BULLETIN

OF THE

UNIVERSITY OF TEXAS

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Bureau of Economic Geology and Technology

J. A. Udden, Director

Geology and Underground Waters of the Northern Llano Estacado

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Charles Laurence Baker

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PUBLICATIONS OF THE BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY

The Mineral Resources of Texas. Wm. B. Phillips. Issued by the State Department of Agriculture as its Bulletin No. 14, July-August, 1910. (Out of print.)

The Composition of Texas Coals and Lignites and the Use of Producer Gas in Texas. Wm. B. Phillips, S. H. Worrell, and Drury McN. Phillips. University of Texas Bulletin No. 189, July, 1911. (Out of print.)

A Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties. J. A. Udden, assisted by Drury McN. Phillips. University of Texas Bulletin No. 246, September, 1912.

The Fuels Used in Texas. Wm. B. Phillips and S. H. Worrell. University of Texas Bulletin No. 307, December 22, 1913.

The Deep Boring at Spur. J. A. Udden. University of Texas Bulletin No. 363, October 5, 1914. (Out of print.)

The Mineral Resources of Texas. Wm. B. Phillips. University of Texas Bulletin No. 365, Scientific Series No. 29, October 15, 1914.

Potash in the Texas Permian. J. A. Udden. University of Texas Bulletin No. 17, March 20, 1915. (Out of print.)

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MAPS (in pocket at end)

INTRODUCTION

For nearly half a century the Llano Estacado has been known as a great stock-grazing country. During the last thirty years many attempts have been made to reclaim it for agriculture, but it must be frankly admitted that such methods have not been highly successful. Ordinary methods of farming, as practiced in wet climates, will in all probability always fail here. Dry-land agriculture, or dry farming, has not yet been given a thorough test but may, with the use of thoroughly scientific methods in the hands of highly intelligent and very industrious men, yet prove to be at least fairly successful. In the last five years there has been a serious attempt to utilize for purposes of irrigation the supply of ground-water in those places where it lies at shallow depths beneath the surface. In the Plainview district alone, of eastern Hale, northwestern Floyd, and southeastern Swisher counties, Texas, 100 irrigation wells had been constructed before January 1, 1915, and about 16,000 acres were irrigated. Other districts in which development of this nature is being undertaken are the Hereford district, in Deaf Smith County, Texas; the Portales Valley district of Roosevelt County, New Mexico; the Hurley-Muleshoe (or Blackwater Draw) district of Bailey County, Texas; and the Littlefield district of Lamb County, Texas. A small amount of irrigation development has also been accomplished in Swisher and Lubbock counties, Texas, and in northeastern Eddy and southeastern Chaves counties, New Mexico.

The writer devoted the autumn of 1914 to an investigation of the water resources of the northern Llano Estacado of Texas and New Mexico. The southern boundary of the area examined is the parallel of 33° north latitude which comes near the north line of Eddy County, New Mexico, and of Gaines, Dawson, and Borden counties, Texas. The original intention was merely to investigate the Hale County area, but it was found that in order to satisfactorily clear up some of the problems of that county it was necessary to investigate adjacent areas, particularly on the west and north. And, as so often proves to be the case in an investigation based primarily on geology, since the work could not be entirely confined to the region embraced within the borders of the State of Texas, it was necessary to prosecute some field work in the adjacent region of eastern New Mexico. Thereupon it was decided to issue a general report upon the entire northern Llano Estacado, based upon, and with more special reference to, Hale County, Texas.

Most of the time devoted to field work was spent in the shallow water districts which have already been noted. The maps accompanying this report are three in number. The map of all of Hale County and the eastern portion of Floyd County, Texas, is compiled from the county maps of the Texas State Land Office and a map of Hale County by County Surveyor Whitis. On this map the contours of the underground water table have been constructed partly from data very generously furnished by the Texas Land and Development Company, and from reconnaissance levels run by Mr. Scott Wilson and the writer. In its preparation, levels were run to every irrigation well in the field, other than those constructed by the Texas Land and Development Company, and the depth from the surface of the ground to the water level in each well was accurately determined. The elevation of the railroad station at Plainview was taken as 3370 feet, which is the figure used by the Texas Land and Development Company engineers. This elevation is probably 45 feet too high.

The underscored figures on the maps represent the depths to the water-level in those localities. Whenever possible the depths to water given are those of actual measurements by the writer; in other cases they are figures given by the owner or driller of the well. Enough of these depths are given for Hale County to enable one to predict within 10 feet the depth to water in any portion of the county. For two other shallow water districts—Hereford and Portales Valley—contour maps showing depths to water beneath the surface have been compiled under the direction of Mr. D. L. McDonald of Hereford and Mr. A. A. Rogers of Portales.

To the early geologic explorers of the region, including in particular W. B. Cummins, N. F. Drake, W. D. Johnson, and C. N. Gould, the writer wishes to express his gratitude. It is a pleasure to be able to confirm in almost every particular the conclusions already reached by these pioneer investigators. The

writer may sometimes be inclined to differ with these gentlemen in the interpretation of geologic phenomena but never with the facts they have recorded. Without seeking to disparage in any way the work of any of the others, special obligations must be acknowledged to the great classic paper on the "High Plains and Their Utilization," by W. D. Johnson, whose views on the agricultural prospects of the region are as true today as they were when first published, fifteen years ago.

The writer is also very greatly indebted to the uniform courtesy and willing aid extended to him on every hand by the hospitable and generous people of the plains. Unfortunately, the exigencies of space can permit the mention of only a few of these. To Mr. O. M. Unger, Secretary of the Plainview Chamber of Commerce, who very generously placed his time and motor car at the writer's service, the writer of this report is very specially indebted. To Messrs. H. I. Miller, R. C. Charles, and Wm. Fyfe of the Texas Land and Development Company, who turned over their records to him and assisted him in every way possible, the writer is very grateful. Among other gentlemen who were of great assistance to the writer may be mentioned Mr. C. F. Layne, of Layne & Bowler, Plainview; Messrs. G. E. Green and James McNaughton of the Green Machinery Company, Plainview; Mr. D. F. McDonald of Hereford; Duggan Bros. of Littlefield; and Mr. A. A. Rogers of Portales. To many others also the writer is very grateful for much assistance.

CHAPTER I

Geologic History

The Llano Estacado is a high isolated plateau situated between the Cordillera of New Mexico and the Gulf Coastal Plain of Texas. It is a flattish island-like mass, rising above surrounding rolling plains. The Llano Estacado is the southern portion of the High Plains, which extend from west central Kansas southward to the Pecos River, cut off from the northern High Plains by the east-west valley of the Canadian River. On the west, southwest, and south, the Llano is bounded by the valley of the Pecos, while its eastern escarpment is drained by the headwaters of the Red, Brazos, and Colorado rivers.

Pennsylvanian

Nothing is known of the geologic history of the region before the Pennsylvanian or Upper Carboniferous period. At that time, a great epicontinental sea covered the site of the Llano Estacado. In this region there were probably deposited beds of marine limestone, which now lie deep beneath the surface. Near the middle of Pennsylvanian times came the first epoch of uplift of the Arbuckle and Wichita Mountains of southwestern Oklahoma and this uplift was probably also felt in the mountain region of New Mexico and the Llano region of central Texas, so that the sediments afterwards deposited near these regions changed from limestone to clastic terrigenous sediments of shale, sandstone, and conglomerate. Most of the deposits laid down around these areas of uplift in late Pennsylvanian and succeeding Permian times, are "Red Beds." The significance of the middle Pennsylvanian uplift for the Llano Estacado region is that at this time there was the beginning of the formation of a structural basin in which the succeeding Permian beds were deposited.

Permian

The Permian of Texas has been divided by Cummins (1, 2, 3, 5)* into three divisions which, beginning at the base, are: the Wichita-Albany, the Clear Fork, and the Double Mountain.

The Wichita is a formation of red clays interbedded with grayish sandstones, which lies southwest of the Arbuckle and Wichita Mountains from which were derived its sediments. The sub-aerial fluviatile and deltaic deposits of the Wichita pass to the southwestward into the marine clays and limestones of the Albany. As the outcrop of the Albany is a considerable distance east of the Llano Estacado—the strata dipping to the westward beneath younger formations of the Permian—it is probable that to the westward underneath the Llano Estacado the Albany sediments are mainly marine limestones, for the Llano appears to have been the site of the middle of the Permian marine basin. The lower Permian in the Guadalupe Mountains and underneath the Pecos Valley of New Mexico, consists of limestone with interbedded lenses of sandstone, which, with the underlying Pennsylvanian limestone and sandstone, have an estimated thickness of 10,000 feet. In the deep drilling at Spur, in Dickens County, Texas (13), lower Permian dolomitic limestones, interrupted by beds of sandstone, shale, and anhydrite, have a thickness of 2,845 feet, and were first encountered at a depth of 1,250 feet. There is much more anhydrite in the upper oolitic and sandy dolomite than in the lower and shaly dolomite. This dolomite series probably includes the whole of the Albany and most of the overlying Clear Fork. Since limestone beds are found in the lower Permian in deep drillings on both the east and west sides of the Llano Estacado they apparently underlie the intermediate region.

In Clear Fork and Double Mountain time, there came on a marked change of the conditions under which the strata were deposited. This is indicated by the beds of anhydrite, gypsum, rock salt and limestone deposited from the evaporation of the sea water and interbedded with the red clays and sands. The beds of anhydrite, gypsum, rock salt, and limestone (generally dolomitic) indicate an arid climate during the latter part of the Permian, at intervals during which the waters of the sea

*The numbers in parentheses refer to the paper of the same number in the bibliography given at the end of the chapter.

evaporated and thereupon deposited the various minerals which they carried in solution.

The amount of anhydrite and gypsum in the Clear Fork formation increases as one goes westward from its area of outcrop. The same may also be said of the dolomite. This indicates that the sediments derived from the erosion of the land and deposited near the shore line of the sea gradually decrease to the westward as the Llano Estacado is approached, implying deeper and clearer waters in the latter locality. There is also a large amount of anhydrite and gypsum in the Red Beds of the Pecos Valley in New Mexico. A marked characteristic of all the Permian red clays is the presence in them of streaks and spots of bluish and bluish-green color.

The beds of salt, anhydrite, gypsum, magnesian limestone and dolomite are markedly lenticular in form. No one layer of these can be traced very far in a horizontal direction. The beds of rock salt are not found in the upper strata of the Permian, although they may have been originally deposited there and subsequently removed by solution. The solution of the rock salt and gypsum beds forms caverns into which in many cases the overlying clays and sands collapse, thus forming the sink holes and salt and alkali lake basins so common in the regions surrounding the Llano. We shall see that these sink holes are also found on the Llano.

Gould (10, 11) has divided the upper or Double Mountain Permian red beds in the valley of the Canadian River into the Greer and Quartermaster formations. The lower or Greer formation consists of red clay-shale interbedded with one or more ledges of hard massive gypsum, with an occasional ledge of magnesian limestone and dolomite. "Resting conformably upon the Greer are 250 to 300 feet of rocks, consisting for the most part of soft red sandstone. sandy clays, and shales named the Quartermaster formation." In the lower part, 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 shales become more arenaceous and not infrequently form a consolidated sandstone which is rather thin-bedded and prone to break into small rectangular blocks.

"In certain beds of the Quartermaster formation, there occur lenticular beds of hard, white, or pinkish dolomite." The formation outcrops in a belt generally 1 to 5 miles wide, at the base of the Llano Estacado. Marine fossils of Permian age are found in the sandstone.

In the Palo Duro Canyon, at Indian Trail, near the west line of Armstrong County, a massive bed of gypsum 16 feet in thickness (Pl. Ia) near the water's edge represents the upper gypsum bed of the Greer formation. Above it in the lower walls of the canyon is exposed the Quartermaster formation, 300 feet in thickness. The uppermost portion of the Permian is exposed underneath the overlying Triassic at the foot of the narrows in Tule Canyon (Pl. Ib) in western Briscoe County. Here the Permian consists of red clays, laminated sandy clays, thin-bedded sandstones and very thin seams of gypsum.

In the deep boring at Spur, Dickens County (13), the uppermost 300 feet of the Red Beds consist of fine silt and clay impregnated with iron oxide, and contain some interlaminated and concretionary gypsum. From 400 to 900 feet below the surface the Red Beds consist for the most part of fine red sand or sandstone. Apparently the sand contains thin layers of gypsum or is impregnated with gypsum or anhydrite. The lower 350 feet of the Red Beds consist of a sandy silt mixed with varying amounts of salt, in which the sand and silt particles are imbedded as in a matrix. Greenish gray circular spots and streaks occur near beds of anhydrite. Beds of anhydrite and gypsum occur throughout the Red Beds in the Spur boring.

In a deep drilling at Post City, Garza County,* the upper four or five hundred feet of the Permian consists of red, green and blue clay and shale, with subordinate beds of sandstone. From 878 to 1694 feet beneath the surface, the strata are clay, mainly silty and marly, generally red and pink in color, although sometimes greenish and greenish-gray, with anhydrite and gypsum and some salt in the lower portion. At Justiceburg, Garza County, an 800-foot drilling penetrated red clay, gypsum, and anhydrite, with rock salt at the base. The Will I. Miller & Sons drilling, in the bed of Palo Duro Creek, 7 miles

*The samples of drillings were examined by Dr. J. A. Udden, of this Bureau.

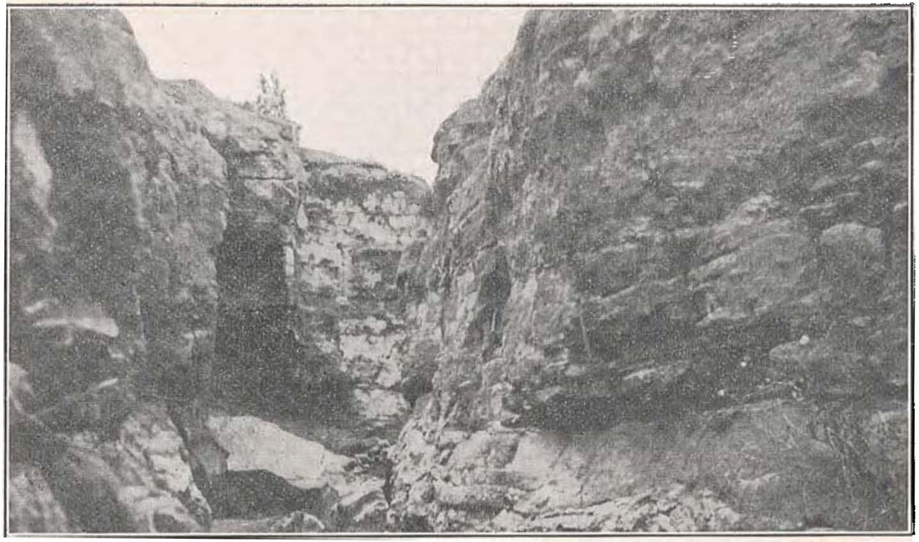

Plate Ia—Gypsum layer, 16 feet thick, in upper part of Double Mountain (Permian) formation. At water-level in Paloduro Canyon at foot of Indian Trail, near Randall-Armstrong county line.

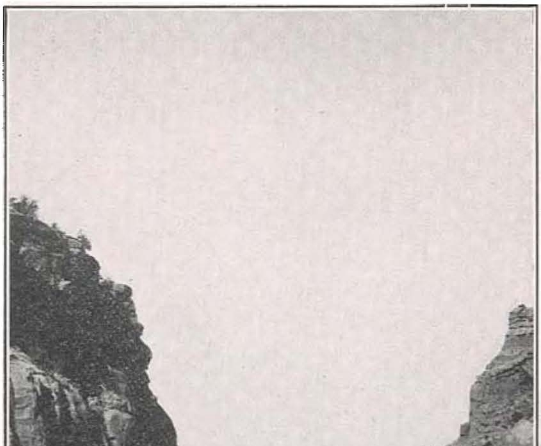

Plate Ib—Foot of narrows in Tule Canyon, Central-western Briscoe County. The basal bed at the bottom of the canyon is upper Double Mountain Permian; the rest of the canyon walls in the foreground is Triassic massive and conglomeratic sandstone; the top strata in the distance, of lighter color, are Cenozoic and probably Pleistocene.

above Canyon City, in Randall County, penetrated over 2000 feet of Upper Permian. The upper 1000 feet of the Permian consists mainly of red shale, with some yellow and gray shale, and subordinately, beds of sandstone, gypsum and anhydrite. The lower 1000 feet is made up mainly of red and blue shales and clays with a large amount of rock salt and some gypsum.**

From the data afforded by the deep boring at Spur, it appears that there is more land-derived material in the upper half of the Permian than in the lower half. This implies that more sediment was being brought into the marine basin during the upper Permian than during the lower Permian, and may mean that the land areas surrounding the shore lines of the sea experienced slight uplift near the middle of the Permian period.

Descriptions, thicknesses, and a preliminary correlation of the upper Pennsylvanian and Permian deposits of the general region are given in the following table.

TABLE OF CORRELATION OF THE UPPER PENNSYLVANIAN AND THE PERMIAN

Pecos Valley between Roswell and Dayton, New Mexico	Trans-Pecos, Texas	Spur Well, Dickens County, Texas	North Central Texas
	PERMIAN		
Red sandstone, shale, magnesian limestone, and gypsum — 1600 ft.+	Red Beds — sandstone, shale, magnesian limestone, and gypsum. Rustler formation, magnesian limestone, 200 ft., and lenses of sandstone. Castile gypsum, 300 ft.	Red Beds, 1250 ft., with gypsum, anhydrite and salt.	Double Mtn., 2000 ft.
Mainly limestone; subordinately sandstone, 10,000 ft.	Capitan limestone, 1,800 ft. Delaware Mtn. formation, 2,225 ft., limestone, sandstone, and shale.	Dolomite, anhydrite, sandstone and shale, 2850 ft.	Clear Fork, 1900 ft. Wichita-Albany, 1000-1500 ft.
	PENNSYLVANIAN		
	Hueco limestone, 5,000 ft.	Cisco, 389 ft.+	Cisco, 800 ft.
Red Beds.			Canyon
			Strawn
			Bend

After the deposition of the Permian sediments, they and the underlying strata were folded into a broad and gentle downfold

**A more complete report on samples from deep drillings in the Llano Estacado area and contiguous regions will be found in Bulletin of the University of Texas, 1915, No. 17: "Potash in the Texas Permian," by J. A. Udden.

or syncline. The axis of this syncline lies somewhere under the present surface of the Llano Estacado, the Red Beds of the Pecos Valley of eastern New Mexico dipping easterly at a low angle while the corresponding beds east of the Llano Estacado dip westerly, also at a low angle.

Locally, as in the valley of the Canadian River and near the eastern foot of the Llano, the Double Mountain beds are rather intensely crumpled on a small scale. It has hitherto been generally supposed that solution of underlying beds of gypsum, causing the collapse of overlying strata, was responsible for this distortion and folding, but it may be suggested that these structures were really caused by compressional stress generated at the time of the synclinal folding of the Permian, the upper beds in the concave side of the syncline being pressed together by the downfolding. (1)

Then ensued a period of dry land conditions during which the folded Permian strata of the Llano Estacado were subjected to erosion. This erosion took place during lower and middle Triassic time.

Upper Triassic

After the lapse of a long period of erosion, the Llano Estacado again became the site of deposition, this time of deposits laid down on a land surface, mainly by rivers. These strata were called by Cummins (1, 2, 3, 4) the Dockum formation and along the valley of the Canadian River they have been divided by Gould into a lower formation—the Tecovas, 90 feet thick along the Canadian River and 220 feet thick in Palo Duro Canyon; and an upper formation—the Trujillo, 250 feet thick in Palo Duro Canyon and 45 feet thick along the Canadian River. According to Dr. S. W. Williston, the strata belong to the upper Triassic, being of the same age as the Keuper of Europe. They underlie practically all of the Llano Estacado of Texas and southeastern New Mexico, and form the basal escarpment of the Llano on the east, north, and west sides.

