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THE GEOLOGY AND WATER RESOURCES OF THE WESTERN PORTION OF THE PANHANDLE OF TEXAS

BY

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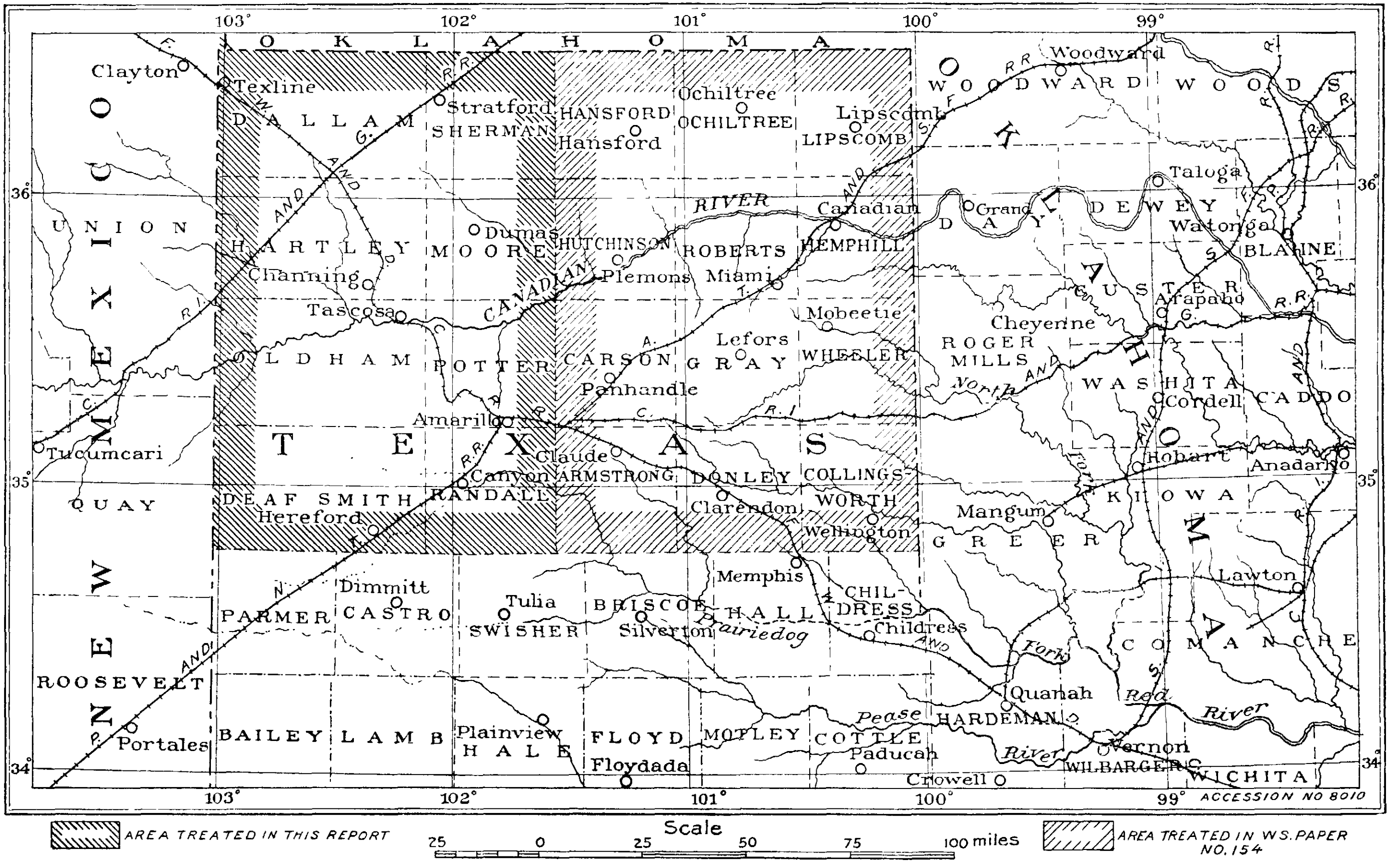
CONTENTS.

ILLUSTRATIONS.



LOCATION OF AREA DESCRIBED IN THIS REPORT.

GEOLOGY AND WATER RESOURCES OF THE WESTERN PORTION OF THE PANHANDLE OF TEXAS.

By Charles Newton Gould.

INTRODUCTION.

Area covered.—The area described in this report lies in the western part of the Panhandle of Texas and includes Sherman, Moore, Potter, Randall, Dallam, Hartley, Oldham, and Deaf Smith counties. The region is 120 miles long and 78 miles wide and contains approximately 9,360 square miles. It extends from 101° 35′ to 103° west longitude and from 34° 45′ to 36° 30′ north latitude, and is bounded on the north by Oklahoma and on the west by New Mexico. Its location is shown in Pl. I.

Sources of data.—During the summer of 1903 the writer, accompanied by several students from the University of Oklahoma, made a reconnaissance across the Panhandle of Texas, noting the general geologic and hydrographic features of the region. The greater part of the field work which forms the basis of this report was done, however, during the field season of 1905, with the assistance of Messrs. T. B. Matthews and E. F. Schramm. A detailed study was made of each of the above-mentioned counties, special attention being given to the valley of Canadian River and to Palo Duro Canyon. The work was done under the direction of Mr. N. H. Darton.

The well records, from which much of the information regarding the underground-water conditions was derived, were obtained partly in the field and partly by correspondence.

This report is a continuation of Water-Supply and Irrigation Paper No. 154, United States Geological Survey, which relates to the eastern part of the Panhandle.

TOPOGRAPHY.

GENERAL FEATURES.

The region described in this report is situated in the southern part of the Great Plains. It has a slope to the east of approximately 10 to 12 feet to the mile and a slight gradient to the south. The highest portion is in the extreme northwestern part of the State, where an elevation of nearly 4,800 feet is attained. The lowest points are in Palo Duro Canyon in eastern Randall County and in the valley of Canadian River in southern Moore County, both of which are approximately 2,800 feet above sea level. The greater part of the area lies at an altitude between 3,500 and 4,500 feet.

The topography of the region is essentially of two types—the High Plains province, which is nearly level, and the canyon district, the surface of which has been deeply eroded.

HIGH PLAINS.

With the exception of Canadian River and Palo Duro Canyon the region here discussed is typical of the High Plains province. To the portion of the plains south of Canadian River the term Llano Estacado, or "Staked Plains," is applied. It is bounded for the most part by a steep escarpment 100 to 400 feet high, separating it from the lower eroded plains which surround it on all sides. In the western part of the Panhandle, however, this steep escarpment is in many places much reduced or entirely absent, and the descent from the High Plains to the river valley is gradual. That portion of the High Plains lying north of Canadian River has no distinctive name. It does not differ materially, however, from the Llano Estacado, except that it is in but few places bounded by steep escarpments, but slopes gradually to the river valleys and the lower eroded plains to the east.

The deposits comprising the Great Plains are probably of river origin. According to the generally accepted theory, this area was formerly occupied by a network of meandering rivers which had their sources in the Rocky Mountains. These streams, being overloaded, were constantly depositing sediment, which filled the stream beds and forced the rivers into new channels. By this continued shifting irregular layers of sand were deposited upon the red beds, which constitute the basal formation of this region. This process was continued until a deposit several hundred feet thick was laid down over much of the region east of the Rocky Mountains.

The present streams are now eroding this level plain, but their work is generally not far advanced. In a few instances, however, they have cut their valleys through the superficial deposits into the underlying red beds, a feature well illustrated by Palo Duro Canyon and Canadian River. Along the edges of the High Plains small streams are cutting their way headward, but their progress is slow, owing to the meager precipitation of the region incident to the general aridity of the climate.

The surface of the High Plains is generally flat, with nothing to break the severe monotony. The drainage is for the most part wholly undeveloped. There is no run-off, and the rainfall either evaporates directly, sinks into the soil, or collects in buffalo wallows and broad, shallow depressions locally known as "playa lakes," from which it can escape only by seepage or evaporation. Here and there on this flat upland is a draw or incipient stream channel, in which after a heavy rain the water collects and runs off. If traced for any considerable distance these immature drainage ways will usually be found to end in a playa lake. Not uncommonly several of these lakes are connected by a shallow stream channel which wanders over the prairie, with a gradient so slight in many places that it is impossible to ascertain the downstream direction. In a number of cases, however, the shallow draws form the beginning of a creek which flows across the escarpment and eventually becomes a stream of some magnitude. On the High Plains north of Canadian River, Coldwater, Carriso, Perico, Big Blue, and Palo Duro creeks are all streams of this type, having their origin in conspicuous draws on the level plains. South of Canadian River Tierra Blanca and Palo Duro[a] creeks are also of this character.

Except for portions of Hartley, Moore, Oldham, Potter, and Randall counties, in which stream erosion has cut relatively deep valleys and canyons in the level surface, practically the entire region included in this report consists of high plains.

The area shown as Tertiary on the geologic map (Pl. III) comprises the greater part of the High Plains area.

VALLEYS AND CANYONS.

CANADIAN RIVER VALLEY.

The Panhandle of Texas is traversed through its central portion by the valley of Canadian River, which enters the State from New Mexico after draining a considerable area in the northeastern part of that Territory. It flows a little north of east across the Panhandle, entering Oklahoma near the middle of the east line of Hemphill County. It leaves the area described in this report near the southeast corner of Moore County. The distance traveled by the river within this area is 85 miles, in which it descends from an altitude of 3,400 to 2,800 feet, a gradient of about 7 feet per mile.

Throughout its course across the Panhandle the Canadian Valley has been excavated in the level plain which formerly extended uninterruptedly across the entire western Texas region. The depth of the valley averages about 600 feet, and its width varies from 20 to 35 miles. The slopes are deeply dissected by numerous tributaries, presenting many irregularities. The stream bed is in most places sand

[a]There are in the Panhandle of Texas two creeks named Palo Duro. One, in the northern part of the area, rises near the Sherman-Moore county line and flows northeastward, emptying into Beaver Creek, a tributary of North Canadian River. The other creek of the same name, which is in the southern part of the Panhandle, flows eastward into South Fork of Red River. It is the latter stream that has carved out the deep canyon described on p. 11.

choked and varies in width from 200 to 600 yards, while the flood plain ranges from a few rods to 3 miles.

The topography immediately adjacent to the stream is of two general types, depending on the character of the rocks. The valley has been cut through the upper Tertiary deposits into the red beds. The Tertiary formations consist generally of soft sands and clays, homogeneous in character, while the red beds are composed of alternating strata of hard and soft rocks. One member of the red beds, a hard, massive dolomite, resists erosion in a marked degree. This ledge of dolomite is in places exposed on the tops of bluffs 200 feet above the river, while in other places it is carried beneath the stream bed by a series of folds. Wherever exposed the dolomite caps conspicuous bluffs bordering the river for miles, and between these bluffs the stream flows in a narrow channel with an inconspicuous flood plain. Where this dolomite ledge is absent the flood plain may reach a width of 2 to 3 miles and is in many places covered with sand hills.

Numerous tributaries, few of which exceed 20 miles in length, enter Canadian River on each side. Each of these streams has carved a valley of greater or less width and depth in the sides of the main valley, the average gradient of these minor valleys being about 35 feet per mile. In the localities where dolomite is present these tributary streams have carved narrow canyons through this and the underlying formations, as in the case of Trujillo, Las Achias, Tecovas, West Amarillo, Big Canyon, Plum, Alibates, and Big Blue creeks. Where the dolomite is absent the side slopes of the minor valleys are more gentle.

PALO DURO CANYON.

Palo Duro Canyon is located in eastern Randall County, near the southeast corner of the region under discussion. Palo Duro Creek has its source in eastern New Mexico, near the western part of the Llano Estacado, as a dry, shallow draw, and continues thus eastward for 40 miles. In the western part of Randall County it has cut a valley averaging 50 feet in depth and a quarter of a mile in width. From this locality springs appear in increasing numbers as far as Canyon, where Palo Duro is joined by Tierra Blanca Creek. The junction of these two creeks, each of which carries approximately 15 second-feet of water, forms a stream of sufficient size to cause considerable erosion, particularly in soft rocks, such as the Tertiary and red-beds formations, and from Canyon eastward the valley deepens rapidly. In its upper course it is typically V-shaped and so continues for a number of miles until in its downward cutting the stream encounters a ledge of relatively hard sandstone in the upper part of the red beds, when corrosion is checked and the valley widens, becoming U-shaped. At the falls, 15 miles northeast of Canyon, the stream

A. TRIASSIC SANDSTONE ABOVE RED CLAY, SHOWING CHARACTERISTIC EROSION.

B. FALLS IN PALO DURO CANYON, CAUSED BY HARD LEDGE OF TRIASSIC SANDSTONE.

cuts through the sandstone, as shown in Pl. II, *B*, and from that point to the eastern side of Randall County it flows through a deep, narrow, V-shaped valley in relatively soft red beds.

In the eastern part of Randall County, Palo Duro Canyon is a picturesque gorge, 700 to 800 feet deep, eroded in the flat surface of the plains. From the rim of the canyon the slope is everywhere abrupt and in many places precipitous for a distance of several hundred feet. At the point where the canyon passes from Randall County the width of the valley at the bottom averages about a quarter of a mile, while the distance from rim rock to rim rock is not more than 1½ miles. Tributary to Palo Duro Canyon are a number of small creeks, the largest being Canyon Cita, Sunday, and Timber creeks, all of which have cut short but deep canyons into the High Plains. The sides of the main canyon, like those of the smaller streams, are cut into innumerable deep V-shaped gullies with sharp intervening ridges. The action of erosion on rocks composed of alternating layers of hard and soft strata has produced an infinite number of the conspicuous and in many cases unique forms characteristic of badlands topography. Some of these forms are shown in Pl. II, *A*. The alternation of varicolored shales, brown sandstone, and green vegetation, mingled with the unique erosional forms, gives to the canyon a degree of picturesqueness not often found on the plains.

MINOR STREAM VALLEYS.

With the exception of the Canadian River valley and Palo Duro Canyon there are no large valleys in the region. In certain places, however, the monotonous level of the High Plains is interrupted by shallow valleys, which extend across it, as a rule, in an easterly direction. These valleys are for the most part nothing but dry, meandering channels a few feet deep, which have been eroded in the level upland. They are known locally as "draws" or "arroyos." Brief descriptions are here given of the more important, in order, from north to south.

Beaver Creek valley.—Beaver Creek, which flows eastward across Beaver County, Okla., for nearly its entire course, bends to the south near the Dallam-Sherman county line and flows for 15 miles or more across the northern part of Sherman County. It is here a dry stream with a sandy bottom in a valley averaging 50 feet in depth and a quarter of a mile in width.

Coldwater Creek valley.—Coldwater Creek is one of the southern tributaries of Beaver Creek, in Beaver County, Okla. In its upper course the stream is sometimes called Rabbit Ear Creek, from the fact that it rises near the Rabbit Ear Mountains, two volcanic peaks in northeastern New Mexico. It flows southeastward across Dallam and Sherman counties in a valley averaging a quarter of a mile in width and 50 feet in depth, becoming wider and deeper to the east. Except in the vicinity of Buffalo and Agua Fria springs, in Dallam County, Coldwater Creek carries only flood water.

Palo Duro Creek valley.—This stream (which must not be confused with Palo Duro Creek, farther south) is also a tributary of Beaver Creek. It rises on the High Plains north of Canadian River and flows for a short distance through southern Sherman and northern Moore counties. The channel is shallow, not averaging more than 25 feet in depth, and is dry for the greater part of the year.

Carriso and Perico Creek valleys.—These are shallow channels, each of which enters Texas from New Mexico and follows a tortuous course among sand dunes southeastward across the western part of Dallam County. The two streams unite just west of Dalhart, forming Rita Blanca Creek, which flows southward entirely across Hartley County and into Oldham County before joining Canadian River. Normally both Carriso and Perico creeks are dry sand beds, 20 to 50 feet deep and 100 to 500 yards wide.

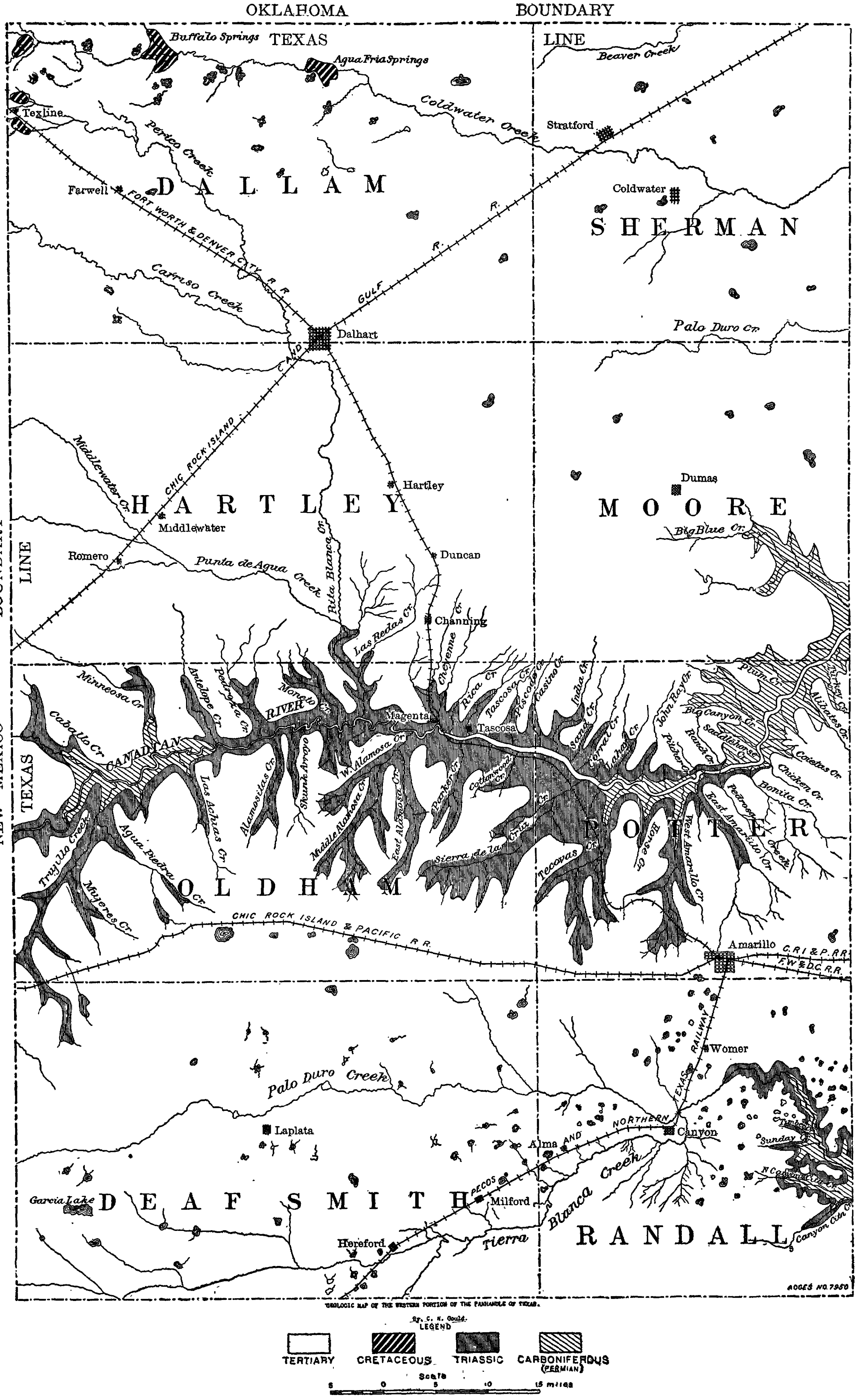
Big Blue Creek valley.—Big Blue Creek rises in Moore County and flows southeastward into the Canadian. In its upper course it is merely a dry sand bed, but it gradually deepens its valley until in the southeastern part of the county it flows in a canyon 400 feet deep, which it has cut through the superficial Tertiary deposits and into the red beds. In its middle and lower portions it carries a considerable amount of water, derived from springs in Tertiary and red-beds rocks.

