Professional Paper No. 52

Series { B, Descriptive Geology, 89
0, Underground Waters, 55

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND UNDERGROUND WATERS

OF THE

ARKANSAS VALLEY IN EASTERN COLORADO

BY

N. H. DARTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
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GEOLOGY AND UNDERGROUND WATERS OF THE ARKANSAS VALLEY IN EASTERN COLORADO.

By N. H. Darton.

INTRODUCTION.

In the valley of Arkansas River in southeastern Colorado there is an area of considerable extent in which artesian flows are available. During the last ten years numerous wells have been sunk to develop this important resource and, in most cases in the lower lands, abundant water supplies have been obtained. The principal water-bearing bed is the "Dakota" formation, which consists of two sheets of porous sandstone separated by a small body of clay and overlain in the greater portion of the area by a mass of impervious shales. The sandstones receive their waters from rainfall and from the sinking of streams along the foothills of the Rocky Mountains and on some of the higher slopes south of the Arkansas Valley. In the passage of this sandstone underground, the waters which it contains are held down by the overlying shales, but, as some of the sandstone outcrops are at relatively low levels to the east only a moderate head or pressure is sustained. On account of this low head, artesian flows are available only in the lower lands, and one of the principal objects of this investigation has been the determination of the area in which flows are to be expected. The "Dakota" sandstone and associated formations do not lie level, or even slope regularly to the east, but are flexed into low arches and shallow troughs of considerable complexity of configuration. Accordingly, in investigating this source of water supply, it has been necessary to ascertain the structure and distribution of the various formations in order to indicate the variations in depth to the water-bearing stratum. The principal results of these investigations are set forth: (1) In the geologic map (Pl. VI), which shows the distribution of the formations on the surface; (2) in the map, Pl. XXV, which shows the depth to the water-bearing horizon, the area in which flows are expected, the head of the underground waters, and other features, and (3) in the cross sections (Pls. VII and XXIII), which show the principal underground features. The investigation has been in progress for several years and is an extension of the preliminary examination of the region by G. K. Gilbert in 1894 and 1895.[a]

[a] Gilbert, G. K., Underground waters of the Arkansas Valley in eastern Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 1-51, Pls. LVI-LXVII.

For the western portion of the area the maps and texts of the Pueblo, Elmoro, Walsenburg, Spanish Peaks, and Pikes Peak folios have been utilized as far as practicable. For the central and eastern portions the larger features of the geology have been specially mapped, and considerable detailed mapping has been done in the region south and southeast of Canyon and Colorado Springs. In the field work I have been assisted by Mr. C. A. Fisher, who has examined in detail the Nepesta quadrangle and contributed numerous other data. Dr. W. S. Tangier Smith and Messrs. C. E. Siebenthal and W. T. Lee have made observations in certain areas. Much valuable information respecting wells has been furnished by Mr. William Archer, of the Atchison, Topeka and Santa Fe Railway Company, and Mr. C. H. McVay, well driller at Rocky Ford.

GENERAL CONFIGURATION.

Eastern Colorado lies on the western portion of the Great Plains, which extend from the foot of the Rocky Mountains to the Mississippi Valley. These plains present wide areas of tabular surfaces traversed by the broad, shallow valleys of large rivers that rise mainly in the Rocky Mountains, and are more or less deeply cut by the narrower valleys of lateral drainage (Pl. II). Smooth surfaces and eastward-sloping plains are the characteristic features (Pl. III), especially of the uplands, but in portions of the region there are buttes, extended escarpments, and canyons of considerable depth. Local areas of sand hills occur, especially along the rivers and on some of the high plains, where there is much loose material that can be blown by the wind. The altitudes average about 6,000 feet at the foot of the mountains and about 3,500 feet along the eastern border of Colorado. Westward the mountains rise steeply to altitudes which reach over 14,000 feet in Pikes Peak, 13,600 feet in Spanish Peaks, and 12,300 feet in Greenhorn Mountain.

The principal streams of the region are South Platte and Arkansas rivers. These rise in the mountains, where they flow in deep canyons, but in crossing the plains their valleys are wide and average about 200 feet below the surrounding higher lands. Near the mountains the Arkansas Valley is bordered in places by cliffs of moderate height, but to the east the side slopes are very gentle. The altitude in the valley at the mouth of Royal Gorge is 5,400 feet; at Pueblo it is 4,675 feet, and at the Kansas line 3,350 feet. The average grade from Canyon to Pueblo is 15 feet to the mile, from Pueblo to La Junta, 8 feet, and from La Junta to the Kansas line, 7.3 feet.

The principal branch of Arkansas River in southeastern Colorado is Purgatory River, which rises in the Culebra Range and empties at Las Animas. The region adjoining this stream is one of unusual topography for the Great Plains; portions of it consist of sandstone plateaus cut by many canyons, that of Purgatory River being in places nearly 500 feet in depth. Other branches of the Arkansas crossing this plateau are Apishapa and Huerfano rivers, which have also cut canyons of considerable depth. Near the southern margin of the State there rise above the plains two large, prominent mesas—the Raton Mesa and the Mesa de Maya—both of which are due to thick sheets of volcanic rocks.

RELIEF MAP OF THE DRAINAGE BASIN OF ARKANSAS RIVER IN COLORADO.

A. THE HIGH PLAINS IN EASTERN COLORADO.

Grass, sunshine, and solitude.

B. VIEW ON THE GREAT PLAINS IN EASTERN COLORADO.

Shows ranch situated in shallow drainage basin.

GENERAL GEOLOGY OF EASTERN COLORADO.

GENERAL RELATIONS.

The eastern half of Colorado is underlain by an extensive series of sedimentary formations of late Cambrian to Tertiary 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, in which the underlying granites and gneisses appear. The larger surface areas are the later Cretaceous and Tertiary formations, the latter covering much of the region north.

STRUCTURE.

The general structure of the region is indicated in Pl. XXVI, which shows the configuration of the "Dakota" sandstone, not only in its surface outcrops, but also under the areas in which it is more or less deeply buried by younger formations. From this illustration it will be seen that there is, along the mountain front, a general steep monoclinal dip, which affects all of the formations except the youngest.

In greater part the monocline of the front ranges descends into deep basins, east of which the strata rise gently. The most extensive of these basins is one having its center near Denver. It extends from North Platte River to the Arkansas, and in its lower portion the granite and gneiss which are supposed to underlie the plains are 2,000 feet or more below sea level. This basin is terminated on the south by an anticline, which crosses the great offset and embayment in the mountain front west of Pueblo, and is a prolongation of the main Front Range of the Rocky Mountains. This anticline pitches downward very rapidly from a short distance south of Pikes Peak and crosses the Arkansas Valley a short distance west of Pueblo, beyond which it coalesces with a prominent anticline extending southeastward from the Wet Mountain Range. Between these two, in the vicinity of Florence, there is a deep synclinal basin lying in the sharp reentrant angle in the front of the Rocky Mountains. South of the eastward prolongation of the Wet Mountain anticline there is another deep basin occupying an area of considerable extent about the Spanish Peaks. The east side of this basin rises into an anticline of moderate prominence, which occupies a broad area in southeastern Colorado, coalescing with the extension of the Wet Mountain anticline to the northwest and extending far to the northeast, with considerable pitch, as the southeastern margin of the Denver basin. At Two Butte there is a small but prominent local uplift due to igneous intrusion.

These flexures affect all of the formations except the later Tertiary sands, gravels, and clays which cap the divides between the larger valleys. In the Denver and Spanish Peaks basins there are extensive deposits of all the formations up to the earlier Tertiary. In the Florence basin a small area of the Laramie occurs. The anticlines north and south of Pueblo are exhibited mainly in "Dakota" to Niobrara formations, and the wide anticline in the southeastern portion of the State presents extensive exposures of the "Dakota" sandstone, which extend to Arkansas River between Las Animas and the vicinity of Lamar.

FORMATIONS.

The sedimentary formations exposed in eastern Colorado represent a large part of geologic time from the later Cambrian to the present. Rocks of Silurian and Devonian age, however, are absent; the Ordovician and earlier Carboniferous appear only in small exposures; the Triassic may be absent in whole or in part; the earlier Jurassic is absent; the later Jurassic extends only a few miles into the northern portion of the State; a large part of the earlier Cretaceous is absent; and there are a number of short breaks in the early, middle, and latest Tertiary times.

Rocks of later Cambrian age appear at a number of points along the Front Range, mainly in small embayments west and northwest of Colorado Springs and north of Canyon, but it is possible that these are projections from a more extended sheet which may underlie the plains eastward. It is evident that the Rocky Mountain Front Range was originally a shore line of irregular contour on which varying degrees of submergence caused an irregular sequence of overlaps. The later Cambrian rocks are sandstones, evidently representing a shore deposit which originally had an irregular western margin, much of which is now buried under later overlapping sediments.

The Ordovician rocks, which consist mainly of limestones (Manitou and Fremont), with an intervening local sandstone (Harding), are also of restricted occurrence. Outcrops appear in Perry Park, west and north of Colorado Springs, west and north of Canyon and Florence, south of Canyon, and southwest of Pueblo. At most localities they are overlain unconformably by the Millsap limestone, of earlier Carboniferous age, which presents irregular overlap relations from point to point. These formations probably extend continuously under the Great Plains, but they have not been reached by any borings in eastern Colorado.

One of the most prominent members along the Rocky Mountain front is the great succession of "Red Beds" which lie on an irregular surface of the granites, except in some of the embayments where Cambrian, Ordovician, and earlier Carboniferous rocks intervene. They have been found to be an extension of the "Red Beds" and underlying Carboniferous limestone of southeastern Wyoming and of the Permian and overlying "Red Beds" of southern Kansas. They are readily divisible into three members. The lowest is the Fountain formation, or lower Wyoming. This consists of coarse, red grits, which I have found represent the Upper Carboniferous limestones of Wyoming. The second is the Tensleep sandstone, or "Creamy sandstone" of Eldridge, which has been traced as far south as the Manitou embayment. The third member consists of the gypsiferous red shales and sandstones known as the Chugwater formation, and is believed to represent the "Red Beds" of eastern Wyoming and the Black Hills. The lower beds of this member are of Permian age and the upper beds are either Permian or Triassic. It appears to terminate a short distance southwest of Colorado Springs. The "Red Beds" underlie the plains in eastern Colorado and have been reached by several deep wells in the Arkansas Valley and by some of the deeper canyons farther south.

The marine Jurassic, which is well characterized in eastern Wyoming, extends only a short distance south into Colorado, where it thins out, but the unconformity

A. HAYSTACK BUTTE, PUEBLO COUNTY, COLO.

Typical flat-topped outline of Timpas limestone or Carlile shale.

B. APISHAPA CANYON NORTHWEST OF THATCHER, COLO.

A typical sharp-edged flat-bottomed canyon in "Dakota" sandstone.

by which it is separated from the "Red Beds" northward continues to the south, and represents, throughout the greater part of eastern Colorado, all of Jurassic and probably also some of Triassic time. Above this unconformity lies a widespread sheet of fine-grained sediments known as the Morrison formation, evidently of fresh-water origin and supposed to represent part of the earlier Cretaceous time. It is usually less than 300 feet thick, but appears to underlie all of eastern Colorado, although thinning considerably eastward.

The Morrison shales and clays are followed by a succession of coarse-grained sandstones, usually designated the "Dakota" sandstone, consisting of two principal masses with an intervening deposit of fire clay, having in all a thickness averaging 300 feet. This series underlies all of the eastern part of Colorado, appearing prominently along the slopes of the Front Range and widely in the anticlinal uplifts south of Arkansas River. Its upper member undoubtedly represents the "Dakota" sandstone, but the medial clay and the lower sandstone series probably represent, respectively, the Fuson and Lakota formations, two Lower Cretaceous members of the Black Hills. The remarkable uniformity of this tripartite succession and its intimate association with the underlying Morrison beds is a most significant feature over a wide area of the Rocky Mountain province. Several years ago fossils of Comanche age were found in the medial, or fire-clay, member in the southeast corner of the State, and recently Mr. T. W. Stanton has obtained these fossils at this horizon at various localities as far west as Canyon.

The "Dakota" sandstone is succeeded abruptly by a great succession of marine sediments, mainly shales, with limestones at certain horizons, representing a long interval of later Cretaceous time. The lower portion of this succession consists of the Benton group, which is from 400 to 500 feet thick in greater part and comprises two shale formations separated by one of limestone. Its character is constant throughout nearly a half million square miles of the central Great Plains. The rocks of the Benton group are exposed in a narrow zone all along the Rocky Mountain front and in extensive areas along the slopes of the anticlinal uplifts south of Arkansas River. They are succeeded by the calcareous deposits of the Niobrara, which attain their greatest development in eastern Colorado. The usual succession in the Niobrara is a lower limestone and an upper series of limy shale, which in portions of the Arkansas Valley attain a thickness of nearly a thousand feet. The Niobrara formation is extensively exposed in the Arkansas Valley east of Florence.

Overlying the Niobrara formation is a thick mass of clay known as the Pierre shale, which has a wide extent and great thickness in the Denver basin, in the southern end of which it extends as far south as Arkansas River east of Pueblo. A smaller area occurs in the Spanish Peaks syncline, and a still smaller one in the Florence basin, where it is the source of petroleum. West of Denver the Pierre formation appears to have a thickness of more than 7,500 feet; about Florence it is more than 3,000 feet thick; and in the Spanish Peaks syncline its greatest amount appears to be not more than 2,000 feet. The formation thins rapidly in eastern Colorado, where its surface has been extensively eroded in earlier Tertiary times. It consists of a succession of dark shales, with occasional beds of sandy shales and sandstones, and usually contains abundant remains of marine shells.

The Pierre shale gives place rapidly to the Fox Hills formation, which in greater part consists of sandstones, and this, in turn, is succeeded by the Laramie formation, a thick succession of sandstones and sandy shales containing extensive and valuable deposits of lignite. The latter formation is of fresh-water origin and represents the product of late Cretaceous time. It occupies a broad area in the Denver basin, in which it extends southeastward from Colorado Springs and northeastward into Wyoming and Nebraska. There is a large area of it in the Spanish Peaks basin and a small area in the Florence basin.

In the two larger basins above mentioned the Laramie deposits are overlain by extensive beds, mainly of conglomerates and sandstones, which may possibly represent the earliest deposits of Tertiary time. Several formations separated by unconformities are comprised in this series, and they constitute the greater part of the elevated region culminating in the Spanish Peaks.

There probably is a considerable interval of early and middle Tertiary time not represented by deposits in eastern Colorado. The White River group of Oligocene age caps the Laramie formation in the northeast corner of the State and occupies an area of considerable extent in the highlands south of Denver, where it is known as the Monument Creek formation. These Oligocene deposits consist of sands, sandstones, and clays, which probably were once of considerably greater extent in eastern Colorado, but were removed by later Tertiary erosion.

On the principal divides in the eastern portion of Colorado there are wide areas of the original high plains capped by later Tertiary deposits, consisting of sands and gravels, often locally cemented into a limestone grit. This formation has been extensively removed along the valleys of Platte and Arkansas rivers, but originally it probably extended to the foot of the higher mountain slopes, as it does in Wyoming. The age of this covering of the old high plains is believed to be Pliocene, but in the northeastern portion of the State there is also an underlying member, the southern extension of the Arikaree formation, which lies on the White River formation for some distance.

The Quaternary system in eastern Colorado is represented mainly by the alluvial deposits along the valleys and by some remnants of earlier terraces of moderate elevation.

GEOLOGY OF THE ARKANSAS VALLEY REGION.

STRATIGRAPHY.

The sedimentary formations exposed in the area drained by Arkansas River in eastern Colorado are mainly of Cretaceous age, but along the slopes of the Rocky Mountains an extensive series of older formations lies on granite. The various formations of Cretaceous age present extensive exposures, but the older formations outcrop only in small areas, and there are among them many irregular overlap relations, due to the unevenness of the surfaces on which they were laid down. The most extensive developments of the older rocks are in the embayments north of Canyon and west of Colorado Springs.

A. "DAKOTA" HOGBACK AT CANYON, COLO.

Valley of "Red Beds" and slopes of Morrison beds to left; minor hogbacks of Timpas limestone to right. Photograph by I. C. Russell.

B. "DAKOTA" HOGBACK RIDGE 2 MILES SOUTHWEST OF CANYON, COLO.

Looking north. Valley of Graneros shale in foreground; mountains of gneiss in distance. Photograph by C. D. Walcott.

Table of geologic formations of southeastern Colorado.

Age.	Formations.	Principal character.	Thickness.
			Feet.
Quaternary		Sand, gravel, and loam	50
		Higher terraces, sand, gravel, and loam	50
Tertiary	Nussbaum-Ogalalla	Sand, gravel, and conglomerate	150
	Monument Creek	Sand, gravel, and clay	200
	Huerfano	Coarse sandstone and conglomerate on clays and marls.	2,900
Cretaceous(?)	Cuchara (Denver)	Massive sandstone; some clay	475
	Poison Canyon (Arapahoe)	Sandstone conglomerate; some clay	1,900
	Laramie	Gray sandstone and shale	2,000
	Trinidad sandstone (Fox Hills)	Massive sandstone	150
	Pierre	Dark-gray shale with concretions	1,300–3,000
	Apishapa, Timpas — Niobrara group	Sandy shale, thin beds of limestone near top	550
		Limestone and limy shale	200
Cretaceous	Carlile, Greenhorn, Graneros — Benton group	Dark shales with sandstone at top	200
		Slabby limestone; shale partings	50
		Dark shales	200
	"Dakota"	Gray sandstone, fire clay in middle	200– 300
	Comanche series	Soft sandstone and sandy clays	20
	Morrison	Gray to maroon joint clays with limestone and sandstone layers.	200
Triassic (?) and Permian	Chugwater	Bright-red sandy shales with thin limestone layers and gypsum; reddish sandstone at top.	100
Carboniferous: Pennsylvanian	Tensleep, Fountain (Badito) — Lower Wyoming	Fine-grained massive sandstone	200
		Coarse red sandstone 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 SYSTEM.

In the Manitou embayment west of Colorado Springs and in a small area north of Canyon rocks of Cambrian age appear lying on the granites. The deposits north of Canyon consist of a thin mass of sandy and cherty beds of variable local development at the base of the Manitou limestone. They have yielded a trilobite, *Ptychoparia*, a form of Upper Cambrian age. In the Manitou embayment west and northwest of Colorado Springs the Manitou limestone is nearly everywhere underlain by 10 to 80 feet of sandstones, mostly of pinkish color, containing Upper Cambrian fossils. Some of these were obtained by Doctor Cross from the east branch of Trout Creek, 45 feet above the granite; they comprised *Lingulepis* sp. (?) and a *Lingula* of elongate form allied to *pinnæformis* of the Upper Cambrian of Wisconsin.

This sandstone appears at Manitou and extends northward along the west side of the Garden of the Gods to beyond Glen Eyrie, where it contains upper Cambrian fossils. One section which has been reported has, beginning at the base, 26 feet of greenish-white sandstone, 4 feet of coarse dark-green sandstone, 6 feet of coarse

gray sandstone, and 20 feet of brick-red sandstone with green layers, overlain by Ordovician limestone. A small area containing fossils was found southwest of Monument Park, and, according to Mr. W. T. Lee, a quartzite which is presumably of the same age appears on Deadman Creek south by west from Monument station.

ORDOVICIAN SYSTEM.

Rocks of Ordovician age are extensively exposed in the embayment north and northeast of Canyon and west of Colorado Springs, and two small areas have recently been observed southwest and south of Canyon. They consist of limestones and sandstones usually lying on a thin deposit of Cambrian sandstone, or quartzite, and 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 (Pl. V, *A*). These have been described in detail by Dr. C. D. Walcott,[a] mainly in connection with the occurrence of fish remains, and by Dr. Whitman 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 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 (Pls. VIII and XIX,). The lower part is sometimes calcareous and develops 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, underlying the Millsap (Carboniferous) limestones in the slopes west of Beulah, is mapped by Gilbert in the Pueblo folio.

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, but two small areas were found, one near the road 4 miles southwest of Canyon and another at the foot of the mountain on one of the branches of Chandler Creek, 7 miles nearly due south of Canyon.

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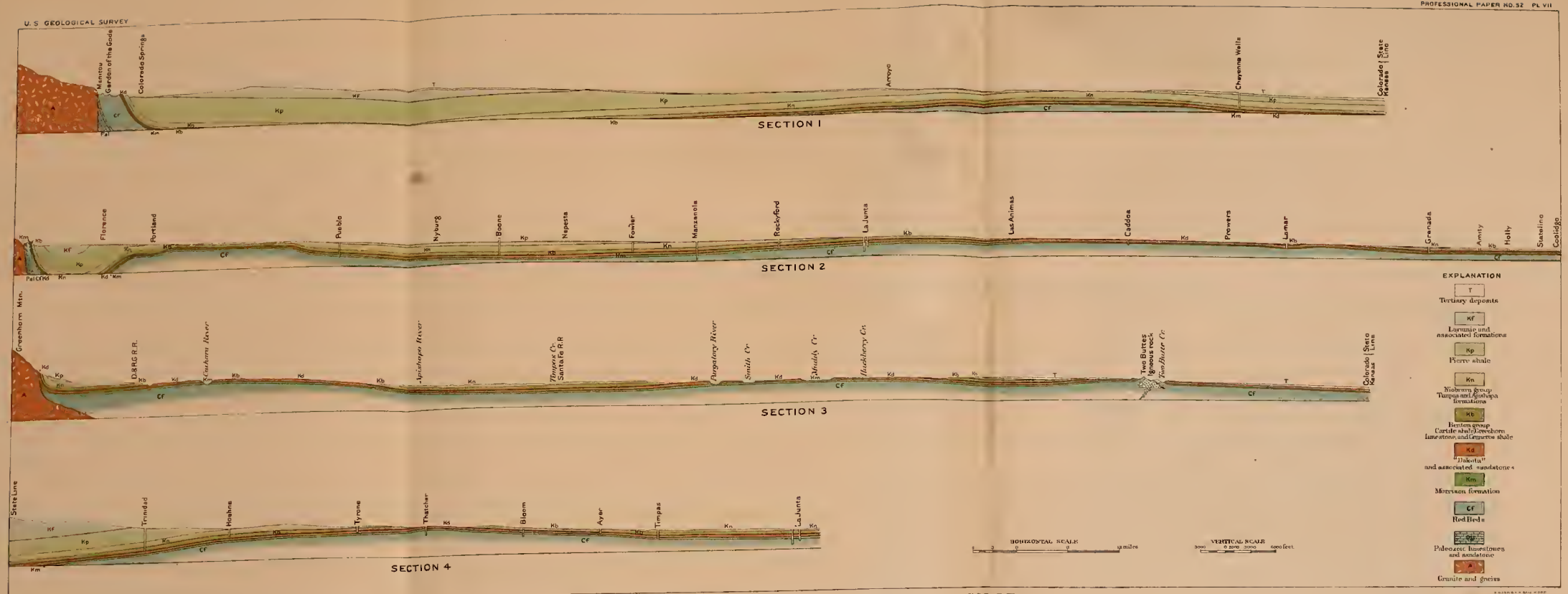
[a] Bull. Geol. Soc. America, vol. 3, pp. 153–167.



GEOLOGIC SECTIONS ACROSS SOUTHEASTERN COLORADO

ALONG LINES 1, 2, 3 AND 4, PLATES VI AND XXV

BY

N. H. DARTON

1905

At Manitou and for some distance northward and in the 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.

Doctor Peale gives the following section of the exposure of Manitou limestone and associated formations at Glen Eyrie:[a]

Geologic section of basal rocks near Glen Eyrie, Colo.

Age.	Description.	Thickness.
		Feet.
Carboniferous (?)	Gray, purplish, and yellow limestones	279
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.

CARBONIFEROUS AND TRIASSIC SYSTEMS.

Millsap limestone.—This limestone of Lower Carboniferous age appears in a few isolated outcrops west of north of Canyon and west of Colorado Springs. North of Canyon it lies on the Fremont limestone and is immediately overlain by the "Red Beds" of the Fountain formation. The locality in which the largest amount is exposed is in the angle between Oil and Millsap creeks, where there are about 30 feet of thinly bedded, variegated, dolomitic limestones, with a few thin sandstone layers. Chert nodules in the upper limestones carry casts of *Spirifera rockymontana* and *Athyris subtilita*. The limestone appears at several points among the outcrops on the slope of the mountain northwest of Canyon. In the limestone area west of Colorado Springs, fossils of Carboniferous age have been discovered by Prof. A. W. Grabau. In a letter Professor Grabau states that they are remains of *Spirifer*, either *rockymontana* or *centronatus*, and small producti. They occur in a light-gray, compact limestone about 10 feet thick, lying from 10 to 15 feet below reddish and purplish shaly beds at the base of the Fountain formation. About 100 feet lower some other remains were found which were not determined.

[a] Peale, A. C., Geology of the South Park division: Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1874, p. 201

[b] Lee, W. T., Geology of the Castle Rock region, Colorado: Am. Geologist, vol. 29, pp. 96–97.

A small area of this limestone appears on the slopes west of Beulah, as described by Mr. Gilbert. In this locality its thickness is 200 feet and it consists of gray and purplish limestone with some shale in its lower part. *Spirifera rockymontana* occurs near its middle. It lies on supposed Harding sandstone, the Fremont limestone apparently being absent.

The "Red Beds."—The most conspicuous sedimentary formations exposed along the Rocky Mountain Front Range is the succession of red sandstones known as the "Red Beds." For the greater part of their course they lie directly on the granite, but in the embayment about Manitou and Canyon they are locally underlain by limestones. Near the Arkansas divide, at Palmer Lake, they are overlapped by Monument Creek beds; west of Monument, southwest of Colorado Springs, and south of Canyon, they are faulted down, and southwest of Pueblo they are locally overlapped by the Dakota and associated formations. The thickness of the "Red Beds" is variable, but it is rarely less than 1,000 feet, and in the Garden of the Gods it is greater. Part of the variation is due to the uneven floor, the thicker masses of the beds lying in the deeper depressions. The "Red Beds" are also exposed extensively in the Purgatory and other deep canyons in the High Plains south of Arkansas River. The rocks are mainly coarse-grained red grits and red sandstones.

