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

BY

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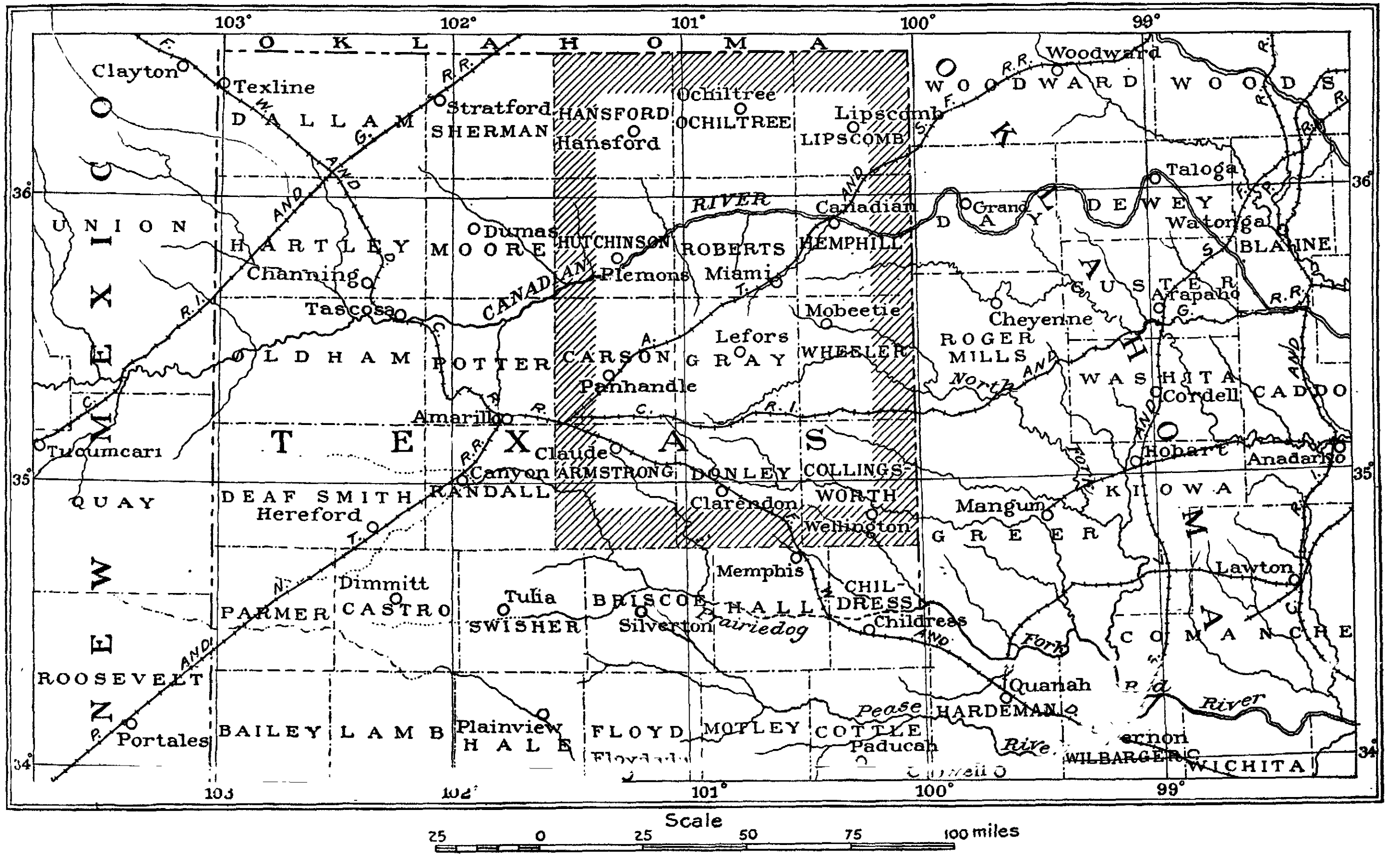
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NEW MEXICO
103°
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36°
35°
34°
Clayton
Texline
Stratford
Hansford
Ochiltree
Lipscomb
Woodward
Taloga
Watonga
Grand
Canadian
Dumas
Channing
Tascosa
Plemons
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CASTRO
SWISHER
BRISCOE
HALL
CHILDRESS
COMANCHE
BAILEY
LAMB
HALE
FLOYD
MOTLEY
COTTLE
HARDEMAN
WILBARGER
WICHITA
CANADIAN RIVER
North Fork
Prairiedog
Pease
Red River
Scale
25
0
25
50
75
100 miles

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

By Charles N. Gould.

INTRODUCTION.

Area covered.—The area described in this report lies in the northeastern part of the Texas Panhandle, and includes the following 12 counties: Lipscomb, Ochiltree, Hansford, Hutchinson, Roberts, Hemphill, Wheeler, Gray, Carson, Armstrong, Donley, and Collingsworth, each of which is approximately 30 miles square. It is an area 90 miles east and west and 120 miles north and south, situated south of the center of the Great Plains. The total area is approximately 10,800 square miles. It extends from 100° to 101° 35′ west longitude and from 34° 45′ to 36° 30′ north latitude. On the north and east it is adjoined by Oklahoma.

Sources of data.—The field work upon which this report is based was done during the years 1903 and 1904. During the former season little more was accomplished than a general reconnaissance in the region adjacent to Canadian River, through Carson, Hutchinson, Roberts, and Hemphill counties to the Oklahoma line, thence south through Hemphill, Wheeler, and Collingsworth counties as far as Elm Fork of Red River. On this trip the writer was assisted by Messrs. Charles T. Kirk, Chester A. Reeds, Charles A. Long, and Pierce Larkin, students in the University of Oklahoma. During the field season of 1904 the writer made an examination of the area to which this report relates, assisted by Prof. E. G. Woodruff. Most of the counties were studied in detail, excepting on the broader plains areas, of which only a reconnaissance was made. The well records were mostly secured from farmers and ranchmen by correspondence. Professor Woodruff has assisted in the preparation of the manuscript, "Topography" and "Water conditions by counties" being principally his work.

TOPOGRAPHY.

GENERAL FEATURES.

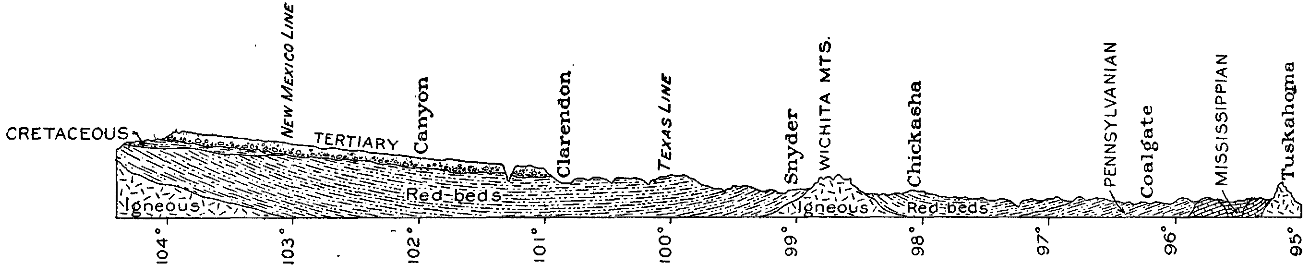
The region here described lies in the southern part of the Great Plains. Its general slope is to the east, with only a slight gradient to the south. The topography is properly divisible into two classes—the High Plains and the eroded plains—with local modifications produced by dune sands. A third and more local phase is found in the river flood plains. The location is shown on Pl. I, and the general features are indicated in the two general cross sections of the Great Plains shown on Pl. II, and on Pl. III, which includes the general region of the High Plains.

HIGH PLAINS.

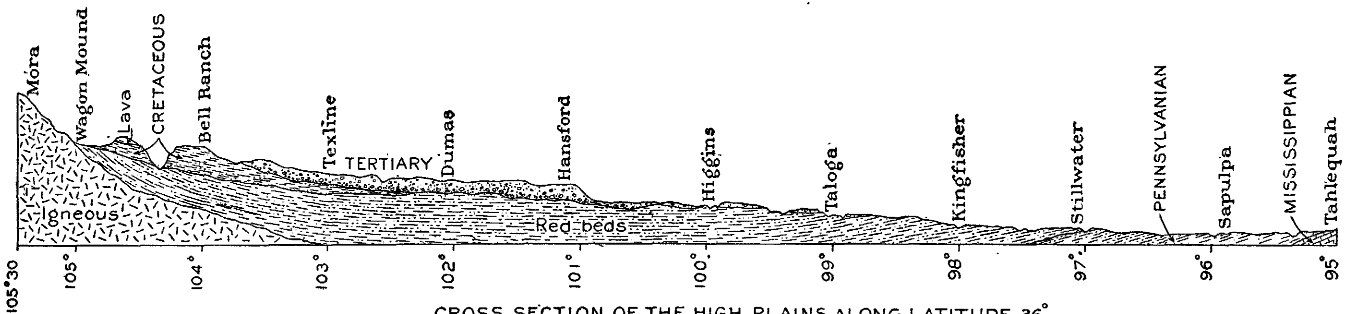
Surface features.—The region here treated as the High Plains includes not only the northern portion of the Llano Estacado or Staked Plains of Texas and New Mexico, but also the high, level plains in the region north of Canadian River. It seems probable that this area was once a great plain extending far to the east, with moderate slope covered by the deposits of the meandering rivers which were flowing from the mountains and depositing their load of sediment. By this deposition of material the stream beds were filled and the water forced to a new channel. By continued shifting of streams, irregular layers were deposited with much less uniform bedding than those of marine deposition. It is thought that the material composing the High Plains was laid down in this way upon the red beds, the basal formation in this region.

In later times the High Plains have been extensively cut into by stream erosion, until at present, in the region under discussion, the original level surface remains only in those localities more remote from the larger valleys. From a geological standpoint the erosion of the High Plains has been rapid and is still vigorously in progress. In the region comprised in this report High Plains constitute portions of the following counties: Western Lipscomb, most of Ochiltree and Hansford, southwestern Hemphill, southern Roberts, northwestern Hutchinson, western Gray, nearly all of Carson, and portions of Donley and Armstrong, including the greater part of the region mapped as Tertiary on Pl. V, an area of approximately 4,000 square miles.

In general the surface of the High Plains is so nearly level that railroads require little or no grading, and wagon roads go directly from point to point. With a surface so nearly level drainage is wholly undeveloped. Rain water can not run off, but either evaporates or collects in broad, shallow depressions, known in some locali-



CROSS SECTION OF THE HIGH PLAINS ALONG LATITUDE 34°45′



CROSS SECTION OF THE HIGH PLAINS ALONG LATITUDE 36°

GEOLOGIC SECTIONS ACROSS A PORTION OF NORTHWESTERN TEXAS.

ties as playa lakes, from which it escapes by evaporation or seepage. The evaporation is very great, but since the showers are generally vigorous, much of the water finds its way into these flat basins. For this reason the agencies which in most regions are carving valleys and hills are here having little effect upon the plains, and the interior surface level remains intact.

Valleys and canyons.—There are, however, upon the surface of the plain a number of streams which have their sources far in from the escarpment, and there are all gradations of topographic form from the almost featureless surface of the High Plains down through valleys and canyons to the general escarpment facing the lower eroded plains.

In the northern part of the Panhandle the High Plains are being rapidly dissected by a number of small streams, of which Coldwater, Palo Duro, and Wolf Creeks, tributaries of North Fork of Canadian River, are the most important. Besides these, the main Canadian, which rises in the mountains of New Mexico and flows east across the plains, traverses this region in a great valley that is from 5 to 20 miles wide and 600 feet deep. Numerous small streams tributary to Canadian River are now cutting back into the plains and giving the edge, when viewed as a whole, a ragged appearance.

To the south several tributaries of Red River, particularly North Fork, Elm Fork, Salt Fork, Spillers Creek, and Mulberry Creek, have their headwaters in the steep slope of the escarpment, and on account of the relatively low level of the main stream are able to erode more quickly. The level surface of the High Plains is generally retained, but the edges are being rapidly eroded by the streams which find their source either in the escarpment or on the plains.

Escarpment.—From the High Plains to the eroded plains there is in most places an abrupt descent. The escarpment is usually steep, in places being a distinct cliff, 200 to 500 feet high above the eroded plains, but ordinarily the descent is more gradual, occupying a distance of 5 or 6 miles. It is usually a distinct topographic unit, varying in width from 1 mile along Palo Duro Canyon to 6 miles or more in Lipscomb County. Along the larger streams, particularly the Canadian and the branches of Red River, the escarpment is usually sharp and steep, while along the smaller streams it has a gradual slope.

The escarpment (Pl. X, *A*), which is known locally as "the breaks," marks the limit of the High Plains. It margins the valleys and passes in a broad curve from one drainage system to another. The region abounds in bad-land erosion forms, short ridges, steep talus slopes, isolated conical hills, buttresses, peaks, and numerous narrow, V-shaped valleys, which on becoming larger develop into impassable canyons. The breaks, particularly along the steep slopes, have a sparse vegetation, since the very rapid erosion prevents most kinds of plants from obtaining a foothold. Bunch grass, yucca, and dwarf mesquite are often present. Such a region is most difficult to traverse, and in localities where the breaks are conspicuous it can be crossed with a wagon only at infrequent intervals over specially selected routes. This escarpment is most typical along the Canadian and in Palo Duro Canyon, in Armstrong County.

ERODED PLAINS.

Interstream highlands.—From the High Plains the escarpment forms a descent to the lower level of the eroded plains, which occupy the entire eastern part of the region to which this report relates. From the eroded plains the Tertiary and Pleistocene rocks, which compose the High Plains, have been entirely removed, and the streams, both large and small, are now cutting deep valleys into the subjacent red beds. This part of the Panhandle is a rolling plain, which is now being eroded rapidly, yet without the conspicuous bad-land forms that mark the escarpment. The streams are confined almost entirely to rather deep, steep-sided valleys; the plains between are rolling and well drained.

Standing on this plain not far from the escarpment are outlying hills, generally conical, but often elongated, and joined into irregular ridges. They sometimes attain a height of 100 to 200 feet. These hills have resulted from the thickening and hardening of certain of the upper members of the red beds, usually ledges of sandstone, gypsum, or dolomite, which resisted erosion and protected the relatively softer clays and shales beneath. A line of such hills extends from near Shamrock, in Wheeler County, southwest to beyond Memphis, the county seat of Hall County. South from Shamrock the ridge reaches its maximum width near the post-office of Dozier, at which place the range is 10 miles wide. Here it consists of a number of isolated mesa-like hills rising 100 feet above the eroded plains and capped by a ledge of sandstone, described under "Geology," 6 to 14 feet thick. The most typical of these hills are Rocking Chair Mountain, north of Elm Fork; Antelope Hills, northeast of Dozier; the Dozier Mounds, southeast of Dozier, and Flat Top, northwest of Dozier. The range is interrupted in northern Collingsworth County by Salt Fork of Red River, but again becomes conspicuous in the southwestern portion of the county, where the creeks are rapidly trenching the valleys between the mesas and bringing the hills into strong relief.

Valleys and canyons.—Crossing the eroded plains at intervals are a number of streams which have their rise on the High Plains, and, after cutting through the escarpment, find their way into the larger

THE HIGH PLAINS.

rivers which receive the drainage of the Panhandle. For the most part these streams have carved valleys averaging 3 miles wide and 100 to 200 feet deep in the eroded plains. These streams have already been mentioned, and they will be discussed in more or less detail under "River plains."

SAND HILLS.

The sand hills form an important topographical feature of the Panhandle. In size the hills range from small mounds to ridges 30 to 40 feet high; in shape they are oval, crescent, or elongated, but when parallel they are separated by trough-like depressions. The hills extend in various directions, although, in certain localities, those ranging S. 15° E. appear to predominate. Within the sand-dune regions are broad, shallow, basin-like depressions which are probably large blow-outs covering 1 to 10 acres. There are a few localities containing migratory dunes. One such is on the south side of Canadian River, in western Roberts County, where the dunes are approaching the river. Another is north of Prairie Dog Fork of Red River, in southwestern Donley County.

The sand composing these dunes is derived from two sources, chiefly from the sandstone ledges of either the red beds or the Tertiary disintegrating in place, or from the river sand which in times past has been transported from farther west. These make two classes of sand hills, both of which are frequently found in the same region. The subject is treated more fully under "Geology."

Sand hills occur chiefly in the escarpment region or along the streams, as in western Lipscomb and northern Roberts and Hemphill counties, in Wheeler County south of Mobeetie, and in Donley and Collingsworth counties along the south side of Prairie Dog Fork. A typical sand hill is shown in Pl. IV, *A*.

RIVER PLAINS.

Canadian Valley.—The north central part of the Panhandle of Texas is traversed by Canadian River, which rises in the mountains of New Mexico and in its eastward course crosses the region under discussion in a valley 5 to 20 miles wide cut deeply into the High Plains. The sides of this gorge constitute a portion of the escarpment, with its bad-lands structure of short, sharp ridges, often destitute of vegetation, separated by V-shaped valleys. The flood plan, 1 to 5 miles wide, occupies the bottom of the gorge, 600 feet below the level of the High Plains. The river runs over a sandy bed varying in width from a half mile to more than a mile. It is constantly shifting, excavating sand in one place and depositing it in another.

Wolf Creek Valley.—Wolf Creek has cut a wide valley in the High Plains in the northeastern portion of this region. It rises in western Ochiltree County, at an elevation of 3,300 feet, and descends to 2,350 feet at the Oklahoma line, 45 miles east—a gradient of 21 feet per mile. The width of the valley varies from 1 to 4 miles, and the breaks which adjoin it are less rugged than those along the Canadian. Sand hills occur along this creek and its tributaries.