Drake (4) divided the Dockum into three main beds, as follows: a lower bed of sandy clay, 0-150 feet thick; a central bed of sandstone, conglomerate, and some sandy clay, 0-235 feet thick; an upper bed of sandy clay and some sandstone, 0-300 feet thick. While these beds are present over most of the Triassic area, there is at some places a thinning out of one, and a thickening of another. "which shows that at the same time the conditions of deposition were somewhat different at different localities." Drake further characterizes these strata as follows:

"*Sandstones.*—The sandstones before exposure to weather are generally nearly white, but sometimes gray, red, or bluish in color. Massive, shaly, and false-bedding are common. The texture varies from a fine, even-grained, to a grit or conglomeratic sandstone. White and a few brown mica flakes, varying in size from a mere speck to one-eighth of an inch in diameter, are nearly always present. The mica is so abundant in some of the rocks as to make them fissile. The sandstones are usually friable, but weather with a smooth flat surface with an average sharpness of angle for sandstone rocks.

"*Conglomerates.*—The conglomerates are of two kinds. The one most characteristic and widespread is composed of small pieces of brownish, yellowish, or bluish colored, sub-angular, indurated, clayey sandstone fragments, averaging about the size of a pea, imbedded in a matrix of sand or grit usually calcareous. The other is composed of siliceous pebbles in a matrix of sand and grit. The pebbles are usually small and well rounded, and of nearly all shades of color, but white quartz are the most numerous. The quantity of siliceous pebbles varies at different localities from more than half the rock mass to very few. Both conglomerates contain silicified wood at some localities. The bedding of the siliceous conglomerate is unusually even and regular, or slightly false, while that of the first-named is false almost without exception. These two conglomerates graduate into each other, and even where one is the most characteristic, the other usually enters into it more or less.

"*Clays.*—The clays are a dark red or blue, with some variations of yellowish and purple, and are calcareous and arenaceous. The blue clays are not very common, are nearly always highly arenaceous, and frequently contain vertebrate remains. The red clays are seen at nearly every outcrop, and are often more than a hundred feet thick, with probably a few layers of sandstone distributed through the strata."

Gould (10, 11) has studied the Triassic along the Canadian River and in Palo Duro Canyon. His Tecovas formation is composed of a lower division of more or less sandy shale of various colors, with maroon, lavender, yellow, and white predominating, and an upper division of dark-red or magenta shale. In the lower division, the rocks consist usually of sandy shales, more or less cross-bedded and lenticular, but contain in many localities beds of variously colored soft sandstone. In general, the variegated shales are made up of three more or less sharply marked zones—a lower zone of white, gray, or lavender; a middle zone of maroon or wine color; and an upper zone of light yellow or sulphur yellow. These three zones are not always to be found, are subject to considerable variation in thickness, and usually the colors grade into each other. In certain localities the variegated shales lose their clayey characters and become largely or entirely sandstone. This sandstone is distinctive of this zone. In general it is white, yellow, or light brown in color, soft and friable, and rather massive, and much of it is very imperfectly cemented.

A good illustration of the essential local character of the lower division of the Tecovas is found at the narrows in Tule Canyon in western Briscoe County. The narrows are formed by a thick massive bed of reddish sandstone, carrying at the base small well-worn quartz pebbles, lying unconformably upon upper Permian brick-red clay, with a line of seepage springs at the contact of the two formations (Pl. Ib). Above the narrows (Pl. IIa) the place of this sandstone is taken by thin alternating beds of vari-colored shales, and sandstones, and the same kinds of beds are found at the same horizon below the narrows (Pl. IIb).

The Trujillo formation of Gould is made up of several ledges of massive more or less cross-bedded sandstone and conglomerate, with interbedded red and gray shales. In most places there are three beds of sandstone but locally there may be five or more, due to local cross-bedding or the appearance of lentils. The upper portion of the formation has locally been removed by subsequent erosion, and the upper sandstone does not appear along the Canadian River. The contact between the upper magenta shale of the Tecovas formation and the lower sandstone of the Trujillo formation in Tule Canyon about 2 miles above the narrows, is shown in Plate IIIa. Drake notes that his upper division of the Triassic is absent from northern Garza County around the northeast and northern boundaries

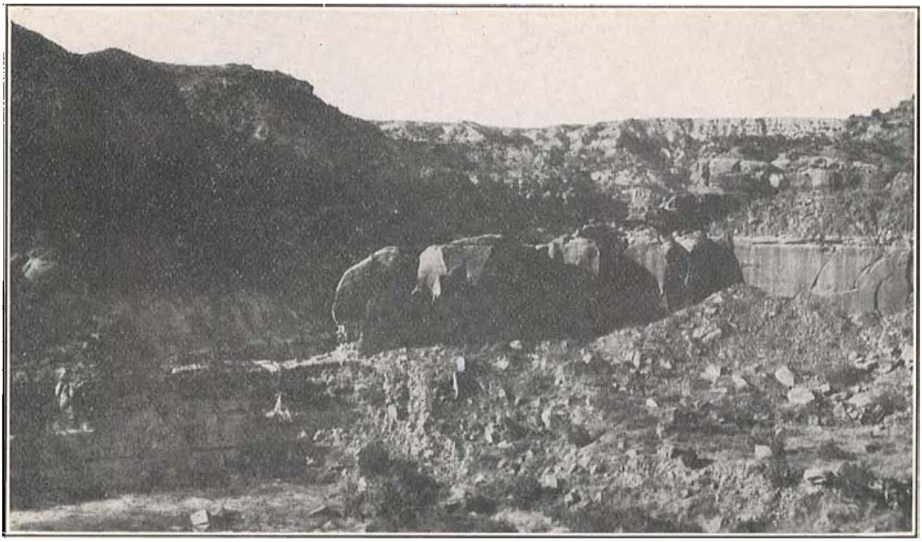

Plate IIa—Upper end of narrows in Tule Canyon, Central-western Briscoe County, The light-colored beds on top at the left are Cenozoic, probably Pleistocene, the remainder of the section exposed is Triassic clays and sandstones, which here replace the massive bed of sandstone occurring lower down in the narrows.

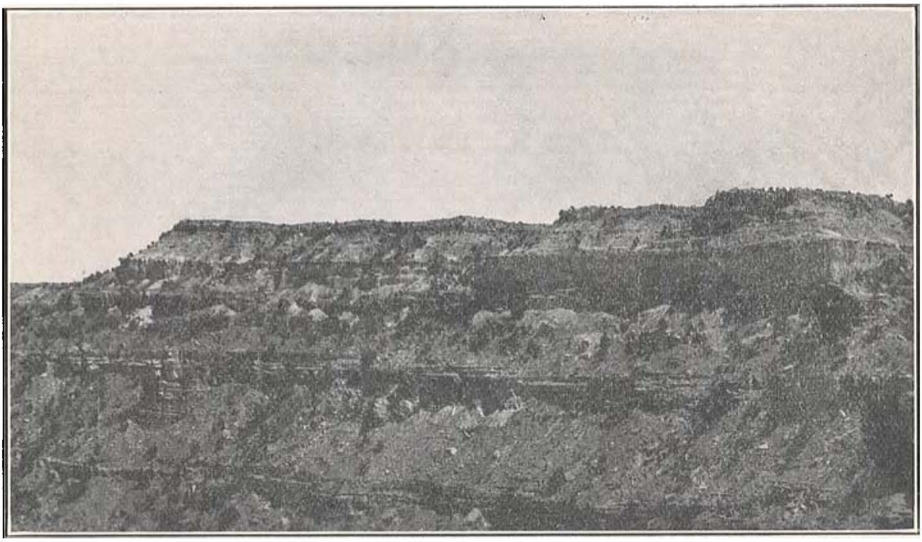

Plate IIb—Canyon wall of the Tule below the narrows. The section includes nearly the entire thickness of the Triassic at the base, and the lighter-colored beds of the Cenozoic (probably Pleistocene) above.

of the Plains as far as southwestern Oldham County. In this region, Gould's Tecovas and Trujillo formations are apparently more or less equivalent to the two lower divisions of Drake.

The following four sections, made by Gould at various places in the northern portion of the Llano Estacado, show the characteristics of the Triassic:

Geologic Section on North Branch of North Canyon Cita Creek, Eastern Randall County, Texas.

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

Generalized Section on West Amarillo Creek, Potter County, Texas

System	Formation	Member	Character	Thickness Feet
Tertiary			Sand and clay	150
Unconformity				
Triassic	Dockum Group: Trujillo		Red clay	30
			Massive sandstone (middle sandstone)	15
			Red shale with thin sandstone ledges	20
			Red or gray massive sandstone and conglomerate, with shale bands (lower sandstone)	25
	Dockum Group: Tecovas		Dark-red shales with bands of white and green, near the base some sandstone bands	50
			Red and yellow shales	15
			Maroon and lavender shales	15
Unconformity				
Carboniferous (Permian)	Quartermaster		Brick-red shales with sandstone ledges	45
		Alibates dolomite lentil	White dolomite	2
			Red shale	6
			Massive dolomite	8
			Brick-red shales with white and green bands	+40

Geologic Section near the mouth of Timber Creek, Eastern Randall County, Texas.

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

Geologic Section near the mouth of Trujillo Creek, Western Oldham County, Texas.

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

The Triassic varies in thickness from a few feet to nearly four hundred feet, averaging probably about two hundred feet. The lower bed of sandy clay of the Triassic is generally a maroon or wine color and is therefore darker than the underlying Permian. Other means of distinction of the Triassic from the Permian are the flakes of mica in the sandstone and the presence of conglomerate beds in the Triassic, neither of which occur in the underlying Permian. The following characteristics of the Triassic strata also serve to separate them from those of the Permian: (1) The Triassic sandstones are gray and brown in color; (2) the lower Triassic shales are variegated, with maroon, wine color, white, lavender, and yellow color predominating, while the upper Permian shales are bright brick-red; (3) the Triassic strata exhibit an extensive development of cross-bedding and local unconformities.

Other than the change of conditions implied by the difference in the nature of the sediments in the Permian from those of the Triassic, an unconformity between the two formations is denoted by a slight difference in dip, which in the Triassic is nearly always in a southeasterly direction, and generally less than the dip of the Permian. On the east side of the Llano the dips of the two formations are in opposite directions. In many places, but not everywhere, there is a pronounced erosion uncomformity between the Permian and Triassic.

Fossils are not very abundant in the Triassic. The most abundant vertebrate remains are reptiles of the order Phytosauria, and amphibians of the order Stegocephalia. The freshwater mussel, *Unio,* is the most common invertebrate. Fragments of petrified wood are often found in the conglomerates and, in places, lignitized wood fragments of no economic value occur, more usually near the top of the formation.

It is likely that a large amount of the Triassic red clay and clay-ball conglomerate was derived from the erosion of the underlying Permian. But the coarse micaceous sandstones and the conglomerates composed of generally, but not always, smooth and water-worn pebbles of quartz, granite, and limestone, have had a different origin. The nearest known sources of these pebbles are the Rocky Mountain ranges and the Wichita Mountains of Oklahoma.

The average dip of the Triassic is to the southeast at the rate of about eight feet per mile, according to Drake. He reports the greatest dip at the northern and northwestern boundaries of the Llano. In Potter and Oldham counties it is 15 to 18 feet or more per mile. The Triassic thickens towards the northwest, from which direction most of the sediments may have come. Gould (11) and Case (12) have noted anticlines in the Triassic strata.

The Triassic beds which lie northwest of the escarpment of the Llano in northwestern New Mexico deserve special notice, since they have a bearing on the question of water supply. According to Case (12), who has recently investigated this territory, the Triassic outcrops in places between Tucumcari and Las Vegas Hot Springs, and between the Canadian and the Pecos rivers. At Las Vegas Hot Springs, along the eastern flank of the Rockies, the Triassic beds are sharply upturned; east of there they dip gently eastwards. They are composed of red clay of varying shades with some blue streaks, sandstones and shaly layers and conglomerate. The altitude of these exposures varies from below 5,000 feet south of Montoya and below 4,000 feet in the Canadian valley north and west of Tucumcari, to about 7,000 at Las Vegas Hot Springs.

Jurassic and Lower Comanchean

During the Jurassic and Lower Comanchean, the region of the Llano was subject to erosion. During this erosion interval a considerable portion of the Upper Triassic was worn away. Since this erosion has nowhere in the region of the Llano Estacado cut through the Triassic into the underlying Permian, it is fairly certain that the Jurassic and Lower Cretaceous land was low-lying and had no great amount of relief, since the unconformity between the Triassic and strata later deposited shows no great amount of angularity, although it is true that this surface was worn down to a certain extent by the wave action of the gradually transgressing Later Comanchean sea.

Later Comanchean

On the western shores of Monument or Montezuma Lake in west-central Bailey County, Texas, the writer found a formation not formerly known from the central portion of the Llano Estacado. Here dark blue-gray, marly, and shaly clay, containing thin flat lenses of concretionary limestone, and weathering on the surface to tawny or ashy gray shades, has a thickness of 25 feet and contains the fossils *Gryphaea pitcheri,* variety *tucumcarii,* and *Ostrea*, probably of the species *quadriplicata.* The presence of these fossils and lithologic evidence, show that this clay belongs to marine Upper Comanchean, either to the stage of the Washita or to the late Fredericksburg.

A sample of dark blue-gray clay was obtained in a well from the depth of 170 feet beneath the surface on the north part of

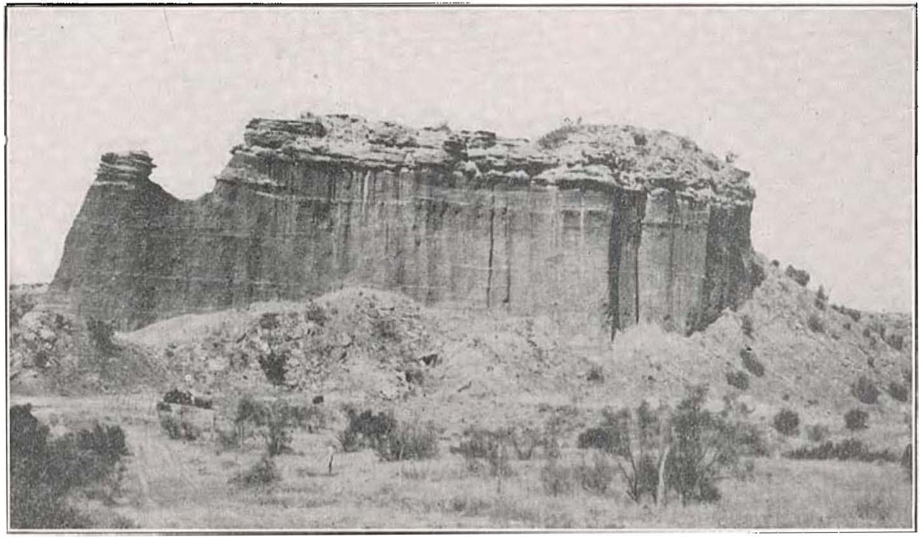

Plate IIIa—Contact between the upper magenta shale of the Tecovas formation (below) and the lower sandstone of the Trujillo formation (above), both of upper Triassic age, just east of the wagon road crossing of the Tule 2 miles above the narrows.

League 213, Lamb County, Texas. Upon microscopic examination, foraminifera of the genera Globigerina and Textularia were found in the clay. This demonstrates its marine origin. It overlies the Triassic and hence is later. Since no marine deposits later than the Mesozoic are known in New Mexico or western Texas, it must be referred either to the Jurassic, Comanchean, or Cretaceous, with strong probability of its Comanchean age, since lithologically it resembles deposits of that date in other parts of New Mexico and Texas. Mr. Wm. Benson, well driller, reports the presence of dark-colored clay in wells in western Lamb County, which clay is probably of Comanchean age.

Comanchean strata have long been known from the vicinity of Tucumcari, New Mexico, on the northwest side of the Llano, and from the southeastern escarpment of the Llano from Borden County southwestward to Crane County. It is probable that the Comanchean sea once covered the entire region of the Llano Estacado. Many water-worn Comanchean fossils are found in the gravels at or near the base of the overlying Cenozoic deposits.

Cretaceous and Lower Tertiary

No deposits of undoubted Cretaceous or Lower Tertiary age have been found in the region of the Llano Estacado, although Fisher (9) found sandstone east and northeast of Roswell, New Mexico, which he thought might be of lower Cretaceous (Dakota) age. Similarly, sandstone, the age of which is not known, is found in northwestern Dallam County, in the northwest corner of the State of Texas (11). Undoubted marine Cretaceous deposits occur in northeastern New Mexico and were found by Lee south of Santa Fe, New Mexico. It is not known whether the Cretaceous sea, which was the last sea that invaded the region of the Rocky Mountains and the Great Plains, ever covered the region of the Llano. It may, however, have done so, the deposits laid down being removed by erosion during the Early Tertiary. Probably most geologists would consider this likely, since the Cretaceous sea covered nearly the whole of both Texas and New Mexico.

Be that as it may, it is certain that the late Mesozoic witnessed the last marine transgression. During the entire Cenozoic the history of the Llano has been one of erosion and of deposition entirely on the land. In order to get the setting of this later history it is necessary to direct our attention to the Rocky Mountain and southern New Mexico regions.

The end of the Mesozoic and the beginning of the Cenozoic witnessed a great revolution in the Rocky Mountain and adjacent regions. The land which had been submerged by an epicontinental sea stretching, at the time of its greatest extent, from the Gulf of Mexico to the Arctic Ocean, emerged from the waters, was folded into mountain ranges, and intruded by large bodies of igneous rock. It is probable that during this epoch of deformation the strata of the Llano Estacado region were gently tilted towards the Gulf of Mexico, thus giving origin to the gentle southeasterly dip of the Triassic and Comanchean. So the region of the Llano once more became dry land and once more became subject to erosive action. By erosion the Cretaceous, if it ever covered the region, was removed, with likewise most of the Comanchean and a large portion of the Triassic.

The Rocky Mountains proper only extend as far south as Las Vegas, New Mexico. It is as yet doubtful whether this Laramide diastrophism caused the formation of mountain ranges in the region of New Mexico lying south of the latitude of Las Vegas and north of the Mexican boundary. Here the uplift may have been of the nature of a broad regional upwarp or doming.

No Cenozoic deposits of earlier date than the Miocene have yet been found in the Llano Estacado. But their supposed absence may not be the fact, since there is more probability of their occurrence on the west side of the Llano than on the east, and the west side has not as yet been carefully examined. Again, the locations of such early Cenozoic deposits would be determined by the courses of streams from the uplifted areas to the west, and such streams may have drained to the west, south, or southeast, instead of to the east. There is also the possibility that sediments once deposited were eroded away before later beds were laid down.

At any rate, the "lost interval" between the Comanchean and the Miocene can at present be considered as a time of dominant erosion on a land surface of rather low gradient, sloping eastwards towards the Gulf of Mexico. At the beginning of the Miocene, the land appears to have been worn down to a rather even surface of small gradient and relief.

Lower Cenozoic deposits have not been found in the southern Great Plains, although they are found extensively developed along the eastern border of the mountain region from New Mexico to Alberta, where they are of Eocene age, and in eastern Colorado, eastern Wyoming, western Nebraska, and southwestern South Dakota, where they are of Oligocene age. It appears hardly probable that they were not deposited over some portions of western Kansas, western Oklahoma, western Texas, and eastern New Mexico. This view is substantiated when one considers the early Cenozoic history of the Rocky Mountain and Great Plains regions and the events taking place at the present time on the Great Plains. In mid-Cenozoic time the Rocky Mountains of Wyoming and Colorado had been brought to a rather low land surface. From it, such deposits as were lodged on the mountain flanks and the adjacent plains during the early Cenozoic were largely removed in the middle of the Cenozoic. In the first epoch, streams flowing eastward from the mountain declivities deposited a portion of their loads of transported material on the lower flanks of the mountains and the adjacent western portions of the plains, because of a decrease of gradients and evaporation and seepage of their waters. But later, as the mountains were worn down, the mountain streams eroded less and in their courses over the plains were able, because of an underload, to erode materials which they had formerly deposited. This very process of erosion by streams of materials which they had formerly deposited is taking place now on the Llano Estacado. If the present cycle of erosion goes on uninterrupted until its finish, the streams and winds will have removed all, or nearly all, of the later Cenozoic deposits and will once again expose and wear away the older Mesozoic and Cenozoic deposits, as is being done at present on the lower eroded plains which border on all sides the High Plains. A former deposition of materials transported from their original sources in the mountains and later removed by erosion appears to be the most probable history of the Llano Estacado in the early Cenozoic. It is also pertinent to call attention to the fact that the Llano Estacado lay much nearer to the absolute base-level of Mid-Cenozoic time, the ocean, than did any other region of the Great Plains. Hence there the altitude of the Mid-Cenozoic surface may well have been lower than on the plains farther north, permitting a more complete removal of the early Cenozoic deposits than, for instance, in the region south of the Black Hills of South Dakota.