In the Manitou embayment there are three divisions of the "Red Beds." The uppermost consists of about 100 feet of red shales, a thick bed of gypsum, and thin beds of limestone, and is believed to represent the Chugwater formation of eastern Wyoming (upper Wyoming beds). The medial member consists of about 200 feet of fine-grained, light-colored, massive sandstone, which in the Boulder region has been designated the Lyons sandstone by Professor Fenneman.[a] The lowest formation, the Fountain, is about 1,000 feet thick and consists of coarse red grits. In southeastern Colorado the upper part of the "Red Beds" consists of gypsum and red shales, which may represent the Chugwater (Lykens) formation; as yet, however, no evidence has been found on which to base correlation.

The "Red Beds" are extensively exposed in the Garden of the Gods and for some distance north and south, dipping nearly vertical. At the south they are cut off by the great fault which passes along the base of Cheyenne Mountain. They give rise to the picturesque features of the Garden of the Gods, the Gateway marking the outcrop of the uppermost hard red stratum. Next above these are some softer striped red sandstones, about 100 feet thick, not well exposed at the Gateway, and then the white sandstone which outcrops a short distance east of the Gateway. This last bed is about 100 feet thick, moderately fine grained, massive, and cross-bedded, and represents the "Creamy sandstone" of Eldridge (or the Lyons sandstone of Fenneman), at the top of the lower Wyoming. 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 of 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

[a] Bull. U. S. Geol. Survey No. 265, 1905.

A. QUARRY IN HARDING SANDSTONE ON EAST SLOPE OF MOUNTAINS 2½ MILES NORTHWEST OF CANYON, COLO.

Looking north Granite to left, Harding sandstone in quarry, Fremont limestone and "Red Beds" in slopes to right. Photograph by C. D. Walcott.

B. FREMONT LIMESTONE NORTHWEST OF CANYON, COLO.

Shows irregular erosion forms.

Morrison shale. This upper series of red shales, limestones, and gypsum undoubtedly is equivalent to the upper Wyoming of Eldridge (or Lykens formation of Fenneman). At its base, overlying the white sandstone, are 55 feet of soft, red shale and red clayey sandstone (Cpeche horizon), 25 feet of thin limestone layers with red shale intercalations (Minnekahta), and 30 feet of red shales surmounted by a 30-foot bed of gypsum ovelain by Morrison shales. The following section was measured a short distance north of the Gateway to the Garden of the Gods:

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

	Feet.
Clays and shale (Morrisou).	
Upper Wyoming beds:	
Gypsum	30
Red shales	30
Limestone	3
Red shales with thin limestones (Minnekahta)	22
Purple limestone, thin layers	1
Soft red shale and sandstone (Opeche)	55
Top of lower Wyoming beds:	
Massive white sandstone (Lyons or Tensleep).	

To the south the "Red Beds," both upper and lower, preserve the same general features to the great fault at the foot of Cheyenne Mountain, though showing local variations. At the Gateway the 30-foot bed of gypsum is a conspicuous feature, and there is a thin bed of gypsum a short distance below its base. Just below the Gateway these beds are offset and twisted, so that they are locally deflected some distance west of the general line of strike. On the roadside south of the Gateway there are seen very coarse, cross-bedded materials in the upper part of the Fountain formation, giving place abruptly to the fine-grained red sandstones and red gypsiferous shales of the upper Wyoming, all vertical or dipping steeply eastward, as shown in Pl. IX, *A*.

In the railroad cut in the western portion of 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 that the basal member may possibly be the upper part of the Lyons.

When the "Red Beds" next appear, beyond the fault southwest of the village of Fountain, they are seen to consist, after the first 1 or 2 miles, almost entirely of coarse-grained materials without the uppermost gypsiferous red shales and to be overlain directly by Morrison beds. This coarse deposit, constituting the entire "Red Bed" section of this region, was designated the Fountain formation by Cross, a name which has been employed by Gilbert in the region still farther south. Here, as in the Manitou and Perry Park embayments, it is underlain by Millsap limestone.

The Fountain formation in the region extending from southwest of Fountain to Canyon consists mainly of coarse-grained, crumbling, arkose 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 (Pl. XX). The beds are prominently reddish, but some are gray and others are mottled gray and red. Finer grained materials, nearly all of a bright brownish-red color, often occur. The thickness is estimated as 1,000 feet, but varies considerably. Nearly everywhere the formation is separated from the granites and gneisses by limestones of Ordovician age, but in places it overlaps the crystalline rocks, and at 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. In the region southwest of Pueblo the thickness of the Fountain formation, as measured by Mr. Gilbert, is 2,100 feet, including practically all of the formation, but it thins out to the southward and is absent for some distance along the foot of Greenhorn Mountain.

At the south end of Greenhorn Mountain there appears a similar succession of rocks which Mr. Hills has named the Badito formation, probably corresponding to the Fountain formation. It comprises an upper member, about 100 feet thick, generally massive or thick-bedded, but sometimes shaly on the weathered surface, and a lower member, of about the same thickness, of very coarse brownish-red conglomerate. Lying on granites and gneisses to the south this succession appears again in the Culebra Range, where it expands to a great thickness. The Carboniferous limestones appear again on this range about Veta Pass, and they 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 "Red 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 formation, 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 mesolobus N. and D.
Productus longispinus Sow.
Productus costatus Sow.
Productus cora D'Orb.
Spirifer cameratus Morton.
Spirifer rockymontanus Marcou.
Squamularia perplexa McCh.
Seminula argentea Shep.
Acanthopecten carboniferus Stev.
Astartella concentrica McCh.
Nucula ventricosa H.
Lida bellistriata Stev.
Pelecypod (genera and sp. undet.).
Bellerophon percarinatus Con.
Euphemus carbonarius Cox.
Patellostium montfortianum N. and P..
Bellerophon sp. undet.
Rotella verrucelifera White.
Soleniscus brevis White.
Soleniscus sp. undet.
Sphærodoma texana Shum.
Sphærodoma sp. undet.
Trachydomia wheeleri Swall. var.
Naticopsis altonensis McCh.
Naticopsis altonensis var. gigantea M. and W.
Pleurotomaria perizomata White.
Pleurotomaria (several species undet.).
Murchisonia copei White.
Orthoceras sp. undet.
Syringopora sp.
Campophyllum torquium Owen.
Straparollus catilloides Con.

[a] Carboniferous of Sangre de Cristo Range, Colorado: Jour. Geol., vol. 10, pp. 393–396.

A. VERTICAL LOWER "RED BEDS," GARDEN OF THE GODS, COLORADO.

The harder portions rise in pinnacled forms.

B. THE STONEWALL ON PURGATORY RIVER 30 MILES WEST OF TRINIDAD, COLO.

Looking southeast across valley of Benton and Pierre shale to ridge of overlying sandstones.

Other fossils, found in loose fragments, were as follows:

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

The following section is given by Mr. Lee:

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

	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 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 at this locality:

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

The Millsap and underlying limestones were not found by Mr. Lee 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 and representing the Fountain formation.

In the canyon of Cuchara River, near the north line of Huerfano County, the upper portion of the "Red Beds," here termed the Badito formation by R. C. Hills,[a] is exposed. At Red Rocks, in the canyon of Purgatory River, in the northern portion of Las Animas County, there are extensive exposures of the "Red Beds" and 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 sandstone the writer found a small bone fragment, apparently a portion of a scapula of a bolodont, which would suggest that this member of the formation is of Triassic age.

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

	Feet.
"Dakota" sandstone:	
Two massive sandstones, with clay between	140
Morrison formation:	
Variegated shales, with thin limestone layers	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
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

[a] Hills, R. C., Description of the Walsenburg district: Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900.
[b] Lee, W. T., Morrison formation of Colorado: Jour. Geol., vol. 9, 1901, p. 346.

	Feet.
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, and 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 over an area of about 3 square miles in the Two Butte uplift on Two Butte Creek in Prowers and Baca counties. They are described by 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 was found to be very like the Minnekahta limestone in thin-bedded character and general aspect in the outcrops. This limestone is overlain by brick-red shales about 150 feet thick, becoming sandy at the top and merging into a massive red sandstone over 300 feet thick, which forms prominent bluffs along the creek and caps the butte, which was uplifted by the laccolithic intrusion of the 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, and somewhat resemble the "Dakota" sandstone, for which it has been mistaken here and elsewhere. It is, however, separated from the "Dakota" and probably represents the Exeter sandstone of Mr. Willis T. Lee, which appears to the south along Cimarron River.

CRETACEOUS SYSTEM.

Morrison formation.—This formation extends along the base of the Rocky Mountains, where it outcrops frequently and presents very characteristic features. In a few localities, as along the foot of Cheyenne Mountain and south of Canyon, it is cut off by faults and for short distances it is overlapped by younger formations. It is also exposed in some of the canyons eastward, notably in the deeper ones of eastern Las Animas County. Its general character is nearly uniform throughout, consisting 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 preponderance 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. The Morrison beds lie unconformably on the Chugwater

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

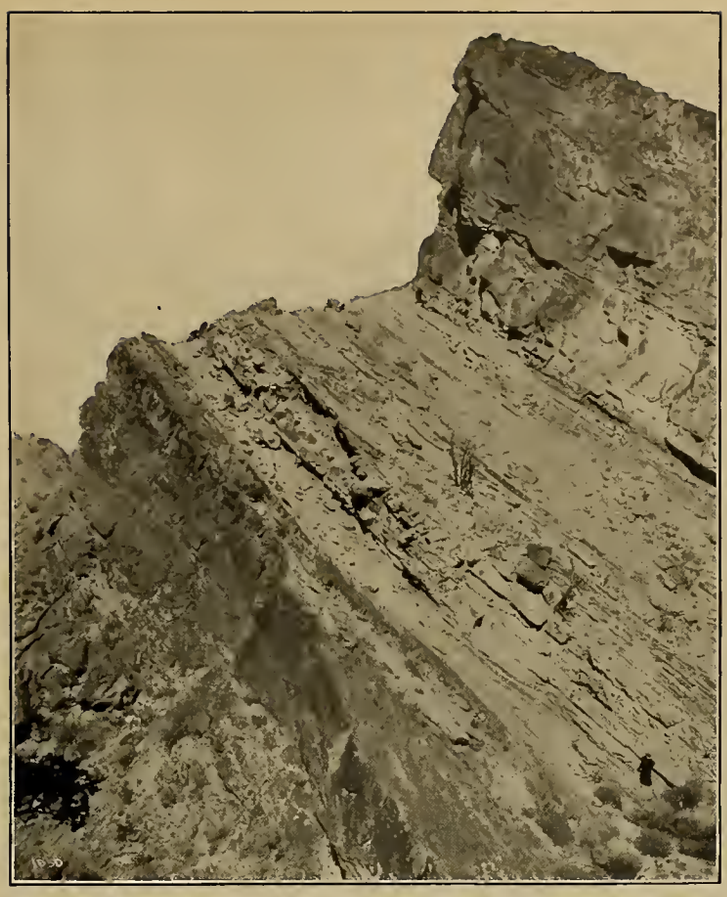
or gypsiferous "Red Beds" for many miles, and, southwest of Colorado Springs, overlap onto the "Red Beds" of the Fountain and Badito formations. In eastern Las Animas County they lie on a bed of gypsum. From the saurian remains which have been obtained so abundantly from the Morrison beds west of Denver and north of Canyon, the formation is regarded as latest Jurassic by some paleontologists and as earliest Cretaceous by others, but from its close connection with the overlying sandstone, the writer considers it preferable to class it as Cretaceous.

The formation is well exposed a short distance north of the Gateway to the Garden of the Gods, where its thickness is 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-gray 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 fault south of Colorado City, but reappears 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. In this region the formation has yielded large numbers of dinosaur remains.

Hatcher[b] has described the Morrison formation and its relations in the Garden Park area and given some details regarding the fossiliferous horizons. He estimated the thickness at 450 feet, placing the upper limit higher than Cross did, so as to include the highest sandstones and shales containing 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. X, *B*, but some occur 30 feet below this stratum and others have been found at various horizons above, both in shale and in sandstones. Just below the main bone-bearing sandstone bed there is a layer of clay with thin limestone beds containing numerous fresh-water gasteropods, and at a somewhat lower horizon, 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. The late J. B. Hatcher found an *Inoceramus* at the Garden Park locality.

Near Canyon there are excellent exposures of Morrison formation on the west slope of the "hogback." At the top are alternating sandstones and shales, 150 feet thick, lying on purple and green shales 160 feet thick, at the base of which there is a prominent layer of limestone 4 feet thick, which contains many fresh-water shells. Below this are 40 feet of pale bluish-green massive shales lying on sandstones. 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 Carnegie Museum, vol. I, 1901, pp. 327–341.



A. DAKOTA SANDSTONE IN HOGBACK RIDGE 2 MILES SOUTHWEST OF CANYON, COLO.

Looking north. Shows upper and lower sandstone members with intermediate shales.

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

Photograph by I. C. Russell.

total thickness appears to be nearly 400 feet. Four miles south of Canyon the formation lies directly on granite, as shown in Pl. XVII, *B*, and described on page 42.

Six miles south of Canyon the Morrison beds are faulted out, or overlapped by younger strata, and do not reappear until in the vicinity of Mineral Creek south of Florence, whence they extend southward into North Creek Valley. According to Mr. G. K. Gilbert, the "Dakota" sandstone lies directly on the Fountain formation north of Beulah for several miles, but probably the Morrison beds formerly covered the region and were removed by pre-"Dakota" erosion. The Morrison beds appear south of Beulah, where, as described by Mr. Gilbert,[a] they 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 onto that rock for a portion of their course; near the contact they are paler in color, white and orange predominating, and no reds appear. The formation comes up again for 5 miles at the south end of Greenhorn Mountains, lying partly on gneiss and partly on the "Red Beds." Its thickness here, according to Hills,[b] 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, but assigns it provisionally to the Jurassic.

Mr. Willis T. Lee has made a special study of the Morrison formation in the southern Colorado region,[c] 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 southward. He has found that it presents its usual characteristics, 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 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 and 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

[a] Gilbert, G. K., Description of the Pueblo quadrangle: Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897.
[b] Hills, R. C., Description of the Walsenburg district: Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900.
[c] Lee, Willis T., Jour. Geol., vol. 9, pp. 343–352; vol. 10, pp. 36–58.

Morrison—Continued.	Feet.
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 and gypsum on Red Beds.	

Lee gives the following section in Red Rock Canyon, a small side canyon of Purgatory River:

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

"Dakota:"	Feet.
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	⅔
Yellow shale	4
Sandstone with agate masses	1
Soft, thin-bedded sandstone	8
Soft massive sandstone	2
Paper shale	2
Soft massive sandstone	7
"Red Beds:"	
Gypsum and clay on red sandstone	12–20

In this canyon the thickness is 132 feet; in Chaquaqua Canyon, 10 miles from the mouth of Plum Canyon, it is 175 feet(by barometer), and the predominating material is 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-fourth 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 limestone 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.

A

B

THE STONEWALL ON PURGATORY RIVER WEST OF TRINIDAD, COLO.; A MONOCLINAL RIDGE OF "DAKOTA" SANDSTONE.

A. Looking west to Culebra Range. *B*. Looking south, showing red valley to right and valleys of Graneros and overlying shales to left.

The gypsiferous shales appear to be distinct, and are regarded as a portion of the "Red Beds." The formation extends down Purgatory River 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 the 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 the writer found it apparently exposed in the Two Butte uplift on Two 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. Willis T. Lee announced that he had traced the formation eastward down the Cimarron Valley into Oklahoma.

Comanche series.—This series was first discovered[a] in Colorado on Two Butte Creek, 5 miles east of Two Butte, and during the summer of 1905 Mr. T. W. Stanton and Mr. Willis T. Lee found Comanche fossils in the fire clay lying between the two sandstones of the "Dakota" in Purgatory Canyon south of La Junta, while later Mr. Stanton found them in the same position west of Canyon. This important discovery indicates a wide extension of the formation to and along the Rocky Mountain Front Range, constituting the middle and lower portions of the "Dakota" formation. At the Two Butte Creek locality the creek crosses a low anticline in which the upper member of the "Dakota" sandstone is seen to be 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. Doubtless the Comanche beds underlie the greater part of Baca County, for they have been discovered by Mr. Willis T. 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 especially examined for outcrops of beds underlying the top "Dakota" sandstone.

"Dakota" sandstone.—Under this heading will be described the entire sandstone succession overlying the Morrison formation, for this always has been known as the "Dakota" sandstone or "Dakota" formation. It generally consists of two bodies of sandstone, each a hundred feet or more in thickness, separated by a deposit of clay or shale from 10 to 15 feet thick. This clay in the Golden region and the top sandstone at various localities have yielded abundant plant remains of the Dakota flora (Upper Cretaceous). The tripartite succession strongly suggests the Dakota sandstone, Fuson clay, and Lakota sandstone of the Black Hills, and the Lower Cretaceous age of the two latter, at least in southeastern Colorado, is proved by the occurrence of Comanche fossils in the fire-clay member, as described in a preceding paragraph.

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 along the foothills (Pls. V and IX, *B*) and plateaus, with steep-walled canyons in the southeastern part of the State (Pl. IV, *B*). The predominating color is light buff, but some portions are light gray or white, and

[a] Described by N. H. Darton, in Science, vol. 22, p. 120, 1905.

darker tints are not infrequent, especially in the upper beds. Cross-bedding is almost general and conglomeratic streaks are frequent, especially at or near the base of the lower sandstone. The contact with Morrison beds is abrupt and often presents evidence of slight unconformity by erosion. There is often a 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 member is thicker than the upper, often somewhat softer, and it contains shale partings at some localities. The middle shale member appears to be present throughout, but generally it is covered by talus. It is well shown in Pl. X, *A*. In the Garden of the Gods region Doctor Peale reports a thickness of 257 feet, 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. The writer's measurement in vertical beds near the Gateway gave considerably less thickness, and the formation was found 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 region of Canyon, 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 in which, in the summer of 1905, T. W. Stanton found Comanche fossils. Fossil leaves are said to occur in thin layers at various horizons.

"Dakota" sandstone is prominent at the foot of Wet Mountains southwest of Pueblo, as 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 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 Greenhorn Mountain the formation is described by Hills as consisting of 350 feet or more of sandstone, of which the lower two-thirds consists generally of a yellowish-gray rock of coarse, porous texture, with some layers of fine conglomerate, commonly cross-bedded. This lower member is separated from the upper one by gray shales 8 to 10 feet in thickness. The upper sandstones aggregate 100 to 150 feet in thickness, are light gray, and of fresh, fine-grained, close texture, regularly bedded. The formation lies in part on the Morrison, but in places along the mountain front overlaps 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 Spanish Peaks and the Sangre de Cristo Range, appearing for many miles as a vertical "stone wall" rising high above the adjoining softer beds.

In the extensive exposures of "Dakota" sandstone in the eastern half of Las Animas County is presented a regular succession of the two massive sandstone layers with their intervening shales or fire clay containing Comanche fossils. Referring

[a] Gilbert, G. K., Description of the Pueblo quadrangle: Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897, p. 6.

A. GREENHORN LIMESTONE NEAR THATCHER, COLO.

Typical view showing limestone with interbedded black shales. Base of this formation is about 200 feet above water-bearing Dakota sandstone.

B. TIMPAS LIMESTONE IN QUARRY SOUTHEAST OF LA JUNTA, COLO.

Shows thickness of beds and intercalations of shale.

to the formation in Purgatory Canyon, near longitude 104°, Hills states that the thickness is about 375 feet, and that 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 more compact 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. In the vicinity of the Two Butte uplift the sandstone has been extensively eroded over an area about a mile square. The 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 supposed Morrison shales and limestones.

Graneros shale.—This shale, which is the basal member of the Benton group, underlies a large portion of eastern Colorado. It outcrops in a narrow zone along the foothills of the Rocky Mountains and in broader areas on the flanks of the anticlines in Pueblo, Huerfano, and Las Animas counties, and along the Arkansas Valley east of La Junta. Its thickness generally averages 200 feet, and it appears to be perfectly conformable to the adjoining formations. Usually there are a few feet of transition beds to the "Dakota" sandstone at its base and to the overlying Greenhorn limestone. The shale is mostly hard and fissile; its color is bluish gray, darkest in the middle and slightly lighter in the upper and lower beds. Thin beds of white clay occur locally. In the region south of Pueblo the formation contains a layer of limy sandstone 1 to 2 inches thick about 50 feet below the top of the formation. It contains fossil shells of several species. Concretions of carbonate of lime occur at various levels in most localities, especially 20 to 30 feet above the base of the formation. In some districts this horizon of concretions changes into a layer of dark-gray limestone, 8 inches to a foot in thickness, which weathers to a bright-orange color. In general the formation appears in gentle slopes of gray clay, with occasional concretions, and in some recently cut banks the shaly character of the less weathered material is apparent. In most of the Arkansas Valley region the thickness varies only from 200 to 210 feet, but north of Canyon it is between 325 and 350 feet, and 3 miles south of that city it is 250 feet. The limestone layer occurring 30 feet above the base of the formation is most conspicuous in the region east and northeast of Trinidad, where its thickness is 1 to 2 feet. It is hard and of concretionary structure. It weathers to a bright-orange color, so that it is a conspicuous feature.

Greenhorn limestone.—This medial formation of the Benton group outcrops along the margin of the Graneros shale area above described. Its thickness varies from 30 to 50 feet. It consists of beds of pale bluish-gray, fine-grained, compact limestone, mostly 3 to 10 inches thick, separated by dark-gray shales 4 to 18 inches thick. (Pl. XII, *A*.) These intermediate shale beds are usually thicker where the formation is thickest. The limestone has a strong tendency to split with vertical cleavage into small slabs one-fourth inch to 2 inches in thickness, which form a conspicuous feature on the slopes. At most localities the formation grades into the

adjoining formations through a few inches of passage beds. A few thin beds of white clay have been reported as occurring in the formation at points in the vicinity of Pueblo. Most of the limestone beds contain an abundance of a highly characteristic fossil, *Inoceramus labiatus*. This form is represented by casts and impressions often closely packed together in some of the layers. The appearance of this fossil is shown in Pl. XIII, *B*. It is not known to occur in any of the formations. In the shales between the limestone layers a somewhat similar fossil occurs, often in considerable abundance. In most districts the ledges of Greenhorn limestone give rise to low mesas or shelves in the slopes and often bear a scattered growth of cedars and piñons. The thickest development of the formation is 2 miles north of the city of Canyon, where it is 60 feet thick, while in Webster Park it is not over 10 feet thick.

Carlile formation.—The Carlile formation, which consists mainly of shale, outcrops along the foothills of the Rocky Mountains in the anticlinal area west, south, and southeast of Pueblo, along the north side of the Purgatory Valley northeast of Alfalfa, and down the north side of the Arkansas Valley below La Junta. Small areas occur on divides southeast and southwest of Lamar. The formation consists mainly of shale of dark-gray color, averaging 200 feet thick. The middle beds are usually the darkest, some of them being black. At the top there is a bed of sandstone varying in thickness from a few inches to 20 feet, the amount increasing to the west. In the same direction, also, the upper fourth of the formation becomes somewhat more sandy and occasional thin beds of sandstone appear. In these sandy beds occur numerous oval and globular concretions which often attain a diameter of 1 foot to 5 or 6 feet. Most of them are traversed by cracks filled with wine-colored calcite. The top sandstone averages 10 to 20 feet in thickness west of longitude 104° and attains a maximum of 30 feet at Greenwood on Hardscrabble Creek, and near Chandler, south of Canyon. Near La Junta it is 3 feet thick, having the relations shown in Pl. XV, *B*. Usually it is soft, somewhat mixed with sandy shale and of yellowish color. The fossil known as *Pugnellus* occurs abundantly in the formation in the southwestern portion of the area. At the top of the Carlile formation in the southern and central portions of the region to which this report relates there is a purplish limestone 6 inches to 2 feet in thickness, in which the large coiled shell *Prionocyclus wyomingensis* is of frequent occurrence. From 50 to 75 feet above the base of the formation in most districts, especially to the east, a thin limy layer containing fossils is often found.

Timpas limestone.—The Timpas limestone is the lower member of the Niobrara group. Its thickness varies from 175 to 200 feet, and it consists of a basal limestone with overlying alternations of limestone and shale, all of light color. It is a conspicuous formation in eastern Colorado, underlying all of the region east of the Rocky Mountains, except on the anticlines south and southeast of Pueblo and along the Arkansas Valley east of La Junta. In the region east of Colorado Springs it lies deeply buried beneath younger formations, but it appears extensively in the Arkansas Valley and in a broad belt extending across the eastern parts of Huerfano and Las Animas counties. A small outlier appears on the high ridge 25 miles southwest of Lamar, and there is continuous outcrop of the formation along the north side of the Arkansas Valley east of Rocky Ford. At the base of the Timpas there is a lime-

CHARACTERISTIC FOSSILS OF NIOBRARA AND GREENHORN LIMESTONES.

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

stone series about 50 feet thick, which usually outcrops in a ledge or rocky slope of considerable prominence. (Pl. XII, *B*, and XV, *B*.) It consists of beds in layers, mostly 6 inches to a foot in thickness, separated by 1 to 2 inches of light-gray, calcareous, limy shale. The limestone is white, or of a very light-gray color, becoming creamy white on weathering. It is compact, fine grained, and has an easy conchoidal fracture rudely parallel to the bedding. Owing to the latter property it usually weathers into flat flakes 2 or 3 inches long, differing in this respect from the Greenhorn limestone, which cleaves into vertical flakes. The lighter color is also a distinguishing feature. In the eastern portion of the area the rock has a more chalky texture. In the lower beds small nodules of a form of iron sulphide known as marcasite occur, which usually weather out as limonite. These are of dark-brown color and spherical or cylindrical in shape, usually one-fourth to three-fourths inch in diameter. These often accumulate in considerable number on the weathered surfaces. The limestone contains a characteristic fossil known as *Inoceramus deformis*, which occurs scattered at intervals through the beds. The shell is thick, has a roughly corrugated surface, and its larger valve has a shallow cup shape. Occasionally shells of a small oyster, *Ostrea congesta*, occur upon it, but these are also sometimes found separately. Much of the limestone consists of minute organisms known as foraminifera, which are plainly visible when thin slices of the rock are examined under the microscope. Above the basal limestone are about 100 to 150 feet of calcareous shale of light-gray color, containing occasional thin beds of grayish-white limestone. Toward the top of this member there are two or three thicker, persistent layers of limestone, 12 to 18 inches thick, separated by a few feet of shales and marking the top of the formation.