Washita River Valley.—The headwaters of the Washita, which in Oklahoma becomes a river of considerable size, rise in Gray County, Tex., in a small creek not differing from many others in this part of the plains. It flows eastward in a valley 1 to 3 miles wide across northern Wheeler County and finally passes from Texas into Roger Mills County, Okla.

North Fork of Red River Valley.—North Fork of Red River rises among the High Plains in the southeastern part of Carson County, and flows east in a broad bend to the north, passing from the State almost directly east of its starting place. It flows in a narrow, sand-choked valley, with sand dunes flanking its south side and with red-beds bluffs guarding it on the north for a considerable part of its course. This river descends from an elevation of 3,000 feet on the plains to 2,050 feet at the State line, making a descent of 950 feet in a passage of 60 miles, or 16 feet per mile.

Elm Fork of Red River Valley.—Elm Fork of Red River, which becomes a stream of considerable importance in Greer County, Okla., is in the Panhandle a mere creek, the greater portion of whose bed is entirely dry during the summer. It rises in the escarpment in northwest Collingsworth County and, flowing southeast in a deep valley cut in the eroded plains, makes its exit from the State 35 miles from its source.

Salt Fork of Red River Valley.—Salt Fork of Red River rises on the High Plains in northern Armstrong County at an elevation of 3,250 feet, crosses the escarpment, cuts a valley in the eroded plains, and after a tortuous course passes from the State in the southeastern part of Collingsworth County at an elevation of 1,900 feet, a descent of 15 feet per mile. It flows in a sand-filled valley, and at times of low water the river is a narrow ribbon upon a sand bed half a mile wide.

Prairie Dog Fork of Red River Valley.—Prairie Dog Fork of Red River crosses Armstrong County in Palo Duro Canyon (not to be confused with Palo Duro Creek, in Hansford County), which is 5 miles wide and which has been cut 875 feet through the Tertiary and the red-beds rocks. The river flows in a narrow valley at the bottom of this gorge, the sides of which present an alternate precipitous and terraced structure according to the nature of the beds. In Armstrong County there are 20 miles of this canyon.

A. SAND HILLS BLOWN FROM CANADIAN RIVER.

B. GYPSUM LEDGE, SHOWING BANDED STRUCTURE.

Minor stream valleys.—Sweetwater Creek, in northern Wheeler County; Spillers Creek, in Collingsworth; Mulberry Creek, in Armstrong; Mammoth Creek, in Lipscomb; Palo Duro and Coldwater creeks, in Hansford; Kit Carson and White Deer creeks, in Hutchinson; Red Deer Creek, in Hemphill, and McClellan Creek, in Gray County, are the largest streams of secondary importance. These smaller streams all form a part of the three major drainage systems, the North Fork of Canadian, the Canadian, and the Red River. Most of these minor streams are periodic, although numerous springs at the base of the Tertiary feed many of the smaller creeks, thus rendering them perennial.

GEOLOGY.

GENERAL RELATIONS.

The general geologic features of the Texas Panhandle are not complex. Most of the rocks belong to two great systems—the Permian and the Tertiary—and there are small amounts of Quaternary deposits, all of which lie nearly level. The lowest formations exposed consist of extensive deposits of red clays and shales known as the red beds, most of which are of Permian age. The greater part of the upper formations are made up of sands, clays, and conglomerates belonging to the Tertiary system. Covering these two members in many places are beds of sand, gravel, and alluvium of Quaternary age. On the geologic map (Pl. V) the distribution of these formations is shown. The relative age and general character of the various deposits are given in the following table:

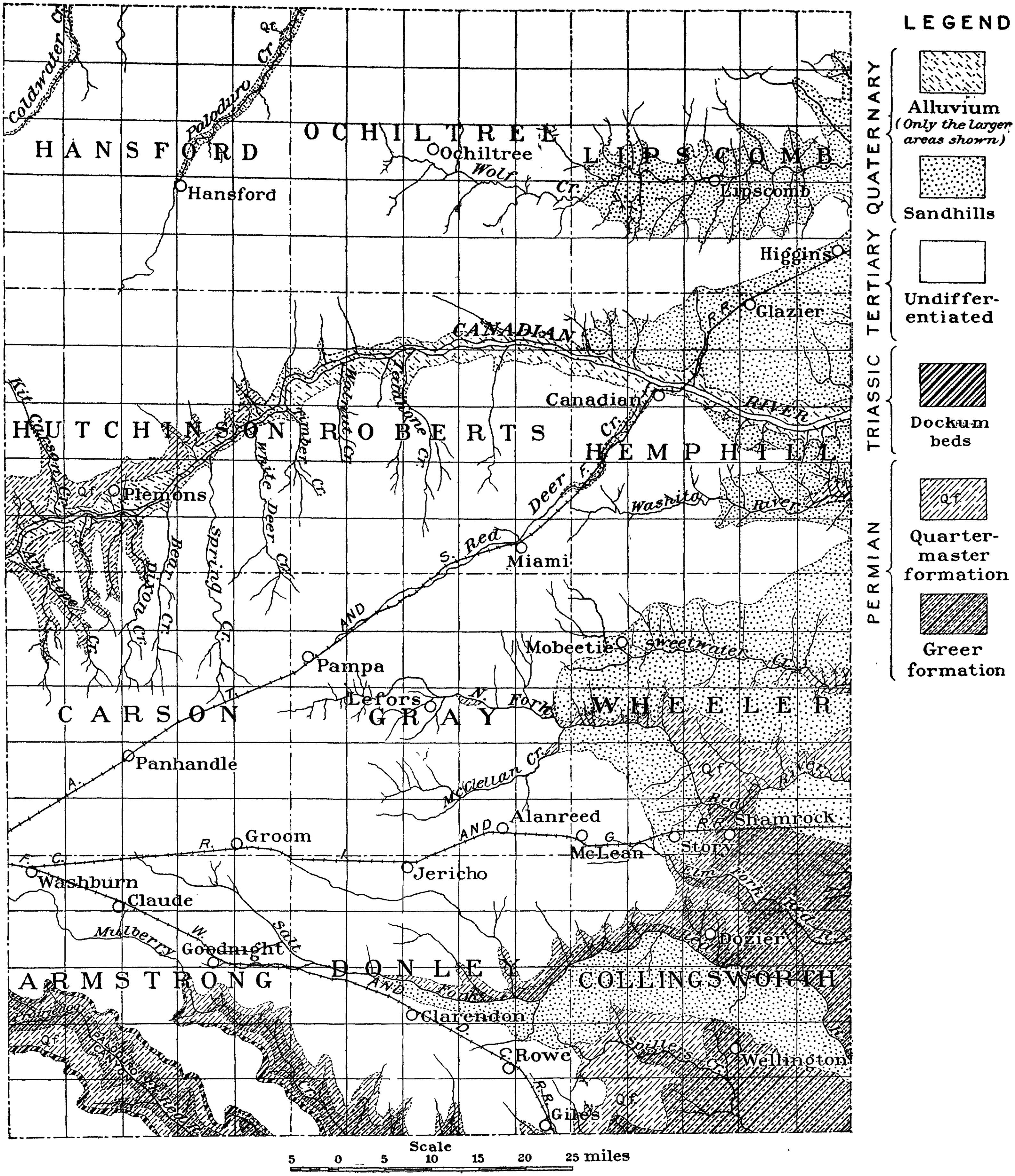
Geologic formations of the Texas Panhandle.

System.	Name.	Predominant characters.
Quaternary	Alluvium	Loam, sand, and gravel.
	Sand hills	Sand, chiefly in dunes.
	Tule formation	Sand, clay, and gravel.
Tertiary	Blanco formation	Clay, sands, and conglomerates.
	Goodnight formation	
	Loup Fork formation	
Triassic	Dockum formation	Clays, sandstones, and conglomerates.
Carboniferous (Permian).	Quartermaster formation.	Red sandy clay and soft sandstone.
	Greer formation	Red clay, with gypsum and dolomite.

A typical section of the Permian, Triassic, and Cenozoic strata in Palo Duro Canyon, 15 miles south of Claude, Armstrong County, Texas, is as follows:

Typical section in Palo Duro Canyon, Texas.

System.	Formation.	Character.	Thickness in feet.
Tertiary		Tertiary clays, varying in color from almost white to pink; usually with calcite concretions and a few pebbles; occasional harder bands forming terraces.	200
Unconformity.			
Triassic	Dockum	Gray to brown or reddish sandstone. Soft and friable, cross bedded; often changing into conglomerate with lenses of blue and red clay. Variegated clays, maroon, wine-colored, drab, gray, bluish, and red, with ledges of sandstone, sometimes becoming hard enough to form an escarpment; often simply a gray arenaceous shale.	270
Unconformity.			
Carboniferous (Permian).	Quartermaster	Red clay shale, with bands of harder clays, sometimes forming a sandstone, and occasional bands of white or gray clay or sandstone, weathering into characteristic buttes or mounds. Seams of satin spar in the lower part.	275
	Greer	Red clay shale, with ledges of massive white or purple gypsum, interstratified with bands of clay and sandstone.	180
		Total	925



GEOLOGIC MAP OF THE EASTERN PORTION OF THE PANHANDLE OF TEXAS.
BY C. N. GOULD.

The following sections made on Palo Duro, Tule, and Mulberry canyons in the southwestern part of the region here discussed, where all formations are best exposed, indicate the relative thickness (in feet) of the various beds:

Geologic sections in Palo Duro, Tule, and Mulberry canyons, Texas Panhandle.

System.	Formation.	Palo Duro Cañon.			Tule Canyon. Silverton-Claude road.	Mulberry Canyon. Silverton-Clarendon road.
		Silverton-Clarendon road.	Silverton-Claude road.			
			South side.	North side.		
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Tertiary and Quaternary.	....	380	220	200	180	240
Triassic	Dockum ...	110	175	260	165	Eroded.
Carboniferous (Permian).	Quartermaster.	305	280	210	50	160
	Greer	175	195	190	Not exposed.	100
Total	....	970	870	860	395	500

PERMIAN RED BEDS.

GENERAL STATEMENTS.

The oldest rocks found on the surface in the Panhandle of Texas are the Permian red beds. These rocks occupy a considerable part of the Great Plains from southern Kansas across Oklahoma and Texas as far as New Mexico and Arizona, and outcrop along the eastern flank of the Rocky Mountains as far north as the Black Hills of South Dakota.

In Oklahoma, where the Permian red beds are typically exposed, they have been divided by the writer into five formations, as follows: [a]

Carboniferous	Permian	Quartermaster.
		Greer.
		Woodward.
		Blaine.
		Enid.
	Pennsylvanian.	

The rocks typically exposed around Chandler, now known to be Pennsylvanian, consist of red shales and red or gray sandstones. The Enid formation is composed largely of red clay shales, with an occasional ledge of soft sandstone. The Blaine is characterized by massive

[a] Gould, Chas. N., General geology of Oklahoma. Second Bien. Rept. Oklahoma Geol. Survey, 1902, pp. 42–58. Revised in Water-Sup. and Irr. Paper No. 148, U. S. Geol. Survey, 1905, p. 39.

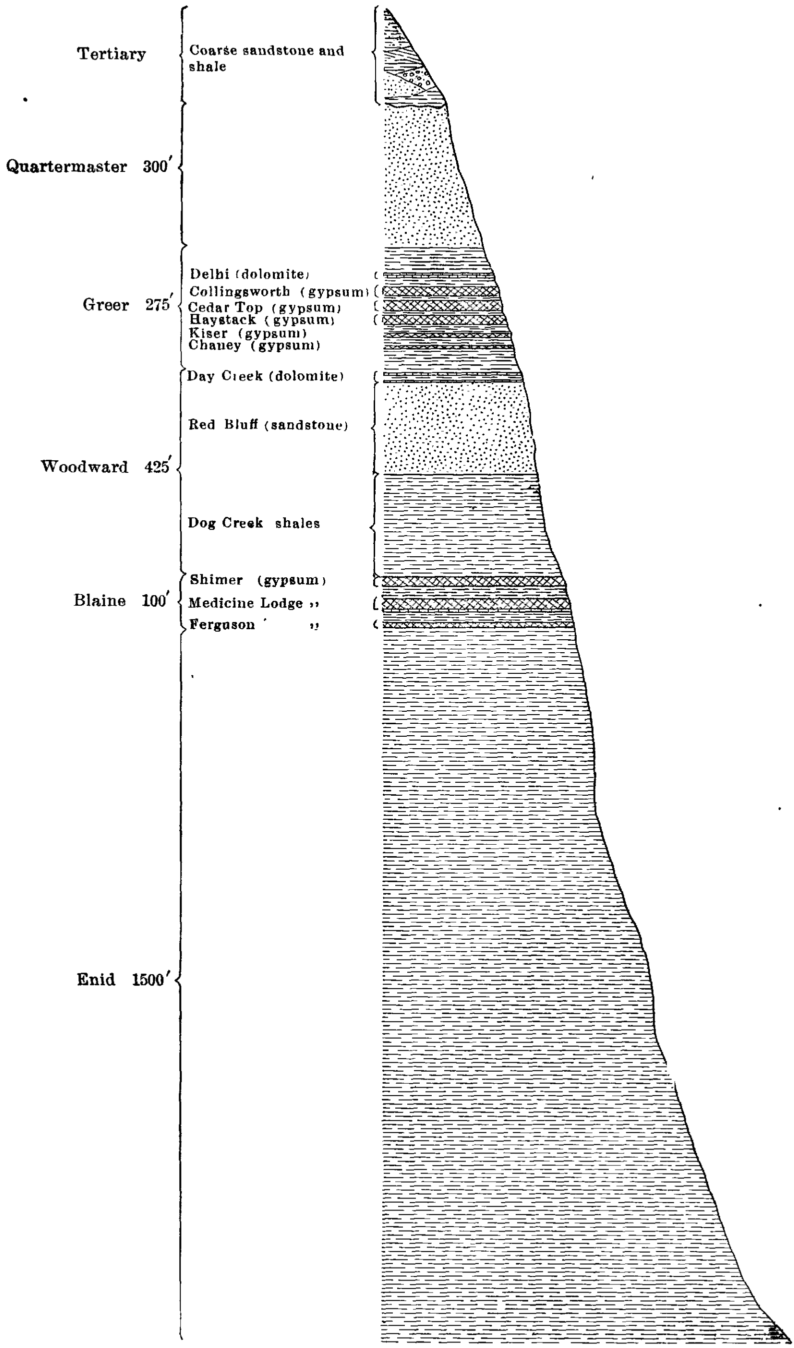


FIG. 1.—Generalized section of Oklahoma red beds. In the above legend "Delhi" should read Mangum, and "Red Bluff" should read Whitehorse.

ledges of white gypsum interbedded with red shales. The Woodward is made up of red shales and sandstones and a ledge of white dolomite. The Greer is also a gypsum formation, in which the ledges are interstratified with red shales. In the Quartermaster the rocks consist chiefly of red shales and clays, with ledges of soft sandstone. Fig. 1 shows the general character and relative thickness of the red beds as exposed in Oklahoma.

Professor Cragin classified the red beds in Kansas and northern Oklahoma, but he did not examine the lower nor the upper members. He divided the portion that he studied into the Salt Fork and Kiger divisions, each consisting of a number of formations.[a]

In comparing this author's classification with the one used by Professor Cragin it may be said that, in general, the Enid, Blaine, and Woodward formations correspond to his Salt Fork and Kiger. Neither the rocks near Chandler nor the Greer nor the Quartermaster formations, as they are now known, were described by Professor Cragin.

Professor Cummins divided the red beds into the Wichita, Clear Fork, and Double Mountain formations, without, however, sharply differentiating them.[b] Doctor Adams, who studied the lower members of the Texas red beds, found that the divisions made by Professor Cummins were unsatisfactory and recommended that they should not be retained.[c] He has also shown that the Wichita beds in Texas, like those near Chandler, in Oklahoma, are Pennsylvanian in age.[d] From the best available information it seems probable that the Wichita beds are approximately the equivalent of those near Chandler, the Clear Fork beds include about the same rocks as the Enid, Blaine, and Woodward formations, and that the Double Mountain beds are practically the same as the Greer and Quartermaster formations. The following table expresses the conditions:

Relationship of formation classifications.

Cummins's classification.	Classification of the writer.	Cragin's classification.
Double Mountain beds	Quartermaster	
	Greer	
Clear Fork beds	Woodward	Kiger division.
	Blaine	Salt Fork division.
	Enid	
Wichita beds		

[a] Cragin, F. W., Permian system of Kansas: Colorado Coll. Studies, vol. 6, 1896, p. 3.

[b] Cummins, W. F., Rept. on the geology of northwestern Texas: Second Ann. Rept. Texas Geol. Survey, 1890, pp. 400–402.

[c] Adams, George I., Stratigraphic relations of the red beds to the Carboniferous and Permian in northern Texas: Bull. Geol. Soc. America, vol. 14, 1903, pp. 191–200.

[d] Ibid., pp. 195–199.

THE PERMIAN IN THE PANHANDLE REGION.

Of the formations of the Permian red beds discussed above, only the Greer and Quartermaster are exposed in the Panhandle of Texas.