Tierra Blanca Creek valley.—Tierra Blanca Creek rises on the Llano Estacado south of Canadian River in eastern New Mexico, flows eastward across Deaf Smith County, Tex., and unites with Palo Duro Creek at Canyon. In its upper course it is only a "draw" in the flat prairie. Near Hereford, the county seat of Deaf Smith County, springs begin to appear, and from that point to Canyon the valley averages 75 feet in depth and half a mile in width. Along the sides of the valley are white cliffs of Tertiary clay.

GEOLOGY.

GENERAL STATEMENTS.

The rocks of the region are all of sedimentary origin and belong to the following geologic systems: Carboniferous (Permian), Triassic, Cretaceous, Tertiary, and Quaternary. The areal distribution of these formations is shown by the geologic map (Pl. III) and their structural relations by cross sections (Pl. IV). All the rocks lie comparatively level or have slight but regular dips to the east.



GEOLOGIC MAP OF THE WESTERN PART OF THE PANHANDLE OF TEXAS.

The order and age of the formations are shown in the following table:

Geologic formations of the Texas Panhandle.

System.	Formation.	Characteristics.
Quaternary	Alluvium	Sand, clay, and loam.
	Sand dunes	Wind-blown sand.
	Equus beds	Sand and clay.
Tertiary	Undifferentiated	Sand, clay, and gravel, loosely consolidated.
Cretaceous	Dakota (?)	Brown to yellow soft sandstone and clay.
Triassic	Dockum group. Trujillo	Red shales. Red to gray sandstone and conglomerate (upper sandstone). Red shales. Red to gray cross-bedded sandstone and conglomerate (middle sandstone). Red shales. Massive to cross-bedded sandstone (lower sandstone).
	Dockum group. Tecovas	Dark-red or magenta shales and soft sandstones. Variegated shales and soft sandstones.
Carboniferous (Permian)	Quartermaster	Red clay. Massive white dolomite (Alibates lentil). Red clays. Massive white gypsum (Saddlehorse lentil). Red shales.
	Greer	Massive white gypsum in ledges interstratified with red shales.

By far the greater part of these rocks are of Permian, Triassic, or Tertiary age. The Permian and Triassic rocks are generally spoken of as red beds, owing to the predominating color of the clay which forms a large proportion of these deposits.

Farther east in Texas and particularly in Oklahoma the Permian red beds are well exposed and have been divided into five formations,[a] the Enid, Blaine, Woodward, Greer, and Quartermaster. In the region here described only the two upper formations of the Permian red beds occur, and these are found in the deep canyons, where erosion has cut through the overlying Triassic and Tertiary formations. The Triassic red beds are exposed along the edge of the Llano Estacado in Texas and New Mexico, as well as in the canyons cut by the various streams that rise in the southern part of the High Plains. Cretaceous rocks are found in but a few small areas in the extreme northwestern part of the region. Tertiary deposits, which make up the greater part of the rocks of the High Plains, are exposed along the escarpments at the edge of the plains, in the shallow valleys, and near the tops of the deep canyons which traverse them. Quaternary rocks, consisting mainly of dune sand and alluvium, form the superficial deposits in parts of the region and are now being shaped by wind, water, and other agents of erosion.

[a] For a discussion of the correlation of the Kansas, Oklahoma, and Texas Permian see Water-Sup. and Irr. Paper No. 148, U. S. Geol. Survey, 1905, pp. 34-39; and No. 154, 1906, pp. 15-23.

PERMIAN.

GREER FORMATION.

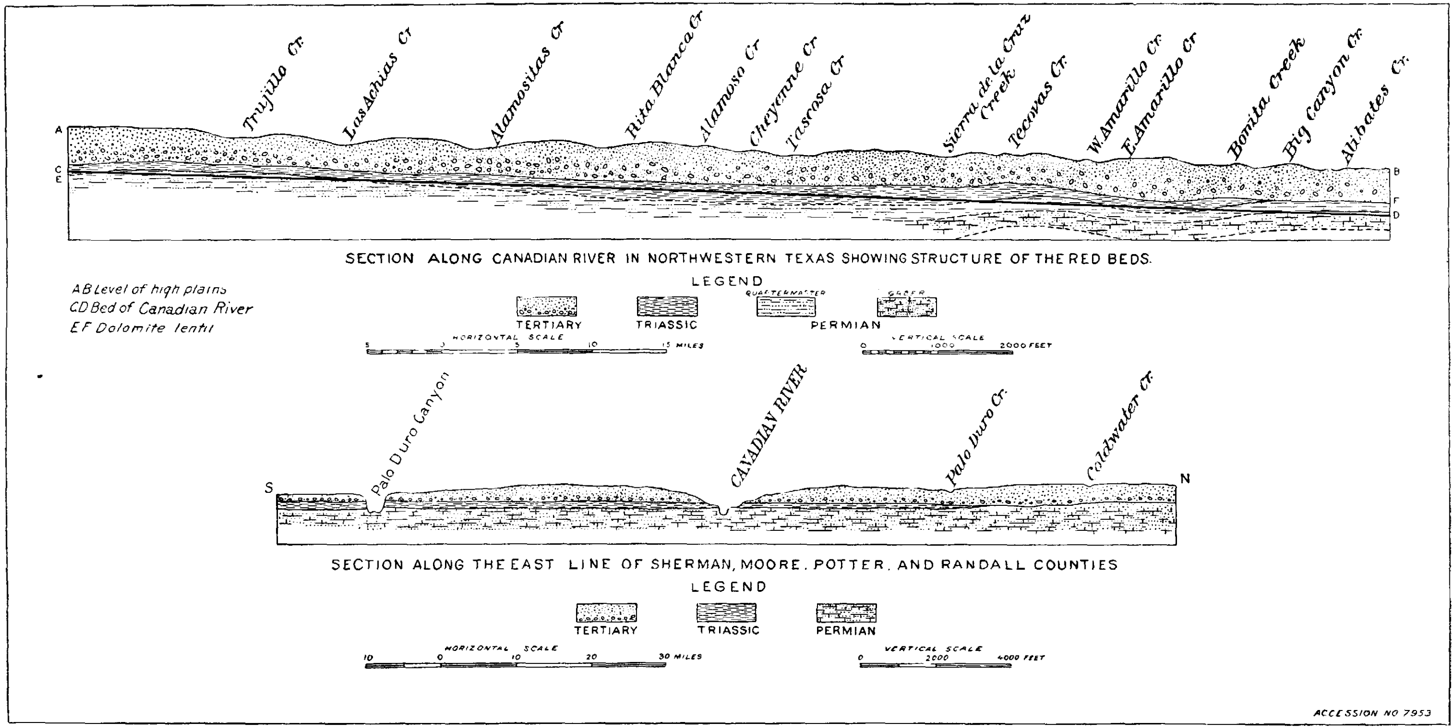
The Greer formation, as exposed in the western part of the Panhandle of Texas, consists of red-clay shale interstratified with one or more ledges of hard massive gypsum, which is white, as a rule, but here and there exhibits pinkish or bluish tints. The greatest thickness of the gypsum observed in the district is 20 feet. It is exposed in the lower portion of Canadian and Palo Duro valleys.

Along Palo Duro Canyon, in the extreme eastern part of Randall County, the Greer gypsum is exposed in the bottom and along the sides of a few small gullies which empty into Canyon Cita Creek half a mile above its junction with Palo Duro Creek. A short distance east of the Randall-Armstrong county line, however, the gypsum becomes more conspicuous along the bottom of the canyon and forms heavy ledges, one of which, 3 miles from the county line, is shown in Pl. V, *B*. About 12 miles farther east the gypsum outcrops as a persistent ledge 20 to 50 feet thick 100 feet or more above the bed of the river, forming the cap of an intercanyon escarpment which extends for more than 50 miles along the stream.

In the valley of Canadian River, in northeastern Potter and southeastern Moore counties, the gypsum beds of the Greer formation outcrop on both sides of the river, as well as along several tributary streams, particularly in the lower valleys of Alibates, Turkey, Plum, Saddlehorse, and Big Canyon creeks. It is most commonly seen capping rounded mounds or small flat-topped buttes standing out in the level valley or as extensive flat areas of soft gray or white gypsite or earth gypsum. The gypsum also occurs locally in this region as a heavy white, pinkish, or bluish ledge 10 to 15 feet thick, exposed along the small ravines which empty into the larger creeks or on the slopes of some of the higher hills. The thickness of the ledges is not constant, for here, as elsewhere, the lenticular nature of the various members of the red beds is well illustrated. If traced for a few hundred yards a 15-foot ledge of gypsum which outcrops along the side of a hill may be found to thin out noticeably or even to disappear entirely, its place being taken by sandstone or shale.

The beds are in many places tilted at various angles, which gives them the appearance of having been folded or thrown into a series of waves. This phenomenon, which is much more pronounced farther east than it is in this region, has usually been explained on the hypothesis of subterranean erosion of the soft shales and gypsum rather than that of regular folding.[a] As is shown later, however (see pp. 18–21), there is in the red beds of this part of the Panhandle

[a] See Water-Sup. and Irr. Paper No. 154, U. S. Geol. Survey, 1906, p. 20.



GEOLOGIC SECTIONS ACROSS AREA TREATED IN THIS REPORT.

a well-marked series of anticlinal and synclinal folds, though it is not known that these had any influence on the relatively small and erratic folds and dips of the Greer formation.

QUARTERMASTER FORMATION.

General description.—The Quartermaster formation, which rests conformably upon the Greer, consists for the most part of soft red sandstones and red sandy clays and shales. In Oklahoma, where it is typically exposed, sandstone predominates to such a degree that the formation was originally designated the Quartermaster sandstone, but in the western part of the Panhandle red shales and clay make up the major portion of the beds, although soft red sandstones are by no means rare. In western Oklahoma and along the eastern escarpment of the Llano Estacado, in the eastern part of the Panhandle, the thickness of the Quartermaster formation varies from 200 to 300 feet, but farther west it is not so thick, averaging perhaps 150 feet, with a known maximum of 240 feet.

The red shales of the lower part of the Quartermaster formation, just above the top of the Greer gypsum, contain a considerable amount of gypsum, most of which is in the form of bands of white or pinkish satin spar. Locally these bands lie parallel to the bedding, but in many places they are arranged in an irregular crisscross manner throughout the shale. At higher horizons there are certain lentils, composed of massive gypsum and dolomite, which are restricted to definite localities. These are described later. (See pp. 16–18.)

The greater part of the Quartermaster formation in the western Panhandle region consists of alternating beds of brick-red, more or less sandy clay and scattered ledges of soft red clayey sandstone. So similar in appearance are the shales and sandstones, however, that it is frequently difficult in the field to separate one sharply from the other. Being soft, both the shales and sandstones are susceptible to weathering and where exposed form typical badlands topography. Owing to the homogeneity of the material of which they are composed, the erosion figures produced are usually more or less conical or pyramidal in form. Many of them are large, reaching 100 feet in height, as shown in Pl. V, *A*.

The Quartermaster formation has many local and erratic dips and folds, which give to the rocks a peculiar wavelike structure, very noticeable along the sides of cliffs in certain localities. As a rule the dipping does not seem to be caused by ordinary folding, but, as in the case of the rocks of the Greer formation, by subterranean erosion, which has carried away the soft shales and soluble gypsums beneath and permitted the upper members to sink to lower levels.

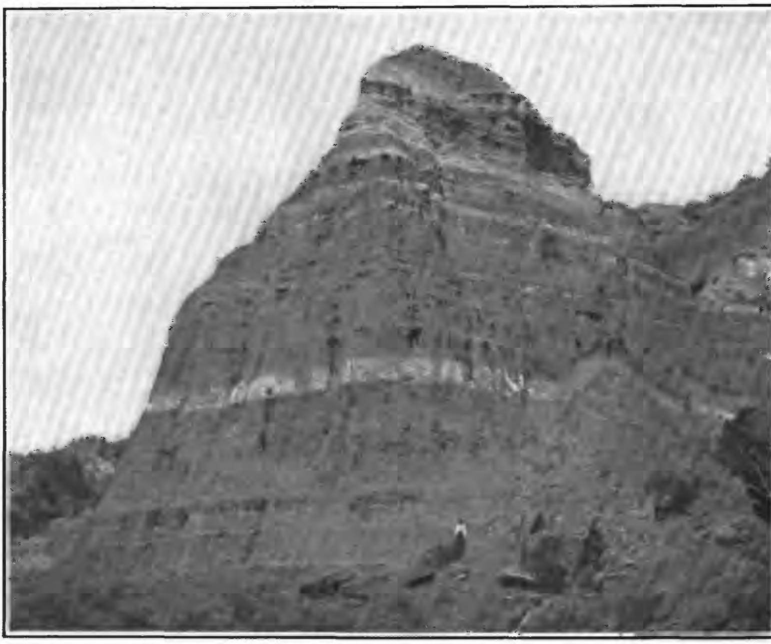
In Palo Duro Canyon, in eastern Randall County, the Quartermaster formation is well exposed both along the main canyon and on various tributary streams, particularly Canyon Cita, Sunday, and Timber creeks. With the exception of a few inconspicuous outcrops of the Greer gypsum it is the lowest formation exposed in the canyon and may be traced for 10 miles or more above the point where Palo Duro Creek leaves the county. Along the edge of the canyon the vivid brick-red shales which constitute the Quartermaster are easily distinguished from the somewhat less brilliant maroon, yellow, magenta, and light-colored shales of the Triassic red beds and Tertiary deposits higher in the canyon wall.

The Quartermaster formation is also well exposed in the valley of Canadian River, where it is characterized by two marked peculiarities not noticeable in Palo Duro Canyon. First, the Quartermaster formation and also the overlying Triassic rocks have been folded into broad, shallow anticlines and synclines (see Pl. IV, p. 14), which are recognized only when the structure is studied in a broad way;[a] and, second, the formation here contains two members (classed as lentils), one of gypsum and one of dolomite, which so far as known do not appear elsewhere in Texas or Oklahoma.

Saddlehorse gypsum lentil.—In the valley of Canadian River, at 60 to 80 feet above the base of the Quartermaster formation, there occurs a ledge or ledges of massive white gypsum interstratified with the red shales. In some places the gypsum is a single ledge 4 feet or more thick; in others there are two ledges respectively 2 and 3 feet thick, separated by red clay; and here and there even three separate ledges are observed. The total thickness of the gypsiferous beds, however, rarely exceeds 10 feet.

This gypsum, known as the Saddlehorse lentil, from one of the creeks on which it typically occurs, is exposed along the bluffs of various creeks tributary to the Canadian, particularly on Big Canyon, Plum, Alibates, Saddlehorse, and Turkey creeks in eastern Potter County, and on Dixon and Antelope creeks in Carson County. Farther west, on West Amarillo, Horse, and Tecovas creeks and along the bluffs of Canadian River, the gypsum appears in the lower part of the bluffs, as shown in Pl. VI, *B*. In the extreme western part of the State, near the mouth of Trujillo Creek and along the bluffs bordering the Canadian both above and below this point, the gypsum also occurs in two ledges, each 3 feet thick. The Saddlehorse lentil is not exposed between Las Achias and Tecovas creeks, a distance of 35 miles, but, as will be explained later, there is in this region a synclinal fold in the red beds which carries all the Permian rocks beneath the surface. The gypsum lentil is not known to occur in Palo Duro Canyon nor at points in western Oklahoma and in the eastern part of the Pan-

[a] See pp. 18-21 for a further discussion of this subject.



A. EROSION OF THE QUARTERMASTER FORMATION IN PALO DURO CANYON.

B. TYPICAL VIEW OF GREER GYPSUM IN PALO DURO CANYON.

handle of Texas, where the Quartermaster formation is typically exposed.

Alibates dolomite lentil.—In the upper part of the Quartermaster formation, wherever it is exposed along Canadian River, there occurs a very persistent ledge of dolomite. It is white, massive, and more or less flinty, and exhibits definite lines of lamination which have a wavy, plicated structure. This dolomite, which is designated the Alibates lentil, from Alibates Creek, where it is well exposed, is the hardest rock exposed in the region, and for that reason resists erosion and forms the cap rock of conspicuous bluffs and cliffs along Canadian River and many of its tributaries. The rock is cut by a regular series of master joints and on weathering breaks into rectangular blocks which lodge on the slopes below. Usually there are two distinct dolomite ledges, the lower being 8 feet and the upper 2 feet thick. They are separated by 4 feet or more of red clay, so that the combined thickness of the dolomite and interbedded clay is approximately 15 feet.

This dolomite is considered a lentil from the fact that so far as known it does not occur elsewhere in the Quartermaster formation. There is a ledge of white dolomite in the Quartermaster on Salt Fork of Red River 3 miles north of Clarendon, Tex., and another on South Fork of Red River about 10 miles southwest of Clarendon, but neither of these is known to occur at the same horizon as the Alibates.

In its general structure the Alibates dolomite resembles very closely the Day Creek dolomite, which constitutes the upper member of the Woodward formation of the Permian red beds in Kansas and Oklahoma. Like the Day Creek it is white, hard, massive, and laminated, consisting usually of two ledges separated by red clay and forming the cap of conspicuous bluffs and numerous small canyon walls in the region where it outcrops.

In some places the appearance of the dolomite differs slightly from the normal. A noteworthy example is near the mouth of Trujillo Creek east of the New Mexico line, where it is a light-brown or yellowish-gray rock. In structure it exhibits peculiar wavy laminations and characteristic block fracture, but as seen in the ledge or in fresh fracture it resembles a hard, fine-grained quartzite. Chemical analysis, however, shows that calcium and magnesium carbonate are present with only a small percentage of silica. In the Trujillo locality the dolomite contains a larger amount of flint, occurring in the form of elongated concretions, than is common in most places. Flint is also present in considerable quantities in the upper ledge of the Alibates along Big Canyon Creek in northern Potter County, where fragments strew the ground along the divides between various branches of the creek. Here and there in this vicinity the dolomite outcrops on the surface, revealing the fact that the entire ledge has here become agatized. It exhibits a most beautiful combination of colors, chiefly red, blue, and white. Rejects and chipped flakes scattered on the surface indicate that the Indians have used the flint in the manufacture of arrow points and other implements.