Later Cenozoic

It was in these comparatively recent times that events began which we can interpret with more certainty, since their records are more accessible. However, there remain many doubtful points which can only be cleared up after a large amount of detailed work. The ages of these later sediments in most parts of the Llano are still unknown, and there is also considerable uncertainty concerning the causes of certain events which have occurred since their deposition.

The later Cenozoic deposits consist of clays of various colors, but generally brownish-red or white, brownish-red or white sands, and gravels, which later are found especially at or near the base. The clays generally contain a somewhat variable amount of sand. The gravel materials are water-worn pebbles and small boulders of quartz, granite, chert, and various metamorphic rocks which could have had their origin only in the Rocky Mountain ranges, or from conglomerate sediments on the eastern flanks of the mountains. The sands are mainly quartzose, but have also small fragments of the rocks found in the gravels as well as of magnetite. Water-worn Comanchean fossils, especially of *Gryphaea pitcheri*, variety *tucumcarii*, are very commonly found in the basal gravels. The abundant occurrence of these fossils denotes that the lowermost Cenozoic was partly derived from Comanchean rocks, which, as has been shown, still underlie the Cenozoic in certain portions of the Llano Estacado. Their presence also shows either that previous to the deposition of the later Cenozoic, high-level gravels covered the surfaces of mid-Cenozoic time, or else that an uplift or warping in the region of the Llano renewed processes of erosion at the same time that streams were bringing deposits derived from the newly-uplifted Rocky Mountain region; for these friable shells could not have been carried any great distance by streams, nor could they have remained for a long period of time on the land surface without crumbling to pieces under the influence of weathering. On the northwest side of the Llano a considerable portion of the Lower Cenozoic has been derived from erosion of the underlying Triassic.

The clays, sands, and gravels do not make up persistent strata distinct from one another, which can be traced for long distances. Rather do they interleave and dovetail with each other, so that the section of the strata at one place is not like that at another place, even a short distance away. A deposit of sand, gravel, or clay is local in its distribution and lenticular in its form. Also there is a considerable development of cross-bedding. Deposits, whether considered in a single section or over the region as a whole, are markedly heterogenous in composition and distribution. But they are also homogeneous in the sense that a section in one locality consists of about the same materials with the same structures as will be found in a section of a far-distant locality, but in different relationships and order of succession. As a whole, therefore, they may be aptly described as a "homogeneous-heterogeneous" complex which is a unit distinct from any of the other formations of the region, easily distinguishable from the underlying deposits and in their make-up implying common conditions of origin. In the main, the clay, gravel, and sand is poorly assorted and deposits of one grade into those of the others. In thickness they vary from less than 50 to more than 300 feet, and may be even thicker in some localities in the midst of the Llano. They are by no means all of the same age, but vary from Lower Miocene to Pleistocene, and in general the only practicable way of separating deposits of different ages is by finding fossils of land mammals in them. Besides mammals, the fossils contained in them are fresh-water mollusks, and turtles, particularly land tortoises. The mammalian and reptilian bones are often checked and weathered by exposure to the atmospheric agencies on dry land before burial and generally they are scattered, so that in relatively few places is it possible to obtain complete skeletons.

The mode of origin of these deposits is easily understood by one familiar with deposits on mountain flanks, or low-lying plains areas adjacent to mountain ranges, or basins of arid or semi-arid western North America, or on the pampas and llanos of eastern South America, or on the desert basin and steppes of central and northern Asia. They were probably formed under climatic conditions of aridity or semi-aridity, since not even the clays contain any great amount of remains of plant life. But the kind of climate is not so certain. The fossils most frequently found are of those animals which have their present-day representatives in plains and desert-living types. But there are also found representatives of modern types of forest-living animals, which may, indeed, have lived in wooded river valleys traversing a dry plains country. The climate could not have been excessively moist, else the clays would contain a larger amount of carbonaceous matter. It is the view of the writer, after ten years of experience in western North America, that the climatic conditions of the later Cenozoic were not greatly different from those of the same regions today.

The composition of the sediments make it certain that the larger part of them came from the rocks of the Rocky Mountains, and the remainder from underlying Triassic and Comanchean sediments. They were deposited as alluvial materials brought down by rivers having their sources in the Rocky Mountain regions. And they were left on river flood plains, because streams became overloaded by decrease in gradient and by evaporation and seepage of their waters. The identical process can be seen going on today, more especially in an arid or semi-arid climate in such regions as have been mentioned above. The Platte and Arkansas rivers of the central Great Plains illustrate the process very well. In their upper courses, owing to abundance of water and high gradient, giving high velocities, they are almost all together eroding streams, carrying, especially in times of flood, large quantities of debris. Lower down in their courses over the central Great Plains, they sluggishly meander over broad flood plains and channels built up by the deposition of their own loads. The Arkansas and other streams of western Kansas actually flow in channels higher than the country on either side, just as do the Mississippi and other streams in the regions of their deltas. In times of high water, these streams may break through their old courses and overflow the lower lands adjoining and thus estab-

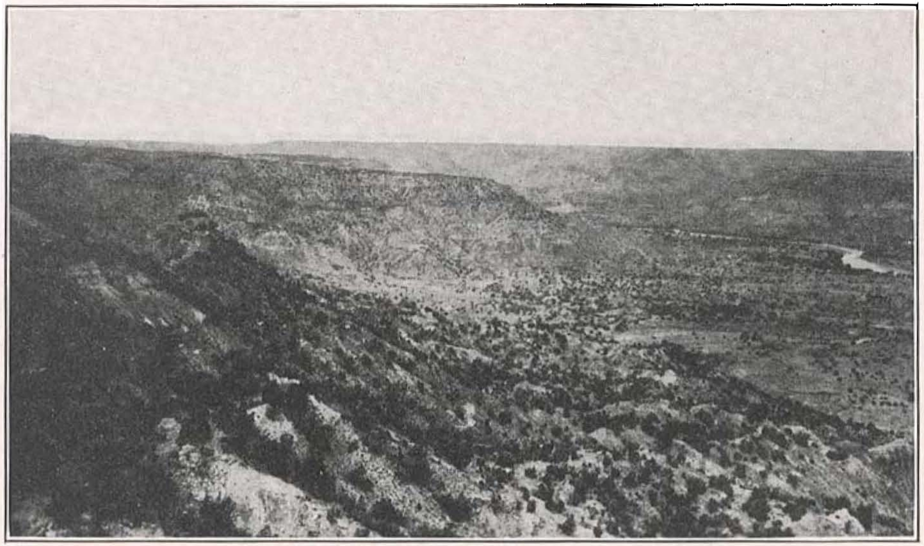

Plate IIIb—Paladuro Canyon from head of Indian Trail, a short distance east of the Randall-Briscoe county line. The canyon is here 800 feet deep and exposes in descending order all of the Cenozoic, all of the Triassic, and the upper gypsum-bearing Double Mountain Permian.

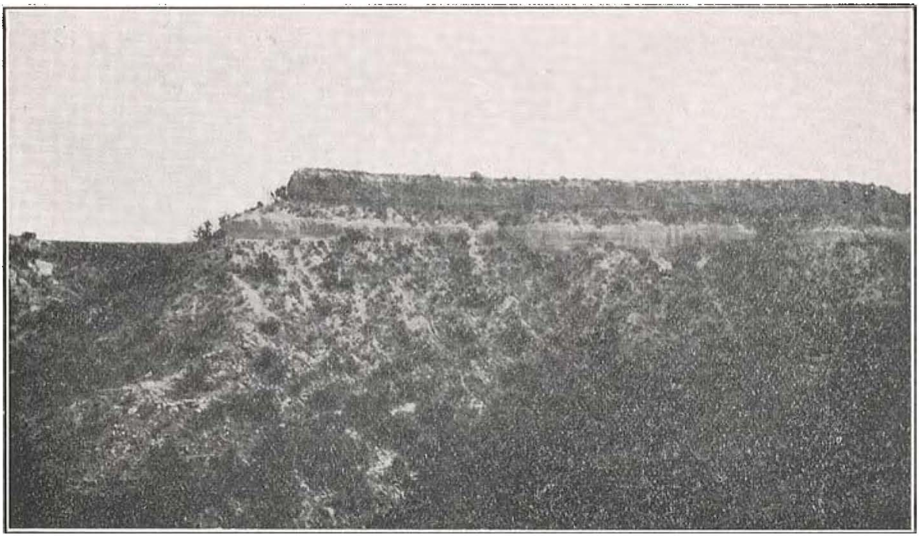

Plate IVa—Cenozoic strata at the top of the wall of the South Canyon Cita, at the Randall-Armstrong county line. Two layers of "caliche" are well shown here.

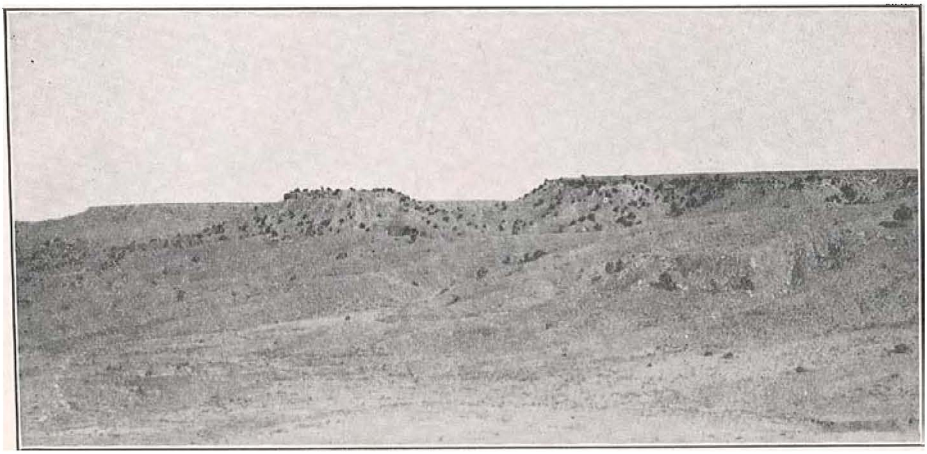

Plate IVb—The "breaks of the plains," or northwestern escarpment of the Llano Estacado in northwestern Deaf Smith County, Texas. Note the resistant layer of "caliche" at the top of the bluff.

lish new channels. When the new channel in turn becomes filled up, the stream again and again breaks through to the lower ground. So these streams are continually shifting their courses and depositing their loads in new localities. In course of time they cover a large area with a considerable thickness of sediments of heterogeneous composition, poorly assorted, anastomosing and dovetailing one with the other. As the lower courses are graded up by deposition the sites of deposition are also shifted higher and higher up the valleys, because, owing to deposition lower down, the sites of decrease of gradient and consequent checking of velocity progressively move up stream. Streams deprived of their loads at the sites of decrease of gradient, because they are overloaded for that gradient, may find themselves underloaded lower down in their courses and again begin to erode where formerly they had deposited. So deposits are constantly shifted nearer and nearer to their final resting-place, the sea. A stream is brought to a condition of grade when erosion (degradation) and deposition (aggradation) become balanced, so that the stream neither cuts into its channel nor deposits on its flood plain. The same stream may attain graded conditions at a number of places along its course at the same time, while in intermediate portions of its course it may either be actively degrading or aggrading. The condition of grade depends on three factors: the slope, which determines the velocity and the carrying power; the volume, which affects the same two functions; and the load, which for a given slope and volume, and consequently for a given velocity, determines whether the stream shall erode or deposit. Change of the relative or absolute ratio of any of these factors will bring to an end the graded conditions. Thus an increase of slope brought about by uplift or tilting will increase the velocity and carrying power and renew erosion. A decrease of volume, brought about by greater evaporation or seepage, will cause increased deposition; a decrease in load, due to any cause whatever—such as, for instance, the gradual wearing down of the region about the headwaters—will cause a renewal of erosion of a formerly graded slope.

Hatcher* cites the present-day conditions in the region about

*Origin of the Oligocene and Miocene Deposits of the Great Plains: Proc. Am. Phil. Soc., Vol. 41, p. 113.

the headwaters of the great rivers of South America as being probably typical of those during a large portion of the Cenozoic on the great Plains. According to Smith* the width of the Paraguay flood-plain at the mouth of the Sao Lourenço can hardly be less than 150 miles. This whole region is a low-lying and flat labyrinth of lakes, ponds, swamps, channels, and islands in a grassy plain, the only forest being near the river. Even at low water, at least one-fourth of it is flooded; the river at the flood season covers these lands almost entirely. When the river is at its highest the whole plain is a vast lake covered with floating grass and weeds. The flood-plains of the upper Paraguay, Amazon, and Orinoco are confluent. Indeed, much of the land along the lower courses of these rivers is flat and low-lying and mostly covered with water during times of flood, but of course there is there much more forest and more humid climate than is found about the headwaters. It is quite certain that there was a mid-Cenozoic mountain uplift in the Rocky Mountain ranges. This uplift was certainly greater in amount in the mountain region than in the adjacent Great Plains region and it also probably affected in like manner the eastern New Mexico region. Streams pouring down from high mountain declivities onto the lower and flatter surface of the plains, would there deposit their loads of debris. As the mountains were worn lower by erosion and less debris, as a consequence, could be gathered by streams in their headwaters regions, the alluvial slopes formerly piled up at the sites of emergence upon the plains of streams from the mountains, would be dissected and their materials shifted farther and farther out on the plains. This shifting of deposits would take place not only laterally along a west-east course, but also transversely to the general trend of the mountains by the shifting of the stream courses. At the same time, owing to the increased attrition in transportation, the size of individual particles would be reduced and sorting of materials of different composition and texture would become more perfect, so that deposits distant from the original mountain sources would be finer and better assorted than those contiguous to the mountain flanks and

*Origin of the Oligocene and Miocene Deposits of the Great Plains; Proc. Am. Phil. Soc., Vol. 41, p. 113.

higher beds finer and better assorted than lower. Gravel and sand deposits would come to occupy the region of the stream channels where the current had greatest velocity and the finer clays would occupy bayous, backwaters, and the flood-plains covered during times of flood. River sediments, however, rarely attain anything like perfect assortment, because of such action as eddying, local scour and fill of channels, and shifting of stream courses. So is it the rule to find cross-bedding, local unconformities, the inleaving and dovetailing of sands, clays, and gravels, and an imperfect assortment along the course of a river flood plain.

On a dry plain the wind is always effective, shifting the finer materials from one place to another, and eroding here and depositing there. So intermixed with the stream deposits are to be found wind-blown sands and finer eolian dust, the latter not being readily distinguished from the alluvial or water-deposited materials with which it is intermixed.

The above outline considers only some of the simpler and more obvious phenomena connected with what may be called the normal course of events. It does not take account of any other conditions which may have prevailed, such as an uplift or depression of the Great Plains region, or differences in its climate from that of the present time. Either one of these may have occurred, but the fact is we have as yet no definite evidence that they did occur. So that they will not be considered at this time.

Summarizing the history of the Cenozoic deposits, we may say that the earlier Cenozoic was a time of erosion and the later Cenozoic a time of deposition. About the middle of Cenozoic time there occurred an uplift of the Rocky Mountain region of Colorado and New Mexico and of the New Mexico region south of the Rocky Mountains proper which permitted the deposition of material upon the plains which had been eroded from the mountain region. The agency of this deposition was streams, aided to a minor extent by the wind.

The later Cenozoic deposits are for the most part unconsolidated. But everywhere near the top of the series at the edge of the escarpment is a creamy-white consolidated layer known as the "cap-rock." (Pls. IV, a and b, V, a.) This layer outcrops about the sides of the "dry lake" and "alkali lake" depressions (Pl. V, a) in the midst of the plains and also forms a rim about the upper boundaries of the valleys of the Llano. (Pl. VIII, b.) This consolidated portion is most common within a few feet of the upper surface of the plains deposits, but consolidated layers of more or less local extent are found throughout the upper Cenozoic deposits. Sometimes, as in the escarpment near the mouth of the South Canyon Cita, on the line between Armstrong and Randall counties, there are two beds of the "cap-rock." The "cap rock" and other cemented beds vary in degree of consolidation, from a rather hard dense rock to soft earthy, chalky material which has practically no coherence. In addition, concretions of irregular shapes, most commonly tuberous, semi-spherical, pipe-like, or branching, are found in the sands and clays. The "cap-rock" and other consolidated layers and the concretions have as cementing material, with the exception of a small amount of amorphous silica in the form of chert, nearly pure carbonate of lime. This substance, found at many places in the arid and semi-arid regions of western North America, was called "caliche" by W. P. Blake* and is also known in many parts of the Western Hemisphere as "tepetate," "tierra blanca," and "tosca." Analyses of four samples from the Llano Estacado were made by Mr. J. E. Stullken, Chemist of the Bureau of Economic Geology and Technology, and are given below:

Analysis No.	2227	2228	2229	2253
Silica	0.20	0.30	0.20	18.80
Alumina, and oxide of iron	0.64	0.42	0.60	6.90[1]
Lime	36.19	40.19	47.07	31.31
Magnesia	0.14	0.14	0.14	4.85
Carbonic acid	28.44	31.58	36.84	29.94
Sulphuric acid	2.01	0.14	0.20	0.55
Loss on ignition	2.60	5.87	8.36	5.86
Insoluble matter	29.00	22.00	5.60	
	99.22	100.64	99.01	98.21

[1]Alumina, separately determined in No. 2253, was 5.8 per cent.

No. 2227—"Cap-rock" at western escarpment of the Llano Estacado, 5 mi. south of House, near north line of Roosevelt County, New Mexico.

No. 2228—"Cap-rock" lime from State Experiment Farm, 2 mi. east of Lubbock, Texas.

No. 2229—"Cap-rock" lime from railroad ballast pit at north edge of Lubbock, Texas.

No. 2253—Soft white chalky bed of Blanco Pliocene age, 1 mi. southwest of Mt. Blanco postoffice, Crosby County, Texas.

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*Trans. Am. Inst. Min. Engrs., Vol. 31, 1902, pp. 220-226.

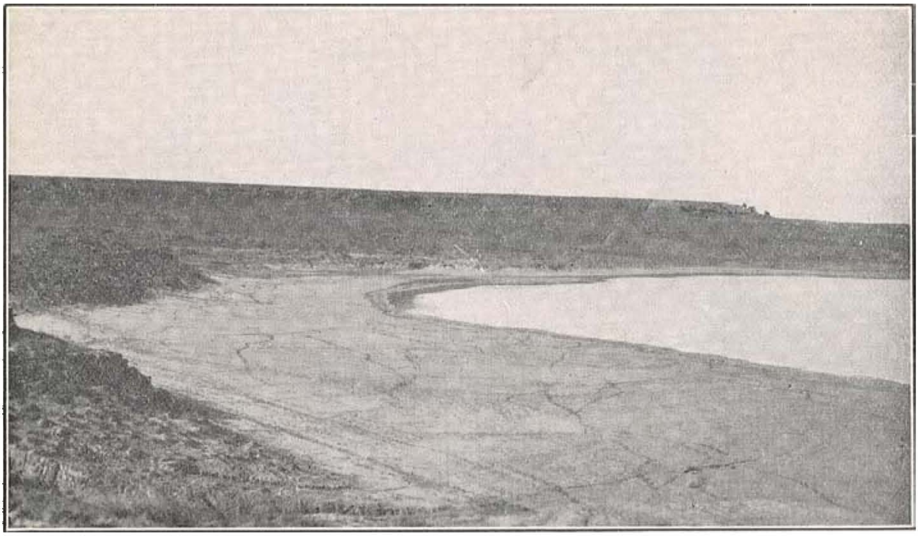

Plate Va—Bull Lake, an "alkali lake" or "sink" in southwestern Lamb County, Texas. The "cap rock" lime or "caliche" is exposed at the top of the bluff in the distance. The cracks in the foreground are caused by flowage of clayey sand into the bottom of the depression.