Fossils occur in the upper shales, consisting mostly of a very broad, flat *Inoceramus*, usually covered by *Ostrea congesta*. In the Pueblo region the lowest stratum of the limestone is an impure sandy limestone 1 to 2 feet thick, of dark-gray color, which weathers to a yellowish-brown tint. It contains teeth of sharks and other fishes and numerous dark pebbles half an inch in diameter.

Apishapa formation.—In southern Colorado the upper part of the Niobrara group has been separated as the Apishapa formation. It consists mainly of shale and calcareous shale, with a few layers of cream-colored limestones at the top. The thickness varies from 400 to 700 feet, but averages about 450 feet in the greater part of the region. Many of the shales vary in color from light gray to dark gray and are sandy, with intercalations at intervals of dull-gray to cream-colored limy shales and impure limestones. The most persistent lime deposits are an alternation of yellow limestones and light bluish-gray limy shales 10 to 20 feet thick, marking the top of the formation. The lowest beds are mostly dark fissile shale about 50 feet thick. These are followed by about 100 feet of soft, papery shales of dark-gray color. The middle portion of the formation is decidedly sandy, while the upper 100 feet of the formation, especially in the region between Pueblo and La Junta, consists of dark bluish-gray fissile shale, containing two and sometimes three horizons of cream-colored limestone. At various horizons in the formation, especially toward the top and eastern part of the district, calcareous concretions occur. They are usually of considerable size and of lens shape. In some areas they give place to thin layers of concretionary limestone, which are of sufficient hardness to form ledges or low hills in

the smooth slopes of the adjoining beds. In the region north and east of Trinidad the Apishapa formation consists of about 40 feet of dark-gray to blue-gray shales at the base, followed by 90 feet of soft, papery shales, which grade upward through the blue, sandy shales into alternations of limy and sandy shales. Near the middle of the formation these sandy shales become coarser and flag-like, constituting about one-third of the formation. This member is usually somewhat bituminous. The upper 100 feet resembles the basal portion, but includes two and in places three thin layers of limestone and lens-shaped concretions of impure limestone. The fossil remains consist of fish scales, which are generally abundant in the shales and sometimes in the coarser flag-like layers. Crustacean tracks also sometimes occur. Fish scales from half an inch to an inch in diameter are usually abundant. Portions of the Apishapa beds weather to a bright-straw color, which is a conspicuous feature in its outcrops. *Ostrea congesta* is a characteristic fossil, usually closely packed in masses a foot or more in diameter, and is from half an inch to an inch thick (Pl. XIII, *A*).

Pierre shale.—The calcareous deposits of the Niobrara group are succeeded by a great thickness of the dark-gray Pierre shales. These underlie the deep structural basin extending from east of Colorado Springs south to the Arkansas Valley between Pueblo and Manzanola, the Florence basin, and the deep syncline in central Huerfano and Las Animas counties. Their thickness is over 3,000 feet in the district east of Colorado Springs and about Florence, but the amount diminishes to the south and is not more than 1,600 feet in the vicinity of Trinidad. In the vicinity of Arkansas River below Pueblo several distinct zones have been recognized in the formation. The lower beds for a thickness of 400 to 500 feet are of medium-gray color and yield no fossils. They contain much selenite in minute flakes. Next above is a zone of similar-colored shales containing less selenite and characterized by a great abundance of oval concretions, usually 4 to 8 inches thick and 1 to 2 feet long. These are fine grained, dark gray in color, and consist of carbonate of lime and carbonate of iron. On weathering these concretions break into small angular fragments of dark rust-brown color, which are often so abundant on the slopes as to give them a reddish color. On this account the beds have been called the "Rusty zone." Their thickness is about 600 feet. Beginning in the top of this zone and extending upward 100 to 200 feet is a noticeable abundance of fossils known as *Baculites compressus*. Their form is that of a flattened cylinder, slightly tapering, and sometimes showing the remains of the shell. They are often a foot in length and 2 inches in diameter, but most of them are smaller. This form occurs at other horizons, but is most abundant here. Next above the "Rusty zone" are shales of somewhat lighter color, in the upper portion of which occur masses of limestone, often constituting small conical hills, or "tepee buttes," as they have been termed (Pl. XV, *A*). These limestone masses consist of coarse-textured, gray, fossiliferous rock, often rudely cylindrical in form and standing vertical within the shale mass. Ordinarily they are 5 to 30 feet in diameter and of considerably greater length. As they offer more resistance to erosion than most of the adjoining shales, the core and the fragments of rock derived from it often rise in conical hills 25 to 50 feet above the surrounding surface. Fossils occur in the limestone in considerable variety, but the most abundant species is a small oval bivalve known as *Lucina occidentalis*. The zone of the tepee

VIEW ALONG ARKANSAS RIVER WEST OF PUEBLO. BASAL TIMPAS LIMESTONE ON CARLILE SANDSTONE.

buttes is apparently several hundred feet thick, but its precise stratigraphic limits could not be determined. In this zone there also occur smaller lens-shaped limestone, concretions, 6 to 12 inches thick and 1 to 3 feet in diameter, containing large numbers of beautifully preserved fossils of various kinds. In many cases the original shell is preserved, retaining its original pearly luster. Above the tepee zone the shales become darker, are less fossiliferous, and contain fewer concretions. The amount of selenite in small crystals increases considerably. The top of the formation is somewhat indefinite, the shales gradually giving place to sandy beds. In the region between Walsenburg and Trinidad the basal and upper zones weather to a yellowish-green color; the middle zone is dark gray and lead gray, occasionally almost black. The latter zone contains an abundance of lime and iron concretions, which break up readily and impart a rusty tint to the surface.

An analysis of a typical sample of tepee rock, made by Dr. W. F. Hillebrand,[a] of the United States Geological Survey, is as follows:

Analysis of limestone in tepee core.

Silica (SiO_2)	7.46
Titanium dioxide (TiO_2)	1.78
Alumina (Al_2O_3)	
Iron sesquioxide (Fe_2O_3)	.94
Lime (CaO)	46.98
Magnesia (MgO)	2.36
Potash (K_2O)	.37
Soda (Na_2O)	
Phosphoric oxide (P_2O_5)	undet.
Carbon dioxide (CO_2)	39.25
Water loss at 100° C	.16
Water loss above 100° C	.70
Organic material	
	100.00

The limestone constituting these tepee cores bears a marine fauna. *Lucina occidentalis* is the most abundant molluscan species, forming a leading constituent of the rock. *Inoceramus* is rather common and cephalopods occur in considerable variety. Foraminiferal forms frequently disclose themselves under the microscope. The occurrence of fossil wood has also been reported from some of the cores. The following is a list of the molluscan species determined by T. W. Stanton, from specimens collected by Mr. Gilbert:

Ostrea inornata M. and H.
Inoceramus crispii var. barabini Morton.
Inoceramus vanuxemi M. and H.
Inoceramus sagensis Owen.
Lucina occidentalis var. ventricosa M. and H.
Thetis circularis M. and H.
Anchura (Drepanochilus) americana E. and S.
Nautilus dekayi Morton.
Baculites ovatus Say.
Baculites compressus Say.
Scaphites nodosus Owen (?)
Scaphites nodosus var. quadrangularis M. and H.
Scaphites nodosus var. brevis Meek.
Ptychoceras crassum Whitfield.
Heteroceras (Exiteloceras) cheyennense M. and H. (?).
Heteroceras (Didymoceras) nebrascense.
Heteroceras (Didymoceras) cochleatum M. and H. (?).
Heteroceras sp. undet.
Helicoceras sp. undet.

[a] Gilbert, G. K., Description of Pueblo quadrangle: Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897, p. 7.

Fox Hills sandstone.—The Pierre shale gives place abruptly to several hundred feet of sandstone which are supposed to correspond to the Fox Hills formation. These sandstones are most extensively exhibited in the region about Walsenburg and Trinidad, where they are of sufficient hardness to give rise to a prominent escarpment, extending from the south side of the Huerfano Valley to the Raton Mesa. In this district they are known as the Trinidad formation, which here consists of a lower member, 85 to 90 feet thick, of thin-bedded, fine-grained, dark-gray sandstone in layers 2 to 4 inches thick, with thin shale partings, and an upper member, 75 to 80 feet thick, of greenish-gray, heavy-bedded, massive sandstone which weathers to a light-gray color. This upper bed is characterized by numerous remains of the fossil *Fucoid halymenites*, which is easily recognized by the pitted cylindrical casts of the branching stems. In the lower beds occasional poorly preserved baculites are found. The total thickness of the formation is about 150 feet in the vicinity of Trinidad and about 170 feet near Walsenburg. At its top there are usually a few feet of brown sandstone in contact with the overlying Laramie. Near Trinidad the thin sandstone layers of the lower member rarely exceed 3 inches in thickness, except near the base, where there is a prominent bed of coarser sandstone 3 to 5 feet thick. These beds become thicker and coarser northward, and to this is due the expansion of the lower zone. In the district east of Colorado Springs there is only a small thickness of sandstone between the supposed top of the Pierre shale and the lowest coal beds, so that there the representative of the Fox Hills is but scantily developed, unless possibly there should be comprised in it some of the underlying shales; similar conditions prevail in the eastern portion of Elbert County and the northern portion of Lincoln County, where the Fox Hills formation has as yet not been differentiated. In the Florence basin the formation consists of about 400 feet of sandy shales, with a few limestone concretions, capped by a persistent bed of yellow fossiliferous sandstone 10 to 50 feet thick.

Laramie formation.—The Laramie formation occurs in three areas in the district to which this report relates. One is in the wide, shallow syncline east of Colorado Springs; the second is in a long, deep syncline south and west of Trinidad and Walsenburg, and the third is in the deep but small syncline near Florence. The rocks are sandstones and shales, and among them at various horizons, especially in the lower beds, are extensive deposits of lignite. The sandstones are mostly massive, soft, and yellowish, 10 to 20 feet thick, with intervening bodies of shales, which are usually sandy and carbonaceous. The thickness varies from 1,000 to 2,500 feet. The Laramie rocks in the basin east of Colorado Springs have not been studied in detail, but in general they present the characteristics above mentioned. The coal is worked from lower beds at several points north, east, and southeast of the city. The Laramie area extends east into the northern portion of Lincoln County, but its limit in that direction was not accurately ascertained, owing mainly to the cover of surficial formations.

In the Florence district the Laramie is composed of a succession of heavy bedded sandstones with intercalated shales, and in the lower portions there are beds of workable coal. These sandstones form an escarpment surrounding the mesa southwest of Florence and constitute one or two small outliers, one of which is known as Castle Rock. In this basin there is more sandstone than shale in the Laramie formation.

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

The core of these buttes is limestone.

B. TIMPAS LIMESTONE ON CARLILE SANDSTONE 2 MILES NORTHWEST OF LA JUNTA, COLO.

Looking northwest. The sandstone is behind the figure.

In the vicinity of Walsenburg the Laramie formation has a thickness of 1,000 feet, which increases to the southward, due to the thickening of the upper member and to diminished erosion of its upper surface, until at the State line south of Trinidad the thickness is 2,500 feet. The basal beds are shales overlying the Trinidad sandstone. 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. There are two principal groups of coal beds—one between the Trinidad sandstone and the massive sandstone 100 feet above, and the other above this sandstone.

The fossil remains of the Laramie formation are limited to the characteristic *Ostrea glabra*, a unio, and a dinosaur of undetermined genus. It contains 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 tulips. In the region of Golden, Colo., there are 83 species that are peculiar to the Laramie.

CRETACEOUS(?) SYSTEM.

Arapahoe formation.—In the Denver basin the Laramie formation is overlain by 600 to 800 feet of conglomerates, sandstones, and shales, which are separated by an unconformity and by some are believed to be of early Tertiary age. At the base are 50 to 200 feet of conglomerates and sandstones of increasing coarseness toward the mountains, while above are several hundred feet of sandy shales containing irregular masses of sandstones. These deposits extend far south of Denver and appear to be represented in the Monument Park region and east of Colorado Springs, but their limits and relations have not been determined. Apparently the coarser, lower beds increase in thickness to the south. The formation appears to be present in small amount in the Florence basin, where a series of conglomerates and sandstones 250 to 300 feet thick is supposed to represent it. It is a prominent component in the Spanish Peaks basin, where it is represented by all or part of the Poison Canyon formation of R. C. Hills.

Poison Canyon formation.—This formation underlies much of the high region rising to the Spanish Peaks between the Purgatory and Huerfano valleys. To the north it is separated from the underlying Laramie beds by marked unconformity, while in the vicinity of Spanish Peaks and southward there appears to have been continuous deposition between the two formations. The thickness is 2,000 feet to the south and 3,500 feet in the extension of the formation northwestward up the Huerfano Valley. The rocks consist of coarse sandstones and conglomerates in beds 10 to 50 feet thick, separated by thinner masses of yellow clay. The conglomerates near the middle of the formation often are not firmly cemented and resemble gravel beds. The overlying sandstones are light gray, weathering pink, while the sandstones lower in the formation are yellowish, with red blotches, but similarly weathering to a pink tint. No fossils have been reported, but, from the relations of the formation, there should be little question that it is approximately the same age as the Arapahoe. Some baculites reported from the section of the

beds in Poison Canyon doubtless were found in or were derived from the Pierre shales, which are overlapped by the formation in that region.

Denver formation.—In the Denver basin the Arapahoe formation is overlain by several hundred feet of coarse deposits, consisting largely in the lower part of débris of younger eruptive rocks and in the upper part of granitic débris. It also includes local sheets of basalt and volcanic tuffs. Its age may be early Eocene. This formation is not known to extend into the Arkansas basin, but may possibly underlie a portion of the high divide near the foot of the mountains. Some small areas of conglomerates, sandstones, and shales overlie the supposed Arapahoe formation in the Florence basin, but they can not certainly be correlated with the Denver formation. In the higher slopes of the Spanish Peaks area, however, there is a formation succeeding the Poison Creek beds which Mr. Hills has designated the Cuchara formation, and the stratigraphic succession strongly suggests that this may represent the Denver beds.

Cuchara formation.—This formation has a thickness of about 500 feet, consisting mostly of massive, yellowish, reddish, or brownish sandstones, with 50 to 100 feet of red, brown, and sometimes white marl, shale, and sand at the bottom. The sandstone is coarse and the conglomerates are often very loosely cemented, the pebbles largely of granite and Carboniferous débris. The formation has yielded no fossils, but the Denver formation has yielded 150 species of plants, only 15 of which are common to the Laramie.

TERTIARY SYSTEM.

Monument Creek formation.—On the high divide between the Platte and Arkansas drainage basins, at the foot of the Rocky Mountains, there is an extensive deposit of conglomerates, sand, sandstone, gravel, and clay, known as the Monument Creek formation. It lies on the Laramie formation to the east and the Arapahoe formation to the west, and at Palmer Lake it abuts against the granite at the foot of the mountain. There are two members, a lower one of sands and clays and an upper one of conglomerate and sandstone. The latter caps numerous buttes and plateaus in the high region west and north of Calhan and north of Monument.

Fossil bones of *Titanotherium* have been discovered by the writer[a] and Mr. C. A. Fisher in the upper member in the region north of Calhan and southwest of Elizabeth, which indicate that this portion of the formation is of Oligocene age. The lower member may be Oligocene, or perhaps Wasatch or Bridger, in age.

Nussbaum formation.—Wide areas of the High Plains adjoining the Arkansas Valley in eastern Colorado are mantled by loams, sands, and gravels of late Tertiary age, of which some outlying portions westward have been designated the Nussbaum formation by Mr. Gilbert. These deposits consist of the "Tertiary grit" and "Plains marl" of the Kansas geologists and are supposed to be of Pliocene age. The formation is composed mainly of loose sand and coarse gravel, which on the higher divides eastward has a thickness of more than 200 feet. Locally some portions often consist of a loose sandstone, and frequently the beds are cemented by carbonate of lime into a very sandy limestone ("mortar beds"), occasionally

[a] Darton, N. H., Age of Monument Creek formation: Am. Jour. Sci., vol. 20, 1905, pp. 178–180.

of considerable extent. The most extensive areas cover the High Plains north of Arkansas River to the east of Fountain Creek Valley, and south of the river in Prowers and Baca counties. Small outliers remain on many of the divides south of the river, west from longitude 104° to the foot of the mountains, probably indicating that originally all of the plains region was covered by the formation. In general the deposits have a smooth surface and slope gently to the east, but there is also a slope into the Arkansas Valley, especially near Boone and Fowler, where it approaches near to the river and ends in a prominent bluff. In Kiowa County two distinct terrace levels are exhibited in the slope toward Arkansas River, with underlying Cretaceous beds showing in places in the intervening escarpment. In the high ridge extending east and north from Calhan the western margin of the formation presents a steep front to the west and northwest, in marked contrast to the gentle easterly slopes. The eastern limits of the formation north of Arkansas River are usually indefinite, owing to wash of the deposits down the general slope. South of Lamar the formation caps an elevated smooth-topped ridge and is terminated to the north by an abrupt slope, especially at the head of Clay Creek. To the east it descends rapidly and crosses Two Butte and adjoining creeks.

QUATERNARY SYSTEM.

Alluvium.—The largest areas of alluvium in this district are along Arkansas River below Pueblo. The width of the bottom lands which they constitute varies from three-fourths of a mile to a mile, and the thickness of the deposit is 50 to 60 feet in the central portion of the valley. The materials are mostly fine sands and loams laid down by the river at various stages; in times of flood more or less new material is deposited, especially on the lower flats. Above Pueblo, where the river flows in a narrower valley, the alluvial flats are narrower.

There are alluvial bottom lands along Fountain Creek and nearly all of the larger branches of the Arkansas, the only exceptions being in some of the narrower portions of the canyons in the southwestern part of the area. Higher terrace levels appear in places, capped by sand and gravel, products of an earlier period of Quaternary deposition.

Dune sands.—Sands which have been heaped up by the wind occur extensively along the south side of Arkansas River from Las Animas eastward, often in a belt a mile wide. Dunes of considerable prominence are found south of Lamar and Granada. Portions of the Nussbaum formation give rise to sand dunes, notably in the region north of Nepesta and in wide areas in Kiowa, Cheyenne, and Lincoln counties. Between Rush Creek and Big Sandy nearly all of the land is capped by sand dunes derived from the Nussbaum formation.

IGNEOUS ROCKS.

In the Rocky Mountain Range adjoining the Arkansas Valley are extensive bodies of igneous rocks, mostly of Tertiary age. Those in the vicinity of Pikes Peak and Cripple Creek have been described by Doctor Cross[a] and others. The extensive series of dikes in the Spanish Peaks and adjacent slopes have been

[a] Cross, Whitman, Description of Pikes Peak quadrangle: Geologic Atlas U. S., folio 7, U. S., Geol. Survey, 1894.

described by Mr. R. C. Hills[a] and the reader is referred to these publications for details. The distribution of the rocks is shown in Pl. VI.

The Mesa de Maya and the Raton Mesa consist of remnants of extensive outflows of basalt of late Tertiary or Quaternary age, and in their vicinity are a number of similar smaller outliers of the same material, as shown in Pl. II. On the south side of the Mesa de Maya the basalt is seen to overlie an outlier of later Tertiary gravels, which indicates that the age is post-Pliocene.

In the Two Butte uplift igneous rocks appear, as described by Mr. G. K. Gilbert,[b] in a laccolithic mass and in numerous dikes.

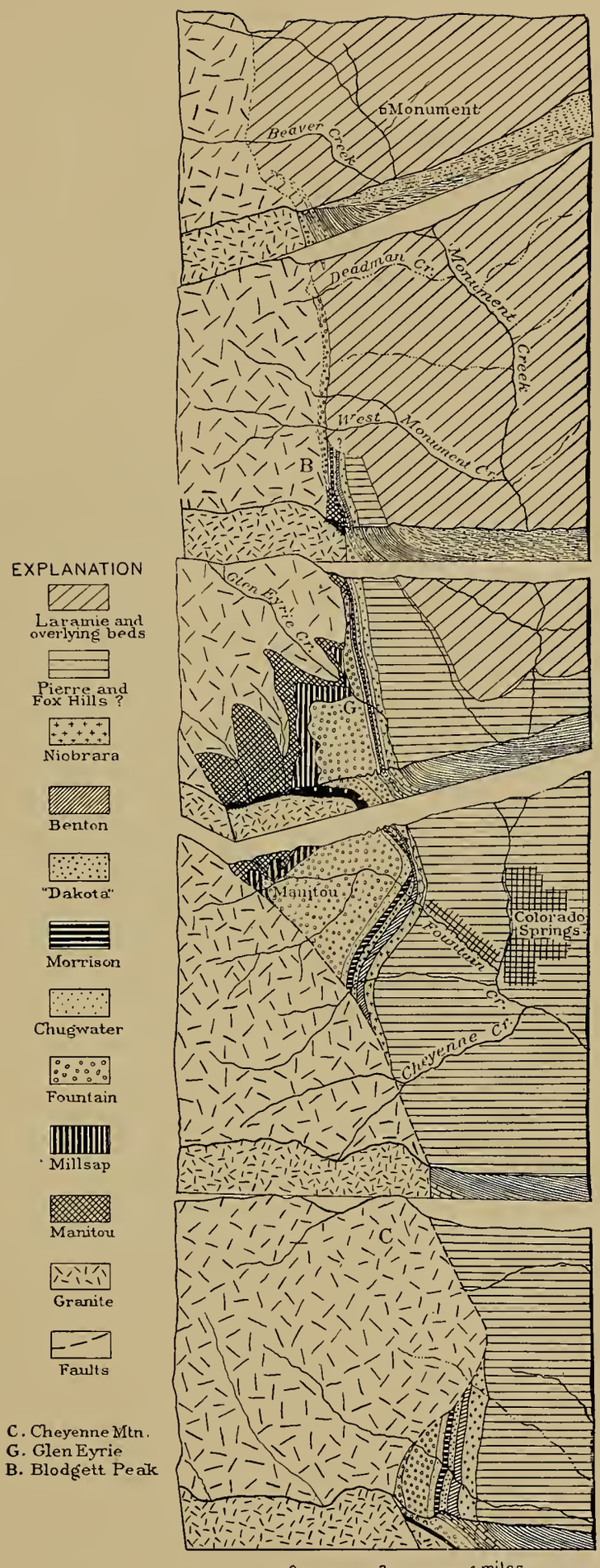
MANITOU EMBAYMENT.

West of Colorado Springs there is a westward deflection in the Front Range of the Rocky Mountains, in which lies a thick development of the Paleozoic rocks. The recess is about 4 miles deep and is due to a westward trend of the granite on the north side and a profound fault on the southwest side, forming a reentrant angle of which the apex is at Manitou. In Pl. XVI the principal geologic relations are shown, and they are especially brought out by the central cross section on that plate. To the north and south the "Red Beds" usually lie against the granite at the surface, but in the embayment the older limestones and sandstones appear at the surface. It is probable that east of the mountain front these rocks extend far to the north and south, but on either side of the embayment they have been eroded from the granite slopes and overlapped by younger sediments. The embayment probably was a valley at the time of this erosion epoch, and the sediments contained in its deeper portion were not removed. Its southwestern margin has been cut off by the great fault, which uplifted the strata so high that they were long ago removed by erosion.

The embayment continues far to the northwest from Manitou, but the strata which it formerly contained are removed for the first few miles. A small area of "Red Beds" and underlying limestones remains in this area in Manitou Park, on Trout Creek, as shown on the geologic map (Pl. VI). From the vicinity of Manitou northward to beyond Glen Eyrie Creek the basal strata are sandstones and limestones of Cambrian and Ordovician age, and these appear again in a small area west of Monument Park. Most of their features were described by F. V. Hayden and Dr. A. C. Peale,[c] and by Prof. W. O. Crosby,[d] in a detailed account of the Archean-Cambrian contact near Manitou.

The basal bed is a sandstone averaging about 50 feet thick, usually light colored and moderately fine grained in its lower beds, and red or pink with greenish layers in its upper ones. It contains Cambrian fossils (determined by Mr. Walcott as *Obolus* (*Linguella*) *similis*), and more or less glauconite. The sandstone lies on the granite along a remarkably smooth plain, which shows occasional local erosion irregularities, and the contact is sometimes faulted or flexed. Many details of these contact phenomena are described in the paper by Professor Crosby, just

[a] Hills, R. C., Description of Spanish Peaks, Walsenburg, and Elmoro quadrangles: Geologic Atlas U. S., folios 71, 68, and 58.
[b] Gilbert, G. K., Laccoliths in southeastern Colorado: Jour. Geol., vol. 4, 1896, pp. 816–825.
[c] U. S. Geol. and Geog. Surv. Terr., Seventh Ann. Rept., 1874, pp. 193–273.
[d] Bull. Geol. Soc. America, vol. 10, 1899, pp. 14–164, pls. 14–18.



MAP AND CROSS SECTIONS SHOWING GEOLOGIC RELATIONS IN THE MANITOU EMBAYMENT AND TO NORTH AND SOUTH.

referred to. Fine exposures may be seen on both sides of Fountain Creek, which the formation crosses 1½ miles above Manitou, in Williams Canyon, and at Glen Eyrie. The formation dips gently to the southwest and extends for some distance west up the divides between the valleys above mentioned. It ends abruptly at a point a mile north of Glen Eyrie, where it is overlapped by Fountain "Red Beds," but reappears for a short distance in a local embayment a mile farther north, and Mr. W. T. Lee reports it on Deadman Creek southwest of Monument station.