The fact has been mentioned that an anticline-syncline structure is exhibited along the valley of Canadian River. As the Alibates dolomite is the hardest rock found anywhere along this valley it serves as a convenient horizon of reference, and by means of it the system of folds may be traced in most places with comparative accuracy. For this reason mainly the structure and exposures of the dolomite will be discussed at the same time. Along Canadian River the dip of most of the formations is about the same as the slope of the plains or of the stream bed, being approximately 10 feet to the mile toward the east. This is shown by the fact that the Alibates dolomite is found at nearly the same height above the river in eastern Moore and Hutchinson counties as it is near the New Mexico line 80 to 100 miles farther west. Pl. IV (p. 14) illustrates the structure of the beds.

The easternmost exposure observed of the Alibates dolomite lentil is on the bluffs north of Canadian River east of Plemons, the county seat of Hutchinson County. It forms the cap of conspicuous bluffs along the river and several of its tributaries, notably Kit Carson, Dixon, and Antelope creeks, in Hutchinson and Carson counties. In southeastern Moore and northeastern Potter counties it is on the bluffs along a number of creeks, the chief of which are Big Blue, Plum, Big Canyon, Saddlehorse, Turkey, and Alibates. In this region the height of the ledge above the river varies from 180 to 250 feet. In this region also the Greer gypsum is exposed along the Canadian and the various minor streams as mounds in the valleys or as ledges near the stream level. The vertical distance between the Greer gypsum and the Alibates dolomite varies locally from 180 to 200 feet, the maximum observed interval being on the Leaverton ranch, near the Moore-Potter county line. The following sections illustrate the structure of the Quartermaster formation in this region:

Section of Quartermaster and Greer formations on Big Canyon Creek, northern Potter County, Tex.

System.	Formation.	Member.	Character.	Thickness.
				Feet.
Carboniferous (Permian.)	Quartermaster	Alibates lentil.	Flinty dolomite capping bluffs	3
			Red shale	4
			Massive white dolomite	8
			Red shale with white bands and ledges of soft sandstone.	60
		Saddlehorse lentil.	White gypsum, locally exposed as one ledge 4 feet thick or as two ledges 2 and 3 feet thick separated by shale.	4-10
			Red shale and sandstone with selenite bands in the lower part.	80
	Greer		Massive gypsum, exposed in ledges, in many places capping low mounds in creek bottom.	15
			Red shales	40

Section of the Tertiary and of the Quartermaster and Greer formations on the bluffs north of Canadian River at Leaverton ranch, southeastern Moore County, Tex.

System.	Formation.	Member.	Character.	Thickness.
				Feet.
Tertiary			Clays and sands exposed in cliffs	150
Unconformity.				
Carboniferous (Permian.)	Quartermaster		Red shale on slope	60
		Alibates lentil.	White massive dolomite forming cap of bluff.	10
			Red shale	50
		Saddlehorse lentil.	White gypsum	4
			Red shale	8
			Blue shale	6
			Red shale and soft red sandstone with satin spar in lower part.	140
	Greer		Massive white gypsum in ledges	10-20
			Red shale	25

Near the mouth of Bonita Creek the dolomite ledge is carried downward under the bed of the river along a synclinal fold, and the upper sandstone and clay members of the Triassic red beds are brought to a lower level, where they form more or less conspicuous bluffs on both sides of the river for several miles. In the vicinity of Ranch and Pedrosa creeks the bluffs are formed by a heavy ledge of sandstone, the lowermost of three heavy sandstone members of the upper formation of the Triassic. The ledge is here approximately 75 feet higher, geologically, than the Alibates dolomite. Near the mouths of Pitcher and East Amarillo creeks the dolomite again appears on the surface along the western limb of the syncline and is exposed along an anticline which extends westward for a distance of about 10 miles up the river. In this locality both the river and its tributary creeks, West Amarillo, Horse, and Tecovas, have cut steep-sided canyons through the dolomite and into the underlying red clays. The height of the Alibates above the river here reaches a maximum of 125 feet on Horse and Tecovas creeks, but is usually considerably less. Pl. VI, *B* shows the dolomite capping a bluff. The stratigraphy of the formations on Tecovas Creek is illustrated in the following section:

Section of Tecovas and Quartermaster formations, 3 miles above mouth of Tecovas Creek, northern Potter county, Tex.

System.	Formation.	Member.	Character.	Thickness.
				Feet.
Triassic	Tecovas		White, lavender, and gray shales with layers of white and gray sandstone.	20
Unconformity.				
Carboniferous (Permian.)	Quartermaster		Brick-red shale with ledges of soft sandstone.	30
		Alibates lentil	White dolomite	2
			Red shales	5
			Massive white dolomite	8
			Red shales with white bands	55
		Saddlehorse lentil.	Massive gypsum, usually in three ledges, 3, 2, and 2 feet thick, separated by red shales.	12
			Red shales and soft sandstones from level of creek.	60

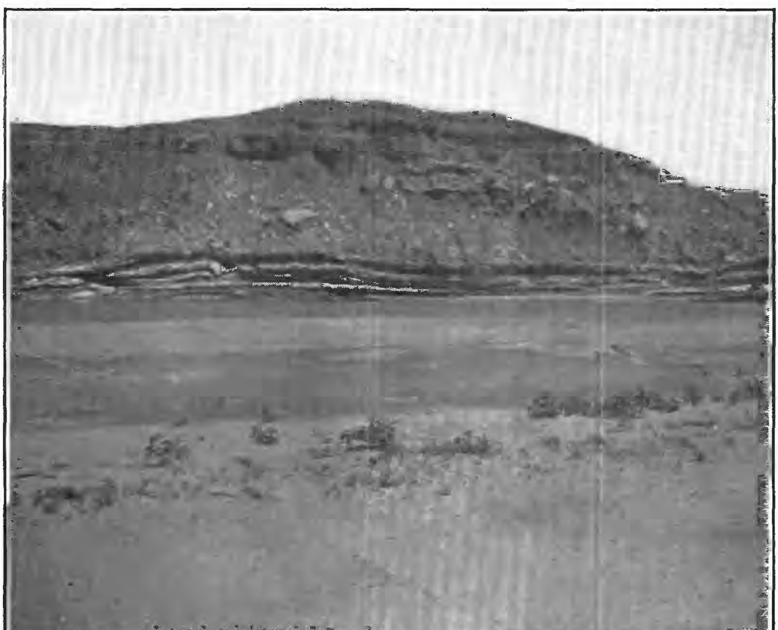
A short distance east of the mouth of Sierra de la Cruz Creek the dolomite ledge is again carried down along a synclinal fold, and for 35 miles only the higher members of the Permian and Triassic red beds are exposed along the Canadian and its tributaries. The Alibates dolomite appears at the surface only at one locality—on Sierra de la Cruz Creek, 3½ miles from its mouth. In this instance it is exposed in the bed of the creek in the form of a truncated dome or uplift, as described in the following section:

Section 3½ miles above mouth of Sierra de la Cruz Creek, northern Potter County, Tex.

System.	Formation.	Character.	Thickness.
			Feet.
Tertiary		Clays, sands, and pebbles forming cap of hills	100
Unconformity.			
Triassic	Dockum group. Trujillo	Massive sandstone forming buttes and tops of mesas (middle sandstone).	20
		Red and gray shales	30
		Massive sandstone and conglomerate forming a conspicuous ledge (lower sandstone).	25
	Dockum group. Tecovas	Dark-red shales with white bands in the upper part	65
		Variegated shales, maroon, yellow, and red, grading down into soft gray and yellow cross-bedded sandstone.	60
Unconformity.			
Carboniferous (Permian).	Quartermaster	Red shale with white bands	50
		White massive dolomite appearing at one place only, along the top of a truncated dome (Alibates lentil).	6

With this exception, the Alibates dolomite lentil is not exposed in this stretch of 35 miles, so far as known, either along Canadian River or on any of its largest tributaries, such as Parker, Lahay, Corral, John Ray, Tascosa, Cheyenne, Alamosa, Rita Blanca, and Alamositas creeks. Near the mouth of Las Achias Creek, however, the dolomite again makes its appearance along the western limb of a syncline and forms conspicuous bluffs for a distance of 20 miles or more, nearly to the New Mexico line. At the mouth of Trujillo Creek, where the bluffs

A. DAKOTA SANDSTONE HILL.



B. BLUFFS ON CANADIAN RIVER, POTTER COUNTY, TEX.

Showing gypsum lentil at base and dolomite lentil at top of bluffs.

reach their maximum development, the top of the dolomite is 120 feet above the bed of Canadian River.

It will be understood from the preceding statements that the various formations along the Canadian are exposed in a series of anticlines and synclines, the axes of which are approximately at right angles to the course of the river, and that there are in all three anticlines with two intermediate synclines. These conditions are illustrated in Pl. IV (p. 14), which represents a profile of the Canadian in the region to which this report relates and shows the location of the various anticlines and synclines with reference to the mouths of the larger tributaries of that river.

That the rocks of the Quartermaster formation are of Permian age has been demonstrated by the presence of fossils identified by Doctor Beede as Permian species. They were obtained near Dozier, farther east in the Panhandle, from a sandstone which occurs at approximately the same horizon as the Saddlehorse gypsum.[a]

TRIASSIC.

GENERAL RELATIONS.

The group of rocks of Triassic age which outcrops along the eastern edge of the Llano Estacado was first described in 1889 by Cummins,[b] under the name Dockum beds. The most comprehensive paper, however, which has been published on the Texas Triassic is by Drake,[c] who describes three more or less definite beds as follows: "A lower bed of sandy clay which is from 0 to 150 feet thick, a central bed or beds of sandstone conglomerate and some sandy clay which is from 0 to 235 feet thick, and an upper bed of sandy clay and some sandstone which is from 0 to 300 feet thick."

Vertebrate[d] fossils from these beds are of Triassic types, while the invertebrates[e] belong to a genus known elsewhere only from more recent rocks, so that the age determination rests chiefly on the vertebrates.

There is a continuous unconformity at the top of the Quartermaster formation which everywhere separates it from the overlying Dockum beds. The upper limit of the Quartermaster, however, is in most places rather regular, and there is but little evidence that any considerable erosion took place previous to the deposition of the Triassic sediments. The red shales which form the upper part of the Quartermaster formation above the Alibates dolomite lentil are relatively

[a] See Water-Sup. and Irr. Paper No. 154, U S. Geol. Survey, 1906, p. 23.

[b] Cummins, F. W., First Ann Rept. Texas Geol. Survey, 1889, pp 189-190.

[c] Drake, N. F., Third Ann. Rept. Texas Geol. Survey, 1891, pp. 225-235

[d] Cope, E. D , Report on the paleontology of the Vertebrata—Triassic or Dockum beds: Third Ann. Rept. Texas Geol. Survey, 1892, pp 257-259.

[e] Simpson, C. T., Description of four new Triassic unios from the Staked Plains of Texas: Proc. U. S. Nat. Mus., vol. 18, No. 1072, 1896, pp. 381-385.

uniform in thickness throughout the region, and in only one locality, so far as observed, have they been entirely removed, so that the Triassic beds rest directly upon the dolomite. This locality is in the western part of the Panhandle, at the mouth of Trujillo Creek, and even here 10 feet or more of the red shales of the upper Quartermaster are locally present.

The Triassic red beds as exposed in the western part of the Panhandle of Texas consist of 150 to 300 feet of shales with interbedded ledges of sandstone and conglomerate. The beds as a whole may be referred to two well-differentiated formations.

At the base of the group are shales known as the Tecovas formation, while at the top are beds composed usually of three ledges of massive, more or less cross-bedded sandstone and conglomerate separated by red shales to which the name Trujillo has been applied. In the following discussion these sandstone ledges will be referred to as the lower, middle, and upper sandstones. The following sections, one on North Branch of North Canyon Cita Creek, a tributary of Palo Duro Creek, and the other on West Amarillo Creek, show the stratigraphy of the Triassic and associated formations.

Geologic section on North Branch of North Canyon Cita Creek, eastern Randall County, Tex.

System.	Formation.	Character.	Thickness.
			Feet.
Tertiary		Sand and clay	70
Unconformity.			
Triassic	Dockum group. Trujillo	Gray sandstone and conglomerate, cross-bedded, with fossil bones and plates (upper sandstone).	30
		Red and gray shales	35
		Gray cross-bedded sandstone and conglomerate, with fossil bones and plates (middle sandstone).	10
		Red shale with white bands of soft sandstone	60
		Massive, cross-bedded sandstone, gray to brown, with shaly members, and conglomerate, locally three well-marked ledges with shale lentils between (lower sandstone.)	75
	Dockum group. Tecovas	Dark-red shale with white bands	140
		Yellow shales with iron concretions	20
		Maroon shales with iron concretions	20
		White to lavender shales	10
Unconformity.			
Carboniferous (Permian).	Quartermaster	Red shales with white bands and ledges of soft sandstone.	150

Generalized section on West Amarillo Creek, Potter County, Tex.

System.	Formation.	Member.	Character.	Thickness.
				Feet.
Tertiary			Sand and clay	150
Unconformity.				
Triassic	Dockum group. Trujillo		Red clay	30
			Massive sandstone (middle sandstone)	15
			Red shale with thin sandstone ledges	20
			Red or gray massive sandstone and conglomerate, with shale bands (lower sandstone).	25
	Dockum group. Tecovas		Dark-red shales with bands of white and green, near the base some sandstone bands.	50
			Red and yellow shales	15
			Maroon and lavender shales	15
Unconformity.				
Carboniferous. (Permian).	Quartermaster		Brick-red shales with sandstone ledges	40
		Alibates dolomite lentil.	White dolomite	2
			Red shale	6
			Massive dolomite	8
			Brick-red shales with white and green bands.	+40

TECOVAS FORMATION.

The Tecovas, the basal formation of the Triassic red beds, as exposed in this part of the State, consists largely of shales. It is divided lithologically into two parts, distinguished by the texture and color of the rocks. Of these the lower is composed of more or less sandy shale of various colors, with maroon, lavender, yellow, and white predominating, and the upper of dark-red or magenta shale. In the following pages these will be referred to as the variegated and magenta shales.

The Tecovas formation, so designated from a creek in Potter County where the rocks are well exposed, rests unconformably upon the Quartermaster beds of the Permian. Its thickness varies in different localities, being 220 feet in Palo Duro Canyon and only 90 feet along Canadian River. It is well exposed in both localities. The following section, on West Amarillo Creek, shows the characteristic stratigraphy of the Tecovas formation in that vicinity:

Geologic section on West Amarillo Creek, 10 miles northwest of Amarillo, Tex.

System.	Formation.	Character.	Thickness.
			Feet.
Triassic	Dockum group. Trujillo	Yellow to gray, cross-bedded sandstone (lower sandstone).	15
	Dockum group. Tecovas	Dark-red shale	30
		Yellow shale	15
		Maroon and reddish-brown shale	12
		Lavender shale	10
Unconformity. Carboniferous (Permian).	Quartermaster	Brick-red shale	25

The variegated shales lie immediately above the upper eroded surface of the Quartermaster formation, with which they form a vivid color contrast. The shales of the Quartermaster are everywhere a brilliant brick-red, while the lower Triassic shales are variegated, with white, lavender, maroon, wine color, and yellow predominating. The rocks consist usually of sandy shales, more or less cross-bedded and lenticular, but contain in many localities beds of variously colored soft sandstone. The color of the shale is due largely to the presence of iron, and many dark-colored clay-ironstone concretions weather out at the surface and lodge on the slopes below. The shales are generally hard and firm, weathering into steep slopes with deep V-shaped gullies and sharp intervening ridges.

In general, the variegated shales are composed of three more or less sharply marked zones—a lower zone of white, gray, or lavender; a middle zone of maroon or wine color, and an upper zone of light yellow or sulphur yellow. Usually the colors grade into each other, so that it is difficult to divide the various zones sharply. The thickness of the zones varies considerably even within short distances, and it is not uncommon for shales of a certain color to disappear altogether. For instance, the white or lavender shales at the base of the formation are usually present, but in some localities this zone is wanting and the maroon and wine-colored shales rest unconformably upon the eroded upper surface of the Quartermaster formation. Even where all the zones are present the thickness is subject to considerable variation, as is illustrated in the following table, which includes typical sections showing the thickness not only of the variegated shales, but also of the overlying and underlying rocks at two localities in this region:

Geologic sections illustrating the varying thickness of the variegated shales.

PALO DURO CANYON.

Formation.	Character.	Thickness.	
		Timber Creek.	Canyon Cita Creek.
		Feet.	*Feet.*
Tecovas	Magenta shales	150	150
	Variegated shales:		
	Yellow	12	20
	Maroon	20	20
	White or lavender	5	10
Unconformity.			
Quartermaster		150	150

WEST AMARILLO CREEK.

Formation.	Character.	Thickness. 1 mile north of Fort Worth and Denver City R. R.	Thickness. 2 miles south of Fort Worth and Denver City R. R.	Thickness. 1 mile south of Fuqua's ranch.
		Feet.	*Feet.*	*Feet.*
Tecovas	Magenta shales	75	45	10
	Variegated shales:			
	Yellow	10	15	15
	Maroon	10	15	5
	White or lavender		10	10
Unconformity.				
Quartermaster		20	20	15

In certain localities the variegated shales lose their clayey character and become largely or entirely sandstone. This sandstone, however, differs so widely in both structure and general appearance from all other sandstone found in either the Permian or Triassic formations of the region that it is always easily recognized. In general it is white, yellow, or light brown in color, soft and friable, and rather massive, and much of it contains only a small amount of cementing material, so that on exposure it weathers easily, forming peculiar rounded or dome-shaped masses, which at a distance bear a fancied resemblance to small buildings. A cluster of these peculiar erosion forms in the valley of Canadian River on the L. S. ranch, 2 miles south of Tascosa, is known locally as "Rock City." At the mouth of Trujillo Creek, near the New Mexico line, the variegated shales are represented by a light-colored soft sandstone with here and there a red member, and near the mouth of Bonita Creek, in northeastern Potter County, by a very similar sandstone. At both localities the sandstone contains a large amount of fossil wood, which, being exposed by weathering, lies scattered on the surface.

Variegated shales lying unconformably upon the Quartermaster formation are exposed all along Palo Duro Canyon in Armstrong and eastern Randall counties, where they are easily recognized by the vivid contrast of their maroon and yellow colors with the duller hues of the associated formations. On Canadian River and its tributaries the variegated shales are in some places exposed and in others covered by Tertiary wash from the hills. In some localities they are carried beneath the surface by the synclines. In the eastern part of the area the variegated shales are exposed at various places along Bonita Creek. Near Lee's ranch, north of Canadian River, the beds are covered, but they appear along both East Amarillo and West Amarillo creeks and on Tecovas, John Ray, and Lahay creeks farther west. In the vicinity of Tascosa the variegated shales appear at intervals on the surface, being here represented by the sandstone phase. This phase is also found along Trujillo Creek and several other creeks near the New Mexico line.

The upper part of the Tecovas formation is composed chiefly of shales having a magenta color, which differs materially from the typical brick red of the Quartermaster shale and other Permian red-beds formations and from the lavender, maroon, and yellow of the variegated shales. The thickness of the magenta shale varies in different localities, being 120 to 150 feet in Palo Duro Canyon and 50 to 75 feet on Canadian River.

