 600 to 700 feet deep. Its depth is shown in Pl. LXIV. Higher in the formation are local bodies of sandstone and sandy shales containing more or less water and supplying numerous wells from 300 to 600 feet deep.

(4) The Denver formation. Some of the shallower wells which formerly flowed

[a] Eldridge, G. H., Geology of the Denver Basin: Mon. U. S. Geol. Survey, vol. 27, 1896, pp. 401-465.

appear to draw their supplies from the irregular beds of sands, sandstones, and conglomerates in this formation.

Most of these water-bearing beds outcrop in a succession of belts of varying widths, lying west of Denver and trending north and south parallel to the Rocky Mountain front. The beds rise gradually to the east as well as to the west, Denver lying across the axis of a broad syncline. The outcrop of Arapahoe formation partly circles about Denver to the southwest, west, northwest, and north, in a zone which is several miles wide for the greater part of its course, especially to the north and northwest. It is in these outcrops that most of the water passes underground, and, as much of the area is somewhat higher than the lower portions of Platte Valley about Denver, the waters have a moderate head in the lowlands. The structural relations are shown in Pl. LXVI. It is estimated by Eldridge that from Platte Canyon to Boulder Creek the outcrop of the Fox Hills and Laramie sandstones may absorb nearly 200,000,000 gallons a year, and the Arapahoe outcrop nearly 17,000,000,000 gallons, based on the calculation that 6 inches of the annual rainfall passes underground, this being the amount remaining after deducting evaporation and amount lost by run-off for the whole area. With diminished volume of water in the beds due to lowering of the water plane by numerous wells, we might expect that the beds would have greater capacity for receiving water at their outcrop and so diminish the run-off. Probably, also, considerable water passes underground without being subjected to as much evaporation as is the case with water flowing over the surface.

The supply of underground water in the Denver basin is far short of the amount of water that it appears should be available. This is probably due mainly to the very slow circulation in the rocks and to the wide-spread influence of leakage from springs in the lower lands eastward. It was estimated by Eldridge that in 1890 the daily yield of wells in Denver and suburbs was about 1,500,000 gallons, or about half as much as in 1886, and since that time the volume pumped has diminished greatly. He predicts that the permanent supply will probably not exceed about 1,350,000 gallons a day, and that if all pumping were discontinued forty years would be required before the volume of water originally available would be restored by underground percolation in the strata. The water level now is from 50 to 200 feet below the surface in most wells in the city. The yield varies from 5 to 200 gallons a minute, depending upon depth, diameter of well, and power of pumps. One well is reported to have flowed 400 gallons a minute.

Analyses of representative deep-well waters in Denver, Colo. [a]

[Grains per gallon.]

	Anderson well, Colfax Avenue Bridge, 375 feet.	Windsor well, Eighteenth and Larimer, 342 feet.	Windsor Hotel, lower flow, 515 feet.	Court-house well, 910 feet.
Calcium sulphate	0.87	0.85	0.92	0.36
Calcium carbonate				1.64
Sodium carbonate	8.22	7.93	8.48	15.83
Sodium sulphate	.44	.44	.44	
Sodium chloride				14.04
Magnesium chloride	.10	.10	.07	
Magnesium carbonate				.32
Ferrous carbonate	.03	.03	.03	.06
Silica	.69	.61	.76	.63
Solid residue	10.41	10.03	10.76	33.01

[a] Eldridge, G. H., loc. cit., pp. 462, 463. Analyses by R. Chauvenet.

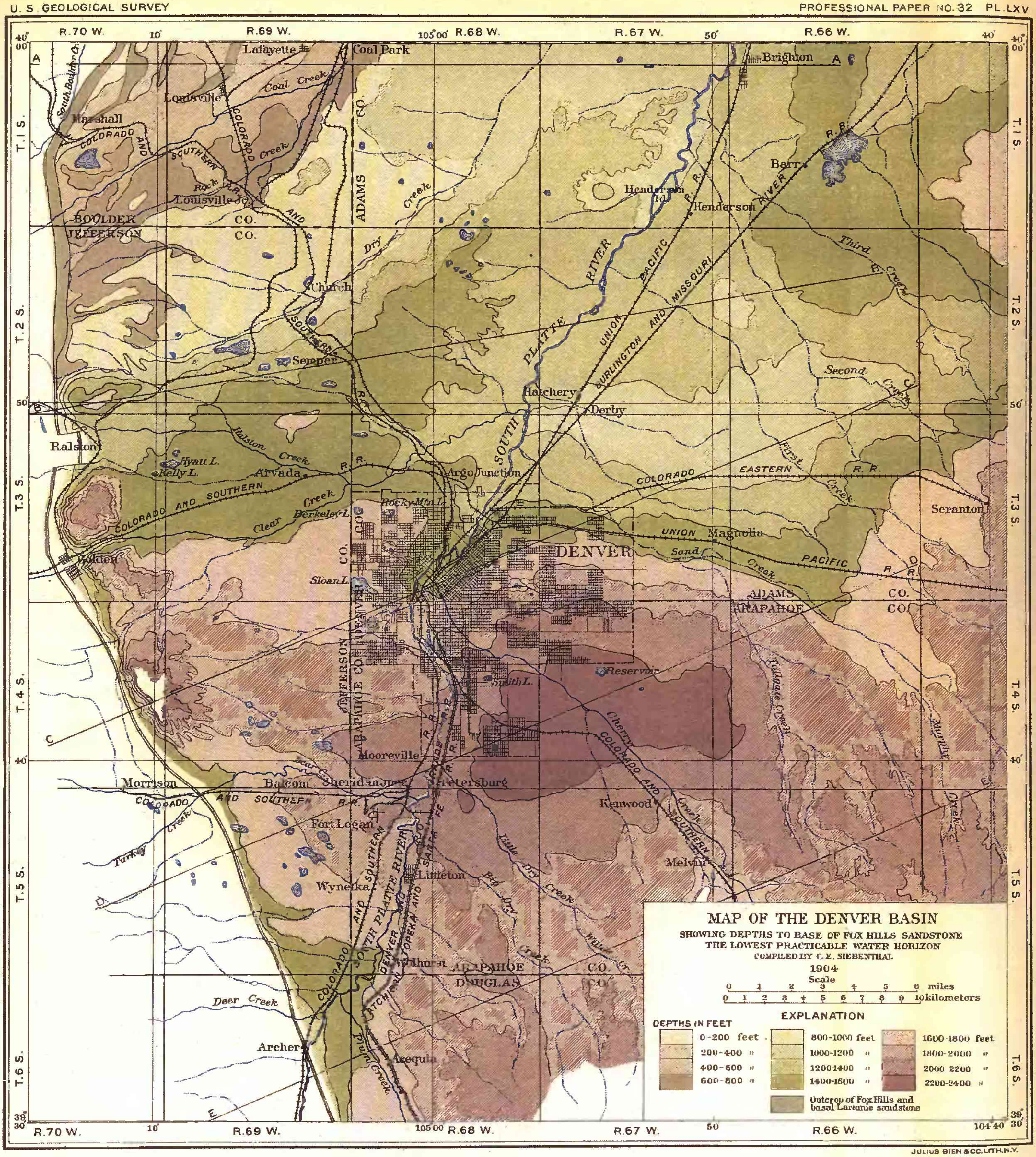
DOUGLAS COUNTY.

Douglas County comprises a portion of the Rocky Mountain Front Range and, to the east, a region of buttes and ridges in the northern portion of the Arkansas divide. In the foothills at the base of the Rocky Mountain Front Range there is a great succession of sedimentary beds lying on the granite, from Ordovician and possibly Cambrian to Tertiary in age, at first steeply tilted, but to the east lying nearly level. Some of the younger formations overlap westward and lie directly against the granite, and some of the older formations also present complicated relations, owing to overlaps among themselves. Owing to the steep dip, the Dakota sandstone is soon carried far beneath the surface, so that it will not be a source of water supply. In the eastern part of the county there is a heavy capping of the Monument Creek beds, which are underlain by the Denver, Arapahoe, and Laramie formations. In the two latter there are probably the same water supplies that yield the flows in the Denver basin, but the land is too high for flowing wells, except in the deeper portion of Platte and Plum valleys in the northern part of the county, where there are several flowing wells from 500 to 1,000 feet in depth.

Sedalia.—Several borings have been made at this place; one to a depth of 1,440 feet obtained water in abundance, but would not flow.

Castle Rock.—At this place a well 1,700 feet deep was reported a failure.

Larkspur.—A well 560 feet deep at Larkspur obtained water in sandstones, but no flow.



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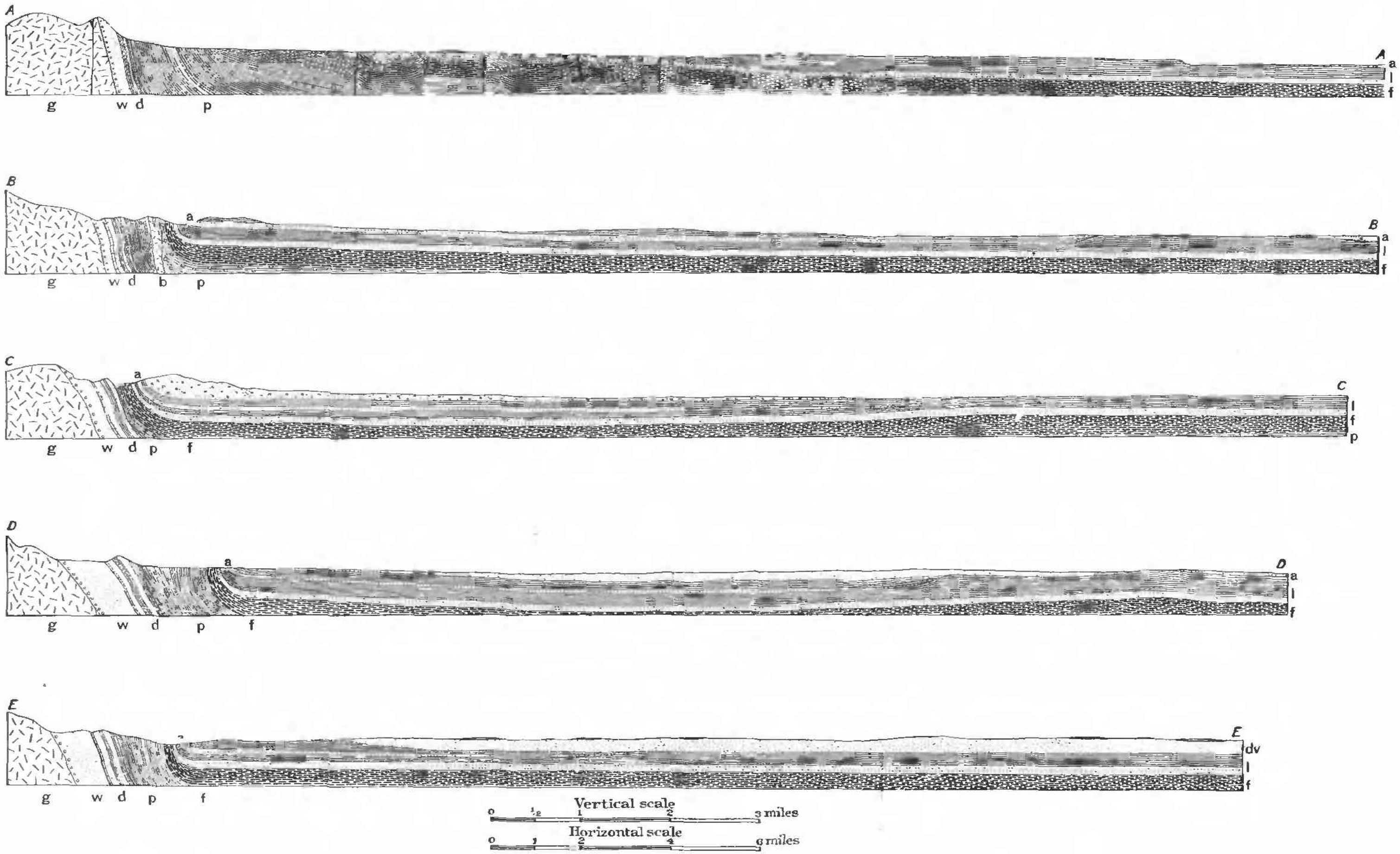


CROSS SECTIONS OF THE DENVER BASIN, ALONG FIVE LINES INDICATED ON PLATES LXIV AND LXV.

Legend: g, granite; w, Wyoming; d, Dakota and associated formations; p, Pierre shale; f, Fox Hills formation; l, Laramie formation; a, Arapahoe formation; dv, Denver formation; b, basalt.

These borings were all in the Laramie or overlying formations, and appear to indicate that there is very poor prospect for obtaining an artesian flow in any portion of the county, except near its extreme north margin.

ELBERT COUNTY.

Elbert County lies mostly on the elevated district southeast of Denver. It is underlain mostly by the Laramie sandstones and shales, which to the west are capped by the Monument Creek formation and to the south by late Tertiary deposits. But little is known regarding its underground geology or water resources; apparently it lies too high for artesian flows of any volume from either the Laramie or the Dakota sandstones, the latter probably lying 3,000 feet or more below the surface.

EL PASO COUNTY.

This county comprises a portion of the Rocky Mountain Front Range, including Pikes Peak and a district of plains to the east. These plains are underlain by sedimentary rocks from Cambrian to Tertiary in age, dipping to the east, steeply along the mountain front, but with gentle inclinations under most of the district.

The prospects for underground waters are somewhat uncertain. The Dakota sandstone doubtless is water bearing, but pitches down very steeply in the foothills of the Front Range and lies so deep under the central and eastern portions of the county that very deep borings would be required to reach it. The Laramie sandstones and shales, which cover nearly the entire east half of the county, are water bearing, but they lie on high lands in such a way that they do not offer much prospect for flowing wells; still, their capability in this regard has not been adequately tested. A deep boring at Calhan was on land so high that flowing water could hardly have been expected. Deep borings at Colorado City penetrated the steeply dipping beds of the foothills, but did not prove successful. A 1,250-foot boring at Franceville and a 765-foot boring at Monument were all in shale and found no water.

Colorado City.—Two deep wells were bored at this place by a local oil company in 1894 and 1895. The first was located on the NW. ¼ of the NE. ¼ sec. 2, T. 14, R. 67. It reached a depth of 2,020 feet, where operations were stopped by the collapse of a string of casing. Below the first 30 feet of surficial materials the formation penetrated was Pierre black shale, except at 1,247 feet, where a 5-foot bed as hard as granite, which yielded some gas, was reported. Boring No. 2 was located on the SW. ¼ of the NE. ¼ sec. 2, T. 14, R. 67 W., and had a depth of 1,300 feet, entirely in shale below the first 60 feet. Both holes are now full of water.

Calhan.—A boring at Calhan, sunk to a depth of 566 feet, obtained a small amount of water at 90 feet. Coal-bearing beds were reported at 250 feet and lower, but the beds were thin and the coal of poor quality.

The following record was reported by the Chicago, Rock Island and Pacific Railroad Company:

Record of boring at Calhan, Colo.

Feet.	
0 – 28	sand.
28 – 38	sandstone.
38 – 63	dark sandy shale.
63 –142	clay and sandy shale grading into soft sandstone.
142 –255	"soapstone," with thin layer of coal at 232 feet.
255 –306	shale.
306 –314	sandy limestone.
314 –323	sandy shale with coaly layers.
323 –324	"false coal."
324 –325½	fire clay.
325½–329	dark shale.
329 –336½	sandy shale.
336½–337	"false coal."
337 –361	sandy shale, micaceous ½-inch coal layer, at 360 feet.
361 –416	"soapstone."
416 –432	micaceous sandy shale.
432 –435	"false coal and poor coal."
435 –480½	shale.
480½–484½	sandy false coal.
484½–487	poor coal.
487 –546	micaceous sandy clay with some shale.
546 –551	sandy false coal.
551 –556½	shale.
556½–566	shale and sandy shale.

Doubtless this boring was entirely in the Laramie formation.

FREMONT COUNTY.

This county includes an embayment into the Rocky Mountain Front Range occupied by a basin filled with a thick series of sedimentary strata, including all the formations from Ordovician high into the Laramie. The deepest portion of this basin lies a few miles southwest of Florence, the beds dipping gently into it from the east and rising steeply to the north, the west, and the southwest, in part abutting against the crystalline rocks of the Wet Mountains.

Florence.—In the vicinity of Florence numerous wells have been sunk for oil, which is obtained from hard shales in the Pierre formation. These beds are local deposits of the great mass of barren clays of which the formation consists in the wide area eastward.

Some of the oil wells in the vicinity of Florence encounter more or less water

at various depths down to about 1,150 feet. The water is strongly mineralized and often in large volume. A typical record is reported as follows:

Record of well in sec. 23, T. 18, R. 78, near Florence, Colo.

Feet.	
0– 20	surface materials.
260– 280	shale and sandy shale; flow of water.
280– 650	shale, with layers of limestone.
650– 695	limestone.
695– 699	sandstone.
699– 722	white sandstone; second flow.
722–1,130	shales, limestone, and sandstone; very large flow.
1,000–1,400	shales and sandstone.
1,400–1,600	soft shale.

One of the wells in the oil field was sunk 3,021½ feet, entirely in shale except for 10 feet of dark rock at a depth of 2,680 feet. It encountered no water.

A well about 1,000 feet deep 10 miles southeast of Florence near the Pueblo County line has a flow of about 600 gallons from Dakota sandstone. It begins on top of the Niobrara at an altitude of 5,500 feet. This well indicates that flowing wells are to be expected in the east-central and southeastern parts of the county.

In 1880 a 4½-inch boring was made on Coal Creek, near Canyon, to a depth of 1,278 feet, prospecting for coal. No coal was found, but at 350 feet a small supply of water was encountered, which rose to within 15 feet of the surface. Three miles east of Canyon a flowing well 900 feet deep is sunk in Laramie beds.

HUERFANO COUNTY.

The conditions in eastern Huerfano County present great diversity both in geologic succession and topographic configuration. To the south are the Spanish Peaks rising to an altitude of over 13,000 feet, to the north the high Greenhorn Mountain of Archean rocks, and to the east a wide undulating region of plains traversed by shallow valleys and some deep canyons, the lower altitudes mostly averaging from 5,500 to 6,000 feet. The Dakota sandstone underlies all of the area except on Greenhorn Mountain and in the deeper portion of the Apishapa Canyon, where underlying beds are revealed. It is upturned against the slope of the mountain, but elsewhere lies nearly horizontal, although brought to the surface by a gentle uplift in the eastern portion of the county. In the slopes of Spanish Peaks it lies at a very great depth under an immense thickness of shales and sandstones. Under the plains to the north and east, however, it may be reached by ordinary borings.

Rouse junction.—Only one boring in the county has been sufficiently deep to penetrate the Dakota sandstone; this is at Rouse Junction, on the Denver and Rio Grande Railroad southeast of Walsenberg, where the railroad company made a boring to a depth of 2,058 feet, but did not succeed in finding an adequate water supply. A small amount of fresh water appeared at 700 and 1,760 feet, and of salt water at 890 feet. These waters rose for some distance, but the greatest height was more than 200 feet below the surface. The following record was furnished by the railroad company:

Record of well at Rouse Junction, Colo.

Feet.	
20– 800	shale.
800	coarse white sandstone.
850	black shale; bad water.
870	hard white sandstone.
930	hard rock (reported as granite).
940	hard white sandstone.
950	black shales.
960	hard white sandstone.
1,010	slate.
1,020	shale.
1,030	hard white sandstone and quicksand.
1,140	hard white sandstone.
1,150	coarse white sand with a little water.
1,160	coarse red sandstone.
1,190	coarse green sandstone.
1,210	pink slate and sand and "granite."
1,290	red sand.
1,320	pink slate.
1,350	drab sand, with shells.
1,380	fine, hard, white sand.
1,390	fine drab sand and white hard clay.
1,450	red flinty rock.
1,500	fine gray sand, very hard.
1,540	red sand.
1,960	hard white sand.
2,058	red, fine, hard sand.

This boring was begun near the base of the Pierre shale and the shales reported to a depth of 800 feet are mainly Niobrara and possibly the upper shale of the Benton. The Dakota sandstone appears to have been reached at 1,140 feet and to have continued to not far below 1,500 feet. The lower 300 feet or more were in the Red Beds and it was from them that the fresh water at 1,760 feet was obtained. The salt water at 890 feet was in sandstones of the the Benton group.

Apparently the Dakota sandstone yielded no water at all, a most discouraging indication, for doubtless its capabilities were thoroughly tested. The explanation probably is that, owing to the extensive outcrops of the Dakota formation north and east, no head is possessed by whatever water may be in the sandstone. It is also likely that the many dikes which penetrate the formations round about Rouse Junction, particularly to the west, have cut off the underground flow.

Walsenberg.—At Walsenberg an unsuccessful boring for gas was made some time ago. It was entirely in the Pierre shale, which there has a thickness of about 1,700 feet. Seven miles below the town, on Cuchara River, an 800-foot well yields sulphur water to a pump.

It is probable that the Dakota sandstone may yield water in the northern portion of the county, between Greenhorn Mountain and the Denver and Rio Grande Railroad, at depths varying from 600 to 2,200 feet, increasing to the west. At Cuchara and Apache sidings the Dakota sandstone water horizon lies about 900 feet below the surface, and at Huerfano siding, 550 feet.

JEFFERSON COUNTY.

Jefferson County extends along the Front Range of the Rocky Mountains and is underlain mainly by granites and schists; west of Denver it comprises a small area of plains and foothills underlain by sedimentary rocks, which dip very steeply to the east in the foothills at the base of the mountains, but soon incline more gently and become nearly level in the vicinity of Denver. The steep dip, however, in the first few miles carries all of the older sedimentary rocks far beneath the surface and under the western margin of the basin of the Laramie and overlying beds, which contain the water tapped by the numerous wells in Platte Valley in the Denver region. The margin of the Denver artesian basin lies for the most part a short distance east of the eastern boundary of the county, extending into it in Platte Valley near the mouth of Deer Creek and continuing in it south to the mouth of the canyon.

KIOWA COUNTY.

This county lies on the sloping plains north of Arkansas Valley and presents considerable diversity of configuration and altitude. Portions of the old high plains are found in the northwest and northeast portions of the county, occupied by a moderate thickness of late Tertiary gravels and sands. The principal formation at or near the surface is the Niobrara, which has a thickness of from 500 to 650 feet, as nearly as can be estimated. To the northwest it is overlain by a small thickness of Pierre shale and underlain by the usual succession of Benton formation, Dakota sandstone, Morrison shales, and Red Beds. The formations dip gently to the north, with some minor undulations which are not as yet clearly

determined. The Dakota sandstone undoubtedly contains artesian waters, but these have been reached at only one point, Sheridan Lake, where they did not yield a flow. The head of the artesian waters is low in the adjoining counties on the south, and, unless possibly in the lower part of Sandy Creek Valley, no flows should be expected. The depths to water are shown on the map (Pl. LXIX), varying from about 500 feet along the south-central margin of the county and increasing to 1,500 feet north of Galatea and in the higher lands north of Sheridan Lake.

Sheridan Lake.—At Sheridan Lake a local company sunk a well to a depth of 1,280 feet, and found considerable water, but without sufficient head to afford a surface flow. The boring is now abandoned. The lowest water in any appreciable volume was at a depth of 1,200 feet in a dark-colored sandstone, from which it rose to within 40 or 50 feet of the surface. No record is obtainable, but as the boring begins in the upper portion of the Niobrara chalk doubtless the sandstone at 1,200 feet above referred to is Dakota.

KIT CARSON COUNTY.

This county is on the High Plains of eastern Colorado, at the headwaters of Republican River and Big Sandy Creek. These plains are capped by a thick mantle of late Tertiary deposits, and, although traversed by many valleys, these all appear to be too shallow to cut through to the underlying Pierre shale. The county is probably underlain by the Dakota sandstone, with its usual water supply, but the land is too high for artesian flows. In the eastern part of the county the sandstone probably lies about 2,000 feet below the surface and the depth gradually increases to at least 3,000 feet in the northwest townships.

Burlington.—The only deep well in the county is at Burlington, which obtains a small supply of good water at a depth of 600 feet, apparently from a local sandstone bed in the Pierre shale.

LARIMER COUNTY.

The Rocky Mountain Front Range rises in the east portion of this county, leaving only a small area underlain by sedimentary rocks which dip steeply in the foothills, but incline more gently east of them. The entire succession of rocks is presented from Carboniferous to Fox Hills and possibly Laramie. The water-bearing horizons in this series are the Dakota, and probably the Fox Hills, sandstone, but the latter, being near the surface, would furnish supplies for shallow wells only.

Owing to the steep dip of the strata the Dakota sandstone is rapidly carried to a great depth, and was not even reached by a boring at Loveland, 2,465 feet deep. At a depth of 1,365 feet this boring found a thin layer of sandstone, which afforded a flow of about 1 gallon a minute. A small amount of salt water was reported at

a depth of 500 feet, but nothing except shale from 1,365 to 2,465 feet. Judging from the thickness of the Pierre shale, which amounts to 2,500 feet near Longmont, the Dakota sandstone lies about 3,000 feet below the surface at Loveland.

At Stout a well sunk by the Union Pacific Railroad Company some years ago reached a depth of 1,225 feet, almost entirely in sandstone. It is reported that at 922 feet water was found which flowed 40 gallons an hour, and that the flow increased until, at 1,000 feet, it amounted to 80 gallons an hour and the pressure was sufficient to raise the water 30 feet or more above the surface. The water carried 150 grains of solids to the gallon, so that it was unfit for boiler use.