Overlying the Cambrian sandstone are several hundred feet of limestones, of which the lower portion is Manitou, containing Ordovician fossils, while the upper members, according to Professor Grabau,[a] contain Mississippian fossils. This limestone caps the sloping ridges west and south of Manitou and appears extensively in the intervening canyons, especially in Williams Canyon. Its outcrop, together with that of the underlying sandstone, is terminated by overlap of the Fountain formation, a mile north of Glen Eyrie, and reappears in the small embayment west of Monument Park. In this outlier there are exposed, lying on the granite, 30 feet of dark-gray, coarse sandstones, thin bedded and glauconitic at the top, overlain by 20 feet of bright-red, sandy limestone with Cambrian fossils, and by 50 feet of massive, pure, fine-grained, light-gray limestone. On this limestone, which apparently is Manitou, lies an impure limestone varying from gray to buff in color, with a heavy breccia at its base, the latter probably marking an unconformity. The limestones are cut off by a fault, bringing down the Morrison and overlying "Dakota," but a short distance to the north and south the Fountain "Red Beds" are exposed lying directly on the granite.

The Fountain formation occupies a wide area in the Manitou embayment, from Glen Eyrie southward. On the west side of the area the dips are low, but to the east they become nearly vertical, a feature exhibited in the ledges at and near the Gateway to the Garden of the Gods, as shown in Pl. IX, *A*. The rocks consist of coarse sandstones, in part conglomeratic and mostly of red color, although some portions are mottled with gray. The thickness is 1,000 feet or more. From Manitou to Glen Eyrie the formation lies unconformably on the Millsap limestone, but no marked divergence of dip or erosion features was observed. To the south the formation is cut off by a great fault, which brings it in contact with the granite. The outcrop of the formation extends northward from Glen Eyrie, where, as above stated, the red grits directly overlap the granite. In places in their northward extension they are cut off by faults and extensively overlapped by Tertiary formations. At the top of the formation there is the well-marked Lyons sandstone, which gives rise to the prominent white ridge a few rods east of the Gateway to the Garden of the Gods. This formation is overlain by the upper "Red Beds," which I have designated the Chugwater formation. The latter consists mainly of soft red shales with layers of limestone in its lower portion, with a thick bed of gypsum at the top. This gypsum bed is 30 feet thick at the Gateway to the Garden of the Gods, and for some distance north. Owing to talus, faults, and overlaps of younger formations the Chugwater formation is not exposed in the region between West Monument Creek and Perry Park, and southeast of Manitou it is cut off by the great fault.

[a] Girty, G. H. Carboniferous formations and faunas of Colorado: Prof. Paper U. S. Geol. Survey No. 16, 1903, p.168.

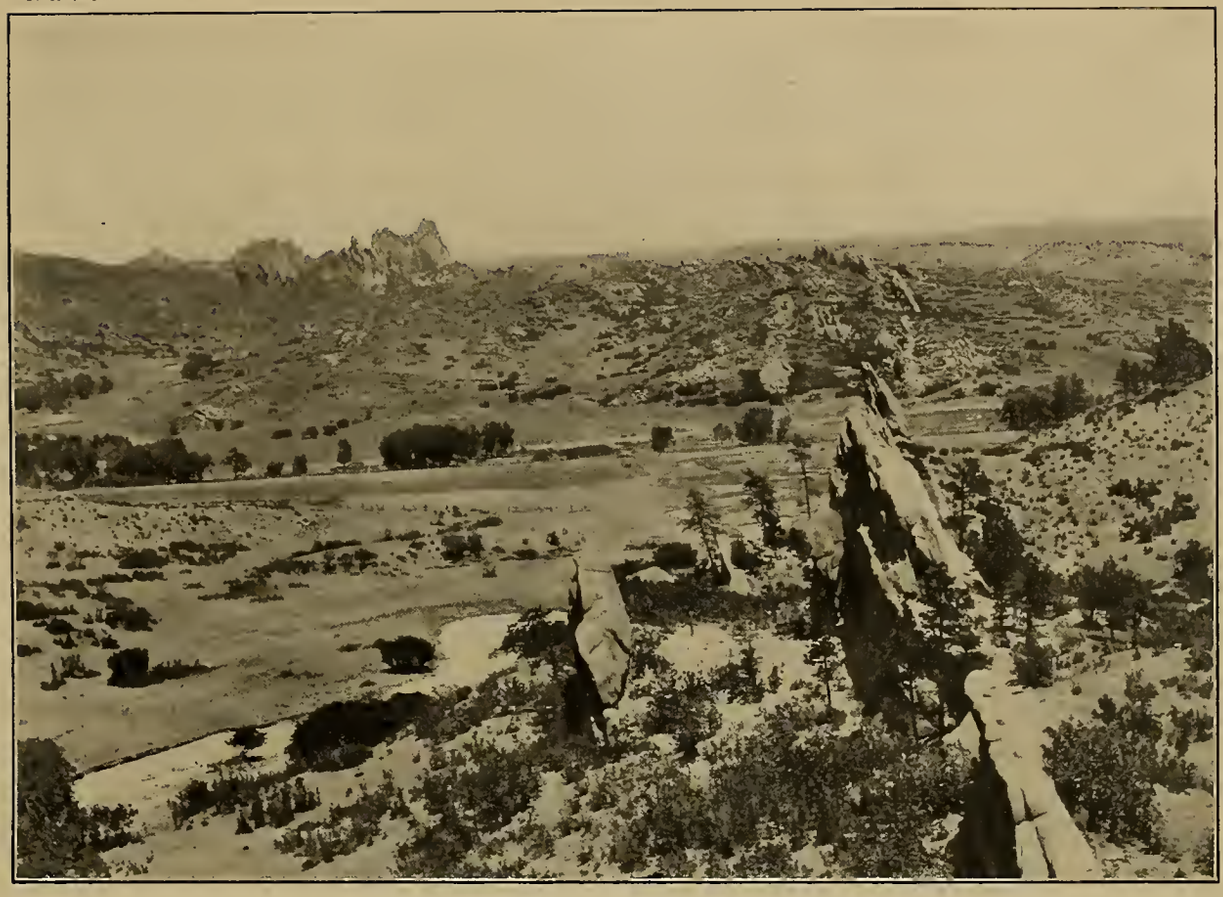
The formations overlying the Chugwater formation in the Manitou embayment are the usual succession of Morrison, "Dakota," Benton, Niobrara, and Pierre, all of which, except the latter, are cut off by the great fault southwest of Colorado Springs. There is also a local interruption in the succession a short distance northwest of Colorado City, owing apparently to a short fault cutting off the "Dakota" and adjoining beds. The Morrison formation west of Colorado Springs exhibits its usual characteristics. Light-colored massive shales predominate, but some fine-grained sandstones and several thin limestone layers are included. Portions of the shale are of grayish-green and maroon tints. The formation lies directly on the 30-foot bed of gypsum at the top of the Chugwater formation. The overlying "Dakota" sandstone varies from 125 to 200 feet in greater part, and is in two massive beds, with shales between. As above stated, the sandstone disappears for a short distance northwest of Colorado City, probably owing to a local fault. The Graneros shale is 240 feet thick. The Greenhorn limestone is well defined and 75 feet thick, consisting of thin beds of limestone with dark shale alternations and containing large numbers of *Inoceramus labiatus*. The Carlile formation, about 250 feet thick, is terminated by the usual bed of sandstone, which is overlain directly by the Timpas limestone. This sandstone and limestone form a prominent hogback extending from north of Glen Eyrie to Bear Creek Canyon, beyond which the Timpas limestone continues nearly to Cheyenne Creek, where it is finally cut off by the great fault.

In the region west of Monument Park the Morrison, "Dakota," Benton, and Niobrara beds appear at intervals, but they are mostly obscured by talus and overlaps. A small exposure of the Timpas limestone appears southwest of Monument station, as shown in Pl. XVI. It dips steeply to the east and appears to be overlapped by Tertiary formations.

CANYON EMBAYMENT.

General structure.—In the region west of Pueblo there is a deep westward deflection or reentrant in the Rocky Mountain Front Range, in which the sedimentary strata extend to a short distance west of the city of Canyon. The granite Front Range, which is so prominent west of Colorado Springs, exhibits an anticlinal structure to the south, and the granite in this anticline pitches beneath the sedimentary strata northeast of Canyon. The sedimentary strata in the syncline on its west side extend northward through Garden Park to the north line of Fremont County, beyond which the granite rises. The prolongation of the anticline, greatly reduced in height, is traceable southward to Huerfano Canyon, crossing Arkansas River 6 miles northwest of Pueblo. The syncline deepens to the south, and in the region southwest of Florence holds a deep basin of Laramie coal measures. Near the south line of Fremont County its western side is faulted so that the Laramie sandstones are in contact with the granite. The west and south sides of the Canyon embayment consist of the Wet Mountain Range, an anticlinal ridge of granite which extends southeastward and finally pitches down near Huerfano River.

In the Canyon embayment are found formations from Cambrian to latest Cretaceous or early Tertiary, presenting considerable complexity in overlap and



A. VERTICAL "RED BEDS" NEAR COLORADO CITY, COLO.

Garden of the Gods to the left; ridge of Niobrara limestone to right. Photograph by I. C. Russell.

B. MORRISON FORMATION ON GRANITES WEST OF GRAPE CREEK, 4 MILES SOUTHWEST OF CANYON, COLO.

Looking north-northeast. The prominent ledge of sandstone is "Dakota."

structural relations. The principal features are shown in Pl. XVIII. The relations shown north of latitude 38° 30′ are compiled from the Pikes Peak folio by Whitman Cross. The dominant structural features have already been alluded to.

Garden Park area.—Oil Creek Valley lies in a syncline pitching southward and exhibiting formations of Ordovician, Carboniferous, and Cretaceous ages. On the west side of the creek, north of Garden Park, is an extensive area of Ordovician limestones and sandstones. At the base is Manitou limestone with a basal cherty and quartzitic portion of Cambrian age lying on the granite and gneiss. Next follows the Harding sandstone, surmounted by long slopes of Fremont limestone. So far as observed, this sequence is general for an extensive area about Garden Park. In portions of the area faults cut out some, or all, of the beds. On the granite slopes east of the creek numerous small outliers occur. The Manitou limestone is 100 feet thick and consists of fine-grained, pink or reddish dolomite with Ordovician fossils. Cherty limestone at the base yields fragments of the trilobite *Ptychoparia*. The Harding limestone consists of fine- and even-grained saccharoidal sandstone in alternating beds of light-gray or pinkish and variegated colors, with a few bands of dark-red or purplish sandy shale. The maximum thickness is about 100 feet. The lower part is sometimes calcareous and locally develops into a thin, fine-grained dolomite. It is succeeded with apparent conformity by the Fremont limestone, which is a bluish-gray or pinkish dolomite of uneven grain, sometimes sandy, weathering to very rough surfaces. Its thickness is about 100 feet, and it is especially characterized by the occurrence of chain coral (*Halysites catenulatus*), which often occurs in masses 2 feet in diameter. It also contains other fossils of later Trenton age.

The Fremont limestone gives rise to long sloping plateaus on the west side of Oil Creek north of Garden Park. At the north end of the park the Fremont limestone is overlain by Millsap limestone in a narrow outcrop about 1½ miles long. Thirty feet of the formation are exposed consisting of thinly bedded, variegated, dolomitic limestone, with a few thin sandstone layers. Chert nodules in the upper limestone layers carry casts of characteristic Mississippian fossils.

The greater part of Garden Park is underlain by the Fountain formation, which reaches a thickness of about 1,000 feet. It lies on the Millsap limestone above mentioned, but overlaps onto the Fremont limestone, presenting unconformable contacts in both cases; for part of its course it is cut off by extensive faults, as shown in Pl. XVIII. The Fountain beds consist of red sandstone, grits, and conglomerates, heavily bedded and with much feldspathic material derived from the adjacent granite. The conglomerate layers contain many pebbles of hard, pre-Cambrian quartzites and of limestones, quartz, and cherts.

The Morrison formation appears extensively along the south and west sides of Garden Park, where the thickness is about 350 feet. It is separated from the Fountain formation by unconformity, but does not present divergence of dip or evidence of deep channeling. The materials are mainly greenish, pink, or gray shales and marls. Sandstone occurs at the base and also at numerous horizons in the upper part of the section, but the beds vary in thickness and extent. In the sandstone deposits about 100 feet from the top of the series, at the locality shown in Pl. X, *B*, large numbers of saurian remains have been obtained. Fresh-water shells also occur.

Gypsum is locally developed, and a thin limestone occurs in the lower portion of the formation.

The Morrison formation is succeeded in regular order by "Dakota" sandstone, which caps high ridges south and west of the park, presenting its usual characteristics and having a thickness of about 300 feet. Southeast of Garden Park lie Sixmile, Eightmile, and Cemetery parks, valleys which mark the eastward and northeastward extension of the Fountain "Red Beds" across the north end of the Front Range anticline. On the north side of these parks are slopes of Ordovician limestones and sandstones, comprising Manitou and Harding, with Fremont as far east as Eightmile Creek, northeast of which the Fountain formation lies directly on the Harding sandstone. Outliers of Manitou limestone occur at intervals high on the granite slopes north. South of the three parks there is a continuation of the "Dakota" hogback, with Morrison formation in its northern and northwestern slopes. On Eightmile Creek the Fountain and associated formations are traversed by a prominent fault which brings up the granite in two prominent knobs on either side of the creek. On Wilson Creek, 8 miles northwest of Garden Park, some small outliers of Morrison formation lie directly on the granite and gneiss and in part are overlapped by small areas of "Dakota" sandstone. Two similar areas of these two formations occur still farther northwest on the small branch of High Creek. Three miles southwest of Garden Park is Shaws Park, underlain by a zone of Fountain "Red Beds" outcrops which extend southward to Arkansas River west of Canyon. On the west side of this zone the Ordovician limestones and sandstones extend far up the mountain slopes, while on the east side is a hogback of Dakota sandstone with Morrison formation in its western slope. At the north end of Shaws Park there is a prominent fault, which crosses Wilson Creek nearly at right angles and brings formations from Ordovician to Cretaceous into contact with the pre-Cambrian rocks, as shown in Pl. XVIII.

West of Canyon.—In the mountain slopes and hogback west of Canyon there is presented the southward extension of the formations of the Garden Park area. The formations all dip steeply to the eastward and there are numerous exposures of all the beds. The high mountain range west, consisting of granite and gneiss, is traversed by Arkansas River in a deep canyon known as the Royal Gorge. On the lower eastern slopes of this ridge the Ordovician rocks are extensively exhibited. The valley of Sand Creek is in the Fountain "Red Beds." The main hogback west of Canyon consists of "Dakota" sandstone, with Morrison formation on its west side and Benton shales on its east slope. There is also a subordinate hogback of small, sharp ridges due to the Timpas limestone of the Niobrara formation. To the east there is a broad, deep basin containing Laramie coal measures.

The principal features of distribution of the formations are shown in the middle portion of Pl. XVIII. On the mountain road 4½ miles northwest of Canyon the Manitou limestone lies directly on the granite. It is 10 feet thick and contains bands of chert. Next above is characteristic Harding sandstone, pink and buff, except at the top, where there is a characteristic succession of reddish shales. The Fremont limestone appears with its usual characteristics, and apparently also the Millsap limestone, although no Carboniferous fossils were observed at this place. The upper portion of the limestone presents a very irregular contact with conglom-

MAP AND CROSS SECTIONS OF "DAKOTA" AND ASSOCIATED FORMATIONS IN THE CANYON EMBAYMENT, COLORADO.

erate beds at the base of the Fountain formation. A typical exposure of this feature is shown in Pl. XX. The conglomerate is about 80 feet thick and is succeeded by about 1,000 feet of red sandstones and grits extending to the base of the "Dakota" hogback. In the vicinity of Harding's quarry, 2 miles northwest of Canyon, the Manitou limestone is seen to have disappeared and it is not found again in the extension of the beds southward. The following detailed section in this vicinity was made by Mr. C. D. Walcott:[a]

Geologic section of Fremont limestone and Harding sandstone near Harding's quarry, northwest of Canyon, Colo.

	Feet.
Fremont limestone:	
Compact, hard, light-gray limestone, breaking into angular fragments, but with a band of purple and gray calcareo-arenaceous shale at the base, containing a large Trenton fauna	45
Dark, reddish-brown sandstone	10
Hard, compact, light-colored limestone with fossils	45
Gray, siliceous, magnesian limestone, somewhat ferruginous in lower portion; weathers locally to reddish friable rock, except that near base limestone weathers into rough irregular cliffs with many caverns and holes; corals and other fossils	170
Red and purple fine-grained, argillaceous, arenaceous shale; fish-plate fragments	2–4
Harding sandstone:	
Coarse purplish sandstone in several layers with gray layers above	11
Gray and buff sandstone	7
Fine-grained, argillaceous, arenaceous shale	3
Massive gray and reddish sandstone with thin irregular beds of reddish-brown, sandy shale in lower portion; numerous fish remains	20
Reddish-brown, sandy shales, partly calcareous in some layers; fish plates and other fossils abundant	7
Compact, thinly bedded, reddish and gray sandstone passing into a gray and more massively bedded, somewhat friable sandstone that changes at 25 feet up into a purplish-tinted, somewhat coarse, friable sandstone; dip 40°	33
Coarse, light-gray sandstone	5
Granite.	

Overlying the Fremont limestone are 15 to 30 feet of impure variegated banded limestones, with interbedded sandstones and argillaceous beds containing Mississippian fossils. The unconformity between the two limestones representing Silurian and Devonian time is not marked by discordance of dip nor by any noticeable erosion features. On the north side of Arkansas River, at the mouth of the Royal Gorge, the Ordovician beds are well exposed, lying on granite and gneiss and dipping steeply eastward. There is a basal conglomerate merging upward into hard gray to pink sandstones, in part coarse grained, 100 feet or more in thickness. These are succeeded by 80 feet of reddish-brown shales and thinly bedded sandstones, 70 feet of gray to pink sandstones (mostly soft and massive), 8 feet of red shales, 30 feet of gray to pink sandstones (mostly massive), followed by a talus-covered interval of about 100 feet, east of which appear ledges of Fremont limestone merging upward into a few feet of gray sandstone. The latter is overlain by the basal conglomerate of the Fountain formation. On the opposite side of Arkansas River the Harding sandstone is about 200 feet thick and is overlain by about 100 feet of limestones, in part sandy, capped by a 20-foot bed of light-gray sandstone. On the irregular upper surface of the latter lie coarse conglomerates at the base of the Fountain formation. Both the

[a] Walcott, C. D., Discovery of a vertebrate fauna in Ordovician strata: Bull. Geol. Soc. America, vol. 3, 1892, pp. 155–157.

Harding sandstone and the Fremont limestone end a short distance to the south on Grape Creek, the sandstone terminating at a point about three-fourths of a mile south of Arkansas River. The Fountain formation also thins rapidly, and at a point a mile south of the river is only about 250 feet thick, including a basal red conglomerate. In this vicinity the unconformity at the base of the Morrison is very marked, there being much deep channeling in the "Red Beds" surface.

On the east side of Grape Creek, just above its mouth, there are nearly continuous exposures from the granite to the "Dakota" sandstone. At the base are about 150 feet of massive gray sandstones, pinkish in their upper portion. These are succeeded by about 50 feet of soft gray sandstone, with some limestone layers, 50 feet of limestone (Fremont), 10 feet of red sand and sandstone, about 900 feet of Fountain beds (with conglomerate and arkose at the base), and the massive pinkish-gray sandstone 30 feet thick at the top. The latter is a noticeable feature west and northwest of Canyon. In a small canyon cut through the hogback ridge 1½ miles south of the mouth of Grape Creek there are extensive exposures. On the west there is, first, the granite, overlain directly by red and gray conglomerates and grits of the Fountain formation, here not over 30 feet thick; then follow Morrison shales about 300 feet in thickness, presenting the usual characteristics. The "Dakota" sandstone presents the features shown in Pl. X, *A*. It has a lower member, 90 feet thick, of massive buff sandstone; a middle member, 100 feet thick, of dark-gray shales[a] with buff sandstone partings, and an upper member, 100 feet thick, of massive buff sandstone which rises to the crest of the hogback ridge. The upper portion of this member grades into the Graneros shales through about 15 feet of beds of passage. The Graneros formation is 250 feet thick and is succeeded by 50 feet of typical Greenhorn limestone in thin layers with shale partings. Large numbers of *Inoceramus labiatus* occur in the upper portion of the limestone.

The Carlile formation consists of 200 feet of dark shale, with 2⅓ feet of sandy limestone with oysters at the top. The basal portion of the Timpas limestone is in massive beds 30 feet or more thick, followed by 600 feet of Timpas and Apishapa beds. Much shale occurs in the lower and middle portion of the latter, and the usual bright-yellow weathered beds at its top.

The "Dakota" hogback extends southwestward to the granite slopes at the foot of the Wet Mountain Range, where all of the strata from the Morrison to the basal Pierre are cut off by the east-west fault, as shown in Pl. XVIII. Along the main road from Canyon to Webster Park, on the hillside above the last big bend in Grape Creek, there is a well-marked fault cutting off the "Dakota" sandstone on the west and bringing it into contact with two small masses of limestone, apparently Fremont, underlain by sandstone, probably Harding, which lies directly on the granite to the west. A short distance south of where the road crosses this fault the "Dakota" sandstone is seen to be underlain by the Morrison formation, which lies directly on granite, showing a definite overlap. This relation is repeated on the west side of Grape Creek, as shown in Pl. XVII, *B*. In both of these contacts the dips are very low, and faulting is out of the question.

Four miles due south of Canyon the Pierre shale appears to extend directly to the granite, from which it is apparently separated by the extension of the fault which

[a] In the summer of 1905 Mr. Stanton discovered Comanche fossils in these shales.

A. SHALE MEMBER LYING BETWEEN TOP OF HARDING SANDSTONE AND BASE OF FREMONT LIMESTONE ON MOUNTAIN SLOPE NORTHWEST OF CANYON, COLO.

Photograph by C. D. Walcott.

B. HARDING SANDSTONE ON GNEISS AND SCHISTS 1½ MILES NORTHWEST OF CANYON, COLO.

Looking north from below spring west of Harding's quarry. The man's feet are on the contact. Photograph by C. D. Walcott.

A

B

CONGLOMERATE AT BASE OF "RED BEDS" LYING UNCONFORMABLY ON MILLSAP LIMESTONE, 4 MILES NORTH-NORTHWEST OF CANYON, COLO.

Looking northeast.

cuts off the "Dakota" sandstone and overlying formations along the foot of the mountains westward. The fault appears to die out at the point where the main mountain slope turns abruptly to the south. In this vicinity the "Dakota" sandstone and overlying formations reappear at first in a steep-dipping monocline with Laramie sandstones less than a mile distant from the granite. At one point 2 miles northwest of Chandler the "Dakota" sandstone lies directly on the granite and is overlain by 400 feet of Benton shales, including the Greenhorn limestone and 25 feet of sandstone at the top of the Carlile formation, on which lies the Timpas limestone. West of Chandler a syncline and anticline develop, the latter marked by a prominent ridge, which is due to the top sandstone of the Carlile and the overlying Timpas limestone. These flexures extend nearly to Oak Creek, where they die out. Near the foot of the mountain slope, 2 miles southwest of Chandler, the "Dakota" sandstone is underlain by 300 feet of Morrison shale, under which for a short distance the Harding sandstone and the Fremont limestone appear. The following section was measured by Mr. C. E. Siebenthal, in beds dipping 80°:

Geologic section 2 miles southwest of Chandler, Colo.

	Feet.
Morrison shale	300
Massive white limestone	40
Massive, red, dolomitic limestone	40
Red shale and brown sandstone, with fish scales	25
Hard and soft sandstones, interbedded	30
Granite.	

A short distance south of this locality a fault develops which cuts off the Morrison, "Dakota," Benton, Niobrara, and Pierre beds in succession and immediately south of Oak Creek brings the Laramie beds into contact with the granite. This relation continues to the southern margin of Fremont County, or to a mile south of Neulan Creek. At the southern margin of Pl. XVIII, which is about a mile south of the southern margin of Fremont County, the Pierre shale and granite are in contact along this fault line.

EAST SIDE OF GREENHORN MOUNTAIN.

Greenhorn Mountain is a southern extension of the Wet Mountain Range, and it terminates southward in a south-pitching anticline, in the same manner as the eastern Front Range does northeast of Canyon. Along its east side, from Hardscrabble Creek to its southern termination at Huerfano River, a considerable variety of overlap relations are presented. The principal features are shown in Pl. XXII (constructed largely from the Walsenburg and Pueblo folios). The lowest beds exhibited appear only in small outliers west of Beulah, where a white sandstone about 30 feet thick is found, supposed to represent the Harding limestone, lying upon gneiss and overlain by limestone supposed to represent the Millsap. Of the limestones 175 feet are exhibited, consisting of gray and purple rocks with some shale, especially in the lower part. The limestone is classified as Millsap by the occurrence of *Spirifer rockymontana*, which appears in the middle of the series, but it is possible that the lower beds are Ordovician. The Fountain formation appears extensively along the valleys of North and South creeks, at the head of Red Creek, and to a limited

extent on Hardscrabble Creek. The rocks consist chiefly of brownish-red sandstones, mostly of coarse texture and containing a considerable proportion of feldspar grains. The upper beds include red and chocolate-brown shale, and at the base there is much coarse conglomerate containing pebbles and bowlders of granite and gneiss. Near Beulah the strata dip eastward at angles of 10° to 20°; the outcrop has a breadth of about 1½ miles, and the thickness of the formation is about 2,000 feet. Four miles south of Beulah the Fountain formation is cut off by a fault. On the head of Red Creek the thickness is much less, and north of Hardscrabble Creek it is in places not over 20 feet thick and is occasionally overlapped by the Morrison formation.