The magenta shales outcrop along Palo Duro Canyon and Canadian River and their tributaries, appearing between the variegated shales and the heavy basal sandstone of the Trujillo formation. From the rim of Palo Duro Canyon the color contrasts between the magenta shales, the underlying variegated shales, and the Quartermaster beds are very striking. No fossils except the petrified wood are known to occur in the Tecovas formation.

TRUJILLO FORMATION.

The upper part of the Triassic red beds, as exposed in the Panhandle of Texas, consists of several ledges of massive more or less cross-bedded sandstone and conglomerate, with interbedded red and gray shales. These constitute the Trujillo formation, so named from a creek in Oldham County. In most sections there are three well-defined ledges, but here and there the number is increased to five or more by local cross-bedding or by the appearance of lentils. This formation is exposed in Palo Duro Canyon and on Canadian River, as well as on the creeks tributary to both streams. As it is the highest formation of the red beds in the region, it outcrops in many cases at a considerable distance back from the larger streams and near the heads of the creeks. Its upper part shows evidence of extensive erosion, and in a number of localities the highest sandstone member and a considerable part of the underlying shale were removed previous to the deposition of the Tertiary rocks, which lie unconformably upon the Triassic. It is noticeable that in many localities where the Tertiary is thinnest the underlying Trujillo formation reaches its maximum thickness. This is well illustrated in Palo Duro Canyon, where 40 feet of Tertiary rocks overlie 250 feet of the Trujillo, while along Canadian River, where the Tertiary deposits are thick, the Trujillo is correspondingly thin.

Along Palo Duro Canyon and in the valley of Canadian River there occurs near the middle of the Triassic red beds a persistent ledge of massive sandstone which constitutes the lower member of the Trujillo formation. This sandstone is in most places fine grained and massive, but here and there it becomes cross-bedded and conglomeratic. In certain localities—as, for instance, in Palo Duro Canyon and its tributaries—the ledge is divided into two or more subordinate beds by the interposition of shale lentils. In color it is gray or brown, rarely white or red, its subdued tint forming a marked contrast to the more vivid red and variegated shales both above and below. The thickness varies in different localities, having an observed maximum of 60 to 75 feet in Palo Duro Canyon and on Canyon Cita Creek, while on Canadian River it does not average more than 25 feet.

In Palo Duro Canyon and its tributaries the lower sandstone is well exposed as a precipitous cliff, which outcrops about halfway up the canyon wall. So steep is this cliff that it forms an impassable barrier for many miles along the canyon, and in only a few localities are there trails where a horse can be led from the High Plains down into the canyon. In this region the sandstone weathers into peculiar erosion forms, some of the most striking of which are shown in Pl. II, *A* (p. 10). Along Canadian River the sandstone is as a rule well exposed. Owing to its hardness it resists erosion, forms conspicuous ledges, and thus becomes a convenient horizon of reference. Particularly is this true in localities where synclines have carried the underlying beds, notably the Alibates dolomite, beneath the surface, in which case the lower sandstone forms the cap of the bluffs along the river. This condition is well exemplified in northern Potter County on both sides of the river, between the mouths of Bonita and East Amarillo creeks. The best examples, however, are farther west in northwestern Potter and northeastern Oldham counties, where the lower sandstone forms conspicuous bluffs on both sides of the river and on such tributary creeks as Sierra de la Cruz, Parker, Cheyenne, and Alamosa. In localities where the Alibates dolomite forms the river bluff the sandstone above described is found near the head of creeks at some distance from the river.

Separated from the lower sandstone by a bed of red or gray shales 15 to 60 feet thick is a very persistent ledge of sandstone and conglomerate, here designated the middle sandstone. It consists in most places either of coarse, heavy, cross-bedded sandstone, red or gray in color, or of cross-bedded lenticular conglomerate with pockets and lenses of clay. The pebbles which make up the conglomerate comprise various rocks, both igneous and sedimentary, with granite, quartz, sandstone, clay, and limestone predominating. In size they vary from sand grains to fragments 3 to 4 inches in diameter. A few of the pebbles are angular, but the majority are smooth and waterworn. In certain localities almost the entire thickness of the ledge consists of a peculiar conglomeratic clay composed of small fragments of clay or limestone, many of them no larger than a pea, contained in a matrix of sandy clay, the whole having a mottled appearance. As in the case of the lower sandstone, this middle sandstone consists locally of two ledges of conglomerate or sandstone separated by shales.

The thickness of the ledge is variable, attaining a known maximum of 40 feet on South Canyon Cita Creek, while in the valley of the Canadian it averages 10 feet with a maximum of 20 feet. In certain localities along the Canadian and its tributaries the middle sandstone has been removed by pre-Tertiary erosion and does not appear. Its best exposures are found along Palo Duro Canyon and its tributaries, where it forms a persistent ledge 40 to 60 feet above the lower sandstone and along Sierra de la Cruz, Alamosa, and Trujillo creeks, southern tributaries of the Canadian, where it is exposed as a prominent ledge, as a rule near the tops of the hills.

The middle sandstone is the lowest horizon of the Triassic in which fossils have been observed. Remnants of bones and plates were secured from the conglomerate beds or as weathered fragments on the slope below. These specimens were referred to Dr. T. W. Stanton, who reports as follows: "The fossils have been examined by Mr. J. W. Gidley, of the National Museum, who reports that they are fragments of jaw, femur, and skin plates of a belodont, probably *Phytosaurus superciliosus* Cope. The fossils are considered characteristic of the Triassic period."

This leaves little doubt as to the age of the middle sandstone, and as the entire group between the base of the Tertiary and the top of the Quartermaster formation is apparently conformable there is good reason for considering both the Tecovas and Trujillo formations Triassic in age.

Still higher in the Trujillo formation as exposed in this region appears another ledge, here called the upper sandstone. It does not differ lithologically from the middle sandstone. It is a brown to gray, coarse, cross-bedded sandstone or conglomerate with pockets and lenses of clay, which divide the member locally into two or more well-defined beds. The pebbles which make up the conglomerate are composed of clay, sandstone, limestone, ironstone, granite, fragments of bone, etc., closely resembling those of the middle sandstone.

The best exposures of the upper sandstone are in Palo Duro Canyon and its tributaries, particularly along Canyon Cita Creek, where it is 30 feet thick. It is noticeable that in this locality the Tertiary deposits, which in most places on the High Plains attain a thickness of several hundred feet, are relatively thin, being here in places not more than 40 to 50 feet thick. So far as observed the upper sandstone is not exposed on the Canadian or its tributaries, having been carried away by pre-Tertiary erosion.

Fossils similar to those from the middle sandstone are found in the upper sandstone. As in the lower beds, fragments of bones, teeth, plates, etc., occur as parts of the conglomerate, or if weathered out are found on the shale slopes below.

The following sections illustrate the stratigraphy of the Permian, Triassic, and Tertiary rocks of this region. The first section was measured on Timber Creek, one of the tributaries of Palo Duro Creek in the southeastern part of the area, while the second is from Trujillo Creek, a branch of the Canadian in the extreme western part of the Panhandle.

Geologic section near the mouth of Timber Creek, eastern Randall County, Tex.

System.	Formation.	Character.	Thickness.
			Feet.
Tertiary		Cliffs of sand, gravel, and clay	200
Unconformity.			
Triassic	Dockum group. Trujillo	Red and gray shale, with ledges of sandstone	40
		Gray to red sandstone and conglomerate, cross-bedded (middle sandstone).	20
		Red and gray clays and shales	35
		Brown, gray, and red massive sandstone and conglomerate, cross-bedded, with shaly members (lower sandstone).	60
	Dockum group. Tecovas	Dark-red shale	140
		Sulphur-yellow shale, with iron concretions	15
		Maroon shale	25
		White to lavender shale	5
Unconformity.			
Carboniferous (Permian).	Quartermaster	Brick-red shale, with ledges of soft red or gray sandstone.	150

Geologic section near the mouth of Trujillo Creek, western Oldham County, Tex.

System.	Formation.	Character.	Thickness.
			Feet.
Tertiary		Sand, clay, and pebbles	100
Unconformity.			
Triassic	Dockum group. Trujillo	Gray to brown sandstone and conglomerate (middle sandstone).	10
		Red shales, with bands of white and blue shale and thin-bedded sandstone.	15
		Heavy brown massive sandstone and conglomerate (lower sandstone).	20
	Dockum group. Tecovas	Clays and soft sandstone; dark-red, yellow, and blue variegated shale; and gray and yellow sandstone, with fossil wood.	90
Unconformity.			
Carboniferous (Permian).	Quartermaster	Red shale and shaly sandstone, unevenly eroded at the top, locally absent.	0-10
		Hard, massive brown to gray, flinty dolomite (Alibates lentil).	15
		Red shales	60
		White gypsum, locally in two ledges separated by red shale (Saddlehorse lentil).	15
		Red shale from bed of Canadian River	20

CRETACEOUS ROCKS.

Exposures of Cretaceous rocks occur in northern and western Dallam County, the northwestern county of Texas, along the valleys of two prairie creeks, Coldwater and Perico. These creeks are, in most places, only shallow draws on the flat Tertiary plains, where erosion has removed the superficial deposits, thus exposing the underlying Cretaceous beds. So far as known, there are only five localities in the county where Cretaceous rocks outcrop.

Near Agua Fria, or Coldwater Springs, in northeastern Dallam County, bluffs composed of brown sandstone and varicolored clays are exposed for a mile and a half along Coldwater Creek. The following sections illustrate the thickness and varying character of the rocks at this place:

Section 200 yards southeast of Agua Fria Springs, Dallam County, Tex.

	Feet.
Yellowish, white, and brown sandstone	3
Yellow to brown sandstone, cross-bedded, locally becoming shaly	30
Shale, bluish to pink and brown	2
	35

Section three-fourths mile west of Agua Fria Springs, Dallam County, Tex.

	Feet.
Yellowish to brown sandstone	5
White shale	4
Shaly white sandstone	3
Blue clay	1
Brown to chocolate-colored shale	3
	16

At Buffalo Springs, 18 miles northeast of Texline, Tex., half a mile south of the Oklahoma line, there is an exposure of yellow and brown sandstone and clay extending a mile or more along two branches of Coldwater Creek. The following section was made near the junction of the creeks:

Section near junction of forks of Coldwater Creek, Dallam County, Tex.

	Feet.
Tertiary deposits covering slope to top of hill	+50
Sandstone, cross-bedded, yellow, brown, and black; as a rule in beds 8 inches to 1 foot thick	12
White, yellow, drab, and red shales, with thin bands of soft sandstone	20
	+82

Other sections taken near this locality show that the Cretaceous rocks here are composed largely of clay. At the base of the sandstone occur the Buffalo Springs. (See p. 45.) A mile and a half to the north, just across the State line in Oklahoma, there is an outcrop of Cretaceous sandstone approaching quartzite, gray, yellow, or brown in color, which stands out as a prominent rounded knoll 20 feet high and 100 yards in diameter.

Near Texline, on the west line of Dallam County, Cretaceous rocks occur in three localities. On Coldwater Creek, approximately 3 miles south and 2 miles east of the northwest corner of the State, Cretaceous shales and sandstone outcrop for 300 yards or more along the bottom of the creek. On North Perico Creek, 2 miles north of Texline, there is a small exposure of thin-bedded, brown to yellow, more or less cross-bedded sandstone and clay. These deposits, which extend about half a mile along the bottom of the creek valley, lie unconformably beneath the Tertiary, the base of which here consists of clay and conglomerate, the conglomerate being composed of sandstone pebbles derived largely from Cretaceous rocks. On South Perico Creek, 1½ miles south of Texline, Cretaceous rocks composed of alternating shales and thin-bedded, brown to yellow, shaly sandstone about 20 feet thick are exposed for about a quarter of a mile.

So far as known, no fossils have been found in either the shale or the sandstone of this part of Texas, nor can continuous outcrop be traced to other Cretaceous beds the age of which has been definitely determined. For these reasons exact correlation is not possible. It is probable, however, that the Cretaceous rocks of Dallam County, Tex., are of the same age as beds which outcrop farther north, west, and southwest on Cimarron and Canadian rivers and their tributaries in western Oklahoma and northeastern New Mexico, where these rocks include part of the Comanche as well as the Dakota.

TERTIARY AND QUATERNARY ROCKS.

GENERAL RELATIONS.

Resting unconformably upon the eroded surfaces of the older formations throughout the western part of the Panhandle of Texas is a series of deposits composed largely of partly consolidated clay, sand, and pebbles of Tertiary age. In former times these Tertiary rocks probably covered all the older formations, and even now the older rocks are exposed only in limited areas, chiefly along valleys where long-continued erosion has removed the Tertiary cover.

Deposits of Tertiary age cover the western part of the Great Plains from Canada to Mexico. To the greater part of these rocks the general term Loup Fork beds has been applied, and they have been classed as late Miocene or Pliocene. In Nebraska Darton separates the so-called Loup Fork into the Arikaree and Ogalalla formations, assigning the former to the Miocene and the latter doubtfully to the Pliocene.[a] Hay and others in Kansas have divided the Loup Fork, on the basis of lithologic character, into "Tertiary grit" and "Tertiary marl," or "mortar beds." In Texas Cummins and Cope have distinguished the Loup Fork, Goodnight, and Blanco beds, the Loup Fork being Miocene, the Goodnight transitional, and the Blanco Pliocene in age.[b]

Lying upon the Tertiary rocks in many parts of the plains are certain Pleistocene deposits, sometimes called the "Equus beds," which in most places do not differ lithologically and can not be distin-

[a] Darton, N. H., Preliminary report of the geology and water resources of Nebraska west of the one hundred and third meridian: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1899, pp. 932 et seq.

[b] See discussion by the writer in Water-Sup. and Irr. Paper No. 154, U. S. Geol. Survey, 1906, pp. 25-28.

guished stratigraphically from the underlying Tertiary deposits. In the Panhandle it has been found impossible to distinguish stratigraphic units in the Tertiary, owing mainly to the fact that the clay, sand, and gravel which make up these deposits are arranged heterogeneously and without similarity of position. The only possible evidence on which these rocks could be divided into formations is paleontologic, and it was on such evidence that Cummins and Cope proposed the formation name mentioned above. Fossils, however, are rare, and up to the present time no systematic effort has been made to collect them from various parts of the Great Plains. For these reasons the term Tertiary will be used in the following discussion to include all the deposits of Cenozoic age which overlie the red beds and the Cretaceous rocks. These deposits include the greater part of the rocks of the Panhandle.

CHARACTER OF THE TERTIARY ROCKS.

The greater part of the Tertiary rocks of the High Plains consist of clays, sandstones, and conglomerates, with clays largely predominat-

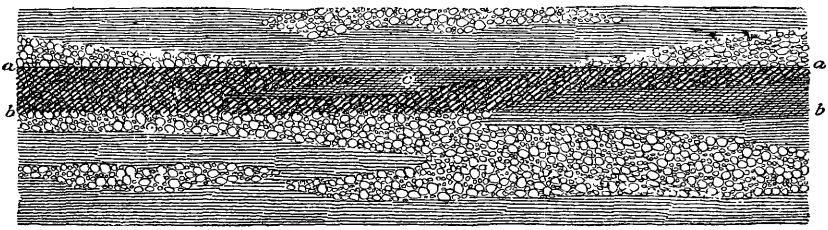


FIG. 1.—Ideal Tertiary structure.

ing. These materials are usually arranged in a heterogeneous manner (see fig. 1), the sand, clay, and other rocks occurring indiscriminately and without similarity of position from place to place. As a rule the coarser materials, such as sand and pebbles, lie near the base of the Tertiary deposits, immediately above the red beds or Cretaceous rocks, while the finer clays and silts occupy a position higher up in the system. Not uncommonly this order is reversed and clays lie directly upon the eroded Permian or Triassic red beds and below strata composed of Tertiary gravel.

The clays are white for the most part, but here and there pink or buff. The various tints are uniformly subdued, however, so that from a distance the Tertiary cliffs appear to be white and are locally known as "chalk" cliffs or "gyp" cliffs, although they contain neither chalk nor gypsum. The clay is generally a soft, homogeneous mass, but it contains indurated beds, which are in places sufficiently calcareous to make good limestone. Not uncommonly these harder layers appear at regular intervals in the softer clays, and the slope on weathering assumes a peculiar "stair-step" appearance, having locally the form of river terraces. All the clays contain lime in greater or less quantities and in many beds there are white calcareous concretions, which give to the rock a mottled appearance, a fact particularly noticeable where the clay is pinkish or buff in color. In many places the lime cements the clay together in the form of elongated "pipy" concretions, or in irregular and grotesque forms which, being harder than the clay, may be left standing when the latter is eroded.

The sand which makes up a considerable proportion of the Tertiary deposits is composed largely of smooth, rounded white or yellow quartz grains. Locally it is cemented by lime into coarse, rough sandstone, but it is more commonly unconsolidated and in many places where erosion has removed the soil it is blown by the wind into dunes. In many instances the sand occurs in beds mingled with small pebbles and clay cemented with lime, forming the so-called "mortar beds" of the Kansas geologists.

The conglomerate of the Tertiary is made up mainly of smooth, rounded, waterworn pebbles of granite and other igneous rocks, although sandstone, limestone, and clay pebbles are present in numerous places, the latter being particularly abundant near the base of the deposits. These pebbles vary greatly in size, shape, and color. In size they range from small sand grains to bowlders 6 inches in diameter; in shape they are, as a rule, more or less rounded, though some are flattened, oval, elongated, or subangular; in color they are most commonly gray, pink, black, yellow, red, or brown, depending on the character of the rock from which they were derived. These pebbles occur generally in more or less lenticular, cross-bedded layers, some of which are 50 feet thick or more, but in many places they are intermingled with fine sand, and locally are scattered through the clay members. The conglomerate is more abundant at the base of the Tertiary, where it forms many conspicuous ledges, as, for instance, near the mouth of Ranch Creek, north of Canadian River, in northern Potter County, where bluffs 100 feet high are composed entirely of coarse, cross-bedded conglomerate.

As the Tertiary rocks are removed by erosion the pebbles weather out and cover the slopes. They are rarely found on the level surface of the High Plains, but appear on their eroded eastern slope, and are thick on the low, rounded hills and bluffs near the larger streams. Near the base of the Tertiary, waterworn *Gryphæa* shells of Lower Cretaceous age are sometimes found scattered among the pebbles. These shells were evidently derived from the Cretaceous beds known to occur farther west and were deposited in their present positions at the same time as the Tertiary material.

It is impossible to do more than roughly estimate the proportions of the various rocks composing the Tertiary deposits, for, as has been stated, there is constant local variation. It appears probable, however, that throughout the region as a whole from two-thirds to three-fourths of the Tertiary material is composed of some form of clay or silt, the remainder being sand or pebbles. In Nebraska and Kansas, to the north, and in Oklahoma, to the east, the proportion of the coarse material is relatively larger.

ORIGIN OF THE TERTIARY ROCKS.

The question of the origin of the Tertiary deposits on the Great Plains has occupied the attention of American geologists for more than fifty years. The thickness of the deposits, their wide areal distribution, and the paucity of fossils in the beds have combined to present unusual difficulties in the solution of the problem.