LAS ANIMAS COUNTY.

This county extends from the summit of the Culebra Range of the Rocky Mountains far east over the Great Plains. In its west portion there are steep mountain slopes and high plateaus traversed by numerous deep canyons, notably those of Purgatory and Apishapa rivers. Along the southern portion of the county are high mesas capped by sheets of volcanic rock. Section 9 (Pl. XI), which passes through the southern portion of the county, shows the principal features of the geologic structure. On the arches in the Rocky Mountain uplift all the sedimentary beds are steeply tilted, rising in succession until the granites and schists are revealed in the central portion of the mountains. A short distance to the east there is a basin holding a great thickness of nearly horizontal sedimentary rocks, below the top of which the Dakota sandstone lies at a depth of more than 4,000 feet. With the diminishing altitude of the country to the east and a slight upward arching of the beds the Dakota sandstone finally comes to the surface and outcrops extensively in the eastern part of the county. In the Mesa de Maya and some associated volcanic areas it is overlain by lava, in places separated by a thin mass of Benton formations. In the canyons of the Purgatory and Chaquaqua, and in some other minor canyons, it is cut through and the underlying Morrison formation and the Red Beds are revealed. In the western portion of the county, where the Dakota sandstone is overlain by the great series of later Cretaceous and other rocks, it lies too deep for well boring. At the top of the Pierre shale its depth is about 2,600 feet, and gradually decreases to the east and north as the intervening formations come nearer to the surface.

Trinidad.—At this town a well has been sunk which reaches the Dakota sandstone at 2,585 feet and at 2,595 obtains an abundant supply of excellent water, which rises to within 195 feet of the surface. The well penetrates nearly the entire thickness of the Pierre shale and the Niobrara and the Benton formations.

Barela.—A well recently sunk by the Colorado Southern Railroad Company at Barela reaches the Dakota sandstone at a depth of 1,040 feet and obtains water, which rises to within 300 feet of the top and pumps 30 gallons per minute. The hole was sunk to the Red Beds, which were reached at 1,340 feet.

Hoehne.—At this station on the Santa Fe Railroad, 9 miles northeast of Trinidad, a boring was made to a depth of 936 feet, but unfortunately was abandoned before it reached the Dakota sandstone, which should there be expected at a depth of about 1,100 feet. The boring was begun at the base of the Pierre shale, penetrated the Niobrara formation, there about 700 feet thick, and passed into the middle of the Benton. Doubtless it would have found water in the Dakota sandstone, and as the locality is nearly 300 feet lower than Trinidad, might have obtained a flow. To the north of this place the depth to the Dakota beds diminishes as the outcrop zone of the Niobrara formation is crossed, and the sandstone comes to the surface a short distance south of Thatcher.

Thatcher.—A 1,006-foot boring begins in top of Dakota sandstone. A second sandstone at 205 feet yields a 10-gallon flow at 245 feet, with pressure enough to rise 50 feet. A flow at 375 feet is from white sand; from 400 to 790 feet is shale, mostly red; at 790 feet is dry red sand, which is underlain by red shale to 985 feet and succeeded at 1,006 feet by red sandstone with some water, which rose 450 feet.

Salt Creek.—This place is a siding on the Denver and Rio Grande Railroad at the crossing of Salado Creek, 6 miles south of Rouse junction. The railroad company made a test boring to a depth of 2,030 feet, but was unsuccessful in finding a sufficient supply of good water. The following materials were reported, but the record evidently is a most unreliable one:

Record of deep boring at Salt Creek siding, Las Animas County, Colo.

Feet.	
0– 6	gravel.
6– 71	hard limestone.
71– 250	black shale with thin limestone layers.
250– 285	sand and shales.
285– 335	black and white sand.
335– 352	gray sand.
352– 365	dark sand.
365– 380	light-gray sand.
380– 410	red sand and hard clay.
410– 450	white shale.
450– 495	gray hard sandstone.
495– 630	greenish sand and sandstone.
630– 750	gray sand.
750– 845	dark-gray sand.
845– 855	white sand.
855– 870	dark-gray sand.
870–1,015	red sand.
1,025	red sand and "granite."

In this boring water was found at the depths and rose to the heights indicated in the following table:

Depths at which water was found and to which it rose at Salt Creek siding, Colorado.

	Feet.
70 feet, which rose to	— 3
283 feet, which rose to	—140
440 feet, which rose to	—220
840 feet, which rose to	—540
1,005 feet, which rose to	—705
1,545 feet, which rose to	—900
1,800 feet, which rose to	—600

Analyses of the two principal waters are as follows:

Analyses of water in boring at Salt Creek siding, Colorado.

Constituent.	Grains per gallon.	
	At 440 feet.	At 1,545 feet.
Sodium chloride	29.40	252.40
Sodium carbonate	43.71	25.16
Sodium sulphate	5.11	133.30
Lime sulphate	12.10	107.60
Magnesia sulphate	7.06	45.99
Silica	0.18	0.35
Undetermined	0.50	1.20
Total	98.06	566.00

This boring, which began in the lower portion of the Pierre shale, penetrated the Niobrara from about 300 to about 950 feet, and the Benton from about 950 to about 1,350 feet, where the Dakota sandstone was entered. It is the latter formation which yields the water at 1,545 feet, a water too highly mineralized to be of any use. The lower 200 feet of the well was probably in Red Beds. The failure of this well to yield a satisfactory water supply is in line with a similar experience at Rouse junction in the adjoining county to the north. The amount of water at Salt Creek was not ascertained, but it was not believed to be great. This and the experience of the Rouse junction well would indicate either that the water leaks out to the northwest, or that its circulation is impeded by the many dikes of igneous rock which intersect the formations in the surrounding region. This diminished circulation would also be indicated by the salinity of the water, which we should expect would be greatly diminished if there were a free underground passage to the

canyons to the north and east; moreover in these canyons very little water is seen to come out of the formations.

In the eastern portion of Las Animas County shallow wells bored into Dakota sandstone often yield a very satisfactory water supply for local use in the area of the Dakota outcrop, and occasional springs which issue from the formation show that it is water bearing. It will be desirable at some time to ascertain the water-bearing capabilities of the lower portion of the Red Beds and of any underlying formations that may be in this district. The most favorable locality for such a test well would be in Purgatory or Chaquaqua canyons, near their junction; for here, owing to local uplift and deep erosion, the Red Beds are extensively exposed and a boring would not have to pass through overlying formations.

LINCOLN COUNTY.

Lincoln County is on the upper slopes and summit of the divide between Arkansas and Platte valleys. The greater part of its surface is covered by a thick deposit of late Tertiary sands and gravels, cut through by valleys into underlying Pierre shales. To the extreme northwest these shales are seen to be overlain by the sandstones of the Laramie formation. The entire county is underlain by the Dakota sandstone, which is doubtless water-bearing throughout, but which lies far beneath the surface and whose water has insufficient head to flow. In the extreme southeast portion of the county the depths to this sandstone are about 1,500 feet, or perhaps slightly less, but, as the formations dip to the north and the land rises to the northwest, the amount increases gradually, probably to considerably over 3,000 feet in the district north of the Rock Island Railroad. No deep wells have been reported in this county.

LOGAN COUNTY.

Along Platte Valley in this county the Laramie formation is extensively developed, and in the higher lands east and north there is a thick mantle of White River, Arikaree, and Ogalalla formations. The thickness of the Laramie formation and its capabilities as to underground waters have not been ascertained. The Dakota sandstone probably lies several thousand feet below the surface, but possibly its waters might have sufficient head to afford flows along Platte River. Several deep borings have been made near Fleming; one on the Rogers farm, a half mile west, has a depth of 423 feet. A very small supply of water was found at that depth, which rose to within 160 feet of the surface; presumably, this water was in one of the sandstone beds of the Laramie formation. The following section is given:

Record of well at Fleming, Logan County, Colo.

Feet.	
0– 50	red clay and gravel.
50– 70	loose gravel.
70– 85	white compact clay.
85– 92	yellow clay.
92–109	dry, loose gravel.
109–194	light-green compact clay.
194–203	rocky layers, with a little water.
203–252	white compact clay and lime rock.
252–318	blue clay.
318–328	bright-yellow clay.
328–383	light-green clay, with fine white sandstone.
383–423	black clay.

MORGAN COUNTY.

Morgan County is in the valley of South Platte River in the northeast portion of the State. It appears to be entirely underlain by the Laramie sandstones and shales, covered by a wide mantle of alluvial materials in the vicinity of the river. The thickness of the Laramie formation here is not known, but it is at least several hundred feet and may be a thousand or more. Doubtless it contains water-bearing sandstones which may possibly afford flowing wells in the lower lands. Apparently no attempts have been made to develop the underground waters in this county, for only shallow wells obtaining small local supplies for pumps have been reported.

OTERO COUNTY.

This county extends from north to south across the artesian basin of Arkansas Valley. It is underlain by rocks from the Red Beds to the Pierre shale, with late Tertiary deposits on some of the higher summits to the north and the west. The formations dip gently to the north, the Dakota sandstone outcropping in the southeast corner of the county and the underlying Morrison shales and Red Beds appearing in the canyons of Purgatory River and some of its branches. To the northwest there is a regular succession of the three formations of the Benton group and a broad belt of Niobrara limestone and clays, and to the north the Pierre shale. The depth to the Dakota sandstone increases gradually to the north and northwest, being about 3,000 feet in the extreme northwestern portion of the county. The sandstone appears to contain water throughout, but the head of this water is sufficient to afford flows only in Arkansas Valley and in the lower lands adjoining.

Numerous wells have been sunk along Arkansas Valley, which yield large supplies of water of excellent quality. The volume is somewhat variable, being moderate at La Junta and very large in the vicinity of Rocky Ford. Wells at

Ordway and Sugar City, which penetrate the sandstone but fail to obtain a flow, indicate that the flowing area is restricted to the region of lower altitudes. In the northern one-third of the county, where also the depths to the water are great, the land is entirely too high for flows.

The geologic formations present very uniform characteristics throughout this county, by which they are easily recognized by the well drillers. The Niobrara shales, and especially the lower limestone of that formation, are distinct features; next the black shales of the Benton, with a thickness of slightly over 400 feet; and then the Dakota sandstone, with the intervening series of shales between its two members. The underlying shales and Red Beds have been reached by the borings at Bloom (Iron Springs) and La Junta, and found to contain waters of very unsatisfactory quality. Possibly the Red Beds may be underlain by sandstones and limestones which would yield better water, but it is not possible to make predictions in regard to this at present. In the southwest corner of the county the Dakota sandstone waters are not of satisfactory quality, as demonstrated by the borings at Timpas, Ayer, and Bloom (Iron Springs). It was for this reason that the well at the latter place was sunk to a great depth, with the hope that the formations underlying the Dakota sandstone might yield satisfactory water supplies, but the result was unpromising. In the southeast corner of the county, where the Dakota sandstone and Morrison formation are exposed, the water of Purgatory River is available, and no deep borings have been made.

Fowler.—The first flowing well below Pueblo is at Fowler on the Atchison, Topeka and Santa Fe Railroad. It has a depth of 1,372 feet, at which it obtains a flow of soft water from the upper sandstone of the Dakota at the rate of about one-half gallon a minute. The record of this well is as follows:

Record of artesian well at Fowler, Colo.

Feet.	
0– 40	surface materials.
40– 825	shale.
825–1,270	limestone.
1,270–1,372	first Dakota sandstone.

This boring begins in the Pierre shale, passes through the Apishapa and Timpas formations of the Niobrara, the limestone at 825 to 875 feet being the characteristic bed at the base of the Timpas, and penetrates 395 feet of Benton formation to the top of the Dakota sandstone.

Manzanola.—At Manzanola there is an artesian well which was sunk by the town company. Its depth is 1,113 feet, with a diameter of 7⅝ inches, and it yields

A. ARTESIAN WELL AT LYNCH, NEBR.

Flows more than 3,000 gallons per minute.

B. ARTESIAN WELL AT ROCKY FORD, COLO.

from 35 to 40 gallons a minute under a pressure of about 55 pounds. The materials penetrated by this well are as follows:

Record of artesian well at Manzanola, Colo.

Feet.	
0– 38	surface materials.
38– 598	shale.
598– 633	limestone.
633– 933	shale.
933– 936	"talc vein."
936–1,033	shale.
1,033–1,113	first sandstone of Dakota.

The record shows beds of the Apishapa formation, with the typical Timpas limestone at 598 to 633 feet, underlain by 400 feet of the Benton group. The latter contains a very distinct bed of hard shale from 933 to 936 feet, which the well drillers designate "the talc vein" and have recognized in many borings in Arkansas Valley.

In 1903 a well was in progress at Manzanola for the purpose of testing the formations below the Red Beds for oil and gas. A depth of 2,110 feet was attained without satisfactory results. The pipe has now been pulled and the well abandoned. The following record has been given:

Record of deep boring at Manzanola, Colo.

Feet.	
0– 50	loam.
50–1,050	limestone and shales (Niobrara and Benton group).
1,050–1,139	sandstone; first Dakota artesian flow, 50 gallons.
1,139–1,239	shales.
1,239–1,375	sandstone; second Dakota artesian flow, 10 gallons.
1,375–1,655	gray clays (Morrison formation).
1,655–2,110	Red Beds, with several water-bearing strata.

Rocky Ford.—There are several artesian wells at Rocky Ford which furnish large supplies of excellent water under considerable pressure. The depths vary from 767 to 1,033 feet. Wells Nos. 1 and 2 have a diameter of 7⅝ inches and a flow of over 100 gallons a minute, with sufficient head to rise 80 feet or more above the surface. One of these is shown in Pl. LXVII, *B*. The materials penetrated by these wells are indicated in the following record:

Record of artesian well at Rocky Ford, Colo.

Feet.	
0– 40	surface materials.
40–250	shale.
250–290	limestone, with salty water at its top.
290–605	shale.
605–608	"talc vein."
608–690	shale.
690–790	first sandstone of the Dakota, with a flow of soft water.

These wells begin in the lower part of the Apishapa formation, pass through the characteristic limestone bed at the base of the Timpas formation at 250 to 290 feet, and penetrate 400 feet of the Benton formation. They contain the characteristic 3-foot bed of "talc" 100 feet above the top of the Dakota sandstone.

An 845-foot well at Wyckoff Park, near Rocky Ford, has a 4-inch bore and a flow of 115 gallons a minute.

La Junta.—In this town there are several artesian wells yielding large flows of salt water, which are extensively used by the railroad company and in part for municipal supply. The principal flow is from the second bed of sandstone of the Dakota formation, which is entered at a depth of 555 feet; most of the wells are only between 405 and 439 feet deep. A boring by the railroad company penetrated both sandstones of the Dakota formation and passed through the underlying shales and sandstone into the Red Beds, which it penetrated from 1,050 to 1,150 feet. The record of this boring is as follows:

Record of deep boring at La Junta, Colo.

Feet.	
0– 37	surface materials.
37– 48	gravel.
48– 230	shale.
230– 235	"talc."
235– 340	shale and light shale.
340– 423	Dakota sandstone; soft water.
423– 451	black shale.
451– 545	gray sandstone.
545– 555	black shale.
555– 605	sandstone; soft water; flows.
605– 950	shale.
950–1,050	sandstone; water; no flow.
1,050–1,150	red and variegated shale.

This well was plugged at 700 feet and obtains its principal supply of water from the second bed of sandstone in the Dakota formation, extending from 555 to 605 feet. The original flow was 35 gallons a minute, but vigorous pumping has lowered the water many feet and it is now forced out by air lift. The wells at La Junta begin in the Timpas formation, but soon pass into the Benton shale, reaching the characteristic "talc vein" at 230 feet and the top of the Dakota sandstone at 340 feet. This formation presents an alternation of heavy beds of sandstone with intercalated shales, and from the record above given extends down to a depth of 605 feet. The underlying shales and sandy beds are those which are found on Purgatory River, 25 miles south of La Junta, lying on the sandstones and shales of the Red Beds. Probably the top of the Red Beds is at a depth of 950 feet at La Junta.

Two other wells of the railroad company are 420 and 439 feet deep, and are pumped by air lift. A well in the McNeen brickyard, with a depth of 405 feet, obtained a small flow at 395 feet, which increased to 8 gallons a minute at 405 feet. Its diameter is 4¼ inches. The well at the flour mill in La Junta is 425 feet deep and flowed 30 to 45 gallons a minute until other wells in the neighborhood were pumped, when the flow ceased. It is now pumped at the rate of 30 gallons a minute, but this is not its full capacity. The water, analyzed by W. A. Powers, is reported to have the following composition:

Analysis of artesian well water at flour mill, La Junta, Colo.

	Grains per gallon.
Sodium sulphate	60.16
Sodium chloride	3.18
Sodium carbonate	22.84
Calcium carbonate	2.12
Magnesium carbonate	3.57
Iron and alumina oxides	.43
Silica	.72
Organic matter	2.16
	95.68
Incrusting solids	6.84

A well on the hill in the southern part of the town, about 150 feet above the railroad depot, has a depth of 750 (or 766?) feet, and when completed flowed 25 gallons per minute. Now the water rises only to the surface, owing to part filling with sand and possibly to a general reduction of the water level in the vicinity by several wells near the depot.

There is also a well, which flows 15 gallons a minute, on J. E. Gauger's place, 5 miles WNW. of town.

In 1902, a company was organized to sink a deep well 2½ miles south of La Junta to test the Red Beds and their underlying formations for gas or oil. A depth of 1,703 feet was attained without obtaining either of these materials. Although a number of beds of limestone were penetrated in the lower portion of the boring, it is probable that they are a part of the Red Bed series. The following record has been supplied:

Record of deep boring south of La Junta, Colo.

Feet.
0– 50..soft gray limestone.
50– 60..rusty limestone at base of Niobrara.
60–440..dark shales of Benton group.
440–504..soft sandstone with artesian flow; first Dakota.
504–584..shales.

Feet.	
584– 700..	soft sandstone; artesian flow; second Dakota.
700– 980..	gray and greenish-gray shales with water at 820 to 120 and 860 to 100 feet (Morrison formation).
980–1,703..	Red Beds with water at intervals which rose to within 200 feet of the surface.

Some samples forwarded to Washington indicated as follows:

Feet.	
1,230–1,290..	sand and fine-grained sandstone of gray color, with some limestone layers and reddish sandstone.
1,300–1,500..	red shale, with some limestone layers.
1,535..	red shale, with some limestone fragments.
1,600..	white sand.
1,612..	red shale, with some limestone fragments.
1,660..	gray limestone and red shale.
1,703..	red shale and gray limestone.

The Lenox well 5 miles west of La Junta has a depth of 740 feet, diameter of 7⅝ inches, and yields a flow of 12½ gallons a minute. The well began in Niobrara limestone 40 feet above its base, passed through 400 feet of Carlile, Greenhorn, and Graneros beds to the top of the Dakota sandstone at 440 feet, and penetrated the two sandstones of the Dakota for 300 feet. The same beds were found at slightly lower levels in the Gauger well, 1½ miles north, indicating a dip of 27 feet to the mile in that direction, according to Mr. McVay, the driller.

Holbrook.—At this place, which is 9 miles due north of La Junta, there is a well 661 feet deep, which flows about 100 gallons per minute. The head of the water is sufficient to raise it 80 feet, and probably much more, above the surface. No record was obtainable, but it is stated that the boring started in shale, was in limestone at a depth of about 350 feet, and penetrated 110 feet into the Dakota sandstone.

Ordway.—At Ordway, on the Missouri Pacific Railroad, several wells have been sunk which have not succeeded in obtaining a flow. The Dakota sandstone was penetrated and found to contain an abundance of water which would not rise higher than 80 or 90 feet below the surface. The materials reported in one of the borings at Ordway, which has a depth of 1,508 feet, are as follows:

Record of boring at Ordway, Colo.

Feet.	
0– 42	surface materials.
42– 60	black shale.
60– 75	blue shale.
75– 90	gray shale.
90–116	shale and shells.
116–145	blue shale.

Feet.	
145– 185	black shale.
185– 245	sandstone.
245– 270	black shale.
270– 345	gray shale.
345– 410	limestone, soft.
410– 473	gray shale, some limestone.
473– 580	gray shale, darker below.
580– 650	black shale.
650– 700	gray shale.
700– 710	shale with shells.
710– 765	shale.
765– 785	brown shale.
785– 800	light-gray shale.
800– 825	brown shale.
825– 845	shale and limestone layers.
845– 855	black shale.
855– 925	shale with limestone layers.
925– 960	limestone and shale.
960–1,010	limestone.
1,010–1,325	black shale.
1,325–1,327	"talc."
1,327–1,410	black shale.
1,410–1,500	sandstone, containing some water.

This boring apparently began in the Pierre shale, passed through the basal limestone of the Timpas formation from 960 to 1,010 feet, but did not obtain flowing water, either because it did not penetrate sufficiently far into the Dakota sandstone or, more likely, because the altitude of Ordway is too great to afford a flow.

Sugar City.—The boring at Sugar City reached a depth of 1,308 feet, but did not obtain a flow. This well reached the Dakota sandstone at a depth of 1,230 feet.

Timpas.—The following report of the well at this place is furnished:

Record of boring at Timpas, Colo.

Feet.	
0– 37	loam.
37– 40	dry gravel.
40– 85	shale.
85–137	limestone (basal Timpas), some water.
137–538	shale with "talc vein" from 440 to 443 feet=398 feet of Benton.
538–580	sandstone (Dakota); poor water at 544 feet rising to —50 feet; 2-gallon flow at 570 feet.
580–605	shale.
605–650	sandstone; poor water.
650–656	shale.
656–716	gray sandstone.
716–790	sandstone (Dakota); 35-gallon flow; 20-gallon flow at 755 feet.
790–795	red shale (Morrison?).

The water which flowed at 790 feet was too highly mineralized to be usable in boilers, so that the boring is regarded as a failure. The water had sufficient pressure to flow into a tank 27 feet above the ground.

Ayer.—This is a siding on the Atchison, Topeka and Santa Fe Railroad, 6 miles southwest of Timpas. The record of the boring is as follows:

Record of boring at Ayer, Otero County, Colo.

Feet.
0– 40..surface material.
40– 43..gravel.
43– 80..gray limestone.
80–249..black shale with "talc vein" 147 to 150 feet.
249–272..sandstone; soft water.
272–280..shale.
280–287..gray sandstone, dry.
287–293..black shale.
293–343..sandstone, with poor water; 25-gallon flow near bottom; 3-gallon flow at 311 feet.

The water is of unsatisfactory quality, containing 18 grains of sulphate of lime to the gallon.

Bloom (Iron Springs).—The boring at this place, sunk for the Santa Fe Railroad, had a depth of 1,162 feet and yielded a flow of 5 gallons per minute, but was abandoned, as the water was too hard for use in locomotives. The following record is furnished:

Record of boring at Bloom siding, Otero County, Colo.

Feet.		
0– 25	clay.	
25– 31	gravel.	
31– 87	shale, with bad water at 76 feet.	
87–154	gray shale.	
154–168	gray sandstone.	
168–170	black shale.	
170–229	sandstone, brown above; poor water.	
229–233	shale.	
233–244	sandstone; 5-gallon flow of water.	
244–255	hard sandstone.	
255–400	sandstone; second water at top, flow at 385 feet.	
400–450	red shale.	Morrison.
450–455	white sandstone.	Morrison.
455–475	red shale.	
475–575	red sandstone	
575–695	light-gray shale.	
695–815	light-brown sandstone.	
815–880	dark-red sandstone.	
880–965	red sandstone.	
965–985	red shale.	

Feet.	
985- 995	red sandstone.
995-1,000	"marble."
1,000-1,007	red shale.
1,007-1,020	red sandstone.
1,020-1,025	white "limestone."
1,025-1,085	red sandstone.
1,085-1,087	"limestone."
1,087-1,125	red sandstone.
1,125-1,128	"limestone."
1,128-1,133	pink sandstone; water rose 80 feet.
1,133-1,140	red sandstone.
1,140-1,145	red shale.
1,145-1,155	white sandstone; water rose 350 feet.
1,155-1,162	red shale.

Two deep wells have been sunk in the eastern portion of the county northeast of Horse Creek Valley; one 18 miles due east of Ordway, in sec. 13, T. 21 S., R. 54 W., had a depth of 715 feet, but, although it reached the Dakota sandstone, did not find water with sufficient head to afford a flow, the water level coming to within 60 feet of the surface. The supply appears to be ample, for the well was pumped 20 gallons per minute. The following record is given:

Record of well in sec. 13, T. 21 S., R. 54 W., 18 miles due east of Ordway, Otero County, Colo.

Feet.	
0- 40	sand and clay.
40-180	blue shale.
180-187	sandstone.
187-227	gray shale.
227-267	limestone.
267-372	brown shale.
372-377	limestone.
377-432	sandy shale.
432-477	slate.
477-584	brown shale.
584-594	slate.
594-688	black sandy shale.
688-703	gray sandstone.
703-715	water-bearing sandstone.

In sec. 36, T. 21, R. 50, a well 780 feet deep has almost exactly the same record, but the water level is considerably lower.

PHILLIPS COUNTY.

Phillips County is heavily mantled by the Ogalalla formation and by extensive areas of sand dunes accumulated by the winds from that formation. Probably the Laramie formation lies at no great depth and might prove to be a source of

water supply for deep-pump wells. The depth to the base of the formation and the thickness of the underlying Pierre shale, Niobrara chalk, and Benton formation have not been ascertained. It is believed that the Dakota sandstone lies several thousand feet below the surface and would not yield a flow, owing to the height of the land. The only deep well is at Holyoke where a depth of 350 feet was attained, apparently all in the Ogalalla and the underlying Tertiary deposits.