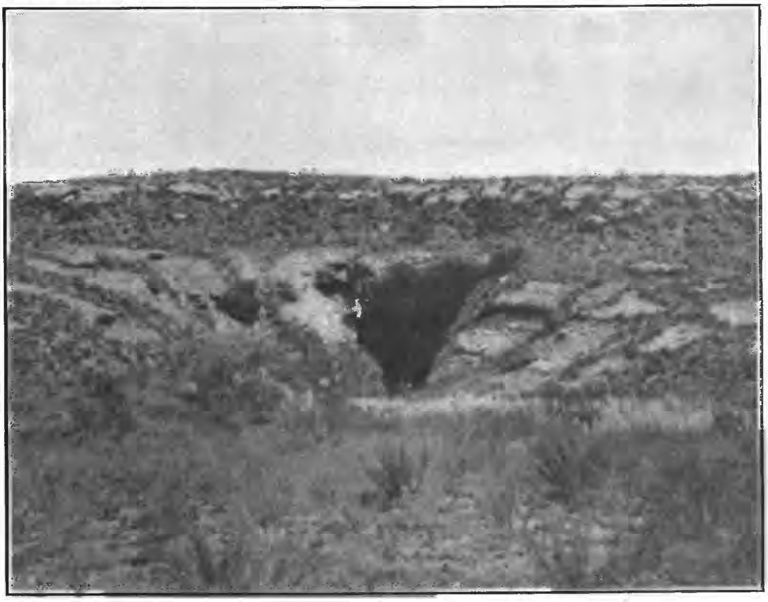
Greer formation.—The Greer formation, the lowest member of the red beds found in the Panhandle, has its type exposure in Greer County, Okla., along Elm Fork of Red River, a few miles east of the Texas line. It is here composed of 150 to 200 feet of brick-red clays and shales interstratified with ledges of white, bluish, and pinkish gypsum, with an occasional ledge of magnesian limestone and dolomite. In many places, however, the gypsum beds are entirely wanting or occur as single ledges, while in other localities there are six or more well-marked beds, ranging from 1 to 30 feet in thickness, besides one or two ledges of irregular gray, honeycombed, magnesian limestone, 1 to 3 feet thick. A number of localities in Collingsworth County, Tex., may be cited where these definite gypsum layers occur, but extensive study in the region has shown that all of them are more or less lenticular and do not persist for any considerable distance. Indeed it is not an uncommon occurrence for two or more of these ledges to merge locally by the thinning out of the intervening clays, while at a short distance beyond the gypsums themselves become thin and disappear. In very few parts of the red beds is the tendency to form lenses better exemplified than in the Greer formation. Along North Fork of Red River, just east of the Panhandle line, the writer has named the following members of the Greer: Chaney, Kiser, Haystack, Cedartop, and Collingsworth gypsums and Mangum dolomite.[a] The sequence of the beds is shown in fig. 2.

In view of the facts as presented above, it appears better not to indicate by name those lenses which persist only for a short distance and which can not be correlated in adjoining regions; hence in the present paper no attempt will be made to subdivide the Greer formation.

Because of the lenticular nature of the beds it is not always possible to locate the exact limits of the various subdivisions of the red beds. In general, however, the upper limit of the Greer is placed either at the top of the highest prominent gypsum ledge or at the top of the ledge of magnesian limestone or dolomite, which appears 10 to 20 feet above the highest ledge of solid gypsum.

The gypsum members of the Greer formation abound in caves and sink holes. In Pl. VI, *A*, is reproduced a photograph of an opening on the surface of a gypsum cave in western Oklahoma. The soft shales which underlie the ledges are easily eroded, and the

[a] Gould, Chas. N., General geology of Oklahoma: Second Bien. Rept. Okla. Geol. Survey, 1902, pp. 55–56.



A. GYPSUM CAVE.

B. SPRING ISSUING FROM A CAVE IN GREER GYPSUM.

gypsum is gradually dissolved by water. It is not uncommon to find a prairie stream of considerable size which disappears in a sink hole. In such case, however, it usually comes again to the surface at no great distance as a spring issuing from a cave (Pl. VI, *B*). These sink holes are of various shapes, with the oblong and circular forms predominating. The oblong sink holes often terminate

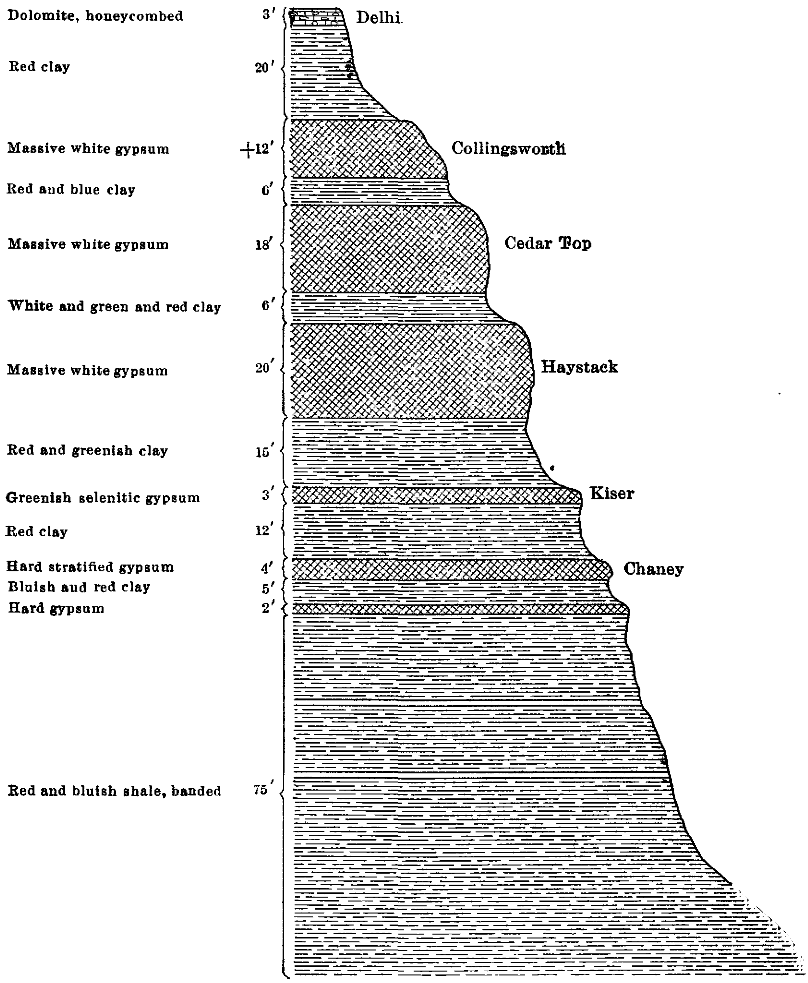


FIG. 2.—Section showing members of Greer formation on Elm Fork of Red River at Salton, Okla. In above legend "Delhi" should read Mangum.

abruptly in caves at one end, while the circular ones exhibit a conical hole in the center, through which the water escapes most freely. These sink holes vary in depth from a few inches to 20 feet or more and are 10 to 100 feet in diameter. In general they are irregularly distributed; in some cases, however, they seem to occur in chains, evidently connected by an underground passage, thus marking the beginning of a drainage channel. These sink holes are probably formed by the subterranean drainage which dissolves the gypsum and clay below the surface, forming caves which eventually collapse and become stream beds. North of Shamrock, 2 miles from North Fork of Red River, there is a typical sink-hole region in which hundreds of these openings occur in an area of a few square miles.

In various places the members of the Greer exhibit a marked peculiarity of stratification not usually found in the rocks of the plains. The gypsum ledges are here often distinctly laminated, as shown on Pl. IV, *B*. Steep local dips, both anticlines and synclines, are often observed along the sides of a cliff.

A striking peculiarity of the Greer formation is the erratic dip of the gypsum. Frequently in tracing a ledge along a small stream it is found that within a distance of perhaps half a mile the stream descends 50 feet, while the gypsum along the bluff still retains the same height above the water channel. On the opposite side of the stream the same ledge may be traced along another branch until less than a mile away it is 75 feet higher than at the main stream. In other words, the dip of the ledge is toward the stream on both sides, though the ledge is continuous. This peculiarity of dip gives the appearance of irregularly folded strata, yet there has been no general folding whatever. The phenomenon is not easy to understand. Perhaps the most plausible explanation is that the shales have been removed from beneath the gypsum ledges, permitting the latter to sink along the streams into the semblance of a local dip. This fact is exemplified on Pl. VII, *A*.

The Greer formation being the lowest member of the red beds in the Panhandle naturally outcrops low in the stream valleys. It is well exposed along the branches of Red River, particularly on Elm, Salt, and Prairie Dog forks. On Elm Fork it outcrops along the valley of the stream from the Oklahoma line as far west as Shamrock, in southern Wheeler County. Between Elm Fork and Salt Fork the Greer forms the plain as far west as the post-office of Dozier, while along the north side of Salt Fork gypsum ledges appear in the bluffs at intervals, finally disappearing in Donley County a few miles east of the center. South of Salt Fork a strip of sand hills covers the red beds, so that the Greer formation is not exposed north of the divide between Salt and Prairie Dog forks of Red River.

It is in the valley of Prairie Dog Fork of Red River and its tributaries, Spillers and Mulberry creeks, and in Palo Duro Canyon, in Collingsworth, Donley, and Armstrong counties, that the Greer formation attains its typical development in the Panhandle. In this locality it is exposed along the bluffs of the main creeks and caps the slopes of the smaller side canyons that are dissecting the red-beds plain. In Palo Duro Canyon, in particular, the gypsums of the Greer are con-

A UNDERMINING OF GYPSUM LEDGES.

B. EROSION IN THE QUARTERMASTER SANDSTONE IN PALO DURO CANYON.

Tertiary cliffs in the distance.

spicuous; here a number of narrow ravines have been cut out. In this locality creeks sometimes pass into caves and sink holes, and after flowing underground for half a mile or more reappear in a deep canyon. Ledges of white gypsum cap the bluffs and wind in sinuous white lines along the streams.

Quartermaster formation.—Resting conformably upon the Greer are 250 to 300 feet of rocks, consisting for the most part of soft, red sandstones and sandy clays and shales. To this formation the name Quartermaster has been applied, the name being derived from a creek in Day and Custer counties of Oklahoma, along which the rocks are typically exposed. In the lower part of the formation the rocks are chiefly shales, usually red, but sometimes containing greenish bands or layers of clay and often (particularly near the base) a considerable amount of gypsum, which is usually in the form of white or pink satinspar or of rounded concretions. At a higher level the red shales become more arenaceous and not infrequently form a consolidated sandstone, which is rather thin bedded and prone to break into small rectangular blocks. These harder members of the Quartermaster formation often weather into long, narrow buttresses and more or less conical mounds, varying in height from 10 to 50 feet, as shown in Pl. VII, *B*. These conical mounds sometimes occur alone, but more often they appear in groups; occasionally there are hundreds of them on a single quarter section.

The sandstone members are further characterized by marked and very peculiar irregular dips and folds. Strata are often seen dipping at an angle of 20 to 40 degrees, but the dip is irregular, varying in direction to all points of the compass, even on a small area. These local dips often produce slopes which have the character of those formed by normal faults or by general folding. The cause of this phenomenon is not well understood, but apparently the erratic dips are caused by the erosion of some of the subjacent gypsum members of the Greer formation.

In certain parts of the Quartermaster formation there occur beds of hard, white, or pinkish dolomite. One such outcrops on Mulberry Creek, 10 miles southwest of Clarendon, as a ledge 5 feet thick. Another, which caps the bluff at the crossing of Salt Fork of Red River, 3 miles north of Clarendon, is 3 to 5 feet thick, white or pinkish in color, hard or even cherty, with characteristic dendritic markings. When traced east for several miles this ledge is found to be a lens changing into sandstone and sandy shale. Another locality where dolomite occurs is on Antelope Creek, in northwestern Carson County, and along the bluffs north of Canadian River, near Plemons, the county seat of Hutchinson County. The red beds in this locality are provisionally classed as Quartermaster.

Throughout the greater part of this region the Quartermaster formation is overlain unconformably by the Tertiary or Quaternary deposits. In the localities where the Dockum beds are present the upper limit of the formation is located at the line where the color of the shales changes from brick red to maroon or wine color.

In general the Quartermaster formation outcrops in a belt 1 to 5 miles wide at the base of the High Plains. It appears in the southern part of Wheeler County, between Shamrock and Dozier, occupies the northwestern part of Collingsworth County, and follows along the north side of Salt Fork as far west as Clarendon. Ir the southern part of Collingsworth County the Quartermaster is exposed south and west of Wellington, the county seat. It forms the dissected plain between Memphis and Giles in southern Donley and eastern Armstrong counties. Along Palo Duro Canyon, in southwestern Armstrong County, it exhibits a maximum thickness of 300 feet and forms the top of the intracanyon terrace, just above the Greer gypsum ledges.

The red beds are exposed along Canadian River in northern Carson and southern Hutchinson counties. The most typical exposures are along Dixon and Antelope creeks, in Carson County, where 250 feet appear in vertical section. They contain some beds of dolomite and gypsum. These beds do not seem sufficiently uniform and persistent to warrant giving them definite names, yet they are more extensive than similar beds that occur in other portions of the formation. It is probable that a detailed study will reveal that these beds extend farther to the west along Canadian River. Plicated structure, noted elsewhere, is exemplified in this region. The following section was made in southwestern Hutchinson County, 2 miles from the mouth of Antelope Creek:

Section of red beds on Antelope Creek, Carson County, Tex.

	Feet.
Red clays, with sandy shale	40
Gray sandstone	8
Red clay	85
Gray dolomite, weathers out in blocks which are scattered over talus slope (this ledge forms a terrace)	8
Red clay	130
Gypsum, bluish in places; a fairly persistent uniform ledge	2
Red clay, lower portion covered	6

For lithological reasons these beds as a whole are considered as belonging to the Quartermaster formation.

Near the middle of the Quartermaster formation, as exposed in Collingsworth and Hall counties, there is a ledge of rather hard, red or pinkish, more or less oolitic sandstone, which on weathering gives rise to a number of flat-topped buttes and ridges. Of these the most typical are Rocking Chair Mountains (Pl. VIII, *A*), southwest of

A. ROCKING CHAIR MOUNTAINS.

A hill capped by the Dozier sandstone.

B. SANDSTONE MEMBER OF THE DOCKUM FORMATION IN PALO DURO CANYON.

Shamrock; Antelope Butte, near the head of Elm Fork of Red River; Dozier Mounds, near Dozier post-office, and 'Possum Peaks, Twin Mounds, and Ragged Top, a few miles farther west of Dozier. Between Salt and Prairie Dog forks of Red River, in the vicinity of Memphis, in Hall County, these buttes are conspicuous. Hogback Butte, 8 miles south of Memphis, is a noted landmark. These buttes persist for an unknown distance south of Salt Fork of Red River.

From the sandstone on Antelope and Dozier mounds, Dr. J. W. Beede identifies fossils belonging to the following genera: *Dielasma*, *Schizodus*, *Allorisma*, *Pleurophorus*, *Edmondia*, *Aviculopecten*, *Leiopteria*, *Capulus?* (*Lepetopsis?*), *Loxonema*, *Strophostylus*, *Murchisonia*, *Pleurotomaria*, and *Worthenopsis;* indicating the Permian age of the sandstone.

TRIASSIC RED BEDS.

Dockum formation.—The upper part of the Texas red beds was described by Professor Cummins under the name of Dockum beds,[a] and afterwards by Drake.[b] This formation, which is composed largely of clays, sandstones, and conglomerates, underlies practically all of the Staked Plains of Texas and southeastern New Mexico. According to Drake,[c] the Dockum beds average 200 feet in thickness, and may be divided into three members, as follows: (1) A lower bed of sandy clay 0 to 150 feet thick, (2) a central bed or beds of sandstone, conglomerate, and some sandy clay 0 to 235 feet thick, and (3) an upper bed of sandy clay and sandstone 0 to 300 feet thick.

Along Palo Duro Canyon in Armstrong and Briscoe counties, where this formation was studied by the writer, it is difficult to divide it into recognizable members. The formation abounds in local unconformities with clay, sandstone, and conglomerate lentils, with cross-bedded structure, and other features indicative of shallow-water deposition. In places the lower portion is made up of red, maroon, or wine-colored clays, while at higher horizons there are more or less lenticular sandstones and conglomerates, as shown in Pl. IX, *B*. On weathering, the sandstones of the Dockum beds give rise to unique erosion forms; the harder members protect the softer shales beneath and produces pillars, chimneys, toadstools, and other unusual figures, some types of which, exposed in Tule Canyon, 6 miles northwest of Silverton, are shown in Pl. IX, *A*.

The lithologic characters which justify the separation of the Dockum beds from the Permian are, (1) the gray and brown color of the sandstones and conglomerates and the abundance of the latter;

[a] Cummins, W. F., First Ann. Rept. Texas Geol. Survey, 1899, pp. 189–190; Second Ann. Rept., 1900, pp. 424–428.

[b] Drake, N. F., Stratigraphy of the Triassic formations of northwest Texas; Third Ann. Rept. Texas Geol. Survey, 1901, pp. 227–247.

[c] Ibid., pp. 229–233.

(2) the maroon, wine-colored, and yellow shales and clays, and (3) the extensive cross-bedding and local unconformities of the various members. Whether or not the Dockum formation is conformable throughout with the subjacent Quartermaster formation is still an open question. There is often local unconformity between the two formations, but on the other hand there are localities in which the brick-red shales and argillaceous sandstone of the Quartermaster grade so imperceptibly into the wine-colored shales and gray-brown conglomerates of the Dockum that the closest search fails to reveal the line of separation between them.[a]

Concerning the age of the Dockum formation it may be said that vertebrate fossils, found in these rocks and described by Cope,[b] as well as certain new forms of *Unios* named by Simpson,[c] indicate that the beds belong to the Triassic. In all, seven species of vertebrates and four of pelecypods have been secured from this formation.