Two general theories have been held regarding the method of their deposition. It was believed by the earlier geologists that they were laid down in the bottom of a vast inland lake. Marsh described a great Pliocene lake covering practically the entire Great Plains area, in which deposits 1,500 feet thick were laid down. Both Cope and Cummins refer to the Texas Tertiary beds as "lacustrine terranes" or "lake deposits." Hay and others accepted the lake theory to account for the deposition of the Kansas beds. At the present time, however, the consensus of opinion among those geologists who have studied the formations in the field is that the Miocene and Pliocene deposits on the Great Plains are due to fluviatile rather than to lacustrine agencies. To quote but two of several authorities on the subject:

> The relative positions of the sand, gravel, and clay of the Tertiary over the whole of Kansas * * * correspond much better to river deposits than to lake deposits. The irregularity of formation succession, the limited lateral extent of the beds of gravel, sand, and clay, and the frequent steepness of the cross-bedding planes all correspond to river deposits. * * * The materials themselves have many indications of river deposits and very few of lake deposits.[a]

> The structure—an uneven network of gravel courses and elongated beds of sand penetrating a mass of silt and sand-streaked clay—is the normal product of desert-stream work under constant desert conditions. The coarse material is not regarded as the product necessarily of strong-running streams and the fine material of sluggish streams in alternating epochs either of humid and dry climate or of high and low inclination of slope, but as the simultaneous product of branching streams of the desert habit, here running in a channel and there spreading thinly.[b]

So far as the writer has been able to ascertain, few, if any, of the more recent investigators accept the theory of lacustrine origin for the Tertiary deposits of the Great Plains. Practically the only point at issue is whether the source of the indiscriminate, uneven, or lenticular deposition of the material by the streams should be sought in climatic changes which produced alternate periods of aridity and humidity or in extended deformation of the earth's crust by which

[a] Haworth, E., Physical properties of the Tertiary: Second Ann. Rept. Kans. Univ. Geol. Survey, 1897, p. 283.

[b] Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 655.

the eastern part of the Great Plains was at times elevated and again depressed, giving rise to alternating steepening and lessening of the gradient of the streams. It seems possible that each of these causes may furnish a partial solution of the problem.

SAND DUNES.

Sand dunes occur in many parts of the Great Plains. Almost invariably the material which makes up these dunes is derived from either the Tertiary deposits or the "Equus beds." As the Cenozoic deposits, which, as above stated, are composed of rather loose, unconsolidated clay, sand, and conglomerate, are eroded, the finer clay and silt are carried away, either in suspension or in solution, and the sand which remains behind is blown by the strong prevailing winds into dunes, many of which cover considerable areas. In central and western Nebraska, for instance, thousands of square miles are occupied almost exclusively by them. Dunes are also common in western Kansas and eastern Colorado and cover considerable areas in the eastern part of the Panhandle of Texas and of western Oklahoma.

In the area described sand dunes are relatively rare, being found chiefly along the breaks of Canadian River. In northeastern Potter County along Chicken and Bonita creeks there is an area of 20 square miles or more containing dunes, some being of considerable size, many of which are barren of vegetation. North of Canadian River a strip of sandy country, in which numerous dunes occur, extends from the head of Big Canyon and Big Blue creeks westward for 20 miles. Dunes are also present over parts of western Oldham, Hartley, and Dallam counties near the New Mexico line and in a relatively small area near the Oklahoma line along Beaver Creek in northern Sherman County.

ALLUVIUM.

Along Canadian River and its tributaries and to a less degree along the waters of Palo Duro Canyon there is a considerable amount of alluvium or valley wash. This material, which is composed largely of more or less modified Tertiary and red-beds deposits naturally partakes of the character of the rocks from which it has been derived. Where it comes mainly from the red beds it consists, as a rule, of a reddish clay loam, and where derived from Tertiary deposits it is normally a light to dark sandy loam, the color depending largely on the amount of organic matter present. In many places the alluvium grades imperceptibly into beds of sand, which if blown by the wind may form dunes. In the valley of the Canadian the alluvium occupies the flat flood plain between the bluffs, which averages from 1 mile to 2 miles in width. In Palo Duro Canyon and other smaller creeks the alluvial valley is narrower, varying in width from a few rods to half a mile or more.

WATER RESOURCES.

UNDERGROUND WATERS.

GENERAL CONDITIONS.

Most of the underground water in the western part of the Panhandle of Texas is derived from the Tertiary depósits, which, as has been stated, constitute the greater part of the surface rocks of the region. Along the valley of Canadian River and in Palo Duro Canyon water is found in the red beds, and in the extreme northwestern part of the State there is a small area where the water in both wells and springs is derived from Cretaceous rocks. With these minor exceptions, however, the Tertiary beds are the source of all the water in the region.

Water which has its source in Tertiary rocks is almost uniformly soft and relatively pure and is suitable for all domestic uses. Analyses of a large number of samples taken both from springs and wells in various parts of the Great Plains reveal little or no harmful salts. Relatively small quantities of lime, gypsum, soda, and a few other salts are locally present, but the average amount rarely exceeds 10 grains per gallon, so that for all practical purposes Tertiary water may be considered pure. Water from the red beds is in some cases pure and in others not, according to the character of the rocks from which it is derived.

WATER FROM THE PERMIAN RED BEDS.

Most of the water which has its origin in the Permian red beds contains a large amount of the various mineral salts which enter into the composition of these rocks. The most common of these are calcium sulphate (gypsum), calcium carbonate (limestone), magnesium sulphate (Epsom salts), sodium sulphate (Glauber's salts), sodium chloride (common salt), sodium bicarbonate (soda), sodium borate (borax), magnesium chloride, magnesium carbonate, and calcium chloride. In the valley of Canadian River and its tributaries the water from many of the springs which issue from beneath the Alibates dolomite or the Greer or Saddlehorse gypsum ledges is so highly mineralized that it is unfit for use. Many wells which obtain their supply in these formations (as, for example, the two deep wells on the L. S. ranch, near Tascosa) contain hard water. There are, however, many springs in the Quartermaster formation, both on Palo Duro Canyon and along the Canadian, which yield soft water. In general, the water from the Permian red beds is slight in amount.

WATER FROM THE TRIASSIC RED BEDS.

Springs in the Triassic red beds occur both in Palo Duro Canyon and along Canadian River. Those in Palo Duro Canyon and along Timber, Sunday, Canyon Cita, and other tributary creeks usually issue from under the various sandstone ledges which occur in the Trujillo formation. Springs are also found in the Triassic beds on Canadian River and its affluents, particularly on Tecovas, Sierra de la Cruz, and Alamosa creeks, where in many places the water issues from joints and fissures in the red clay and also from beneath sandstone ledges. As a rule water from springs in the Triassic is fresh and pure, owing largely to the fact that Triassic rocks contain very few harmful salts.

Few wells have been sunk in the Triassic formations in this part of the State. In several instances, however, wells which were started in the Tertiary penetrated the upper beds and obtained water in the Triassic. Wells of this character occur on the High Plains near the edge of Canyon Cita Creek. A few wells on the divides between creeks which empty into Canadian River obtain water from the Triassic beds, the water in almost every case being soft and relatively pure.

WATER FROM CRETACEOUS ROCKS.

The Dakota sandstone, which is one of the great water-bearing formations of the Great Plains, outcrops along a line extending from Minnesota to New Mexico, as well as along the Rocky Mountain front range. In most regions where the Dakota is exposed springs are numerous, and wells sunk into the formation furnish an abundance of water. Almost without exception the water from the Dakota is good. In the northwestern part of the Panhandle there are two large springs in the Dakota sandstone, Agua Fria and Buffalo, both of which are located on Coldwater Creek in northern Dallam County. Buffalo Springs flow approximately 5 second-feet. Wells in this part of the State which are begun on the Tertiary-covered plain pass through the upper beds and find an abundant supply of water in the Dakota sandstone. The wells are comparatively shallow, so that the region is known locally as the "shallow-water district."

WATER FROM TERTIARY ROCKS.

Occurrence.—In order to understand underground-water conditions, it is necessary to know the geologic structure of the rocks from which the water is obtained. In the Panhandle of Texas, as has been stated, by far the greater part of the water comes from Tertiary rocks, and for that reason a brief discussion of the origin and structure of these rocks will be given here.

The Tertiary rocks found in the Panhandle consist of deposits in most places several hundred feet thick, made up chiefly of alternating, more or less lenticular, or cross-bedded layers of clay, sand, and gravel, the latter being composed mainly of smooth, rounded, waterworn pebbles. There seems little doubt that the original material of these deposits was derived largely from the Rocky Mountains. Streams which flowed away from the mountains carried material out on the plain and left deposits in some places of sand, in others of clay, and in still others of gravel or pebbles, which in turn were covered by other deposits, here and there the same, but more commonly of other material. This process, which continued for a long period, resulted in the accumulation of several hundred feet of alternating beds of irregularly stratified rock. Being laid down under such conditions the Tertiary series as a whole is necessarily composed largely of beds irregularly lens-shaped in cross section and in most cases not continuous over large areas. In some localities the greater part of the thickness may consist of fine materials, while in others sandstone and gravels may predominate; but in general the beds of fine and coarse material are mixed in a heterogeneous manner.

The terms "sheet water" or "underflow" are often used in the States of the Great Plains to indicate any fairly constant supply of water at a more or less uniform depth. The general impression seems to be that at some depth beneath the surface there is a continuous "sheet" or "lake" of water which if tapped by a well will yield a fairly constant supply. In some places two or even three such "sheets" are supposed to exist, and the expressions "first sheet" and "second sheet" or "first water" and "second water" are common. Another prevalent notion is that the water in these "sheets" is constantly flowing streamlike beneath the surface, an idea disclosed by the common expression that the "underflow is to the east."

While it is true that these popular ideas are widespread and in general are based on common observation, there is, however, in them much that is erroneous and not based on a correct conception of the conditions found in the nature and relations of the water-bearing strata. Rounded grains of sand and gravel such as make up the lenticular beds which constitute the majority of the Tertiary rocks do not lie closely enough together to fill all the space, but have very small interstices between them. These pores or spaces are minute reservoirs for the water, which in its passage through such materials either vertically or laterally seeps from one of these minute reservoirs to the next, and thus very slowly flows along underground. This movement is popularly called "underflow," but it is not nearly so rapid as is commonly supposed. A number of experiments have been made on the rate of flow of underground waters, and it has been found that even along stream valleys, where the material is coarse, the pores large, the gradient relatively steep, and all conditions favorable for a rapid flow (as, for instance, along Arkansas River in western Kansas), the rate of underflow does not average more than 10 feet a day.[a] On the High Plains, such as constitute the region under discussion, where the gradient is low, much of the material fine, and the pores relatively small, and where the lenticular beds dip in many places at different angles in different directions, it is doubtful if on an average the water moves more than 10 feet in a year.

According to the theory just advanced dry ground is ground in which the pores between the rock particles contain no water, while wet or saturated ground is that in which the pores are filled. Since water always tends to sink to the lowest levels, there is in most regions a certain but variable thickness of beds filled with water in what is technically known as the "zone of saturation." The upper surface of this zone of saturation is called the "water table" or "water plane," and this is in many places identical with what is meant by the popular phrase "sheet water," so common on the Great Plains. Since water moves slowly underground, this water table becomes approximately similar in contour to the surface of the ground, being high on the divides and low near the streams, where the water may escape in springs.

As originally deposited the lenticular beds which constitute the greater part of the Tertiary deposits must have had an irregular outline and surface, especially where they were laid down in swamps or lakelets. Where the material is clay or very fine sand the interstices between the particles are very minute and practically impervious to water. Fine deposits such as those just described are in numerous instances overlain by sand and gravel which was originally laid down in basins or channels, and these in turn by other fine-grained deposits in varying succession, so that the alternation of water-bearing and impervious beds is, in many places, very irregular. If deposits of this nature are penetrated by a well, the first sand encountered will furnish water, the quantity depending on the size of the water-bearing deposit, the coarseness of its grains, the height of its edges, etc.; in the next coarse sand bed a second water stratum will be found, and so on, until finally the main water table is penetrated. This may be considered a probable explanation of the "first and second water" or "first and second sheet" so often spoken of on the Great Plains. It also possibly accounts for conditions found in many parts of the region where records obtained from a relatively small area show well depths varying up to a hundred feet. These conditions are set forth in fig. 2.

[a] Slichter, C S., The motions of underground waters: Water Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, pp. 41–43.

In general the average depth of the wells in any particular locality may be considered the approximate depth of the water table at that place. As will be understood from what has been stated, the water-table, or the level at which the top of the ground water stands, varies constantly from place to place, from year to year, and even from day to day. It is supplied chiefly from rainfall and is lowered whenever the water is removed—as, for instance, by springs, artesian wells, or heavy pumping. Ordinarily the water table is at a considerable distance below the surface, but here and there it reaches the surface level, as in springs, swamps, or marshes.

On the High Plains the water table is located at the upper point of saturation of the pervious beds. Well records from widely separated localities show that this water level for the High Plains as a whole averages from 200 to 250 feet beneath the surface. So far as known, this level in each locality is fairly constant, the amount of water taken away by springs and wells being approximately equaled by the amount added each year by precipitation.

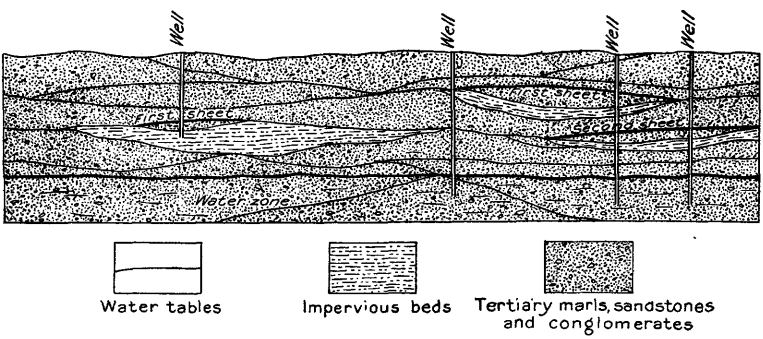


FIG. 2. Ideal Tertiary structure showing water-bearing beds at different levels.

In the area described the depth of the wells in the Tertiary deposits of the High Plains varies from 50 feet to more than 400 feet. On the High Plains north of Canadian River the deepest wells (which are in eastern Dallam County) are between 400 and 450 feet deep, while in Moore and Sherman counties they do not average more than 250 feet. South of this river, on the Llano Estacado, the deepest wells are in the eastern part of Potter County, where water is occasionally found at depths exceeding 400 feet. In Deaf Smith and Randall counties, in the southern part of the Panhandle, the wells are shallower, in many localities not averaging more than 75 feet; in the vicinity of Hereford, the county seat of Deaf Smith County, many of the wells are not more than 60 feet deep.

Sources.—There is a prevalent but erroneous idea in most parts of the High Plains that the water which supplies the wells on the plains comes from the Rocky Mountains. That this can not be true is very evident to any one who has studied the geologic structure of the plains as a whole. All available data point to the fact that local precipitation is the only source of the underground water of the High Plains. This subject is discussed more fully under the head of artesian water (pp. 42–43).

Rainfall on the surface of the earth is disposed of by evaporation, run-off, and percolation. It is estimated that in general the amount of water disposed of in each of the three ways is about equal, but the relative amounts in different regions depend on several local conditions; for instance, on a steep slope or in a region of stiff clay soil the greater part runs off; in a warm, arid climate the greater part evaporates, while in loose soil the greater part is absorbed.

Throughout a considerable part of the Great Plains, where the surface is level and the drainage systems undeveloped, there is no run-off and all the rainfall is either absorbed or evaporates. After a rain the greater part of the water soaks into the ground, and the remainder, which does not evaporate immediately, accumulates in broad shallow depressions on the surface, known as buffalo wallows or lakes, in which it remains until it evaporates or disappears beneath the surface. Johnson estimates that not more than 3 or 4 inches of rain annually sinks into the ground,[a] an amount which would not saturate more than about 1 foot of sandy strata. This estimate of the amount of water absorbed seems to the writer to be rather small, but in all probability the rainfall does not add more than 18 inches to the ground water each year. An amount approximately equal is lost through springs and wells, so that in general the level of the water table remains constant. There are no data which would lead to the inference that the amount of water is either increasing or decreasing

WINDMILLS.

In a country such as the Panhandle of Texas, where water is practically everywhere abundant in wells, but occurs at considerable depths beneath the surface, one of the most vital problems is that of finding a relatively cheap and efficient means of bringing it to the surface. For this purpose the ordinary force pump is almost universally used. In a few shallow wells along stream valleys or among the breaks a rope and bucket are employed to supply water for household use, but it is safe to estimate that 99 per cent of the wells in the Panhandle are provided with a pump. Power is usually furnished by windmills, of which several forms are employed, by far the greatest number being of the ordinary turbine type. On the larger ranches, particularly where water is deep and it is necessary to raise considerable amounts for cattle, a wooden wheel from 16 to 20 feet in diameter, mounted on a relatively low tower, and a 3-inch pump are usually

[a] Johnson, W. D., The High Plains and their utilization: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 645.

employed, while on smaller ranches and farms and in the towns an iron wheel is generally used.