PROWERS COUNTY.

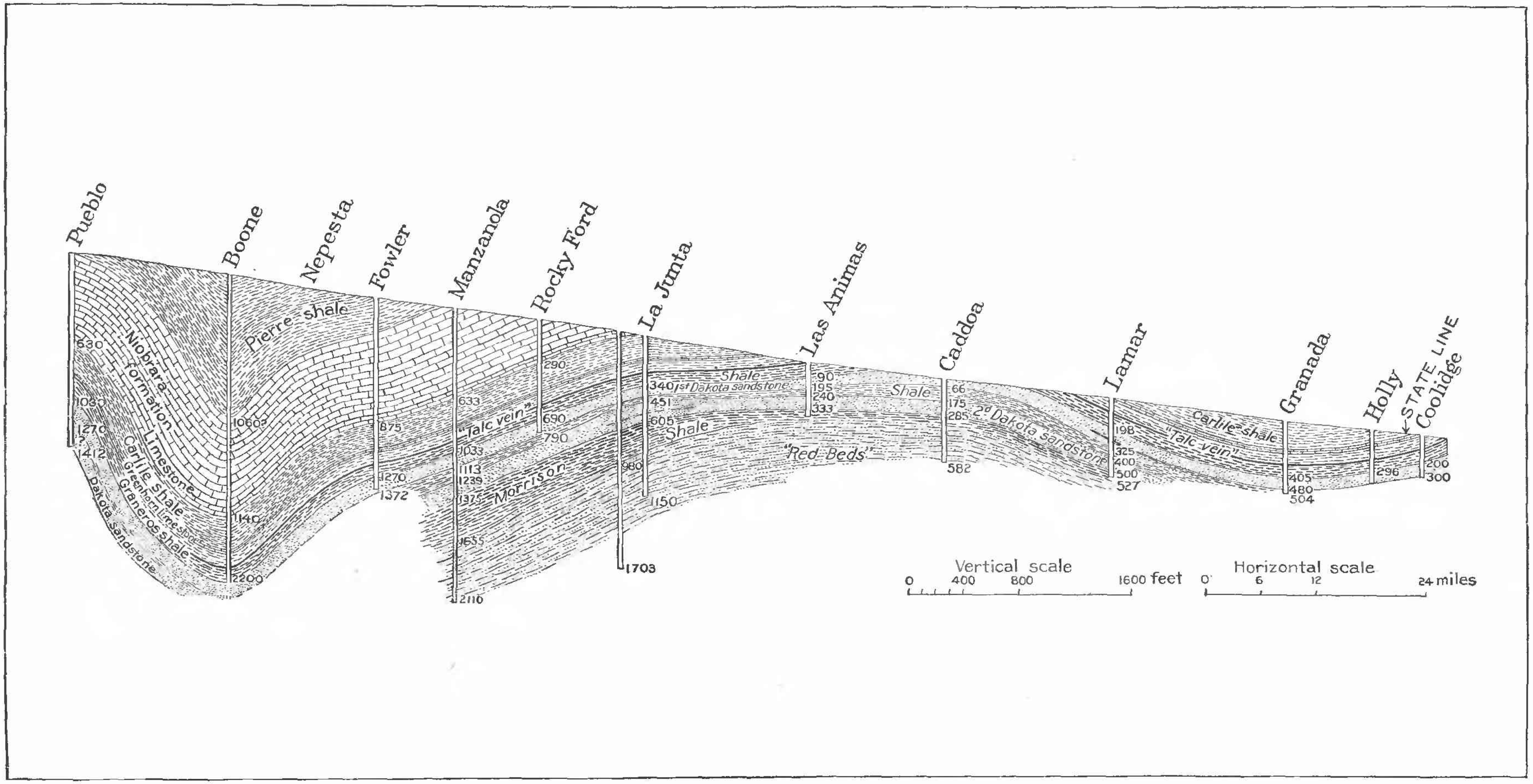
This county is in the valley of Arkansas River, extending up the slopes to an elevation of 800 feet above the valley on the south and about 300 feet on the north. In the south part of the county the Dakota sandstone is at or near the surface for a considerable area, extending down into Arkansas Valley to the west. It pitches beneath the Benton and the Niobrara formations to the north and northeast. In much of the region the conditions are favorable for artesian waters, and such have been obtained at a number of points in Arkansas Valley and at one locality southward. The head of the water is not great and the volume is moderate, but the quality is excellent and the wells have proved to be of great value to the communities which have them. It is probable that no flows should be expected in the extreme northeast part of the county for the land is somewhat too high, and very little head can be sustained, owing to the low level of the sandstone outcrops in the bottom of Arkansas Valley above the mouth of Sandy Creek.

Lamar.—There are several wells 226 to 522 feet deep at Lamar, which furnish water for the railroad and the town. Some of them afford a flow, but the head is very slight. The well at the railroad tank pumps 80 gallons a minute, with the pump barrel 200 feet below the surface. Its record is reported as follows:

Record of well at Lamar, Colo.

Feet.	
0– 34	surface materials.
34– 72	shale.
72– 75	"talc vein."
75–198	shale.
198–265	Dakota sandstone, with water to —20 feet.
265–270	shale.
270–325	sandstone, soft water.
325–400	shale.
400–404	sandstone.
404–460	sandy shale.
460–500	sandstone, with soft water, which at 480 feet rises to —10 feet and at 500 feet just flows.
500–527	variegated shale, red, chocolate, and brown.

The variegated shales in the bottom of the well are probably at the top of the Morrison formation. At the waterworks in Lamar a large supply of water



GEOLOGIC SECTION ALONG ARKANSAS VALLEY, SHOWING RELATIONS OF DEEP WELLS.

is pumped from the Dakota sandstone at a depth of 300 feet, rising to within 28 feet of the surface. The water has the following composition, according to an analysis by D. O'Brien:

Analysis of deep-well water at Lamar, Colo.

Solids, 737 grains per gallon.	Per cent.
Iron and alumina, Fe_2O_3, Al_2O_3	0.74
Lime, CaO	7.77
Magnesia, MgO	6.78
Carbonic acid, CO_2	9.43
Sulphuric acid, H_2So_4	43.10
Potash and soda, K_2O, Na_2O	20.39
Chlorine, Cl	11.82
Total	100.04

Granada.—The railroad well at this place has the following record:

Record of artesian well at Granada, Colo.

Feet.	
0– 36	surface materials; hard water.
36– 58	shale.
58– 60	limestone.
60– 78	shale.
78– 80	limestone.
80–195	gray shale.
195–323	black shale.
323–326	"talc vein."
326–353	black shale.
353–405	sandy shale; some soft water.
405–480	Dakota sandstone; soft water.
480–497	shale.
497–504	white clay.

The water level in the well was about 25 feet below the surface, but it is pumped down to below 80 feet, yielding about 80 gallons per minute.

Holly.—At Holly there is a flowing well which is said to have reached the Dakota sandstone at 296 feet and to have obtained a satisfactory flow. The diminished depth to the Dakota at this place indicates that the strata are rising eastward from Granada, as shown in the section, Pl. LXVIII.

Plum Creek.—At a point on Plum Creek, about 20 miles south of Granada, there is a small artesian well, which obtains its flow from the Dakota sandstone at a depth of 200 to 300 feet, from which no definite report has been obtained. It is important in indicating that artesian waters may be expected in the central and east-central portions of the county, at some distance south of Arkansas Valley. Much of

this region is occupied by the Greenhorn limestone in the middle of the Benton group, so that about 250 feet of shales would have to be passed through to reach the top of the Dakota sandstone, and this formation penetrated for a hundred feet or more to obtain a water supply. North of Arkansas River, especially in the basin which passes through Granada, the depth to the Dakota sandstone rapidly increases owing to the downward dip and the rise of land. In the extreme northwest corner of the county it probably lies a thousand feet below the surface.

PUEBLO COUNTY.

This county comprises a portion of Arkansas Valley extending east from the Rocky Mountain Front Range. Owing to its relatively complicated geologic structure, it presents great diversity of features. In general its rocks dip to the northeast, but there are numerous local flexures and dislocations in the region west of Pueblo. The Dakota sandstone outcrops at intervals along its south margin, on the flanks of Wet Mountain range, on the southern extension of Pikes Peak uplift, and in the valley of Arkansas River a short distance above Pueblo. There are extensive basins occupied by Benton and Niobrara formations and, to the northeast, a deep basin filled with Pierre shale and apparently with the lower portion of the Fox Hills and the Laramie beds.

The depths to the Dakota sandstone vary greatly. Southwest of Pueblo, in the western and southern portions of the county, the amount is mostly less than 500 feet. At Pueblo it averages somewhat over 1,000 feet, increasing eastward to about 1,300 feet on the Arkansas at the east margin of the county, and to more than 3,000 feet in the northeast corner of the county.

The underground waters have been explored by a group of wells in the Pueblo region, while the well at Fowler, just east of the eastern margin of the county, indicates that artesian waters are available in Arkansas Valley below Pueblo.

The Dakota sandstone is underlain by Morrison clays and this in turn by Red Beds, which probably are very thick, and, as these have not been found to contain water of satisfactory quality or volume, the Dakota sandstone must be depended upon for artesian supplies.

Pueblo.—The first deep well in Arkansas Valley was a boring for petroleum, made at South Pueblo in 1879. At a depth of 1,166 feet a flow of mineral water was obtained, amounting to about 100 gallons a minute. The boring was continued to a depth of 1,412 feet and cased to a depth of 900 feet with 6-inch casing. The well has continued to flow with nearly its original volume and a pressure of 60 pounds to

the square inch. The water is not suitable for domestic use, but is the basis for the Clark mineral spring resort, where it is employed for bathing and medicinal purposes.

The record of this well is as follows:

Record of deep well at Clark's mineral spring, Pueblo, Colo.

Feet.	
0- 34	soil and gravel.
34- 58	blue shale.
58- 630	black shale.
630- 690	sandstone, white below.
690- 700	black shale.
700- 735	soft coarse sandstone.
735- 900	black shale.
900- 940	sandstone.
940-1,030	black shale.
1,030-1,045	sandstone.
1,045-1,148	soft black shale.
1,148-1,180	sandstone with flow of water.
1,180-1,195	black shale.
1,195-1,230	coarse sandstone.
1,230-1,240	purple shale.
1,240-1,270	sandstone.
1,270-1,400	not given.
1,400- (?)	purple shale.

The Colorado Coal and Iron Company has a well on the mesa south of and about 100 feet higher than the Clark well. The depth is 1,260 feet and the flow, which is from 20 to 25 gallons a minute, is not utilized. The following analysis, by H. L. Wells, is given:

Analysis of water from artesian well of Colorado Coal and Iron Company, Pueblo, Colo.

	Grains per gallon.
Sodium chloride	1.82
Sodium sulphate	41.43
Potassium chloride	1.82
Calcium sulphite	16.94
Calcium carbonate	2.64
Magnesium carbonate	11.65
Ferrous carbonate	1.17
Silica	.55
Total	78.02

Another well in the same vicinity obtains a small flow from a depth reported to be 1,150 feet. At the Fariss House in Pueblo a well said to be 1,400 feet

deep flows 13 gallons a minute and has a pressure of 60 pounds to the square inch. The following analysis, by Von Schultz and Low, Pueblo, is given:

Analysis of water from Fariss artesian well, Pueblo, Colo.

	Grains per gallon.
Sodium chloride	2.42
Sodium sulphate	41.92
Calcium sulphate	3.43
Calcium carbonate	6.28
Magnesium carbonate	6.16
Ferrous carbonate	0.91
Silica	.91
Total	62.03

At the Grand Hotel in Pueblo is a well 1,219 feet deep, 4½ inches in diameter, which has a flow of about 20 gallons a minute of mineral water, under a pressure of 50 pounds per square inch. At 1,050 feet the flow was fresh water under pressure of 15 pounds. On Columbia Heights, a suburb of Pueblo, there is a 789-foot well which found a small flow at 516 feet and a second flow at 779 feet—in all about 8 gallons a minute. The following record is given:

Record of well in sec. 9, Columbia Heights, Pueblo, Colo.

Feet.	
0– 23	soil.
23– 31	gravel.
31– 99	shale.
90–105	limestone.
105–516	black slate.
516–616	sandstone; with water.
616–779	black slate.
779–789	sandstone; second flow.

On the adjoining section, 17, is a well sunk by C. H. Small, which, in 1888, had a depth of 772 feet and a small flow. It was deepened later to a second flow. The following record is given:

Record of artesian well of C. H. Small, Pueblo, Colo.

Feet.	
0– 12	black soil.
12– 72	blue shale.
72– 82	limestone.
82–413	black shale.
413–575	white sandstone.
575–760	red rock.
760–772	gray sandstone.

The water is similar to that in the other wells in the Pueblo region in containing considerable mineral matter.

In North Pueblo Heights a well was sunk 1,820 feet, striking small flows at 1,200 and 1,820 feet. All the Pueblo wells draw their water supply from either the upper or the lower sandstone of the Dakota formation, but the water is too much mineralized to be of general use.

In 1903 a deep boring was made at Boone to explore for oil or gas, but only reached the top of the Dakota sandstone. The sandstone was not penetrated sufficiently to afford a water supply. The following record is furnished:

Record of boring at Boone, Colo.

Feet.	
0- 25	surface materials.
25-1,560	shale.
1,560-1,610	limestone.
1,610-1,720	shale.
1,720-1,740	limestone.
1,740-2,200	shale, with "talc vein."
At 2,200	Dakota sandstone.

The first 1,000 feet of shale probably are of the Pierre, while the Niobrara, with its Apishapa shales above and Timpas limestone below, extends to 1,740 feet, a thickness of about 740 feet. The Carlile, Greenhorn, and Graneros beds comprise a thickness of 460 feet. This boring is near the axis of a deep north-pitching syncline, a fact which accounts for the great thickness of Pierre shale.

In 1903 two deep borings were made in the north-central portion of the county, with the hope of finding oil or gas, but without success. Both borings are situated north of Arkansas River—one, 1,900 feet deep, 7 miles northeast of Pueblo, and the other, 2,655 feet deep, 10 miles northeast of Pueblo. The shallower boring appears not to have reached the Dakota sandstone, but found some water, which rose to within 550 feet of the surface; the other penetrated the Dakota sandstone 55 feet and found water, which rose 1,000 feet or more.

Record of well 7 miles northeast of Pueblo.

Feet.	
0-1,400	shale.
At 1,400	limestone.
At 1,440	sandstone.
(?) 1,875	shale.
1,875-1,900	sandstone (probably Carlile).

The altitude of this well is about 4,900 feet, and its precise location is 4½ miles north and a half mile west of Baxter siding, on the Missouri Pacific Railroad.

Record of boring 10 miles northeast of Pueblo, Colo.

Feet.	
0–2,000	shale.
2,000–2,100	limestone.
2,100–2,140	sandstone (Carlile).
2,140–2,600	shale.
2,600–2,655	Dakota sandstone.

This boring is at an altitude of 4,750 feet, and its location is 6 miles north and 3 miles west of Chico siding, on the Santa Fe Railroad. Probably if the Dakota sandstone had been more deeply penetrated the water would have risen to within 100 feet of the surface, but the land is too high for artesian flow.

A boring for oil on the high mesa in the extreme northwest corner of the county reached Dakota sandstone at a depth of 1,300 or 1,400 feet. Water rose to within 100 feet of the surface, or to an altitude of 5,100 feet. Two miles northeast, on lower lands in the adjoining county, a large flow under much pressure is obtained. These borings indicate that flows may be expected in much of the broad area lying between the mountains and Arkansas River.

SEDGWICK COUNTY.

In this county the Tertiary deposits descend to the level of Platte River and the underlying formations do not appear. Apparently the county is underlain by the Laramie sandstone, and although the water resources of that formation have not as yet been ascertained there appears to be a possibility of flows for wells of moderate depth. Doubtless the Pierre shale occurs at no great depth below the surface, but the position of the Dakota sandstone can only be conjectured; it may be within 2,000 feet of the surface, but possibly lies much deeper.

YUMA COUNTY.

This county is overlain in greater part by a covering of Tertiary deposits, 200 feet or more in thickness on the divides. It is underlain by the Pierre shale, which appears in the Arikaree and other valleys, and possibly to the west by the Laramie sandstones and shales. The Tertiary deposits usually afford excellent water supplies for pump wells at depths averaging from 200 to 250 feet, but in the great mass of underlying shales there appear no prospects for water.

The Dakota sandstone doubtless lies considerably over 2,000 feet deep, and its waters have insufficient head to rise to the surface. The deep boring at Otis, in the adjoining county west, probably penetrated very nearly the same formations which should be expected here. It is claimed that a well was sunk at Wray to a depth of 400 feet or more for coal, but neither coal nor water were found.

WASHINGTON COUNTY.

This county extends from the valley of the South Platte southeast across the divide of the High Plains. The latter are heavily capped by gravels and sands of late Tertiary age, which in the slopes to the west are seen to be underlain by the White River deposits and by a considerable thickness of Laramie sandstones and shales.

The prospects for underground waters in this county have been tested by two deep wells at Akron and Otis, the former made under the direction of the Department of Agriculture and the latter made by the Burlington Railroad Company. Both penetrated deeply into the Laramie and Pierre formations, but both were discontinued apparently far above the Dakota sandstone. Even if this sandstone were reached, the water which it probably contains would not have sufficient head to afford a flow on the highlands, although it might reach the surface and possibly have considerable pressure in the immediate vicinity of Platte River.

Owing to our lack of information as to the thickness of the Laramie and the Pierre formations in this region no prediction can be made as to the depth to the Dakota sandstone. The thicknesses indicated in the sections of upturned beds west of Denver probably diminish rapidly to the east, but the rate of diminution has not been ascertained.

Akron.—The boring at Akron was made over twenty years ago and reached a depth of 1,155 feet without obtaining a flow. Considerable water was found near the bottom, but the boring ended in shale. The following record to the depth that had been attained in February, 1883, has been furnished by the Department of Agriculture:

Record of well at Akron, Washington County, Colo.

Feet.	
0– 30	clay and gravel.
30– 40	gravel.
40– 50	chalky bed.
50– 100	conglomerates, sand, and gravel.
At 100	water to —85 feet.
100– 108	hard sand rock.
108– 128	chalky rock.
128– 140	gravel and clay and small amount of water.
140– 232	dry clay.
232– 242	sandstone.
242– 255	blue shale, with water in its lower portion rising 80 feet.
255–1,063	shale, with water near 550 feet which rose 305 feet.

The upper portion of the well was cased with 10 and 8 inch casing, and with 6-inch casing to the depth above given. The materials were late Tertiary and

White River deposits lying on more or less Laramie; the great mass of shale below doubtless is Pierre.

Otis.—The Otis boring was continued to a depth of 2,400 feet, but obtained no water. It had the following record:[a]

Record of well at Otis, Colo.

Feet.	
0- 206	surface materials.
206-1,400	shale mixed with sandy clay.
1,400-1,500	shale or joint clay.
1,500-2,000	shale.
2,000-2,200	shale mixed with fine sandy shale.
2,200-2,400	shale, compact.

It is probable that the lower formations penetrated are the Pierre shales, the highest beds being Tertiary deposits for the first 206 feet and then an unknown thickness of Laramie formation.

WELD COUNTY.

Weld County is underlain by Laramie and associated formations, which, in the northern portion of the county, are overlain by White River and later Tertiary deposits. The Laramie sandstones contain water at various depths, and in the lower lands of a portion of the county some of the beds afford flows. The principal wells are at Greeley, where flowing waters were found in considerable volume. Flows are obtained also in Platte Valley, in the north extension of the Denver basin above Fort Lupton. Only a few wells have been sunk and the only information obtainable regarding them is that, at a depth of several hundred feet, flows of moderate volume and pressure are obtained.

The extent of the Greeley artesian basin has not been determined. It does not extend far to the north, for in the deep well at Eaton the water does not flow, but it may extend for some distance up Platte, Cache la Poudre, and Thompson valleys. Its extension up Thompson Creek is indicated by the flow in the deep well at Loveland, but apparently no wells have been sunk which indicate whether or not the Greeley and Denver basins are continuous from Lasalle to Fort Lupton.

Greeley.—The underground waters have been developed to a considerable extent at Greeley, where 8 wells are reported. The principal water-bearing horizon lies between 1,165 and 1,200 feet below the surface, and, before being subjected to continued pumping, yielded a small flow.

[a] Fifty-first Congress, first session, Senate Ex. Doc. No. 222, 1890, p. 217.

The first deep well was sunk by the city in 1883, reaching a depth of 2,260 feet. The following record is given:

Record of well at Greeley, Colo.

Feet.	
0– 4	soil.
4– 35	sand and gravel.
35–1,160	bluish-gray shale with thin beds of sandstone every 40 to 50 feet.
1,160–1,200	soft grayish sandstone, with some water.
1,200–2,260	bluish-gray shale.

The sandstone and the lower shale were somewhat impregnated with carbonaceous matter and gas. At the base of the sandstone was found a flow of water amounting to about 2,000 gallons a day. An analysis of this water, made at the University of Michigan, is as follows:

Analysis of water from artesian well at Greeley, Colo.

	Grains per gallon.
Sodium bicarbonate	44.43
Magnesium bicarbonate	.50
Calcium bicarbonate	.57
Sodium chloride	37.33
Ferric oxide	.24
Aluminum oxide	.06
Silica	6.30
Sulphates	trace
Carbon dioxide	11.10

No water was found in the lower shale, so the boring was filled with gravel to the water horizon and its moderate flow utilized. The other wells were not sunk below the water-bearing bed. All the wells were pumped and furnished moderate supplies, but soon after pumping was begun the flows ceased. Several of the wells have been abandoned.

Evans.—A well at Evans found the water-bearing sandstone at a depth of 1,125 feet and flowed at first, but is now pumped with a yield of about a gallon a minute.

Eaton.—At Eaton, 7 miles north of Greeley, a well was sunk to a depth of 970 feet, finding, from 230–260 feet, a large supply of water, which came to within 20 feet of the surface; additional supplies were found at about 400 and 625 feet.

DEEP WELLS AND WELL PROSPECTS IN EASTERN WYOMING.

GENERAL CONDITIONS.

In the regions lying east of the Bighorn Mountains and the Laramie Front Range there is a wide deep basin containing several sandstone series which have not been extensively explored for underground waters. A few wells along the west slope of the Black Hills obtain flows of water in some cases too highly mineralized

for use and in others of excellent quality. The Laramie sandstones, which cover a wide area in the basin, contain numerous water-bearing beds, which have been explored by wells along the railroad and found to yield satisfactory supplies, but to be without sufficient head to flow, so far as yet ascertained.

In the greater part of the district the Dakota sandstone lies so deep that it is out of reach of the well driller, and, even if it were penetrated, its waters would probably have sufficient head to yield flows only in the lower lands.

CONVERSE COUNTY.

There is considerable diversity in the geology and configuration of Converse County. To the northeast it comprises part of the western slope of the Black Hills uplift; to the south, the western extremity of Pine Ridge; to the southwest, the northern extremity of the Laramie Range; and, to the north, an extensive district of high plains and ridges, consisting of the Laramie formation. The southwest corner is crossed by the valley of North Platte River and its north half drained by the headwaters of Cheyenne River. There extends across the eastern portion of the county the prominent anticline which connects the Laramie Range with the Black Hills. This uplift is in part buried under the Miocene and the Oligocene deposits of Pine Ridge, but its presence and relations are indicated by exposures of granites, schists, and Carboniferous limestones, and, along the east side of Oldwoman Creek, by a succession of formations from Sundance to Laramie. East of this uplift, in the northeast portion of the county, there is a synclinal basin in which the Dakota sandstone lies from 400 to 1,700 feet beneath the surface. It is probable, however, that the only portion of this area in which flowing waters should be expected is in the lowest lands of Cheyenne River and Beaver Creek valleys in the extreme northeast corner of the county, the flowing well at Argentine in the adjoining county in South Dakota indicating the presence of the water in the sandstone. In the southeast corner of the county the artesian basin is deeply buried beneath the thick mantle of White River and Arikaree formations in Pine Ridge, and its relations are not fully ascertained. It is possible that a well in the Niobrara Valley near the State line would reach the Dakota sandstone at a depth not much greater than 2,000 feet, but the water could not be expected to come within several hundred feet of the surface. West of Oldwoman Creek the formations on the west side of the anticline dip under the surface so rapidly that the Dakota sandstone soon sinks below the limit of ordinary well boring.

It is probable that in the entire central, northern, and western portions of the county the Dakota sandstone lies several thousand feet below the surface, there being a considerable thickness of Laramie formation at the surface. Possibly the

sandstones of this formation would yield flows in some areas, but their capabilities in this respect have never been tested. In the southern portion of the county, about Orin junction, there is probably a basin underlain at moderate depth by Dakota sandstone, which would yield water under sufficient pressure to come nearly or quite to the surface along Platte River, but, owing to the heavy covering of younger formations, the depths and structural relations are not ascertained. Along the foot of the mountains west from Douglas there is a fault which drops the Dakota and associated sandstones far beneath the surface. South of Glenrock they rise again, but apparently present little prospect of affording a flow of water. South of the fault, 10 miles southwest of Glenrock in the vicinity of the county line, there is a small syncline in which the Dakota sandstone lies at a moderate depth below the surface, and in this restricted area there are prospects for an artesian flow in wells from 300 to 1,500 feet deep.

CROOK COUNTY.