Plate Vb—Falls in the uppermost conglomerate sandstone of the Triassic, here overlain unconformably by the Cenozoic, at Rock House in Blanco Canyon, 4 miles east of Crosbyton, Crosby County, Texas.

Nearly all the insoluble matter in the first three samples is quartz sand.

The top of the "caliche" is in nearly all cases more hard and dense than the lower portions. The top crust is more likely to have a rather smooth, though somewhat undulating surface than the bottom of the deposit, but often there is an irregular upper surface or a gradation from both upper and lower surfaces into the sandy, gravelly and clayey beds. The cementing material is always porous and often cavernous. It cements together sand, gravel, and sandy clay. The deposit is more likely to conform roughly with the general land surface. Often it exhibits an indistinct platy layering more or less parallel with the surface and a rude columnar fibrous structure in a more or less vertical direction. In structure it is amorphous and seldom crystalline and the outer surfaces may exhibit mammillary or stalactitic incrustations. On the plains of western Kansas, caliche-cemented sediments are known as "mortar beds."

The "caliche" is clearly a secondary deposit, formed after the deposition of the sediments which it binds together, by the precipitation in the interstitial spaces between the pebbles and sand grains of calcium carbonate dissolved in ground water. The calcium carbonate was first brought down with the sediments or carried in solution in the river waters. When the waters evaporated the lime carbonate was deposited and when they seeped into the Cenozoic deposits they carried their dissolved lime with them. Upon evaporation of these ground waters when they came close to the surface, due to capillary action in the soils or to the formation of cracks in the upper soil layers, the calcium carbonate was deposited, much as more soluble alkaline salts form efflorescences in the soils of desert regions. A constant upward movement of the water by capillary action is induced by the constant and rapid evaporation at the surface. The rain-water does not penetrate to great depths but leaches out the soil to a depth of a few inches or a few feet, and, upon redeposition of the lime, produces the more dense upper crust of the "cap-rock." It may well have been that during the time of formation of the "cap-rock caliche" the ground water level stood higher than it does at present, so that capillary action was much more effective. That at least a part of the "cap-rock caliche" was formed at a period antedating the present is shown by the fact that the deposit has been cut into in the valleys of the present stream courses and has been removed from the basins of the "alkali lakes" and "dry lakes." Layers of "caliche" beneath that of the "cap-rock" probably were deposited at an earlier date. The conditions of deposition of these lower layers are not adjudged to have been in any important respect different from those of the upper layer. They were apparently consolidated near the top of land surfaces lower than the present ones and were later buried by other and younger sediments. If this explanation is correct, it implies that the older and lower Cenozoic deposits were made under climatic conditions very like the present, for "caliche" is a deposit only of arid or semi-arid climates.

A large amount of careful work must be done before the ages of the later Cenozoic can be determined throughout the Llano· and sections and age determinations of the strata in one locality will not necessarily apply to other localities. Age determinations of the strata have so far been made only in the northern portion of the eastern escarpment. Here the following four formations have been named:

Middle or Lower Miocene	Panhandle beds (Gidley)	"Loup Fork" and Goodnight of Cummins.
Upper Miocene	Clarendon beds (Gidley)	
Pliocene	Blanco beds (Cummins)	
Pleistocene	Tule division (Cummins) or Rock Creek beds (Gidley)	

Panhandle Beds

These, the oldest known Cenozoic deposits of the Llano, are found in the northeastern portion; according to Gidley, they form practically the whole area of the Llano Estacado. The present writer declines to accept this statement pending detailed examination of other portions of the Llano. Gidley examined these beds in the region between Clarendon, Donley County, and Mt. Blanco, Crosby County, in all of which region they closely resemble each other in a general way and the formation is traceable from one locality to another around the escarpment.

Clarendon Beds

The Clarendon beds are known from Mulberry Canyon in the eastern edge of Armstrong County, a few miles southwest of the town of Goodnight, and from the following localities in northern Donley County, east of the Llano Estacado proper: between Barton Creek and the Salt Fork of Red River; at the head of Petrified Canyon; and on the divide east of Skillet Creek. "The main body of the Donley County beds consists for the most part of cross-bedded sands and sandstones intermixing more or less and cross-bedding with the clays." (Gidley.) Running through these beds are several narrow channels of sandy clay, some of them traceable for long distances and all having a direction nearly east and west, or approximately the same as that of the streams draining the country at the present time.

Blanco Beds

The Blanco beds are found on the eastern escarpment of the Llano three miles north of the old town of Dockum, Dickens County, and at the mouth of Crawfish (Catfish?) Draw about a mile southwest of Mount Blanco postoffice, Crosby County (Cummins and Gidley) Pl. VI, a). The beds at Mount Blanco occupy a comparatively narrow valley or basin formed for their deposition by erosion of the older, probably Miocene, beds They extend a long distance in one direction, being traceable from the Mount Blanco locality southeastward for fifteen or twenty miles to the edge of the Llano. They are probably a stream deposit. According to Gidley, "The occasion beds of diatomaceous earth are easily accounted for by supposing that there were in this ancient valley occasional ponds filled with clear water, enduring for various periods of time, partially or totally isolated from the stream that ran through the valley, such as exist at the present time in the west, especially in the Sand-hills country of northern Nebraska and southern South Dakota. The diatomaceous deposits are for the most part quite impure and contain great quantities of remains of rushes and pond grasses, indicating that these ponds were never of any great depth and probably occasionally received an overflow from the stream in times of freshet.''

Tule or Rock Creek Beds

These beds are found along Tule Canyon and Rock Creek in Swisher and Briscoe counties. They occur from above the head of Tule Canyon east to and beyond Rock Creek on the south side of the canyon, for some distance along the north side, and at the head and on both sides of Rock Creek. The Rock Creek beds lie unconformably on older formations. North of Mayfield's ranch they lie directly upon the Triassic (Pl. VI, b). The tooth of a young Pleistocene horse was found in a well on Judge Kinder's ranch on South Tule Creek, Swisher County, and Pleistocene fossils were found on the Blanco fork of the Brazos just south of Running Water postoffice, and at Plainview, Hale County, and on the Double Mountain fork of the Brazos at Eagle Springs, south of Bartonsite postoffice, Hale County. It is, indeed, probable that Pleistocene deposits will be found at a number of other localities on the Llano. Gidley gives the following opinion concerning the mode of deposition of the Rock Creek beds: ''The distribution of the beds, which are nowhere very wide, but extend several miles east to the edge of the Plains, indicates, rather, an alluvial origin. The sharp cross-bedding of sand, gravel, and clay, which the writer observed at certain points in the formation, and the peculiar distribution of the coarser gravels, all indicate the depositions of a river or smaller stream, rather than those of a lake. A further indication of the alluvial derivation of these beds is that the fauna represented consists wholly of land forms, and some of the bones show weather-checking. The wind, carrying large quantities of fine sand and dust from the surrounding plains, may also have played a very important part in forming these deposits.''

Lull and Troxell found Pleistocene vertebrate fossils all the way from McLean, Gray County, and Clarendon, Donley County, through the Palo Duro Canyon to the region all about Rock Creek and Tule Canyon. They also found Blanco Pliocene fossils at Rock Creek on Mayfield's ranch and on the Tule near Rodgers. Dr. E. L. Troxell writes as follows: ''I

Plate VIa—Exposure of the whitish Blanco Pliocene beds in Blanco Canyon just north of the mouth of Crawfish Draw, northeastern Crosby County, Texas.

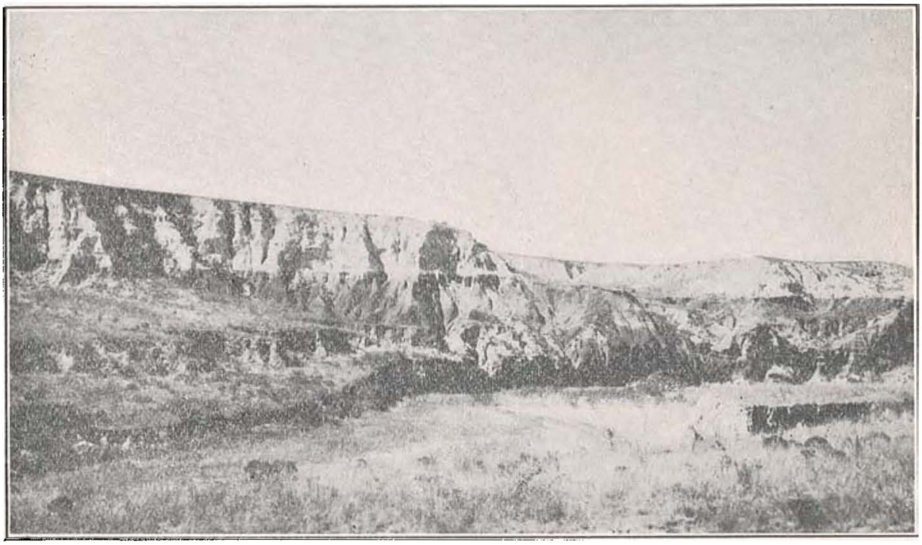

Plate VIb—Fossiliferous Pleistocene beds of the Rock Creek formation (white in color) unconformably overlying Triassic (darker in color) on Rock Creek north of Mayfield's ranch, in western Briscoe County, Texas.

am therefore led to believe that the Pleistocene formation is a veneer, varying in depth, but spread out smoothly and constituting practically the whole surface of the Llano Estacado. Naturally the last stages of the building of this great plain would be by streams which had almost reached grade. Hence:

(a) Only fine material would be carried.

(b) There would be no definite channels; the material would be spread out as a flood plain over the older even or uneven surface.

(c) It might well occur at the beginning of the glacial period when the climate would be more humid—this is in harmony with the early Pleistocene age of the fossils."

A layer of pure volcanic ash 7 feet in thickness is found near the middle of the Rock Creek beds on the north side of Tule Canyon at the Swisher-Briscoe County line. This volcanic ash is well exposed on the southwest quarter of Sec. 60, Blk. B3, Swisher County, and probably extends up-stream along the Tule until it crosses that stream about 200 yards west of the Rock Crossing. It was probably deposited during one of the later eruptions of the volcanoes of southeastern Colorado, settling out of the air upon the early Pleistocene land surface. It will furnish the geologist with a definite stratigraphic horizon in the midst of beds in which ordinary stratigraphic methods can be applied only with difficulty. Since the ash must have settled from the atmosphere in a very short period of time, its time of deposition will everywhere be the same, provided, of course, that there is only one bed of ash to be found in the sequence of strata.

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CHAPTER II.

PHYSIOGRAPHY

General Features

The Llano Estacado is a nearly flat and level tableland or mesa, surrounded on all sides by more rolling eroded plains of lower elevation. It is a part of the High Plains, from the northern portion of which it is separated by the deep valley of the Canadian River. The southern High Plains, or the Llano Estacado, is bounded everywhere except on the south side and in the vicinity of Clarendon, Donley County, by an abrupt escarpment, rising above the adjoining country to heights of 50 to more than 300 feet. This escarpment is formed by the "cap rock," which, more resistant to forces of erosion than the underlying beds, forms an abrupt, precipitous and nearly horizontal rim.

The term "High Plains" is a physiographic one. The High Plains is a surface formed by deposition; while the surrounding "eroded Plains" is a surface formed by denudation. The "cap rock" escarpment forms the boundary between the two. The High Plains and the Eroded Plains together form the physiographic province known as the Great Plains, a collective term for the region bounded on the west by the eastern front ranges of the Great Cordillera of western North America, and on the east by the valleys of the Mississippi River and of the Red River of the north. The High Plains is characterized by a sparse, uniform covering of grasses, and is called the "short grass" country. The Eroded Plains bounding the High Plains on the west, have a steppe type of vegetation, in which the growth of grasses and herbs is patchy, with a good deal of moth-eaten and mangy aspect—the "bunch grass" country. The High Plains or "short grass" country extends from about the northern boundary of western Kansas as far south as the Pecos River in southwest Texas; the Great Plains, from the Arctic Ocean from northern Alaska and the mouth of the Mackenzie River to the Gulf Coastal Plain of southern Texas.

To the observer, the surface of the Llano appears to be a quite flat and monotonous grass-covered plain. In reality, however, the surface has a slope in an east and southeast direction of about nine and one-half feet per mile. The amount and direction of maximum slope varies somewhat in different portions but the above figure and directions are about the average. From southern Curry County, New Mexico, to Crosbyton, Crosby County, Texas, in a south 50° east direction, the difference of elevation is 1400 feet or 9.3 feet per mile. From central Roosevelt County, New Mexico, east to Floydada, Floyd County, Texas, the difference of elevation is 1225 feet and the easterly slope is 9.4 feet per mile. From Amarillo southward to Lamesa, Dawson County, Texas, a distance of 170 miles, the difference in elevation is 680 feet, or a southward slope of 4 feet per mile. From Texico, on the Texas-New Mexico boundary, to Southland, Garza County, Texas, in a south 50° east direction, the difference in elevation is 1113 feet, and the distance 112 miles, giving an average southeasterly slope of nearly 10 feet per mile. From Amarillo to Douro, Ector County, Texas, a distance of 240 miles in a south 9° west direction, the difference in elevation is 540 feet, and the south-southwesterly slope is 2.25 feet per mile. The altitude varies from over 4500 feet at the northwest margin of the Llano in New Mexico, to about 2900 feet at the southeast margin in Texas; from about 4000 feet in southern Oldham County, Texas, in the north, to about 3000 feet in southwestern Ector County, Texas, on the south. The greatest length of the Llano Estacado in a north-south direction is about 250 miles; and the greatest width in an east-west direction is about 175 miles.

Features which interrupt or destroy the otherwise even surface are: (1) Stream channels, generally quite shallow in the interior, but breaking into narrow, steep, and deep canyons as they near the escarpment; (2) undrained depressions, known as "alkali lakes," "dry lakes," and "buffalo wallows;" and (3) sand hills and low ridges, which rise above the general level.

In this chapter, the surface features will be described and their origin discussed. Finally, the relations of the Llano to the surrounding eroded Plains, the origin of the bounding and dissecting streams, and of the escarpment will be considered.

Constitution of the General Upland Surface*

The surficial deposits of the Llano Estacado consist of chocolate-brown to slightly reddish-brown soils with brown to reddish-brown subsoils, overlying white or pinkish-white limy materials, sometimes loose, sometimes consolidated into the "cap rock." The limy material underlies the surface soils at variable depths, but perhaps the general average is about three feet in the northeastern portion of the Llano. In eastern Eddy and Chaves County, New Mexico, and adjoining sections of Yoakum, Cochran and Bailey counties. Texas, the "cap rock lime" is practically on the surface, with very little or no covering of soil. It is worthy of note that the writer found at no place on the upland surface any waterworn gravel.

The soil materials may be differentiated into three groups: silty clay loam, sandy loam, and sand. The silty clay loam forms the surface material of the northern and northeastern portions of the Llano Estacado. With it are interspersed, especially in Randall County, Texas, and in Quay and northern Roosevelt counties, New Mexico, some small areas of sandy loam. Carter** accurately describes the silty clay loam as follows: "The surface soil consists of a light brown or chocolate-brown silty loam, having in places a slight reddish tinge. The depth of the soil varies from two to eight inches, but the usual depth is three to five inches. Below this the subsoil to a depth of 18 to 24 inches is redder and heavier in texture than the surface soil. It may be described as a reddish-brown silty clay loam with a hard compact structure. Usually this material does not persist to a depth of more than 24 to 30 inches, though in rare cases it may extend to 36 inches. * * *

"At a depth ranging from 18 to 30 inches, spots of a white calcareous material are always encountered, and this calcareous material increases in amount with depth until at 4 to 5 feet it becomes almost a solid white, mottled with red."

The silty clay loam, in its original state on the grass-covered

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*In the preparation of this section, some data have been used from the report entitled "Reconnaissance Soil Survey of the Panhandle Region of Texas," by Wm. T. Carter, Jr., and party: Field operations of the Bureau of Soils, 1910, U. S. Department of Agriculture.

**"Reconnaissance Soil Survey of the Panhandle Region of Texas," by Wm. T. Carter, Jr., and party: Field Operations of the Bureau of Soils, 1910, U. S. Department of Agriculture.

uplands, is to quite a marked extent impervious to the downward passage of water, moisture from the rainfall seldom penetrating to a depth of three feet. In the following table are shown the results of 16 microscopic mechanical analyses of this material The dimensions are given in millimeters; one m. m. equals one-twenty-fifth of an inch (about):

	1 to 1/2 mm.	1/2 to 1/4 mm.	1/4 to 1/8 mm.	1/8 to 1/16 mm.	1/16 to 1/32 mm.	1/32 to 1/64 mm.	1/64 to 1/128 mm.	1/128 to 1/256 mm.	1/256 to 1/512 mm.
1.	-------	0.7	15.7	48.2	25.0	6.2	2.7	1.3	-------
2.	-------	0.7	23.7	56.4	11.7	3.8	2.8	0.7	0.3
3.	-------	3.7	42.8	31.5	14.3	5.7	1.4	1.3	-------
4.	-------	1.2	20.6	31.9	22.4	2.9	0.7	0.2	-------
6.	0.2	3.9	25.6	40.7	14.4	8.1	4.6	1.7	0.6
7.	-------	1.3	17.1	45.0	17.9	11.6	4.1	3.0	-------
8.	-------	1.3	19.5	48.3	17.4	8.6	5.2	1.6	0.5
9.	-------	1.5	21.6	50.8	21.1	6.2	0.6	0.2	-------
10.	-------	0.9	11.7	46.5	24.9	9.0	5.0	2.0	-------
11.	-------	1.5	19.0	57.6	18.7	2.7	0.4	0.1	-------
12.	0.2	1.7	22.6	26.6	21.2	22.6	3.7	1.1	0.3
13.	0.5	2.8	43.1	38.1	11.9	3.0	-------	-------	-------
14.	0.8	2.8	22.8	48.9	12.5	8.0	2.6	1.1	0.3
15.	-------	0.2	5.5	53.8	34.2	5.5	0.7	0.2	-------
16.	-------	0.7	7.4	57.9	26.6	5.9	1.4	0.4	-------
17.	Tr	0.8	24.8	54.2	19.6	0.5	-------	-------	-------
18.	22.8	29.5	33.6	11.2	2.2	-------	-------	-------	-------
19.	3.3	6.0	18.5	43.4	15.8	10.1	2.0	-------	-------

NOTE.

1. In front of E. Dowden's house, Hale County.
2. Highest point in Hale County, Anderson Farm, 4¼ miles west of Hale Center, and ¼ mile south
3. Surficial 6 inches of soil, at syndicate well No. 2-1, on high point due east of Hale Center.
4. Surficial 1 foot of soil. Shier well at Hale Center.
6. Surficial 6 inches of soil, 10 miles southeast of Plainview (in sandy country).
7. Surficial 6 inches of soil near northwest corner Sec. 6, Blk. G, 3¾ miles north of Running Water P. O, Hale County.
8. Top 1 foot of soil near middle of south line of T. H. Miller pre-emption, 3½ miles north-northwest of Hale Center.
9. Limy soil 5 feet beneath surface, middle of south line of T. H. Miller pre-emption, 3½ miles north-northwest of Hale Center.
10. Soil 6 inches below surface, 1½ blocks north of northwest corner of court-house square, Plainview, Hale County.
11. Soil 5 feet below surface, 1½ blocks north of northwest corner of public square, Plainview, Hale County.
12. Crosbyton cellar, from depth of 2 feet.
13. Crosbyton cellar, from depth of 3 feet.
14. Loess. Edge of plain north of Spur Ranch.
15. Top soil, Amarillo, 4–5 feet thick.
16. Under 4–5 feet at Federal Bldg., Amarillo.
17. Dust on bale of cotton, 2 feet above ground, Amarillo.
18. Wind drift by a fence, 7 miles southwest of Amarillo.
19. Blown on floor in theatre vestibule, Amarillo.