At the south end of the Greenhorn Mountain Range, under the Morrison formation, there appear about 200 feet of red sandstones, which have been termed the Badito formation by R. C. Hills, who states that it apparently corresponds to part of the Fountain formation. The lower half of the formation consists of very coarse brownish-red conglomerate, and the upper part is a brick-red sandstone, generally massive, but in part thin bedded. The Morrison formation appears at intervals along the east side of the Greenhorn Mountain Range, usually lying on the Fountain formation but overlapping the granite on Muddy Creek and near the south end of the mountain. At St. Charles Canyon it is in contact with the granite, apparently because of a fault. The rocks are chiefly massive clays of light color, with thin beds of limestone, sandstone, and gypsum. The lower beds are mostly white and the upper ones chocolate-brown and maroon. On the slopes of Hogback Mountain the formation consists chiefly of red shale with a few layers of hard red sandstone, in all about 70 feet thick. Near the southern end of Greenhorn Mountain the Morrison formation is 270 feet thick and dips steeply down the mountain slope. The lower beds consist of about 60 feet of soft white sandstone having a conglomerate layer at the base. "This is followed by hard shaly beds of pinkish and greenish tints, which break into fragments with conchoidal fracture. The upper portion consists of variegated shales and clays alternating with bands of hard, fine-grained limestone, often containing vermilion-colored cherts. One band of conglomerates a few feet thick contains green pebbles. At one point the basal sandstone overlaps the Badito formation and rests on the gneiss at an angle of 15°."[a]

The "Dakota" sandstone extends along the foothills from Adobe Creek to the end of the mountain just north of Huerfano River, except for a short distance near Muddy Creek, where it is dropped by a fault. To the south it lies directly upon the granite, but at St. Charles Canyon and northward it is underlain by older sedimentary rocks, and this also is the case at the south end of Greenhorn Mountain. On the headwaters of Muddy Creek the formation spreads out extensively in a shallow basin, as shown in Pl. XXII, where it appears lying directly on the granite. The outcrop is also of wide extent on St. Charles River and northward to Red Creek. In Barton Park the formation occupies a shallow syncline which crosses Hardscrabble Creek near the junction of North and South forks. Just east of this place the anticline east of the syncline pitches down and at Greenwood the "Dakota" sandstone gives rise to a prominent anticlinal ridge. The formation presents its usual features of a light-colored, massive sandstone partly coarse grained, especially in the lower beds, where there is more or less conglomerate; the color is mostly

[a] Hills, R. C., Description of the Walsenburg quadrangle: Geologic Atlas U. S., folio 68, U. S. Geological Survey, 1900, p. 1.

A. TWO BUTTE, IN SOUTHWEST PROWERS COUNTY, COLO.

Exeter sandstone at top of "Red Beds" uplifted by igneous intrusion.

B. WATER HOLE IN "DAKOTA" SANDSTONE NEAR THATCHER, COLO.

pale buff. Considerable shale is included at some localities, especially in the middle of the formation. The thickness varies. In the vicinity of Beulah Mr. Gilbert reports 650 feet, consisting almost entirely of sandstone. Farther north and south the thickness averages about 300 feet. Along the southern slopes of Greenhorn Mountain there is included in the lower half of the formation a persistent bed of gray shale 8 to 10 feet thick. The upper sandstones, aggregating 100 to 150 feet in thickness, are light gray when unweathered, of fine grain, close texture, and regular bedding. "The lower two-thirds of the formation consists, as a rule, of yellowish-gray sandstone of a coarse, porous texture, and some of the layers are really fine conglomerate. Cross-bedding is rather common."[a]

The Graneros and Carlile formations, with the intervening Greenhorn limestone, extend all along the east side of the range and present no special features of stratigraphy or overlap. They are traversed by numerous faults, especially in the area between Greenhorn and Rush creeks, as shown in Pl. XXII.

GEOLOGIC HISTORY.

The Great Plains region is underlain by sedimentary rocks affording a record of physical geography from 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 an outline of the general sequence of events can be given. One significant feature is that some 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.—During early Cambrian time a large part of west-central United States was a land surface. In middle Cambrian time there began the development of an interior sea which finally reached the Rocky Mountain province, where it had 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 seabeaches, partly in shallow waters offshore and partly in estuaries. In some areas there are 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 for a long period highlands rising out of the Cambrian sea. In the northern portion of the province thick masses of deposits accumulated as submergence progressed in middle Cambrian time, but it is not known that this deposition extended into eastern Colorado. The scanty deposits of later Cambrian age appearing near Manitou and Canyon indicate that the waters finally reached the line of the present Rocky Mountain Front Range. As these deposits lie in embayments which probably were connected with wider areas of open waters, doubtless there was a wide area of later Cambrian deposition eastward under Colorado.

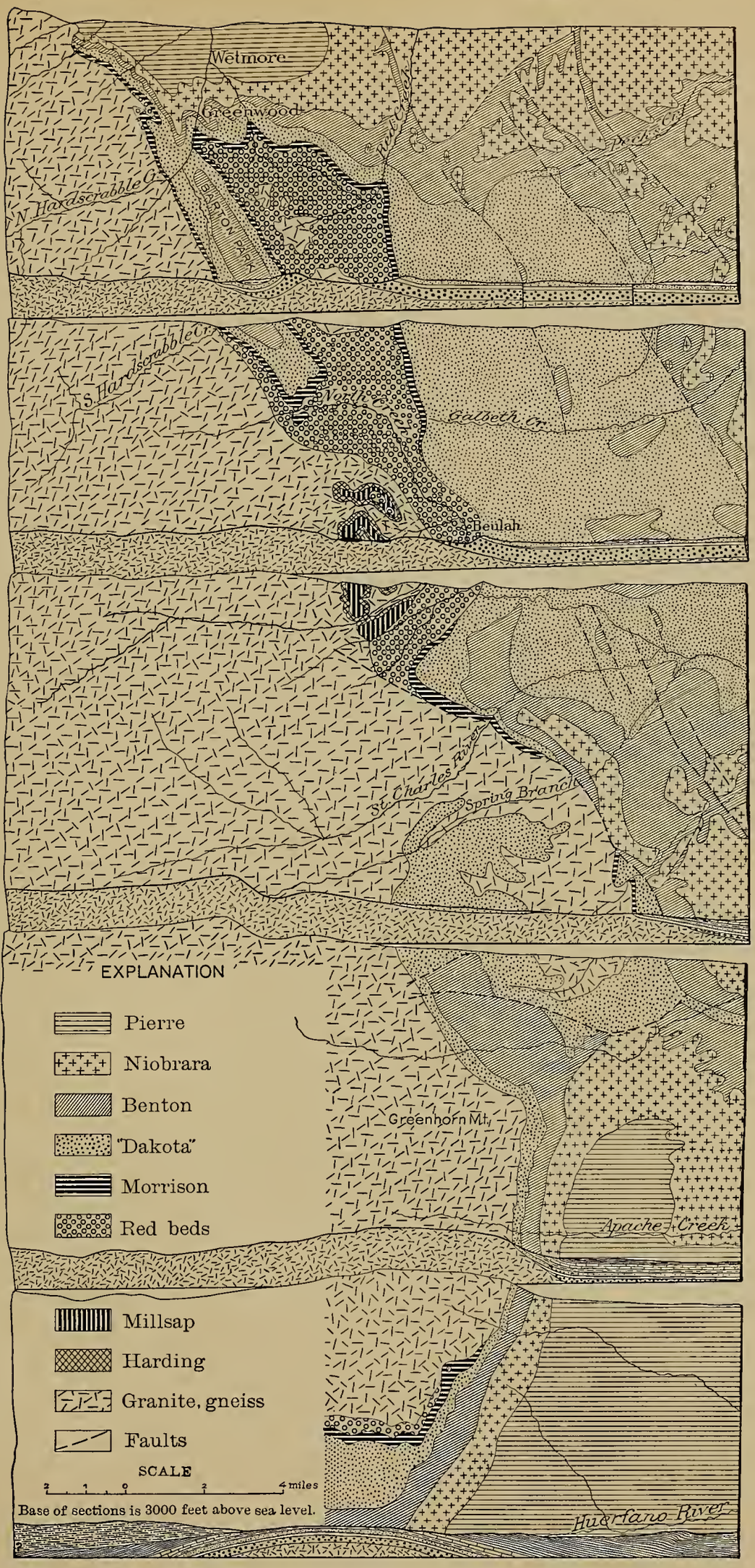
[a] Hills, R. C., Description of the Walsenburg quadrangle: Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900, p. 1.

Ordovician.—Apparently the submergence above described continued with similar shore lines through a portion of Ordovician time, for the later Cambrian and earlier Ordovician appear to have about the same limits in the exposures in the embayments above mentioned. Doubtless to the east of the Rocky Mountain front there was extensive deposition of the lime sediments such as appear in the outcrops, and these may attain considerable thickness under eastern Colorado. Except in the embayments, the western shore apparently was located east of the extensive "Red Beds"–granite overlap. Perhaps the deposits originally extended farther west all along the slopes and were removed by later erosion along the steeper shores, leaving remnants or projections in the embayments where the erosive forces were less vigorous.

Silurian-Devonian.—From the close of the Ordovician to the time of 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.

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, exhibited in the Black Hills, the Bighorn Mountains, and the Hartville uplift, and, with less thickness, in isolated areas in Colorado. Along the Rocky Mountain front in Colorado the Millsap limestone, representing the Lower Carboniferous, appears at only a few points, apparently in estuaries which extend west of a general shore line now buried under the Upper Carboniferous sediments by the overlap of the latter on the crystalline rocks. In the later part of earlier Carboniferous time there was uplift, resulting in shallower waters, with sediments of mixed limy and sandy nature in some portions of the region to the northwest, while along the Front Range, in Colorado, there was recession of the shore lines to an unknown distance eastward, a condition indicated by pronounced unconformity at the top of the Millsap limestone.

During Pennsylvanian or later Carboniferous times the shore line extended along the foot of the present Rocky Mountain Front Range, and the coarse red sediments of the "Red Beds" were laid down in part on a granite floor. There were strong currents, and possibly at some stages estuaries and swift-flowing streams. Shallow waters extended far to the east, and especially to the southeast, but finally the depth increased somewhat in these directions, the coarse deposits giving place in greater part to limestones and shales. Limestones also appear to the north in Wyoming and southward toward New Mexico, so that the principal area of deposition of the coarser shore deposits was between Huerfano River and the Wyoming line. In Permian time there was a shallow basin which extended across the western portion of the Central Plains region and far to the northwest. In this basin were laid down the great mass of red shales of the Chugwater formation, or upper "Red Beds," with their extensive interbedded deposits of gypsum, presumably products of an arid cli-



MAP AND CROSS SECTIONS SHOWING RELATIONS OF "DAKOTA" AND ASSOCIATED FORMATIONS ON EAST SIDE OF WEST MOUNTAINS, COLORADO.

mate. The sandy clay of this formation accumulated in thin layers to a thickness of 500 to 1,000 feet in Wyoming and the Black Hills, but is much thinner in Colorado. There is such uniformity of the deep-red tint that it is undoubtedly the original color, and 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, 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; otherwise 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 subsidence which kept pace with deposition most of the time.

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 Beds" 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 Plains region is not known, but evidently it was terminated by uplift which brought the region above water. Probably this condition extended through the latter part, if not all, of the Triassic and through Jurassic time, during which there was no deposition and probably some slight erosion. South of the vicinity of the Wyoming line this interval is represented by the general hiatus between the upper "Red Beds" and the Morrison deposits.

Cretaceous.—East of the Rocky Mountains Morrison sedimentation was in a long, relatively narrow trough extending along the west side of the Great Plains. This trough was occupied by a shallow body of fresh water which deposited 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 impure carbonate of lime. Huge saurians were numerous, 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 Morrison time appear to have continued into the next epoch. In the region in southeast Colorado, western Kansas, and a

wide area southward, where the Morrison formation is absent, there probably was dry land during Morrison time, but there may have been deposition of more or less Morrison sediments which were afterwards removed by erosion in an early Cretaceous uplift. Marine conditions followed, during which the great Comanche series was accumulated. Farther north and west in Comanche times there was at first a land surface and then shallow waters, in which were deposited the sands now constituting the Lakota sandstone. This was followed by deeper waters, with widespread deposition of the material of the fire clay (Fuson) separating the Lakota and Dakota sandstones. Next came a recurrence to conditions similar to those of Lakota time, and the Dakota sands were laid down, marking the beginning of later Cretaceous time. The Lakota and Dakota sands were derived from various sources, probably to the west, and spread by strong currents in two thick deposits separated by the interval of invasion of deeper water and cessation of strong currents, in which the widespread intervening fire clay was laid down. The sandstones overlap the granites in portions of the region—for instance, southwest of Pueblo and north of Canyon—and there are other places in the granite area from which the sandstones evidently have been but recently removed. These features indicate the position of a portion of the shore lines at least. The extent of the Lakota, as separated from the Dakota, not having been ascertained, except 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 formation is a wonderful feature, and it is difficult to picture the conditions under which it accumulated. The writer 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 as the very characteristic 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 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 carbonate 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.

Post-Laramie conditions.—There was extensive uplift in the Rocky Mountain province following Laramie deposition. This fact is clearly indicated in some areas in the mountains, where the next succeeding deposits lie on an eroded surface having the general outlines of the present configuration, a relation which shows that some of the mountain uplifts were truncated and the larger outlines of topography established by earlier Eocene time. This erosion was largely effected by streams which had strong declivities due to the uplifts. The earliest deposits were the coarse beds of the Arapahoe and Poison Creek formations, which mark one subperiod of uplift and deposition, the Denver, Cuchara, and Huerfano formations marking another. Later, 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 and Monument Creek deposits. These began with the sands, 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 eastern Colorado and Wyoming and western Nebraska and South Dakota, and probably also farther north, for the deposits have been found in western 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.

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 Plains area. To the north the stream channels extended across this surface, and running water laid down a widespread sheet of sands derived from the mountains to the west. Probably the streams were 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 portions 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 mountains to the north. It was followed by uplift, and by erosion which removed the Arikaree and parts of the underlying formations from the south and the east, leaving the thickest mass of the deposit in western Nebraska and eastern 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-Nussbaum and other late Pliocene formations, especially in southern Colorado, southern Nebraska, Kansas, and regions farther south. At this time deposition appears to have been mainly in the south, erosion probably predominating 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 Great Plains, the

mountain torrents and resulting vigorous erosion furnishing large amounts of débris, which the streams of low declivity and constantly diminishing volume 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.

Quaternary.—During early Quaternary time there was uplift and floods from increased precipitation, causing widespread denudation and trenching of the preceding deposits. The smooth, high plain mantled by the Ogalalla-Nussbaum formations, which originally extended to the foot of the mountains, was deeply trenched and widely removed, especially along the Arkansas and Platte valleys. These were wide and very shallow at the end of Tertiary time, when the present drainage system was outlined, but they were cut deeply in the succeeding uplift and the smaller side valleys were then developed. The two large streams east of the mountains have since cut their valleys to a low gradient and in times of flood build up their flood plains, but the smaller streams are still cutting.

UNDERGROUND WATERS.

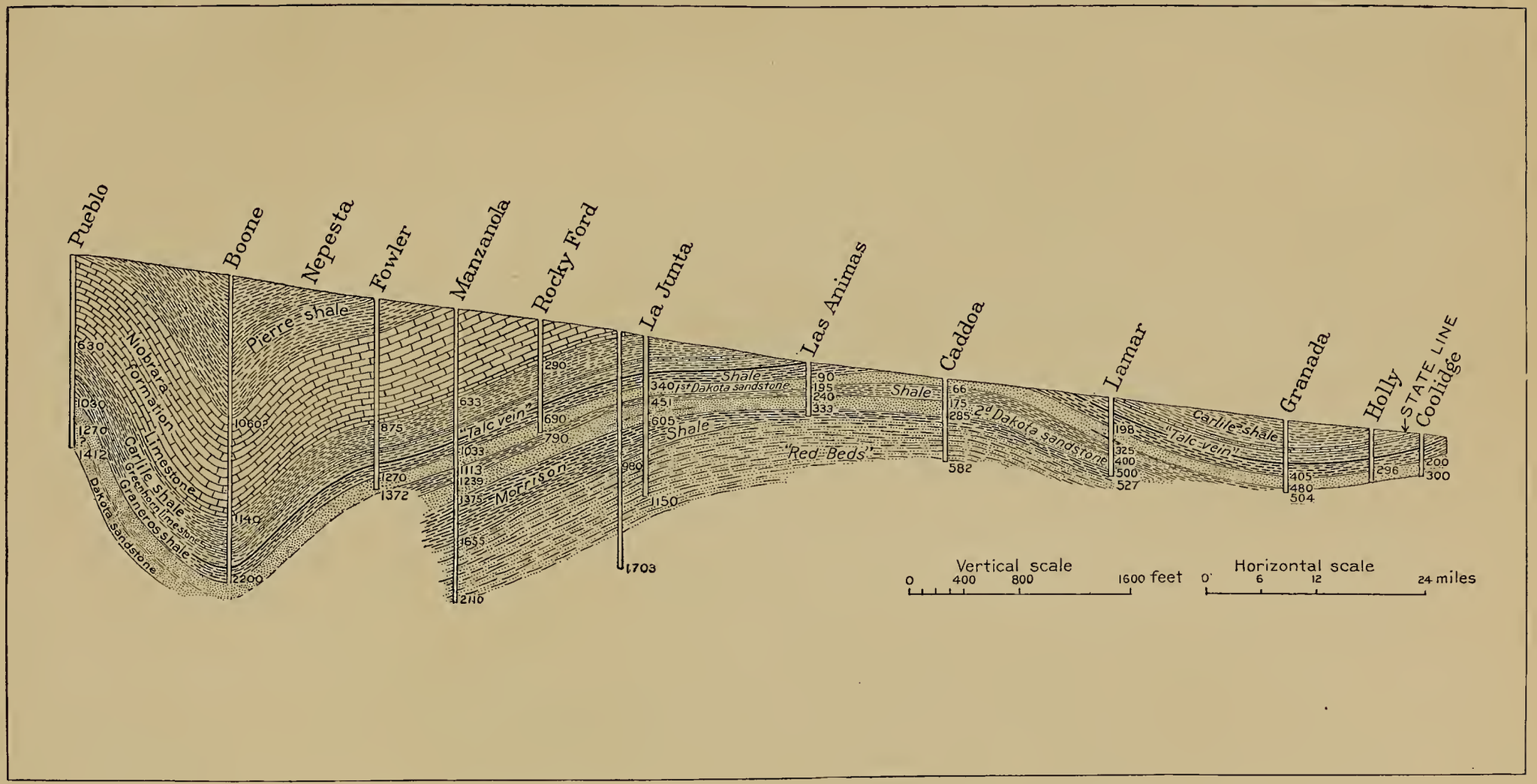
In the thick series of sedimentary rocks underlying southeastern Colorado are several deposits which contain water. The principal water-bearing formation is the "Dakota" sandstone, but waters also occur extensively in the alluvial deposits along the valleys, in the sands and gravels mantling parts of the upland east of the mountains, and in the sandstones of the Fox Hills, Laramie, and overlying formations. Smaller amounts, mostly of bad quality, occur in the "Red Beds."

"DAKOTA" SANDSTONE WATERS.

GENERAL CONDITIONS.

Throughout its wide extent in the Great Plains region the "Dakota" and associated sandstones contain water, usually of good quality and under considerable pressure. This water passes into the sandstones in their elevated outcrop zone along the foot of the mountains and in some of the highlands to the south, and flows slowly eastward through the permeable sandstone, in most cases finally escaping in springs in the areas of low-level outcrop eastward. In the greater part of their area the sandstones lie beneath a mass of impervious shales, which in central-eastern Colorado attain a thickness of several thousand feet. The general structural relations of the formation are shown in detail in the cross sections of Pl. VII.

As the waters pass underground in high areas they have considerable pressure, or "head," under the impermeable strata in the lower lands. In parts of eastern Colorado pressures of 20 to 60 pounds are sometimes presented, which can be explained only by the hydrostatic influence of a column of water extending to a high altitude in the region 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 high altitude 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



SECTION SHOWING RELATIONS OF WELLS IN ARKANSAS VALLEY FROM PUEBLO TO COOLIDGE.

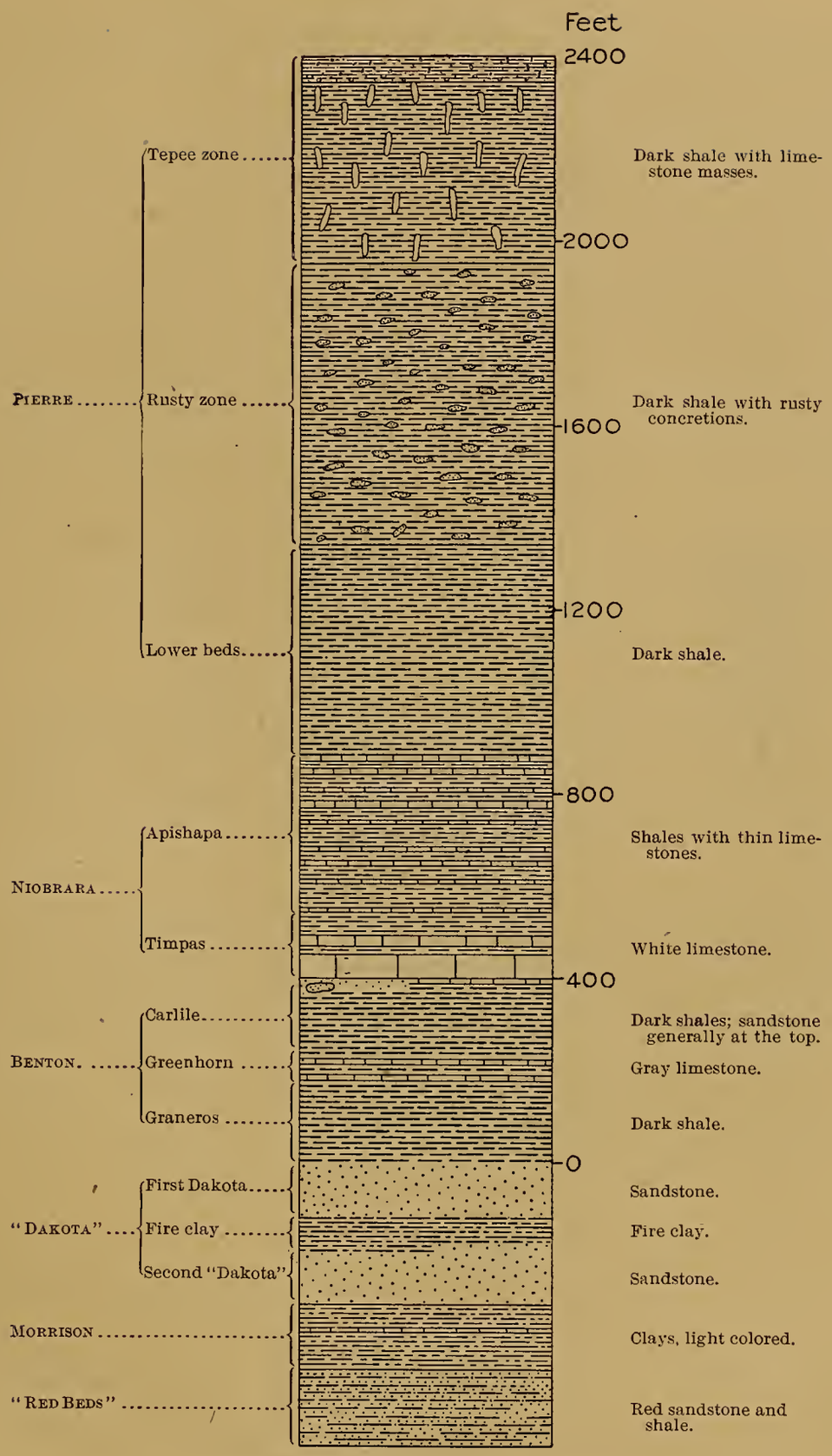


FIG. 1.—General section showing thickness of strata overlying the "Dakota" sandstone in the Arkansas Valley.

"hydrostatic grade," a slope sustained by the friction of the water in its passage through the strata. In fig. 2 is shown a simple apparatus which illustrates the general conditions.

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. From the altitudes of outcrops of this sandstone and pressures observed in many wells the lines in Pl. XXVIII 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. The latter is shown by the brown lines in Pls. VI and XXV.

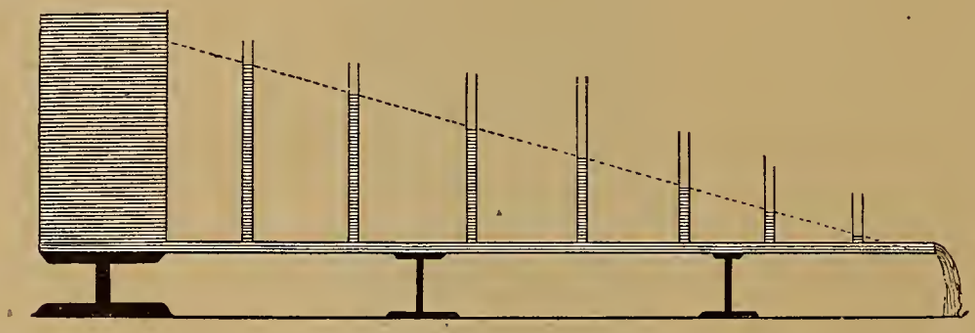


FIG. 2.—Diagram of apparatus for illustrating the declivity of head of liquids flowing from a reservoir. The shaded portions represent water.

FLOWING WELLS.

Rocky Ford.—Nearly all of the flowing wells in the Arkansas Valley derive their water from the "Dakota" sandstone. 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 per minute, with sufficient head to rise 80 feet or more above the surface. One of these is shown in Pl. XXIV, *B*. The materials penetrated by these wells are indicated in the following record:

Record of artesian well at Rocky Ford, Colo.