This county comprises the north end of the western part of the Black Hills uplift and the wide area of plains to the west. In the uplift rocks of Paleozoic and Mesozoic age appear, which, in the east-central portion of the county, dip gently to the west and pass under a thick mass of Laramie shales and sandstones. The underground water conditions vary greatly in different portions of the county, there being several horizons which doubtless contain abundant water supplies. In the Black Hills uplift there is probably water in the Deadwood sandstone, which lies on the granites and schists, and in the sandstones of the Minnelusa formation and of the Dakota-Lakota series. The waters of the older formations have not been explored, and but little can be said of their prospects. The well at Cambria, in the adjoining county south, found an abundant supply below the Minnelusa formation, which is itself too fine grained to carry much water. Doubtless the Cambria water extends under the county and lies at a moderate depth in Belle Fourche, Sundance, Red Water, and Inyankara valleys. Its distance below the top of the Red Beds is probably about 1,500 feet, so that in the Red Valley its average depth would usually be 1,300 feet or less, depending upon the horizon in the Red Beds. At Aladdin a well was sunk 1,150 feet, which appears not to have reached the Minnelusa formation. It began in Morrison formation, and is said to have entered the Red Beds at 400 feet and continued in them to 1,150 feet.

The Dakota-Lakota sandstones extend around the end of the Black Hills uplift, dipping to the west in the east-central part of the county, to the north in the region about the big bend of the Belle Fourche, and mostly to the northeast in the region north of Aladdin. That this formation is water bearing is proved by the numerous wells around the margin of the Black Hills, especially those at Belle Fourche, which yield abundant flows under considerable pressure. It is

probable that these flows are available at moderate depths in Belle Fourche and adjoining valleys in the extreme northeast corner of the county, in Little Missouri Valley for several miles above Alzada, and in Belle Fourche Valley to the north of Moorcroft. To the north and west the sandstones are soon carried to great depths, so that in the higher lands the waters would not flow. This is shown at Thornton siding, where the formation was reached at a depth of 980 feet, but owing to the high land the water would not flow.

In wells sunk for oil north of Moorcroft the Dakota sandstone was found to be water bearing, but this resource was not developed. In the central and western portions of the county there are waters in the sandstones of the Laramie formation, which afford supplies to a number of deep wells along the railroad. Such wells are at Rozet, 883 feet deep; at Gillette, 865 feet deep; at Felix, 1,080 feet deep; and at Croton, 803 feet deep. At the latter place the water is said to have nearly reached the surface when the well was completed, which would suggest that flows might be obtainable in the lower lands westward. It is possible that in the valleys of Little Powder and Powder rivers, flowing waters might be obtained from this source. In this region the Dakota sandstone probably lies 3,000 or 4,000 feet below the surface, so that it is out of reach for well boring.

Gillette.—Water rises to within 485 feet of the surface in a well having a record as follows:

Record of well at Gillette, Wyo.

Feet.	
0– 60	sandstone.
60– 70	black shale.
70–190	white sandstone.
190–335	gray shale.
335–345	black shale.
345–400	coal.
400–410	white shale.
410–420	black shale.
420–485	blue shale.
485–520	coal.
520–700	black shale.
700–760	sandstone with water.
760–800	shale.
800–855	sandstone.
855–860	shale.

JOHNSON COUNTY.

This county extends from the summit of the Bighorn Range east beyond the valley of Powder River. There are large supplies of excellent water in the mountain streams, but in the eastern portion of the county the surface waters are not altogether satisfactory for use, as they usually contain much alkali.

The geologic structure of the county is relatively simple. The mountains to the northwest consist of granites, which, on the lower slopes, pass beneath the sedimentary strata that underlie the eastern and southern parts of the county. These strata consist of limestones and sandstones dipping steeply to the east on the slopes and lying nearly level under the plains eastward. The steep dip carries all of the older formations far beneath the surface, and the eastern half of the county is occupied by sandstones and shales of the Laramie formation.

These sandstones contain more or less water, but give no promise of artesian flows. In the mountains north and northeast, along the railroad, deep wells have been sunk, which have developed these waters to some extent; in the southeastern portion of the county a deep boring made for oil found considerable water.

LARAMIE COUNTY.

This county is, in greater part, covered by a thick deposit of the Arikaree formation extending to the foot of the Laramie Range, which rises along the western margin of the county. This range consists of granite flanked to the east by a regular succession of sedimentary rocks dipping east. North of Iron Mountain there is an extensive anticline which branches from the main ridge and extends northeast toward the Black Hills. The principal features of this uplift are exhibited in the north-central portion of the county, about Hartville and northward. The precise relations of the rocks under the Arikaree formation are probably complex, and, owing to the wide scattering of the outcrops, can only be surmised. Along the front range of the Laramie Mountains the dips are steep wherever the rocks are exposed, so that the Dakota and associated sandstones descend rapidly to great depths, finally being overlain by the Laramie formation, which extends in a basin northeast from Cheyenne. These Laramie beds are exposed extensively in Goshen Hole, where the overlying Arikaree beds have been removed from a considerable area. It is probable, therefore, that in the southeastern and eastern portions of the county the Dakota sandstone lies several thousand feet below the surface, too deep to be reached by an ordinary boring. Probably it immediately underlies the Arikaree formation all along the foot of the mountains, for it appears at intervals, especially on Horse Creek and at Iron Mountain. From the latter place it trends northeast along the east side of the anticline and doubtless passes near Fort Laramie and a short distance east of Rawhide Butte. Its depth beneath the surface along this line probably varies from a small amount to several hundred feet. Even if the sandstone were reached by a well along this line of outcrop, it might not contain water, on account of the thick mantle of fine-grained materials by which it is overlain.

Next west of the Dakota sandstone and associated shales are the Red Beds of the Chugwater formation and a thin series of sandstones and limestones, which appear

not to give much promise of water. These lower members extend northeast from near Iron Mountain station to beyond Rawhide Butte along the east side of the Hartville uplift, lying on granites and schists and deeply buried under Tertiary deposits. They are extensively exhibited along North Platte River above Guernsey and in the plateau northward. They pass near Wheatland, but the relations under the heavy cover of Arikaree formation in that vicinity can only be conjectured. The rocks undulate considerably under the northwest corner of the county, a basin of the Dakota sandstone and associated formations being exhibited along North Platte River and the slopes to the north. The extension of this basin to the west is concealed by the Arikaree formation, so that its relations to underground water supplies can not be predicted. Deep wells in the region about Wheatland and to the north would throw much light on the underground relations and might find a water supply within a reasonable depth, but no definite predictions can be made until the Arikaree formation has been perforated.

Cheyenne.—The only deep well known in this county was bored at or near Cheyenne some years ago, to a depth of 1,145 feet. Though a small flow of water was obtained, the well was not regarded as a success. The materials penetrated were all sands, apparently representing the Arikaree and the White River formations and the Laramie sandstone. The top of the latter probably lies about 500 feet below the surface at Cheyenne, and if penetrated to a sufficient depth may prove to be a source of water supply. According to another authority this deep boring was at Fort D. A. Russell, and had a depth of 800 feet all the way through gravel and bowlders. No bed rock was found, and below the surface supplies no water was obtained.

In 1903 a series of 6 wells was bored at Fort D. A. Russell, just outside of Cheyenne, which obtained an artesian flow of water of excellent quality at a depth of 140 feet, probably from the basal beds of the Arikaree formation, which slopes gently east from the foot of the mountains.

SHERIDAN COUNTY.

Sheridan County extends from the summit of the Bighorn Range east across the plains to Powder River Valley. It is a region traversed by large volumes of running water, especially in the vicinity of the mountains, but in the divides between the streams on the plains water supplies are very scanty. In the western portion of the county the sedimentary rocks lie on the granite and dip steeply to the northwest. Owing to this steep dip the older formations rapidly sink to a great depth and pass beneath a thick mass of Laramie shales and sandstones, which, in the central and eastern portions of the county, lie nearly horizontal. The sandstones of this formation contain considerable water which is available for wells, and have been developed to some extent by a number of deep borings along the railroad,

viz, at Sheridan to a depth of 500 feet; at Verona to 540 feet; and at Clearmont to 790 feet, all obtaining a moderate supply of water which in most cases rises to within about 100 feet of the surface.

There appear to be no prospects for artesian flows in this county, and, although possibly some of the deeper-seated beds of the Laramie sandstone may yield flows in the lowest valleys, no wells have yet been sunk far enough to reach them.

WESTON COUNTY.

Weston County extends from the slope of the Black Hills west across the plains to beyond the Powder River divide. To the south it is drained by Cheyenne River and to the North by the Belle Fourche. On the slope of the Black Hills there is a west-dipping succession of all the formations from the Pahasapa limestone upward, the Dakota hogback extending diagonally across the northeast corner of the county. The Dakota and associated sandstones pass beneath the surface with dips which are moderate to the north and steep near Newcastle and southward. For some distance from the flank of the Hogback Range the Dakota sandstone is within reach of well boring, and the conditions are favorable for artesian wells, several of which have been sunk, furnishing water supplies in a number of localities. To the west, as the depth increases, the sandstone finally lies at too great a depth to be reached by wells. At the east edge of the Fox Hills sandstone the depth is believed to be about 2,000 feet. Thence, westward, there is an extensive region of Laramie ridges, buttes, and valleys, which, owing to their elevation and to the depth to the Dakota sandstone, appear to have no prospect of artesian waters. There are, however, sandstones in the Laramie formation which contain water at some localities and would probably furnish supplies for nonflowing wells. As the district has not been explored for underground waters no precise predictions can be made as to prospects.

Newcastle.—In the various borings which have been made for oil about Newcastle more or less water has been found in the Dakota-Lakota sandstones. Two miles west from the town there is a boring said to be 1,950 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. It 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 1,340 feet, but its record could not be obtained. Only a small flow of water was found, so mixed with oil that it was of no use. 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.

In two deep borings for oil a short distance south of Newcastle several hundred feet of the lower portion of the Graneros formation were penetrated. The following beds were reported.

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

	Feet.
Gravel, sand, and clay	50
Shale	150
Sand, with some oil (?)	15
Shale	188
Shale, with much gas	8
Sand, with gas	15
Shale	204
Sand, with oil and water; main "oil sand"	10
Shale, with a few layers of sandstone	160
Sandstone, with much water	30
No record	492

This boring is about a half-mile south-southwest of the depot, and was made several years ago. The main oil sand appears to be 630 feet below the surface 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, the following beds were reported:

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

	Feet.
Shale	150
Hard sandstone	14
Dark shale	239
Hard sandstone (concretion)	2
Light-colored shale	7
Dark shale	52
Very hard sandstone (concretion)	2
Gray shale	8
Very hard coarse sandstone	14
Very hard fine-grained rock	4
Shale	7
Sandstone, water, and oil; main "oil sand"	32
Dark shale	30
Sandstone	7
Shale and sandstone	5
Shale	200+
Sandstone (Dakota) to bottom, 900 feet.	

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 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.

Clifton.—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. A flowing well 4 miles north of Clifton, at the side of the railroad just south of Whoopup Creek, yields water too highly mineralized to be of any use. Its depth is 1,002 feet, with 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 record, as reported by the well drillers, is as follows:

Record of artesian well at Whoopup draw, near Clifton siding, Wyoming.

Feet.	
0- 12	soil.
12- 22	gravel.
22- 62	shale.
62- 82	sandstone.
82- 147	shale.
147- 157	sand.
157- 200	shale.
200- 255	sandstone.
255- 270	shale.
270- 290	sandstone.
290- 335	shale.
335- 347	sandstone.
347- 367	shale.
367- 382	sandstone.
382- 392	shale.
392- 417	sand.
417- 457	shale.
457- 537	sandstone.
537- 582	shale.
582- 642	sandstone.
642- 652	shale.
652- 682	sand.
682- 735	shale.
735- 757	sandstone.
757- 792	white shale.
792- 912	red shale.
912- 962	white sand.
962- 974	shale.
974- 994	sandstone.
994-1,002	shale.

The upper 20-foot sandstone bed appears to be in the lower part of the Graneros shales, which outcrop in the small ridge east of the well; it contained water. 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 Morrison and Sundance beds are not clearly indicated by the report of the borings, the sandstones reported at 582 and 652 feet probably being sandy portions of the Morrison formation. The 120 feet of red shale reported to extend from 792 to 912 feet probably is the usual red member of the upper part of the Sundance formation, but also includes some adjoining shales which are not red. The white sand and sandstone 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 water, but its depth could not be ascertained.

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

Analysis of artesian water from Jerome, Wyo.

	Grains per gallon.
Sodium chloride	10.7
Sodium sulphate	29.8
Magnesia sulphate	7.0
Lime sulphate	2.3
Magnesia carbonate	0.5

Cambria.—The deep boring at Cambria was begun just below the base of the Lakota sandstone and continued to a depth of 2,345 feet, with the purpose of testing all the formations down to the granite, which was expected to lie not far below 2,500 feet. When the boring had reached 2,345 feet, the owners concluded to test a water supply found at about 2,115 feet before going any farther. This water was found to yield 200 gallons a minute of entirely satisfactory quality, so that it has been utilized for supplying both Cambria and Newcastle. The record of the boring is given as follows:

Record of well at Cambria, Wyo.

Feet.	
0– 20	debris.
20– 150	shale, light gray and pinkish, from 65 to 72 feet.
150– 300	shale, light gray.
300– 350	shale, sandy, pinkish.
350– 379	shale, sandy, light gray.
379– 410	shale and sandstone, light gray.
410– 435	sandstone, soft buff.
435– 496	shale, dark greenish gray.
496– 504	gypsum.
504– 532	red clay.
532– 560	red and dark-gray clay.
560– 741	red clay.
741– 748	gypsum.
748– 806	red clay.
806– 810	gypsum.
810– 888	red clay, some gypsum.
888– 900	gypsum.
900– 988	red clay.
988–1,022	Minnekahta limestone.
1,022–1,096	red sandy clay, purplish at top.
1,096–1,147	sandstones, calcareous, buff to brown.
1,147–1,191	sandstones, buff.
1,191–1,222	sandstone, very calcareous, light brown and buff.
1,222–1,240	sandstone, calcareous, buff, red at top.
1,240–1,300	sandstone, calcareous, light pinkish buff.
1,300–1,390	sandstone, pink.
1,390–1,430	sandstone, calcareous, pink.
1,430–1,470	sandstone, pale pink.
1,470–1,496	sandstones and dark shale.
1,496–1,591	sandstones, light gray and buff, on a 4-foot layer of dark shale.
1,591–1,640	sandstones, calcareous, light gray and buff, on a 2-foot layer of dark shale.
1,640–1,713	sandstones, calcareous, gray and buff.
1,713–1,738	sandstones, light colored.
1,738–1,810	sandstones, gray, calcareous near top.
1,810–1,893	sandstones, chocolate brown.
1,893–1,947	sandstones, brown with layers of gray limestone.
1,947–2,345	limestone, white, pale buff, pinkish, and gray; water at 2,115 feet.

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. The well reached the base of the Sundance formation at 496 feet, passed through the distinctive gypsiferous red beds 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 as nearly as could be ascertained to 1,096 feet, and then a great thickness of sandstones, mainly calcareous, extending to 1,947 feet. The lowest beds are light-colored nearly pure limestone, of the Pahasapa formation. The water-bearing horizon may be the same as the one which yields the numerous springs, often of large volume, that appear at the contact of the Pahasapa limestone and the Minnelusa formation in the outcrop region east, apparently rising through fissures in the limestone. If so, it indicates the extent of the water horizon which furnishes the supply at Cambria. From the results of the Cambria boring it is probable that this water supply would be available in a wide area along the western slope of the Black Hills. It lies 1,125 feet below the base of the Spearfish red beds, so that it can be reached by wells in Red Valley from 1,125 to 1,500 feet deep. Outside of the Dakota Hogback Range the depth would be over 2,500 feet from the base of the Benton shale and correspondingly deeper to the west, so that it lies almost too deep to be reached at Newcastle and westward.

Thornton.—The well at Thornton is 980 feet deep and furnishes a satisfactory water supply for railroad use, but the land is too high for a flow. No record was obtained, but the boring begins high in the Benton group and appears to have reached the top of the Dakota sandstone.

ECONOMIC GEOLOGY.

COAL.

COLORADO.

Lignite coal occurs in the sandstone series that outcrops near the base of the Laramie formation along the foothills of the Front Range in a belt extending from near Greeley, 50 miles north of Denver, to Wildcat Mountain, 25 miles south of that city, and appears again, after an interval of 50 miles, in the vicinity of Colorado Springs. Farther south there is coal in the Laramie formation in the vicinity of Canyon, and there are extensive deposits in the northern portion of the great Raton coal field in the Walsenburg-Trinidad region.

Denver region.—Coal occurs in the Denver region about 200 feet above the base of the Laramie formation in beds which are steeply inclined near the base of the mountains, but lie nearly level out under the plains. At Scranton, 20 miles east of Denver, coal occurs in clays of the upper Laramie, a horizon usually barren of coal.

The coals of the Denver region have variations in character which appear to be closely related to their method of occurrence. The steeply inclined coals, to a depth of 300 feet, have a relatively higher specific gravity but a lower fuel

ratio than the prairie coals which, in their higher fuel ratio, as well as their higher water content, more closely resemble in appearance the bituminous coals of the East. The coal at Scranton in the upper Laramie is a true lignite with a high water content and a low fuel ratio.

From Ralston southward the Laramie formation dips steeply at angles varying from 70° to 80°, and the outcrops of the coal-bearing portion of the series lie in a narrow band about 250 feet wide. Workable coal beds are not continuous throughout this zone, but here and there seams thicken up and yield from 4 to 10 feet of coal. The workings in this region can not be profitably pushed more than 600 or 700 feet in depth. At 600 or 800 feet these steeply dipping strata begin to incline more and more gently until they stretch away under the plains. Workable coal undoubtedly occurs here and there under the plains, but it could be found only by expensive prospecting and at depths too great to be profitably worked.

North of Ralston and east of Boulder the dip becomes more gentle and a succession of folds and faults brings the coal within profitable working distance over a large area, in which many productive mines have been and are in operation. The coal is black, lustrous, and breaks in blocks. The beds have a thickness of from 4 to 10 feet, but often thicken to 14 feet.

The Scranton mine shaft shows two workable beds of coal, 6 feet and 7½ feet thick respectively, separated by 115 feet of shale and sandstone containing a 3-foot bed of coal.

Colorado Springs region.—Several mines are in operation north, east, and southeast of Colorado Springs on coal beds in the lower portion of the Laramie formation. The product is used mainly in the near-by settlements.

Canyon region.—Southeast of Canyon the Laramie forms an extensive mesa made up of a series of heavily bedded sandstones with intercalated shales; in the lower portion of this series there are workable beds of excellent coal.

Walsenburg-Trinidad region.—This region comprises the northern extension of the Raton field of New Mexico. The coal is found principally in the sandstone series at the base of the Laramie formation, the principal beds occurring less than 150 feet above the base, although valuable deposits also occur higher in the formation.

Toward the southern margin of this field in Colorado the coal is much changed or totally destroyed by igneous intrusions. The excellent coking qualities of some of the coal in this region is thought to be directly due to the influence of the intrusions. In those cases in which the lava sheet flowed on top of the ground it does not seem to have affected, to any great degree, the formation below, but when it was injected between the strata it changed into coking coal all lignite for 100 feet above and for 20 to 30 feet below.

In the vicinity of Walsenburg and Picton only the basal coals of the Laramie are worked. There are three workable beds within a space of 108 feet from the base of that formation. The lowest, with a thickness of 6 to 7 feet at Rouse and 39 inches on the Cuchara, thickens to 5 feet at Picton, and thins again northward. At Walsenburg there is another bed, 35 feet higher, consisting of a lower bench 48 inches, and an upper bench 36 to 40 inches, in thickness, separated by 2 inches of clay. Sixty feet above the lowest coal there is a 6½-foot seam, which thins to 4½ feet in the Picton district. The upper coal of the Laramie formation shows a thickness of 4 to 4½ feet near Rouse, but is not worked.

Trinidad region.—The Berwind-Aguilar-Engle group includes the coal within 100 feet of the base of the Laramie; sometimes there are two workable beds. At Engle and Gray Creek the coal has an average thickness of 6 to 7 feet, with a maximum of 11 feet. On the Purgatory it outcrops for a distance of 10 miles, with a thickness of 6 to 11 feet. There are large areas where the coal has been destroyed by igneous intrusions. The coal is in general a higher grade coking, semiblock coal, the "blocky" character as well as the purity diminishing to the northwest. This character of the coal favors its easy mining. The thicker coal beds usually result from the coalescing of two benches, due to the thinning out of a clay parting.

The Sorpis group is mined in Purgatory Valley only. There are two and occasionally three workable beds, with a maximum thickness of 7 feet at Sorpis. The upper and lower beds are separated by 75 feet of massive sandstone. The lower bed is 140 feet above the base of the Laramie formation. The coal is fairly clean and blocky.

In the "Morely beds," from 700 to 850 feet above the base of the Laramie, there is coal, which at Morely is 6 feet thick and in Smith and Zarcillo canyons ranges from 5 to 7 feet in thickness.

In a coaly series 1,000 to 1,100 feet above the base of the Laramie formation there are no workable beds and the coal is of bad quality.

The total area in Colorado in which the coal of the lower group is available and workable is probably over 800 square miles. The coal produced in 1902, along the Front Range, in Colorado, amounted to 6,029,024 tons, valued at $6,924,344.

WYOMING.

Cambria.—In the vicinity of Cambria, north of Newcastle, there is a coal basin of considerable extent, in which the principal bed is 7 feet or more in thickness and of excellent quality. Coal has been mined at Cambria for the last decade, during which time nearly 4,000,000 tons have been produced, having an average shipping value of about $1.50 per ton. The product in 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. It is connected with Newcastle by a branch line from the Burlington and Missouri Railroad. The coal underlies all of the plateau on the west side of Salt Creek, but the horizon has been cut through by Little Oil Creek, Oil Creek, Plum Creek, and their branches. To the south and west it dips beneath the surface, and passes deeply beneath a thick mass of overlying sandstone and shale. The coal in this area varies greatly in thickness and purity, but there is a large area in which it is 5 feet or more thick, attaining in places a thickness of over 7 feet. In the adjoining areas the thickness rapidly diminishes and the coal becomes extremely impure, in greater part giving place to dark carbonaceous shales. The principal basin of purer and thicker coal trends northeast and southwest, with its center passing through Cambria. To the northwest it has been entirely eroded away by the valley of Salt Creek, and, although some Lakota sandstone remains on the high ridges east of that valley, these appear not to be underlain by coal. To the southwest the coal slopes gently downward, at from 250 to 325 feet below the surface of the table, to the Mount Zion ranch, beyond which the sudden 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, Wyoming.

Feet.	
½	bony coal.
3	hard sandstone.
4	good coal.
½–1½	sandstone with coaly streaks.
2	coal.

This section is 150 feet below the top of the table; the overlying formation is sandstone and conglomerate; underneath there are 40 feet of very light-colored massive sandstones, in part cross-bedded, lying on Morrison shale. A mile northeast of this locality two shafts were sunk, in which 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 in which are the present workings; in these the thickness of the coal averages from 6 to 7 feet over a wide area. In Camp Canyon, northwest of Cambria, a trial pit exhibited the following section:

Section in Camp Canyon, Wyo.

Feet.	
2½–3	coal.
1½	shale and bone.
6	coal.

There are three mines: Jumbo, lying east of Cambria; Antelope No. 1, between Cambria and Camp Canyon; and Antelope No. 2, between Camp Canyon and Grant

Canyon. The two Antelope mines are connected by a continuous main gallery leading out to a breaker on the west side of the valley at Cambria, while the Jumbo mine is worked from the main drift opening on the east side of that valley. The dip is gentle to the southwest, so that the drainage of the mines is easily effected, the workings being 50 to 60 feet above the valleys which cut across the coal horizon.

A coal bed averaging 6 feet in thickness contains about 3,000,000 tons of coal per square mile, but there is considerable loss in working. There are now in the Cambria coal field about 10 square miles underlain by coal in beds averaging 5 feet or more in thickness, so situated that it is available for working. On this estimate the field should yield a total of 30,000,000 tons.

Hay Creek.—At Aladdin, on the north slope of the Black Hills, deposits of coal in the lower portion of the Lakota formation are worked to a considerable extent. A branch railroad extends down Hay Creek from the mines to connect with the Northwestern Railroad near Belle Fourche. The shipments in 1902 amounted to about 10,000 long tons, and the product is a good, soft, bituminous coal, suitable for locomotive and domestic use. The principal basin lies along and north of Hay Creek, thinning and merging into more impure beds laterally. Two principal beds, separated by about 10 to 12 feet of sandy shales, are worked—an upper, 3 to 5 feet thick, and a lower, 2 feet thick. The deposits are broken by a number of small faults, which add greatly to the difficulties of mining.

Skull Creek and Sundance.—In the region extending north from Cambria to Sundance there are local deposits of coal, which, however, are not continuous, and thicken and thin irregularly. Owing to the talus of sandstone blocks that accumulates on the slopes along the Lakota-Morrison outcrop, there is great difficulty in exploring the coal horizon, which is found bare only at a very few points. In some localities, where the coal appears to be absent, it may have weathered or burned out and the sandstone roof have closed down.