The area of the silty clay loam is *par excellence* the "Short-grass country." The two principal grasses are the buffalo grass and mesquite grass. There is also the turpentine weed (*Gutierrezia sarothrae*), and the loco-weed (*Astragalus mollissimus*). The Russian thistle and the blue weed are introduced on cultivated land.

The area of silty clay loam is bounded on the southwest by the region of sandy loam. The boundary between the two runs from Clovis and Texico, New Mexico, southeastwards through southwestern Palmer, northeastern Bailey, northern Lamb, and western, southern, and southeastern Hale counties. The surface soil of the sandy loam area is made up of brown or reddish-brown medium to fine-grained sandy loam, of about one foot in thickness. The subsoil is sandy loam to sandy clay, chiefly reddish-brown in color, grading down into white calcareous material at a depth of from 20 to 30 inches. The material is porous, permitting the downward passage of water. Characteristic plants are the bear-grass (*Yucca augustifolia*), wormwood (*Artemesia filifolia*), sedge-grass (*Adropogon sp.*) and cat's-claw. A few small mesquite trees grow on the heavier soils, especially in Lubbock and Crosby counties. The sandy loam area has a topography not quite so monotonously flat as that of the silty clay loam area.

The region of sandhills lies to the southwest of the sandy loam area, into which it gradually merges on the northeast. The sand hills stretch in a belt extending from the western escarpment of the Llano south of the Portales Valley, eastwards through central Bailey County, Texas, to the center of the western boundary of Hale County. Another area of sand hills begins in central eastern Chaves County, New Mexico, stretches eastwards through southern Cochran and northern Yoakum counties, Texas, through eastern Yoakum County, and to the eastward covers most of Terry County and a portion of Lynn County, Texas. Southwestward of the sand hill areas the "cap rock lime" lies at or close to the surface. The sand hills form only a superficial covering over the white limy material. The sands are rather fine in texture and generally have a brownish or reddish-brown color, which is, however, generally of a lighter shade than that of the materials already described. The vegetation is made up of the plants occurring on the sandy loam and in addition hackberry, vetch, and stunted shin-oak (*Quercus undulata* Torr.). The topography is more rolling than other portions of the upland with often rounded low hills and dune ridges. None of the dunes are of great height, few rising more than 30 feet above their surroundings. The sand hills are made up of very porous sands and consequently readily permit the downward seepage of water into the underlying Cenozoic strata.

Origin of the Surficial Materials

The arrangement of the surface deposits in three belts trending east-southeast west-northwest, bounded on the southwest by an area where such deposits are nearly or entirely lacking and the materials of the three belts decreasing in coarseness of texture from southwest to northeast, must be considered in any theory of their origin. The deposits of the sand hill areas have been congregated by the winds, which in the region now blow mainly from the south and south-southwest. The source of the sand is either from the surfaces of the Llano farther southwest, or from the sandhill regions overlying the Red Beds of the Pecos Valley to the south or west, or from both of these regions. The brown or reddish-brown tinge of the sands, caused by a surface coating of the grains with iron oxide, suggests that they may originally have come from the Red Beds region, but this is simply a suggestion, since the sands of the Cenozoic deposits are of the same colors.

The sand hill materials grade northeastward into the sandy loam and the slightly finer materials of the latter may most reasonably be regarded as deposited by the wind in the lee of the sand hills.

The different grades of texture of the silty clay loam have been shown in the table of mechanical analyses in the previous section. The two coarsest grades (½—¼ and ¼—⅛ millimeters) are made up almost entirely of rounded grains of clear white quartz sand. The maximum amount of material in all the samples of silty clay loam is in the grade consisting of particles from ⅛—1/16 mm. in diameter. In all the samples of silty clay loam the maximum is one grade finer than in dune sand and one grade coarser than in most dusts, but nearer to the composition of dust than of dune sand. It therefore contains too much fine material to be classed as dune sand and perhaps too much coarse material to be classed as dust. But analyses numbers 17 and 19, of wind-blown dust from Amarillo, have the maximum grade of the same degree of texture as the silty clay loam and differ very little from it in other respects. Analysis No. 18 is interesting because it probably represents something like the average texture of materials moved by winds of the present time which blow close to the ground.

The average of 12 samples of silty clay loam shows that the maximum grade of the texture of 1/8—1/16 mm. forms one-half of the sample, and that there is a larger proportionate amount of grades finer than the maximum than of those coarser than the maximum; which last fact is of importance in distinguishing this type of deposit from dune sand, in which there is a greater amount of materials of grades coarser than the maximum than of those finer than the maximum. That the silty clay loam is partially a wind deposit may be regarded as certainly shown by its uniformity and degree of texture. But it is either a mixture of two heretofore recognized types of wind deposits, or it represents a type intermediate between the two. It can be said to be partly dust, partly dune sand or lee sand. But what causes would form a mingling of the two? The two grades coarser than the maximum belong to the type of dune sand or of sands on the lee side of dunes, and can be regarded as deposited by winds of the same intensity as deposited the materials of the sand hills and the sandy loam farther to the southwest. That is equivalent to saying that the two coarser grades of the silty clay loam have been deposited by the winds of exceptional intensity and that winds of this intensity have deposited practically all of the material of the sand hill and sandy loam belts, but only a small percentage of the material in the silty clay loam belt. Without complicating the problem any farther just now, the arrangement of materials into belts becoming increasingly coarser towards the southwest would mean, if the materials of all the belts were derived from the same source, that the average intensity of the prevailing wind decreased rather rapidly and evenly in a northeastward direction; or, if the average intensity of the wind remains uniform for the entire area, that the materials of the three belts have not been far transported from their original positions, that they were originally different in texture in their original positions, and decreased in coarseness towards the northeast. Either one of these views would account for the origin of the two coarser grades in the silty clay loams as deposits of winds of exceptional intensity, or, according to the second, because the original material in its original position, chanced to have something like the present percentage of the two coarser grades. In wind deposits, just as in water-born detritus, a distinction must be made between grades so coarse that they are shifted but short distances at a time by rolling, and those that are carried in suspension. It is evident that a wind or water current of uniform intensity will carry the materials of the latter class a longer distance from their place of origin than those of the former. Hence it takes the coarse wind-blown particles a longer time to make the journey across the plains than it does for the finer; and the coarser particles will be found in most abundance nearer to the original source of both the coarse and the fine wind-transported materials.

Vegetal covering might entrap finer material settling from the atmosphere during periods of decreased wind velocity and prevent its subsequent removal during periods of higher winds, while in an adjoining region bereft of such vegetal covering, materials of such fineness could not permanently accumulate. Much of the finer materials might be brought down with the rain, and being in a moistened condition would adhere to other particles which together would make so large a mass that when dry the wind would not be able to move it. Or some or most of the finer material may be chemical precipitates deposited with the "caliche" upon the evaporation of ground waters rising through the soil by capillarity. But this latter process ought to operate equally over the entire surface of the Llano, save the capillary action is greater in the silty clay loam than in the sandy loam and sand. So, given already a high percentage of finer material, the process of evaporation of waters rising under capillary force would tend to increase this percentage, but it would not be a primary cause of the deposition of the finer materials in but one belt, that of the silty clay loam.

If the wind-blown material came originally from the Red Beds of the Pecos Valley, the present distribution in belts would seem to be best explained by a gradual decrease in force of wind from south and southwest to north and northeast. On the other hand, if the wind-blown materials were originally on the Llano and have only been shifted a short distance from their original situations, the present distribution might be accounted for by original decrease in coarseness due either to sorting action of water or of wind in a previous epoch. For instance, water-deposited materials on the Llano, originally derived from the erosion of the Rocky Mountains, would decrease in general in coarseness from west to east.

On a plains surface as nearly level as that of the Llano and offering practically no initial obstructions to the transportation of wind-blown materials derived from a source other than that of the plain itself, it is difficult to conceive of any cause for locality of deposition other than a decrease at that locality of the velocity of the transporting agent. The only decrease of average wind velocity that can be conceived of on a very level plain is a gradual one. Such gradual decrease to the northeast would allow the settling of the largest amount of material of a given grade of coarseness at a certain locality, bounded in the direction from which the prevailing wind came by an area of slightly coarser deposits and in the direction towards which the prevailing wind blows by an area of slightly finer deposits. Because material classed as clay or dust has the property of adhering when wet and forming a more or less solid mass upon subsequent drying, the winds of exceptional strength are not able to remove all of it which was formerly deposited, although finer sand can be fairly completely removed from coarser sand during dry periods by winds of exceptional strength, which, however, are not strong enough to carry far the coarser particles. In this distinction between sand and clay, therefore, lies the reason why in a transitional deposit, intermediate in a composition between sand and clay, finer and coarser materials may be present in the same sample. Fine particles dropped during lulls in the wind will adhere together, provided they are wetted and present in enough abundance and so will be mixed with sand just coarse enough to resist the moving force of the average or the stronger wind.

If the present surface of the Llano is wind-built and not wind-eroded it may now present a more even surface than at the end of the period of alluvial deposition, the low places of its surface having been filled in by wind deposits. At the present time, however, there are numerous depressions in the plains surface and these seem to be increasing in size by agencies other than that of the wind. The formation of these depressions, however, does not at all imply that wind erosion is greater at present than wind deposition, for it is certain that the chief agency in the building of the Llano upland surface has been depositional rather than erosional.

The "Alkali Lakes"

The larger depressions of the Llano, none of which have a surface outlet, are known as "alkali lakes" or "salt lakes," although not one of them known to the writer is a permanent body of water. The largest of these depressions visited by the writer, Garcia Lake, in southwestern Deaf Smith County, has an area of about six square miles. but Shafter or Salt Lake in northeastern Gaines County is reported to be of considerably greater extent. The bottom of these depressions generally is one hundred to one hundred fifty feet lower than the surrounding uplands, and when dry they are covered with a glittering white efforescence of salt and alkali and of many rather large crystals of selenite. One of these, Coyote Lake in Bailey County, Texas, occurs in the midst of sand hills and differs from all the other lakes visited, in that nowhere about the margin of its basin was the "cap rock lime" visible. Coyote Lake and Rich Lake, in northeastern Terry County, have areas of higher land in them, which become islands when the floors of the basins are covered with water. On the southeast margin of the basin floor of the lake is a ridge of sand which, on the side facing the basin, has a steep side and on the opposite side, away from the basin, has a more gentle slope interrupted with hummocks of sand. This sand ridge has been built up of materials blown from the bare surface of the basin floor during periods of the year when the surface is dry, and its position on the southeastern margin implies that during the dry season of the year, or the winter, the prevailing winds are northwesterly. There is considerable slumping of the sand on the basin side of the ridge, and since the sand is always mixed with a considerable percentage of alkaline salts which binds together the sand grains, cracks are often formed in the downward movement of a portion of the mass at the line of its breaking away at the surface from an adjoining higher portion. (See Plate

Plate VIIa—Looking northward over the east end of Bull Lake, southwestern Lamb County, Texas, showing the steep sand ridge on the southeast shore.

Plate VIIb—A nearer view of the features shown in Plate VIIa.

V, a, and VII, a and b, for views of Bull Lake, in Lamb County, Texas.)

These depressions have been caused by a sinking of the surface. Beds of salt and gypsum in the underlying Permian sediments have been removed by solution by underground waters and caverns thus formed, the caving of the roofs of which has caused the depression of the surface of the Llano. Often one can note the slumping of the surface in a series of benches successively lower in altitude as he approaches the bottom of the depression. Such evidence of slumping can be seen along the road from the railroad station of Littlefield to Yellowhouse Ranch, in southwestern Lamb County, as one approaches from the east the basins of Yellow and Illusion Lakes and also on the east side of Montezuma or Monument Lake in west central Bailey County, between the 64-Ranch headquarters and the lake. Silting up of the bottoms of these lakes by sediments washed in from their margins finally renders them impervious to the downward passage of water, and thus after a rain, water remains on their surfaces until it evaporates and leaves behind it a coating of the salt and alkali dissolved in the water. A number of these depressions are found along the course of an old stream channel which will be noted later on in this chapter. Nearly all of the deeper depressions have short and shallow tributary streams.

The "Dry Lakes"

Smaller depressions, known as "dry lakes" or "playa lakes" are scattered rather uniformly over the upland surface of the Llano. (Pl. VIII, a.) In Hale County, Texas, there is an average of one of these depressions to every square mile of area. In area they range from less than ten acres to at least three sections, and in depth they average 20 to 30 feet. Around the upper margins of most of the depressions, the "cap rock lime" outcrops. The smaller ones are apt to be symmetrically round in ground plan, and to exhibit a symmetrical bowl-shape depression of about the same steepness of slope on every side. The large ones may be roughly elliptical or irregular in shape. The larger and deeper ones, which , however, are not nearly so large or deep as the "alkali" or "salt lakes" described in the previous section, have sometimes a low ridge of sandy material on the southeastern margin, like in the case of the larger "alkali lakes" and this ridge is probably of the same origin in both cases. The "dry lakes" probably have originated in the same way as the "alkali lakes." The smaller and more symmetrical ones do not appear to have been modified to any appreciable extent by wind action. A few of the larger and less symmetrical have been so modified to a minor extent. But they are certainly not "blow-holes" excavated by the wind, as some have thought, else there would be ridges of higher land on the margin of them opposite the direction of the prevailing wind, and the slopes on various sides would have different angles.

After a large rain or during wet seasons of the year, these lakes hold water for short periods of time. The soil of the bottoms is a black silty loam containing a considerable percentage of humus derived from the decay of vegetation which grows more luxuriantly in the bottoms of the depressions than on the surrounding uplands. This denser vegetal covering of the bottoms of the depressions would seem able to prevent erosion by the wind more than on the less covered surfaces of the upland. Although this protection may be more fancied than real, seeing that neither surface is very closely covered by a protective blanket of vegetation, yet it appears certain that the force of the wind is necessarily stronger on the unsheltered upland surface than on the lower lying and consequently more protected bottoms of the "dry lakes." The particles of soil of the bottoms adhere strongly to each other and upon the drying up of the water, cracks form. Until these close by swelling of the soil after a considerable rain, they permit the leakage of water through the bottom of the depression and also increase evaporation of soil water by presenting a greater evaporating surface to the rays of the sun. Sometimes these "dry lakes" are more or less connected by shallow drainage channels. A few have small tributary drainage channels, but the great majority are entirely isolated from each other.

The "Buffalo Wallows"

These are the minor, very shallow, depressions on the upland

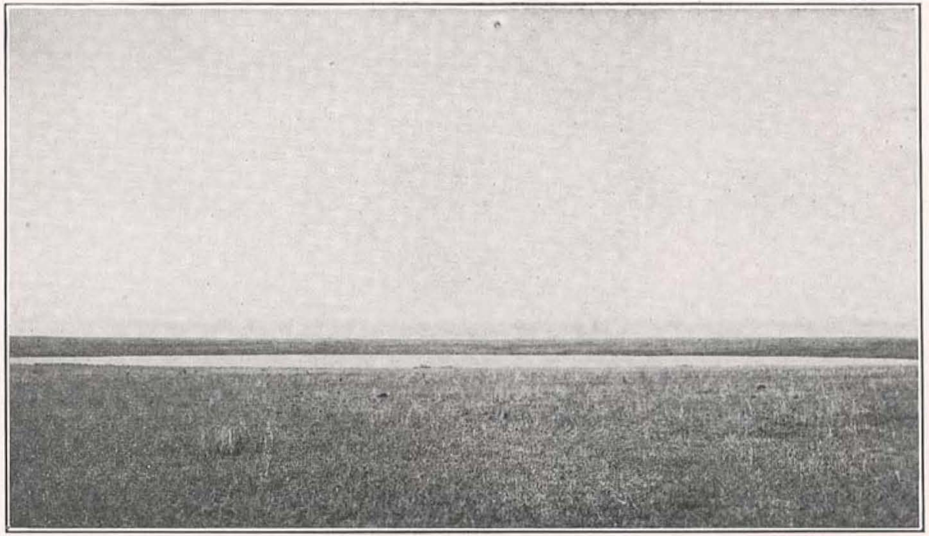

Plate VIIIa—One of the ephemeral "dry lakes" of the plains after a recent rain. The general levelness of the plains surface is also shown.

surface. They may be from a few feet to a few rods in diameter and from a fraction of a foot to several feet in depth. They may be bare spaces scooped out by the wind, or spots where the soil contains substances relished by stock, which there paw up the soil and render it more easily transportable by the wind. Or in some cases they may be places where the "cap rock" caliche has been dissolved away. In many cases they are perhaps incipient "dry lakes" formed by sinking of the surfaces caused by solution of underground strata.

Features of the Llano Caused by Erosion of Running Water

The Cap Rock Escarpment

The upland flat of the Llano Estacado which has so far survived erosion is bounded by the escarpment or "break of the plains." The general flattish surface continues to the very edge of the escarpment and then breaks off abruptly into cliff and badland slopes which constitute the inner margin and highest portion of the eroded or prairie plains. The escarpment, in its ground plan, exhibits a much indented and lobate margin, the lobes being the interstream areas which stretch outwards into the farthest headlands and outposts of the Llano, broken down on three sides by the erosion of running water, the drainage courses of which reach back into the body of the plains. Isolated buttes beyond the margin of its continuous surface are outliers which once formed a portion of the uninterrupted body of the plains and show that the area of the Llano is constantly becoming smaller by the backward recession of the escarpment. The cliff-like aspect of the escarpment owes its characteristic appearance to the superior resistance of the cap rock indurated "mortar bed" layer. The wearing away by rain and wind of the less resistant unconsolidated beds under the cap rock layer undermines the latter and causes blocks to break off from it, usually with vertical fracture lines. The sub-aerial forces of recession are also aided by the water seeping out as springs, especially along the eastern escarpment. These by saturating the unconsolidated sediments, cause them to flow down and slump on steep slopes, thus removing the support for material farther up the slope, which in turn is made to begin its downward journey. A thick sod covering also aids in the preservation of the general upland surface by preventing to a large extent the erosion of sheet-wash during rainstorms. The sod-covering is responsible for the blunt heads and steep sides of gullies. When it is once cut through, erosion of the unconsolidated sands and clays becomes easy and its downward progress is inhibited only by decrease of gradient and upon reaching the cap rock layer underneath.