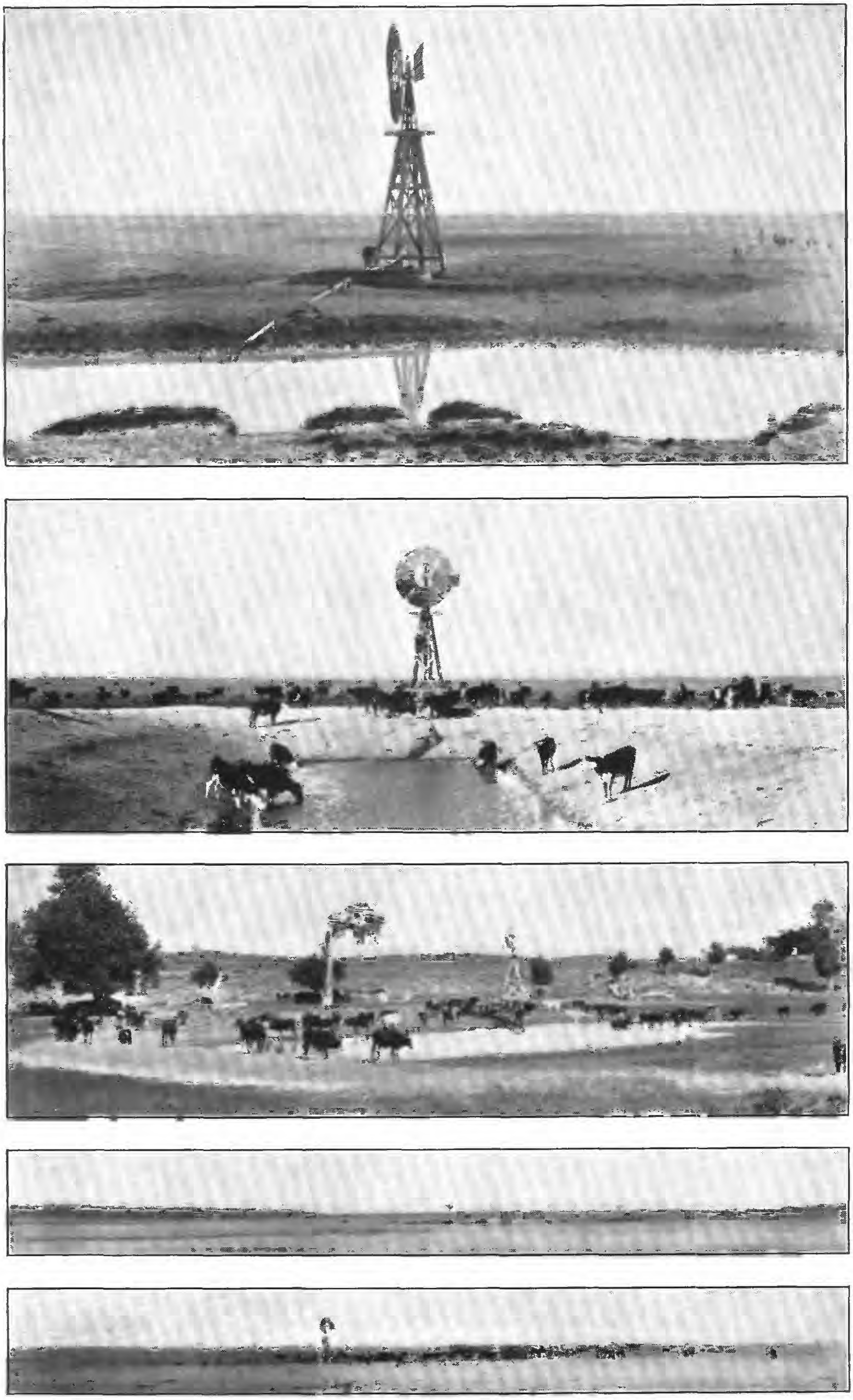
On the larger ranches, where thousands of cattle graze, it is necessary to provide a constant and convenient supply of water, and for this purpose wells have been put down at intervals of 2 to 3 miles in all directions. In many parts of the prairie the only evidence that the country is inhabited is furnished by a lone windmill, surrounded at certain times of the day by herds of cattle. The water is pumped from the well into large circular tanks of wood or iron, to which the cattle have access. In many instances there is an arrangement whereby when the tank is full the overflow passes into an earthen reservoir which has been excavated near by, the object being to provide an emergency supply in case the wind does not blow for several days. Rarely do extended periods of calm occur, however, and the windmill once set going is never stopped until it wears out. On the larger ranches men known as "windmill greasers" are employed, who do nothing but oil and repair windmills. Two men usually travel together, camping out wherever night overtakes them, visiting each mill on an average of twice a week.

In the Panhandle of Texas it is usually estimated that the cost of sinking a well and installing a mill, pump, and tanks averages about $2 a foot for deep wells and a relatively larger sum for shallower ones. In localities where the wells are 400 to 500 feet deep the cost of the well, mill, pump, and tanks complete is $800 to $1,000, while if the well is but 100 feet deep the cost is $250 to $300. Pl. VII shows characteristic windmills on the plains.

DEEP-SEATED WATERS.

In the various parts of the Panhandle of Texas the project of obtaining artesian water is often considered. There is perhaps not a county in which the subject has not been agitated, and as the country is now being rapidly occupied by settlers it is altogether probable that a number of attempts will be made in various localities to secure an artesian supply. In most cases, as above stated, it is assumed that the water found in the wells of the High Plains comes from the Rocky Mountains. But this is not so. The Llano Estacado, or that part of the plains south of the Canadian, is cut off from the mountains by the valley of this stream and by Pecos River in eastern New Mexico, so that it is impossible for water to pass from the mountains into the Tertiary beds which carry the water on the High Plains. North of the Canadian the Tertiary deposits thin out to the west and disappear before the Rocky Mountains are reached, so that the probability of any extensive artesian flow, having its origin in the Tertiary beds in this part of the country, is very small.

There are a few artesian wells in the region, as for instance, one on



HIGH PLAINS WINDMILLS.

Big Blue Creek in eastern Moore County. This well, which is 123 feet deep, flows about 1 gallon per minute. From the record obtained it appears that the well passed through 25 feet of Tertiary clay and then entered the red beds. The water was found in a sandstone, possibly one of the members of Trujillo formation, in the upper part of the Triassic red beds. It is probable that the supply of water in this well is governed by local conditions, and that while other similar wells may be developed here and there their number will never be sufficiently large to be of economic importance. There are a number of other wells along Big Blue Creek that find water at about the same depth, but none of them flow. An artesian well is reported on Rita Blanca Creek, west of Channing. The supply is limited and the well is not important.

At the L. S. ranch, 2 miles west of Tascosa, at an elevation of 3,160 feet, there are two artesian wells a quarter of a mile apart which draw their supply of water from the red beds. The wells are of equal depth, approximately 340 feet, and the water from each fills a 5-inch pipe. The water, however, contains so high a percentage of mineral salts that it is unfit for domestic use. These wells are located in one of the synclinal troughs described on page 20, and the source from which this water derives its head is probably located along the anticline to the west, possibly in the vicinity of Trujillo Creek. As this syncline extends 30 miles or more up and down the river there is a possibility that more extensive drilling might result in a number of such wells in the red beds along the Canadian in this region. The source of the water is probably in the Permian red beds, somewhere about the horizon of the Greer gypsum, and it is very likely that the water from any wells in this locality would be so highly mineralized as to be undesirable for either domestic use or for irrigation. Fortunately this district is traversed by a number of flowing streams, so that there is no particular need of resorting to wells for stock water.

In the northwestern part of Dallam County, where the Dakota sandstone approaches the surface, it is possible that artesian water might be obtained. It is reported that a well, drilled in 1888 on the high divide near Coldwater Creek, 6 miles north of Texline and 3 miles from the northwest corner of the State, reached a depth of 1,250 feet and that the water stands within 100 feet of the surface. The record can not be had, but it is probable that this well penetrated both the Tertiary and the Dakota and stopped in the red beds. The water may come from the Dakota sandstone.

SPRINGS.

GENERAL CHARACTER.

The springs in the western part of the Panhandle of Texas may be classed under three general heads, according to the geologic formation from which they are derived—red-beds springs, Cretaceous springs, and

Tertiary springs. The red-beds springs are usually found in the valleys of the larger streams, such as Canadian River and Palo Duro Creek. The water is in some places pure and in others not, depending on the amount of mineral salts contained in the rocks from which the spring issues. The water from Cretaceous springs, which are found in Dallam County only, is always good. Tertiary springs are by far the most important, with regard to both number and amount of water, and the water is almost uniformly fresh.

RED-BEDS SPRINGS.

Springs from the Permian red beds are found chiefly in the valley of Canadian River, although a few are known to occur in the deeper parts of Palo Duro Canyon and its tributaries. In the latter locality the water usually issues as seeps from the argillaceous sandstone of the Quartermaster formation along some small canyon or gully. Farther east, in Oklahoma, the Quartermaster formation is more sandy and is noted for its large number of small springs. In Palo Duro Canyon, however, there is a larger amount of shale in the formation and the number of springs is not so great.

In the valley of the Canadian and its tributary creeks Permian red-beds springs are often found. In the eastern part of the region, particularly on Big Blue, Plum, Big Canyon, Turkey, and Alibates creeks, many springs issue from beneath the massive ledges of the Greer gypsum, the water of which is strongly impregnated with calcium sulphate and other salts. The majority of the springs, however, come from the Quartermaster formation and many of them issue at the base of the Alibates dolomite lentil. Springs of this character are found on all the creeks named above and also on West Amarillo, Horse, Tecovas, Las Achias, Trujillo, and others. These springs usually issue as bold, gushing streams at the point of contact between the dolomite and the underlying clay. Seep springs issuing from the sandy beds of the Quartermaster are also common in this region. Many of the springs from below the dolomite ledge contain appreciable amounts of mineral salts, so that the water is undesirable for ordinary domestic use, while the water of seep springs from the sandstone is usually soft and pure.

Springs from the Triassic red beds are found both in Palo Duro Canyon and in the valley of Canadian River. Along Palo Duro Creek and its tributaries they issue as a rule from beneath the various sandstone members of the upper or Trujillo formation, although springs in the Tecovas shale formation are not uncommon. On Canyon Cita Creek springs issue from beneath all three of the sandstone members of the Trujillo formation, while in the main canyon, a few miles east of the falls, there are strong springs which issue from joints in the magenta shales. The water from the Triassic sandstone in Palo Duro

Canyon is generally soft and pure, but because of the inaccessibility of the springs it is not utilized. In the valley of Canadian River springs occur in the Triassic, not only near the river where it has cut through the rocks of this series, but also on the tributary creeks—East Amarillo, West Amarillo, Tecovas, Sierra de la Cruz, Parker, Alamosa, Alamositas, Las Achias, and Trujillo. In some places the water issues from beneath the lower or middle sandstone of the Trujillo, in others from joints in the clay, and in still others from the sandstone which in this region locally takes the place of the variegated shales of the Tecovas. Some of the springs are strong and some mere seeps. The water is almost invariably soft and suitable for household use.

CRETACEOUS SPRINGS.

In the Cretaceous rocks of the Panhandle, which, as has been stated, occur only in limited areas in the extreme northwestern part of the State, there are two springs worthy of note. Both are situated in the valley of Coldwater Creek near the northern part of Dallam County.

Agua Fria Springs are located about 10 miles west of the Sherman County line. At this place Coldwater Creek has cut through the Tertiary deposits, here comparatively thin, and for 35 feet into the brownish-yellow Cretaceous sandstones and clays, which are exposed for 1½ miles along the creek. At several points in this distance the water issues from the bottom of the creek and collects in pools, finally forming a running stream.

Much more important from an economic standpoint are Buffalo Springs, which are located 17 miles east of the northwest corner of the State, at the point where two branches of Coldwater Creek unite. The stream has cut through the Tertiary deposits, exposing the Cretaceous sandstone and clay along both branches. Here a number of strong springs issue near the bottom of the valley. Their waters unite to form a stream which flows approximately 5 second-feet and which is utilized to irrigate 150 acres of alfalfa, garden, and trees. When not used for irrigation the water from the springs is allowed to run down the creek, and is sufficient to flow for 5 to 8 miles along the sandy channel before finally disappearing.

TERTIARY SPRINGS.

By far the most numerous and also the most important of all the springs in the Panhandle are those in which the supply of water comes from Tertiary rocks. These springs occur at numerous points along the edge of the High Plains where the water-bearing beds are exposed and in practically every ravine and canyon that has cut its way through the Tertiary deposits and into the underlying formations. The greater part of the springs are contact springs, issuing at the point of unconformity at the base of the Tertiary. If a well on the level plain penetrates a saturated zone, water is obtained, and if a stream in its downward cutting encounters the same zone a spring will result, as shown in fig. 3. So it happens that many of the small streams which are cutting their way headward into the High Plains in all directions encounter these water-filled gravel and sand beds in the Tertiary and permit the water to escape to the surface as springs. These springs are found in all parts of the Great Plains from Canada to Mexico and have played an important part in the economic development of the region. Numerous farm houses, ranches, factories, forts, and towns throughout this part of the United States have been located with reference to some Tertiary spring.

Tertiary springs are found in all parts of the Panhandle except on the level surface of the High Plains and in the bottoms of the larger stream valleys. In the southern part of the area both Palo Duro and Tierra Blanca creeks are fed by springs which issue from sand beds along the low bluffs near the bottoms of the valleys. Near the point where these creeks unite at Canyon each has a flow of approximately

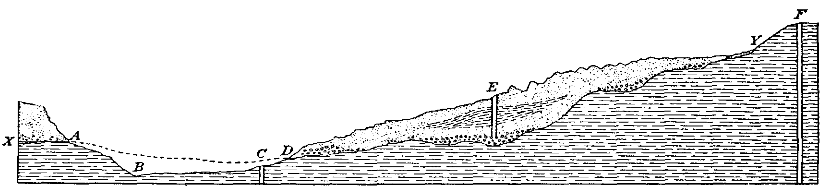


FIG. 3.—Ideal section of Tertiary springs. *A*, *D*, Tertiary springs; *C*, *F*, wells in red beds; *E*, well in Tertiary.

15 second-feet. As the canyon deepens numerous small branches, which rise on the level plain and cut their way downward through the Tertiary rocks, reach the zone of saturation and springs result. This condition is well illustrated on the head branches of Timber and Sunday creeks and on both North and South Canyon Cita creeks.

Practically every stream which enters Canadian River in this region is fed by Tertiary springs, but only the principal spring-fed creeks and a few of the most important springs can be mentioned.

North of Canadian River, Tertiary springs occur in considerable numbers along Big Blue Creek in eastern Moore County. They are also present on Plum and Big Canyon creeks, although not in large numbers, because these streams flow for the greater part of their course through the red beds. Ranch Creek is a perennial stream fed by Tertiary springs. Near Lee's ranch, 20 miles north of Amarillo, several strong springs issue from Tertiary sand wash in the valley of the Canadian. Pitcher Creek, though a relatively short stream, carries sufficient water to irrigate 50 acres of alfalfa, the entire amount being supplied by Tertiary springs. John Ray, Lahay, India, Corral, Sand, Casino, and Tascosa creeks are all fed by springs which issue near their heads at the base of the Tertiary. The amount of water, however, is rarely sufficient to keep the streams flowing continuously, and most of these creeks are dry sand beds for the greater part of the year. The town of Tascosa is supplied with water from a spring which issues from the Tertiary sand a short distance away. On Cheyenne Creek a lake has been formed by the construction of a dam across the stream, and the water is conveyed by gravity to the railroad station at Magenta, where it is used by locomotives. On Rita Blanca, Moneto, Minneosa, and several other smaller streams which enter the Canadian from the north, in the western part of the Panhandle, a number of strong Tertiary springs issue from the top of the red beds.

The creeks which empty into the Canadian from the south are also fed by springs which issue from the red beds and Tertiary contact along the northern edge of the Llano Estacado. In the eastern part of the region Turkey and Alibates creeks are supplied near their heads by Tertiary springs, but the water sinks into the sand before reaching the river. Chicken Creek is fed by springs which issue from sand dunes. Bonita Creek, which is supplied by Tertiary springs, flows a steady stream throughout the year, while Pedrosa Creek, a few miles farther west, receives water from a much smaller number of springs and is in consequence a dry sand bed. Both East and West Amarillo creeks receive water from Tertiary springs, as do Tecovas, Sierra de la Cruz, and Parker creeks, although in none of these streams is the amount of water sufficient to form a running stream all the year. Along the heads of the various branches of Alamosa Creek there are many Tertiary springs, near one of which is located the old L. S. ranch. On Skunk Arroyo and Alamositas Creek there are also numerous springs, some of which have a flow of nearly 1 second-foot. The spring at the old X I T headquarters, on Alamositas Creek, has been used for irrigation for a number of years. Springs occur at the foot of the plains on Las Achias Creek and on the various tributaries of Trujillo Creek, particularly Agua Piedra and Mujeres.

STREAMS.

The drainage of the Panhandle of Texas flows into Mississippi River. The extreme northern part is drained into Beaver Creek, one of the head tributaries of North Fork of Canadian River, and the central part is crossed by Canadian River. These two streams flow eastward across Oklahoma and unite before entering Arkansas River. The water from the southern part of the region flows into Palo Duro Creek, one of the head tributaries of Red River.

NORTH FORK OF CANADIAN RIVER.

Beaver Creek flows for 15 miles in a broad bend to the south in the northern part of Sherman County. It is here a dry sand bed for the greater part of the year.

Coldwater Creek flows from New Mexico into Texas and passes eastward across the northern part of Dallam and Sherman counties before turning to the north to enter Beaver Creek in Oklahoma. For the greater part of its course in the counties named Coldwater Creek is merely a dry sand bed. In two places, however, the stream has cut through the Tertiary deposits into the Cretaceous rocks below, and at these points springs issue, known as Buffalo and Agua Fria springs. (See p. 45.)

Palo Duro Creek (not to be confused with the stream of the same name farther south, in Palo Duro Canyon) rises in southern Sherman County and flows northeastward in a shallow valley on the level prairie. In this region the stream rarely contains water.

CANADIAN RIVER.

Canadian River flows eastward across the Panhandle just south of the center. It is the largest stream in this part of the Great Plains and has the largest drainage area of any stream in the district. It rises among the high peaks of the Rocky Mountains in northern New Mexico and flows southeastward as far as the vicinity of Tucumcari Mountain, New Mexico, where it turns to the northeast and continues in that general direction across Texas and into Oklahoma. In New Mexico it drains a large area and receives several tributaries of considerable size, but near the Texas line the drainage area decreases in width, and in its course across the Panhandle the stream has a relatively narrow valley, the distance between the heads of the short tributary creeks on opposite sides of the stream averaging not more than 35 miles.

For practically its entire course from northern New Mexico across Texas and Oklahoma into Indian Territory the Canadian is a wide sand-choked stream. The channel is filled with shifting quicksand and is noted for being the most treacherous stream of the plains. Part of the year the channel is dry or contains only a small amount of water in an otherwise dry sand bed, but frequently it is a raging torrent. Sudden and rapid rises are common but irregular. The channel may have been dry for weeks when, without warning, a wall of water several feet high may rush down the stream bed, carrying everything before it. The river may continue high, sometimes for days, sometimes for weeks, and then it will gradually subside and the channel again become dry. In this region the bed of the stream averages perhaps half a mile in width, although there are localities where the distance from bank to bank is more than a mile, and in a few places, where the river flows between high bluffs, the stream bed is constricted until it is not more than 200 yards wide. The banks are in most places low and sandy, except where the stream flows through a canyon bordered by bluffs, as, for instance, near the mouth of Trujillo Creek, not far from the New Mexico line, where the river flows for 10 miles or more between high bluffs of red shale capped with Alibates dolomite. Near the mouth of Amarillo Creek the same condition occurs, and in the eastern part of the region the Alibates dolomite is again carried up along an anticline and forms conspicuous bluffs averaging 200 feet high for 20 miles or more. In these localities the valley of the river is comparatively narrow.

The water of the Canadian is usually turbid, and, particularly in times of freshet, red. The color is derived from the red-beds clays over which it passes, and is so marked that in its upper course the stream is known as Red River.

In the western part of the Panhandle the Canadian receives about 50 tributary creeks, the greater part of which are relatively short, only four being more than 20 miles in length. Of those which enter from the north the most important are Big Blue, Plum, Big Canyon, Saddlehorse, Fort, Ranch, Pitcher, John Ray, Lahay, Corral, Sand, India, Casino, Piscodo, Tascosa, Rica, Cheyenne, Rita Blanca, Moneto, Pedroza, Antelope, Minneosa, and Caballo. From the south the larger tributaries are Turkey, Alibates, Short, Molyneux, Coietas, Chicken, Bonita, Pedrosa, East Amarillo, West Amarillo, Horse, Tecovas, Sierra de la Cruz, Cottonwood, Parker, Alamosa, Skunk, Alamositas, Las Achias, and Trujillo creeks. Perhaps half of these streams flow all the year; some are always dry except after heavy rains, and others are intermittent. The water in the majority of them is derived from Tertiary springs near the heads of the creeks, and is consequently fresh. In a few creeks, however, particularly Big Canyon, Saddlehorse, and Alibates, in the eastern part of the region, the water, which comes largely from springs in the Permian red beds, contains gypsum and other salts in greater or less proportions, so that it is not suitable for irrigation or domestic uses.