Coal has been mined to some extent for local use 2 miles southeast of the Holwell ranch and at several localities west of Sundance. Recently some openings have been made 3 miles west of Inyankara Mountain, exposing a thick deposit. The main opening southeast of Holwell's is on the southeast quarter of sec. 31, T. 48, R. 62. An adit about 115 feet in length has been run, exposing a face of coal 8½ feet thick, comprising 5 feet of hard pure coal, 1½ feet of bone merging into cannel coal, and at the base about 2 feet of pure, very hard coal which is found particularly valuable for blacksmiths' use. The upper coal contains considerable sulphur, a mineral of infrequent occurrence in the lower bed. Over the coal are about 2 feet of sandy shale overlain by a hard sandstone that makes an admirable roof. The floor is sandstone of the basal sandstone bed of the Lakota formation. The bone burns well, but leaves a large amount of white ash, and it also slacks readily. The dip is

gentle to the west. About 60 feet above the main deposit is a smaller one, varying from 1½ feet to 3 feet in thickness, of a mixture of clay, sand, and coal, too impure for fuel.

In the same quarter-section, about 500 feet west, is another adit 100 feet long on the main coal bed, which is here 6½ feet thick, and does not contain the bony deposit near its bottom. The coal is very firm and of excellent quality. It is overlain by 3 feet of light-colored sandy clay, capped by a thick mass of smooth uniform sandstone, which forms a good roof. The floor is a very hard sandstone, as in the other adit. Two miles to the southwest, on sec. 12, T. 47, R. 63, near the north line of the northwest quarter, is another adit 100 feet long. The same bed is exposed, here about 5 feet 4 inches thick and nearly all of pure coal of great hardness. The roof at this place is of sandstone, without the intervening shale. West of Holwell ranch, on the west side of Skull Creek, coal has been exposed at one or two points at the base of the sandstone cliffs, but its thickness and extent have not been ascertained, although apparently the deposit in this locality is of diminished thickness.

On the ridge west of Inyankara Mountain it is reported that the coal deposit near the base of the Lakota formation has a thickness of 9 feet, including a number of layers of shale and bone. West of Sundance the principal coal opening exposes a bed somewhat over 4 feet in thickness and of excellent quality.

Sheridan-Buffalo.—A large amount of excellent lignite is produced in the vicinity of Sheridan and Buffalo, from the middle or upper portion of the Laramie formation. The coal measures are of wide area, reaching continuously from Montana through central and eastern Sheridan and Johnson counties and western Crook and Converse counties. The coal beds are numerous, often attaining a thickness of from 6 to 14 feet, and the quality is good, though, unfortunately, the coal slacks when it is stored for much time. The principal mines are north and south of Sheridan and about Buffalo. A large amount is shipped by the Burlington and Missouri River Railroad to points in Nebraska and adjoining States.

Analyses of a number of Wyoming coals may be found in Bulletin No. 14, of the University of Wyoming agricultural college department, October, 1893.

Converse County.—The mine at Glenrock, in this county, has been in operation since 1888, and of later years has been worked to a moderate extent. The coal averages 6½ feet thick and is a pure lignite of excellent quality, finding a ready market along the line of the Wyoming branch of the Northwestern Railroad. It occurs in the lower portion of the Laramie formation, here dipping gently to the east.

Near Inez, 12 miles east of Glenrock, there is another mine producing from the lower portion of the Laramie formation. The bed is about five feet thick and dips from 12° to 18° to the northeast.

Other beds occur in lower horizons at this locality. Lignite is worked for local use near Douglas, on Shawnee Creek northeast of Douglas, and at a few other points in Converse County. The shipments from the county in 1901 are reported to have been slightly less than 50,000 long tons.

SOUTH DAKOTA.

The valuable coal deposits occurring in South Dakota are the lignites found in the northwest part of the State, in the region comprised between Belle Fourche and Little Missouri rivers, and for the most part underlain by the Laramie formation. The principal deposits are in Butte County, where some of their relations have been determined by Prof. J. E. Todd.[a] A vertical section about 500 feet in length at the south end of Cave Hills, in Butte County, is reported as showing ten beds of lignite ranging from 3 inches to 5 feet in thickness. Two of the beds, 5 feet in thickness and of good quality, appear to extend over a wide area in this vicinity, although there is a great variability in sections of Laramie formation a few miles apart.

One conspicuous feature in the upper part of the Laramie in the Cave Hills district is a thick development of massive sandstones, which thins toward the south and east. The upper bed of lignite ranges from 5 to 7 feet in thickness and is from 150 to 200 feet below these massive sandstones. It can be traced eastward from Cave Hills for 25 or 30 miles along the valley of the North Fork of Grand River, and probably may be correlated with the thick bed in the Slim Buttes sections and in the Long Pine Hills. The lower lignite bed lies from 100 to 125 feet below the upper. The two beds are found to a certainty in the same section in but one case, that mentioned above, but this is probably due to the fact that erosion around the other buttes has not cut deep enough to reach the lower bed. Two thick beds at Florman's coal camp, with comparatively little material between them, may represent the two beds in the Cave Hills section. In that case there is the same gradual thickening to the northwest of the clays and sands separating the coal beds that was noticed in the heavy sandstone above.

Edgemont.—The Lakota formation here contains local coal basins, but none of them have been found to contain any large amount of coal. The principal openings have been made on the north bank of Cheyenne River in NW. ¼ of NE. ¼ of sec. 24, R. 3 E., T. 9 S., where there are two tunnels 75 feet or more in length about 30 feet above the river, from which a small supply of coal has been obtained. The bed is 5 feet thick for some distance, but averages much less. It thins out to the east and gives place to sandstone, as may be plainly seen in the bluffs below the river, and grades into very coaly shale to the northwest. The mine product was in part

[a] Bull. South Dakota Geol. Survey No. 2, Vermilion, 1898.

of good quality light-weight bituminous coal, containing thin bony layers but only a moderate amount of pyrite. To the east but little trace of coal was found in the Lakota formation, though to the north there are occasional thin bodies of coal and considerable coaly shale in the river gorge. In Craven Canyon there was at one time a small mine, and from Coal Canyon there was also a small production.

NEBRASKA.

The question of obtaining a local supply of coal in Nebraska has excited much interest in that State, but no deposits have been found which promise to be of much value. The Carboniferous rocks in the southeast counties contain thin beds which have been worked slightly for local use, but their output has been small and in most cases unprofitable. Most of the efforts have been directed to prospecting for coal in dark shales at various points in formations which are known not to be coal bearing. The beds of coal associated with the sandstones and the shales included in the limestone series of the southeast part of the State are usually less than a foot thick in the outcrops, and in the various deep borings only thin beds have been found. In the northeast corner of the State, extending from Ponca in Dixon County to Homer and Jackson in Dakota County, the Dakota formation contains several beds of lignite from 6 inches to 2 feet in thickness, recently described by Mr. Burchard.[a] They occur in association with the sandstones and shales of the formation and have been explored by 2 shafts and 10 drill holes in the vicinity of Jackson. Some of the beds outcrop in the bluffs near Ponca and near Homer, and others lie below the river level. In most cases so much water is found in working the lignite as to prove a serious difficulty.

When freshly mined the lignite is very moist, and by drying in the air loses 15 to 18 per cent in weight. It is nearly black, splintery, and slacks readily on exposure. Air-dried samples are reported to contain in round numbers from 4 to 7 per cent of moisture, 31 to 54 per cent of volatile combustible matter, 26 to 49 per cent of fixed carbon, 9 to 16 per cent of ash, and on an average 1 per cent of sulphur.

PETROLEUM AND NATURAL GAS.

GENERAL CONDITIONS OF OCCURRENCE.

The petroleum of eastern Wyoming and of Colorado occurs mainly at two horizons and under very uniform conditions in both. The essential features appear to be a porous sandstone or sandy layer or series of layers included in a thick

[a] Burchard, E. F., Lignites of the middle and upper Missouri Valley: Bull. U. S. Geol. Survey No. 225, 1904, pp. 276-288.

mass of carbonaceous shale. The oil is developed from the carbonaceous material in the shale and passes in part into the porous sandy beds, which readily absorb and store it. Probably the movement is facilitated if not caused by pressure due to the weight of the overlying rocks, which forces the oil out of the relatively soft shales. Oil is found under these conditions in the sandy shales and sandstones in the Pierre shale at Boulder in Colorado, and on Salt Creek and in a sandstone in the the lower part of the Graneros (lower Benton) shales along the west slope of the Black Hills in Wyoming.

COLORADO.

Florence field.—The Florence oil field is unusual in occurring in a well-defined synclinal basin of which Florence, near which most of the wells have been drilled, is about the center. This basin is a local development of the northern end of the Canyon-Florence syncline, which lies west of the great échelon fold that carries the face of Front Range 25 miles to the east. The basin is elliptical in shape, its longest diameter lying in a north-northwest direction, with a length of 14 miles and a width of 8 miles. Aside from the Laramie-capped mesa southwest and west of Florence, the surface formations of the basin are mainly Pierre shale and Fox Hills; it is the former of these which yields the oil. The Pierre has an estimated thickness of 4,450 feet, consisting chiefly of shales. Coarse materials are wanting, but there are numerous beds of fine-grained sandy shale which occur either as a succession of layers or as lenticular masses of widely varying lateral extent. The three zones in which these strata have yielded oil are at 1,600 feet, at from 1,600 to 2,000 feet, and at from 2,600 to 2,800 feet; recent developments have shown a rich horizon at 3,650 feet. It is to the lack of continuity of the sandy shale beds that the ability to absorb and store the oil derived from the softer shales is due. Another fact that falls into line with this is that for the most part the wells are free from water, whether "dry" originally or after the exhaustion of the oil. Were the beds continuous and did they reach the surface around the rim of the basin, water would enter them, and, by hydrostatic pressure, displace the oil.

The Florence oil field is a very old one for the western country, dating from 1862, although of commercial importance only since the early eighties. The yield of the wells has varied from 5 to 350 barrels per day. For the most part, after a longer or shorter interval, a gradual and uniform decrease sets in, though in some instances there has been an increase, and still other wells, pumped dry, have, after a rest, recovered their normal yield. The well known as "No. 49," drilled in 1890, which for several years flowed 350 barrels per day, still yields 40 barrels, and has nearly a million barrels to its credit.

At the close of 1902 there were 72 producing wells in the Florence field. The

production for that year was 385,901 barrels. The value of the total product of the State, of which the Florence field furnished nearly 98 per cent, was $484,683.

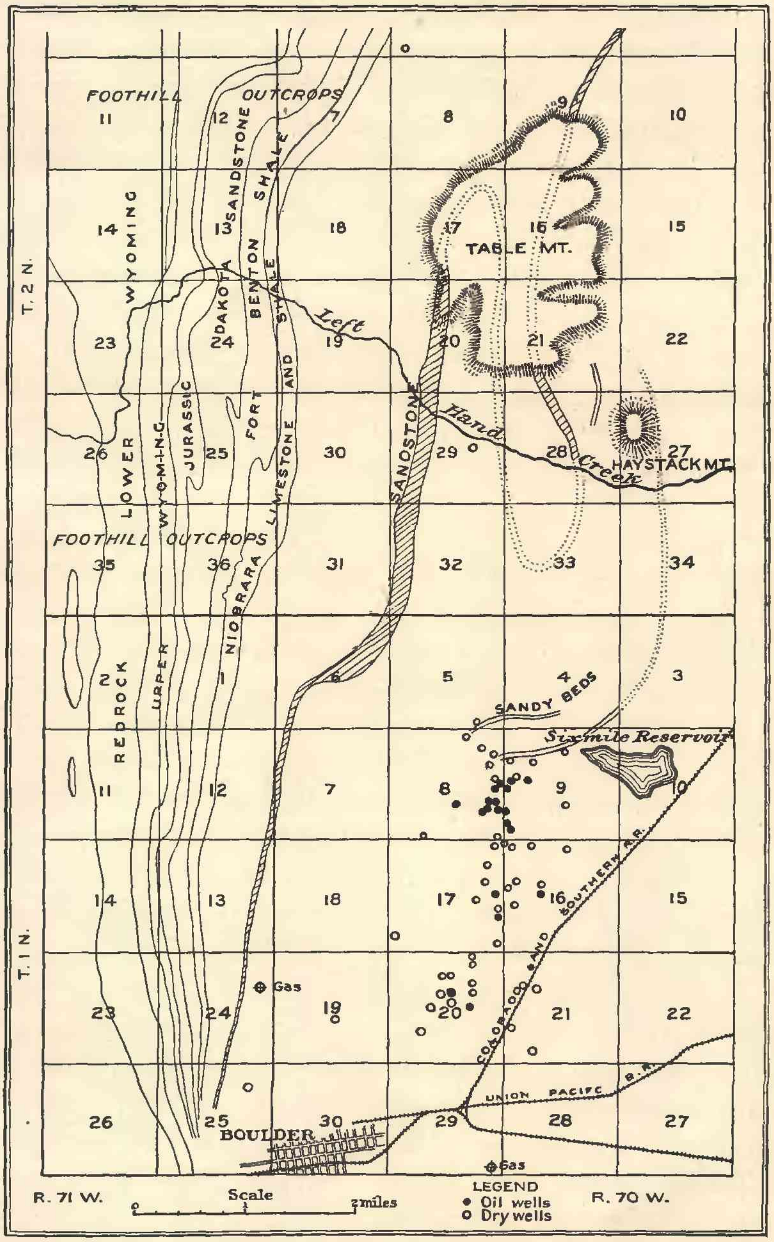


FIG. 16.—Map of the Boulder oil field, showing distribution of representative wells.

Boulder oil field.[a]—The productive territory of the Boulder field, excluding two gas wells which are apparently but indirectly connected with it, covers an area 2

[a] Fenneman, N. M., the Boulder, Colo., oil field, Bull. U. S. Geol. Survey No. 213, 1903, p. 322; Structure of the Boulder oil field, Bull. U. S. Geol. Survey No. 225, 1904, p. 383.

miles in length by 1 in width, lying about 3 miles northeast of Boulder and the same distance east of the foothills of the Front Range.

The source of the oil and gas, as well as the reservoir, is found in the Pierre formation, the former in the bituminous shales and the latter in the extremely variable and local sandy members of the formation. The Pierre in the region is several thousand feet thick, and in it since 1901 a hundred wells have been sunk to depths varying from 200 to 3,400 feet. Of these, 18 wells produced oil during 1903 and previously, and two produced more or less gas, though not of sufficient importance to be utilized.

The production of the field for 1902 was 11,000 barrels, and for 1903, 39,000 barrels. The oil brings $1.10 per barrel and is practically all taken by the refinery at Florence, Colo. The quality of the Boulder oil is claimed to be superior to that of any other west of Mississipi River.

So far as the structure of the field is concerned, the oil territory may possibly have some relation to the attenuated end of one of the smaller folds *en échelon* which characterize the foothills of Front Range from Boulder north. As these folds pass from the harder upturned outcrops of the formations of the foothills to the softer shales of the more level Pierre, their effect upon the topography becomes inconspicuous, and their existence can be made out only from the drill records and obscure outcrops. On the map it is shown that the outcrop of sandstone, in passing north from the vicinity of half a mile west of Boulder, widens as the dip decreases, and, doubling upon itself in Table Mountain, 10 miles north of Boulder, with a recurrent S curve 3 miles in length, again resumes its northward course. By the time the flexure which causes this sinuosity of outcrop reaches the oil field, it is so low that it merely results in an arrest of the easterly dip, forming a bench. It is along the easterly side of this bench that the string of producing wells is located. Transverse flexures are supposed to cut this oil belt into individual pools.

WYOMING.

Petroleum occurs at a number of localities in eastern Wyoming, but in most cases the quantity available has proved to be very small. The only locality which yields a sufficient amouut of oil for shipment is Salt Creek. The school of mines of the University of Wyoming has published a number of bulletins of a "Petroleum Series," describing the principal oil fields of the State, to which those interested are referred for detailed information.

Salt Creek.—This oil field is situated on Salt Creek, a branch of Powder River, in the northern portion of Natrona County. The principal developments are in Tps. 40 and 41, Rs. 78, 79, and 80, the product being hauled to Casper, 50 miles

south. Oil springs were discovered in Salt Creek Valley at an early date, and the first successful well drilled in 1889; others have since been sunk at intervals by the original company and by two later ones. So far as reported the wells vary in depth from 800 to 1,200 feet and are 10 in number. The average yield is about 20 barrels a day, the total for 1902 being reported as 6,253 barrels and the total output since 1894 as about 40,000 barrels.

The oil appears to occur in sandstone layers included in the Pierre shale, Fox Hills fossils having been reported a thousand feet above the producing horizon. The following record is given of one of the wells:

Record of oil well, Salt Creek, Wyoming.

Feet.	
0– 20	surface wash.
20–350	bluish shale.
350–400	sandstone, some water.
400–780	bluish shale.
780–785	fire clay.
785–865	dark shale.
865–900	gray sandstone, artesian water.
900–940	gray sandstone, dry.
940–980	gray sandstone, oil bearing.

The oil consists mostly of lubricants.

Powder River.—Considerable oil issues in springs on the headwaters of some small branches of South Fork of Powder River, in the southern portion of Johnson County and adjoining northern portion of Natrona County, about 60 miles northwest of Casper. Several wells have been sunk, but they have not yielded oil, although a small supply has been obtained for several years past from pits 30 to 50 feet deep. It is reported that the oil is derived from Dakota sandstone and also from underlying sandstones, which here rise in a local uplift of considerable prominence. One of the wells is reported to have been drilled to a depth of 1,010 feet; it passed far below the oil-bearing beds, a common mistake of those who explore for oil. A stream of sulphurous water flows from the boring. Like most of the eastern Wyoming oil, the product of this locality is a high-grade lubricant.

Newcastle.—In the vicinity of the town of Newcastle explorations to develop an oil field have been in progress for several years. Small supplies of excellent petroleum have been obtained from borings and from two oil springs. The oil is very heavy, and even in its crude state is a high-grade lubricant. It occurs in a sandstone in the lower portion of the Graneros formation, which is extensively developed in the vicinity of Newcastle. The sandstone lies 250 to 275 feet above the Dakota sandstone, from which it is separated by the basal black shales of the

formation. The Graneros sandstone here varies in thickness from 10 to 30 feet in greater part, and its surface outcrops give rise to ridges of considerable prominence. The first line of ridges lying west-northwest of Newcastle owe their prominence to the locally increased thickness and hardness of this sandstone. Where the rock has been exposed to the weather it is a hard, moderately fine-grained, light-gray sandstone in massive beds. Below the surface it is softer in texture, buff or brown in color, and usually strongly charged with petroleum. At two localities the oil oozes out of the sandstone and collects in springs, which for many years have yielded a small supply of oil for local use. One of these springs is 2¼ miles due west of Newcastle, just north of the railroad, and the other is 2 miles farther northwest and slightly farther north of the railroad. At these points the oil-bearing sandstone passes beneath the surface in small draws, and the escaping oil accumulates in the loose materials adjacent. Cisterns have been constructed in such manner as to catch the oil—a few gallons a week—which finds ready sale as a lubricant. Several attempts have been made to develop the oil sand in its extension underground by means of wells in the region west and southwest of Newcastle, but so far these operations have not yielded a supply of oil. In most cases the oil horizon has been passed through and the boring uselessly extended far into underlying shales and sandstones. As the Graneros sandstone appears to contain considerable oil in the vicinity of the oil springs, and as it underlies a wide area about Newcastle, it is difficult to understand why the wells have not obtained more encouraging results. From the statements made by the promoters of the enterprise, it seems probable that the oil sand was not always recognized in the boring operations, and at any rate was not adequately tested. The oil is very viscid, and should hardly be expected to flow from wells at any point in the area, but possibly by dynamiting and pumping a supply can be obtained.

The sections in fig. 17 show the conditions under which the oil sand passes underground, the thickness and nature of the overlying materials, and the location of some of the wells which have been bored. These formations are relatively uniform in thickness and invariably lie in regular sequence. In surface exposures they are all distinctive in appearance, particularly the bed of Greenhorn limestone, which lies 800 feet above the oil sand; the thin sandstone layers, 300 feet higher; and the Niobrara chalk, which begins about 1,500 feet above. In sections *A* and *B* may be seen the manner in which the formations dip steeply beneath the surface in the vicinity of the railroad, so that to the southeast the oil sand soon lies under 2,500 feet or more of shales. Approaching Newcastle, as shown in sections 3 and 4, the dips diminish rapidly, and there is a basin of considerable size in which the formations are spread out widely. The distinctive fossils of the Greenhorn limestone and of the Niobrara chalk are shown in Pl. XXIV.

The deepest boring in the region, the one shown in section 3, has a depth of 1,950 feet. It passed through the oil sand at a depth of about 100 feet and then penetrated the basal Graneros shales, the Dakota and Lakota sandstones, and the underlying shales and Red Beds. From the Lakota sandstone it obtained a flow of water which is still running out of the well. Only a small amount of oil was observed.

The well a half mile southwest of Newcastle, 1,340 feet deep, penetrated the oil

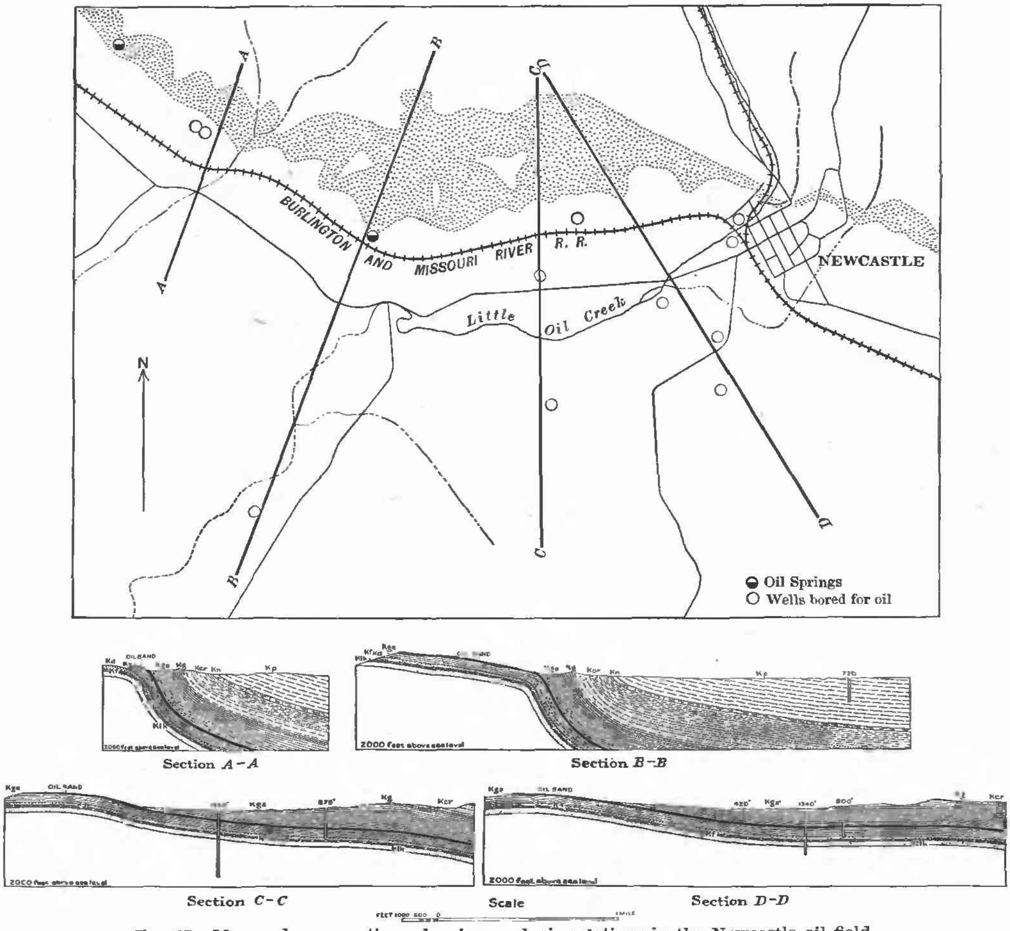


FIG. 17.—Map and cross sections showing geologic relations in the Newcastle oil field.

sand at a somewhat greater depth than the first well. Oil is brought up by water still flowing out of the casing from the underlying sandstones. The 420-foot well, which is a short distance northwest of the 1,340-foot well, is said to have just reached the top of the oil sand, where a promising showing was observed. The 720-foot well, 3½ miles southwest of Newcastle, as shown in section 2, was entirely in shale, and failed to reach the oil-bearing sandstone by about 2,000 feet. It is greatly to be

regretted that this boring was not continued sufficiently deep to test the contents of the oil sand, where it lies deeply buried and so far from surface outcrop as to permit the accumulation of considerable head if there is any oil present.