TERTIARY AND QUATERNARY FORMATIONS.

REFERENCE LIST OF PUBLICATIONS.

For extended discussions of the Tertiary rocks of various parts of the Great Plains the reader is referred to the following publications:

Cummins, W. F., Notes on the geology of northwest Texas: Fourth Ann. Rept. Texas Geol. Survey, 1893, pp. 190–203.

Dumble, E. T., Cenozoic deposits of Texas: Jour. Geol., vol 2, No. 6, 1894. pp. 549–563.

Hay, Robert, Water resources of a portion of the Great Plains: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 569 et seq.

Haworth, E., Physical properties of the Tertiary: Univ. Geol. Survey Kansas, vol. 2, 1897, pp. 247–284. Underground waters of southwestern Kansas: Water-Sup. and Irr. Paper U. S. Geol. Survey No. 6, 1897.

Darton, N. H., Report on the geology and water resources of Nebraska west of 103d Mer.: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1899, pp. 719–785. Also in Prof. Paper U. S. Geol. Survey No. 17, 1903.

Darton, N. H., Rept. on the geology of the central Great Plains: Prof. Paper U. S. Geol. Survey No. 32, 1905.

Johnson, Willard D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, pp. 601–741. Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 4, 1902, pp. 631–669.

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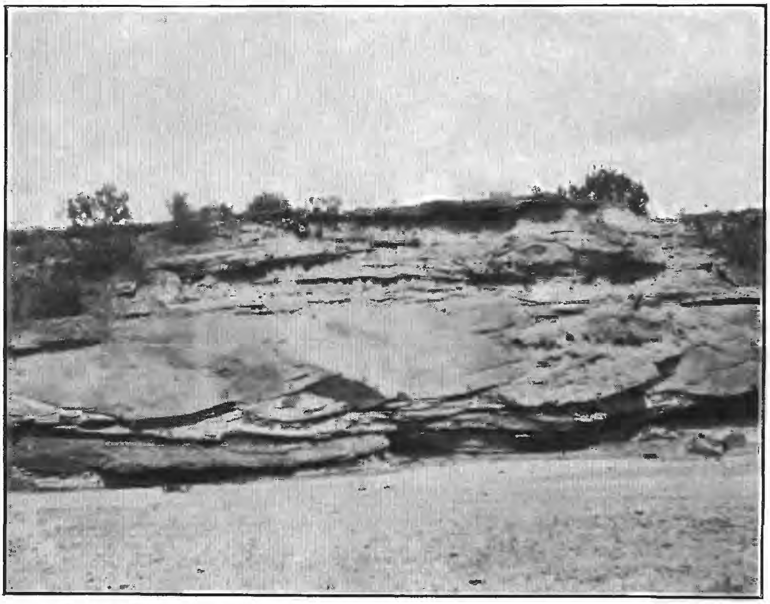
[a] Since the above was written opportunity has been afforded for studying these beds in the western part of the Panhandle of Texas, both on upper Palo Durc Canyon and along the valley of Canadian River. The writer finds that in this region the Triassic is everywhere separated by a pronounced unconformity from the subjacent Permian red beds and that it is clearly divisible into two formations, each consisting of well-marked members. These formations and members will be described in a forthcoming water-supply and irrigation paper.

[b] Cope, E. D., Vertebrate remains from the Dockum Terrane of the Trassic system: Fourth Ann. Rept. Texas Geol. Survey, 1903, pp. 11–17.

[c] Simpson, C. T., Descriptions of four new Triassic Unios from the Staked Plains of Texas: Proc. U. S. National Mus., vol. 18, No. 1072, 1896, pp. 381–385.

A. EROSION FORMS IN THE DOCKUM SANDSTONE IN TULE CANYON.



B. SANDSTONE AND SHALE MEMBER OF THE DOCKUM FORMATION.

Showing lenticular nature of the strata.

STRATIGRAPHY.

General statement.—After the deposition of the Permian and Triassic red beds in the Panhandle region the area was elevated and for a long period of time the land was extensively eroded. Farther south and west extensive deposits of Cretaceous rocks rest on the red beds, but in the part of the Panhandle under discussion Cretaceous formations are absent.

Resting uncomformably upon the eroded surface of the red beds throughout the region described in this paper are extensive deposits of the Cenozoic age—Tertiary or Quaternary—which make up the rocks of the High Plains. These formations, which consist largely of loosely consolidated clays, sands, and conglomerates, typically white, but varying locally into gray, buff, brown, or other colors, constitute the "Tertiary grit" and the "Tertiary marl" or "mortar beds" of the Kansas geologists. In Nebraska, Mr. Darton subdivides the beds of approximately this age into the Arikaree and the Ogalalla. In the Panhandle of Texas Professor Cummins has distinguished four horizons. basing his classification upon the evidence afforded by vertebrate fossils obtained in the different beds and identified by Professor Cope.[a]

The following table sets forth the names of the members as used by Professor Cummins, the geologic age, and the number of species Professor Cope found in each:

Vertebrate fossils distinguishing four horizons in the Panhandle of Texas.

Period.	Epoch.	Formation.	Number of species.
Quaternary	Pleistocene	Tule (*Equus* beds)	10
Tertiary	Pliocene	Blanco	16
	(Transition)	Goodnight	8
	Miocene	Loup Fork	17

Loup Fork formation.—The term "Loup Fork" has long been used to include a series of rocks, usually considered later Miocene in age, which are extensively exposed on the Great Plains, particularly in Colorado, Nebraska, Kansas, Oklahoma, Texas, and New Mexico. The rocks consist largely of sands, clays, and conglomerates, the latter made chiefly of smooth water-worn pebbles presumably derived from the Rocky Mountains. The thickness of the deposits varies, but the maximum is several hundred feet. The Loup Fork beds constitute the lowest Tertiary formation known to exist in the Panhandle. According to Professor Cummins these beds do not extend

[a] Fourth Ann. Rept. Texas Geol. Survey, pt. 8, 1893, pp. 18-86.

farther south along the eastern edge of the Llano Estacado than the Prairie Dog Fork of Red River.[a] On Mulberry Creek, 12 miles west of Clarendon, where Cummins and Cope obtained the fossils identified by the latter, the Loup Fork beds are 30 feet thick and "composed of alternating beds of bluish and almost pure white sand."[b]

Goodnight formation.—This division, named by Professor Cummins from the town in Armstrong County, Tex., consists of calcareous and arenaceous clays, sands, and heavy conglomerates. Lithologically, it is practically impossible to differentiate these beds from those of the Loup Fork or Blanco, and it is only by means of fossils contained in them that the beds are known to be of different age. Professor Cope identified eight vertebrates from these beds and assigned them to an age intermediate between the Loup Fork and the Blanco.[c] Professor Cummins states that the Goodnight beds have extensive development south of Mulberry Creek. The maximum thickness as given by him is approximately 150 feet.[d]

Dall, on the authority of Dumble, has called these beds Palo Duro. He classes them as transitional between the Miocene and Pliocene, and says: "These beds, identified in western Texas by Scott as transitional, also had the absurd name of Goodnight applied to them."[e] Certainly no one who has ever been in that portion of the Panhandle would consider the name of Goodnight as absurd, for it is the name of one of the largest of the old-time cattle ranches, as well as of a good-sized town, the seat of a flourishing college.

Blanco formation.—Professor Cummins gave the name Blanco beds to those Tertiary rocks which rest unconformably upon the Dockum conglomerate at the type locality of the latter—i. e., at Dockum, Dickens County, Tex. Vertebrate fossils from that region have been identified by Professor Cope, who states that "the horizon is more strictly and nearly Pliocene than any of the lacustrine terranes hitherto found in the interior of the continent."[f] The rocks consist of alternating layers of sand, clay, and diatomaceous earth, approximately 160 feet in thickness.

Tule formation.—These beds, described by Professor Cummins[g] and by Professor Cope, were assigned by the latter to the *Equus*-bed

[a] Cummins, W. F., Notes on the geology of northwest Texas: Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 203.

[b] Ibid., p. 204.

[c] Cope, E. D., Vertebrate fauna of the Loup Fork beds: Fourth Ann. Rept. Texas Geol. Survey, pt. 8, 1893, p. 46.

[d] Cummins, op. cit. pp. 201–202.

[e] Dall, Wm. H., Table of North American Tertiary horizons, etc.: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, p. 338.

[f] Cope, E. D., Vertebrate fauna of the Blanco beds: Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 47.

[g] Cummins, op. cit. pp. 199–200.

PROPERTY OF U. S. GEOLOGICAL SURVEY.

horizon of the early Pleistocene, on account of vertebrates from Tule Canyon in Swisher County. In general, the statement made by Professor Cope that "*Equus* beds form the superficial formation of the country at various points on the Staked Plains and about its eastern escarpment,"[a] may be considered as accurate. However, the *Equus* beds are by no means confined to the top of the Llano Estacado, but occur in other localities as well, notably north of Canadian River. These rocks consist of coarse sand, clay, and gravel, with variable thickness.

Age of beds.—It is the experience of the writer, after ten seasons spent in studying these deposits in Kansas, Oklahoma, Texas, and New Mexico, that it is practically impossible to separate either the Tertiary or Pleistocene deposits of the plains into mappable formations. From the bottom of the Loup Fork to the top of the *Equus* beds the general character of the rocks changes so constantly and with such extreme irregularity that they can not for the most part be differentiated in the field. Sections made at about twelve points in eastern Colorado, western Kansas, western Oklahoma, and in the Panhandle of Texas show such a marked similarity of structure that without the evidence of fossils it is impossible to determine whether the rocks belong to the Miocene, the Pliocene, or the *Equus* beds. Even Professor Hay, who studied these rocks in Kansas and applied to them the descriptive terms "Mortar beds," "Tertiary grit," "Tertiary marl," etc., did not succeed in differentiating them into definite horizons. If it were possible to distinguish formations stratigraphically, the matter of classification would be greatly simplified, but in the light of present knowledge, it seems not only inexpedient but even impossible to differentiate them structurally. In view of these facts, therefore, the general term Tertiary will be used to include the Loup Fork, the Goodnight, the Blanco, and in most cases also the Tule or *Equus* beds. The *Equus* beds are classed with Tertiary chiefly, as stated above, because these beds can not be distinguished in the field, nor, indeed, by any other means than that of vertebrate fossils, which are present only in scattered localities.

ORIGIN OF THE TERTIARY DEPOSITS.

With regard to the origin of the Tertiary deposits of the Great Plains two general theories have been advanced. The earlier geologists who studied these rocks considered them lacustrine in origin; Professor Marsh, for instance, described a great Pliocene lake covering practically the entire Great Plains area, in which deposits 1,500 feet thick were laid down.[b] Professor Cummins, in speaking of the

[a] Cope, E. D., Vertebrate fauna of the Blanco beds: Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 75.

[b] Marsh, O. C., Amer. Jour. Sci., vol. 9, Jan., 1875, p. 52.

Goodnight beds, says, "They seem to have been deposited in a lake much more extensive to the south than the Loup Fork, which latter seems to have had its southern termination here" (at Mulberry Canyon).[a] Professor Cope has already been quoted regarding "Lacustrine terranes." Professor Hay accepted the lake theory, although he did not account for the formation of these supposed bodies of water.[b] Later investigations, however, have led to the opinion that it is to fluviatile rather than to lacustrine agencies that we must look for the origin of the Tertiary deposits.

Professor Haworth, in discussing the Kansas Tertiary,[c] observes: "The relative positions of the sand, the gravel, and the 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 a very few of lake deposits."

Mr. Johnson, in his report on "The High Plains and Their Utilization," expresses the opinion that "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 of necessarily strong-running streams and the fine material of sluggish streams, in alternating epochs 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."[d]

The only point at issue among these writers seems to be whether the cause of the deposition of the material by the streams is to be sought in climatic changes which produced alternate periods of aridity and humidity, or in deformation movements of the earth's crust by which the eastern part of the Great Plains was elevated and the gradient of the streams lessened. With regard to this matter the writer does not express an opinion. The subject has been discussed by Johnson, to whose article the reader is referred.[e]

GENERAL CHARACTER OF THE TERTIARY DEPOSITS.

It has been stated already that the greater part of the rocks consists of clays, sandstones, and conglomerates with clays predominat-

[a] Cummins, W. F., Notes on the geology of northwest Texas: Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 201.

[b] Hay, Robert, Water resources of a portion of the Great Plains: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 571.

[c] Haworth, E., Physical properties of the Tertiary: Univ. Geol. Survey Kansas, vol. 2, 1897, p. 283.

[d] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, 655.

[e] Ibid., chap. 2, p. 612–656.

A. EDGE OF TERTIARY ESCARPMENT.

Showing alternation of hard and soft beds.

B. PECULIAR WEATHERING OF TERTIARY CLAY IN PALO DURO CANYON.

ing. In color the clays are normally white, so white that when exposed they are frequently spoken of as "gyp" cliffs or "chalk" cliffs, although they contain neither gypsum nor chalk. However, the color of the clays is not invariably white; it often grades into the various other light tints. In structure the clay is usually so soft that it may be crushed with the fingers; but, on the other hand, the more calcareous members are frequently indurated and make a fair quality of limestone. Occasionally beds are found full of white calcareous lumps or concretions, which give to the rock a mottled appearance. The lime often cements the clay together in the form of elongated concretions, which, on weathering, have a resemblance to stalactites, as shown in Pl. X, *B*, and form what one author calls "pipy" concretions.[a]

Sand beds and ledges of conglomerate also constitute a considerable part of the Tertiary and Quaternary. The sand is usually in smooth, rounded, white or yellowish grains and the material is of quartz. The conglomerate is made up typically of smooth water-worn pebbles, usually composed of quartz, granite, porphyry, and other igneous rocks, varying in size from sand grains to bowlders as large as a peck measure. These pebbles most commonly occur in beds or layers sometimes as much as 25 feet thick, but often they are intermingled with fine sand and sometimes sprinkled through the clay members.

In a number of localities the gravel beds at the immediate base of the Tertiary contain considerable numbers of water-worn *Gryphæa* shells of lower Cretaceous age. It has been stated that at the present time there are no Cretaceous rocks exposed between the red beds and the Tertiary deposits in this part of the Panhandle, but that extensive Cretaceous deposits are found along the southern and western edges of the Llano Estacado. Whether these shells were derived from the lower Cretaceous rocks in place, or were transported by streams from beds farther west, it is impossible to determine, but in the light of available data the latter supposition seems probable.

The relative proportion of the different rocks enumerated above varies with the locality, but it is probable that three-fourths of the Tertiary and Pleistocene material exposed along the eastern edge of the Staked Plains is some form of clay, silt, or marl, the other one-fourth being sand or conglomerate. Farther north, in Kansas and Nebraska, the proportion of coarser material is relatively larger, often being more than one-half.

In all places on the plains, so far as known, these materials are arranged in a heterogeneous manner—the clays, sand, pebbles, silt, conglomerate, and other forms of rock occurring indiscriminately and without similarity of position. In one place a section of a hill

[a] Darton, Nelson H., Report on the geology and water resources of Nebraska west of 103d Mer.: Prof. Paper U. S. Geol. Survey No. 17, 1903, p. 25.

shows nothing but clay and silt; half a mile away beds of sandstone and gravel occur; and still farther away the section reveals little besides sand and conglomerate. (Pl. X, *A*, *B*, exhibits typical Tertiary structure.)

SAND HILLS.

There are two general classes of sand hills in the Panhandle, those derived from the disintegration of rocks in place and those blown by the winds from some stream channel. The sand hills of disintegration occur usually either along the base of the escarpment at the foot of the High Plains or along the divide between two river systems. The material of which these sand hills are composed has been largely derived in place by the disintegration of Tertiary rocks. As the clay and silt which make up a considerable part of the Tertiary deposits were removed by the action of water the sand and gravel remained behind and the finer materials have been shaped by the wind. In each of the four eastern counties of the Panhandle there are considerable areas of sand hills which have been formed in this manner. In Lipscomb and Hemphill counties sand hills occur along Wolf Creek and on the divide between that stream and Canadian River. Much of Wheeler County is covered with sand hills, particularly in the region between Sweetwater Creek and North Fork of Red River. In Collingsworth County there is a region 10 to 15 miles wide south of Salt Fork, extending entirely across the county, composed wholly of these sand hills, and in southeastern Donley County there are large areas covered with sand hills.

In the second class of sand hills are those formed of wind-blown sand derived from the stream channels. In the Panhandle region they seem to occur indiscriminately on both the north and south sides of the various rivers, usually along the flood plain between the channel of the stream and the bluffs. Hills of this character, which are composed of fine white or yellowish quartz grains, are usually barren of vegetation, as shown in Pl. IV, *A*. They are present along practically all the larger streams, particularly along Canadian River and Salt Fork of Red River. Migrating dunes are not uncommon.

ALLUVIUM.

Along all the large streams in this region there have been deposited materials of greater or less thickness that have been brought by the streams from higher levels. In the valley of Canadian River is a broad belt of bottom land made up largely of alluvium, which here consists chiefly of fine sand and clay mixed with decayed organic matter and occasional coarser gravels, the whole constituting a sandy loam. As much of the clay is derived from the red beds, the loam often partakes of a reddish color. Along all the small streams emptying into Canadian River are bottom lands or flood plains composed of practically the same material, and there are deposits along the various tributaries of Red River. Along North Fork and Salt Fork the bottom lands are from half a mile to a mile wide.

WATER RESOURCES.

UNDERGROUND WATERS.

GENERAL CONDITIONS.