The Drainage Courses of the Llano

Three large streams of the Texas region—the Red, the Colorado, and the Brazos rivers—have their sources in the Llano Estacado, and two other large rivers—the Canadian and the Pecos—form its boundary on three sides. The heads of the uppermost branches of the Red, Brazos, and Colorado rivers are in New Mexico near the western edge of the Llano and these headwater drainage lines have a southeasterly course and accordingly are consequent to the general surface slope. For more than a hundred miles the headwater channels of each of these rivers have shallow, rather broad valleys. The real drainage channel itself is quite narrow and is incised but a few feet below the level of the flood-plain. In these upper courses are no continuous streams of running water. As they near the eastern edge of the Llano, their valleys are cut deeper and when they have cut as deep as the general ground-water level, a supply of water from springs affords small running streams. Near the eastern margin of the Llano the valleys abruptly become deeper and steep benches or rock terraces are formed whenever they cut through indurated "mortar-beds" or the more consolidated sandstone and conglomerate layers of the Triassic. The box canyons cut through the more resistant layers and head upstream in a fall (Pl. VIb) or rapids along the stream course, while downstream they form the steeper slopes along the sides of the valleys, each resistant layer constituting a distinct bench or terrace in the valley side. Near the outer edge of the Llano the canyons become quite deep and picturesque (Pls. Ib, IIa, IIb, IXa, IXb, Xa and Xb). The most noteworthy of these are the Palo Duro and Tule canyons. The Palo Duro Canyon near the eastern edge of the escarpment is

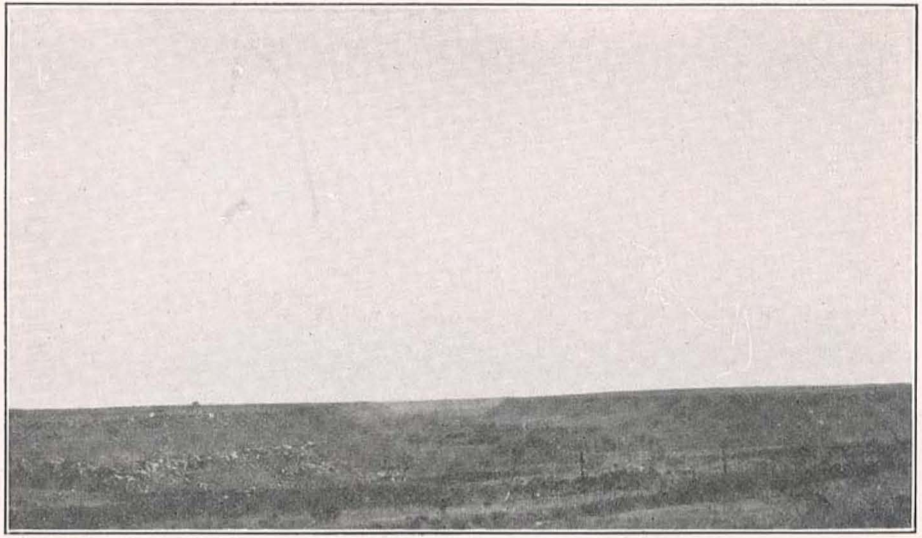

Plate VIIIb—Head of Blanco Canyon, southeastern Floyd County, Texas, with the "cap-rock caliche" forming the top of the canyon walls.

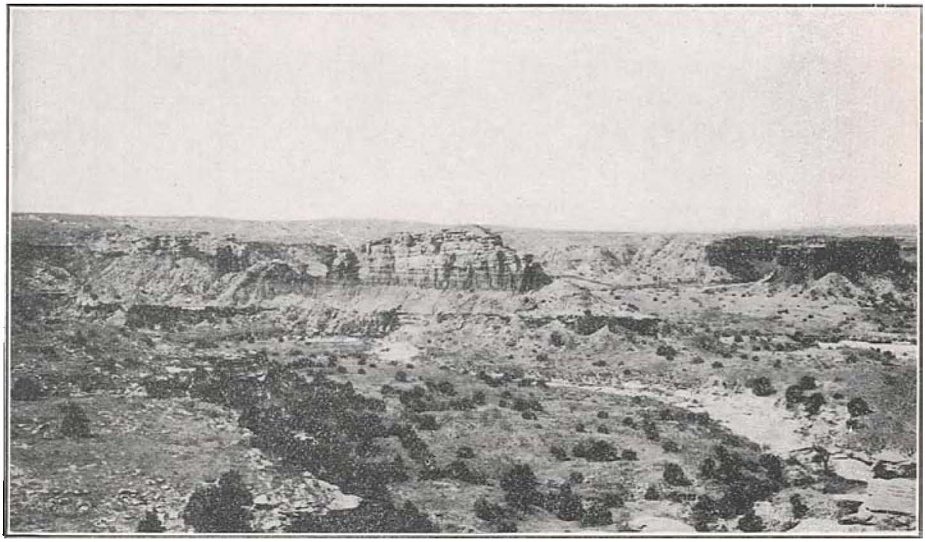

Plate IXa—Triassic badlands in Tule Canyon near the Swisher-Briscoe county line, 2 miles above the narrows.

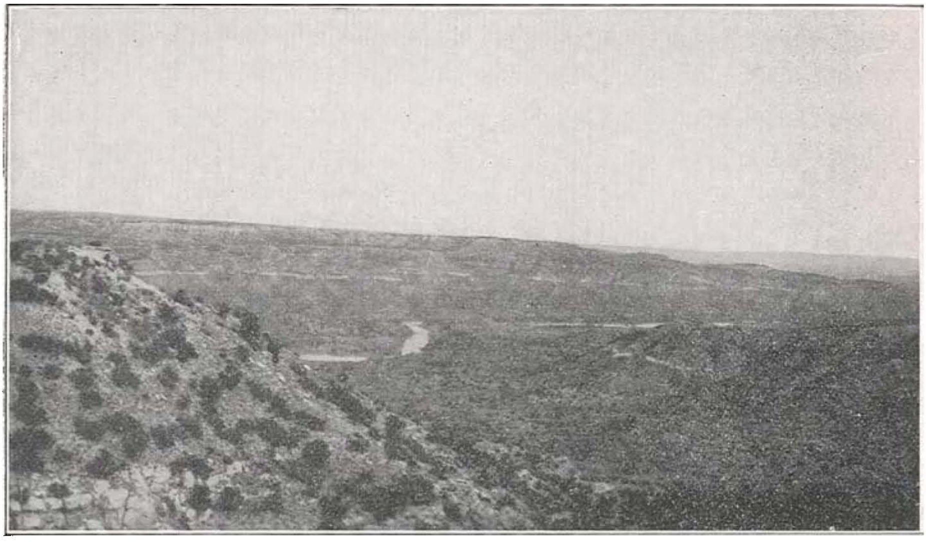

Plate IXb—Tule Canyon below the narrows at the edge of the eastern escarpment of the Llano Estacado.

more than 800 feet in depth and rivals, in striking beauty of color contrasts, the Grand Canyon of the Colorado of the West.

The canyons have been caused entirely by the wearing away of the rocks by the erosion of running water. The cutting out of the canyons is quite late—in fact, since the early Pleistocene. Much of the sedimentary material is either not at all consolidated or, at the most, very poorly consolidated, and offers very little resistance to erosion. The more resistant sandstones, conglomerates, and "mortar beds" are not so rapidly removed by erosion and hence form more precipitous surfaces, but the removal of underlying, less resistant beds causes their undermining and the formation of cliffs. The processes of erosion are greater in this semi-arid country than in a more humid region where a denser vegetation affords more protection to the surfaces of soil and rock. On the steep, bare slopes of the valleys erosion is very rapid.

The canyon portions of the valleys are very young and in the present stage down-cutting by streams is more active than valley-broadening by the process known as lateral plantation. As the main stream carries most of the water and of the load effective for erosion, it is able to cut into its bed and at the same time remove all deposits brought into it by its tributaries, so that all the deeper valleys within the Llano are still steep-sided and V-shaped in cross-section, which is only another way of saying that they are canyons.

The upper courses of at least two of the shallow "draws" of the Plains, the Palo Duro or Prairie-dog Town Fork of the Red River, and the Blanco or Running Water Fork of the Brazos River, in their courses above the points where they are affected by recent rejuvenation, have actually less gradients than have the adjoining interstream surfaces of the Plains. Thus the Palo Duro between the point where it is crossed by the Santa Fe Railroad, 23 miles northeast of Texico, and the town of Hereford, Deaf Smith County, has an air-line gradient of 10.8 feet per mile and measured along the windings of the stream, the gradient is considerably less. The gradient of the Plains upland between these two points is 10.7 feet per mile. The Blanco Fork of the Brazos between the point where it is crossed by the Santa Fe Railroad 8 miles northeast of Texico and the town of Plainview, has an air-line gradient of 8.73

feet per mile while the gradient of the interstream Plains surface between these two points is 9.76 feet per mile. In other words, the valleys of these streams are deeper at places near their heads than at places lower down their courses, but still upstream from the upper limit of recent rejuvenation. This shallowing in depth of the valley downstream can be well seen on the Blanco Fork of the Brazos between Running Water postoffice in Hale County and Plainview, Hale County, Texas. The lessening of gradient and shallowing in depth of valley downstream is rather characteristic of streams which are today, or in a former time have been, engaged in building up the plains surface. The process has already been described in the previous chapter on geologic history.

The Palo Duro or Prairie-dog Town Fork of the Red River, which is really the head of that river, has its source very near to the edge of the northwestern escarpment of the Llano Estacado, in New Mexico. Consequently, the suggestion is inevitable that formerly the Red River really headed farther west and beyond the present western escarpment of the Llano and perhaps even as far west as the eastern foothills of the New Mexico Cordillera, and that subsequently tributaries of the Pecos or Canadian rivers beheaded and diverted the former headwaters of the Red River.

Capture of the Upper Portales Valley by the Pecos River.

The Portales Valley now heads somewhere south of Cantara or Krider station on the Santa Fe railroad very near the western escarpment of the Llano Estacado in northwestern Roosevelt County, New Mexico. The valley near its present head is about 12 miles wide and about 250 feet deep. Bluffs faced with "cap rock" are conspicuous along the south margin of the valley at its present head, but the north side of the valley is covered with sand hills beneath which, at a shallow depth, "cap rock" *in situ* and transported fragments of "cap rock" are exposed almost down to the shores of Lake La Tule (Horn Lake), an "alkali lake" about 7 miles south of the town of Melrose. Since the prevailing winds here are southerly or southwesterly, the sandhills are on the north and northeast sides of the valley. Moving dunes of light cream-colored sands occur one-half mile to a mile west of Lake La Tule. The "cap rock" mesa at its point of farthest northward projection from the south bluffs of the valley, is probably almost due south of the divide between the present Portales Valley and Pecos River drainages. To the south of this projection is a large broad re-entrant in the bluff on the southwest side of which enters a narrow V-shaped valley, 75 or 100 feet deep. This valley is tributary to the Portales Valley drainage, and has its source at least eight miles distant from the place where it breaks through the "cap rock."

Allimaso Creek heads in a depression, probably of the same nature as the "alkali lakes," very close to the northwestern escarpment of the Llano, and flows southeastwardly through southern Quay County, New Mexico, as far as the place where Quay, Curry, and Roosevelt counties corner. Then it turns abruptly at right angles to its former course, and flows west-southwest to its junction with Taiban Creek, a tributary of the Pecos River. Just north of Clegg's Ranch (west line of Sec. 16, Twp. 5N, R. 29 E) on the upper, southeasterly course of the creek is a large shallow sink with a spring of fairly good water at the bottom. This sink is a short distance north of the present drainage course of the creek. Some miles downstream from Clegg's Ranch another sink receives all of the upper drainage of the Allimaso.

The Portales Valley drains southeastwardly and extends in that direction through the town of Portales and through southern Bailey County, Texas, at least as far south as 6 miles southeast of the Yellowhouse Ranch in northwestern Hockley County, Texas. Beyond this point the writer did not have the opportunity of tracing it, but it was in all probability formerly tributary to the Double Mountain Fork of the Brazos river. Its former course is now much obliterated by sandhills and by numerous "alkali lake" sinks, which have apparently been almost all developed since the stream valley was first formed. Among the "alkali lakes" in this valley may be mentioned Lake La Tule, Tierra Blanca Lake, "Great" Salt Lake, and other salt "lakes" in Roosevelt County, New Mexico; Coyote Lake, Heifer Lake, Monument or Montezuma Lake, and White Lake in Bailey County, Texas; Bull Lake in southwestern Lamb

County, Texas; and Yellow, Illusion and Silver Lakes near the northwest corner of Hockley County, Texas.

The size and depth of the Portales Valley at its head indicates that its present head could not have been the original source. Apparently the Pecos River in later Pleistocene times has cut back and beheaded the headwaters of this once very considerable valley. It is possible that the upper Pecos River above Fort Sumner, New Mexico, was really in early Pleistocene time the headwaters of the present Portales Valley, which at that time formed the headwaters of the Brazos River; which river, consequently, had its source formerly in the mountains of north-eastern New Mexico. When the capture of the perennial stream of its headwaters by the Pecos took place, the Portales Valley lost the water which had been the chief agency in excavating its broad and deep valley and so permitted the development of the numerous sinks and the building up of sand dunes in its valley. Nowadays, Taiban Creek, a tributary of the Pecos, is gradually working eastward into the Plains and has already been able to divert the drainage and abruptly change the course of Allimaso Creek, which formerly was a southeastwardly-draining tributary of the Portales Valley.

Later Pleistocene Stream Rejuvenation and Its Cause

The Tule and Palo Duro canyons have been cut since early Pleistocene time, as is shown by the excavation of the Tule through the widely distributed and comparatively thick Rock Creek or Tule formation of early Pleistocene age. No fossil collecting has yet been done in the Cenozoic deposits forming the upper walls of the deeper portions of the Blanco and Double Mountain canyons and the precise age of the Cenozoic deposits along the deeper canyon courses of these streams is not yet known. But it is altogether likely that the canyon-cutting along these streams began at the same time as on the Palo Duro and Tule canyons. Pleistocene fossils, most probably belonging to the stage of the early Pleistocene, are found in gravel and sand alluvial deposits at the bases of the shallow draws of both the Blanco and Double Mountain forks in Hale County. These fossils demonstrate that these shallow draws were in existence during Pleistocene time. The later rejuvenation has worked upstream along the Blanco Fork into southeastern

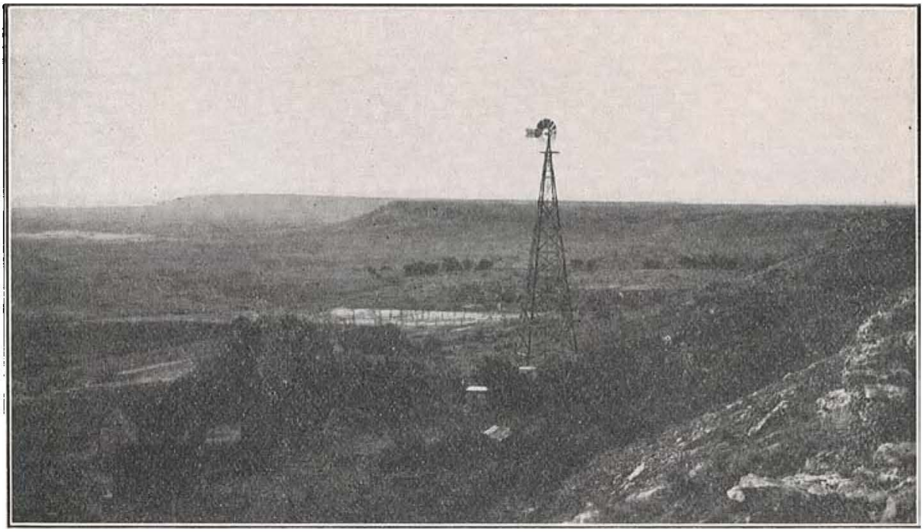

Plate Xa—Old abandoned river valley at Yellowhouse Ranch, northwestern Hockley County, Texas.

Plate Xb—Tule Canyon just below the narrows, western Briscoe County, Texas. Cenozoic beds on rim, Triassic sandstones and clays in the middle and Permian red clays of the upper Double Mountain formation at bottom.

Floyd County, along the Double Mountain Fork some distance upstream from the town of Lubbock, in Lubbock County, along the Palo Duro (here called the Tierra Blanca) to some distance upstream from the town of Hereford, Deaf Smith County, and along the Sulphur Draw, a tributary of the Colorado River, at least as far as the town of Plains, in Yoakum County. This rejuvenation is working headwards on these streams as a series of benches held up by more resistant layers of Triassic sandstone and conglomerate or of Cenozoic "cap rock." Above the farthermost points upstream affected by rejuvenation along all these drainage courses, the shallow draws are still in the older cycle of erosion and are mainly valleys in which aggradation is still taking place. It is only in times of exceptionally heavy and continued rainfall that water accumulating in these shallow draws reaches the rejuvenated portions lower down. Normally water runs for only a few miles and disappears because of evaporation and seepage. Any debris carried by the water which runs only during and immediately after a rainstorm, is deposited in the channel above and at the point of the final disappearance of the water.

The cause of the rejuvenation in the canyon portion of these streams must be a later Pleistocene uplift. Mere change of climate, increasing the forces of stream erosion, would not be sufficient in itself to cut such deep canyons or to cause the development of such a high and persistent escarpment as that which bounds the Llano Estacado. A uniform down-tilting of the entire region towards the Gulf of Mexico would not explain the facts, for in case such had occurred, the entire region should more or less uniformly feel the effects of the rejuvenation at the same time and there would not exist the contrast between the older valleys of a former cycle of erosion upstream and the rejuvenation of younger valleys of a later cycle of erosion downstream. So the uplift must have been either in the nature of a broad regional uplift substantially the same in amount everywhere in the region, or else it was differential in amount in the nature of a warping of the old surface with the greatest amount of downwarp in the region of the present eastern escarpment of the Llano or east of the site of the present escarpment. Until the region between the eastern escarpment and the Seymour Plateau of north-central

Texas has been studied physiographically, it is impossible to decide between these two alternatives.

The Palo Duro has reached a condition of grade from a point near the Randall-Armstrong county line eastwards and in that region is now engaged more in widening its valley by lateral plantation than in deepening it by perpendicular down-cutting. At the Randall-Armstrong county line the stream level is 800 feet below the top surface of the Llano Estacado.

The date of the rejuvenation is to be assigned to the time beginning with the post-Lafayette and pre-Port Hudson epoch of erosion, as it is known in the Gulf Coastal Plain, and continuing to the present day. The rejuvenation is still going on.

History of the Canadian River

The Canadian River heads on the eastern flanks of the southernmost portion of the Rocky Mountains in northern New Mexico, and like the Cimarron and Arkansas rivers farther north, crosses the High Plains and finally adds its waters to those of the Arkansas. The Canadian has a relatively narrow valley in its course across the Texas Panhandle, the distance between the heads of the short tributary creeks on opposite sides of the stream averaging not more than 35 miles. It is a wide, sand-choked stream for practically its entire course across the Panhandle. The stream has continuous running water for only a portion of the year and is noted for its sudden rises and treacherous quicksands. Across the Panhandle the stream has cut a broad canyon in the High Plains. Locally the high bluffs approach nearly to the river, but generally the sandy flat flood-plain is 2 to 4 miles wide. The channel of the river is a sandbed, averaging about three-fourths of a mile in width. In places, where the river flows between high bluffs, the stream bed is not more than 200 yards wide. The banks are in most places low and sandy, except in those rare instances where a bluff-bordered canyon occurs.

The Canadian is clearly the oldest river of northwest Texas. It was existent in the region in early Pleistocene time and at that time probably flowed in a wide shallow valley and contributed much of its sediment to the upbuilding of the High Plains surface. When the later Pleistocene uplift occurred it was able, because it was supplied by water from the mountains, to maintain its course by cutting down its channel as fast as the land rose up in its path, and it may have been aided in its down-cutting by a greater amount of uplift in the region of its mountain headwaters than in the region of the Texas Panhandle. Today, in its course across the latter region, it is at grade and has built up a flood-plain which is generally broad and deeply filled with alluvium.

History of the Pecos River

The Pecos River rises in the region between Las Vegas and Santa Fe, New Mexico, on the very southernmost flanks of the Rocky Mountains. As far as Fort Sumner its course is southeastwardly, but at Fort Sumner it turns southward and continues in that direction nearly as far south as the Texas-New Mexico line. In the region between Carlsbad, New Mexico, and the Texas line, it has the characteristics of a young river, flowing in a narrow valley with little or no flood plain, and cutting in general into the east bluffs in which the strata dip easterly.