In the vicinity of section 1 three deep borings have been made in the steep-dipping beds near the outcrop of the sandstone, but the results so far have not been successful, although the borings are midway between the two oil springs described above. A well nearly a mile south of Newcastle was completed in 1902,

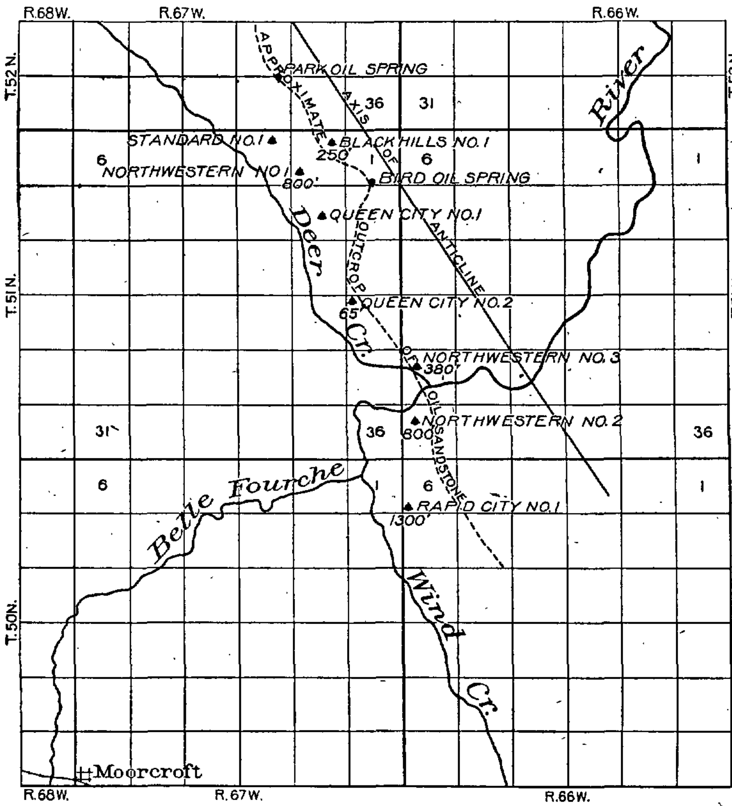


FIG. 18.—Map of oil district northwest of Moorcroft, Wyo.

but found only a very small supply of oil in the oil sand at a depth of 500 to 531 feet. It was drilled to 900 feet, passing into the Dakota sandstone, and, as was to be expected, obtained no oil from that formation. Another well a mile west of the last was sunk to 879 feet, and, although obtaining a large flow of water found no indications of an oil supply.

The prospects of the Newcastle oil field as an oil producer appear not to be good, but it is believed that the capabilities of the oil-bearing sand have not been

adequately tested, and further exploration may be warranted. The oil-sand horizon extends south nearly to Clifton and is over 30 feet thick near the LAK ranch. To the north it thins out near Skull Creek. Whether it contains oil away from the immediate vicinity of Newcastle remains to be ascertained by borings.

Moorcroft.—At the northwest margin of the Black Hills uplift, 15 miles northeast of Moorcroft, the Dakota sandstone contains oil, which appears in a number of springs. Some years ago several wells were sunk to intersect the sandstone in its underground extension; one of these, 306 feet deep, is reported to have yielded 5 barrels a day for a while. Other deeper wells obtained no satisfactory supply of oil, and some of them were sunk in such manner that they could not possibly reach the oil sand. Two of the borings, 800 and 1,300 feet deep, respectively, were bored on the south side of Belle Fourche River.

The locations of the springs and wells at this locality are shown in fig. 18. Queen City wells, Nos. 1 and 2, and Northwestern, No. 2, obtained a small amount of oil, but the others shown on the map obtained none.

Douglas.—Some indications of oil are reported in the vicinity of La Prele Creek, west of Douglas, and a number of wells have been sunk, but the results so far are not encouraging. In one well, at a depth of 500 feet, a considerable volume of gas was found under a pressure of 300 pounds to the square inch, and is now being utilized on some of the adjacent ranches. For several years a small amount of oil has been observed in sandstone outcrops, into which a small tunnel has been run for some distance.

CENTRAL AND WESTERN KANSAS.

Only a small portion of the Kansas oil and gas field, as at present known, extends west of the ninety-sixth meridian. A small field, in which there were in 1901 eight producing wells, lies about the town of Peru, Chautauqua County. Five yield oil, one oil and gas, and two gas only. The gas is used locally, while the oil is shipped to the refinery at Neodesha. Between Peru and Sedan six wells were drilled, three of which yielded oil in small quantities, but as they were not considered profitable the casing was withdrawn and the wells abandoned. Prospect wells have been sunk at Elk Falls, Howard, Winfield, Madison, and Emporia, and while some show some gas there have been no producers.

The source of the gas lies in the bituminous Cherokee shales, the lowest member of the Kansas coal measures. These, of course, extend westward beneath the region in question, and there is always a possibility of finding a local reservoir of oil or gas. The most recent development of the Kansas field has been the discovery of a rich local basin about Bolton, some 15 miles east of Peru.

SOUTH DAKOTA AND NEBRASKA.

Although numerous deep wells have been bored in these two States, none of them have yielded any petroleum of value, and only in a small area in central South Dakota has any gas been found. Among the sedimentary series underlying the district there are sandstones and limestones such as yield gas and oil in other regions, and many of them have been well tested without favorable results. The well at the salt lake near Lincoln appears to have gone through the entire sedimentary series and obtained nothing but salt water. Other deep borings in the older rocks in the southeast part of the State have found only a few thin layers of coal. The Dakota sandstone has been well explored in the eastern part of the State, and, although a small amount of oil was reported at one locality north of Omaha, apparently no valuable supplies were obtainable. The Pierre shales have been penetrated by a number of wells at various localities, but they appear not to contain such sandstones as carry oil in the Boulder, Florence, and Wyoming fields.

Across western and central Nebraska there extends an anticlinal axis, which is clearly defined in the vicinity of Stockville and a short distance north and east of Chadron, and is supposed to be continuous under the intervening district, though heavily covered by Tertiary formations. If there is oil in western Nebraska the best prospects for obtaining it would be along this uplift, for in many regions the oil occurs in largest amounts along anticlinal axes. In the region north of Chadron and along Republican Valley near Indianola borings 2,000 feet deep would probably test the strata satisfactorily. It is believed, however, from the character of the rocks where they are uplifted to the north and the west, that the prospects for oil in western Nebraska are not encouraging.

In South Dakota the numerous deep artesian wells, many of them extending to the crystalline bed rock, have found no petroleum. The Dakota sandstone, from which the water supply is obtained, is entirely barren of oil, and the great series of overlying shales, although favorable in general character for the production of oil, and containing sandstone beds in which oil might be stored, have yielded no indications of this material. West of the Missouri the strata have not been extensively explored, and it is possible that the Pierre shale, to the west, may contain oil-bearing sandstones. Judging from the character of the formation along the Black Hills uplift, however, it is probable that they do not contain such sandstones as yield oil in the Florence, Boulder, and Wyoming fields.

At Pierre and in several wells north of that town a moderate amount of gas has been found and utilized to some extent. The supply is not large, and the district appears to be very limited in extent.

SALT.

KANSAS.[a]

Salt occurs in Kansas in three forms—as brines in salt springs and marshes, as brines from wells reaching into the Permian and Carboniferous shales, and as rock salt. These occurrences form a belt across the State from north to south about two counties wide, reaching from Republic County on the north to Harper County on the south.

Marshes and springs.—North of the center of the State the salt occurs mostly in springs and marshes. The first salt manufactured in the State was made from the incrustation and from the brine of the Tuthill Marsh, in Republic County. There are two other salt marshes in the southwest part of Republic County and adjoining counties, one in the south part of Mitchell County, two in the north part of Lincoln County, and two in the northeast part of Stafford County. Three springs in the Cretaceous in the north edge of Lincoln County yield, respectively, 891, 1,008, and 1,023 grains of salt to the gallon, with considerable sulphates, but these waters are not used. The Waconda, or Great Spirit, Spring, in the northwest portion of Mitchell County, contains per gallon 775 grains of salt, 206 grains of sodium sulphate, 66 grains of magnesia sulphate, 41 grains of magnesia carbonate, and 31 grains of lime carbonate. It forms a deep crater-shaped pool in the top of a circular mound, which has probably been built up by the spring deposits. There is no outlet to the spring, the overflow escaping through minute crevices at the base of the mound. It is in upper Cretaceous. A salt spring at Solomon, Dickinson County, led to sinking several wells in which brine of good quantity and quality was found at from 35 to 100 feet. Salt has been made here for a long time by the solar process, i. e., by evaporation by the sun's rays. Geuda Springs, on the line between Sumner and Cowley counties, comprises seven springs yielding from 100 to 450 gallons per hour. The principal ingredient of these is salt, ranging from 358 to 1,057 grains per gallon, the water being derived largely from the Tertiary.

In 1878 a circular area in the Tertiary, 200 feet in diameter, in Meade County, suddenly sank over a hundred feet and the opening filled with salt water, which rose to within 25 feet of the surface. It contains about 4¼ per cent of salt.

Brine wells.—In Kansas, west of the ninety-sixth meridian, there are many salt wells, some of which are used in making salt. At St. Mary and at Wamego, in Pottawatomie County, artesian flows of brine were struck, which Professor Hay thinks may, in the former case, come from a bed of rock salt. If so, it is from a rock-salt horizon below the Permian.

[a] Compiled by Mr. C. E. Siebenthal from reports of the geological survey of Kansas.

Salt wells in west Kansas.

Location.	Depth.	Chloride of sodium per gallon.	Source.
	Feet.	*Grains.*	
Abilene	1,260	8,352	Lower Carboniferous.
Marion	150	3,191	Permian.
McPherson		10,472	
Newton			
Madison		392	
Eureka	140	400	Upper Carboniferous.
Wichita	1,975		
Arkansas City	250	1,809	Permian.

Rock salt.—Rock salt was first discovered in Kansas in a deep well at Ellsworth, in August, 1887, and later in the same year at Hutchinson, at Kingman, at Lyons, and at Anthony, and in 1888 at Nickerson, at Great Bend, and at Sterling. Many other deep wells have since been put down, developing the limits of the territory as shaded on Pl. LXX. Some details of these wells are as follows:

At Wilson, in a prospect well, salt was found at a depth of 835 feet continuing down for 270 feet, followed below by an alternation of shale, gypsum, and limestone to 1,385 feet.

At Ellsworth solid rock salt begins at a depth of 730 feet and continues to 880 feet, except as interrupted at 785 feet by 5 feet of shale. Sixty feet below the lower salt, separated from it by light and dark shales, is a 30-foot bed of gypsum.

At Great Bend a boring for water entered a salt bed at 1,202 feet and penetrated it for 163 feet.

At Little River a salt bed was reached at 585 feet and continued, with alternations of shale, to a depth of 964 feet. There are five of the shale beds ranging from 4 to 10 feet in thickness.

At Sterling salt was struck at 700 feet and continued, with many alternations of shale, to the depth of 980 feet.

At Nickerson there is no record.

Hutchinson is the center of the salt industry of Kansas, producing 90 per cent of the total output of the State. It is all obtained from wells. Salt is found at a depth of 482 feet and continues, with intercalated beds of shale, to 810 feet, below which there is a succession of shale, gypsum, limestone, and sandstone beds to 1,307 feet.

At Arlington a salt-bearing series has been found to extend from a depth of 600 feet to 1,000 feet without reaching its base.

At Pratt there is no record.

At Rago the salt bed was struck at about 900 feet and penetrated for 100 feet or more.

At Anthony, at a depth of 946 feet, the drill struck a bed of rock salt 275 feet thick, below which came 139 feet of sand with a small flow of gas, and beneath this a thickness of 139 feet of shale and rock salt. The remainder of the hole to 2,335 feet was a succession of shales, gypsum, limestone, etc.

Wellington, being near the east limit of the great salt bed, struck its attenuated edge at a shallow depth, reaching salt at 240 feet and penetrating it for 50 feet.

Salt mines.—At Lyons a shaft 7 by 16 feet was sunk to a depth of 1,005 feet, passing through 212 feet of salt measures. For an accurate section of the shaft, showing the alternation and mixture of salt and shale in the salt measures, see Mineral Resources of Kansas for 1898, page 93. The mine is equipped with channeling machines, air drills, and compressors, and works an 18-foot bed by the room-and-pillar method. The product is crushed, graded, and shipped without refining. A second shaft put down to the salt bed has been abandoned.

At Kanopolis there is a shaft 8 by 22 feet, having the usual two hoisting compartments and the air shaft. The bed worked is 10 feet in thickness with a good roof, permitting the rooms to be 30 feet wide. The salt measures reach from 645 feet to 880 feet, being richest from 665 to 855 feet, through which distance the record of the prospect well shows salt in bright crystals.

At Kingman two shafts, one 4½ by 8½ feet and the other 14 by 16 feet, have been sunk, but at present both are abandoned. Four plants operating wells have also been in existence at Kingman, but at present two only are in operation. The salt measures extend from 665 feet to 1,028 feet in depth and are made up of alternations of salt, shale, and limestone. Several beds of gypsum were penetrated before reaching the salt, but none is noted below it.

Geologic position.—The rock-salt bed in Kansas occupies a position in the Kansas Permian between the Marion shales and limestones below and the Wellington shales above, so that in point of time their deposition was later than that of the gypsum of the northern, but earlier than that of the central, area. Various well records show beds of gypsum above and below the salt measures. The extent of the bed is shown on the map Pl. LXX, more definitely on the east, less so on the west.

Production.—The Kansas salt production for 1901 was 2,087,791 barrels, valued at $614,365, being 10.2 per cent of the total production in the United States. For 1902 the production was 2,158,486 barrels, valued at $514,401.

EASTERN WYOMING.

The salt springs at the head of Salt Creek issue in large volume from the red shales of the Spearfish formation, giving rise to a creek that flows for many miles and finally empties into Stockade Beaver Creek. For a number of years the waters have been evaporated for the purpose of obtaining salt for local use. It is possible, however, that the output could be increased and a moderate amount of salt of good quality obtained for shipment. An analysis of the brine, made in the laboratory of the Geological Survey by Mr. Steiger, gave the following results in parts per hundred:

Analysis of brine from salt from Salt Creek, Wyoming.

	Per cent.
Lime	0.20
Magnesia	0.04
Soda	2.73
SO_3	0.36
Chlorine	3.15
Bromine	None.
Iodine	None.
	6.48
Less O=Cl	0.71
	5.77

This is equal to a little more than 5 per cent of sodium chloride, or common salt. The flow from the spring is about a gallon a second, which is equivalent to a production of about 35,000 pounds of salt every twenty-four hours.

NEBRASKA.

Salt occurs in moderate amount in the valley of Salt Creek at Lincoln, and was formerly worked to a moderate extent. In the creek flats there are several small springs or seeps of salt water giving rise to small marshes in which there is a considerable thickness of a mixture of salt, clay, and vegetable matter. The deposits are now of no commercial importance.

GYPSUM.

BLACK HILLS.

In the Black Hills uplift an elliptical outcrop of the Red Beds is brought to the surface in Red Valley, which surrounds the high ridges and plateaus of the central portion of the hills. The area is about 100 miles long by 50 miles wide, and the outcrop zone has an average width of 3 miles, except in a few districts where the rocks dip steeply, where it is much narrower. The Red Beds

have been designated the Spearfish formation. While they have usually been classed in the Triassic period, there is evidence that they may represent the Permian. The formation consists mainly of red sandy shales, with included beds of gypsum at various horizons, some of which are continuous for long distances, while others are of local occurrence. The thickness of the deposits varies greatly; in some of the sections over 30 feet of pure white gypsum occur, and nearly throughout the outcrop of the formation there are deposits of sufficient thickness and extent to have commercial value.

Gypsum is a prominent feature about Hot Springs, where the principal beds occur about 60 feet above the base of the formation and have a thickness of 33½ feet, exclusive of the 10-foot parting of shale between them. This thickness diminishes somewhat to the north and rapidly to the south. The following section is exposed on Cold Brook, a short distance west of Hot Springs:

Section of gypsum deposits on Cold Brook, South Dakota.

	Feet.
Red shale and thin beds of gypsum	5
Gypsum	15
Red shale with thin beds of gypsum	10
Gypsum	4½
Red clay	1
Gypsum	14
Red clay	2
Gypsum with clay partings	5
Red shale with gypsum veins	10
Gypsum	3
Red clay with gypsum veins and nodules	7
Irregular breccia of gypsum	2
Red clay with gypsum veins	13
Red clay with a thin gypsum bed	3
Banded red and white gypsum	4

In the region north of Edgemont the principal bed of gypsum lies about 80 feet above the base of the Spearfish formation and is continuous for many miles, with a thickness of 25 feet in most places. It is exposed extensively about Cascade Springs and in Red Valley east and west of Minnekahta station.

The following analysis of a typical gypsum from near Cascade Springs was made by Mr. Steiger in the laboratory of the United States Geological Survey:

Analysis of gypsum from near Cascade Springs, S. Dak.

	Per cent.
Lime, CaO	32.44
Magnesia, MgO	.33
Alumina, Al_2O_3	.12
Silica, SiO_2	.10
Sulphuric acid, SO_3	45.45
Carbonic acid, CO_2	.85
Water, H_2O	20.80
Total	100.09

East of Newcastle there are thick beds of gypsum in the lower portion of the Spearfish formation and a thick deposit at its top extending over an area of considerable size. The lower beds have a thickness of 40 feet at some localities, and the upper bed of 30 feet. About Sundance and in the northern portion of the Black Hills there is a continuous deposit of gypsum about 80 feet above the base of the formation, extending around the northwestern portion of the hills and thence south for many miles. About Rapid the gypsum beds vary considerably in thickness, but 10 feet is the average. Portions of Red Valley, along the eastern side of the Black Hills, are filled with thick deposits of White River beds, which cover up the Spearfish formation; but exposures are seen at intervals, in which the usual occurrence of gypsum is exhibited.

Owing to remoteness from market the gypsum deposits of the Black Hills have not been utilized to any great extent. A plaster mill at Hot Springs has been operated at intervals, and its very satisfactory product has found ready market, but the expense of long shipment has greatly diminished the profits. Plaster of Paris has been produced to a moderate extent at Sturgis, especially for local use in Deadwood, Lead, and the other settlements of the northern Black Hills.

KANSAS.

The Kansas gypsum deposits extend in a belt across the east-middle portion of the State from northeast to southwest, in line with deposits in Iowa and with those to the southwest. During Permian times the northeast quarter of the State was part of an interior land mass, while the remainder was covered by waters of the sea. In pools and in inclosed arms of the sea along the shallow, shifting coast line the rapid evaporation of that arid time caused the deposition of extensive beds of gypsum and rock salt. The main gypsum deposits lie in three areas, with smaller outliers. The age of these deposits is successively younger from north to south, and their

stratigraphic relations are likewise different, shale becoming increasingly more abundant in the younger deposits.

The gypsum is found in the original deposits, interstratified with limestone and shale, as well as in secondary derivatives of the original deposits, i. e., gypsum earth, consisting of gypsum and clay intermingled. The gypsum-earth deposits are of two classes. Those that have proved the most important have originated as spring, or bog, deposits where exuding waters carried the calcium sulphate in solution and redeposited it on the surface. Such deposits are marked by the absence of any fragments of the original gypsum rock, by the perfection of the microscopic gypsum crystals, and by the admixture of sand and clay. The presence of shells of recent types in the bottom of such deposits shows their recent origin. Another class of gypsum-earth deposits is simply the residual clay resulting from the weathering and disintegration of a rock-gypsum stratum. In the latter case the clay gives a pleasing terra-cotta color to the plaster, and in both cases the clay and sand act as retarders and increase the value of the cement plaster.

The northernmost of the gypsum areas is in Marshall County. The gypsum stratum here has a thickness of from 8 to 9 feet and is separated from the Cottonwood limestone, the top of the Carboniferous, by 30 feet of shale and limestone. In all cases here the gypsum lies upon a limestone bed rock and is overlain by shale. The gypsum occurs as a mottled-gray rock, of a granular texture, with crystallized fibers and plates, and an irregular fracture. In many of the mines in this area the upper surface of the gypsum lies in rounded masses, upon which the sands and shales rest unconformably, showing erosion at the close of the deposition of the gypsum.

The central gypsum area is in Salina and Dickinson counties, about Gypsum City and Hope. There are two well-marked horizons of gypsum rock in this area, and perhaps a third. The bed quarried at Solomon, 5 feet thick, increases to 14 feet in the shaft at Hope. The next horizon above, at Hope, is 5 feet in thickness and 100 feet above the lower bed.

The gypsum of the lower horizon is white, compact, granular, with scattered crystals of darker selenite, some as much as 2 inches long, the rounded edges of which indicate partial resorption. From this the inference is drawn that evaporation must have proceeded very slowly to permit the growth of large crystals and that the water was again freshened so that the crystals were partially dissolved. In this area the secondary deposits of gypsum earth are more valuable than the rock deposits on account of ease in working. The material is a granular earth found in low swampy ground, dark colored when freshly dug, but drying to light ash gray.

The southern gypsum area lies between Medicine Lodge and Coldwater, in Barber, Comanche, and Kiowa counties, and is continuous with the great deposits that extend through Oklahoma and disappear beneath the Tertiary of Texas. There

are also various isolated deposits both of rock gypsum and gypsum earth between the middle and southern areas in Kansas. The gypsum of this area is wholly rock gypsum and is associated with red sandstone and red shales. The gypsum sheet, 20 to 30 feet in thickness, forms the cap rock of the hills in the vicinity of Medicine Lodge, dipping lower and disappearing beneath the Tertiary on the northwest. Near Big Gypsum Cave an upper ledge of gypsum, 15 feet in thickness, is separated from the main ledge below by 15 feet of shale.

In 1901 nine mills made plaster and other products from the rock-gypsum and gypsum-earth deposits of Kansas, producing 49,217 tons, valued at $209,172, not including the product of the Medicine Lodge mill.

COLORADO.

The Chugwater formation contains extensive deposits of gypsum at intervals along the foothills of the Rocky Mountain Front Range, but the deposits have not yet been worked to any great extent. There is a deposit 30 feet thick at the top of the formation just east of the gateway of the Garden of the Gods, shown in the foreground of Pl. I, and in Perry Park a deposit near the base 81 feet thick. At most localities the amount is very much less, but deposits from 5 to 20 feet in thickness are of frequent occurrence.

In the Purgatory and other canyons in southeast Colorado there are deposits of gypsum at the top of the Red Beds, some of which are sufficiently thick to be of economic importance.

WYOMING.

The Chugwater formation in the Black Hills, Laramie, and Bighorn uplifts contains deposits of gypsum which often are from 15 to 20 feet in thickness. Those of the Black Hills area have been described on a previous page. The principal deposits in the Laramie range are on the headwaters of La Bonte Creek, where a very large amount of gypsum is available.

CEMENT.

Until recent years all the cement used in the Great Plains region was shipped from distant points, but now much of the local demand is supplied from works at Yankton and Florence. These works are said to produce annually about 120,000 barrels of highly satisfactory quality. The material used is chalk rock of the Niobrara formation, mixed with clay or shale. There is a large amount of this chalk rock available in Colorado, Kansas, South Dakota, and Nebraska, and, doubtless, as the demand for cement increases other works will be established. On the map, Pl. LXX, is shown the outcrop area of the limestones and chalk rock of the Niobrara formation, much of which is suitable for the manufacture

of cement. Some of the limestones of other formations may also serve satisfactorily, and in some cases these may prove to be natural cement rocks that need only to be calcined and ground.

FIRE CLAY.

There are vast deposits of clays of many kinds in the Great Plains region, some of which are known to be suitable for the manufacture of fire brick. This material has been worked for several years near Golden, in the Denver basin, from clays occurring between the two sandstones of the so-called Dakota series. The mines are about 2 miles north of Golden, where several bodies of excellent fire clay are exposed; numerous openings have been made at other points. The following analysis has been reported:[a]

Analysis of fire clay from mines north of Golden, Colo.

	Per cent.
Silica (SiO_2)	50.35
Titanic acid (TiO_2)	.80
Alumina (Al_2O_3)	33.64
Iron oxide (Fe_2O_3)	.75
Magnesia (MgO)	trace.
Soda (Na_2O)	.09
Potash (K_2O)	.49
Water and organic (H_2O)	13.88
Total	100.00

Fire bricks of superior quality and many other furnace materials of finest quality are manufactured from this clay.

It is reported by Mr. G. K. Gilbert that samples of fire clay from the beds of the Dakota formation were collected from outcrops at various points in the Arkansas basin and that most of them were found to have the proper refractory qualities to a greater or less degree. Excellent fire clay occurs under the coal at Cambria, Wyo.

The Fuson formation, probably of the same age as the Golden deposit, is worked to some extent for fire clay a short distance south of Rapid, in South Dakota. At many localities there is undoubtedly a large amount of this material available, which will prove valuable as the demand increases.

SODA.

The only occurrence of natural soda recorded in the area to which this report relates is the one known as the Gill deposit, about 7 miles northeast of Casper, Wyo. The material, which consists mainly of sulphate of soda, occurs in four small areas situated in sec. 26, T. 35, R. 78, covering in all between 80 and 90 acres. Explorations to a depth of 16 feet have not reached the bottom of the deposit. The mineral

[a] Eldridge, Geo. H., Geology of the Denver basin: Mon. U. S. Geol. Survey No. 27, 1896, p. 390.

is white, clear, and almost transparent. The following analysis is given by L. D. Ricketts, former Territorial geologist:

Analysis of soda from the deposits northeast of Casper, Wyo.

	Per cent.
Sodium sulphate	94.50
Magnesium sulphate	2.52
Sodium chloride	.54
Water	1.61
Undetermined and loss	.83
Total	100.00

The sample had been exposed to the air for some time, so that probably it had lost some of the water which would be expected in the freshly mined material. The deposits lie in shallow basins in the Fox Hills sandstone, the excavation of which is probably due to the wind.

SHERMAN GRANITE.

On the summit of the Laramie Range, west of Cheyenne, Wyo., the granite is disintegrated to a considerable depth, giving rise to a material which has proved to be of great value as road metal. It consists of angular quartz and feldspar fragments, with sufficient koalin to pack into a hard pavement. The Union Pacific Railroad Company has shipped large quantities of this material, the amount in 1900 being estimated at a half-million tons.

FULLER'S EARTH.