The underground waters of the Panhandle of Texas may be discussed under two general heads—red-beds waters and Tertiary waters. Under the latter head is included water from the sand hills. The water of the red beds occurs chiefly on the eroded plains at the foot of the escarpment in the southern and eastern part of the region. The water of the Tertiary is found on the High Plains and in the escarpment regions—that is, on the greater part of the area under discussion. The water of the red beds is limited in amount and usually impregnated with mineral salts, particularly gypsum ($CaCO_4$) and common salt (NaCl), so that it is often unfit for general use, while the Tertiary water is uniformly abundant and almost always pure and wholesome. So different both in quality and quantity are the waters from these two horizons that it seems best to discuss them separately.

WATER FROM THE RED BEDS.

Character.—Wherever the Permian red beds are exposed the water is unsatisfactory in quality, although it ordinarily is plentiful. Water from the red beds generally contains appreciable amounts of mineral salts, which in many cases are so abundant as to render it unfit for general use. To all this salt-impregnated water the common term "gyp" water is applied. In point of fact, however, much of the water does not contain any considerable per cent of calcium sulphate. A number of other mineral salts are found in the red beds, the most abundant of which are sodium chloride, sodium sulphate, sodium carbonate, magnesium carbonate, magnesium sulphate, calcium chloride, and sodium borate, in about the order named. In some instances all of these salts are found in the water of a single well; but in most cases only two or three of them appear in appreciable quantities.

It must not be understood, however, that all the water from the red beds is bad, for there are numerous localities where soft and pure water is found. Especially is this true of the localities where the water is obtained in the Quartermaster formation, which, as has been stated, consists largely of soft sandstones and sandy shales. In this formation but little gypsum occurs, and the proportion of the other mineral salts enumerated above is not as great as in the rocks of the Greer formation. The general statement may be made, however, that water from the red beds is not good water.

Occurrence.—Water in the red beds is usually found under one of two conditions: first, in sandstones or sandy clay beds, and second, in underground veins, either joints in the clay or in gypsum caves. As has been stated, the red beds consist largely of red clay shale with occasionally interbedded members of sandstone and gypsum. In part the clays are composed of very fine-grained material which is practically impervious to water. Frequently they contain a high proportion of sand, in which case the interstices between the sand and clay particles are sufficiently wide for the seepage of water, and it is from beds of this character that perhaps the greater part of the wells obtain their permanent supply. In many parts of the red beds, especially in the Quartermaster formation, the arenaceous clay beds become a true sandstone and the relatively large spaces between the sand grains afford ready passage for water.

Many of the wells, however, find their supply not in sand nor even in sandy shales, but, if the testimony of drillers is given credence, in joints in the red clay. Those who have had experience in drilling wells agree in stating that while the greater part of the water in the red beds is found in sand, many of the wells penetrate nothing but the red clay. It is not uncommon for the drill to strike a so-called vein in the clay, in which the flow is so strong that the water rises many feet before the tools can be lifted. It has been said that the red beds abound in sink holes and caves, and that from many of the caves springs issue. In a number of cases the drill has been known to penetrate these caverns, which thus become reservoirs for the wells. The depth of wells in the red beds varies from 20 to 190 feet, averaging 60 feet.

WATER FROM TERTIARY ROCKS.

Character.—Almost without exception the water obtained in the Tertiary and sand-hills deposits of the Great Plains is good. Analyses of water from a number of wells and springs in these formations in Nebraska, Kansas, Oklahoma, and Texas have almost invariably shown that the water contains little or no harmful mineral salts. There are to be found small amounts of calcium sulphate, calcium chloride, calcium carbonate, magnesium carbonate, and sodium bicarbonate in the water of some of the wells, but the average amount of mineral salts in 7 samples was but 15 grains per gallon. The water on the plains is almost universally soft, pure, and wholesome, suitable for household and stock use.

Occurrence.—In order to appreciate the underground-water conditions of the High Plains, an understanding of the rocks from which the water is obtained is necessary. As has been shown under "Geology," pages 25–31, the Tertiary deposits, several hundred feet thick, which cover this region, consist chiefly of alternating layers of clay, sand, and gravel. It is generally believed by geologists that the material which comprises these rocks was derived largely from the Rocky Mountains, and that it was spread out in the beds of streams which in time past flowed from the mountains and were lost on the plains. These streams left deposits, now of sand, now of gravel or clay, and now of pebbles, which, in time, were covered by other deposits, sometimes of the same, but more often of other material. This process was continued until several hundred feet of alternating beds of the various kinds of rocks were deposited. From this it will be understood that the greater part of the beds must necessarily be irregularly lens-shaped in cross section, and in most cases will not be found continuous over large areas. In some places the greater part of the thickness consists of clay or silt, while in other localities sand and gravel predominate. In general, it is observed that the deposits near the base of the Tertiary have a greater proportion of the coarser material, consisting of sand and gravel beds, and that at a higher level they have clays and silts in greater abundance.

Most of the water of the High Plains is known as "sheet water." This is a term almost universally used in the western part of the United States to indicate any fairly constant supply of water at a more or less uniform depth beneath the surface. The term "underflow" is sometimes used to indicate practically the same phenomenon. The general impression seems to be that at some depth beneath the surface there is a regular "sheet" or "lake" of water, which if tapped by a well will yield a constant supply. In some places two or even three "sheets" are supposed to exist, and the expression "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, stream-like, beneath the surface, an idea disclosed by the expression "the underflow is to the south," or "the underflow is east." Much of this theory, however, is erroneous and not based on valid conceptions of the conditions found in the nature and relations of the water-bearing beds. Rounded grains of sand and gravel do not lie close enough together to fill all of the space, but have interstices between them. These pores or spaces are minute reservoirs for the water which, in its passage through such materials, seeps from one of these minute reservoirs to the next, and thus very slowly flows along underground. This movement is called "underflow," but it is not nearly so rapid as popularly supposed. Experiment has shown that even along stream beds, such as the Arkansas River in western Kansas, the rate of underflow does not average more than 10 feet a day.[a] On the High Plains, where the gradient is exceedingly low, it is doubtful if the water moves more than this distance in a year. This is a point, however, upon which there are practically no data, and estimates may be misleading.

Dry ground, according to the theory just advanced, is ground the pores of which contain no water, while wet or saturated ground is that in which the pores are filled. Since water 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," and this is often identical with the popular phrase "sheet water." Since water moves so slowly underground, this water table often becomes approximately similar in contour to

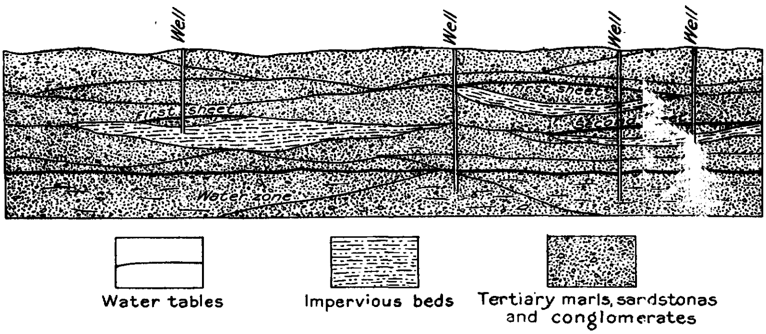


FIG. 3.—Ideal section of Tertiary, showing first and second sheet water.

the surface of the ground, being high on the divides and low near the streams where the water may escape in springs.

Attention has been called to the conditions under which these beds were laid down. As originally deposited they must have had an irregular outline and surface, especially when laid down in swamps or lakelets. Where the material is clay or very fine sand its interstices are very minute and practically impervious to water. Such fine deposits are often overlain by sand and gravel in basins or channels, and these in turn by other fine-grained deposits in varying succession, so that the alternation in water-bearing and impervious beds is most irregular, as shown in fig. 3. If such deposits are penetrated by a well the first sand encountered will supply water, the quantity of which depends upon the size of the water-bearing deposit, its coarseness of grain, the height of its edges, etc.; in the next coarse sand bed a second water stratum is found, and so on until finally the main water table is penetrated. This may be considered a probable

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

explanation of the "first and second water," "first and second sheet," etc. It also possibly accounts for conditions similar to the one found near Groom, Gray County, where records obtained from a relatively small area show well depths ranging from 300 to 360 feet, except in one well where water is obtained at 228 feet. This shallower well probably finds its source of supply in one of these buried basins.

Wells throughout the Tertiary area usually secure water at depths varying from 20 to 500 feet. On the High Plains the average of twenty wells, taken at random from half a dozen counties, was 258 feet. The deepest wells are found along the line of the Santa Fe Railroad on the high divide south of Canadian River, in Carson and Gray counties, where the wells are from 350 to 500 feet deep. On the High Plains in Hansford, Ochiltree, and Lipscomb counties, north of Canadian River, the average depth is 240 feet. In Armstrong County, along Prairie Dog Fork of Red River, the average depth is less than 200 feet. In certain parts of the region, notably in Hansford and Carson counties, the driller sometimes fails to obtain a water supply, and instances are reported where the entire thickness of the Tertiary has been penetrated without finding an adequate amount. It is the experience of drillers that if the "red clay" (evidently red-beds clay) is encountered without finding a sufficient amount of water, it is useless to go deeper.

SOURCE OF THE UNDERGROUND WATER.

Local precipitation is the source of the underground water of the High Plains. The rainfall at Amarillo, Tex., a few miles west of the region here discussed, averaged 21.94 inches annually for a period of twenty years.

Rainfall on the surface of the earth is disposed of chiefly by evaporation, run-off, and sinking, or seepage into the ground. 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 upon several local conditions. For instance, on a steep slope the greater part runs off; in a warm, arid climate the greater part evaporates, while in loose soil the greater part soaks in.

On a considerable part of the Great Plains, where the surface is level and the drainage systems undeveloped, there is no run-off, and the rainfall is either absorbed by the ground or evaporates. After a rain the water which does not evaporate immediately or is not absorbed by the ground accumulates in broad, shallow depressions on the surface, known as "buffalo wallows," or "lakes," and there remains until it evaporates. Johnson estimates that not more than 3 or 4 inches annually soak into the ground, an amount which would not saturate more than about 1 foot of sandy strata.[a] This estimate

[a] Johnson, Willard D., The High Plains and their utilization: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 4, 1902, p. 646.

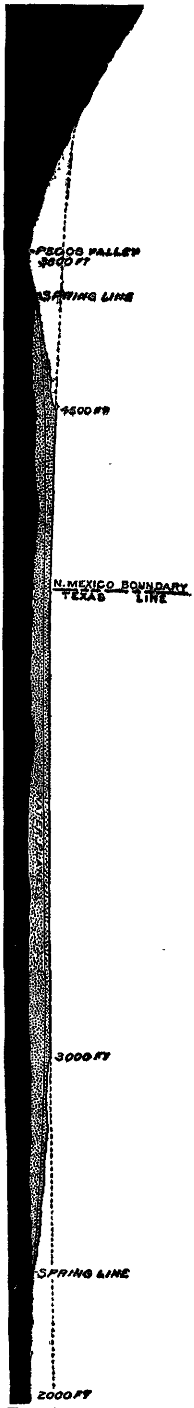


FIG. 4.—East-west section of High Plains, showing position of water table.

of the amount of water absorbed seems rather small, but in all probability not more than 6 inches of rainfall are added to the ground water each year.

THE WATER TABLE.

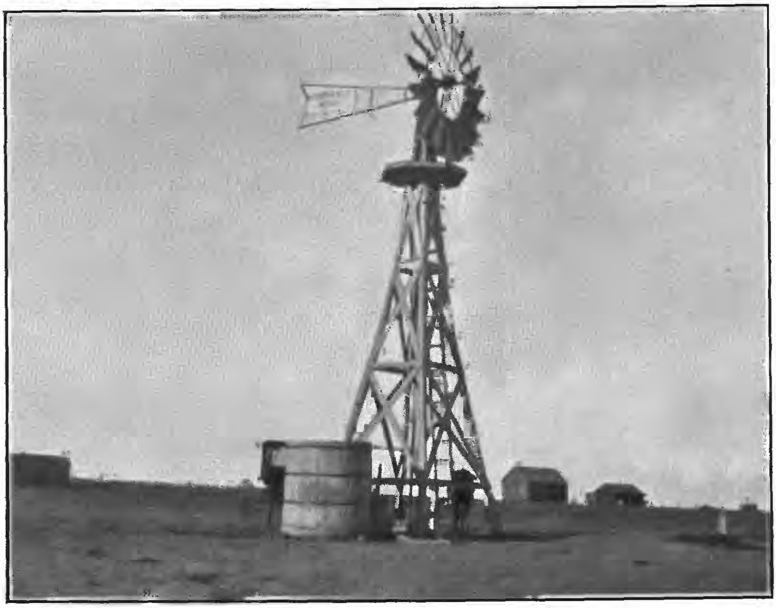
As stated on page 34, the "water table" or "water plane" is the subsurface plane beneath which the ground is saturated with water; in other words, the level at which the top of the ground water stands. It varies constantly from place to place, from year to year, and even from day to day. It is supplied chiefly from rainfall and is lowered when the water is removed, as, for instance, in the case of springs, by artesian wells, or by heavy pumping. Ordinarily it is at a considerable distance below the surface, but occasionally 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 show that this water level for the High Plains, as a whole, averages approximately 250 feet below the surface. So far as known, this level 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. 4 shows an east-west section of the plains and the position of the water table.

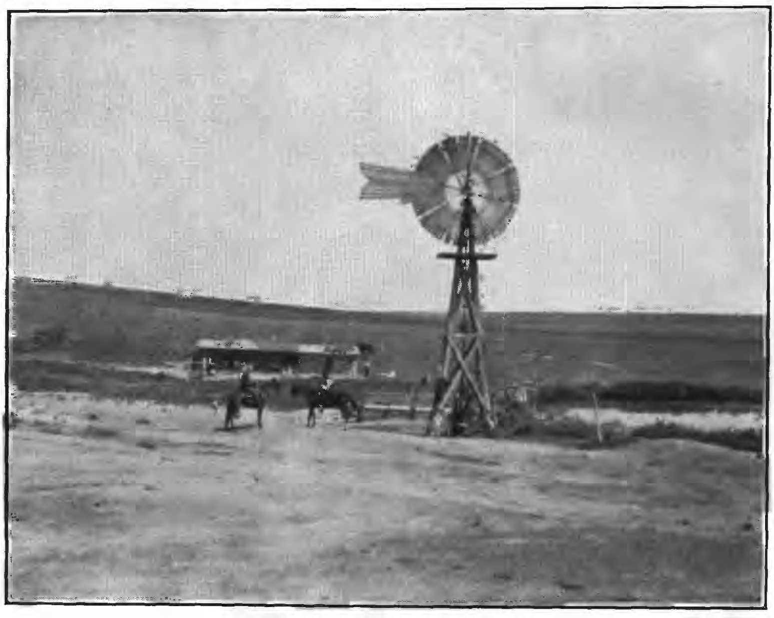
USE OF WINDMILLS.

As the Panhandle is chiefly a grazing country, most of the wells have been put down for the purpose of furnishing water for cattle. On the greater number of the larger ranches wells are located 2½ to 3 miles apart, and windmills are almost universally used to bring the water to the surface.

Often upon the prairie the only object in view to indicate that the locality is inhabited is a solitary windmill. These mills are placed upon towers 20 to 30 feet high, constructed of wood or steel. All types of factory-made turbines are used, but the steel mill with a wheel 8 to 10 feet in diameter seems to be most effective for general purposes. Larger wheels, some even 20 feet in diameter, are employed to elevate the water for the entire supply of some of the larger towns, as, for instance, Panhandle and Ochiltree. (Pl. XI, A.) On the



A. WINDMILL AND TANK AT OCHILTREE, TEX.



B. TYPICAL WINDMILL AND TANK.

range the water is pumped into large steel or wooden vats or into shallow basins (locally called "tanks") excavated in the ground or formed by damming a shallow draw. These tanks are of various sizes, but ordinarily they have a capacity of several thousand barrels and are very serviceable, since the soil is of such nature that when thoroughly compact and saturated it permits but little seepage. Typical views of windmills and tanks are shown in Pl. XI, *A*, *B*. The mill is allowed to operate continuously, and is visited occasionally by a rider for purposes of repairs or oiling. Wind is such a constant factor on the plains that little concern is felt regarding the power to raise the water, and in very few instances are provisions made, or are other means necessary, for lifting it. In a few instances gasoline engines are installed for use in case of emergency. In the Panhandle a week seldom passes without wind to drive the mills so that they will supply sufficient water for the stock.

DEEP-SEATED WATERS.

The project of obtaining artesian water in various parts of the Panhandle, particularly in the red-beds areas at the foot of the High Plains, is often considered. In general, the arguments advanced in favor of the project are based on the mistaken idea that there is an underground source of supply from the High Plains or the Rocky Mountains.

From what has been stated already it will be understood that the water supply of the High Plains is derived wholly from the rainfall, and while the part which sinks into the ground and is added to the ground water may amount to 5 or 6 inches a year, the geologic structure is not favorable for artesian conditions. Between the Tertiary and the underlying red beds there is everywhere a pronounced unconformity, and the rocks of the red beds beneath this unconformity are composed chiefly of impervious clays and shales, through which the water can not pass readily. These conditions, then, preclude the probability of artesian water supply having its source on the High Plains.

That the Rocky Mountains are a source for an artesian supply through the red beds is also improbable. These red beds, which are covered by the Tertiary of the High Plains, reappear in New Mexico beyond the western escarpment of the plains, and are exposed along the eastern base of the mountains at a higher altitude than in the region east of the plains escarpment. Some of these beds are coarse-grained, and doubtless they contain water in some places, but whether they could be reached by deep wells and would yield water in the Panhandle region remains to be determined. Their general relations are shown in Pl. II and fig. 3. In the eastern part of the Panhandle these beds must be very deep seated, probably more than 2,000 feet, and the drill has never reached this depth in the red beds anywhere in this part of the plains. The only place where the red beds have been well explored is along their eastern margin in eastern Oklahoma, where, however, artesian water was not found.