RED RIVER.

A considerable part of Deaf Smith and Randall counties, in the southern part of the region, drains into Red River through Tierra Blanca and Palo Duro creeks. These streams, which rise as shallow prairie draws on the highest portion of the Llano Estacado in eastern New Mexico, pass into Texas, and for a distance of 25 miles in Deaf Smith County carry no water except after heavy rains. Near the center of this county the streams cut into Tertiary deposits and springs appear low down in the valleys. These springs increase in number and size as far as the junction of the two creeks at Canyon, where each creek carries about 15 second-feet of water. From this point to the east line of Randall County Palo Duro Creek flows in a deep canyon. In this part of its course it receives the water from a number of short creeks fed largely by Tertiary springs. The largest of these are Timber, Sunday, and Canyon Cita creeks, which empty from the south and drain the southeast corner of Randall County.

DRAINAGE OF THE HIGH PLAINS.

A considerable portion of the High Plains region does not drain into any stream. This part constitutes the original level of the High Plains, "unscored by drainage, yet standing in relief," from which there is practically no run-off. The headwaters of the small creeks tributary to Canadian River and Palo Duro Canyon are working their way headward into this level plain and a few meandering shallow draws, such as those which form the upper courses of Coldwater, Perico, and Tierra Blanca creeks, traverse the plain in various directions; but by far the greater part has not yet been encroached on by stream channels.

The supply of rainfall on the greater part of the High Plains is collected in shallow saucer-shaped depressions known as "lakes" or as "playa lakes," which are scattered at irregular intervals on the plains. These depressions vary in size from the ordinary "buffalo wallow," a few feet across and a foot or two deep, to lakes several hundred rods in diameter, sunk 20 to 40 feet below the general surface level. In Deaf Smith County, for instance, there are a number of these depressions, each of which occupies an area of more than a square mile. In several instances, particularly in localities near the edge of the plains, the depressions are deep and bowl-shaped. Many of the lakes are perennial and afford an abundant supply of stock water throughout the year; others are ephemeral, being filled by rains and soon becoming dry; while still others contain water only rarely. These lakes occur on the plains with no regularity; in some localities there are none for miles, while in others there are scores in a single township.

Many of the larger depressions have drainage basins, some of which are several square miles in area. The traveler crossing the High Plains not infrequently encounters a shallow draw on the level surface along which after a heavy rain the water is carried to a near-by lake. Few of these small stream beds, however, exceed a mile or two in length and 10 feet in depth.

The influence of these lakes on the settlement of the country has been important, for on the High Plains the matter of water supply is vital. In the early history of the Panhandle, before wells had been sunk, these lakes constituted practically the only supply. Wagon trains in crossing the Llano Estacado came to camp beside lakes which always contained water, and many of the first "cow camps" were located in similar positions. In a number of instances a town grew up at the site of the cow camp, and to-day some of the largest of the county seats in the Panhandle, such as Amarillo, Hereford, Panhandle, Clarendon, and Claude, owe their location to the presence of lakes on the High Plains.

IRRIGATION.

NECESSITY FOR IRRIGATION.

The part of Texas to which this report relates is located in the semiarid belt of the Great Plains. At Amarillo the annual rainfall for twenty years has averaged 21.94 inches. At Albert, N. Mex., west of this region, the average annual precipitation for fourteen years was 16.32 inches. This amount, however, is very irregularly distributed, the greater part of it falling in a few violent rains. During certain seasons there is little or no rainfall, and occasional years of drought occur, during which the precipitation does not exceed 15 inches. The soil is extremely fertile and wherever water can be obtained is capable of producing abundant crops.

Farming has often been attempted on the High Plains. In former years the field crops like those raised farther east, such as wheat, cotton, corn, oats, and the ordinary garden vegetables, were planted in many parts of the Panhandle. Occasionally such a crop matured, but more often sufficient rainfall at critical periods was lacking and the result was failure. At present very few attempts are being made to raise ordinary farm crops, cultivation being restricted to such forage plants as milo maize, kaffir corn, and sorghum, which mature with a minimum of moisture. In seasons of average rainfall these forage plants produce practically as many bushels of grain per acre as do ordinary farm crops in more humid regions, and each year the acreage of such crops is increasing. There is a Government experiment station at Channing, in the western part of the Panhandle, where experiments have been conducted during the last few years with grains such as macaroni wheat and spelt, brought from semiarid regions in other parts of the world, notably from southern Russia, in the endeavor to obtain plants that would mature and produce staple crops in this part of the High Plains.. It is very probable that within the next few years, as suitable crops are found and more intelligent methods of farming are introduced, the Panhandle will produce without irrigation many times the amount of grain raised at the present time. It is doubtful, however, if the ordinary field crops raised in the Eastern States will ever be successfully produced here.

It is obvious, however, that in a region with climatic conditions such as those just described irrigation would be a great aid to successful farming and the ultimate development of the region. This fact has not escaped the attention of the inhabitants and in a number of localities in the Panhandle irrigation on a small scale has been attempted, the source of supply in most cases being a creek fed by Tertiary springs. Up to the present time, however, no large system of irrigation has been planned.

SOURCES OF WATER SUPPLY.

There are at present four sources of water supply for irrigation in the Panhandle of Texas, viz, streams, springs, storm waters, and wells. None of these, however, except the streams, has been used extensively.

Irrigation from streams.—In this region very few streams carry sufficient water for irrigation on a large scale. The Canadian is the only river which has its source in the Rocky Mountains, and, as has been stated, its flow is very irregular, being sometimes a rushing torrent and again for long periods almost or quite dry. There is no gaging station on the Canadian in Texas, but the following records, taken at Logan, N. Mex., a few miles west of the State line, indicate the extreme variability of the river.

Discharge measurements of Canadian River near Logan, N. Mex.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Sq. feet.*	*Ft. per second.*	*Feet.*	*Sec.-feet.*
1904.						
June 29	W. G. Russell	245	64	0.87	0.55	56
August 10	do	388	1,400	5.32	4.50	7,446
October 2 [a]	do		13,520	11.05	31.30	149,400
October 22	do	119	174	3.72	3.00	647
1905.						
October 10	E. Patterson	30	22	.61		14
November 20	do	43	43	1.70		73

[a] October 2, 1904, one of the most disastrous floods in the history of the river occurred, destroying most of the wagon and railroad bridges along the entire course of the stream. The normal discharge except in time of floods is probably less than 100 second-feet.

It appears that the water in the Canadian is sufficient, if all is utilized, to irrigate many thousands of acres, but unfortunately under present conditions it does not seem possible to make it available. In most cases the difficulties of storage would be great. Dam sites are rare on most of the streams of the Great Plains and so far as known none are available on the Canadian in the Panhandle of Texas. The channel is broad and shallow and filled with sand, in places, to considerable depths. For instance, at the point where the Fort Worth and Denver City Railroad crosses the river between Tascosa and Channing, in northeastern Oldham County, the sand was found to be 160 feet deep.[a] The scarcity of suitable building

[a] On the authority of the bridge foreman.

materials is a serious problem over a great part of the High Plains, but in this region this difficulty does not exist, for there is at various localities an abundance of dolomite and sandstone, of which masonry dams might be constructed. But even if it were possible to build reservoirs the river valleys contain few areas of any considerable size capable of being irrigated. The flood plains are in most places narrow, or, if wide, are generally composed of sandy soil across which it would be difficult to carry water in ditches. All of these conditions lead to the conclusion that irrigation on a large scale can not be successfully practiced along the Canadian in the western part of the Panhandle.

Irrigation along Palo Duro Canyon in eastern Randall County is not feasible because the canyon is so narrow that there are no sufficiently large areas suitable for irrigation. The supply of water in this canyon approximates 20 second-feet, an amount sufficient to irrigate a considerable area if land were available.

For a number of years irrigation on a limited scale has been successfully practiced along some of the smaller streams in the region. In almost every instance the stream so utilized is fed by Tertiary springs. Along various tributaries of the Canadian in northern Potter County several projects have been in successful operation for some time. At the headquarters of the L. X. ranch, 25 miles northeast of Amarillo, the water from Bonita Creek is utilized to irrigate 150 acres of alfalfa, and on the same ranch, a few miles farther west, the water from Pitcher Creek is utilized in the same way. On Palo Duro and Tierra Blanca creeks in western Randall and eastern Deaf Smith counties there are several small irrigation plants. A number of other creeks in the region carry sufficient water to irrigate considerable areas, and as the country becomes more densely populated there is little doubt that year by year a greater percentage of this surplus water will be so utilized.

Irrigation from springs.—A considerable number of springs in this region can be utilized for irrigation purposes. In several instances this has been done, but in most of such cases there are several springs close together, the combined flow of which is taken. At best, however, irrigation from springs in the Panhandle must be confined to limited areas, for the amount of water flowing from a single spring is in no case large.

At Buffalo Springs, near the Oklahoma line, in northwestern Dallam County, irrigation has been in successful operation for more than ten years. The water, which has its origin in the Dakota sandstone, issues at a number of vents along two branches of Coldwater Creek, and half a mile below the junction of the two branches a ditch has been led off to irrigate 150 acres of alfalfa and garden. The amount of water at this place is approximately 5 second-feet.

At Tascosa, the county seat of Oldham County, strong Tertiary springs furnish the water supply for the town, and at various times irrigation has been practiced. At the farm of J. M. Morris, half a mile east of Tascosa, where the water from a Tertiary spring is utilized to irrigate an orchard and garden, good results have been obtained. At the old X I T headquarters on Alamositas Creek several acres have been irrigated from a Tertiary spring, and on Rita Blanca and Minneosa creeks small irrigation plants have been established at various times.

There are in the region hundreds of Tertiary springs with flows of 1 second-foot or less which at present are not utilized. On many of the numerous tributaries of Canadian River there are scores of such springs. As settlement increases it may be confidently expected that those who come into the country will take advantage of these natural irrigation sites and that within the next decade irrigation from springs will be greatly developed.

Irrigation from storm waters.—As has been stated, much of the rainfall of the Panhandle occurs as dashing showers at irregular intervals, chiefly during the spring and summer months. After a shower the water on the High Plains accumulates in shallow sags, and the greater part eventually finds its way into the broad, shallow lakes which are scattered over the plains. Among the breaks it passes into the smaller streams which empty into Canadian River or Palo Duro Creek. In numerous places the sags on the plains or the dry channels among the breaks have been dammed, forming reservoirs known locally as "tanks," to hold stock water. In several instances a ditch has been led out of one of these artificial ponds to irrigate a few square rods of garden or orchard. During the last few years the number of such plants has increased, and while it is obvious that irrigation of this character can never be practiced on a large scale it is nevertheless possible for hundreds of families in the region to be provided by this means with home-grown vegetables and fruit.

Irrigation from wells.—In the discussion of artesian water in another part of this report the conclusion was reached that the prospects for an artesian supply over the greater part of the Panhandle of Texas were not good. On the other hand, ordinary wells, which are common in all parts of the region, furnish as a rule more water than is needed for stock and domestic use. In most of the wells on the plains the supply is practically inexhaustible with ordinary windmill pumping, and the surplus above what is used for the purposes named might well be utilized for irrigation. In many places the chief difficulty in the way of such utilization is the expense of lifting the water to the surface. In this region wind power is almost universally used for this purpose, and in localities where wells are shallow (as, for instance, along stream valleys or in the vicinity of Hereford, in Deaf Smith County, where the water is not on an average more than 60 feet below the surface) it has been found profitable to use well water for irrigating small areas.

In the greater part of the Panhandle, however, the water is too deep to be available. As has been stated, the average depth of the wells on the High Plains is over 200 feet and in some localities the water is 400 to 500 feet below the surface. It is obvious that under such conditions little more can be done than to irrigate a garden or an orchard, and so far as observed this is all that has ever been attempted. Examples of this method of irrigation are not uncommon in many parts of the region, many ranchmen having a small garden irrigated from a deep well.

FUTURE OF IRRIGATION.

The local conditions being taken into account, there is little reason to suppose that there will ever be any extensive irrigation works constructed along the streams in this region. The supply of water is insufficient except in Canadian River and Palo Duro Creek, and on neither of these streams are the conditions such that large irrigation projects could be successfully carried out. Small streams, springs, artificial ponds, and wells supply water for limited irrigation—sufficient in many cases to raise vegetables and fruit for a family and even to irrigate several acres of field crops. But there is little to warrant the hope that change of climatic conditions will cause the water supply of the Panhandle to increase, and unless some means more efficient than the ordinary windmill be obtained to lift the water from deep wells, it is extremely improbable that extensive works can ever be installed. On the other hand, it is obvious that only a small part of the available water is now being utilized and it is possible that the future will witness in this region thousands of small pumping plants, each capable of supplying sufficient water to irrigate a small tract. By the utilization of spring waters now allowed to go to waste and of surplus water from wells it will be possible to secure home comforts otherwise unattainable.

WATER CONDITIONS BY COUNTIES.

GENERAL STATEMENT.

Of the eight counties under discussion the four lying farthest east—Sherman, Moore, Potter, and Randall—are each 30 miles square, while the four lying to the west, touching the New Mexico line, are 30 miles north and south and approximately 48 miles east and west. The usual system of public-land surveys, so common in the central and western parts of the United States, is not employed in Texas for the reason that when this State came into the Union by annexation it retained its own public lands. There are no regular section, township, or range lines, but the land has been laid off into irregular blocks and subdivided into tracts containing either a square mile or a league. Some of the earlier surveys employed the Spanish vara, which equals 33.385 + inches; 1,897.7 + varas equal 1 mile. No accurate base maps of the region are available; that which forms the basis of Pl. III was compiled from a number of county maps.

SHERMAN COUNTY.

Topography.—Sherman County is situated in the northeastern part of the region and is bounded on the north by Oklahoma. Its surface is generally a level plain with a mean elevation of 4,000 feet, sloping gradually to the east. Beaver Creek has eroded a valley averaging half a mile wide and 100 feet deep for 5 miles through the northern part. Coldwater Creek flows eastward across the county north of the center in a meandering valley 50 feet deep and a quarter of a mile wide. In the southeast corner is the head of Palo Duro Creek, here only a shallow draw.

Geology.—The rocks of Sherman County are all of Tertiary and Quaternary age, this being the only county in the region in which pre-Tertiary rocks are not exposed on the surface. White cliffs of Tertiary clay outcrop here and there along the creeks, but throughout the greater part of the county few rocks are exposed, the surface being everywhere covered with a thick sod carpet of buffalo grass.

Water supply.—Beaver, Coldwater, and Palo Duro creeks are tributary to North Fork of Canadian River, but, except after local rains, rarely contain any water. Numbers of shallow "lakes" are scattered over the surface in nearly all parts of the county, into which is gathered the greater part of the rainfall, to remain until it evaporates or soaks into the ground. The surface is level, with few canyons where erosion has exposed the water table; consequently there are few springs. Well water is abundant in all parts of the county, and because of the absence of springs and running streams is depended on entirely for water supply. The depth of the wells varies considerably. At Stratford, the county seat, the court-house well found water at a depth of 230 feet, while from 15 to 18 miles south of the town a number of wells vary from 300 to 400 feet in depth. North of Stratford the wells average 250 feet and a few miles farther east from 175 to 225 feet in depth. A few wells located in the valley of some creek, such as Beaver or Coldwater, are not more than 60 feet deep, but on the High Plains most wells are more than 150 feet in depth. The average depth of 28 wells in different parts of the county is 197 feet.

DALLAM COUNTY.

Topography.—Dallam County is located in the northwest corner of Texas, and is bounded on the north by Oklahoma and on the west by New Mexico. The surface is a level plain sloping eastward from an elevation of 4,800 feet near the northwest corner, the highest elevation in the Panhandle, to approximately 4,100 feet in the northeast corner, an average slope of 12 feet to the mile. Coldwater Creek in the north and Perico and Carriso creeks in the southwest have cut shallow valleys into the level upland plain.

Geology.—The greater part of the surface rocks of Dallam County are of Tertiary origin, and where exposed along the bluffs of shallow stream valleys exhibit the ordinary white clay cliffs, with a few ledges of sand, gravel, and pebbles. In the southwest part of the county there is a sandy region with low irregular dunes. Along some of the creek beds in the northern and western parts, where erosion has removed the Tertiary deposits, Cretaceous rocks, consisting of beds of soft yellow to brown sandstone interbedded with shales, are exposed here and there. These exposures occur on Coldwater Creek at Buffalo and Agua Fria springs, at a point near the New Mexico line in the extreme northwest, and near Texline on both the north and south branches of Perico Creek.

Water supply.—Across the county from northwest to southeast flow three shallow creeks—Coldwater, Perico, and Carriso. Coldwater Creek, which is locally known as Rabbit Ear Creek from the fact that it rises in the Rabbit Ear Mountains, flows in a meandering valley across the northern part of the county. It carries water only below the points where Cretaceous springs occur. Perico and Carriso creeks, which rise among volcanic peaks on the High Plains of northeastern New Mexico, flow southeastward across Dallam County and unite near Dalhart, forming Rita Blanca Creek, a tributary of the Canadian. Both Perico and Carriso creeks are shallow sand draws and rarely contain water. The greater part of the rainfall soaks into the ground or flows into prairie lakes, where it evaporates.

The only springs of importance in Dallam County are Buffalo and Agua Fria (see p. 45), both of which are located on Coldwater Creek. They issue from Cretaceous rocks exposed near the creek bed, and after flowing for a few miles disappear beneath the sands. The flow from Buffalo Springs approximates 5 second-feet; that from Agua Fria Springs is not nearly so great, perhaps less than 1 second-foot.

Wells are common in all parts of Dallam County. By far the greater part of them have been drilled for stock water by the Capitol Land and Cattle Company, the owners of the noted X I T ranch, which formerly contained 3,000,000 acres of land located in ten of the counties of northwestern Texas. In the northwestern part of Dallam

County, where Cretaceous rocks approach the surface and the superficial Tertiary deposits are thin, water is found at comparatively shallow depths. Some wells here encounter a supply ample for stock and domestic use at 10 to 25 feet, but the greater number go down for 75 to 100 feet. Farther southeast, where the Tertiary deposits are thicker, the depth to water increases, and in the region north of Dalhart in the south-central part of the county much of the water is found at depths ranging from 250 to 400 feet. In one area 15 miles square in this vicinity the average depth of the wells is 400 feet. The average depth of 27 wells in Dallam County is 212 feet.

HARTLEY COUNTY.

Topography.—Hartley County lies south of Dallam, being the second from the north in the western tier of counties in the Panhandle. The surface for the greater part slopes gradually to the south and east. All of the county is typical of the High Plains, except certain areas in the southern part, which lie in the breaks along the heads of various creeks flowing southward into Canadian River. In this region the heads of these streams have cut into the flat upland, forming numerous shallow valleys. The valley of Rita Blanca Creek, which averages 75 feet in depth and a mile in width, extends from north to south across the eastern part of the county.

Geology.—The greater part of the surface rocks in Hartley County are of Tertiary age. Along the upper courses of some of the creeks which rise in the High Plains in the southern part and flow southward into the Canadian are white cliffs composed of Tertiary clay. A considerable part of the western half of the county contains low sand dunes derived from Tertiary sand. Triassic red beds are exposed along the streams in the southern part of the county where Tertiary deposits have been eroded.