That portion of the Pecos which lies between Fort Sumner and the Texas line is in all probability younger than early Pleistocene, because it is certain that the Pecos could not have existed there during the period when the latest Cenozoic (early Pleistocene) sediments were deposited on the Plains surface. The materials forming the Rock Creek beds had their origin in the New Mexico mountains and were brought down from those mountains by eastwardly-flowing streams, one of which may well have flowed in the upper drainage course of the present Palo Duro. The upper Pecos, as far southeast as Fort Sumner, New Mexico, may once have been the headwaters of the Brazos River, as already stated, and if such is the case, this upper portion may once have contributed its share of sediment to the upbuilding of the Plains surface. At any rate, it is apparent that the present isolated Plateau of the Llano Estacado has been cut off from its former surface connection with the foothills of the New Mexico mountains by the headward development of the Pecos River, and the down-cutting of the Canadian, and this isolation has been brought about in Later Pleistocene and Recent time.

SUMMARY OF GEOLOGIC HISTORY AND PHYSIOGRAPHY

The geologic history of the Llano Estacado opens with the deposition, near the end of the Paleozoic era, of about 4,000 feet of clays, sandstones, limestone, gypsum, and rock salt in the bottom of a sea which gradually, though intermittently, dried up. Then these sediments, belonging, as the geologist knows them, to the Permian Redbeds, were down-folded into a broad and shallow trough, basin, or syncline, so that on the west side of the Llano the strata now dip eastwards and on the east side of the Llano, westwards. Following this folding, the country was for a long time dry land, during which a considerable amount of the Permian strata were worn away and removed by the action of streams. Next, streams flowing probably from the west, deposited over the country a thin mantle of reddish, greenish, purple, and yellowish clays and gray sandstones and conglomerates, which belong to the Triassic period. Then again the streams, flowing over land surfaces, eroded away portions of the strata until only a few hundred feet of the Triassic remained. Then again in the Comanchean, and probably later in the Cretaceous also, the sea advanced over the region, for a time extending from the Gulf of Mexico to the Arctic Ocean, and laid down deposits of clays, sands and limestones. At the end of the Mesozoic era the sea finally withdrew, never again to cover the region. At the time of its withdrawal, the rocks of the Triassic and Comanchean, and with them the entire region, were gently tilted to the eastward, probably at the same time that the Rockies first were uplifted as mountains. For a long time the region of the Llano was subjected to erosion which removed all of the Comanchean except a remnant on its southeastern border, another remnant on its northwestern border in the vicinity of Tucumcari, New Mexico, and a third remnant which is exposed on the western shore of Monument or Montezuma Lake, in Bailey County, Texas. In the latter part of the Cenozoic era, streams flowing eastwards from the Rocky Mountains deposited a thin mantle, not more than 300 feet thick, of clays, sands and gravels over the old surfaces, just as similar streams today from the Sierra Nevada and Coast Ranges are depositing rocks and soils worn away and carried from those mountains in the Great Central Valley of California. The soil of the upper few feet of the Llano's surface has been deposited by the wind.

Then the Pecos River cut its valley on the west and south sides of the Plains, the Canadian River cut through the Plains on the north, separating the Llano Estacado from the rest of the High Plains, and the various tributaries of the Red, Brazos and Colorado rivers cut back on the east. Today the Llano Estacado is a high, eastwardly-sloping plateau or mesa, separated by its bounding escarpment or "breaks" from the lower, more eroded plains which surround it. The Llano has the appearance of a broad, nearly flat, island rising above a billowy sea of lower plains. The valleys and canyons, like those of the Canadian and the Pecos, the Palo Duro and the Tule, have been made entirely by the erosion of running water in the most recent epoch of geologic history.

CHAPTER III

Climate

The climate, or average weather of a region, is mainly the product of the three factors of temperature, moisture, and wind. The temperature of an inland region, like the Llano Estacado, is largely determined by its latitude and altitude. The mean annual temperature of the Llano Estacado, which is 56.1° F. at Amarillo and 60° F. at Mt. Blanco and Plainview, is the same as that of the region extending from central Illinois, northern Ohio, central Pennsylvania, and northern New Jersey southward to west-central and southeastern Tennessee and southwestern and northeastern North Carolina. The range of mean annual temperature is from 50° on the west to 60° on the southeast and east. This difference is mainly the effect of a higher altitude. The average temperature for the warmest month, July, along the Texas-New Mexico boundary on the Llano Estacado, is the same as that for the same month in north-central Illinois: and for January, the average temperature of the northern two-thirds of the Llano is the same as that of southern Illinois.

In the following tables is given a summary of temperature data for the northern Llano Estacado, taken from records of the U. S. Weather Bureau:

MEAN TEMPERATURE: Deg. F.

Station	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Amarillo	23	37.1	36.0	46.8	55.5	63.9	72.4	75.9	75.6	69.4	57.3	46.6	36.5	56.1
Mt. Blanco	26	40.2	40.8	51.3	58.8	68.7	75.9	78.8	77.9	72.3	61.0	49.3	43.1	60.0
Plainview	16	42.3	41.5	51.6	60.4	68.5	75.4	76.7	77.0	71.4	62.0	50.1	42.1	60.0

HIGHEST TEMPERATURES.

Amarillo	23	82	77	96	90	98	105	101	102	101	94	82	75	105
Mt. Blanco	26	87	92	96	98	103	110	104	105	102	95	85	78	110
Plainview	18	84	91	92	96	100	108	108	101	101	94	88	79	108

LOWEST TEMPFRATURES.

Amarillo	23	-11	-16	- 2	6	14	41	51	49	36	23	4	-1	-16
Mt. Blanco	23	-10	-14	11	17	28	43	48	50	33	20	5	-6	-14
Plainview	10	8	- 8	12	25	24	44	52	50	33	21	6	-4	- 8

FROST DATA.

Station	Length of record in years	Average date of first killing frost in autumn.	Average date of last killing frost in spring.	Earliest date of killing frost in autumn.	Latest date of killing frost in spring.
Amarillo	18–23	(18) Nov. 1	(18) Apr. 16	(23) Oct. 16	(23) May 23
Claude	4	Oct. 29	Apr. 21	Oct. 21	May 3
Mt. Blanco	16–21	(16) Oct. 31	(16) Apr. 9	(21) Oct. 13	(21) May 1
Nazareth	4–6	(5) Oct. 9	(6) Apr. 12	(5) Oct. 2	(6) May 4
Plainview	11–15	(11) Oct 30	(11) Apr. 2	(15) Oct. 15	(15) Apr. 30
Tulia	11–16	(11) Oct 26	(11) Apr. 15	(16) Sept. 26	(16) May 6

SUNSHINE (Percentage) AT AMARILLO.

No. of years.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
5	68	86	75	76	82	84	76	80	80	69	64	72	76

The average direction of winds for the northern Llano Estacado is southerly or southeasterly. The prevailing wind directions at Plainview, however, for the five months, November to March inclusive, are northerly, westerly, and northwesterly; the average direction for the summer months is southerly. The winds are strong at all seasons of the year, as shown by their average annual hourly movement of 16 miles at Amarillo. The strongest winds occur in the early spring months of March and April. The anticyclones, known commonly as "northers," occur twice as frequently here as in south Texas. To their frequency is largely due the average occurrence of 111 days of freezing temperatures each year in the Texas Panhandle.

PREVAILING WIND DIRECTION.

Station	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Amarillo	18	S	S	SW	S	SE	SE	S	S	S	S	NW	S	S
Mt. Blanco	11	S	S	S	SE	SE	SE	SE	SE	SE	SE	S	S	SE
Plainview	12	W	W	NW	S	S	S	S	S	S	S	N	N	S

AVERAGE HOURLY WIND MOVEMENT (In Miles) AT AMARILLO.

Jan.	Feb.	Mar.	Apr.	May	June	July	A	Sept.	Oct.	Nov.	Dec.	Ann.
15	16	19	19	17	16	14		16	16	15	14	16

The average annual rainfall in the northern Llano Estacado varies from about 22 inches on the east to about 15 inches on the west. Of the yearly total between 70 and 75 per cent. falls in the six months of the crop-growing season from April first to October first. About three-fourths of the total rainfall is therefore distributed through the months in which it can be of the most good to growing crops; but, unfortunately, in the months when excessive evaporation prevents most of it from being stored up in the soil. Most of the winter precipitation falls in the form of snow and is therefore in the best possible form to protect and nourish the grasses of the plains. In general, an annual precipitation of less than 12 inches produces desert conditions; a precipitation of from 12 to 20 inches renders the land suitable for grazing only; and a precipitation of more than 20 inches is favorable to agriculture. But such a general statement must be greatly modified for our region, and the chief modifying factors are (1) the seasonal distribution of rainfall; (2) the occurrence of great annual fluctuations in amount of rainfall; and (3), the relative humidity of the atmosphere, which determines the amount of evaporation. The first of these factors is favorable to agriculture on the Llano Estacado; the other two are distinctly unfavorable.

The source of the rainfall is evaporation from the Pacific Ocean which is carried eastward by the prevailing westerly winds of the north temperate zone. All air holds a certain amount of moisture but the point of saturation of air with moisture is much higher for warm air than for cold air, i. e., warm air can hold much more moisture than cold air. Wheneven air is cooled below the point of saturation, rain falls, and it can only fall when the air is thus chilled. There are several ways in which air currents may be cooled: by rising when they encounter a mountain range across their path; by coming into contact with colder air currents; and by passing over a cold land. The Pacific Ocean is warmer in winter than the coast lands of the western United States. The prevailing westerly winds come off the Pacific Ocean laden with moisture and having the temperature of the ocean. When they reach the colder land surfaces they are chilled below the point of saturation and some of the moisture is precipitated in the form of rain or snow. Hence the winter is the rainy season for the north Pacific Coast. In winter the coast country drains the air currents of their moisture and they pass eastwards over the Rocky Mountains and Great Plains as dry winds. In the summer the north Pacific Coast land is warmer than the adjacent sea, and the air currents, although containing at least as much moisture as in winter, pass over the coast land with comparatively little loss from precipitation and carry most of their moisture over the mountains and precipitate it upon the Rocky Mountains farther to the east and upon the Great Plains. Hence in these two interior regions the greater part of the year's rainfall falls in the warmer, summer months.

Precipitation on the Llano Estacado is mainly from local thunderstorms. These thunderstorms are caused by the lower layers of air becoming heated on hot days by the radiation of heat from the hot lands. Warm air being lighter than cold air has a tendency to rise, and take the place of cool air which has a tendency to fall. In rising, the warm air is cooled, and if cooled far enough, becomes saturated with the moisture it contains which thereupon falls as rain. Thunderstorms usually give rain to only a limited area. The essentially irregular and local distribution of thundershowers cause great inequalities and fluctuations in the yearly total of rainfall. For instance, one locality may, during a given year, have a rainfall sufficient to produce good crops while a locality fifty or one hundred miles away is undergoing a drought. The same locality may have an abundant rainfall one year and experience a drought the following year. Or there may be several years of abundant rainfall followed by one or more years of marked deficiency of rainfall. In a single year the rainfall may rise to nearly twice the normal and another year it may fall to nearly half the normal. A 33-year record at Amarillo, with an average yearly rainfall of 21.9 inches, shows 17 years with rainfall below normal, and 16 years with rainfall above normal. For 15 years out of the 33 the rainfall at Amarillo was less than 20 inches. At Mt. Blanco, Crosby County, with an average yearly rainfall of 21 inches, 19 years fell below the average and there were only 9 years above the average. Seventeen years out of a total of 28 at Mt. Blanco had less than 20 inches. Hale County has an average rainfall of 20.9 inches. In a 21-year period, the rainfall for 13 years fell below normal and 8 years had a rainfall greater than normal. For 10 years out of the 21, the rainfall of Hale County fell below the 20-inch limit which is regarded as favorable for agriculture. For the entire region the average rainfall is so little above the lower limit that can be considered favorable for agriculture that the frequent deficiencies work great hardships for the farmer. The sporadic distribution of rainfall is one of the features which make agriculture such a precarious pursuit in this region.

The fall of rain during the summer thunderstorms is usually rapid and violent, the storm soon passes over, and is followed by warm sunshine, which causes rapid evaporation. The silty clay loam soil, which is the predominating type for a large part of this region, does not readily absorb moisture so that the largest part of the rainfall remains on or near the surface from which it is rapidly evaporated. Evaporation is aided by a high normal summer temperature, by a low relative humidity, by a large number of sunshiny days, and by a large amount of wind, which, during the summer, is prevailingly from the south, is warm, and therefore has a drying effect.

The relative humidity is the percentage of moisture which the air contains at a given temperature of that amount which it would contain at that temperature if it were saturated. At the same temperature warm air has a lower relative humidity than cool air. The average relative humidity at Amarillo is 61.5 per cent. This means that the air is dry and is able to take up moisture by evaporation. The mean total evaporation from an open body of water during the six months (April 1st to October 1st) at Amarillo is 53.26 inches, while the average total rainfall for the same period is 14.41 inches. That is, nearly four times the average rainfall would be evaporated from an open body of water, provided a sufficient supply were furnished to the evaporating agencies. It is this large amount of evaporation which gives to the Llano Estacado really a desert climate. The famous wheat lands of the Dakotas and Minnesota have no greater rainfall than the Llano Estacado, but have only half the evaporation. In order to raise the wheat crops of the northwest, it would be necessary for the Llano to have twice its present rainfall, the amount of evaporation remaining the same as at present.

When the agricultural experiment was first tried on the High Plains it was generally believed that cultivation of the soil, along with other agencies, would cause an increase in rainfall, and this idea is prevalent, even today. Whenever, because of a climatic accident, a succession of wet years, like the years from 1883 to 1887 inclusive, at Amarillo, follow each other, this hope is again revived; but, always, during the last forty years, sooner or later, the years of drought again make their appearance. Climatic records have now been kept for at least a century and nowhere in the whole world has there been found any evidence of a permanent change in climate or rainfall. The settling up a new country has apparently little or no effect, one way or another, on its climate. Go to the High Plains of Western Kansas or to such places as Hereford, Monument and Olton on the Staked Plains of Texas, and you will see deserted farmsteads and abandoned towns for which the constantly recurring drought is responsible. Years of fairly good rainfall have always been followed by years of drought which have caused the abandonment of many farms once settled with high hopes; and the settlers, broken in spirit and depleted in resources, have emigrated to regions of greater promise.

Now, the experience of the last forty years has demonstrated it to be a certainty that ordinary methods of farming, without the growing of a large amount of stock, will never be a success on these essentially arid plains of the West. Dry farming, aided by stock raising, constitutes the only hope of profitable agriculture without the help of irrigation.

In a number of places, as for example, India, observations have shown an apparent fluctuation in rainfall and temperature for a period of eleven years, corresponding to the sun-spot period or the periodicity of the earth's magnetic phenomena. A thirty-five year period of oscillation, known as the Brückner cycle, has also been discovered by Professor Brückner. The cycle varies from 30 to 50 years, but 35 years is its average duration. During any one of these thirty-five year cycles the average annual temperature and rainfall seems to be the same as that for any other period of years of equal duration. So the average of the thirty-three-year climatic record for Amarillo may be accepted with a very small margin of error as representing the average temperature and rainfall conditions for that locality.

The climate of the Llano Estacado is extremely healthy and invigorating. The yearly extremes of temperature are less than in many more productive regions. Periods of extremes of heat and cold are short, while the pure, bracing air and the large percentage of sunshiny days are favorable for the highest and best activities of mankind. It is the high percentage of relative humidity, which this country does not possess, which makes the extremes of temperature most annoying to animal life. Hot air, which is at the same time dry and most favorable to animal life and activity, since the evaporation which it causes keeps down bodily temperature, is, on the contrary, harmful to plant life; and to cultivated plants especially, is seriously harmful. necessitating resort to irrigation in order to compensate for the loss sustained from excessive evaporation.

RAINFALL, RELATIVE HUMIDITY, AND EVAPORATION RECORDS.

Rainfall at Amarillo, Texas, in inches—Elevation, 3676 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov	Dec.	Ann.	Departure from normal
				Apr.	May	June	July	Aug	Sept.					
1879	----	----	----	----	----	----	----	----	----	----	----	0.10	-----	---------
1880	T	0.05	0.40	0.16	4.48	4.50	2.11	1.70	0.54	2.40	0.10	0.35	16.79	—5.13
1881	0.47	0.74	T	1.26	5.27	0.10	3.28	0.49	3.18	0.69	0.42	0.26	16.16	—5.76
1882	0.33	0.16	0.53	0.66	7.48	1.54	5.65	1.55	3.18	2.32	0.96	0.40	24.76	+2.84
1883	T	0.53	0.04	0.82	4.56	1.66	2.87	6.56	4.97	5.32	0.04	0.84	28.21	+6.29
1884	0.61	0.27	0.34	1.08	6.29	6.86	1.29	5.60	0.84	5.54	2.14	3.05	33.91	+11.99
1885	0.45	0.87	1.86	4.67	7.23	9.82	3.62	4.91	0.65	0.60	0.25	2.11	37.07	+15.15
1886	0.62	1.44	1.49	2.44	0.23	3.45	1.50	4.57	3.00	5.04	0.18	0.09	24.05	+2.13
1887	0.01	0.06	0.19	6.06	7.01	2.39	0.92	3.52	1.67	0.69	0.23	0.08	22.83	+0.91
1888	0.32	0.61	0.40	2.69	3.19	1.34	2.50	2.27	0.71	0.85	0.70	0.84	16.51	—5.41
1889	1.63	0.89	1.28	4.86	0.72	1.64	0.88	1.83	1.94	2.99	0.74	0.00	19.40	—2.52
1890	2.40	0.01	0.02	2.94	1.69	1.71	0.88	2.89	0.05	----	----	----	-----	---------
1891	----	----	----	----	----	----	----	----	----	----	----	----	-----	---------
1892	0.42	0.57	2.10	0.21	2.70	1.49	1.85	1.93	0.21	2.86	0.16	1.08	15.60	—6.32
1893	0.09	2.03	T	0.16	2.19	2.03	2.05	2.67	5.27	0.03	0.28	0.43	17.23	—4.69
1894	0.02	1.15	0.05	0.85	1.30	3.59	1.82	3.41	2.41	0.29	0.00	0.82	15.81	—6.11
1895	1.60	1.92	0.16	1.31	1.78	6.84	2.88	3.87	0.77	2.26	0.81	0.79	24.79	+3.87
1896	0.76	0.41	0.21	1.95	2.20	2.31	7.04	0.63	2.15	3.09	0.35	2.88	24.28	+2.36
1897	2.26	0.65	0.47	1.08	4.44	2.32	2.16	2.71	0.73	1.63	0.08	0.63	19.16	—2.76
1898	0.86	0.82	0.35	0.98	3.52	4.81	3.88	4.03	0.48	0.41	0.34	2.06	22.54	+0.62
1899	0.29	0.07	0.17	0.23	3.12	4.45	6.96	0.51	6.09	1.15	3.24	1.11	27.39	+5.47
1900	0.59	0.47	0.48	5.47	4.53	1.84	3.21	0.83	5.25	1.58	0.08	0.07	24.40	+2.48
1901	0.03	0.48	0.02	4.90	5.99	0.92	1.56	3.03	2.19	3.26	2.00	0.04	24.42	+2.49
1902	0.04	T	0.74	1.83	9.14	2.01	1.45	2.42	0.95	1.74	2.24	0.55	23.11	+1.19
1903	0.12	2.93	0.26	0.90	1.79	2.83	3.88	4.67	0.82	2.58	0.00	T	20.28	+1.64
1904	0.16	0.08	T	0.63	2.88	5.53	2.48	4.69	3.55	0.44	0.20	0.69	21.33	—0.59
1905	1.00	1.52	2.62	4.52	6.16	2.19	3.76	0.63	3.08	0.30	5.09	1.45	32.32	+10.40
1906	0.41	0.51	0.64	3.23	1.18	2.07	2.90	6.76	1.96	2.49	2.58	0.19	24.92	+3.00
1907	1.11	0.24	0.02	1.25	0.99	1.97	1.49	6.20	0.91	1.79	0.66	0.46	18.09	—3.83
1908	0.26	0.72	T	1.90	3.55	1.73	5.40	2.75	1.83	0.40	0.51	0.00	19.05	—2.87
1909	0.07	0.28	1.28	0.50	1.08	4.72	3.63	0.87	2.19	1.18	3.25	0.54	19.59	—2.33
1910	0.05	0.17	0.54	0.59	2.99	0.66	3.57	2.19	0.05	0.26	0.28	T	11.15	+0.77
1911	0.15	2.88	0.30	2.76	5.89	0.20	3.85	2.97	0.83	0.84	0.94	0.95	22.73	+0.86
1912	T	1.94	0.82	0.72	1.67	1.90	1.88	2.28	2.28	0.39	0.02	1.18	15.08	—6.84
1913	0.11	0.55	0.39	1.76	1.41	2.32	1.80	0.61	4.19	0.81	1.98	2.84	18.97	—2.95
1914	0.06	0.10	0.15	0.97	4.43	0.84	3.07	2.97	1.09	4.46	T	1.17	19.27	—2.65
Monthly Average	0.51	0.77	0.55	1.98	3.62	2.78	2.87	2.93	2.06	1.84	0.94	0.83	-----	---------