	Feet.
Surface materials	0– 40
Shale	40–250
Limestone with salty water at its top	250–290
Shale	290–605
"Talc vein"	605–608
Shale	608–690
First sandstone (Dakota) with a flow of soft water	690–790

These wells begin in the lower part of the Apishapa formation, pass through the characteristic limestone bed at the base of the Timpas formation from 250 to

290 feet, and penetrate 400 feet of the Benton formation. The latter contains 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.

The well of the American Beet Sugar Company, sunk by C. H. McVay in 1901, had the following record:

Record of artesian well of sugar company at Rocky Ford, Colo.

	Feet.
Surface materials	0– 30
Gray shale	30–265
Limestone	265–312
Black shale, with salt water at 382 feet	312–700
"Dakota" sandstone	700–806⅔

At 793 feet this boring yielded a 50-gallon flow, which increased to 80 gallons at the bottom.

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 35 to 40 gallons a minute under a pressure of about 55 pounds. The materials penetrated by this well are as follows:

Record of first artesian well at Manzanola, Colo.

	Feet.
Surface materials	0– 38
Shale	38– 598
Limestone	598– 633
Shale	633– 933
"Talc vein"	933– 936
Shale	936–1,033
First sandstone (Dakota)	1,033–1,113

The record shows beds of the Apishapa formation, with the typical Timpas limestone at a depth of 598 to 633 feet, underlain by 400 feet of the Benton group. The latter contains the very distinct bed of hard shale at 933 to 936 feet which the well drillers designate the "talc vein," and have recognized in many borings in the Arkansas Valley.

In 1903 a well was sunk 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 been pulled and the well abandoned. The following record has been given:

Record of deep boring at Manzanola, Colo.

	Feet.
Loam	0– 50
Limestone and shales (Niobrara and Benton groups)	50–1,050
Sandstone; first "Dakota" artesian flow, 50 gallons	1,050–1,139
Shales	1,139–1,239
Sandstone; second "Dakota" artesian flow, 10 gallons	1,239–1,375
Gray clays (Morrison formation)	1,375–1,655
"Red Beds," with several water-bearing strata	1,655–2,110

The water in the "Red Beds" was too impure for use, and had only pressure enough to rise to 700 feet below the surface.

Fowler.—The first flowing well below Pueblo is about 2 miles east of Fowler, on the Atchison, Topeka and Santa Fe Railway. 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 near Fowler, Colo.

	Feet.
Surface materials	0– 40
Shale	40– 825
Limestone	825– 875
Shale	875–1,270
First "Dakota" sandstone	1,270–1,372

This boring begins on 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 the Benton formation to the top of the "Dakota" sandstone.

La Junta.—In this town there are several wells, formerly flowing, which yield soft water that is extensively used by the railroad company and in part for municipal supply. The principal supply is in the second bed of sandstone of the "Dakota" formation, which is entered at a depth of 555 feet. Most of the wells are between 405 and 439 feet deep. A boring by the railroad company passed through both sandstones of the "Dakota" formation and the underlying shales and sandstone into the "Red Beds," which it penetrated at 1,050 to 1,150 feet. The record of this boring is as follows:

Record of deep boring at La Junta, Colo.

	Feet.
Surface materials	0– 37
Gravel	37– 48
Shale	48– 230
"Talc"	230– 235
Shale and light shale	235– 340
"Dakota" sandstone, soft water	340– 423
Black shale	423– 451
Gray sandstone	451– 545
Black shale	545– 555
Sandstone; soft water, flows	555– 605
Shale	605– 950
Sandstone; water, no flow	950–1,050
Red and variegated shale	1,050–1,150

This well was plugged at 700 feet and obtains its principal supply of water from the second bed of sandstone in the "Dakota" formation at 550 to 605 feet. The original flow at 420 feet was 35 gallons a minute, but vigorous pumping has lowered the water level many feet and the water 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" formation at 340 feet. This formation presents an alternation of heavy beds of sandstone with intercalated shales, and from the record above given may extend to

A. ARTESIAN WELL ON RIDGE SOUTH OF LA JUNTA, COLO.

Depth 750 feet to Dakota sandstone. Not flowing at present.

B. FLOWING WELL AT ROCKY FORD, COLO.

Flows from a depth of 790 feet from Dakota sandstone.

a depth of 605 feet. The underlying shales and sandy beds are those which outcrop on Purgatory River, 25 miles south of La Junta, lying on the sandstones and shales of the "Red Beds," which were entered at a depth of 980 feet in the deep boring near 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 flouring 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. An analysis of the water is given on pages 80, 81.

A well on the hill in the southern part of the town is about 150 feet above the railroad depot, and its depth is 750 (or 766) feet. When completed, it flowed 25 gallons a minute. Now the water rises only to the surface, owing to partial filling with sand and possibly to a general reduction of the water level in the vicinity by the several wells near the depot. A view of this well is given in Pl. XXIV, *A*.

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 reached without obtaining either of these products. 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 Beds" series. The following record has been supplied:

Record of deep boring south of La Junta, Colo.

	Feet.
Soft gray limestone	0– 50
Rusty limestone at base of Niobrara	50– 60
Dark shales of Benton group	60– 440
Soft sandstone with artesian flow; first "Dakota"	440– 504
Shales	504– 584
Soft sandstone; artesian flow; second "Dakota"	584– 700
Gray and greenish-gray shales with water at 820 to 120 and 860 to 100 feet (Morrison formation)	700– 980
"Red Beds" with water at intervals which rose to within 200 feet of the surface	980–1,703

Some samples forwarded to Washington are as follows:

Samples of borings from La Junta, Colo.

	Feet.
Sand and fine-grained sandstone of gray color, with some limestone layers and reddish sandstone	1,230–1,290
Red shale, with some limestone layers	1,300–1,500
Red shale, with some limestone fragments	1,535
White sand	1,600
Red shale, with some limestone fragments	1,612
Gray limestone and red shale	1,660
Red shale and gray limestone	1,703

The Lenox well, in SE. ¼ sec. 2, T. 24 S., R. 56 W., 5 miles west of La Junta, has a depth of 740 feet, a diameter of 7⅝ inches, and yields a flow of 12 gallons a minute. The well began in Timpas 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. In the northeast quarter of the same section, on J. E. Gauger's ranch, there is a similar

well flowing 15 gallons a minute. According to Mr. McVay, the driller, the beds are at slightly lower levels, indicating a dip of 27 feet to the mile in that direction.

Holbrook.—At this place, which is 9 miles due north of La Junta, in SE. ¼ sec. 27, T. 22 S., R. 55 W., there is a well 661 feet deep, which flows about 100 gallons a minute. The head of the water is sufficient to raise it 80 feet, or probably much more, above the surface, and the flow is about 50 gallons a minute from a 3-inch pipe extending to the bottom. The water is soft. No record was obtainable, but it is stated that the boring passed through 155 feet of limestone, 385 feet of Benton shale with some limestone at a depth of 350 feet, and penetrated 110 feet into the "Dakota" sandstone. In the next township east are two shallower wells which have flows from the sandstone.

Timpas.—The following report of the well at this place has been furnished:

Record of boring at Timpas, Colo.

	Feet.
Loam	0– 37
Dry gravel	37– 40
Shale	40– 85
Limestone (basal Timpas), some water	85–137
Shale, with "talc vein" at 440 to 443 feet=398 feet of Benton	137–538
Sandstone ("Dakota"); poor water at 544 feet, rising to 50 feet; 2-gallon flow at 570 feet	538–580
Shale	580–605
Sandstone; poor water	605–650
Shale	650–656
Gray sandstone	656–716
Sandstone ("Dakota"); 20-gallon flow at 755 feet	716–790
Red shale (Morrison)	790–795

The water which flowed at 755 feet was too highly mineralized to be usable in boilers, so that the boring is regarded as a failure. The water flowed into a tank 27 feet above the ground.

Ayer.—This is a siding on the Atchison, Topeka and Santa Fe Railway, 6 miles southwest of Timpas, and the record of the well is as follows:

Record of boring at Ayer, Otero County, Colo.

	Feet.
Surface material	0– 40
Gravel	40– 43
Gray limestone	43– 80
Black shale, with "talc vein" 147 to 150 feet	80–249
Sandstone (Dakota); soft water	249–272
Shale	272–280
Gray sandstone; dry	280–287
Black shale	287–293
Sandstone; poor water; 25-gallon flow near bottom; 3-gallon flow at 311 feet	293–343

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 Railway, had a depth of 1,162 feet and yielded a flow of 5 gallons a minute, with a pressure sufficient to raise it 50 feet or more above the surface, but it was abandoned, as the water was too hard for use in locomotives. The following record is furnished:

A. Hoen & Co. Baltimore

MAP SHOWING STRUCTURE OF "DAKOTA" SANDSTONE IN EASTERN COLORADO

BY N. H. DARTON

1905

Scale

20 10 0 20 40 60 miles

Black contours have 1000-foot intervals; broken lines hypothetical

Record of boring at Bloom siding, Otero County, Colo.

	Feet.
Clay	0– 25
Gravel	25– 31
Shale, with bad water at 76 feet	31– 87
Gray shale	87– 154
Gray sandstone	154– 168
Black shale	168– 170
Sandstone, brown above; poor water	170– 229
Shale	229– 233
Sandstone; 5-gallon flow of water at 240 feet	233– 244
Hard sandstone	244– 255
Sandstone; second water at top, first flows 3 to 4 gallons; another flow at 385 feet	255– 400
Red shale (Morrison)	400– 450
White sandstone (Morrison)	450– 455
Red shale	455– 475
Red sandstone	475– 575
Light-gray shale	575– 695
Light-brown sandstone	695– 815
Dark-red sandstone	815– 880
Red sandstone	880– 965
Red shale	965– 985
Red sandstone	985– 995
"Marble"	995–1,000
Red shale	1,000–1,007
Red sandstone; water rose 450 feet; quality bad	1,007–1,020
White "limestone"	1,020–1,025
Red sandstone	1,025–1,085
"Limestone"	1,085–1,087
Red sandstone	1,087–1,125
"Limestone"	1,125–1,128
Pink sandstone; water rose 80 feet	1,128–1,133
Red sandstone	1,133–1,140
Red shale	1,140–1,145
White sandstone; water rose 350 feet	1,145–1,155
Red shale	1,155–1,162

The boring begins near the base of 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.

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.
Surface materials	0– 36
Shale	36– 90
Sandstone; water at a depth of 90 feet, rising to —10 feet	90–195
Shale	195–240
Sandstone; flow at 330 feet	240–333
Shale	333–360

This well begins in the lower part of the Benton shale and reaches the "Dakota" sandstone at a depth of 90 feet, as this 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. XXIII.) Other wells in Las Animas have depths of 250 and 267 feet and flow 17 and 5 gallons, respectively. A well sunk in 1904 on the Cooper place, a mile north of Las Animas, has a depth of 316 feet and a flow of 10 gallons a minute from a depth of 285 feet. It is cased with 5⅝-inch tubing. The pressure is sufficient, it is said, to lift the water 20 feet above the surface. The following record has been furnished by John Baugh, the driller:

Record of Cooper well, 1 mile north of Las Animas, Colo.

	Feet.
Surface materials	0– 10
Sand, with water	10– 30
Black, sandy shale	30– 60
Black shale	60– 70
Sandstone (Dakota), with water to —6 feet	70–170
Shale, with sandstone layers	170–266
Sandstone (second "Dakota"), with main flow at 285 feet	266–316

Twelve miles northeast of Las Animas is the well which was sunk in 1881 by the Government under direction of the Department of Agriculture. It was known as well No. 1, and is located 7 miles northeast of Fort Lyon. It had a depth of 815 feet, but obtained only a small amount of water from a depth of 430 feet, which flowed at the surface at a rate reported by some persons as 2 gallons a minute, and by others as only 3 gallons an hour. The head was stated to be just sufficient to raise the water 10 feet above the surface of the ground. This boring cost $18,353; the record is as follows:

Record of boring at Fort Lyon, Colo.

	Feet.
Sand, gravel, and quicksand	0– 74
Soft, blue clay	74– 80
Blue shale	80– 86
Gray sandstone	86–116
Dark shales	116–120
Streaked sandstone	120–140
Gray, clean grit	140–150
Black, sandy shale	150–180
Mottled, gray sandstone	180–190
Mica sandstone	190–200
Mixed sandy shale, light, very soft	200–225
Mixed sandy shale, dark, very soft	225–250
Black, variegated shale, very soft	250–275
Mottled purple shale, soft	275–300
Gray shale, soft	300–320
Mottled shales, soft	320–340
Black shale, soft	340–344
Gray sandstone	344–355
Coarse sandstone	355–368
Gray sandstone	368–382
Greenish clay	382–386
Marl	386–396
Green and red sandstone, soft	396–439

	Feet.
Dark-red shale	439–445
Rusty gray sandstone	445–450
Green shale	450–460
Green and red shale, soft	460–500
Gray sandstone	500–520
Compact gray shale	520–550
Hard shales	550–570
Fine, red sandstone	570–590
Coarse, red sandstone	590–630
Hard, red sandstone; some gypsum	630–650
Spotted sandstone	650–662
Mixed sandstones	662–703
Red sandstone, massive	703–751
Soft, red sandstone	751–783
Spotted red sandstone	783–815

The Marlaman well on Horse Creek, 12 miles northwest of Las Animas, has a depth of 493 feet, and a 7-gallon flow from the second "Dakota" sandstone. The following record was furnished:

Record of artesian well, 12 miles northwest of Las Animas.

	Feet.
Surface materials	0– 30
Limestone and shale	30–230
Dakota sandstone, small flow	230–330
Shale and sandstone	330–443
Second "Dakota" sandstone	443–493

Plum Creek.—At the Blackwell ranch, 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 155⅔ feet. It is in sec. 1, T. 26 S., R. 44 W. The head was found more than sufficient to raise the water to the top of the tubing, 46 feet above the ground. The volume is 18 gallons or more a minute. This well is important as indicating that artesian waters may be expected in the central and east-central portions of the county, at some distance south of the Arkansas Valley. Much of this region is occupied by the Greenhorn limestone in the middle of the Benton group, so that ordinarily 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.

Pueblo.—The first deep well in the 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 was 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 the well is as follows:

Record of deep well at Clark's mineral spring, Pueblo, Colo.

	Feet.
Soil and gravel	0– 34
Blue shale	34– 58
Black shale	58– 630
Sand rock, white below	630– 690
Black shale	690– 700
Soft, coarse sand rock	700– 735
Black shale	735– 900
Sand rock	900– 940
Black shale	940-1,030
Sand rock	1,030–1,045
Soft black shale	1,045–1,148
Sand rock with flow of water	1,148–1,180
Black shale	1,180–1,195
Coarse sand rock	1,195–1,230
Purple shale	1,230–1,240
Sand rock	1,240–1,270
Not given	1,270–1,400
Purple shale	1,400

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 of 20 to 25 gallons a minute is not utilized. An analysis of this water is given on pp. 80–81. Another well at Mineral Park in the same vicinity obtains a small flow from a depth reported to be 1,150 feet. At the Fariss House, north of the river, 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. An analysis of this water is given on pp. 80–81.

At the Grand Hotel in Pueblo is a well 1,219 feet deep and 4½ inches in diameter which has a flow of about 20 gallons a minute of mineral water under a pressure of 50 pounds to the square inch. At 1,050 feet there was a flow of fresh water under a pressure of 15 pounds. An analysis of the water is given on pp. 80–81. 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.

Record of well in sec. 9, T. 21 S., R. 65 W., Columbia Heights, Pueblo, Colo.

	Feet.
Soil on gravel	0– 31
Shale	31– 90
Limestone	90–105
Black slate	105–516
Sandstone, with water	516–616
Black slate	616–779
Sandstone, second flow	779–789

In 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 water is similar to that of other wells in the Pueblo region, containing a good deal of mineral matter. The following record is given:

Record of artesian well of C. H. Small, Pueblo, Colo.

	Feet.
Black soil	0–12
Blue shale	12–72
Limestone	72–82

	Feet.
Black shale	82–413
White sandstone	413–575
Red rock	575–760
Gray sandstone	760–772

On North Pueblo Heights a well was sunk by a suburban company to a depth of 1,820 feet, finding small flows at 1,200 and 1,820 feet. This well is in sec. 12, T. 20 S., R. 65 W. A flow of 1½ gallons was reported in 1889. 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. There was formerly a well known as McLane's, 9 miles west of Pueblo and 4 miles south of Arkansas River, on Boggs Flat. It was sunk for oil, but none was found. Water was reported at several horizons, but no depths were stated.

A well on the south side of the river 10 miles west of Pueblo is 795 feet deep and has a 30-gallon flow. Sandstone was entered at 535 feet. The water contains 110 grains of solid matter per gallon.

Florence.—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 is in large volume. A typical record is reported as follows:

Record of well in sec. 23, T. 19 S., R. 69 W., near Florence, Colo.

	Feet.
Surface materials	0– 20
Shale and sandy shale; flow of water	260– 280
Shale, with layers of limestone	280– 650
Limestone	650– 695
Sandstone	695– 699
White sandstone, second flow	699– 722
Shales, limestone, and sandstone; very large flow	722–1,130
Shales and sandstone	1,300–1,400
Soft shale	1,400–1,600

In 1905 an artesian well was completed 6 miles north of Florence, which is reported to have a flow of 360 gallons a minute from a 5⅝-inch casing. It is located in the SW. ¼ sec. 26, T. 18 S., R. 69 W., and has a depth of 1,230 feet. The water rises 6 feet above the surface and has sufficient head to rise 80 feet or more. The temperature of flow is 87°. Water was found at depths of 230 to 235, 300 to 345, and 815 to 900 feet, besides the main flow at 1,210 feet. The record is as follows:

Record of well in SW. ¼ sec. 26, T. 18 S. R. 69 W.

	Feet.
Sandy loam, reddish	0– 13
Conglomerate	13– 18
Light-blue clay (Pierre)	18– 210
Light-blue lime	210– 250
Light-colored sand	250– 255
Shale and limestone, alternating	255– 780
Light-colored limestone	780– 810
Light-colored sandstone	810– 825
Shale, with hard layers, some limestone	825–1,025
Drab shale	1,025–1,195
Sandstone, with hard layers	1,195–1,210
"Dakota" sandstone	1,210–1,230

Canyon.—Three miles east of Canyon there is a flowing well 900 feet deep which appears to derive its flow from a sandy member in the Pierre shale. Another well 5 miles south, 360 feet deep, has a large flow from the same source, or the basal Laramie sandstone. A new well at the Sanitarium, 3 miles northeast of Canyon, has a depth of 1,670 feet. It is 6 inches in diameter and yields a 300-gallon flow under a pressure of about 30 pounds, probably from the "Dakota" sandstone.

Portland.—This well is 10 miles south of Portland, on a branch of Ritchie Creek, near the south margin of Fremont County. It flows about 600 gallons a minute from a 6-inch casing and has a depth of 1,135 feet. It begins in the upper beds of the Apishapa formation, at an altitude of about 5,550 feet, but no reliable record could be obtained of the beds penetrated. Probably the Niobrara group has a thickness of about 650 feet and the Benton about 415 feet, for it is stated that the "Dakota" sandstone was entered at a depth of 1,065 feet. The water contains some iron and other salts, but appears to be satisfactory for domestic use and irrigation. Two views of this well are given in Pl. XXVII, which also show the deep hole washed out by the water that escapes along the side of the casing. This well indicates that wide areas of flat lands, extending east and north for many miles, are within reach of flowing waters which may prove to be valuable in reclaiming the land. Much of this area has the fertile, limy soils of the Apishapa formation.

Chandler.—A short distance west of Chandler, which lies south of the city of Canyon, there is a flowing well 1,075 feet deep sunk in a syncline near the foot of the Wet Mountain Range. Its flow is derived from the "Dakota" sandstone and is reported to be 80 to 100 gallons a minute. The water is tepid, has a decided iron and sulphate taste, and deposits a yellowish-red precipitate on standing. Two other wells in the same vicinity yield flows from depths of 487 and 364 feet.

St. Mary.—A 1,670-foot well just east of St. Mary obtains a strong flow from Dakota sandstone. The water is "alkaline" and is not used.

NONFLOWING DEEP WELLS.

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 by these and was found to contain an abundance of water, which, however, would not rise higher than to 80 or 90 feet below the surface. The materials reported in one of the borings, which has a depth of 1,508 feet, are as follows:

Record of boring at Ordway, Colo.

	Feet.
Surface materials	0– 42
Black shale	42– 60
Blue and gray shale	60– 90
Shale and shells	90–116
Blue shale	116–145
Black shale	145–185
Sandstone	185–245
Black shale	245–270
Gray shale	270–345
Limestone, soft	345–410
Gray shale, some limestone	410–473

A

B

ARTESIAN WELL 10 MILES SOUTH OF PORTLAND, COLO.

Depth about 1,000 feet; flow about 700 gallons a minute from Dakota sandstone.

	Feet.
Gray shale, darker below	473– 580
Black shale	580– 650
Gray shale	650– 700
Shale with shells	700– 710
Shale	710– 765
Brown shale	765– 785
Light-gray shale	785– 800
Brown shale	800– 825
Shale and limestone layers	825– 845
Black shale	845– 855
Shale with limestone layers	855– 925
Limestone and shale	925– 960
Limestone	960–1,010
Black shale	1,010–1,325
"Talc"	1,325–1,327
Black shale	1,327–1,410
Sandstone (Dakota) containing some water	1,410–1,500

This boring apparently began in the Pierre shale, passed through the basal limestone of the Timpas formation at 960 to 1,010 feet, but either did not penetrate sufficiently far into the "Dakota" sandstone to obtain flowing water or more likely the altitude of Ordway is too high 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 is reported to have entered the "Dakota" sandstone at a depth of 1,230 feet.

Arlington.—A well has been sunk in sec. 13, T. 21 S., R. 54 W., in the northeast corner of Otero County, 10 miles southwest of Arlington and 18 miles due east of Ordway. It has a depth of 715 feet, but, although it reached the "Dakota" sandstone, the head was not sufficient to afford a flow, the water level coming only to 60 feet of the surface. The supply appears to be ample, for the well was pumped 20 gallons a 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.
Sand and clay	0– 40
Blue shale	40–180
Sandstone	180–187
Gray shale	187–227
Limestone	227–267
Brown shale	267–372
Limestone	372–377
Sandy shale	377–432
Slate	432–477
Brown shale	477–584
Slate	584–594
Black sandy shale	594–688
Gray sandstone	688–703
Water-bearing sandstone	703–715

Las Animas.—A well was sunk in 1903 in sec. 36, T. 21 S., R. 52 W., 6 miles west of the Government well, to a depth of 720 feet. A satisfactory supply of water was found in sandstone at 452 to 474 feet, but, as it rose only to within 300 feet of

the surface the well is regarded as a failure. The following record was furnished by the owner, Mr. O. G. Scott:

Record of well 8 miles north-northeast of Las Animas, Colo.

	Feet.
Loam and sandstone	0– 25
Dark shale	25–452
Dakota sandstone; water to —300 feet	452–475
Dry sandstone	475–596
Dark shale	596–656
Gray shale with "bowlders" (?)	656–700
"Talc"	700–710
Gray shale lying on red shale	710–720

This well began at the top of the Carlile formation and passed through the formations of the Benton group to the top of "Dakota" sandstone, at 452 feet. The sandstone is reported to be 144 feet thick and underlain by 124 feet of Morrison shales to the top of the "Red Beds," at a depth of 720 feet.

Caddoa.—At this station, which is on 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 described on page 58. The water obtained at 285 feet was hard, so that the wells which are 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.
Surface materials	0– 29
Yellow clay	29– 33
Sandstone, soft water at 50 feet	33– 66
Shale	66–175
Sandstone, hard water	175–285
Variegated shale, water to —75 feet	285–300
Sand rock, water to —60 feet	300–345
Shale	345–384
White sand rock	384–425
Red shale and sand	425–492
White slate	492–582

Lamar.—At Lamar there are several wells 226 to 522 feet deep, 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.
Surface materials	0– 34
Shale	34– 72
"Talc vein"	72– 75
Shale	75–198
Dakota sandstone; water to —20 feet	198–265
Shale	265–270

	Feet.
Sandstone; soft water	270–325
Shale	325–400
Sandstone	400–404
Sandy shale	404–460
Sandstone; soft water, which at 480 feet rises to —60 feet and at 500 feet just flows	460–500
Variegated shale—red, chocolate, and brown	500–527

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 is pumped from the "Dakota" sandstone at a depth of 300 feet, rising to within 28 feet of the surface. The water has the composition stated on page 80.

A well 107 feet deep, in the NE. ¼ sec. 36, T. 24 S., R. 47 W., found a large supply of water in "Dakota" sandstone. Its diameter is 5 inches and one large windmill does not pump it dry. The water is soft, but contains an appreciable amount of salts.

Granada.—The railroad well at this place has the following record:

Record of deep well at Granada, Colo.

	Feet.
Surface materials; hard water	0– 36
Shale	36– 58
Limestone yielding bad water	58– 60
Shale	60– 78
Limestone	78– 80
Gray shale	80–195
Black shale	195–323
"Talc vein"	323–326
Black shale	326–353
Sandy shale; some soft water	353–405
Dakota sandstone; soft water	405–480
Shale	480–497
White clay	497–504

The original 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 a minute.

The town well at Granada, drilled in 1904, in the center of the town, has a depth of 480 feet, where a large supply of water is obtained. The water is soft and rises to within 30 feet of the surface.

Amity.—The well at Amity has a depth of 384 feet, reaching the "Dakota" sandstone at 310 feet. The water rises to within 19 feet of the surface; the supply is very large, and the quality is highly satisfactory. The well is cased with 100 feet of 7½-inch casing through sand and gravel to the first shale, 187 feet of 6¼-inch casing to shut out some very hard water at a depth of 187 feet, and 380 feet of 5-inch casing reaching into the "Dakota" sandstone. In one report it is stated that the top of the "Dakota" sandstone is at 297 feet, consisting of 4 feet of sand lying on shale, and that the second sand with the principal flow was entered at 376 feet and penetrated 8 feet. The head of the water in this well is below the level of Arkansas River.