At Childress, Tex., 20 miles south of the southeastern corner of the region discussed, the Fort Worth and Denver City Railroad has drilled a well to a depth of 1,300 feet in search of water for engines and shops. From the surface to the bottom of the well the drill passed through nothing but red clay shales containing a few ledges of sandstone and gypsum. Several horizons of salt water were encountered, but no fresh water was obtained.

At a number of points in Oklahoma wells have been drilled in search of coal, oil, gas, and water, but so far artesian supplies have never been found. At Fort Reno the Government sunk a well to the depth of 1,400 feet in search of water for the post, but none was secured. Near Oklahoma City a well 2,050 feet deep passed out of the red beds at 1,550 feet. No artesian water was found.

From all data at hand the conclusion must be drawn that the chances are very poor for finding artesian water in the red beds under the plains. The red beds present difficulties to very deep drilling which usually have been insurmountable, and if artesian water does exist in the lower members of this series it is doubtful if it can be reached at a cost which would be generally profitable. However, it is to be hoped that at some time the experiment will be tried of testing all of the red-bed strata.

SPRINGS.

There are in the region under discussion two general classes of springs—those from the red beds and those from the Tertiary and sand hills. Both in amount of flow and in character of water these springs differ considerably, and for that reason it is thought best to describe the two classes separately.

RED-BEDS SPRINGS.

Springs in the red beds are of infrequent occurrence, and those present are rarely strong. They may be classified, according to the character of their water, as salt springs, gypsum springs, and fresh-water springs.

Salt springs.—Along the branches of Red River, Prairie Dog, Salt, and Elm forks, there are a number of weak salt-water springs, often little more than seeps. The horizon from which the water comes is usually near the base of the Greer formation. On Elm Fork of Red River in western Greer County, Okla., 5 miles east of the Texas line, there are two salt plains of considerable size, fed by a number of strong salt springs, the combined flow of which approximates hundreds of thousands of gallons of salt water a day. No springs as strong as these are found in any part of the Panhandle. Some salt springs occur, however, but so far as known the salt brine of Texas springs is not used, and it is not probable that the salt water of the Panhandle will ever be utilized, on account of the much larger amounts near at hand in Oklahoma.

Gypsum springs.—Practically all the gypsum springs in the Panhandle issue either from beneath or in close proximity to the massive gypsum ledges that make up a considerable part of the Greer formation. Such springs occur along Elm Fork of Red River in Collingsworth County and on the branches of Prairie Dog Fork in Collingsworth, Donley, and Armstrong counties. Sometimes these springs are mere wet-weather seeps, but in a number of cases they are strong, boiling, perennial springs derived from underground streams, flowing from beneath ledges of white gypsum.

Fresh-water springs.—The greater number of the fresh-water springs of the red beds issue from the Quartermaster formation, which, as has been stated, consists largely of sandstone and sandy shale, with but little gypsum or other mineral salts. The conditions are ideal for springs, provided there is a source of supply, and in a region of greater rainfall a large number might be expected to exist. In the Panhandle, however, the number is small. In the Quartermaster formation there are very few bold flowing springs. This is due to the peculiar lithologic character of the rocks, mostly soft sandstones and sandy clays, which, as stated on page 21, usually weather into peculiar rounded knobs and buttresses and into narrow canyons. It is in the latter that the springs occur, and it is not uncommon to find at the head of a little canyon an outcropping ledge of sandstone, beneath which the water seeps out of the bank. The flow is rarely strong, but it is often very persistent, and the water usually accumulates to form a tiny rill in the bottom of the canyon. Ranchmen and farmers frequently take advantage of the soft rock to hollow out a small basin, in which the water collects, often in quantities sufficient to supply a farmhouse, or even to furnish water for a number of cattle.

Springs are occasionally found in the Dockum beds, issuing from beneath ledges of sandstone or from under the conglomerate members. These springs are usually weak and unimportant and so far as noticed not utilized. This latter fact may be attributed chiefly to their inaccessibility, for the Dockum is exposed only along the steep escarpment at the foot of the High Plains.

TERTIARY SPRINGS.

Throughout the High Plains region the Tertiary deposits yield numerous springs, which are always of good water and have long been most advantageous to the settlers and travelers. Camps, forts, farms, and even cities have been located with reference to the proximity of a Tertiary spring or spring-fed creek. In the Texas Panhandle there are thousands of such springs. They are found, usually in great numbers, in every one of the twelve counties described in this report.

The source of supply of the Tertiary springs is chiefly in the ground water, otherwise called the "sheet water," or "underflow," of the High Plains, and they are usually found where deep canyons have been cut into the highlands.

Not infrequently springs occur at the line of contact between the Tertiary deposits and the clay strata of the upper part of the red beds. This condition is due to the ready seepage of water through the Tertiary sands to the top of the impervious red beds, where it flows laterally until it reaches the surface. Many of these contact springs do not issue from a single opening, but the water finds its escape along a zone of seepage extending sometimes for hundreds of yards along the side of a cliff. In such cases the amount of water discharged at any one place is not large, but the aggregate is often considerable.

Excellent springs frequently occur in the sand hills at the contact of the sand and the relatively impervious underlying strata. The flow from these sand-hill springs is seldom strong, but the water is pure and wholesome. Springs of this type occur chiefly in the sand-hill regions of the four eastern counties.

In a region where the underground supply is scanty the water that issues from springs is necessarily limited in amount. Very few of the springs discharge half a second-foot of water, and perhaps the greater number of them will not average one-tenth of that amount. The water usually flows but a short distance and then disappears in the sand. Where there are a number of strong springs in a locality the water unites to form a small creek, which is sometimes perennial, but usually intermittent.

STREAMS.

CLASSIFICATION OF DRAINAGE.

The drainage of this region flows into Mississippi River. The water from the northern part of the area flows into either the Canadian or the North Fork of the Canadian, tributaries of Arkansas River, while the water from the southern part reaches Red River. The drainage may be classified as follows:

North Fork of Canadian drainage.—Coldwater, Palo Duro, and Wolf creeks are tributary to North Fork of Canadian River.

Canadian drainage.—Canadian River flows northeast across this region into Oklahoma, traversing Hutchinson, Roberts, and Hemphill counties. It receives as tributaries a number of small creeks which rise on the plains both north and south of the river, cutting their way through the escarpment and entering the river nearly at right angles. The width of the basin from watershed to watershed averages not more than 35 miles.

Red River drainage.—Five main branches of Red River either rise in or pass through this part of the Panhandle. Beginning on the north they are as follows: (1) Washita River, which in Oklahoma and Indian Territory becomes a stream of considerable size, rises in southwestern Hemphill County and flows east; (2) North Fork has its source in Gray County and flows east across Wheeler County into Oklahoma; (3) Elm Fork has its origin in northwestern Collingsworth County and flows southeast; (4) Salt Fork rises in northern Armstrong County and flows east across Collingsworth County before reaching Oklahoma; (5) Prairie Dog Fork rises on the High Plains far to the west, and in this region flows through Palo Duro Canyon across the southwest corner of Armstrong County. These four branches, North, Elm, Salt, and Prairie Dog forks join at the southeast corner of Greer County, Okla., forming Red River, a tributary of Mississippi River.

STREAMS IN DETAIL.

Coldwater Creek.—In its upper course this stream is known as Rabbit Ear Creek, from the fact that it rises near the Rabbit Ear Mountains, two volcanic peaks in northeastern New Mexico. It flows southeast across Dallam and Sherman counties, then turning northeast crosses the northwest corner of Hansford County, passes into Beaver County, Okla., and empties into Beaver Creek at the town of Hardesty. In its course through Hansford County it has cut a canyon 1 to 3 miles wide and approximately 100 feet deep into the Tertiary rocks of the High Plains. The stream is fed by Tertiary springs. Consequently its water is fresh.

Palo Duro Creek.—This stream flows diagonally across Hansford County from southwest to northeast. It is a typical High Plains stream. Rising on the level prairie, it soon begins to cut a trench, which becomes deeper and wider until in Hansford County it is a canyon 1 to 3 miles wide and 100 feet below the level of the plains. Only in parts of its course is there water the year around. At Hansford, the county seat, the stream is dry except after heavy rains, but

15 miles downstream running water appears. This stream also empties into Beaver Creek in Beaver County, Okla.

Wolf Creek.—Wolf Creek rises on the High Plains a few miles southwest of Ochiltree, the county seat of Ochiltree County, and flows east across Ochiltree and Lipscomb counties into Woodward County, Okla. At old Fort Supply it joins Beaver Creek, forming North Fork of Canadian River. In its upper course it has cut a narrow canyon with precipitous bluffs. Farther down it passes out of the High Plains and enters the sand-hills region, where the bed is wide and sandy. The creek is fed by small branches—Camp, Willow, Cottonwood, Plum, Mammoth, and others—the water of which comes from Tertiary springs among the sand hills. Wolf Creek has the reputation among the cattlemen of being the most constant stream in the Panhandle.

Canadian River.—The largest stream in the Panhandle of Texas, Canadian River, has its headwaters among the high peaks of the Rocky Mountains in northern New Mexico. In its upper course it receives a number of tributaries which are fed by mountain springs. After leaving the mountains it flows southeast first across a plain composed of upper Cretaceous rocks, then for nearly 100 miles through a canyon 500 to 800 feet deep in the Dakota sandstone, finally reaching the red-beds plain in the region north of Tucumcari, N. Mex. At this point it changes its direction to the northeast and so flows out of New Mexico and across the Panhandle of Texas into Oklahoma, where it again turns southeast, finally joining Arkansas River in the eastern part of Indian Territory. Of the 700 miles of its course only about 100 miles are included in the part of the Panhandle under discussion. Across this region it flows in a broad curve, convex to the north, crossing southeastern Hutchinson, northern Roberts, and middle Hemphill counties before passing into Oklahoma. Throughout this distance the river has cut a broad canyon in the High Plains. In places the headlands between the tributary creeks approach almost to the river, but at most points the flood plain, usually a sandy flat, is 2 to 4 miles wide. The channel of the river itself is a sand bed averaging three-quarters of a mile in width.

Canadian River is perhaps more treacherous than any other stream of the plains. The stream is either dry or a raging torrent. The river may have been dry for weeks at a time, when suddenly, without warning, a wall of water several feet high rushes down the channel, sweeping everything before it, and for a number of days the river continues high, then gradually subsides. following this period of abnormal flow the sand in the stream becomes "quicksand," or loose sand which appears firm but gives way suddenly under foot, rendering the stream extremely dangerous to cross. Many a herd of

A

B

FRESHET ON RED DEER CREEK AT MIAMI, TEX.

cattle has been mired in Canadian River, and every year loaded wagons and even teams are abandoned. The cause of the sudden and rapid rises is not yet fully understood, but most of them are caused by heavy rains near the head of the stream.

Such sudden rises are not confined to the Canadian River, or to the larger streams, for the small streams exhibt the same phenomena, though on a much diminished scale. Pl. XII, *A*, *B*, shows a rise which occurred on Red Deer Creek, a tributary of the Canadian, at Miami, Roberts County, August 16, 1904. The town lies in a rather narrow valley cut by the stream into the High Plains. There had been no rain at Miami for several weeks and the bed of the creek was a dry sand flat. A heavy rain occurred at the head of the creek a few miles southwest, and two hours later the water came down the stream channel, a narrow tongue of white foam, as shown in Pl. XII, *A*. This was followed by a wall of turbid, yellow water that filled the banks of the stream. In half an hour the flood was at its highest, a seething, foam-capped torrent. By next morning the water had disappeared except from a few pools in the channel, as shown in Pl. XII, *B*, and by noon even these were dry.

Canadian River does not receive any large tributaries in its course across the plains. In three counties which it crosses in the region to which this report relates there are a number of small creeks none more than 25 miles long, emptying into the river. Of these the most important are Spring, Kit Carson, Dixon, Antelope, Blue Bear, Walnut, Buffalo, White Deer, and Red Deer, all of which rise on the High Plains and cut their way through the escarpment before reaching the river.

Washita River.—Only the upper course of Washita River is in Texas, where it is a small creek, not differing from scores of others which take their rise in the escarpment and sand-hill regions. It flows east across the southern part of Hemphill County. Farther east in Oklahoma the valley of the Washita lies almost entirely in the red beds, and it is there known as the muddiest stream of the plains. In Hemphill County, Tex., however, it has not yet cut through the Tertiary, and is here a clear, fresh-water stream.

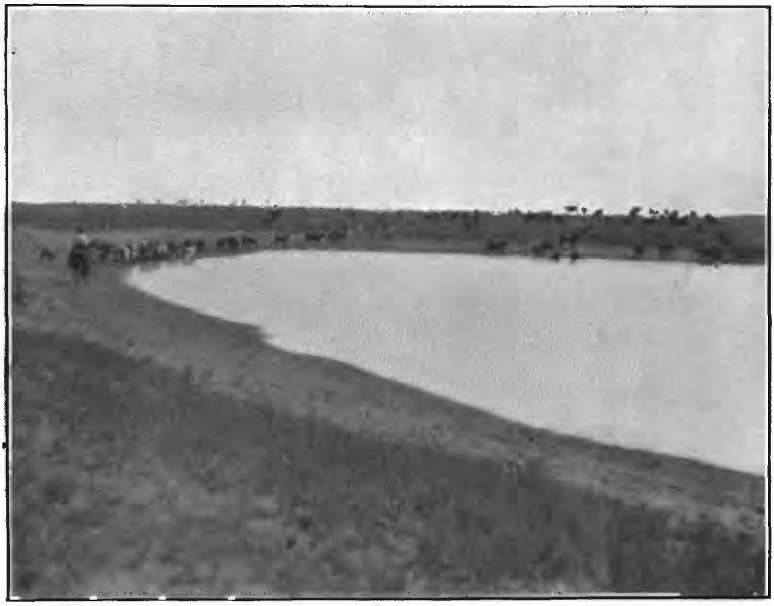
North Fork of Red River.—This, the northernmost of the four branches which make up the Red River, rises on the High Plains, in Carson County, breaks through the escarpment in Gray County, and flows northeast into Wheeler County, then southeast into Oklahoma. East of the Gray-Wheeler county line the stream has cut through the Tertiary deposits and into red beds, which are here exposed along its north bank, while on the south side sand hills occur. Across Gray and Wheeler counties the bed of North Fork is sand choked and has a surface flow only part of the year. The chief tributaries of North Fork are McClellan Creek, which drains southern Gray County, emptying near the Wheeler County line, and Sweetwater Creek, which drains northern Wheeler County and passes into Oklahoma before joining the main stream. All of these streams are fed by Tertiary springs, and even where the surface sand is dry water may usually be obtained by digging a few feet.

Elm Fork of Red River.—Northern Collingsworth and southern Wheeler counties are drained by Elm Fork, which rises along the escarpment, but soon reaches the red beds, across which it flows for the greater part of its course in Texas. The water of the upper branches is derived from the Tertiary springs in the sand hills along the escarpment, but as soon as the river enters the red-beds formations, gypsum and salt water flow into it, until by the time it reaches the Oklahoma line the water has lost its purity. Shortly after entering Greer County it receives water from a number of salt springs, and from that point is considered to contain the saltiest water of any stream of the plains.

Salt Fork of Red River.—Salt Fork is a typical stream of the plains. It rises far out on the Llano Estacado in southern Carson County, crosses northeastern Armstrong County, and flows entirely across Donley and Collingsworth counties before reaching the Oklahoma line. In its upper course it is but a shallow draw in the level prairie, but eastward it soon flows in a trench, and 10 miles from its source this deepens into a canyon with cliffs of white Tertiary beds. Up to this point the stream receives no water except the run-off, but a few miles lower in its course it reaches the Tertiary springs level and has a surface flow the greater part of the year. Eastward the bed widens and becomes sand choked, until in central Donley County, north of Clarendon, it cuts through the lower members of the Tertiary and enters the red beds. From that point almost to Mangum, in Greer County, Okla., it flows between red-beds bluffs on the north side and sand hills on the south side. It is a sandy, treacherous stream, dangerous to cross except when low.

Prairie Dog Fork of Red River.—This stream flows southwestward across Armstrong County in Palo Duro Canyon, which has been discussed under "Topography," page 12. This canyon is perhaps the most notable canyon in the High Plains. Near its mouth the walls are approximately 1,000 feet high, composed of red beds in the lower part and of Tertiary deposits above. Several creeks are tributary to this stream, the chief of which, Spillers and Mulberry creeks, drain parts of southern Collingsworth and Donley counties. These streams do not differ materially from others in this region. Spillers Creek rises in the sand hills of Collingsworth County and flows southeast across the red beds into Childress County

A. BUFFALO WALLOW.



B. LAKE ON HIGH PLAINS.

before joining Prairie Dog Fork. Mulberry Creek rises on the High Plains and has cut a deep canyon entirely through the Tertiary to a depth of several hundred feet into the red beds.

DRAINAGE OF THE HIGH PLAINS.

From what has been said it will be understood that there is a considerable portion of the Panhandle which has no developed drainage; in other words, from a great part of the High Plains there is no run-off. The headwaters of the various small streams tributary to Canadian or Red rivers have cut into the slope of the escarpment, but so far, except in a few isolated localities, the flat upland has not yet been invaded and remains still uneroded. It is graphically described by Johnson,[a] who says the plains are the remnants of an old débris apron, unscored by drainage, yet standing in relief.