A portion of the earlier deposits of the White River group consists of fuller's earth, a hydrous silicate of alumina possessing a peculiar spongy texture, which is mainly serviceable in absorbing coloring matters from oils filtered through it. The material is in considerable demand for this use and deposits of satisfactory quality have commercial value. The Chadron formation consists partly of fine deposits of this earth of various degrees of purity. Working samples of the material were shipped from Fairburn and from near Argyle, a siding on the Burlington Railway between Edgemont and Custer. Small samples from these places were very promising, but the material shipped for large scale tests proved less satisfactory. It is explained that this result was due to carelessness in excavating the earth, resulting in intermixture of unsuitable materials which could have been separated. Samples of excellent fuller's earth were obtained at Valentine, Nebr., and at several places along the east side of the Black Hills. There are extensive deposits of fuller's earth in western South Dakota, in the Big Badlands, on slopes of the Black Hills, along the northern slope of Pine Ridge, in North Platte Valley, and elsewhere in the Chadron formation, as shown in Pl. LXX.

LIMESTONE.

There is an enormous supply of limestone of various kinds in portions of Kansas, east Colorado, South Dakota, east Nebraska, and Wyoming, some features of the distribution of which are shown in Pl. LXX. The largest deposits of limestone are those in the lower Carboniferous of the Bighorn Mountains, the Hartville uplift, and the Black Hills. Extensive deposits also occur in the upper Carboniferous of southeast Nebraska and east Kansas, in the Permian of the Black Hills, Rocky Mountain, east Kansas, and southeast Nebraska regions, and in the Niobrara formation. Minor deposits occur in the Benton and White River groups.

Limestone is used to a considerable extent in the West for lime, cement, and flux, and there is also a large demand now for pure lime for the beet-sugar process. The limestones of the central Great Plains and adjoining regions vary greatly in composition, and as but few analyses are on record it is not practicable at present to describe their composition in the various beds and districts.

Considerable limestone is burned for lime at various localities, and lime for flux is quarried in portions of the Black Hills and in the foothills of Rocky Mountain Front Range. On Whitewood Creek, 3 miles below Deadwood, Ordovician limestone is quarried to a moderate extent for flux for the smelters. The Niobrara limestones are extensively used for lime and other purposes at various localities along the foot of the Rocky Mountains. An analysis, by L. G. Eakins, of a typical specimen of Niobrara limestone from west of Denver, is as follows:

Analysis of a specimen of Niobrara limestone from west of Denver, Colo.

	Per cent.
Insoluble	12.01
Lime (CaO_1)	27.49
Magnesia (MgO)	18.03
Manganese (MnO)	.20
Alumina (Al_2O_3)	.54
Iron oxide (Fe_2O_3)	.11
Phosphoric acid (P_2O_5)	.03
Water (H_2O)	.61
Carbonic acid (CO_2)	41.40
Total	100.42

An analysis of Niobrara limestone from west of Pueblo, made by the Pueblo Smelting Company, is as follows:

Analysis of a specimen of Niobrara limestone from west of Pueblo, Colo.

	Per cent.
Silica	6.4
Alumina	1.3
Iron, sesqui-oxide	2.1
Lime	50.4
Magnesia	Trace
Carbon dioxide	39.5
Total	99.7

BENTONITE.

This mineral is a silicate of alumina, mingled with small proportions of some other components, and is valuable on account of its high absorbent qualities, it being capable of absorbing three times its weight of water. It has been found in considerable abundance along the west side of the Black Hills north of Newcastle, and has been mined three-quarters of a mile east of Pedro switch and at a point 3½ miles northwest of Osage on the east side of the railroad track. It occurs between thin layers of reddish-brown concretionary material. Near Pedro the dips are very steep, but north of Osage the inclination of the beds is low and the deposit lies exposed 12 feet thick on the surface over a considerable area. Near Osage the beds are about 4 feet thick, and the material appears as a very light-gray, fine-textured, soft, massive stone; locally it occurs as a light powdered substance resembling white corn meal. It has been traced, with a thickness of from a few inches to 12 feet, from the LAK ranch to a point 5 or 6 miles northwest of Osage, though at many points obscured by local wash.

The mineral has been used with some degree of success as a paper filler and also in the manufacture of soap, but has proved most valuable for a packing for horses' feet and as a diluent for a powerful drug sold in powdered form as a patent medicine.

VOLCANIC ASH.

Extensive deposits of volcanic ash occur in the Tertiary and Quaternary formations in parts of Nebraska, Kansas, and South Dakota. The material is of commercial importance, because it is employed to some extent as a polishing powder, both in the powdered form and in scouring soaps.

The largest deposits are found in North Platte Valley, in Cheyenne, Scotts Bluff, and Banner counties, where they are contained in the Brule and Arikaree formations. One extensive bed, 15 feet thick, is in a detached butte 6 miles southeast of Gering, and beds from 8 to 10 feet thick mark two horizons in the Brule clay

over a wide area in the slopes in North Platte Valley in the counties mentioned. An extensive deposit was discovered in the Arikaree formation, 3 miles east of the Pine Ridge Agency and others occur in various places in the Big Badlands. The material has been reported from nearly all of the west, southwest, and central counties of Nebraska, and at intervals in the northeast portion of the State.[a] A considerable amount has also been found in Kansas.

The quality varies greatly, both in purity of the material and in the shape of the grains. Much of the ash, unfortunately, consists of flat glassy scales, and, although these are sharp edged, they do not polish as effectively as the thicker and more vesicular variety. In some of the beds there is considerable admixture of sand and clay, but in others a large amount of pure ash is available and proves very satisfactory as a polishing powder.

Volcanic ash has not been mined extensively, although it is used yearly to the extent of several hundred tons in the manufacture of abrasive soaps, and at many places is placed in small boxes and sold locally as a polishing powder.

GOLD.

There is more or less gold in the pre-Cambrian rocks uplifted on the west margin of the Great Plains, but only a few deposits of economic importance have been discovered. The well-known Cripple Creek, Clear Creek, and Boulder districts lie some distance back in the Rocky Mountains. In the Laramie Range small amounts of gold have been reported at various localities and north of Laramie Peak there is a small district in which gold-bearing quartz veins are reported to yield good assays. Several claims have been located in the gneiss of the Casper Range, and also along Whalen Canyon, east of Hartville, but they have not been developed.

BLACK HILLS.

In the Black Hills the annual gold production has exceeded $4,000,000 for many years, and in 1902 was reported as $6,965,400. The principal mine is the "Homestake" at Lead, which has an output of over $4,000,000 a year. The ore occurs in a wide zone of silicification in the gneiss or schist, mainly as free gold and with an average assay value of about $4 a ton. The Holy Terror and some associated mines at Keystone also produce considerable gold which occurs in quartz veins in the schists. Farther west and south, especially about Custer, there are zones of silicification in the schists which contain more or less gold, but they have not been extensively developed. Besides the great body of low-grade ore in the Homestake group of mines there is in the north Black Hills a district of considerable size in which the Deadwood sandstone and associated igneous rocks yield a large amount of gold. In one area gold also occurs in limestone

[a] Rept. Nebraska Geol. Survey, vol. 1, 1903, pp. 214-220.

in connection with igneous intrusions. The ores of this class vary greatly in richness, but a large proportion of the yield averages $20 a ton. In most cases they carry the gold in such condition that the ore has to be smelted or chlorinated. A detailed account of the geology and relations of the ores of the northern Black Hills may be found in a report by T. A. Jaggar and others.[a]

In Mineral Hill, in the Nigger Hill uplift, a mill has been erected to work a mineralized schist and some low-grade porphyry, but the result appears to have been unsatisfactory. Mineral Hill is a mass of porphyry, cut by dikes of various kinds. In it gold has been found in varying amounts in many prospects. One very thin vein in a fissure on the west slope shows much free gold, but there appears to be no workable ore body.

In Bearlodge Range there has been extensive prospecting for gold in the porphyry and overlying quartzite, but in most cases only small values have been reported. In Rudy Canyon a drift has been run on the Deadwood sandstone, which, it is claimed, gave encouraging prospects.

Placer gold has been obtained in considerable amount along the streams flowing north and east out of the Black Hills, and the great rush to the hills in 1876 was for gold which could be worked out of the stream deposits. Most of the richer "bars," for which there was ample water, were finally washed out, but a large amount of low-grade gold-bearing gravel still remains. Operations are in progress in a small way at various points west of Hermosa, as far as Rockerville, and near Bear Gulch, in the Nigger Hill uplift.

There is considerable gold in the old gravels on some of the divides along the east slopes of the Black Hills, especially in those between Battle Spring and Rapid creeks, but they lie from 150 to 300 feet above the streams, and, under present conditions, no water is available for working them.

BIGHORN MOUNTAINS.

Prospects for gold in the rocks of Bighorn Mountains appear not to be encouraging. The granite has not been altered to any great extent, and later igneous intrusions consist only of a few dikes of basalt of pre-Cambrian age. In some places quartz veins are found in connection with the dikes, but they appear not to contain gold, except in the vicinity of Bald Mountain, where a few low-value assays are reported. Small amounts of free gold occur in the basal sandstones and conglomerates of the Deadwood formation lying on the granite floor. These are being worked to some extent at Bald Mountain and northwest of Buffalo, but not at much profit, if any. The Bald Mountain district has

[a] Irving, J. D., Emmons, S. F., and Jaggar, T. A., jr., Economic resources of Black Hills, Professional Paper U. S. Geol. Survey No. 26, 1904; Irving, J. D., Ore deposits of northern Black Hills, Bull. U. S. Geol. Survey No. 225, 1904, pp. 123-140.

attracted considerable attention at intervals in the last decade, and mills of various kinds have been tried. The ore is in gravel, due to disintegration of the Deadwood sandstone on the divide at the base of Bald Mountain. It varies in thickness from 15 feet down, and the amount of material is large, although much of it appears to be too low grade to work. Nothing could be learned as to the results of the prospect drifts on the headwaters of Kelly Creek, west of Buffalo. They extend laterally into the basal beds of the Deadwood formation, which here dips steeply eastward.

NEBRASKA.

There have been a number of gold excitements which have involved the expenditure of considerable money, at many localities in this State. Near Milford, west of Lincoln, Nebr., a large amount of prospecting has been done and several working tests made of gravels in the till. It is reported that favorable assays were obtained; but the enterprise has not proved successful. Small amounts of gold have been found at many points, but there are probably no prospects for obtaining the metal profitably.

IRON ORE.

HARTVILLE.

In a portion of the Algonkian rocks of the Hartville uplift, in the vicinity of Hartville, there is an extensive deposit of rich iron ore. It is found mainly in the schist and limestone of the Whalen group, occurring in both members, mainly along or not far from the contact between them. In the limestone the ore is found to lie in scattered pockets, the larger and purer ore masses occurring in the schist in long narrow lenses, apparently of considerable extent. There are two varieties of the ore—a soft, fine-grained, light-red "paint ore," and a harder, dark, bluish-gray ore, which is the more valuable.

Although it has been found that the ore underlies several claims, only one mine has been developed. This is known as the Sunrise mine, and is in active operation. It is the property of the Wyoming Railway and Iron Company, but is leased to the Colorado Fuel and Iron Company, which recently sank a three-compartment shaft to a depth of 350 feet and started three levels. Heretofore the ore has been principally worked in open cuts by a steam shovel, which loads directly onto the cars. The soft ore is easily excavated, but the harder blue ore beneath requires to be blasted.

The ore is exceptionally high grade, averaging 62 per cent metallic iron and 2½ per cent silica, with practically no phosphorus nor sulphur. From the beginning of operations up to 1903 it is reported that 400,000 tons have been mined, with a mine value of about $600,000.

BLACK HILLS.

In the Black Hills there are iron ores of considerable promise, but, except for some shipments for trial and local use, there has been no production. The deposit at Iron Mountain, 4 miles south of Custer, occurs in a vein in the Algonkian schists which is traceable for some distance along a northwest-southeast course. The ore body is several hundred feet wide, but much of the material is too impure for use. Assays of selected ore vary from 55 to 60 per cent of iron, 6 to 7 per cent of silica, 0.34 to 0.88 of phosphorous, 2 to 2½ per cent of manganese and some copper. Large deposits of siliceous hematite on Box Elder Creek were described by Newton,[a] as follows:

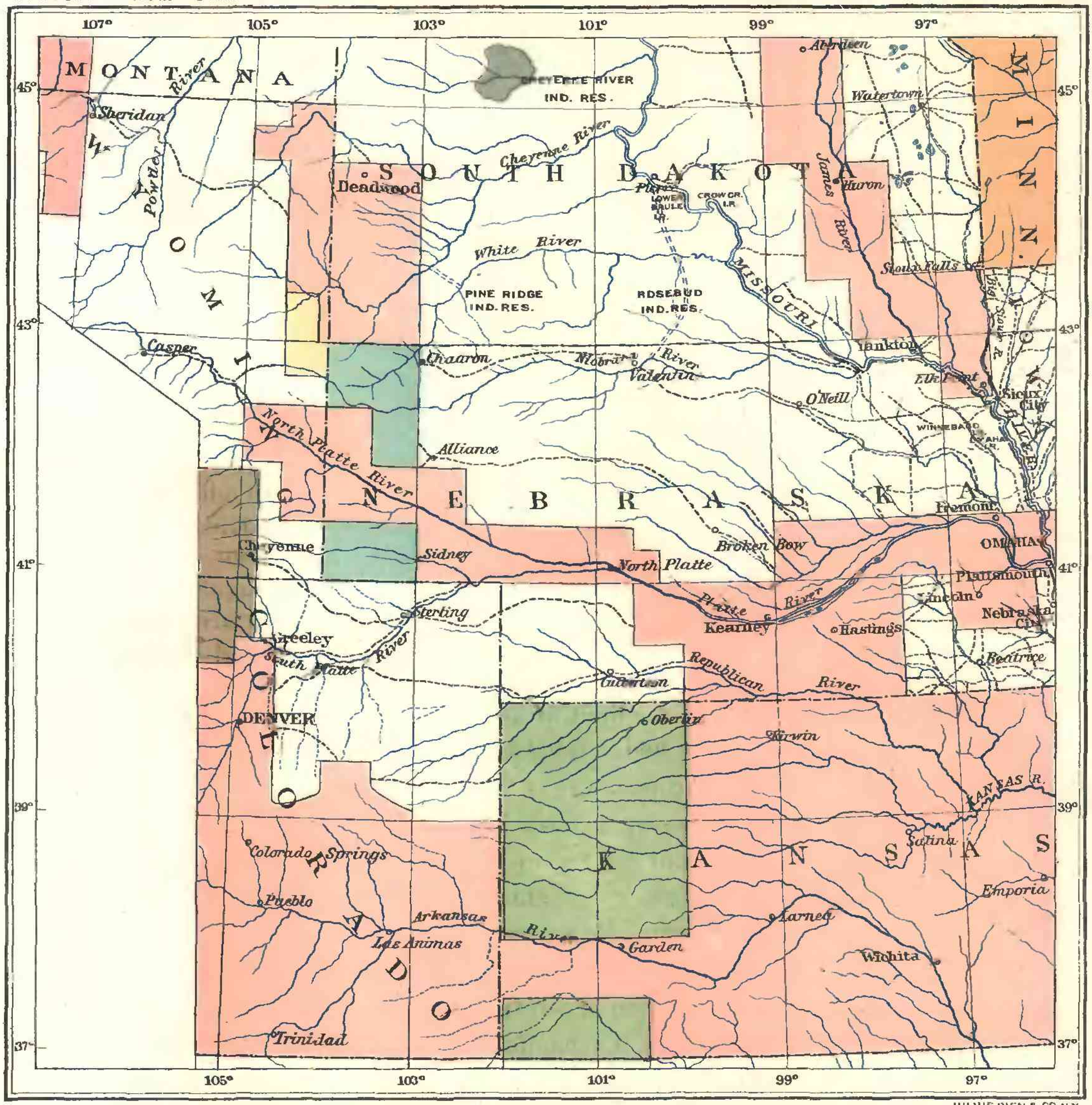
"On Boxelder Creek a ridge some 400 feet in height is composed of a vast deposit of siliceous hematite, which was estimated to be from 800 to 1,000 feet in thickness across the upturned strata. Occasional bands of almost pure specular hematite several inches in thickness are found in the mass, with frequent layers of highly crystallized micaceous hematite. The body of the ferriferous strata, however, is highly siliciferous and entirely useless as an iron ore, consisting of thin strata an inch or less in thickness of specular hematite alternating with siliceous slate or with pure white quartz in seams or irregular masses, the whole presenting a remarkable resemblance to the siliceous banded hematite of the Huronian of the Lake Superior region. In other localities on the same creek hematites were also found in the siliceous slates, but nowhere of any practical value, because of their highly siliceous character. The slates associated with these iron deposits are commonly highly argillaceous as well as siliceous, as is indicated by their color, texture, and strong clayey odor. Similar ferruginous slates occur also on the headwaters of Rapid Creek, a short distance north of the Elkhorn prairie."

Since Newton's exploration other deposits of purer ore have been discovered in Boxelder Valley, which may prove to be of value. According to Professor O'Harra, there is a body of compact red hematite on a small branch of Bogus Jim Creek a mile above its mouth, 10 miles west-northwest of Rapid. The ore is in a vein in the schists and quartzites and assays Fe_2O_3 82 per cent and SiO_2 15½ per cent.

LARAMIE RANGE.

At Iron Mountain, on the east slope of the Laramie Range, there is an extensive deposit of ilmenite, or titanate of iron. It is on the headwaters of Chugwater Creek, a short distance west of Iron Mountain station on the Colorado Southern Railroad. The deposit is very extensive and occurs in the pre-Cambrian crystalline schists.

[a] Newton, Henry, U. S. Geog. and Geol. Survey Rocky Mountain Region, Geology of the Black Hills, 1880, pp. 57–58.

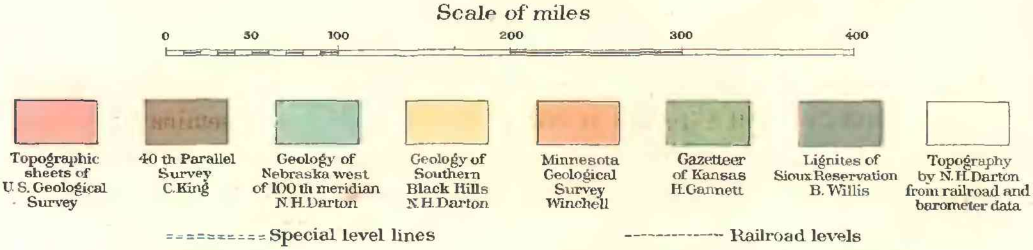


MAP OF THE CENTRAL GREAT PLAINS

showing sources of information for topographic map

BY N. H. DARTON

1904



The following analysis has been given by Prof. Wilbur Knight:

Analysis of the Iron Mountain iron ore.

	Per cent.
Ferric oxide	47.21
Ferrous oxide	25.80
Titanic acid	22.43
Sulphur	1.14
Silica	1.21

Other elements not estimated.

SILVER AND LEAD.

Silver occurs with most of the gold in the northern Black Hills and also occurs in or with galena in the Galena district southeast of Deadwood, in the Carbonate district northwest of Deadwood, at Spokane 5 miles southeast of Keystone, and at a few other points. The total production in 1902 had a value of $180,306. A large amount of the production is from the gold bullion. The silver and lead ores have been worked to considerable extent near Carbonate, where, at the Iron Hill mine, the ore bodies occur along the contact of porphyry dikes cutting the Carboniferous limestone. A mine at Spokane at one time produced considerable lead and silver, which occurred in quartz veins in the crystalline schists. The deposits near Galena occur in the lower sandstone and the overlying shales of the Deadwood formation, the principal supplies being in the shales.

In Black Buttes, on the west slope of the Black Hills, there are several silver-lead claims in which the ore is rich but apparently only in small amount. It occurs in the Pahasapa limestone along a porphyry contact.

South of Casper, on Casper Mountain, there has been considerable prospecting for lead, silver, and copper in the limestone, and also in the altered pre-Cambrian schists. In the schists west of Lusk small amounts of silver ore have been obtained.

COPPER.

The principal occurrences of copper so far reported are in the Black Hills, the Hartville region, and the Bighorn Mountains. Numerous copper claims have been located in the central Black Hills region, but the only ore that has been shipped was for smelting tests. The following statement is quoted from a report by Prof. C. C. O'Harra in Mineral Resources of the Black Hills:[a]

"'Beginning with the 'Blue Lead' near Sheridan on Spring Creek and going northward, we find near Pactola on Rapid Creek the 'Poisoned Ox,' the 'Copper Reef,' and the 'Copper Glance.' On the county line near the headwaters of Bogus Jim Creek is the 'Rio Tinto.' Farther north, one-half mile southeast of Nemo, on the Boxelder, is the 'Holy Fright,' and 3 miles northwest of this the

[a] Bull. South Dakota Geol. Survey No. 3, 1902, pp. 54-55.

'Copper Castle,' the line then gradually deflecting more to the west, crossing Elk Creek near Elk Creek station, and crossing Windy flats north of Perry; then by rather obscure outcroppings it reaches Deadwood, within the city limits of which considerable exploratory work has been done. Occasionally prospects are reported extending from Deadwood southwestward to the county line, near which are grouped the 'Copper Cliff,' the 'British American,' and the 'Black Hills.' These lie near the South Fork of Rapid Creek, northwest and west of Rochford. Southward 2 or 3 miles is the Reynolds property, and still farther south the Palmer property. West of Hill City is the 'Mastiff,' and beyond this, southward, are the 'Truax' and the 'Vigilante.' Other prospects of more or less interest lie along the lines indicated, while some have been found having no apparent relation to these lines.

"Practically all of these properties carry a copper-stained gossan, some of them showing it in great quantity and not infrequently with a considerable amount of copper. In sinking through this gossan a leached material known as 'ash' is reached. This is a soft, black, decomposed slate, quite free from minerals of value.

"Thus far no one has gone through this ash, but the Black Hills Copper Company is now working to this end, their inclined double-compartment shaft of 800 feet having penetrated beneath the surface to a perpendicular depth of more than 400 feet. At the 'Blue Lead' a tunnel cutting below the surface outcroppings for a perpendicular distance of more than 600 feet has penetrated the unchanged slates, charged with iron and copper pyrites. Thus, notwithstanding the great amount of work done, the lower limit of ash is not yet reached, and the conditions in the zone between the ash and sulphides remain to be learned."

In the Hartville region copper ore is mined at the Welcome mine, a mile east of Hartville, from a replacement deposit in a mineralized band in the schists and quartzites of the Whalen group. The ore is banded, bronze colored, and consists largely of pyrrhotite with more or less intermingled chalcopyrite. At various other localities the indications appear to be favorable for paying ore. Copper mining was formerly much more extensive in this region than at present. A mine just northeast of Guernsey yielded $60,000 worth of ore from a replacement deposit in the massive gray limestone of the Guernsey (Carboniferous) formation. The surface workings of the Sunrise iron mine also yielded a considerable amount of copper.

In the Bighorn Mountains there has been considerable prospecting for copper, but the results are not encouraging. Some ore occurs in the southeastern portion of the central granite area in thin seams in the granite, which yields promising assays, but there are no indications of ore bodies of commercial value.

TIN.

The mineral cassiterite is found at various localities in the Black Hills, especially in the vicinity of Hill City and at Nigger Hill. It occurs disseminated in coarse-grained granites, or pegmatites, cutting the crystalline schists. Several years ago very extensive tin-mining and milling operations were begun at Hill City, but the

project was finally abandoned. The amount of the tin mineral available in the numerous pegmatite dikes about Hill City and eastward is very large, but it is disseminated in the rock in an irregular manner and much of the ore is too poor to be profitably worked. Most persons who are familiar with the district believe that on an economical basis the tin could be produced profitably, and doubtless the Hill City region will eventually be given a further trial. In a small area at Nigger Hill similar bodies of tin-bearing pegmatite occur, of which the capabilities are now being tested. In Bear Gulch, in this district, considerable stream tin has been obtained in the placer diggings for gold, and several shipments of ore have been made.

MANGANESE.

Oxide of manganese has been found at various points in the Black Hills, mainly in the crystalline rocks of the central area. The chief occurrences reported are in Pennington and Custer counties, in the basal beds of the Carboniferous near Redfern, and in the Minnelusa sandstone near Argyle. At the latter place, according to Prof. C. C. O'Harra, the mineral pyrolusite is disseminated through a sandstone stratum 35 feet thick, which is well exposed in a cut made by a tributary of Red Canyon Creek.

CLIMATE.

The central Great Plains region presents considerable variety of climate. To the east, on the plains, the precipitation varies from moderately humid to nearly arid, the change taking place gradually from east to west. In Pl. LXXII there is shown the mean annual precipitation, from which it will be seen that to the east there are 40 inches of rainfall per year, while to the west, in the region adjoining the Rocky Mountains and the other ranges, there are less than 12 inches over an area of considerable extent. To the east the precipitation is ample for crops, and that portion of the region is one of the greatest producers of corn, wheat, and other agricultural products in the world, while to the west there are broad tracts in which no crops can be produced without irrigation. On the mountains in the western portion of the area there is locally increased precipitation, which in many areas is sufficient for agriculture. The amount of water that falls in the arid area is enormous when the number of cubic feet per square mile is calculated, but much of it comes in very heavy showers, after long intervals of drought, often with severe hot winds. If a portion of the rainfall could be stored, much of it could be used for irrigation.

Evaporation also increases rapidly in amount from east to west in nearly inverse ratio to the precipitation. Its estimated amount is 3 feet in the eastern portion of the region and 6 feet in the western, including the mountains. This

large amount of evaporation in the arid belt is a serious consideration in the storage of water for irrigation.