Three miles north of Amity, in SE. ¼ sec. 25, T. 22 S., R. 43 W., there is a deep well, sunk by the Sugar Beet and Irrigated Land Company in 1902. It is 699

feet deep, 8 to 6 inches in diameter, and yields a large supply of excellent soft water, which rises to within 100 feet of the surface. Some water was found at 300 feet and other depths, but the water utilized is from the bottom of the well. The following record of this well was supplied by the company:

Record of well 3 miles north of Amity, Colo.

	Feet.
Gravel and sand	0– 92
Limestone	92–132
Dark shale	132–610
Dakota sandstone	610–699

Holly.—At Holly there is a well which reaches the "Dakota" sandstone at 296 feet and obtains a satisfactory supply of excellent water. At the sugar factory, one-half mile west of Holly, a new well 412 feet deep obtains a water supply which rises to within 20 feet of the surface. The diminished depth to the "Dakota" at this place indicates that the strata are rising eastward from Granada, as shown in the section, Pl. XXIII.

Delhi.—At a siding on the Santa Fe Railway 8 miles north of Thatcher a well was sunk in 1901–2 by the railway company to a depth of 322 feet. The well draws water from several beds, from 132 feet down to its bottom. The original water level was 50 to 75 feet below the surface, but it has been greatly lowered by pumping. With the cylinder at 152 feet it yields 37 gallons a minute. The following record was furnished:

Record of well at Delhi, Otero County, Colo.

	Feet.
Clay	0– 75
Dark-gray sand	75–110
Light-gray sand	110–120
Dark-gray sand, with water at 130 feet	120–141
Light-gray sand	141–161
Dark-gray sand	161–176
Black shale	176–185
Dark-gray sand	185–205
Shale	205–218
White sand	218–305
Water-bearing beds	305–322

This boring begins near the bottom of the Graneros shale and penetrates nearly to the bottom of the "Dakota" sandstones. The failure of this well to afford a flow is due to outcrop of the sandstones in the depressions west and north.

Tyrone.—This is a siding on the Santa Fe Railroad 8 miles south of Thatcher. The well was sunk in 1902 by the railroad company to a depth of 580 feet. It draws its main supply, which pumps 50 gallons a minute, from a depth of 577 feet, with the pumping cylinder at 423 feet. The height to which the water rose originally is not stated. The following record is furnished:

Record of well at Tyrone, Las Animas County, Colo.

	Feet.
Loam and clay	0– 30
Limestone	30– 70
Black shale with bad sulphur water at 175 feet, rising to —70 feet	70–345
"Talc vein"	345–350

	Feet.
Black shale	350–438
Sandstone (first "Dakota"), with water at 458 feet, which rose to about —375 feet	438–480
Black shale	480–490
Sandstone (second "Dakota"), main water supply	490–577
Black shale	577–580

This boring begins in the lower portion of the Timpas formation, passing out of the Timpas limestone at 70 feet and through 368 feet of beds of the Benton group, with characteristic "talc vein" at 345 feet, to the "Dakota" formation at a depth of 438 feet. The low head of the water is due to the low level of "Dakota" sandstone outcrops to the west, north, and east.

Trinidad.—Several deep borings have been made in and near Trinidad for gas, oil, and water, but only water has been obtained. One boring southwest of the city is claimed to have reached a depth of 3,000 feet. Two borings in the railroad yards have reached depths in excess of 2,600 feet and obtained water from the "Dakota" sandstone, which lies at a depth of 2,585 feet. One well, reported by the Colorado Southern Railroad Company, has a depth of 2,713 feet; at 2,595 feet an abundant supply of excellent water is obtained, which rises to within 195 feet of the surface. The well begins about 150 feet below the top of the Pierre shale. The following partial record is given:

Record of railroad well at Trinidad, Colo.

	Feet.
Loam and gravel	0– 42
Gray shale, some water from 150 to 250 feet	42–2,200
Lime shale and black shale with some gas at 2,220 feet	2,200–2,400
Black shale (Graneros)	2,400–2,585
"Dakota" sandstones, close and hard	2,585–2,713

Barela.—A well sunk by the Colorado Southern Railroad Company at Barela has a depth of 1,340 feet, obtaining water which rises to within 300 feet of the surface, and pumps 30 gallons a minute. The following record has been furnished by the railroad company:

Record of well at Barela, Las Animas County, Colo.

	Feet.
Gravel and loam	0– 27
Gray shale	27– 680
Limestone (Timpas)	680– 704
Black shale	704–1,063
First "Dakota" sandstone	1,063–1,213
Shale	1,213– ?
Second "Dakota" sandstone	? –1,323
Red rock	1,323–1,340

This boring began in the Apishapa shales about 100 feet below the top of the formation and passed through the basal Timpas limestone at 704 feet. The Benton group has a thickness of 359 feet, in which the Greenhorn limestone was not reported. The "Dakota" sandstones have a thickness of 260 feet and the underlying "red rock" reported is probably in the Morrison formation. The thickness of shale between the upper and lower sandstones was not given.

Watervale.—A well sunk by the Colorado Southern Railroad Company at Watervale, near the southeast corner of Las Animas County, has a depth of 327

feet. "Dakota" sandstone was found under gray shale at a depth of 100 feet and penetrated to 285 feet, where red rocks were entered and bored into for 42 feet. Water, which rose some distance, was obtained in the "Dakota" sandstone.

Wetmore.—In Pueblo County, 1½ miles east of Wetmore, a boring for oil reached a depth between 1,300 and 1,400 feet. It penetrated the "Dakota" sandstone for 30 feet. The rock was found to be very hard. Water was encountered, which rose to within 100 feet of the surface, which is a high mesa near the foot of the mountains. This boring is about a mile south of the flowing well described on page 62, but is on land about 450 feet higher. It began in terrace deposits capping Pierre shale.

UNSUCCESSFUL DEEP BORINGS.

Cheyenne Wells.—The well at this place was bored under the direction of the Department of Agriculture more than twenty years ago, by means of 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, as the gas was found to be of insufficient quantity. Through the kindness of Mr. McLane, of Cheyenne Wells, the following record was obtained:

Record of boring at Cheyenne Wells, Colo.

	Feet.
Clay	0– 30
"Magnesia"	30– 60
Sandy gravelly clay	60– 110
White sandy clay	110– 130
Soft white sand	130– 145
White sandy clay	145– 185
Soft white sand	185– 215
Soft black shale; good water at 257 feet	215– 534
White sandy shale; gas	534–1,260
Chalk rock; brackish water	1,260–1,330
Fine sand	1,330–1,360
Soft black shale	1,360–1,460
Soft white sand or limestone	1,460–1,510
Black shale	1,510–1,700
(Not given, but thought to be shale)	1,700–1,770

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 it 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 at 1,260 to 1,330 is a portion of the Niobrara. The supposed limestone at 1,460 to 1,510 feet is probably the Timpas limestone, at the base of the Niobrara, and if this is the case the boring stopped in the top of the shales not far above the top of 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 there were excellent prospects of 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 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.

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 is "Dakota."

Hoehne.—At this station on the Santa Fe Railroad, 9 miles northeast of Trinidad, a boring was made to the depth of 936 feet, but, unfortunately, it 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 Apishapa and Timpas formations, here about 700 feet thick, and passed low into the Carlile shale. Doubtless it would have found water in the "Dakota" sandstone, and, as the locality is nearly 300 feet lower than Trinidad, it 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.—In 1884 a boring was made at this place to a depth of 920 feet. It began near the top of the "Dakota" sandstone and penetrated several hundred feet into the "Red Beds." Some water was found near the bottom, which rose 300 feet. No record was obtainable, and neither the quality nor the volume of water was stated.

Troy.—At a transient settlement by this name, 25 miles north of Watervale, a boring 400 to 500 feet deep was sunk several years ago. It began in "Dakota" sandstone. No record or other information was obtained, except that it was regarded a failure.

Rouse Junction.—At Rouse Junction, a station on the Denver and Rio Grande Railroad southeast of Walsenburg, the railroad company made a boring to a depth of 2,058 feet, but did not find 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.
Shale	20–800
Coarse white sandstone	800
Black shale; bad water	850
Hard white sandstone	870
Hard rock (reported as granite)	930

	Feet.
Hard white sandstone	940
Black shales	950
Hard white sandstone	960
Slate	1,010
Shale	1,020
Hard white sandstone and quicksand	1,030
Hard white sandstone and quicksand	1,140
Coarse white sand with a little water	1,150
Coarse red sandstone	1,160
Coarse green sandstone	1,190
Pink slate and sand and "granite"	1,210
Red sand	1,290
Pink slate	1,320
Drab sand with shells	1,350
Fine hard white sand	1,380
Fine drab sand and white hard clay	1,390
Red flinty rock	1,450
Fine gray sand, very hard	1,500
Red sand	1,540
Hard white sand	1,960
Red fine hard sand	2,058

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 sandstone of the Benton group. Apparently the "Dakota" sandstone yielded no water, a most discouraging indication, for its capabilities seem to have been thoroughly tested. The explanation probably is that, owing to the extensive outcrops of the "Dakota" formation, a short distance north and east, no head is possessed by whatever water may be passing through the sandstone. There is also a likelihood that the many dikes which penetrate the formations near Rouse Junction, particularly to the west, may cut off the underground flow.

Walsenburg.—At Walsenburg an unsuccessful boring was made sometime ago for gas. It was 1,300 feet deep and entirely in the Pierre shale, which here has a thickness of about 1,700 feet.

Cuchara.—On Cuchara River 7 miles below Walsenburg an 800-foot boring was made for coal, oil, or gas. It found an abundant supply of sulphur water, which is pumped to the surface. The boring probably reached the top of the "Dakota" sandstone.

Elmoro.—A 400-foot boring at Elmoro is entirely in Pierre shale and yielded no water.

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, which did not find a sufficient supply of good water. Analyses of the two principal waters are given on pp. 80–81. The following materials were reported, but the record evidently is unreliable:

Partial record of deep boring at Salt Creek siding, Las Animas County, Colo.

	Feet.	
Gravel	0–	6
Hard limestone; water at 70 feet rose to —3 feet	6–	71
Black shale; thin limestone layers	71–	250
Sand and shales; water at 283 feet rose to —140 feet	250–	285
Black and white sand	285–	335
Gray sand	335–	352
Dark sand	352–	365
Light-gray sand	365–	380
Red sand and hard clay	380–	410
White shale; water at 440 feet rose to —220 feet	410–	450
Gray hard sandstone	450–	495
Greenish sand and sandstone	495–	630
Gray sand	630–	750
Dark-gray sand; water at 840 feet rose to —540 feet	750–	845
White sand	845–	855
Dark-gray sand	855–	870
Red sand; water at 1,005 feet rose to —705 feet	870–1	015
Red sand and "granite"		1,025

At 1,545 feet water rose to —900 feet, and at 1,800 feet rose to —600 feet.

This boring 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 were 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 believed not to be great. This and the experience of the Rouse Junction well 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 is also indicated by the salinity of the water, which we should expect would be greatly decreased if there were a free underground passage to the canyons north and east; moreover, in these canyons very little water is seen to come out of the formation.

Boone.—In 1903 a deep boring was made at Boone to explore for oil or gas. It reached the top of the "Dakota" sandstone, which was not penetrated sufficiently to afford a water supply. The following record is furnished:

Record of boring at Boone, Colo.

	Feet.	
Surface materials	0–	25
Shale	25–1,	560
Limestone	1,560–1,	610
Shale	1,610–1.	720
Limestone	1,720–1,	740
Shale with "talc vein"	1,740–2,	200
"Dakota" sandstone	2,200–	

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.

Pueblo.—In 1903 two deep borings were sunk in north-central Pueblo 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 2,655-foot well penetrated the "Dakota" sandstone 55 feet and found water which rose 1,000 feet or more. The following records were furnished:

Records of wells 7 and 10 miles northeast of Pueblo, Colo.

	Feet.
Well No. 1:	
Shale	0–1,400
Limestone	1,400
Sandstone	1,440
Shale	(?) 1,875
Sandstone (probably Carlile)	1,875–1,900
Well No. 2:	
Shale	0–2,000
Limestone	2,000–2,100
Sandstone (Carlile)	2,100–2,140
Shale	2,140–2,600
"Dakota" sandstone	2,600–2,655

The altitude of the first 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. The other boring is at an altitude of 4,750 feet and its approximate location is 6 miles north and 3 miles west of Nyburg siding, on the Missouri Pacific Railroad. It is probable that if the "Dakota" sandstone had been more deeply penetrated by this boring the water would have risen to within 100 feet of the surface, but the boring is situated on land too high for artesian flow.

Colorado City.—Deep borings at Colorado City penetrated the steeply dipping beds of the foothills, but did not prove successful. Two deep wells were bored there by a local oil company in 1894 and 1895. Boring No. 1 was located on the NW. ¼ of NE. ¼ sec. 2, T. 14 S., R. 67 W. 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 black shale, except at 1,247 feet, where a 5-foot bed as hard as granite was reported, which yielded some gas. The boring was entirely in Pierre shale. Boring No. 2 was located on the SW. ¼ of NE. ¼ sec 2, T. 14 S., 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, doubtless entirely in the Laramie formation, was sunk to a depth of 566 feet, and 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 was of poor quality. The following record was reported by the Chicago, Rock Island and Pacific Railroad Company:

Record of boring at Calhan, Colo.

	Feet.
Sand	0 – 23
Sandstone	23 – 38
Dark sandy shale	38 – 63
Clay and sandy shale grading into soft sandstone	63 –142
"Soapstone;" thin coal layer at 232 feet	142 –255
Shale	255 –306
Sandy limestone	306 –314
Sandy shale with coaly layers	314 –323
"False coal"	323 –324
Fire clay	324 –325½
Dark shale	325½–329
Sandy shale	329 –336½
"False coal"	336½–337
Micaceous sandy shale; ½-inch coal layer at 360 feet	337 –361
"Soapstone"	361 –416
Micaceous sandy shale	416 –432
"False coal and poor coal"	432 –435
Shale	435 –480½
Sandy false coal	480½–484½
Poor coal	484½–487
Micaceous sandy layer with some shale	487 –546
Sandy false coal	546 –551
Shale	551 –556½
Shale and sandy shale	556½–566

Franceville Junction.—At this place, which is on the slope southeast of Colorado Springs, a 1,250-foot boring is reported, which was entirely in Pierre shale and yielded neither water, oil, nor gas.

Monument.—A 765-foot boring is reported at Monument. It began in or above the Laramie beds and probably penetrated Pierre shale, but without result.

Florence.—In the oil fields about this place there are many deep borings, mostly in the Pierre shale, which rarely find much water. One with a depth of 3,021 feet was entirely in shale, except 10 feet of dark hard rock at 2,680 feet. It encountered no water.

SOURCE OF THE "DAKOTA" WATER.

The artesian waters of the "Dakota" sandstone enter this formation in the outcrop zone along the foot of the Rocky Mountains and also in the wide area of exposures in the southeast corner of the State. The exposed surface of the sandstone directly absorbs a portion of the rainfall and some of the water of streams crossing the outcrop also sinks into the porous beds. In the southeast corner of the State the formation is extensively overlain by deposits of gravel and sand, and much of the water which falls on this surface passes underground and in part enters the "Dakota" sandstone. Some of the water absorbed on the higher ridges escapes again at lower levels along the canyons and draws, either in springs or as small seeps. These are occasionally observed along the hillsides, and doubtless there are many others covered by talus and wash.

The area of "Dakota" sandstone exposed in the "hogbacks" along the foot of the mountains is relatively small; the outcropping beds usually dip steeply,

and much of the rock is so hard that water falling upon its surface runs off into the adjoining shale valleys, so that probably only a limited amount passes underground in this zone. Probably most of the water is absorbed in the wide outcrop area extending from Huerfano River to Apishapa River, northwest of Thatcher, and especially in the wide plateaus south and southeast of La Junta. In the latter area the sandstone constitutes the surface for many square miles; much of the land is level or gently sloping and the sandstone is soft, so that it is capable of absorbing a large volume of water. On the other hand, this region is traversed by numerous deep canyons cut entirely through the "Dakota" sandstone, so that part of the underground drainage of the formation is intercepted. Purgatory River and Smith and Muddy creeks probably intercept all of the underground drainage of the sandstone in the region north and northwest of the Mesa de Maya.

DEPTHS TO "DAKOTA" SANDSTONE.

Owing to the irregular dips of the rocks in southeastern Colorado, the depth to the water-bearing "Dakota" sandstone varies considerably in different portions of the district. From a study of the distribution of the overlying formations and a knowledge of their thickness, obtained by measurements on the surface and in wells, the position of the top of the "Dakota" sandstone has been ascertained as shown on the map, Pl. XXV. This map also shows the area in which the "Dakota" sandstone is at or near the surface and the region in which there is no "Dakota" sandstone. It will be seen from this illustration that, along the greater part of the Arkansas Valley, the water-bearing horizon lies at a moderate distance below the surface and over wide areas it is within the reach of wells 300 to 1,500 feet deep. In a wide district extending from northeast of Pueblo to northwest of Ordway the strata dip steeply into a deep basin, so that in northeastern Pueblo County, northwestern Otero County, central and eastern El Paso County, and Lincoln County the "Dakota" sandstone lies too deep for well drilling, and, moreover, the land in this region is too high for the water to flow. The beds also lie in a deep basin in central and southern Huerfano and Las Animas counties, as well as in the area about Florence. From Portland to Pueblo, in the vicinity of Arkansas River, the "Dakota" sandstone is less than 1,200 feet below the surface, and in a small anticline 6 miles west of Pueblo the top of the formation is exposed in the river bed. East of this exposure the dips increase gradually, so that the depths are about 1,200 feet at Pueblo, 1,900 feet at Nyburg, and about 2,000 feet at Boone, which is near the center of the basin. East of Boone the amounts diminish gradually, being 1,800 feet at Nepesta, 1,270 feet at Fowler, 1,033 feet at Manzanola, 690 feet at Rocky Ford, and 340 feet at La Junta. There is still further decrease to Las Animas, a short distance east of which the "Dakota" sandstone reaches the surface, outcropping along the bottom of the valley nearly to the mouth of Big Sandy Creek. East of this point the dip carries the beds down again and the depths gradually increase to 405 feet at Granada, which is in the center of a shallow basin. On the east slope of this basin there is a gradual rise to a depth of 200 feet at Coolidge. Many of these features are shown on Pls. XXIII, XXV, and XXVI.

The figures above given are to the surface of the "Dakota" sandstone, and, while in many districts a flow of water is obtainable from the top bed of this formation, the principal supply is usually looked for in lower beds, 100 to 160 feet deeper. In Kiowa County a prominent anticline extends northward from the Arkansas Valley, raising the beds in a low arch which extends northward to Kit Carson County. Owing to this uplift the "Dakota" sandstone lies at moderate depths as far north as the Union Pacific Railroad, especially in the lowlands of Big Sandy and Big Spring creeks. Unfortunately, however, all of this region is too high for artesian flows. Along the Rocky Mountain front the "Dakota" sandstone varies greatly in attitude, and in the vicinity of Colorado Springs and for several miles north and south the dips are steep and the sandstones are carried rapidly beneath the surface, soon reaching a depth of 3,000 feet. In the region northwest of Pueblo where the dips are gentler, the depths are much more moderate and the sandstone may be reached by wells 200 to 1,000 feet deep over an area of considerable extent. Along the base of the Wet Mountain Range the "Dakota" sandstone is extensively exposed, except to the south near Huerfano River, where it dips steeply under the great basin in which the Spanish Peaks are situated. On the east side of this basin there is a zone passing through Huerfano, Cuchara, Hoehne, Elmoro, Barela, Trinchera, and Watervale, in which there is a gradual increase of depth from east to west of 600 to 1,500 feet in greater part.

AREA OF FLOW.

Apparently the "Dakota" sandstone contains water throughout its extent, especially where it passes underground below the younger formations. As explained above, the sandstone receives much of the water at moderately high elevation, so that this water possesses considerable head in its passage underground. This head is sufficient to afford flows in nearly all of the lower lands near Arkansas River and along some of the confluent valleys, especially to the west. The areas in which flows may be expected are shown by the overprinted pattern on the map, Pl. XXV. This representation is based on the observed pressures in wells, together with deductions as to gradient slopes drawn between many points along the outcrops of the water-bearing beds. These lines of the grade of the water head have been found to slope from the outcrops at high levels, where the water passes underground, to the outcrops at lower levels where there is leakage from springs. The principal area of low-level leakage in the district is along Arkansas River, between Las Animas and the mouth of Big Sandy Creek, where the "Dakota" sandstone is free to lose much of its water, consequently the head of the water becomes zero along this outcrop zone. The hydrostatic gradient rises to the southwest, but not rapidly, owing to the low declivity of the Purgatory Valley, which cuts into and through the sandstone for many miles. West of longitude 104° the rate of increase is very much higher, although it is locally diminished by the deep valleys of Apishapa and Huerfano rivers. Although the sandstones lie high on the mountain slopes in the western portion of Pueblo and the eastern portion of Fremont counties, there is a rapid diminution of head toward Pueblo, possibly due in part to the rise of the formation to the surface along the river 6 miles west of Pueblo.

The flowing wells south of Portland, at Pueblo, Fowler, Manzanola, Rocky Ford, Holbrook, La Junta, and Amity are along the main zone of flow. At La Junta there was originally a flow of considerable pressure, and also at Lamar, but pumping has reduced the water level considerably below the present surface of the land. Flows at Timpas and Thatcher show an extension of the flow area to the southwest up the Timpas Valley, and similar lateral extension may be expected in the Apishapa, Huerfano, St. Charles, and other large valleys leading into Arkansas River. At Ordway and Sugar City the water-bearing beds appear to have been reached, but the land was too high for a flow and this probably was also the case at Sheridan Lake and Kit Carson in the wells sunk and abandoned long ago. The Government well northeast of Fort Lyon evidently was near the northern margin of the flow area, as its pressure was very slight, and two wells to the north and northwest have water levels considerably below the surface. The well 10 miles due south of Portland indicates a wide extension of the flow area in the southeast corner of Fremont County and adjacent portions of Pueblo County. A small flowing well on Plum Creek 20 miles south of Granada indicates that flows may be expected in the lower valleys in the central-eastern portion of Prowers County, probably as far south as South Butte Creek. The water level 100 feet below the surface at Trinidad and 80 feet below the surface at Barela indicates that the area of flow does not extend as far up Purgatory River and its branch valley as originally supposed.

PRESSURE OR HEAD OF THE WATERS.

As explained above, the waters in the "Dakota" sandstone under the greater part of southeastern Colorado possess considerable pressure, which ordinarily is sufficient to bring the water to the surface and in portions of the district to carry it to a greater or less distance above. In Pueblo the wells have a pressure of 50 pounds to the square inch, and at Manzanola it is reported that the original pressure was 55 pounds. At Rocky Ford and Holbrook the water was found to have sufficient pressure to rise 80 feet, or more, in the pipe. At La Junta the well south of the town is about 150 feet higher than the depot, and when the well was first sunk the water had sufficient force to rise considerably above the surface. A heavy draft on the water supply at La Junta has since lowered the water level so greatly that even the wells on the lower land do not flow. In Pl. XXVIII the head of the waters is shown, and in the following table are given data from various flowing and nonflowing wells, throwing light on the head of waters in the "Dakota" sandstone. Unfortunately, it was impracticable to obtain the pressures, or facts relating to the water level, in some of the wells, and even the figures given in most cases are only approximate.

A. Hoen & Co. Baltimore

MAP OF PART OF THE ARKANSAS VALLEY, SHOWING HEAD OF WATER IN "DAKOTA" SANDSTONE

BY N. H. DARTON

1905

Figures in blue indicate altitude of head at wells

—7000— Artesian head (contour lines showing approximate altitude to which the artesian waters may rise. Intervals vary from 100 to 500 feet)

Scale

20 10 0 20 40 60 miles

Black contours have 1000-foot intervals; broken lines hypothetical

Area underlain by "Dakota" sandstone

Outcrop area of "Dakota" sandstone

List of wells in eastern Colorado affording data as to head of waters.

Locality.	Height to which water will rise.	Altitude of the land.	Head of water above sea level.
FLOWING WELLS.	*Feet.*	*Feet.*	*Feet.*
Portland (10 miles south)	100±	5,550	5,650±
Florence (6 miles north)	+ 80	5,400	+5,480
Pueblo (South)	138	4,750	4,888
Farriss House	138	4,670	4,810
Grand Hotel	115	4,690	4,805
Rocky Ford	80	4,177	+4,257
Manzanola	?126½	4,251	?4,377
La Junta (originally)	+150	4,061	+4,210
Holbrook	+ 80	4,260	4,340
Timpas	+ 27	4,480	+4,507
Bloom	+ 50	4,691	+4,741
Fort Lyon	10	3,955	3,965
Blackwell ranch (Plum Creek)	46	3,900	3,946
NONFLOWING WELLS (WATER BELOW SURFACE).			
Ordway	− 80	4,300	4,220
Arlington (10 miles southwest)	− 60	4,180	4,120
Las Animas (10 miles north)	−300	4,100	3,800
Caddoa	− 15±	3,765	3,750±
Lamar	0	3,592	3,592
Granada	− 25	3,445	3,420
Amity	− 19	3,450	3,431
Amity (3 miles north)	−100	3,550	3,450
Delhi	− 50	5,057	5,007
Trinidad	−195	5,980	5,785
Barela	−300	5,723	5,423
Wetmore (1½ miles east)	−100	6,000	5,900
Sheridan Lake	− 50	4,065	4,015
Rouse Junction	−200	6,128	5,928
Salt Creek	−900	6,480	5,580

The lines in Pl. XXVIII are constructed from the altitudes of "Dakota" sandstone outcrops and the water levels given in the above table. It is assumed that the gradients of head are uniform from point to point, as shown in the diagram, fig. 2, and this is found to be verified at numerous points in the Arkansas Valley.