Water supply.—Rita Blanca Creek is the largest stream in Hartley County. It is a typical High Plains stream and is formed by the junction of Perico and Carriso creeks, which unite near Dalhart at the north line of the county. Neither of these creeks carries water except after heavy rains, and Rita Blanca throughout the greater part of its course southward across Hartley County is merely a dry sand bed. At a point about 15 miles above the mouth of the creek the stream cuts through the Tertiary rocks and exposes the underlying red beds, which outcrop along the creek from this point to the river. Springs, which issue at the line of unconformity, furnish sufficient water to produce a running stream below this point for the greater part of the year. Punta de Agua Creek, which flows eastward and empties into Rita Blanca Creek in the southern part of the county, is ordinarily a dry sand bed. Its chief tributary, Middlewater Creek, carries little or no water except after heavy rains.

Besides Rita Blanca and its tributaries some of the streams which rise in Hartley County and flow southward into Oldham County before reaching the Canadian are the following: Tascosa, Rica, Cheyenne, Moneto, Pedroza, Antelope, Minneosa, and Caballo. On the High Plains in the northern and central parts of the county there is no run-off, and the water derived from rainfall either soaks immediately into the ground or passes into shallow lakes, whence it is slowly evaporated.

Springs, mostly of Tertiary origin, are found along certain creeks in the southern part of Hartley County. Some of these springs issue at the red beds—Tertiary contact, and some from a sandy stratum in the Tertiary. Much of the water that supplies Tascosa, Cheyenne, Rita Blanca, Antelope, and Minneosa creeks comes from Tertiary springs in southern Hartley County. In general these springs are not particularly strong, averaging perhaps not more than one-tenth to one-fourth second-foot, but the water derived from them is sufficient for stock, so that in this vicinity wells are not as common as on the High Plains farther north.

In the northern and northeastern parts of Hartley County the depth to water varies from 250 to 400 feet. Near Hartley, east of the center of the county, the wells are 350 to 375 feet deep, and at Channing, the county seat, their average depth is 300 feet. In the western part of the county, in what is known as the Middlewater district, water is found at depths varying from 160 to 200 feet. Among the breaks in the southern part of the county the wells vary from 10 to 150 feet in depth. At Willow Springs ranch, 12 miles west of Channing, an artesian well is reported. The records of 76 wells in all parts of Hartley County show an average depth of 240 feet, a greater average depth than in any other county in this part of the Panhandle.

MOORE COUNTY.

Topography.—Moore County is situated south of Sherman and east of Hartley. It is the second county south of Oklahoma and the second east of New Mexico. Its greater part lies on the High Plains, at an elevation varying from about 4,000 feet in the northwest corner to a little less than 3,000 feet along Canadian River in the southeastern part. The latter elevation is the lowest in the region to which this report relates. In the southern and southeastern parts of the county the topography is rough, the High Plains being dissected by several short creeks tributary to the Canadian, which crosses the extreme southeast corner of the county. Several of these creeks, particularly Big Blue and its tributaries, have carved narrow, steep-sided canyons in places as much as 200 feet deep.

Geology.—Throughout the greater part of Moore County only Tertiary rocks are exposed on the surface. White Tertiary cliffs occur in the breaks near the heads of various creeks, and in certain localities low sand dunes are found. Permian red beds outcrop along the Canadian and on the lower course of Big Blue Creek, both the Greer and Quartermaster formations being exposed. A prominent member of the Quartermaster formation is the Alibates dolomite lentil, which forms the escarpment of the canyon of Big Blue Creek. The Alibates is also conspicuously exposed on the bluffs along the river.

Water supply.—The drainage of Moore County flows southeastward into the Canadian. This river, which flows for 3 miles across the southeastern part of the county, is here contained between high bluffs of red clay capped by the Alibates dolomite. Big Blue Creek, which drains a considerable area in the central and southeastern parts of the county, is formed by two branches, both of which begin as flat draws on the High Plains. In the course of their development they have cut through the Tertiary deposits, exposing the water table, whence springs issue. From this point to its mouth, just across the line in Hutchinson County, Big Blue Creek is a running stream. Farther west are Corral, Sand, India, and Casino creeks, which rise in Moore County and pass into Potter County before emptying into the Canadian. All these streams are fed by Tertiary springs and contain water for parts of their courses only. A considerable portion of central and northern Moore County has no drainage except into lakes on the High Plains.

Most of the springs in Moore County occur in the southern and southeastern parts near the heads of the creeks just mentioned, particularly Big Blue Creek. As a rule, they issue at the Tertiary and red beds contact, but a few start at a higher horizon. Their water is almost uniformly fresh and pure. The flow from any one spring is in few cases large, but the aggregate from the hundreds that occur in the region is considerable, so that not many wells are necessary to furnish stock water. Springs in the red beds occur along the Canadian and the creek valleys. The water from some of these springs is fresh, but in most cases it contains a sufficient amount of mineral salts, chiefly gypsum, to make it unpalatable and even to render it unfit for domestic use.

Few of the wells which have been bored on the High Plains in the central, northern, and western parts of Moore County fail to obtain an abundant supply of water. At Dumas, the county seat, wells are 260 feet deep. East of Dumas they are from 160 to 200 feet deep, while in the western part of the county the average is 240 to 300 feet. Near the northern line the depths vary from 150 to 225 feet, and along Blue Creek and in the breaks in the southern part of the county they average from 10 to 100 feet. There is an artesian well on Big Blue Creek in the eastern part of the county, the water of which probably comes from the Triassic formations below the Tertiary. In the red-beds area in the valley of the Canadian, where but few wells have been sunk, the water is generally poor. The average depth of 36 wells in Moore County is 161 feet.

POTTER COUNTY.

Topography.—Potter County is situated west of the center of the Panhandle, in the third tier of counties from the Oklahoma line, and the second tier east of New Mexico. Its extreme southern part only is on the High Plains; the Canadian flows eastward across the northern part. The greater part of the county lies in the breaks of the Canadian, and the topography is consequently rough, being characterized by rounded hills and knolls and in places by rather narrow, steep-sided canyons and intervening slopes. Sand dunes occur on Chicken Creek and neighboring streams in the northern part of the county and on the slope north of Canadian River.

Geology.—Both Tertiary rocks and red beds are well exposed in Potter County. On the High Plains near Amarillo, in the southern part of the county, the rocks are the ordinary High Plains Tertiary. Near the edge of the Llano Estacado there are conspicuous cliffs of white clay, while farther north in the breaks, particularly along the divides between the small creeks, are rounded knolls and small ridges, many of them covered with smooth waterworn pebbles, weathered out from the lower members of the Tertiary. Along the river and most of the tributary creeks both Permian and Triassic red beds occur, all the members of both series from the Greer gypsum to the middle sandstone of the Trujillo formation being well exposed. Prominent cliffs of red shale occur in various localities, capped here by the Alibates dolomite and there by the lower sandstone of the Trujillo.

Water supply.—The channel of Canadian River, the largest stream in Potter County, averages half a mile in width. The banks are for the most part low and sandy, although in certain localities—as for instance, near the mouths of Bonita and Amarillo creeks—steep bluffs occur, capped usually with Alibates dolomite. As has been stated, the channel is usually dry, but the river is subject to sudden and rapid rises, in which great quantities of water pass down the stream in a few hours. The chief tributary creeks which enter the Canadian from the north in Potter County are Plum, Big Canyon, Saddlehorse, Fort, Ranch, Pitcher, John Ray, Lahay, Corral, Sand, India, and Casino, while those from the south are Turkey, Alibates, Short, Molyneux, Coietas, Chicken, Bonita, Pedrosa, East Amarillo, West Amarillo, Horse, Tecovas, and Sierra de la Cruz. Practically all of these creeks rise as shallow sand draws on the High Plains and flow toward the river, finally cutting through the Tertiary deposits and into the red beds before reaching the main stream. Most of them have water in their lower courses only; a few are dry except after heavy rains; while others, notably Bonita, Ranch, and Pitcher creeks, have sufficient water all the year for a small amount of irrigation. On the High Plains in the southern part of the county there are a number of lakes into which the surplus water from rainfall collects and remains until it evaporates.

Springs occur in Potter County chiefly at the usual horizon, viz, the line of unconformity at the top of the red beds. Water from the Tertiary deposits of the High Plains both north and south of the river comes to the surface at this level and issues as springs which supply the creeks mentioned above. Few individual springs afford more than one-fourth or one-half second-foot of water, but the aggregate from the great number of springs is considerable, as illustrated by such streams as Bonita, Chicken, Ranch, and Pitcher creeks, each of which flows several second-feet. Springs also occur in the red beds in this county. As a rule the water from those in the Triassic formations is good, but much of that from the Permian beds contains appreciable amounts of mineral salts and is unfit for domestic use.

Very few wells have been put down in Potter County except on the High Plains in the southern part. In the breaks along the river an ample supply of water for both stock and domestic uses and in many places a surplus for irrigation is furnished by springs. At Amarillo, the county seat, the wells average 240 feet in depth. Farther east, in the direction of Panhandle, their depth increases in some cases to 300 or 350 feet. An average of 23 records obtained in this county is 260 feet, but this average is misleading, for in the breaks near the river, where wells are not common, those that have been put down are relatively shallow, not averaging more than 50 feet, so that for the entire county the average depth is perhaps not more than 150 feet.

OLDHAM COUNTY.

Topography.—Oldham County is located on the west line of the State, being the third county south of Oklahoma. Its topography is very similar to that of Potter County. The southern part lies on the High Plains, and Canadian River flows eastward near the northern line. Thus the greater part of Oldham County lies on the slope south of the river, and into this slope a number of short creeks, flowing northward, have cut minor valleys, producing a rugged topography. North of the Canadian also the country is broken. In the western part of the county the Canadian flows between cliffs of red shale 150 feet high, capped by the Alibates dolomite, and in the same region a number of creeks have cut canyons through this formation.

Geology.—The rocks of Oldham County are all red beds or Tertiary deposits. Along the river near the mouth of Trujillo Creek the

Quartermaster formation is exposed and with it the Saddlehorse gypsum and Alibates dolomite lentils, the latter forming the cap of conspicuous bluffs for miles along the various streams. Most of the red beds, however, are of Triassic age, both the Tecovas and the Trujillo formations being well exposed along the river and in the valleys of the various creeks, extending in places as far back as the edge of the High Plains. Along the creeks red clays and gray and yellow sandstones are conspicuous. Near the mouth of Trujillo Creek the variegated shales of the Tecovas formation are represented by a ledge of soft yellow to red sandstone containing fossil wood. The High Plains in the southern part of the county are composed of Tertiary rocks, as are also the divides between many of the creeks. The northern edge of the Llano Estacado in this county is in most places a cliff 50 to 200 feet high, composed of white clay. Along the slopes and on the smaller divides smooth waterworn pebbles cover the ground and gravel points are common.

Water supply.—Oldham is the best watered county in the western part of the Panhandle. Canadian River, which flows eastward across its northern part, is in most places a broad, shallow, sand-choked stream, often dry, but subject to rapid rises. Along a part of its course in Oldham County the river is narrow and is contained between bluffs 100 to 140 feet high. In general, however, its valley is from 1 mile to 2 miles wide. Numerous tributary creeks which rise near the edge of the High Plains enter from both north and south. Those from the north are Piscodo, Tascosa, Rica, Cheyenne, Rita Blanca, Moneto, Pedroza, Antelope, Minneosa, and Caballo. Of these Rita Blanca, the most important stream, is formed by the junction of Carriso and Perico creeks in southern Dallam County and flows entirely across Hartley County before entering Oldham. Practically all the creeks mentioned rise in Hartley County and are fed by Tertiary springs, so that in their course in Oldham County they are running streams for at least part of the year. Cottonwood, Parker, Alamosa, Skunk, Alamositas, Las Achias, and Trujillo creeks enter Canadian River on the south. Trujillo Creek, which is the largest, rises at the base of the High Plains in New Mexico and flows northeastward, receiving as tributaries Mujeres and Agua Piedra creeks before joining the river. Alamosa Creek is also a large stream and drains a considerable area. All of these streams are spring fed, but in most of them the water sinks into the sand before reaching the river.

Springs occur along all the streams in Oldham County, and particularly in the region south of the river hundreds issue at the Tertiary and red beds contact or from sandy beds in the Tertiary deposits. A notable example of a Tertiary spring is the one near Alamositas Creek at the old X I T ranch headquarters, which flows half a second-foot. Another valuable spring on Skunk Arroyo, a few miles east of the one on Alamositas Creek, flows more than 1 second-foot. Strong Tertiary springs occur on Las Achias, Trujillo, Caballo, Minneosa, and Alamosa creeks.

Springs from the red beds are common. On Sierra de la Cruz, Parker, and Alamosa creeks the water issues in places from beneath the various sandstone ledges of the Trujillo formation and in places from joints in the red clay. On Las Achias Creek a number of strong springs issue near the Alibates dolomite. All the Tertiary springs and the majority of those from the red beds in Oldham County supply fresh water. The water from a few springs which issue in the Permian red beds, however, contains gypsum and other mineral salts.

Wells are not common in Oldham County, except on the High Plains near the southern line, for the reason that springs are abundant in most localities and furnish an ample supply of stock water. North of the river there are a few wells which average 100 to 150 feet in depth. On the Llano Estacado in the southern part the average depth is 200 feet, varying from 160 to 245 feet. The average depth of 12 wells in Oldham County is 160 feet.

DEAF SMITH COUNTY.

Topography.—Deaf Smith County, the southwesternmost county in the region, is bounded on the west by New Mexico and is the fourth county south of Oklahoma. All of it is situated on the Llano Estacado except the extreme northwest corner, which lies in the valley of Trujillo Creek at the foot of the plains. The shallow channels of Palo Duro and Tierra Blanca creeks each follow a meandering course eastward across the county. At the eastern line these streams have cut canyons averaging 50 feet in depth and a quarter of a mile in width.

Geology.—The rocks of Deaf Smith County are chiefly of Tertiary age, but, as is usual on the High Plains, very few outcrops occur. In the northwestern part of the county, at the edge of the Llano Estacado, there are cliffs 100 to 150 feet high composed of white Tertiary clay, and at the foot of the plains in the same locality ordinary pebbles are found. Red beds of Triassic age occur at the foot of the plains along the various small tributaries of Trujillo Creek.

Water supply.—Streams are rare in most parts of Deaf Smith County. A few small creeks, all of which flow northward into Trujillo Creek, rise at the foot of the High Plains in the northwestern part. On the Llano Estacado Palo Duro and Tierra Blanca creeks flow entirely across the county from west to east. Both of these streams have their origin in New Mexico as shallow draws on the level plains and extend for more than 30 miles before carrying any water in their channels. About 15 miles from the eastern line of the county both streams have cut down to the water table and springs begin to appear along the creek beds, increasing in both number and volume until at the point where they leave the county each creek carries approximately 5 second-feet of water. Most of the rainfall flows into the numerous lakes, which include some of the largest in the Panhandle.

A few springs issue from the red beds and Tertiary contact at the foot of the plains in the northwestern part of the county, but none of them are of any great importance. Hundreds of springs issue along the beds of Palo Duro and Tierra Blanca creeks in the eastern part. The water of these evidently does not issue as usual from the unconformity at the base of the Tertiary deposits, but from sand and gravel strata in the Tertiary. Few of the springs are strong, but the aggregate flow from the great number that occur is considerable.

Wells are abundant in Deaf Smith County. At the foot of the plains in the northwestern part there are a few wells averaging 80 feet in depth, which obtain water in the red beds; this water is usually not good. On the plains the depth varies considerably in different localities. In the western part 13 wells average 254 feet, varying from 155 to 375 feet. In the northeastern part wells vary from 100 to 150 feet in depth. Near Hereford, the county seat, in the southeastern part, water is shallower than on any part of the High Plains south of the Canadian in this region, the average depth being 60 feet. In the town of Hereford there are nearly 200 windmills. The average depth of 21 wells in the eastern part of the county is 71 feet, while southwest of Hereford the depth to water is in places 300 feet or more. The average depth of 120 wells in all parts of Deaf Smith County is 94 feet, being the lowest of all the counties in this part of the Panhandle.

RANDALL COUNTY.

Topography.—Randall is the southeasternmost county in the region to which this report relates. The surface is a level plain trenched in its eastern part by the deep gorge of Palo Duro Canyon. The canyon proper, which begins near Canyon, not far from the center of the county, is formed by Palo Duro and Tierra Blanca creeks, both of which, in the western part of the county, flow in valleys averaging 100 feet in depth and half a mile in width. From the junction of these two streams the canyon deepens steadily until at the eastern line of the county it is 800 feet deep. Throughout a considerable part of its course this canyon is not more than a mile wide, with steep, in many places, precipitous sides. Several smaller streams which enter from the south, notably Sunday, Timber, and Canyon Cita creeks, have cut short canyons which at their mouths are as deep as the main canyon.

Geology.—On the High Plains and along the upper part of Palo

Duro Canyon only Tertiary rocks are exposed. White cliffs, 50 to 200 feet high, occur at the brink of the canyon and along Palo Duro and Tierra Blanca creeks in the western part of the county. Red beds are conspicuously exposed in the lower part of Palo Duro Canyon. The brick-red clays of the Quartermaster formation outcrop near the base of the canyon wall. Unconformably above these lie the variegated lavender, maroon, yellow, and red clays of the Tecovas formation, and still higher are the various sandstone members interbedded with shales which comprise the Trujillo formation.

Water supply.—All the streams of Randall County are affluents of Palo Duro Creek. On the High Plains above the head of the canyons of Palo Duro and Tierra Blanca creeks are spring-fed streams which enter from Deaf Smith County. At the point of junction near Canyon each stream flows approximately 15 second-feet, and they continue fairly constant from this point to the eastern line of the county. A number of short creeks, the chief of which are Timber, Sunday, and Canyon Cita, enter from the south and carry water only a part of the year. Lakes, which are common on this part of the High Plains, receive the drainage of most of the county.

Springs occur in Randall County chiefly along Palo Duro and Tierra Blanca creeks and their tributaries. As was stated under the discussion of Deaf Smith County (p. 64), springs begin to appear along these creeks about 15 miles west of the Randall County line. As these streams cut deeper into the Tertiary rocks the springs increase in both number and volume as far as the junction near Canyon. Along the edges of Palo Duro Canyon and of the small side canyons numerous springs occur at the Tertiary and red beds contact. Canyon Cita, Sunday, and Timber creeks are supplied from springs which issue at the point where the small head canyons have cut back into the plains. The water from these springs is rarely of sufficient volume to form running streams for any considerable distance, and the creeks are dry for the greater part of the year. Springs are found locally in the red beds on the slopes and near the bottom of the canyon, but the flow in few of them is strong.

Wells are common in all parts of Randall County. West of Canyon they vary from 60 to 120 feet in depth; 6 to 8 miles farther north they have a fairly constant depth of 125 feet, and thence increase gradually to 250 feet near Amarillo, which lies just across the north line in Potter County. South and east of Canyon the wells vary from 150 to 200 feet, and in the northeastern part of the county from 160 to 240 feet in depth. The average depth of 24 wells in Randall County is 181 feet.

INDEX.

O.

P.

Q.

R.

S.

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