The mean annual temperature (see Pl. LXXII) falls gradually in going from north to south, and rapidly in ascending the mountain slopes. The entire region to which this report relates receives more or less snow during the winter, the amount diminishing in the arid plains westward and increasing very greatly on the high mountains, amounting to several feet in portions of the latter. On the western plains, owing to the clearness of the atmosphere, the sun's heat is more intense during the day than in the region eastward. For the same reason, and also because of the increased evaporation, the nights are cooler and, in general, the heat less oppressive.

MAP OF THE GREAT PLAINS AND ADJOINING REGIONS

SHOWING MEAN ANNUAL PRECIPITATION AND MEAN ANNUAL TEMPERATURES

BY HENRY GANNETT

Scale

100 0 100 200 300 miles

1904

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10001—No. 32—05——28

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[Professional Paper No. 32.]

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PP 32. Preliminary report on the geology and underground water resources of the central Great Plains, by N. H. Darton. 1905. 433 pp., 72 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Part II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Part II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Part II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Part IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Part IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Part IV; Artesian well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

Correspondence shonld be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

FEBRUARY, 1905.

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Author.

Darton, N[elson] H[oratio] 1865–

. . . Preliminary report on the geology and underground water resources of the central Great Plains, by N. H. Darton. Washington, Gov't print. off., 1905.

433, v p. illus., LXXII pl. (incl. front., maps, 2 in pocket) diagr. 29½ x 23cm. (U. S. Geological survey. Professional paper no. 32)

Subject series: B, Descriptive geology, 45; C, Systematic geology and paleontology, 68; O, Underground waters, 28.

1. Geology—Great Plains. 2. Water, Underground—Great Plains.

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Professional papers.

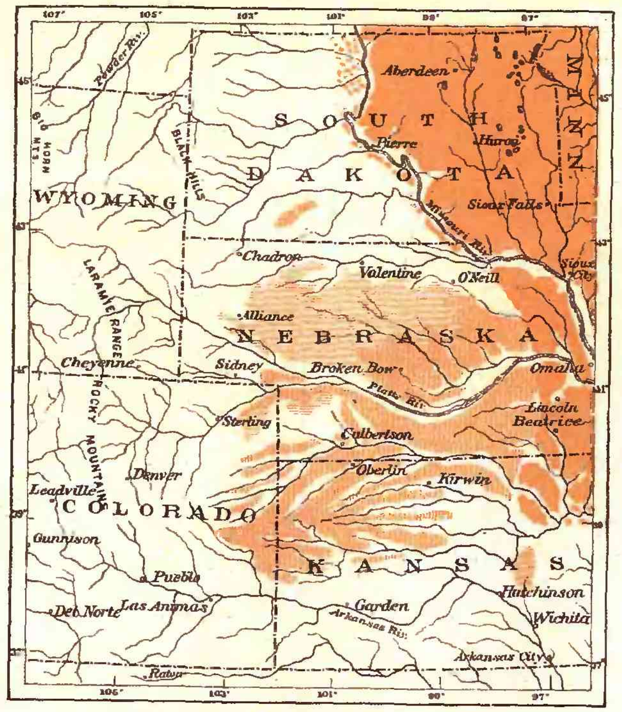
no. 32. Darton, N. H. Preliminary report on the geology and underground water resources of the central Great Plains. 1905.

Reference.

U. S. Dept. of the Interior.

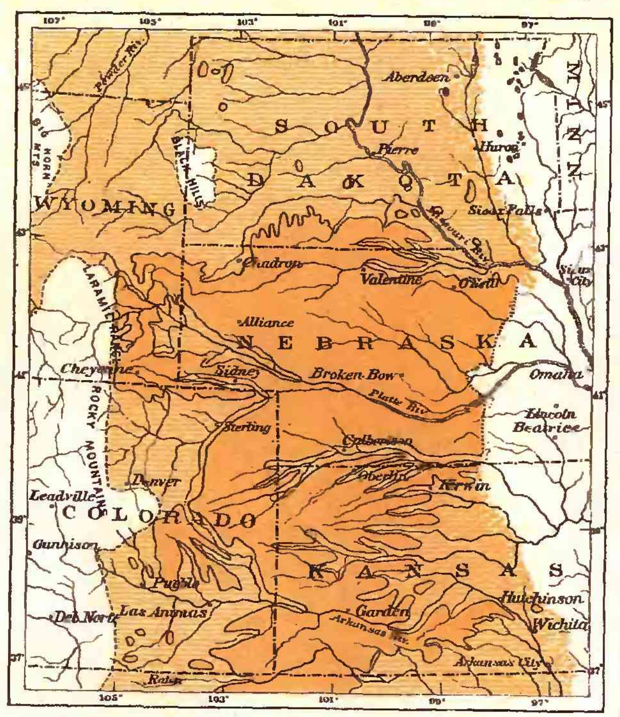
see also

U. S. Geological survey.



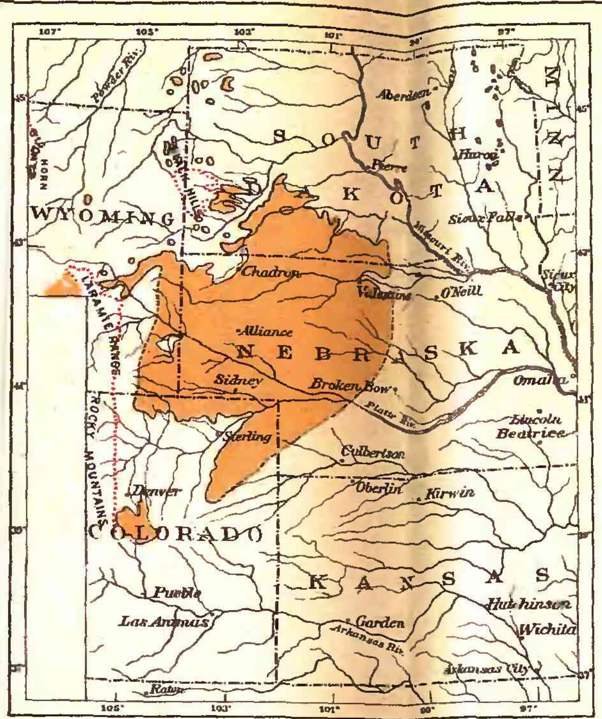
QUATERNARY

- Glacial drift *(overlain by loess to the south)*
- Loess *(outside of drift area)*
- Sand hills and Equus beds



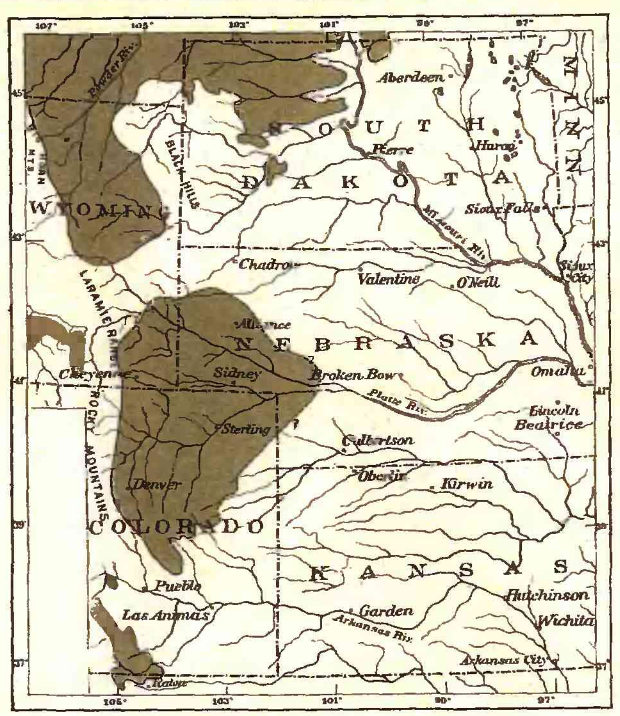
LATER TERTIARY

- Ogalalla and Arikaree formations
- Area probably once covered by Later Tertiary deposits
- Probable western limit of Later Tertiary *(eastern limit unknown)*



OLIGOCENE

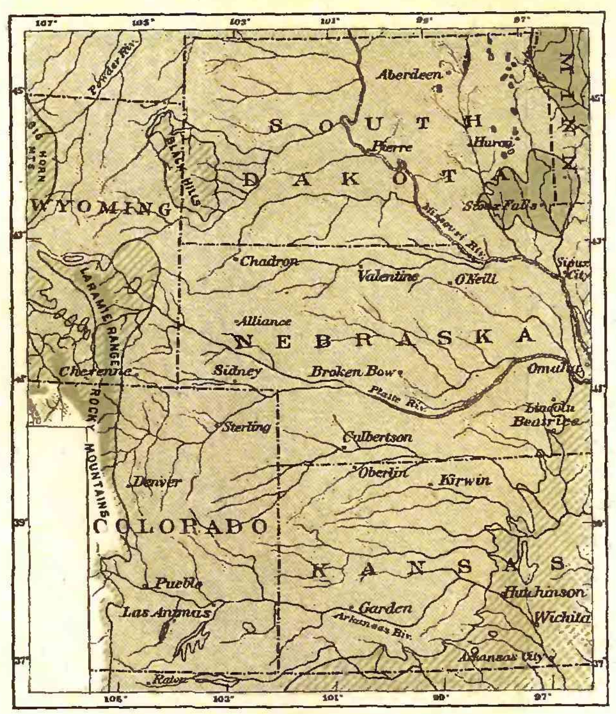
- White River group
- Probable western limit of Oligocene deposition *(eastern limit unknown)*



FOX HILLS TO FORT UNION

- Fox Hills to Fort Union formations *(mainly Laramie)*

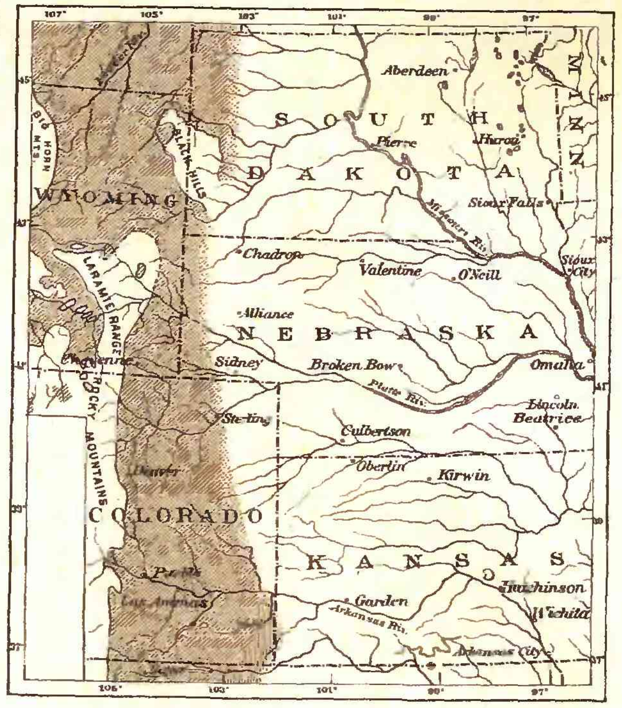
(eastern margin in Platte Valley overlain by Oligocene and Later Tertiary deposits)



DAKOTA TO LAKOTA

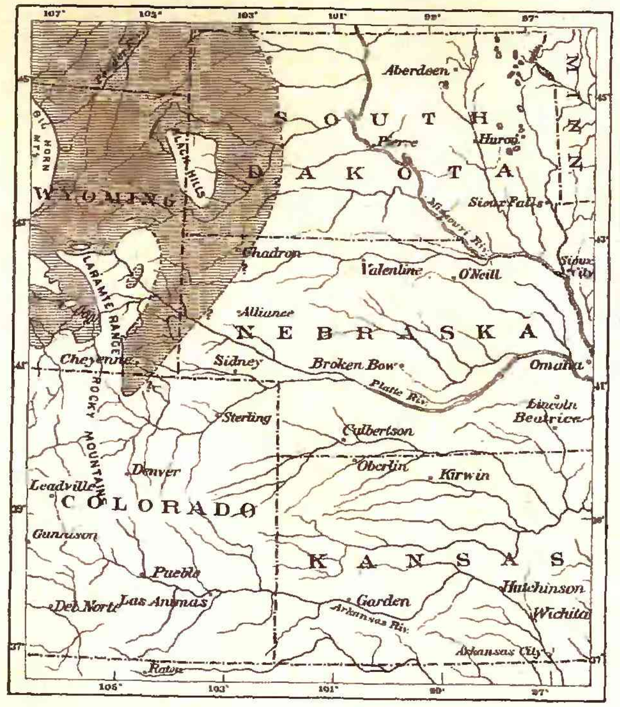
- Area of Dakota-Lakota sandstones
- Area probably formerly covered by the sandstones
- Area in which Dakota sandstone probably never was deposited

Note: *Pierre, Niobrara, and Benton formations probably were deposited over the entire area shown on these maps except possibly along the central axis of the Rocky Mountains*



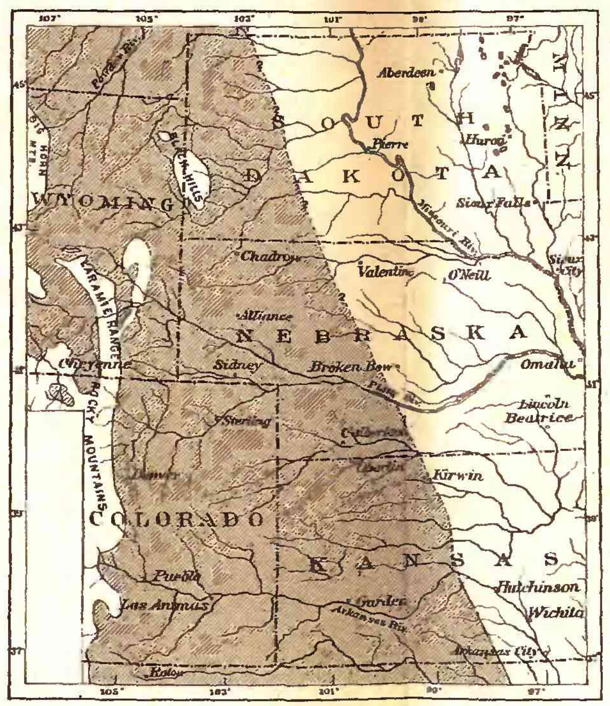
MORRISON AND COMANCHE

- Area underlain by Morrison formation *(eastern limit mostly hypothetical)*
- Area underlain by Comanche series
- Outcrop of Kiowa shale and Cheyenne sandstone



LATER JURASSIC

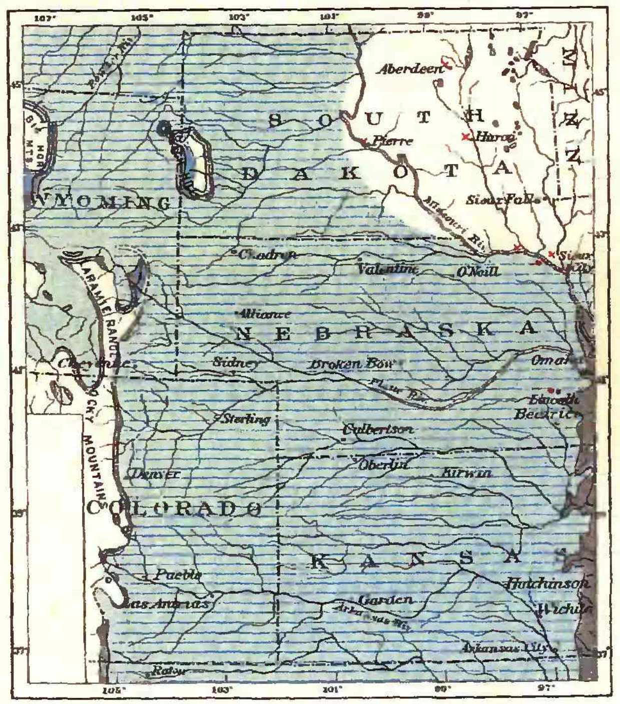
- Area probably underlain by Sundance formation *(eastern limits hypothetical)*



"RED BEDS"

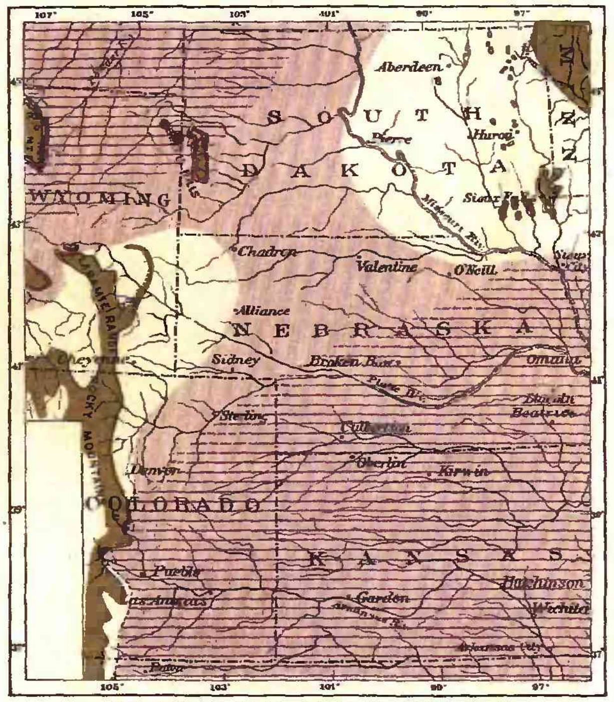
- Area probably underlain by Permian to Triassic (?) red beds

(these in part grade into Permian shales and limestone in south-central Kansas)



CARBONIFEROUS

- Outcrops of limestones, shales, and red beds of Pennsylvanian age
- Area probably underlain by rocks of Pennsylvanian age
- Outcrops of limestones of Mississippian age
- Area probably underlain by rocks of Mississippian age
- Deep borings into probable Carboniferous rocks
- Deep borings in which Cretaceous appears to lie directly on pre-Cambrian



ORDOVICIAN AND CAMBRIAN

- Ordovician outcrops
- Area probably underlain by Ordovician rocks *(mostly hypothetical)*
- Cambrian *(middle and upper)* outcrops
- Area probably underlain by Cambrian rocks
- Pre-Cambrian rocks

JULIUS BIEN & CO. LITH. N.Y.

MAPS SHOWING THE DISTRIBUTION OF PRINCIPAL FORMATIONS OF THE CENTRAL GREAT PLAINS, BY N. H. DARTON

Scale

0 50 100 200 300 miles

1904

PRELIMINARY MAP OF THE CENTRAL GREAT PLAINS SHOWING THE STRUCTURE OF THE DAKOTA SANDSTONE

BY N. H. DARTON

1904

Scale

20 0 20 40 60 80 100 120 140 miles

Black contours have 1000 feet interval, broken lines hypothetical.

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PRELIMINARY MAP OF THE CENTRAL GREAT PLAINS SHOWING ALTITUDE OF HEAD OF WATER IN DAKOTA AND ASSOCIATED SANDSTONES

BY N. H. DARTON

1904

Scale

20 0 20 40 60 80 100 120 140 miles

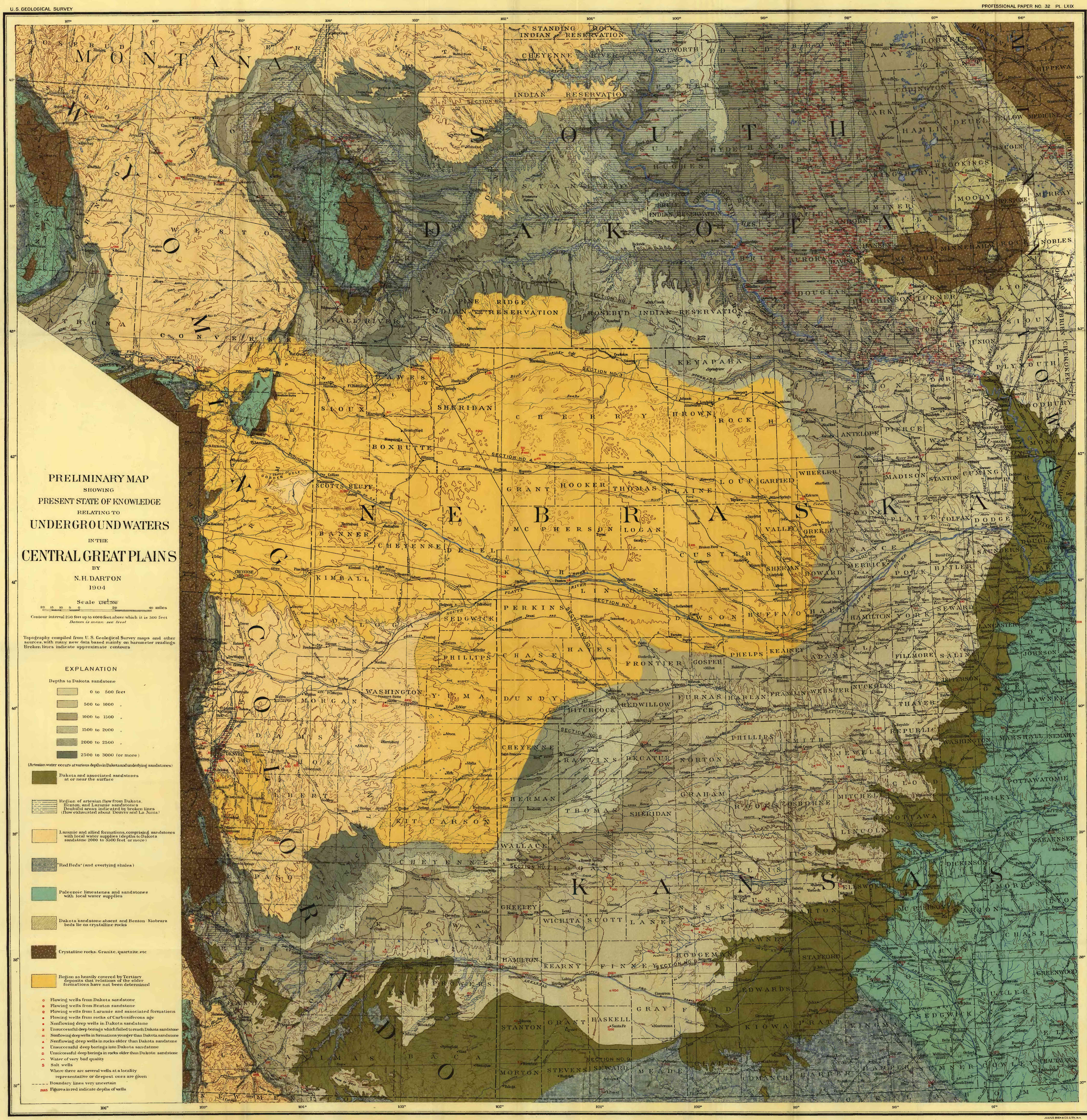
Black contours have 1000 feet interval, broken lines hypothetical

Figures in blue indicate altitude of head at wells (in most cases calculated from observed pressure)

Artesian head (contour lines show approximate altitude above sea level to which the principal artesian waters may rise)

Broken lines indicate general approximation Intervals vary from 100 to 500 feet

Area underlain by Dakota and associated sandstones


PRELIMINARY MAP
SHOWING
PRESENT STATE OF KNOWLEDGE
RELATING TO
UNDERGROUND WATERS
IN THE
CENTRAL GREAT PLAINS
BY
N. H. DARTON
1904
Scale 1/1,267,200
20 15 10 5 0 20 40 miles
Contour interval 250 feet up to 6000 feet, above which it is 500 feet
Datum is mean sea level
Topography compiled from U. S. Geological Survey maps and other sources, with many new data based mainly on barometer readings
Broken lines indicate approximate contours
EXPLANATION
Depths to Dakota sandstone
0 to 500 feet
500 to 1000 "
1000 to 1500 "
1500 to 2000 "
2000 to 2500 "
2500 to 3000 (or more)
(Artesian water occurs at various depths in Dakota and underlying sandstones)
Dakota and associated sandstones at or near the surface
Region of artesian flow from Dakota, Benton, and Laramie sandstones
Doubtful areas indicated by broken lines
(flow exhausted about Denver and La Junta)
Laramie and allied formations, comprising sandstones with local water supplies (depths to Dakota sandstone 2000 to 3500 feet or more)
"Red Beds" (and overlying shales)
Paleozoic limestones and sandstones with local water supplies
Dakota sandstone absent and Benton Niobrara beds lie on crystalline rocks
Crystalline rocks: Granite, quartzite, etc
Region so heavily covered by Tertiary deposits that relations of the older formations have not been determined
Flowing wells from Dakota sandstone
Flowing wells from Benton sandstone
Flowing wells from Laramie and associated formations
Flowing wells from rocks of Carboniferous age
Nonflowing deep wells in Dakota sandstone
Unsuccessful deep borings which failed to reach Dakota sandstone
Nonflowing deep wells in formations younger than Dakota sandstone
Nonflowing deep wells in rocks older than Dakota sandstone
Unsuccessful deep borings into Dakota sandstone
Unsuccessful deep borings in rocks older than Dakota sandstone
Water of very bad quality
Salt wells
Where there are several wells at a locality representative or deepest ones are given
Boundary lines very uncertain
2665 Figures in red indicate depths of wells
MONTANA
WYOMING
SOUTH DAKOTA
NEBRASKA
COLORADO
KANSAS
IOWA
MINNESOTA

PRELIMINARY MAP OF THE CENTRAL GREAT PLAINS SHOWING THE ECONOMIC GEOLOGY

BY N. H. DARTON

1904

Scale

20 0 20 40 60 80 100 120 140 miles

Contours have 1000 feet interval, broken lines hypothetical.