QUANTITY OF "DAKOTA" WATERS.

The volume of water available from the "Dakota" sandstone in eastern Colorado is variable, and in portions of the region it has been found inadequate. The three principal factors in this connection are the original volume of supply, the head of the water, and the porosity of the sandstone. No matter how much water is available along the intake zone, nor the head that may be developed in its passage to lower levels, there can be but little volume of water available if the sandstone is not porous. In its surface outcrops, as well as in the borings, the rock is found to vary considerably in porosity, but in general it usually appears to be capable of holding a moderately large volume of water. The amount of water that passes underground seems to be large, judging from the wide area of the formation exposed and its surface porosity, but much of the water taken in at high altitudes is free to

escape at lower ones, so that from this cause there is not only loss of water but diminution of head. Where the rock is saturated with water and the head is high, a well tapping the sandstone will yield a larger flow than one in an area where the pressure is low. As heretofore explained, nearly all the pressures in the Arkansas Valley are low, so that there is relatively little power to force the water into the sandstone interstices in the vicinity of the well, so as to sustain a vigorous flow. In most of the wells in the Arkansas Valley only a moderate volume of water was found, and, when the wells are subjected to pumping, the water surface is quickly lowered in most cases.

The wells at Rocky Ford exhibit a larger volume of water than any others in the Arkansas Valley below Pueblo. Of the several that have been bored, the larger ones have sustained a flow of 100 to 115 gallons a minute. The well at Manzanola, only 10 miles west, yields less than 40 gallons a minute, and the well at Fowler only half a gallon a minute. This rapid diminution to the west apparently is due to diminished porosity of the sandstone. There is similar but less marked diminution to the east, as illustrated at La Junta. At this place there are several wells which originally flowed 12 to 35 gallons a minute, but vigorous pumping has lowered the head greatly and materially diminished the volume. North and northwest of La Junta the volume increases, a flow of 100 gallons a minute being reported at Holbrook. About Las Animas the wells have flows of 10 to 20 gallons. At Caddoa, Lamar, Granada, and Amity, where the waters are pumped, supplies of 40 to 80 gallons a minute are obtained. In the various wells along the Santa Fe Railroad southwest of La Junta the amount of water flowing or available for pumping varies greatly. At Delhi 37 gallons and at Tyrone 50 gallons are obtained. At Timpas and Thatcher the volume was very small, but at Ayer the poor water obtained had a flow of 25 gallons. In the vicinity of Pueblo the volume also is variable. The first well in South Pueblo flows 100 gallons a minute, of mineral water, while other wells in the vicinity flow 13 to 25 gallons.

The well having the largest flow in the Arkansas Valley is the one 10 miles south of Portland, where, from a depth of about 1,100 feet, about 600 gallons a minute flow from a 6-inch casing. It is possible that the large amount of water in this locality is due to the proximity to the intake zone along the mountain front a short distance south and west. It gives promise that in the extensive prairies lying east and north, similar large flows may be obtained, which could be used extensively for irrigation.

In the eastern portion of Huerfano and the western portion of Las Animas counties there appears to be but a limited supply of water in the "Dakota" sandstone, except about Trinidad and southeastward, where some of the wells obtain fair supplies by pumping. Deep borings at Rouse Junction and Salt Creek, on the Denver and Rio Grande Railroad, found only a very small amount of water in the "Dakota" sandstone, and at the latter place it was too much mineralized for use. Probably the small volume of water in this district is due to the escape of the underground supplies in the outcrops of "Dakota" sandstone at lower levels to the east. Possibly also the flow of underground currents is greatly impeded by the numerous igneous masses which traverse the strata in many directions.

QUALITY OF THE "DAKOTA" WATERS.

All waters which flow over or through rocks and soil dissolve various chemical compounds, the nature and amount of which have great local variation. Water passing through pure sand or sandstone can be contaminated only to a very slight degree, but nearly all rocks contain soluble minerals, especially shales, limestones, and red beds, which often yield a large amount of salts to waters which come in contact with them. Red beds generally contain gypsum and salts of various kinds and yield highly mineralized waters. The deep waters of the Arkansas Valley vary greatly in quality, but nearly all contain a noticeable amount of mineral matter. Only a few analyses are available, and these are given in the following tables. The chemicals are reported in their theoretic combinations, and it should be pointed out in this connection that there is considerable difference of opinion among chemists as to the probable compounds indicated by analyses. Most of the waters from the "Dakota" sandstone in the Arkansas Valley region contain 50 to 100 grains per gallon of minerals. Sulphate of soda, or Glauber's salts, is the most prominent constituent, usually with smaller amounts of sodium chloride, or common salt, and sodium carbonate. Small amounts of carbonates of lime and magnesia appear in all the analyses reported, and usually there is also some sulphate of lime or gypsum.

In some districts the quality is satisfactory; in others the waters are much mineralized. In the vicinity of Pueblo the principal flow contains so large an amount of saline ingredients that it is regarded as a valuable medicinal agent and is extensively bottled as such. At Grand Hotel the flow at 1,050 feet near the top of the "Dakota" sandstone is reported to be of excellent quality. At Fowler, Manzanola, Rocky Ford, La Junta, Las Animas, Caddoa, Lamar, and Granada the quality is very satisfactory. At Ayer and Thatcher the water contains too much mineral for use in locomotives, while at Trinidad and Barela it is satisfactory for this use. In the well 10 miles south of Portland the water contains considerable iron, but appears to be satisfactory for drinking and irrigation. At Salt Creek and Rouse Junction waters of decidedly saline character were reported. At St. Mary the water is too alkaline for use.

Analyses of waters from "Dakota" sandstone in southeastern Colorado.

[Parts per million.]

Locality.	Depth.	Sodium.	Potassium.	Calcium.	Magnesium.	Sulphuric acid.	Chlorine.	Carbonic acid.	Silica.	Iron oxide+aluminum oxide.	Organic and volatile.	Other constituents.	Total solids.	Year.	Analyst.
	Feet.	*Na.*	*K.*	*Ca.*	*Mg.*	SO_4.	*Cl.*	CO_3.	SiO_2.	$Fe_2O_3+Al_2O_3$.					
Granada	580	160	.....	48	6.0	133	28	186	.....	.....	40	.....	602	1899	W. A. Powers.
Lamar	226	368	.....	42	27	692	33	114	49	.....	.....	.....	1,325	.....	Do.
Do	500	543	.....	96	39	853	54	369	17	.....	72	.....	2,043	1897	Do.
Do	300	355	.....	42	27	717	33	114	50	.....	.....	.....	1,338	.....	Dearborn Drug Co.
Caddoa	50	32	.....	46	10	89	19	63	.....	.....	59	.....	318	.....	W. A. Powers.
Do	280	436	.....	142	114	922	31	462	.....	.....	267	.....	2,375	1899	Do.
Las Animas	340	380	.....	14	7.2	440	18	244	.....	.....	40	.....	1,144	1899	Do.
La Junta	439	360	6.4	74	20	676	54	170	16	1.71	.....	0.17	1,378	1895	W. F. Hillebrand.
Do	420	415	.....	16	7.4	578	58	171	20	.....	96	.....	1,362	1898	W. A. Powers.
Do	420	358	.....	5.5	4.4	520	24	140	17	.....	39	.....	1,108	1898	Do.
Do	425	524	.....	14	18	695	33	286	12	7.3	37	6.0	1,627	.....	
Rocky Ford	700?	259	7.0	15	12	454	28	96	12	4.0	(a)	2.2	888	1895	W. F. Hillebrand.
Timpas	554	639	.....	84	39	1,180	70	247	15	125	.....	.....	2,390	.....	W. A. Powers.
Do	580	255	.....	90	54	775	31	91	16	.....	104	.....	1,416	.....	Do.
Do	620	260	.....	118	72	905	21	108	.....	.....	140	.....	1,624	1898	Do.
Do	755	312	.....	264	42	1,190	24	141	.....	.....	215	.....	2,189	1899	Do.
Ayer	252	638	.....	31	.....	756	133	295	.....	.....	48	.....	1,901	.....	Do.
Do	267	702	.....	35	.....	933	104	205	.....	.....	70	.....	2,140	.....	Do.
Do	311	182	.....	98	30	575	25	76	.....	.....	113	.....	1,098	.....	Do.
Do	340	135	.....	97	41	487	21	101	.....	.....	80	.....	963	.....	Do.
Bloom	240	89	.....	91	46	411	16	96	.....	.....	96	.....	845	1899	Do.
Do	358	109	.....	76	40	418	18	80	13	.....	419	.....	873	1899	Do.
Delhi	322	107	.....	166	50	666	14	85	.....	.....	112	.....	1,200	.....	Do.
Tyrone	580	213	.....	140	31	317	125	260	.....	.....	62	.....	1,148	.....	Do.
Pueblo (Farriss)	1,400	249	.....	60	30	526	25	139	16	16	.....	.....	1,061	.....	Von Schultz & Low, Pueblo.
(C. C. & I. Co.)	1,260	242	16	103	57	683	34	169	9.4	20	.....	.....	1,334	.....	H. L. Wells.
(Grand Hotel)	1,219	202	79	177	232	1,175	186	270	.....	71	.....	108	2,499	.....	A. A. Cunningham.
Salt Creek siding	1,545	2,515	.....	542	159	3,235	2,615	258	6	.....	.....	20	9,350	.....	Denver and Rio Grande R. R. Co.

(a) Present.

These constituents may be hypothetically combined as follows:

Analyses of waters from "Dakota" sandstone in southeastern Colorado.

[Expressed in hypothetical combinations and in grains per gallon.]

Locality	Depth.	Sodium sulphate.	Sodium chloride.	Sodium carbonate.	Potassium chloride.	Calcium sulphate.	Calcium carbonate.	Magnesium carbonate.	Magnesium sulphate.	Silica.	Iron and alumina.	Organic and volatile matters.	Other constituents.	Total.	Year.	Analyst.
	Feet.															
Granada (railroad)	580	11.50	2.72	10.48	.....	.....	7.08	1.22	.....	.....	.....	2.33	.....	35.33	1899	W. A. Powers.
Lamar (railroad)	226	59.87	3.20	.19	.....	2.11	4.52	5.43	.....	2.89	.....	.....	.....	78.21	.....	Do.
Do	500	73.84	5.17	13.33	.....	.....	13.98	7.95	.....	1.02	.....	4.20	.....	119.49	1897	Do.
Lamar (city well)	300	60.08	3.21	.....	.....	.....	6.07	4.26	1.69	2.92	.....	.....	.....	78.23	.....	Dearborn Drug Co.
Caddoa (railroad)	50	3.45	1.88	.....	.....	4.04	3.69	2.09	.....	.....	.....	3.45	.....	18.60	1899	W. A. Powers.
Do	280	75.21	3.04	.....	.....	4.39	17.53	23.17	.....	.....	.....	15.63	.....	138.97	1899	Do.
Las Animas (railroad)	340	38.09	1.78	21.15	.....	.....	2.08	1.47	.....	.....	.....	2.33	.....	66.90	1899	Do.
La Junta (railroad)	439	58.33	4.66	.64	0.70	.....	10.73	4.20	.....	.93	0.10	.....	0.01	80.30	1895	W. F. Hillebrand.
Railroad well	420	50.03	5.60	13.40	.....	.....	2.30	1.50	.....	1.20	.....	5.60	.....	79.63	1898	W. A. Powers.
Railroad well No. 2	420	45.00	2.30	12.50	.....	.....	.80	.90	.....	1.00	.....	2.30	.....	64.80	1898	Do.
Flouring mill	425	60.16	3.18	22.84	.....	.....	2.12	3.57	.....	.72	.43	2.16	.....	95.18	.....	Do.
Rocky Ford	700?	39.14	1.87	3.90	.76	.....	2.16	2.51	.....	.70	.35	.....	.35	[a] 51.74	1895	W. F. Hillebrand.
Timpas	554	102.08	6.73	2.53	.....	.....	12.24	7.96	.....	.99	.....	7.29	.....	[b] 139.82	.....	W. A. Powers.
Do	580	42.44	2.98	.....	.....	17.85	.....	7.48	5.06	.93	.....	6.10	.....	82.84	.....	Do.
Do	620	44.20	2.30	.....	.....	23.52	.....	8.89	8.11	.....	.....	8.16	.....	95.18	1898	Do.
Do	755	53.41	2.31	.....	.....	33.72	13.79	.....	12.13	.....	.....	12.59	.....	127.95	1899	Do.
Ayer	252	65.40	12.80	25.60	.....	.....	4.60	.....	.....	.....	.....	2.80	.....	111.20	.....	Do.
Do	267	80.80	10.00	25.20	.....	.....	5.10	.....	.....	.....	.....	4.10	.....	125.20	.....	Do.
Do	311	29.90	2.40	.....	.....	19.00	.30	6.00	.....	.....	.....	6.60	.....	64.20	.....	Do.
Do	340	22.00	2.00	.....	.....	19.30	.....	8.30	.....	.....	.....	4.70	.....	56.30	.....	Do.
Bloom	240	14.03	1.63	.....	.....	18.13	.....	7.87	2.22	.....	.....	5.60	.....	49.48	1899	Do.
Do	358	17.67	1.69	.....	.....	15.15	.....	6.59	2.27	.75	.....	6.99	.....	51.11	1899	Do.
Delhi	322	17.72	1.35	.....	.....	32.92	.....	6.97	4.69	.....	.....	6.53	.....	70.18	.....	Do.
Tyrone	580	23.68	12.07	.....	.....	3.59	17.84	6.37	.....	.....	.....	3.65	.....	67.20	.....	Do.
Florence (6 miles north)	1,230	.....	13.61	15.95	.....	26.71	11.37	18.97	.....	.....	.....	20.30	.....	106.90	1905	Wm. P. Hadden.
Pueblo (Fariss)	1,400	41.92	2.42	.....	.....	3.43	6.28	6.16	.....	.91	.91	.....	.....	62.03	.....	Von Schultz & Low, Pueblo.
(C. C. & I. Co)	1,260	41.43	1.82	.....	1.82	16.94	2.64	11.65	.....	.55	1.17	.....	.....	78.02	.....	H. L. Wells.
(Grand Hotel)	1,219	22.92	11.02	.....	8.81	.....	25.90	.35	66.67	.....	4.14	.....	6.30	[b] 146.11	.....	A. A. Cunningham.
Salt Creek siding	1,545	113.30	252.40	25.16	.....	107.60	.....	.....	45.99	.35	.....	.....	1.20	546.00	.....	Denver and Rio Grande R. R. Co.

[a] Including lithium chloride, 0.17; ammonium carbonate, 0.12; strontium carbonate, 0.06; and manganese carbonate, trace.

[b] Including lithium chloride, 6.3.

In the analysis of the water of the first well at La Junta it is reported that when the analysis was made the water had deposited a slight brown sediment containing iron, manganese, silica, and a trace of phosphoric acid, all of which, except the last, are included in the analysis. Free and semicombined carbonic acid (CO_2), 124.4 parts per milion; total CO_2, 250.2 parts per million. A trace of lithium was found.

When the water from the first artesian well at Rocky Ford was received in Washington it had deposited a sediment containing silica, iron oxide, a trace (?) of alumina, and phosphoric oxide. Traces of bromides (?), iodides, and phosphates were found in the water and some organic matter not determined. Boron, fluorine, and barium were absent. Free and semicombined carbonic acid (CO_2), 106.57 parts per million; total CO_2, 176.90 parts per million.

WATERS OF THE "RED BEDS" AND THE MORRISON FORMATION.

Under the greater part of southeastern Colorado the top of the "Red Beds" lies 100 to 300 feet below the base of the "Dakota" sandstone. In the region north of Arkansas River and east of Fountain Creek these "Red Beds" are too deep to be reached by ordinary well drilling, but along the river valley and southward they are at moderate depths. The deep borings at La Junta, Manzanola, Thatcher, Rouse Junction, Salt Creek, Caddoa, Fort Lyon, and Bloom penetrated more or less deeply into the "Red Beds," but obtained no satisfactory water supplies. At a few points in Kansas the "Red Beds" have been found to contain good water, but in most cases it is too highly mineralized to be of any use. Probably water-bearing strata will be found in the "Red Beds" in Colorado, but it is doubtful if any of them will yield useful supplies, and ordinarily a boring should be discontinued as soon as it enters the "Red Beds." The Morrison formation includes thin beds of sandstone which often contain water, but the amount so far found is too small to be of value. At Manzanola the "Red Beds" were penetrated from 1,653 to 2,110 feet and several water-bearing strata were found, but it is reported that the water was very impure. In the Bloom boring, the "Red Beds" extend from 455 to 1,162 feet and yielded some water of bad quality at 1,006 and 1,145 feet, of which analyses are given in the table below. At Rouse Junction the water found in the "Red Beds" at a depth of 1,760 feet was reported as "fresh," but it rose only about 200 feet. The following are analyses, made by W. A. Powers, for the Atchison, Topeka and Santa Fe Railway Company, of waters from the "Red Beds" at Bloom and from the Morrison formation at La Junta and Caddoa, at the depths stated:

Analyses of waters from "Red Beds" and Morrison formation in eastern Colorado.

[Parts per million.]

Constituent.	Bloom.		La Junta.		Caddoa.	
	1,006 feet.	1,145 feet.	663 feet.	757 feet.	440 feet.	560 feet.
Sodium, Na	2,131	846	323	270	586	753
Potassium, K						
Calcium, Ca	146	229	23	12	143	38
Magnesium, Mg	88	65	24	6.4	75	23
Sulphuric acid, SO_4	1,844	1,342	572	424	1,282	702
Chlorine, Cl	221	254	24	11	39	82
Carbonic acid, CO_3	1,871	553	136	109	329	587
Silica, SiO_2			56	17		
Iron oxide+aluminum oxide, $Fe_2O_3+Al_2O_3$						
Organic and volatile	255	138	66	58	199	136
Other constituents						
Total solids	6,556	3,427	1,224	907.4	2,653	2,321

Analyses of waters from "Red Beds" and Morrison formation in eastern Colorado.

[Expressed in hypothetical combinations and in grains per gallon.]

Constituent.	Bloom.		La Junta.		Caddoa.	
	1,006 feet.	1,145 feet.	663 feet.	757 feet.	440 feet.	560 feet.
Sodium sulphate	159.63	116.13	49.54	36.70	101.18	60.79
Sodium chloride	21.29	24.56	2.31	1.40	3.73	7.96
Sodium carbonate	148.36	4.92	4.40	7.70		48.72
Calcium sulphate					9.38	
Calcium carbonate	21.30	33.61	3.32	1.80	13.94	5.62
Magnesium sulphate						
Magnesium carbonate	17.85	13.20	4.90	1.30	15.31	4.77
Silica			3.26	1.00		
Iron and alumina						
Organic and volatile matters	14.93	8.08	3.85	3.40	11.66	7.93
Total solids	383.36	200.50	71.58	53.30	155.20	135.79

WATERS OF LARAMIE AND ASSOCIATED FORMATIONS.

The Fox Hills (Trinidad), Laramie, and overlying formations all contain water, but unfortunately these formations are so distributed that their water supplies are not likely to be very useful. The area extending from the Raton Mesa to the Spanish Peaks and beyond is a rough upland of high ridges and steep-sided valleys, and, moreover, the conditions are not favorable for flowing wells, except possibly in some of the deeper valleys. In the large synclinal area east of Colorado Springs well water is obtainable at various depths in the Laramie and associated beds, a few ranches drawing their supplies from this source. A deep well at Calhan, described on page 72, failed to obtain satisfactory water supplies in the Laramie formation, and there was a similar experience with a well at Monument.

In the Florence basin the Laramie formation lies at moderate depths and doubtless will prove to be water bearing. Some of the wells west of Florence obtained a moderate amount of water from this source, and in some of the coal mines there is sufficient water to be an obstacle to mining operations.

WATERS OF THE LATER TERTIARY DEPOSITS.

In the wide areas covered by later Tertiary deposits abundant water supplies are usually obtainable for pump wells. The deposits consist of various materials which absorb a large proportion of the rainfall. This water sinks low in the deposits, and usually the largest amounts are found in the basal portions lying on the Pierre and Niobrara shales. Where the contact of the shales and overlying sands is exposed there are usually springs, by which a portion of the water escapes to the surface.

Wells in the later Tertiary deposits vary in depth from 10 to 250 feet, the deepest ones being in the eastern portion of Cheyenne County. At Cheyenne Wells a large supply of excellent water is obtained at the base of the later Tertiary deposits at a depth of 257 feet. Ordinarily a large supply is found in these lower gravels, but it is well known among drillers that after the shale is reached it is useless to sink deeper.

WATERS IN THE DUNE SANDS.

Owing to their porous nature the dune sands absorb a large percentage of the water that falls upon them, and they usually lie in such manner as to intercept more or less of the surface run-off from the adjoining slopes. Accordingly they accumulate considerable water and afford excellent supplies for shallow wells throughout their area.

INDEX.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Professional Paper No. 52.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of the United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are allotted every Member of Congress, from whom they may be obtained, free of charge, on application.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at practically cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the eighty-ninth in Series B, and the fifty-fifth in Series O, the complete lists of which follow. (PP=Professional Paper, B=Bulletin, WS=Water-Supply Paper.)

SERIES B, DESCRIPTIVE GEOLOGY.

B 23. Observations on the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 124 pp., 17 pls. (Out of stock.)

B 33. Notes on geology of northern California, by J. S. Diller. 1886. 23 pp. (Out of stock.)

B 39. The upper beaches and deltas of Glacial Lake Agassiz, by Warren Upham. 1887. 84 pp., 1 pl. (Out of stock.)

B 40. Changes in river courses in Washington Territory due to glaciation, by Bailey Willis. 1887. 10 pp., 4 pls. (Out of stock.)

B 45. The present condition of knowledge of the geology of Texas, by R. T. Hill. 1887. 94 pp. (Out of stock.)

B 53. The geology of Nantucket, by N. S. Shaler. 1889. 55 pp., 10 pls. (Out of stock.)

B 57. A geological reconnaissance in southwestern Kansas, by Robert Hay. 1890. 49 pp., 2 pls.

B 58. The glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, by G. F. Wright, with introduction by T. C. Chamberlin. 1890. 112 pp., 8 pls. (Out of stock.)

B 67. The relations of the traps of the Newark system in the New Jersey region, by N. H. Darton. 1890. 82 pp. (Out of stock.)

B 104. Glaciation of the Yellowstone Valley north of the Park, by W. H. Weed. 1893. 41 pp., 4 pls.

B 108. A geological reconnaissance in central Washington, by I. C. Russell. 1893. 108 pp., 12 pls. (Out of stock.)

B 119. A geological reconnaissance in northwest Wyoming, by G. H. Eldridge. 1894. 72 pp., 4 pls.

B 137. The geology of the Fort Riley Military Reservation and vicinity, Kansas, by Robert Hay. 1896. 35 pp., 8 pls.

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Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

JULY, 1906.

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GEOLOGIC MAP OF THE ARKANSAS VALLEY IN SOUTHEASTERN COLORADO

BY

N. H. DARTON

1905

Scale

Contour interval 100 feet up to 8000 feet, above which it is 200 feet

Topography compiled from U. S. Geological Survey maps

Datum is mean sea level

Geology from maps by N. H. Darton, G. K. Gilbert, R. C. Hills, C. W. Cross, C. A. Fisher, and C. E. Siebenthal

LEGEND

Pliocene — Tn — Ogallala formation

TERTIARY (Oligocene?) — Tm — Monument Creek formation (?)

Eocene and CRETACEOUS — Kf — Laramie, Fox Hills, and associated formations

Kp — Pierre shale

Kn — Niobrara group (Timpas and Apishapa formations)

Kcl — Carlile formation

CRETACEOUS — Kgr — Graneros shale

Kd — Dakota sandstone

Km — Morrison formation

TRIASSIC and CARBONIFEROUS (Permian to Pennsylvanian) — Cf — Red Beds, Fountain and Lyons(?) formations

CARBONIFEROUS (Mississippian) — Mb — Mississippian stone

ORDOVICIAN AND CAMBRIAN — Fremont limestone, Harding sandstone, and Manitou limestone

PRE-CAMBRIAN — A — Granite, schists, etc.

Igneous rocks

PRELIMINARY MAP OF ARTESIAN CONDITIONS IN THE ARKANSAS VALLEY IN SOUTHEASTERN COLORADO.

BY

N H DARTON

1905

Scale

Datum is mean sea level

Contour interval 100 feet up to 8000 feet, above which it is 200 feet

Topography compiled from U.S. Geological Survey maps

EXPLANATION

Depths to "Dakota" sandstone

- 0 to 200 feet
- 200 to 400 "
- 400 to 600 "
- 600 to 800 "
- 800 to 1000 "
- 1000 to 1200 "
- 1200 to 1400 "
- 1400 to 1600 "
- 1600 to 1800 "
- 1800 to 2000 "
- 2000 to 2200 "
- 2200 to 2400 "
- 2400 to 2600 "
- more than 2600 "

Artesian waters occur in various beds of the "Dakota" and underlying sandstones, in all about 400 feet thick

Region of artesian flow. Doubtful areas as indicated by broken lines

"Dakota" and underlying sandstones at or near the surface

Area not underlain by "Dakota" sandstone

Flowing wells

Non-flowing wells

Figures in blue show depths of wells

EL PASO

PUEBLO

OTERO

LAS ANIMAS

BENT

PROWERS

KIOWA

BACA

CHEYENNE

KIT CARSON

HUERFANO

LINCOLN

ELBERT

COLORADO BOUNDARY LINE

NEW MEXICO BOUNDARY LINE

OKLAHOMA BOUNDARY LINE

ARKANSAS RIVER

SECTION 1

SECTION 2

SECTION 3

SECTION 4

2nd Correction Line South

3rd Correction Line South

4th Correction Line South

5th Correction Line South

6th Correction Line South

6th Guide Meridian West

7th Guide Meridian West