Scattered at irregular intervals on this flat surface are saucer-shaped depressions, in which water collects. In size these depressions vary from the ordinary "buffalo wallow," a few feet across (Pl. XIII, *A*), to lakes hundreds of rods in diameter (Pl. XIII, *B*). In a few instances, particularly in localities near the edge of the plain, the basins are deep and bowl shaped, as shown on Pl. XIV, *B*. Often the lakes are perennial and afford an abundant supply of stock water the year round; others are ephemeral, being filled by rains but soon becoming dry, while still others contain water part of the year. These lakes occur with no regularity. In some localities on the High Plains there are none of these basins for miles, while in other sections there are scores of them in a single township. Pl. XV represents the conditions on the High Plains in parts of Carson and Gray counties.

Many of the larger depressions have extensive drainage basins, which sometimes collect the water from a number of square miles. Small prairie streams receive the run-off from the outer part of the basin and lead to the lake. It is not infrequent in traversing the High Plains to encounter a sag in the surface along which storm water is carried to a near-by lake. These small stream beds, however, rarely exceed a mile or two in length. In view of the admirable treatment of the subject by Johnson,[b] there seems no need to enter upon a discussion of the origin of these lakes. The writer agrees that the "innumerable hollows in the High Plains surface, large and small alike, are due to ground settlement rather than to some process either of original construction or of subsequent erosion."[c]

The influence of these lakes upon the settlement of the country has been important, for on the High Plains the matter of water supply is

[a] Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 626.
[b] Ibid., pp. 695–711.
[c] Ibid., p. 702.

vital. In the early history of the Panhandle, before wells had been sunk, these lakes constituted the only source of supply, and thus it happened that the early cow camps were located beside some permanent body of water. In a number of instances a town grew up at the site of the cow camp, and to-day some of the largest county seats—for example, Clarendon, Claude, and Panhandle—owe their location to the presence of such basins. Although windmills are now used to draw water for household use, as shown in Pl. XI, *A*, *B*, a great part of the stock water still comes from the lakes.

IRRIGATION.

NEED OF IRRIGATION.

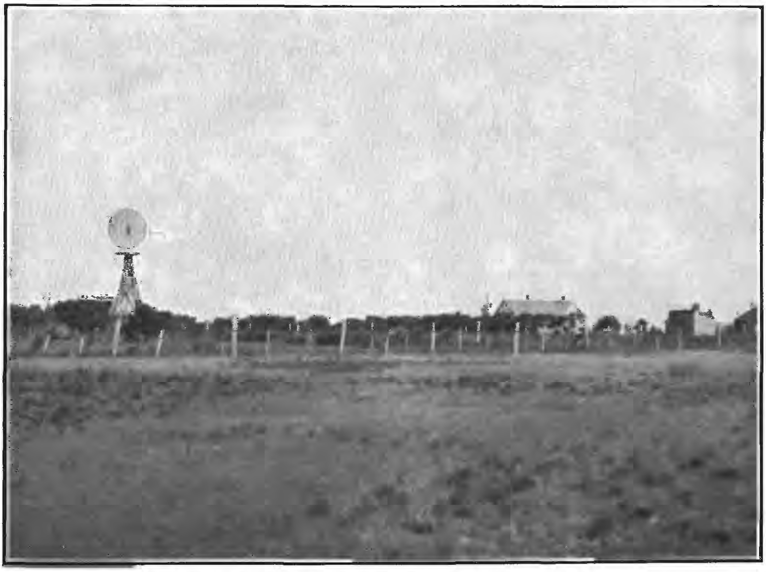
The Panhandle of Texas is located in the semiarid belt of the Great Plains. The annual rainfall averages approximately 20 inches, but the greater part of this amount is from dashing rains. During certain seasons there is little or no rain. The soil is extremely fertile, and if water were present it is capable of producing abundant crops. At various times on the High Plains farming has been attempted, and often with success for a few years, but usually seasons of drought have ensued and the effort has been abandoned. In general, practically all the crops that have been raised successfully on the High Plains are such forage plants as kaffir corn, sorghum, and milo maize, which are able to mature with a minimum of moisture. At the foot of the plains, particularly along some of the stream valleys, the culture of corn, oats, cotton, and alfalfa is now being attempted with considerable success. Crops are frequently abundant for several successive years, but occasionally fail during periods of drought.

It will be readily understood that in a region with climatic conditions such as those in the Panhandle, irrigation is necessary for successful farming. This fact has long been recognized and a number of desultory attempts have been made to irrigate small tracts, but nothing approaching a large system has ever been projected.

POSSIBLE METHODS OF IRRIGATION.

It is proposed in the following pages to discuss four possible modes of irrigation which might be put into operation in the Panhandle of Texas, viz, (1) irrigation from streams, (2) springs, (3) storm water, and (4) wells.

Irrigation from streams.—It has been shown above that the larger streams of this region practically all flow in broad, shifting, sand-choked channels, contained between low, sandy banks, and that the water varies constantly, the stream being at one time a rushing torrent, at another nothing but a dry sand bed. Only one of these rivers—the Canadian—has its headwaters in the mountains; all the



A. ORCHARD AND GARDEN AT CLAUDE, TEX.

B. JACOB'S WELL, IN A DEEP BASIN NEAR EDGE OF HIGH PLAINS.

others take their rise on the High Plains and are fed by local rains or by springs.

There are no Government gaging stations in the Panhandle of Texas, and no accurate data are available regarding the amount of flow in the various rivers. It is known, however, that enough water passes down the streams each year, particularly during times of flood, to irrigate considerable areas of valuable land. In most cases, however, there would be great difficulty in storing these flood waters. In the first place, so far as known, there are no available dam sites along the larger streams. The broad, shallow channel, sometimes filled to a depth of 100 feet with fine sand, precludes the construction of masonry dams. Besides this, in most cases material for dams is rare, or, indeed, entirely wanting. There are few hard rocks in this region except an occasional local ledge of sandstone or dolomite in the red beds and some indurated Tertiary limestone along the bluffs. Again, the sandy nature of the soil along the streams presents difficulties in the way of the construction of ditches.

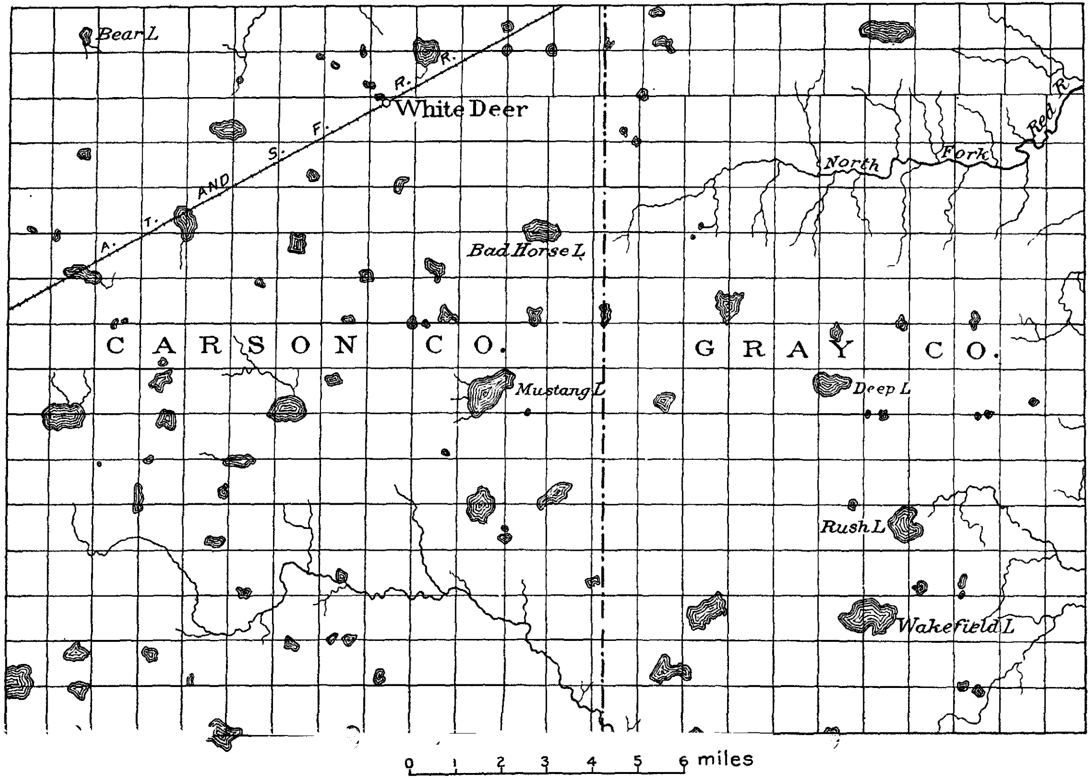
Along some of the smaller streams irrigation has been carried on with more or less success. Along Palo Duro Creek, near the post-office of Mulock, in northeastern Hansford County, Robinson Brothers have a plant in operation from which 35 acres are irrigated. The difficulty at this place has been in securing a suitable site for the dam, and the scarcity of material with which to construct it. In former years several dams here have been washed out during times of high water. Other similar plants are projected farther down Palo Duro Creek; one at Range, Okla., 12 miles below Mulock, has been in successful operation for a number of years. In eastern Wheeler County the water of Sweetwater Creek was formerly utilized to irrigate a tract of 60 acres, but in the last few years the project has been abandoned. There are a number of smaller streams where small plants sufficient to irrigate 10 to 25 acres might be successfully installed. Particularly are there opportunities for such projects along Mammoth, Wolf, and Sweetwater creeks, the upper branches of the various forks of Red River, and some of the short tributaries of Canadian River.

Irrigation from springs.—Since only springs that have a considerable flow can be utilized for this purpose, irrigation from springs must, at best, be confined to limited areas. In the Panhandle it is rather an unusual occurrence for a spring to be located where the water may be led off to irrigate a tract of land, but in a few cases there are springs which are so located that they might be thus utilized. So far as known there is no irrigation directly from a single spring in this region, but there are localities in which a small creek, formed by a number of springs uniting, might be deflected from its channel and carried by a ditch over a tract of land. Examples of this condition might be cited along the smaller tributaries of Wolf and Sweetwater creeks and Canadian River.

Irrigation from storm waters.—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 which empty into broad, shallow "lakes;" while among the breaks and at the foot of the plains it passes into the streams. In numerous places the sags on the High Plains or the dry channels among the breaks have been dammed, forming reservoirs, known locally as "tanks," to hold stock water. and in a few instances a ditch has been led out from one of these artificial ponds to irrigate a few square rods of garden or orchard. 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 with home-grown vegetables and fruit by irrigation from storm waters.

Irrigation from wells.—In the discussion of the subject of artesian water in another part of this report, the conclusion was reached that the probabilities for artesian supply in the Panhandle are not good. On the other hand, however, ordinary wells, which are common in all parts of the region, usually supply considerable amounts of water, often more than is needed for stock water and domestic use, and the surplus might well be used for irrigation. The chief difficulty in the way of the utilization of well water for these purposes is the matter of expense in lifting the water to the surface. In this region wind power is almost universally used for this purpose. In localities where wells are shallow, as, for instance, along stream valleys or among the sand hills, it has been found profitable to use water from wells for irrigating areas of considerable size. In the greater part of the Panhandle, however, the water is too deep to be used in this way. As has been stated, the average depth of the wells on the High Plains is over 200 feet, while on the eroded plains the wells average nearly 100 feet in depth. It is obvious that under such conditions little more can be done than to irrigate a garden or an orchard, and so far as has been observed this is all that is ever attempted. Pl. XIV, *A*, page 46, shows an orchard and garden at Claude, which is irrigated from a well over 250 feet deep. Examples similar to this are not uncommon.

In the sand-hill regions, where the water is not so deep, there are a number of instances of small plots irrigated with water obtained from a well. On the red-beds plain there is less irrigation by this means, partly because the gypsum water is not suitable for irrigation, but chiefly because the need of irrigation is not realized.



MAP SHOWING LOCATION OF LAKES ON A PORTION OF THE HIGH PLAINS.

FUTURE OF IRRIGATION.

Taking into account the local facts it seems very doubtful if there will ever be any extensive irrigation in the region under discussion. The supply of water is not sufficient for this purpose except along the larger streams, where the conditions are such that dams can not be constructed. Small streams, springs, artificial ponds, and wells supply water for limited irrigation, sufficient often to raise vegetables and fruit for a family, but not more. As time goes on and the region is more thickly settled, these small plants will increase in number. There is little to warrant the hope that the water supply in the Panhandle will ever increase, and unless some more efficient means than the ordinary windmill be secured to lift the water from deep wells to the surface it is extremely improbable that anything like extensive works can ever be installed. On the other hand, it is obvious that only a very small part of the available water is now being utilized. 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 garden and an orchard.

WATER CONDITIONS BY COUNTIES.[a]

LIPSCOMB COUNTY.

Topography.—Lipscomb County is in the northeastern corner of the Panhandle. Its surface is a level plain trenched from west to east through the middle by the valley of Wolf Creek. This valley is like a great sloping groove, 250 feet below the level of the High Plains at the west line of the county and 500 feet below at the east line. The High Plain along the northern line of the county is being cut into by branches of Beaver Creek. Wolf Creek Valley separates the county into two areas of plains, one forming the table-land between Wolf Creek and Beaver Creek drainage basins, the other lying between Wolf Creek and Canadian River. Sand hills are present in the northeastern part of the county and between Wolf Creek and the southern line.

Geology.—The rocks of the surface in Lipscomb County are en-

[a] There are no Federal public lands in Texas. This State, when it came into the Union by annexation, retained its public lands, and the general system of township and range lines, by which the lands of the greater part of the United States are surveyed, is not employed. No regular section lines exist, but various-sized tracts are laid off, usually in blocks of square miles as they were selected by the land-grant railroads or purchased by individuals. Some of the earliest surveys employed the Spanish vara, which equals 33.385 inches (1,897.7 + varas equal 1 mile). With such a system of survey the roads are irregularly distributed, no correction lines exist, and the location of points by township and range is impossible. In the eastern part of the Panhandle, however, the counties are uniformly 30 miles square, each containing 900 square miles, a condition which tends to obviate much of the difficulty otherwise encountered in attempting to map the region.

tirely of Tertiary and Quaternary age. Gray sandstones and clays predominate and form conspicuous bluffs along the larger streams.

Water supply.—The two largest streams in the county are Wolf Creek and its tributary Mammoth Creek. Wolf Creek enters from Ochiltree County near the center of the west line of the county and flows directly east; Mammoth Creek rises in the northwest part of the county and flows southeast, joining Wolf Creek in Oklahoma a few miles east of the State line. These creeks, as well as a number of other smaller tributaries of Wolf Creek, are spring fed, but in their lower courses flow through sand-choked beds. Ordinarily the amount of water is small, flowing but 1 or 2 second-feet, and at places entirely disappearing under the sand. The streams are subject to sudden rises of a few hours' duration, at which time the creeks flow several hundred second-feet. In this county the drainage is so well developed that few lakes exist on the High Plains. Lipscomb has the reputation among cattle men of being the best watered county in the Panhandle. The sand strata, both that of the Tertiary and in the sand-hill regions, furnishes an abundance of good water, issuing in the form of numerous springs, which reach the surface along the streams. Although their flow is seldom large, these springs are constant in volume and usually perennial in their character. The water is pure and wholesome and almost always free from notable amounts of salts. It is these springs which feed the numerous tributaries of Wolf Creek and render the water so abundant in the county.

Wells on the uplands in the county range from 130 to 333 feet in depth, with an average of 150 feet. In the valleys a maximum depth of 50 feet usually secures an abundance of water, but along Wolf Creek and some of the smaller streams many of the best wells are not more than 20 feet deep. Of the well records secured in Lipscomb County, the average depth was 121 feet.

OCHILTREE COUNTY.

Topography.—Ochiltree County is in the northern part of this region, lying almost wholly on the High Plains and having uniform plains topography. Near the center it is trenched by the head branches of Wolf Creek, in a valley which gradually deepens to the east. Some of the small side branches of Canadian River which head in the southern part of this region are actively eroding the plains, forming rugged breaks. A few of the small branches of Beaver Creek, which head in extreme northern Ochiltree County, have caused but little erosion.

Geology.—The rocks are entirely Tertiary and Quaternary, and, with the exception of the regions of the breaks near the streams, the surface is flat. Along the bluffs there are ledges of Tertiary clay and sand.

Water supply.—There are two drainage systems in this county. The eastern portion is drained by Wolf Creek, which has its source in the central part of the county, where it is a small fresh-water stream, fed by perennial springs, and flows through a wide gorge in the Tertiary rocks. Canadian River drains the southern portion, and branches of this stream, which have their origin in Tertiary springs along the breaks, flow south into Roberts County. A few minor branches of Beaver Creek drain the northern part.

The High Plains surface is entirely without drainage, and shallow lakes are abundant and often of relatively large size, sometimes covering 100 acres or more. Ochiltree County has an abundance of good well water, but ordinarily it is found at a considerable depth. In the southern part of the county, near the breaks, the depth to water exceeds 400 feet, while farther north water is obtained in abundance from 150 to 300 feet. In the Wolf Creek Valley the wells are shallow, many of them finding good water at 50 to 100 feet. The average depth of twenty-four wells in Ochiltree County is 245 feet.

HANSFORD COUNTY.

Topography.—Hansford County is in the northwestern part of the region to which this report relates. It includes a portion of the High Plains, trenched by two streams, Palo Duro Creek, which rises in the extreme southwestern portion of the county and passes into Oklahoma near the northeast corner, and Coldwater Creek, also known as Rabbit Ear Creek, which enters the county near the center of the west line and flows across the northwest corner, passing into Beaver County, Okla. The greater portion of the county retains its original plains features, while a lesser part consists of valleys and breaks. The entire county presents a gradual slope to the east. The highest point in this part of the Panhandle is attained in this county, just south of the center, along the west line—an altitude of 3,750 feet.

Geology.—Nearly all of the surface rocks of Hansford County are of Tertiary and Quaternary age. In the extreme northeast corner Palo Duro Creek has cut through the Tertiary and exposes the underlying red beds. Along Coldwater and Palo Duro creeks bluffs of hard Tertiary rocks occur, but for the most part nothing appears on the surface except ledges of soft Tertiary marl exposed along prairie draws.

Water supply.—With the exception of a small portion at the south which drains into Canadian River, all the waters of this county find their way into the Beaver Creek drainage system. Palo Duro Creek is a small stream which rises in the southwestern part of the county, and gradually deepens its valley in its passage northeast until at the county line it has attained a depth of approximately 300 feet below the level of the High Plains. Its numerous lateral branches receive the drainage from a considerable area, and at times of heavy rains these discharge their waters into a main trunk, which for a short time becomes a torrent. In its central and lower courses there are fertile valleys which afford good farming land, especially adapted to alfalfa culture. Several small irrigation works have been constructed along the lower part of Palo Duro Creek. The difficulty in maintaining these plants is that the dams, built of rough stone uncemented, wash out in times of freshets. Coldwater Creek crosses the northwest corner of the county, entering from Sherman County, Tex., and passing northeast into Beaver County, Okla. It is a small stream flowing through a well-developed gorge. Lakes similar to those in other parts of the region occur upon the High Plains. Hansford County has an abundance of good well water at depths varying on the High Plains from 190 to 300 feet, and rarely does a well fail to encounter an ample supply. In the valleys springs occur, the water from which is like water from the Tertiary beds, pure and wholesome. The average depth of thirteen wells in this county is 235 feet.

HUTCHINSON COUNTY.

Topography.—Hutchinson County lies in the western part of the region to which this report relates. The surface of its northern part is High Plains. The central and southern part is occupied by the canyon of Canadian River and the breaks on either side formed by short tributary creeks.

Geology.—Along Canadian River and along the small streams flowing into it in the central and southwestern part of the county there are extensive exposures of Permian red beds, consisting of red clays and shales with interbedded dolomite and gypsum members. These rocks have been provisionally referred to the Quartermaster formation. The remainder of the county is composed of typical Tertiary and Quaternary deposits, the former being exposed as bluffs along the streams and the latter as sand hills and alluvium.

Water supply.—The entire drainage of this county flows into Canadian River, which crosses the county from southwest to northeast. On the north side there are several small streams, the chief of which are Kit Carson and Coldwater creeks, while from the south flow White Deer, Spring, Bear, Dixon, and Antelope creeks. Thus the greater part of Hutchinson County is well drained. It has an abundance of good water, and, with the exception of some wells in the Canadian Valley and in its tributary creeks, which find their supply in the red beds, the water is wholesome and free from injurious salts. West from Plemons a number of strong springs occur at the line of contact between the red beds and the Tertiary. On the

High Plains water is obtained at depths ranging from 136 to 320 feet, and in the valleys at less than 20 feet. The well records collected show an average depth of 243 feet.

ROBERTS COUNTY.

Topography.—Roberts County lies in the north central part of the region embraced in this report. The surface of the southern portion is High Plains trenched to the east by the gorge of Red Deer Creek. The northern portion is occupied by the valley of Canadian River, with its broad flood plain bordered by a region of breaks on either side. The breaks are so extensively dissected by the smaller stream canyons that the northern portion of Roberts County is one of the most rugged localities in the Panhandle.

Geology.—The surface rocks are mostly of Tertiary age, with the usual sand hills along the streams. In the northwestern portion of the county Canadian River has cut down into the red beds which are exposed in the bluffs along the north bank. Alluvium deposits occur along this river and its tributaries.

Water supply.—The drainage belongs entirely to the Canadian River system. This river flows through a broad flood plain occupied occasionally by low sandy marshes. The waters of a considerable portion of this country reach the river by parallel streams rising in the south central part and flowing north. Few streams enter from the north side, and those which do are short, steep, and intermittent. Red Deer Creek, a tributary of Canadian River, rises in the southern portion of the county and flows northeast into Hemphill County. Ordinarily this stream has no surface flow, but it becomes a raging torrent when there are sudden storms about its head. Tertiary springs occur along the breaks and canyons and supply a number of small creeks. Wells in the High Plains area are 150 to 350 feet deep, and in the valleys water is obtained at from 0 to 20 feet.

HEMPHILL COUNTY.

Topography.—Hemphill County is in the eastern portion of the Panhandle. Its topography is varied, for Washita River rises in the southwestern corner and its northern portion is crossed by Canadian River. These two river systems have removed practically all of the original High Plains level and reduced the region to broad valleys with undulating surfaces between. Along Canadian River is a wide, sandy flood plain, occupied by sand hills in scattered areas. Sand hills also occur in the north, central, and eastern parts of the county.

Geology.—The rocks are chiefly Tertiary deposits, sand hills, and wash. Small areas of red beds are exposed along the Canadian and

Washita rivers in the eastern portion of the county. Along the streams there are bluffs and outliers of white Tertiary rocks, but the greater part of the county consists of rugged breaks and undulating sand hills.

Water supply.—The drainage system is well developed. The water from more than half of this county finds its way into Canadian River through a number of short, swift streams, many of which are perennial, having their source in Tertiary springs. The southern portion of the county is drained by Washita River, a stream which becomes a prominent river in Oklahoma, but is only a small creek in the Panhandle. Its water, being derived from the Tertiary springs, is fresh and free from the injurious salts so common in the large rivers. Springs are not uncommon in this county, and the water obtained from both springs and wells is almost uniformly soft and pure. The depth at which water is found in Hemphill County varies greatly. In the north, south, and southwest the Tertiary beds of the High Plains furnish fresh water at depths ranging from 100 to 333 feet. In the northern sand-hill regions water occurs at depths of 75 to 150 feet. In Canadian and Washita valleys wells are less than 20 feet deep. Records of nineteen wells at various places in this county show an average depth of 94 feet.

WHEELER COUNTY.

Topography.—Wheeler County lies in the eastern part of the Panhandle. The surface is a part of the eroded plains, except small areas in the northwest and southwest. The region is a rolling plain dissected by two principal streams—Sweetwater Creek and North Fork of Red River—with their tributaries. There are extensive sand-hill regions, one of which, 5 to 10 miles in width, and being widest near the center of the county, extends along the south side of Sweetwater Creek almost the entire length of the county. An area of very prominent sand dunes occupies part of the northeastern corner of the county. The hills are mostly low ridges from one-eighth of a mile to 1 mile long and 10 to 20 feet high. Broken ridges and knolls occur everywhere and blow-outs are common. A third sand-hill region is found in the southwestern part of the county, between North Fork and the headwaters of Elm Fork, and a fourth region is in the extreme southeastern part.

Geology.—Red beds belonging to the Greer and Quartermaster formations appear along North Fork of Red River and the branches of Elm Fork in the southern part of the county. Gypsum, dolomite, and red shales of the Greer formation and the red sandy shales and thin sandstones of the Quartermaster formation may be seen in the vicinity of Shamrock, and red bluffs outcrop along the north side of North Fork entirely across the county. The greater part of the surface rocks, however, consist of sand derived from the Tertiary deposits and of alluvium along the valleys.

Water supply.—The drainage of this county is through three streams, Sweetwater Creek and North Fork and Elm Fork of Red River. The first named, farthest to the north, is a small perennial stream which rises just beyond the limits of the county and in the eastern part was formerly used to some small extent for irrigation. North Fork of Red River crosses this county from west to east a little south of the center. Ordinarily it is a small stream flowing in a sand-choked bed and receives no important tributaries in this county. The waters of this river are highly impregnated with calcium sulphate and sodium chloride. The extreme southern part of the county drains to Elm Fork of Red River. As might be expected in a region of sand hills, there are in Wheeler County a number of fine springs. Six miles southwest of Mobeetie is Anderson's spring, which boils up out of the sand and runs off down a little canyon. It is one of the strongest springs in the Panhandle and flows perhaps 1 second-foot. It is said to be artesian in character and the water if confined will rise 15 feet. Other noted springs in the county are Nasby Spring (which fills a 3-inch pipe), Broncho Spring, and Stanley Spring (both of which have a very strong flow). Well water from the Tertiary and sand hills is obtained through the greater part of the county at depths of 80 to 200 feet. In the red-beds region, in the southern part, wells are not so deep, rarely exceeding 50 feet, and the water is usually not good, containing a considerable percentage of mineral salts. Records of nineteen wells in this county show an average of 71 feet.

GRAY COUNTY.

Topography.—Gray County occupies the south central part of the region here discussed. The surface is a portion of the High Plains cut into by two streams—North Fork of Red River, which flows through a gorge crossing the county from west to east, and McClellan Creek, flowing in a similar gorge from southwest to northeast, joining North Fork near the eastern line of the county. Wide breaks border the gorge of these two principal streams.

Geology.—With the exception of a small area of red beds near the mouth of McCellan Creek along the eastern line, the rocks of Gray County are entirely Tertiary and Quaternary. High white cliffs are exposed along the edges of the High Plains, and along the breaks and streams there are alluvial deposits and sand hills.

Water supply.—The greater part of the drainage is through North Fork of Red River and McClellan Creek. The former stream, which rises in Carson County just west of the Gray County line and flows east, drains only a limited region at the south through a few short tributaries, none of which are more than 5 miles in length. The southern portion of the county is drained by McClellan Creek, a branch of North Fork, which rises west of the south central part of the county. Springs from the Tertiary and sand hills occur in a number of places along the streams. Many are from small seeps, but several have an estimated flow of 40 gallons per minute. On the plains good water is obtained at depths ranging from 100 to 280 feet. In the valleys depths to water do not exceed 35 feet. Along North Fork in the eastern part of the county a few wells afford gypsum water; otherwise the supply in this county is pure and wholesome. Records of eleven wells show an average depth of 166 feet.

CARSON COUNTY.

Topography.—Carson County lies in the western part of the region. With the exception of Ochiltree County, Carson contains a larger proportion of the High Plains than any other county here described. The northern part is dissected by tributaries of Canadian River and a very small portion of the eastern part is occupied by the headwaters of Salt Fork of Red River. With these exceptions its surface is the uniform level of the High Plains, dotted at intervals by shallow lakes.

Geology.—In the extreme northwestern portion of the county along the canyons of Antelope and Dixon creeks, tributaries of Canadian River, there are exposures of the red beds, consisting of red clays and shales with ledges of gypsum and dolomite. With this minor exception, the rocks are Tertiary and Quaternary. Along the breaks high Tertiary cliffs are present, but the flat, upland Tertiary constitutes the greater part of the rocks of the county.

Water supply.—The drainage of Carson County is into two systems, Canadian River and Red River, between which is a great flat table-land divide. The former stream receives the water from the northern part of the county through a number of creeks—the most important being White Deer, Spring, Dixon, and Antelope—all of which have their rise near the central line of the county and flow north. The headwaters of Salt Fork of Red River occupy a few square miles in the southwestern part of the county. Most of this county, however, has no drainage other than that which finds its way into the shallow lakes on the level upland and disappears by seepage and evaporation.

In the southern part of Carson County the water table seems to be very deep, for while a few wells secure permanent flows at depths of less than 250 feet, many of them are obliged to penetrate 400 to 450 feet for an adequate supply; but water when found is both abundant and pure. Among the breaks and along the creeks in the northern part of the county the wells range from 50 to 200 feet. Few springs occur, those which are found being near the base of the Tertiary in the northwestern part of the county.

ARMSTRONG COUNTY.

Topography.—Armstrong county is in the southwestern part of the region. It is a level plain cut by three canyons trending southeast. The central and northwestern part of the county has the uniform surface of the High Plains. The northeastern portion is trenched by the upper course of Salt Fork of Red River, which has its source near the center of the north line of the county. Mulberry Creek Canyon crosses the county from northwest to southeast. In the southwestern portion is Palo Duro Canyon, through which flows Prairie Dog Fork of Red River. Twenty-five miles of this gorge, 875 feet deep and 5 miles wide, lies in Armstrong County. The sides of the canyon are frequently precipitous and exhibit typical banded structure so rough that the canyon is passable by wagon only along selected routes.

Geology.—The best geological sections obtainable in the Panhandle are found along Palo Duro Canyon in Armstrong County, where all the formations discussed in this report are exposed. The Greer and Quartermaster formations of the Permian red beds are particularly well exposed in this canyon. The Dockum formation outcrops halfway up the escarpment, and Tertiary clays, sand, and conglomerate lie along the upper part of the bluffs. The level upland in other parts of the county exhibits the ordinary Tertiary and Quaternary rocks.

Water supply.—Northeastern Armstrong County is drained by the headwaters of Salt Fork of Red River, and Mulberry Creek receives the drainage from the central and southeastern parts of the county. Prairie Dog Fork of Red River in Palo Duro Canyon, in the southwestern part, has no large tributaries in the county, and although it flows through a great canyon the stream itself ordinarily has little or no surface flow, but, like other streams of the plains, is subject to rapid rises after heavy rains near its head. The drainage of a large portion of the county is undeveloped, and the shallow lakes which occur at frequent intervals often reach considerable size. Springs are not common, but a few are found at the base of the Tertiary and among the red beds. On the High Plains water is obtained in abundance in wells ranging in depth from 120 to 320 feet. Few wells have been sunk in the red beds, but those that have been dug usually find water of rather poor quality at depths ranging from 20 to 100 feet. Records of eighteen wells in Armstrong County show an average depth of 207 feet.

DONLEY COUNTY.

Topography.—Donley County lies in the southern part of the region. The northern and western portions are level High Plains. On the eroded plains which occupy the eastern and southern parts of the county the surface is rolling and dissected by many streams. Even on the High Plains the streams occupy well-marked courses and have so dissected the surface that only in a few instances is the upland sufficiently level to permit the water to collect in lakes. The western extension of the sand-hill region, which crosses Collingsworth County south of Salt Fork of Red River, finds its terminus in the escarpment at the base of the High Plains in Donley County.

Geology.—Both red beds and Tertiary rocks are exposed in Donley County. The red beds, including both the Greer and Quartermaster formations, outcrop along the streams, particularly along North Fork of Red River in the region northeast of the center of the county and along Mulberry Creek in the southwestern part. Along the latter stream the Dockum beds occur. Tertiary rocks constitute the High Plains in the northern and western parts of the county; while the sand hills derived largely from Tertiary deposits occupy considerable areas in the central and southern portions. Alluvium is found along the stream valleys.

Water supply.—The drainage of the county is through two branches of Red River—Salt Fork, which crosses the county, and several smaller branches of Prairie Dog Fork, which rise in the county and flow south. Salt Fork flows almost due east across the center of the county. It is a small stream with a sand-choked bed and a flow of but a few second-feet, the water being free from disagreeable salts. The southern part of Donley County is drained by the branches of Salt Fork, the chief of which is Mulberry Creek, rising in Armstrong County and flowing across the southwest corner of Donley County. It is an ordinary stream of the plains, with a wide, sand-choked channel and ordinarily little water, but at times of heavy rainfall it assumes the proportions of a river. Springs are found in both the sand-hill regions and among the red beds. On the High Plains and in the escarpment region wells are from 40 to 250 feet deep. In the valleys and lower portions of the county water is obtained at 20 to 165 feet. The Tertiary and sand-hill water is good, while that found in the red beds is usually bad. Records from thirty wells show an average depth of 152 feet.

COLLINGSWORTH COUNTY.

Topography.—Collingsworth County forms the southeastern portion of the region here discussed. This county, which is almost wholly in the eroded plains, presents the most diverse topography of all here described. It is trenched from northwest to southeast by three stream systems—Elm and Salt forks of Red River, and Spillers Creek, a branch of Prairie Dog Fork. Just west of the center and extending entirely across the county, trending slightly west of south, are the Dozier Mounds, composed of hard ledges of sandstone underlain by stratified clays, shales, and sandstones. In the southwestern corner of the county these hills are deeply dissected by streams, rendering the region very rugged. On the south side of Salt Fork is a sand-hill region ranging from 2 to 9 miles in width, extending from northwest to southeast entirely across the county.

Geology.—The greater part of the rocks of Collingsworth County belong to the Greer and Quartermaster formations of the red beds. Along the various streams ledges of gypsum and dolomite outcrop, while at a higher level soft sandstones occur. The extreme northwestern part of the county is in the escarpment region, and Tertiary and Quaternary sand hills appear south of Salt Fork of Red River.

Water supply.—Elm Fork of Red River rises in the northwestern portion of the county and flows southeast, leaving the county 9 miles from the northern limit, thus draining the entire northern portion. Salt Fork of Red River crosses the county from west to east in a tortuous course near its center and drains the middle portion of the county. Spillers Creek, a branch of Prairie Dog Fork of Red River, has its source in Donley County and flows southeast across Collingsworth, draining the southwestern part. Except in the sand-hill regions south of Salt Fork, good water is difficult to obtain for the reason that the county is underlain by red beds, which contain large quantities of gypsum and other mineral salts. There are a number of springs of good water among the sand hills. Springs occur in the red beds also, but the water often contains salt or gypsum and is not suitable for general domestic use. Wells in the sand hills are 10 to 220 feet in depth and in the red beds 40 to 190 feet. Records from twenty wells in Collingsworth County show an average depth of 105 feet.

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[Water-Supply Paper No. 154.]

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WS 153. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906.

WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

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