Normal for 33 years.......................21.92 inches
Number of years below normal......................17
Number of years above normal......................16

Rainfall at Clarendon, Donley County, Texas, in inches. Elevation, 2,719 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1907	1.11	0.13	0.10	1.68	1.98	5.48	1.94	3.83	3.98	5.24	0.76	1.35	27.58
1908	1.03	0.65	0.79	2.21	4.31	3.10	1.93	0.85	3.67	0.69	1.67	0.00	20.90
1909	0.40	T	1.46	T	2.74	4.21	2.02	1.12	0.60	1.22	6.63	0.65	21.05
1910	T	T	0.60	1.50	2.59	1.77	0.94	4.71	0.10	0.41	0.25	T	12.87
1911	0.27	5.67	0.15	0.85	5.31	0.12	5.59	2.09	3.69	3.03	0.90	2.44	30.11
1912	T	1.76	1.00	2.14	0.88	1.70	1.73	2.55	6.20	0.44	0.04	0.28	19.22
1913	0.00	0.70	0.85	1.38	1.48	5.81	2.16	0.09	3.06	0.88	2.38	2.35	21.14
1914	T	0.04	0.13	1.74	4.92	1.13	2.87	4.16	2.37	2.52	0.01	1.36	21.25
Monthly Average	0.35	1.12	0.63	1.44	3.03	2.91	2.10	2.42	2.96	1.80	1.58	1.05	21.76

Rainfall at Claude, Armstrong County, Texas, in inches. Elevation, 3,397 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1890	1.36	0.04	0.00	4.52	1.26	1.70	3.29	0.92	0.00	0.00	0.52	0.20	13.81
1904	----	----	----	----	----	----	----	----	----	----	----	----	----
1905	0.90	1.09	1.99	5.26	4.14	1.19	4.32	2.71	1.86	0.30	0.47	0.29	24.62
1906	0.01	0.02	0.64	1.60	1.30	1.80	3.90	2.60	3.00	3.20	2.50	0.00	23.57
1907	1.11	0.00	0.10	1.60	3.40	1.97	1.49	6.20	0.60	5.50	0.66	1.46	24.09
1908	1.03	1.50	T	5.40	2.86	1.90	4.10	0.85	3.67	1.00	1.67	0.02	23.94
1909	0.22	0.10	0.60	T	1.25	2.39	4.09	0.51	0.47	0.97	4.22	0.75	15.63
1910	0.60	0.10	0.41	1.34	2.07	3.74	2.05	1.15	0.00	0.02	0.00	0.00	10.90
1911	0.00	4.98	0.74	1.01	5.62	0.04	4.67	2.90	1.22	1.57	0.25	0.80	23.11
1912	0.00	1.20	0.15	1.60	0.65	2.50	1.96	3.20	3.34	T	0.02	1.05	15.67
1913	0.06	0.90	0.14	----	2.10	T	T	0.25	4.95	----	3.20	2.03	13.63
1914	0.04	0.00	0.00	1.81	5.47	1.40	2.24	3.12	1.05	7.31	0.00	0.90	23.24
Monthly Average	0.43	0.90	0.44	2.47	2.73	1.72	2.92	2.22	1.83	1.81	1.23	0.68	19.29

Rainfall at Clovis, Curry County, New Mexico, in inches. Elevation, 4,218 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1911	----	----	----	----	----	0.40	3.39	2.23	1.67	1.01	0.25	1.56	----
1912	0.00	2.05	0.38	0.20	3.05	1.07	0.78	6.26	3.72	0.37	0.00	0.07	17.95
1913	0.21	0.82	0.04	1.61	0.12	5.39	1.62	1.62	1.69	0.76	0.91	1.16	15.95

Rainfall at Hereford, Deaf Smith County, Texas, in inches. Elevation, 3,750 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1904	----	----	----	----	----	----	----	----	4.58	----	----	----	----
1905	1.00	1.90	2.49	3.70	2.07	2.19	3.57	0.57	2.27	0.30	4.35	0.76	25.17
1906	0.35	0.51	1.30	2.96	1.06	0.49	4.23	3.33	2.88	1.22	2.29	0.14	20.76
1907	1.31	T	0.00	1.30	1.75	0.72	2.97	8.00	0.40	4.35	0.71	0.60	22.11
1908	0.70	1.00	0.00	1.10	4.24	1.98	2.03	4.06	3.13	0.40	0.81	0.00	19.45
1909	T	0.08	1.55	0.10	2.23	2.79	2.69	1.25	1.50	1.40	1.75	0.40	15.74
1910	0.25	T	0.56	1.15	0.95	1.10	3.52	3.86	T	0.20	0.03	0.15	11.77
1911	0.15	2.80	0.40	2.05	1.65	T	4.25	1.80	1.00	2.55	1.00	2.21	19.68
1912	0.15	1.50	1.75	2.05	----	----	----	----	----	----	----	----	----
1913	----	----	----	----	----	----	----	----	----	----	----	----	----
Monthly Average	0.49	0.97	1.01	1.79	1.99	1.32	3.36	3.27	1.97	1.49	1.52	0.61	19.24

Rainfall at Lamesa, Dawson County, Texas, in inches. Elevation, 2,940 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1911	0.66	5.08	0.71	2.80	0.11	0.62	3.24	0.45	2.26	0.43	0.22	2.08	18.61
1912	0.20	0.45	0.97	0.47	0.67	0.70	1 02	2.48	0.61	5.02	0.00	0.71	13.30
1913	0.00	0.15	1.13	1.11	0.30	10.30	1.11	1.24	4.80	6.02	3.04	0.70	29.90
1914	0.25	0 08	0.56	0.87	4.30	1.33	5.32	3.89	0.44	6.84	1.00	2.02	26.90
Monthly Average	0.28	1.41	0.84	1.31	1.34	3.24	2.67	2.02	2.03	4.58	1.06	1.38	21.18

Rainfall at Logan, Quay County, New Mexico, in inches.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1910	0.00	0.18	0.00	0.24	T	0.42	2.68	4.38	0.15	0.24	0.00	0.00	8.29
1911	0.21	1.22	0.07	0.39	4.50	0.47	5.54	3.90	3.91	1.81	0.23	0.67	22.92
1912	0.00	2.20	0.69	0.98	1.59	1.80	3.90	4.21	0.85	0.08	0.00	0.35	16.65
1913	0.15	0.45	0.13	2.09	1.25	3.18	0.10	1.27	1.72	0.33	1.23	1.61	14.41
1914	0.00	T	T	2.11	9.61	2.25	4.71	2.27	0.75	2.85	0.00	0.62	25.17
Monthly Average	0.07	0.81	0.18	1.34	3.30	1.62	3.39	3.21	1.48	1.06	0.29	0.65	17.49

Rainfall at Lubbock, Lubbock County, Texas, in inches. Elevation, 3,155 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1911	----	----	----	2.36	0.72	0.28	6.75	0.21	1.33	1.08	0 23	1.55	----
1912	0.02	1.28	0.61	0.50	1.58	0.96	3.35	2.37	0.73	2.81	0.01	0.38	14.60
1913	0 04	0.20	1.18	1.82	0.24	5.88	0.40	0.32	4.19	1.53	1.54	2.13	19.47
1914	0.15	0.10	0.29	1.47	4.04	3.86	6.17	5.95	0.46	7.12	0.35	1.47	31.44
Monthly Average	0.07	0.53	0.69	1.54	1.64	2.74	4.17	2.21	1.68	3.13	0.53	1.38	21.84

Rainfall at Montoya, Quay County, New Mexico, in inches.

Year	Jan.	Feb.	Mar.	Crop-growing Season Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
1910	T	T	0.02	1.26	0.00	0.15	1.69	9.83	0.25	0.54	T	0.14	13.88
1911	0.01	1.42	0.20	0.89	0.46	0.60	2.62	3.17	1.45	1.50	0.25	0.60	13.17
1912	0.10	1.47	T	0.45	1.51	2.10	0.18	2.50	0.96	T	0.00	0.36	9.63
1913	0.32	0.59	0.33	1.86	0.25	4.15	0.15	1.52	0.79	0.00	0.72	2.51	13.19
1914	0.12	0.30	0.30	0.74	6.05	0.26	4.28	1.25	2.16	2.78	0.00	0.66	18.90
Monthly Average	0.11	0.76	0.17	1.04	1.65	1.45	1.78	3.65	1.12	0.96	0.19	0.85	13.75

Rainfall at Monument, Eddy County, New Mexico, in inches.

Year	Jan.	Feb.	Mar.	Crop-growing Season Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
1906	0.26	0.40	0 00	1.88	0.11	0.00	4.11	1.89	0.08	0.04	2.73	1.10	12 66
1907	0.95	0.00	0.00	0 00	0.90	1.20	4.45	0.90	0.92	8.05	1.50	0.00	17.87
1908	1.00	0.00	0.00	0.50	3.70	1.10	6.85	2.90	0.75	0.00	0.25	0.00	17.05
1909	0.08	T	T	0 00	----	----	----	----	----	----	----	----	----
Monthly Average	0.57	0.10	0.00	0.59	1.37	0.77	5.14	1.90	0.58	2.70	1.39	0.37	16.17

Rainfall at Mount Blanco, Crosby County, Texas, in inches. Elevation, 2,750 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.	Departure from normal
1886	----	----	----	1.87	0.01	1.07	3.06	3.43	5.58	3.44	0.03	----	-----	--------
1887	T	2.07	T	1.9	4.25	0.98	1.89	2.37	1.19	2.10	0.31	0.14	17.23	—3.77
1888	0.44	1.59	0.93	4.45	1.21	1.25	T	4.29	0.27	1.88	4.68	0.86	21.85	+0.85
1889	1.75	0.60	0.00	1.25	0.82	3.47	1.39	0.00	1.50	2.98	1.11	0.00	14.37	—6.63
1890	0.79	0.50	0.40	4.34	2.75	3 84	2.46	1.07	0.34	1.96	1.34	T	19.79	—1.21
1891	1.28	T	0.37	4.58	1.47	3.22	1.45	0.82	3.42	1.01	0.04	2.03	19.69	—1.31
1892	0.60	0.10	1.03	0.00	0.70	2.06	1.43	2.72	1.73	3.63	0.45	0.92	15.37	—5.63
1893	0.76	1.29	0.93	0.03	1.60	1.39	1.01	3.63	3.80	0.05	0.10	1.00	15.59	—5.41
1894	0.05	0.12	T	T	2.90	2.80	2 00	6.10	0.60	2.00	0.00	T	16.57	—4.43
1895	0.50	3.80	T	1.20	3.20	7.20	7.90	2.00	0.00	3.30	1.40	T	30.50	+9.50
1896	1.80	0.60	0.10	2.30	0.40	1.90	5.00	1.10	1.40	6.40	0.80	1.50	23.30	+2.30
1897	1.20	1.00	1.60	0 50	1.60	3.60	3.30	5.10	1.00	1.10	0.40	0.20	20.60	—0.40
1898	0.80	0.60	T	0.90	2.20	2.50	3.30	3.30	0.50	0.30	0.20	2.10	17.20	—3.80
1899	0.30	0.00	0.00	0.40	3.20	9.50	6.20	0.00	2.20	0.90	2.30	1.70	26.70	+5.70
1900	0.50	T	0.90	4.90	3.00	4 00	8.40	2.70	4.90	3.50	1.20	0.00	34.00	+13.00
1901	0.00	1.00	T	2.50	1.80	T	1.50	1.50	4.00	T	2.50	0.60	15.40	—5.60
1902	T	T	0.20	0.30	3.20	0.10	5.60	0.20	1.00	2.70	2.60	0.20	16.10	—4.90
1903	0.60	2.60	T	1.50	0.10	5.30	0.70	4.30	1.20	T	0.00	0.00	16.30	—4.70
1904	0.00	0.20	0.20	0.20	4.60	2.40	0.90	3.80	4.10	1.60	0.60	0.30	18.90	—2.10
1905	1.00	1.60	4.90	5.30	3.90	4.20	6.90	3.00	4.20	2.45	2.30	0.62	40.46	+19.46
1906	0.33	0.90	0.51	3.37	1.29	2.04	2.27	4.21	6.26	0.75	1.94	0.36	24.23	+3.23
1907	1.63	T	0.2[illegible]	0.17	2.18	4.15	5.49	1.37	0.17	5.81	1.10	0.79	23.08	+2.68
1908	0.49	0.24	0.00	2.98	5.32	1.60	2.29	1.98	1.18	0 28	1.25	0.00	17.61	—3.39
1909	0.10	0.00	1.10	0.00	1.23	1.94	1.69	2.25	0.55	2.45	5.89	0.60	17.80	—3.20
1910	0.08	T	0.45	2.85	2.39	2.53	1.93	3.91	0.00	1.13	0.27	0.26	15.80	—5.20
1911	0.16	4.61	0.15	2.10	0.77	1.58	3.52	0.52	1.93	1.72	0.24	1.81	19.11	—1.89
1912	T	1.35	0.60	1.21	2.15	3.58	1.96	4.05	3.27	1.85	0.05	0.15	20.22	—0 78
1913	0.05	0.30	1.75	1.00	5.99	8.79	1.05	0.00	3.66	2.37	4.16	1.35	30.47	+9.47
1914	0.05	T	0.05	1.80	3.95	0.49	4.27	5.88	0.00	2.04	0.00	1.41	19.94	—1.06
Monthly Average	0.54	0.90	0.59	1.86	2.35	3.17	3.81	2.60	2.17	2.55	1.29	0.67	-----	--------

Normal for 28 years.............................21.00 inches
Number of years below normal.............................19
Number of years above normal.............................9

CHAPTER VII

Analyses and Quality of Water

ANALYSES OF HALE COUNTY WELL WATERS, made by J. E. Stullken, Chemist, Bureau of Economic Geology and Technology. (Expressed in parts per million.)

No. of Analysis	1988	1989	1990	1991	1992	1993	1994	2000	2001
Silica (SiO_2)	73.6	70.0	77.6	69.2	76.4	95.2	80.0	61.2	67.2
Aluminum (Al)	1.3	0.2	0.2	0.0	0.0	0.0	0.0	0.0	1.5
Iron (Fe)	1.1	1.2	1.0	1.4	1.2	0.5	0.5	0.4	0.4
Calcium (Ca)	51.4	86.9	65.1	51.4	57.1	62.9	35.4	65.1	80.0
Magnesium (Mg)	39.3	73.8	48.0	27.8	11.2	56.3	47.5	41.4	44.9
Sodium (Na) + Potassium (K)	1.4	34.0	43.7	24.6	80.4	16.2	44.6	11.7	5.0
Carbonate radicle (CO_3)	38.4	0.0	21.6	0.0	0.0	19.2	26.4	0.0	0.0
Bicarbonate radicle (HCO_3)	221.8	307.4	268.4	290.4	331.8	297.7	385.5	290.4	292.3
Sulphate radicle (SO_4)	39.5	151.4	85.6	39.5	38.9	65.8	13.2	50.0	102.1
Nitrate radicle (NO_3)	1.3	8.8	4.4	0.0	2.2	0.9	4.4	1.1	1.8
Chlorine (Cl)	44.0	128.0	80.0	42.0	36.0	56.0	6.0	48.0	40.0
Total dissolved solids	444.0	70.4	598.0	401.0	402.0	472.0	402.0	352.0	556.0
Hardness (parts per million):									
Temporary	231.8	307.4	268.4	290.4	331.8	297.7	385.5	290.4	192.3
Permanent	137.8	244.6	171.3	118.4	96.6	181.8	118.8	160.2	186.8
Total	369.6	552.0	439.7	408.8	428.4	479.4	504.3	450.6	479.1
Mineral content	Moderate	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	High
Suitability for irrigation	Good	Fair	Good	Good	Fair	Good	Fair	Good	Good
Suitability for domestic use	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Scale forming ingredients	Poor-295	Bad-450	Poor-351	Poor-269	Poor-264	Poor-375	Poor-263.7	Poor-322	Poor-381
Alkali coefficient (K)	46.4	15.9	25.5	48.6	12.7	36.4	17.8	42.5	51
Suitability for drinking	Good	Good	Good	Good	Good	Good	Good	Good	Good
Corrosion	-1.68	+1.115	-1.118	-4.56	-5.5	-8.8	-3.08	-1.34	-0.82
Foaming coefficient	Very good 40	Good 92	Good 118	Very good 66.5	Very good 21.7	Very good 43.7	Very good 120	Very good 31.6	Very good 13.5
Suitability for washing	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair

No. of Analysis	2058	2059	2060	2061	2062	2063	2072	2073	2074
Silica (SiO_2)	58.0	62.4	71.6	74.8	70.0	70.0	60.4	79.6	72.4
Aluminum (Al)	2.8	1.8	13.1	6.3	10.6	4.7	0.6	0.7	1.9
Iron (Fe)	0.5	0.8	0.6	1.5	0.6	0.8	2.0	0.5	0.3
Calcium (Ca)	44.3	62.1	65.5	82.7	66.0	60.9	56.4	62.1	56.4
Magnesium (Mg)	46.8	32.7	61.1	50.2	43.3	46.3	41.1	50.7	13.2
Sodium (Na) + Potassium (K)	14.3	21.3	5.2	5.4	0.2	10.8	1.1	3.9	85.7
Carbonate radicle (CO_3)	26.4	12.0	14.4	28.8	28.8	21.6	36.0	36.8	36.8
Bicarbonate radicle (HCO_3)	218.4	246.0	409.9	263.5	200.1	275.7	236.7	266.0	261.1
Sulphate radicle (SO_4)	39.8	44.4	82.3	84.9	15.3	14.4	28.0	45.4	52.7
Nitrate radicle (NO_3)	0.6	0.4	9.0	0.2	0.6	0.4	0.4	0.2	0.4
Chlorine (Cl)	30.0	62.0	62.0	70.0	50.0	44.0	20.0	36.0	36.0
Total dissolved solids	354.0	356.0	524.0	470.0	326.0	400.0	350.0	408.0	400.0
Hardness (parts per million):									
Temporary	268.4	246.0	409.9	263.5	200.0	275.7	236.7	266.0	261.1
Permanent	140.1	141.4	193.5	199.5	164.6	164.5	125.2	173.1	101.1
Total	408.5	387.4	603.4	463.0	364.7	440.2	361.9	439.1	362.2
Mineral content	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Suitability for irrigation	Good	Good	Good	Good	Good	Good	Good	Good	Fair
Suitability for domestic use	Fair	Fair	Unfit	Fair	Fair	Fair	Fair	Fair	Fair
Scale forming ingredients	Poor-271	Poor-304	Poor-391	Poor-414	Poor-357	Poor-335	Poor-298	Poor-348	Poor-264
Alkali coefficient (K)	68	32.9	32.9	29.2	41	46.4	102	56.7	10.31
Suitability for drinking	Good	Good	Good	Good	Good	Good	Good	Good	Good
Corrosion	-1.108	-1.53	-6.8	-6.29	-.83	-.69	-1.72	+.04	-4
Foaming coefficient	Very good 38.6	Very good 57.5	Very good 14	Very good 14.6	Very good .53	Very good 29.4	Very good 29.7	Very good 10.5	Fair 2.32
Suitability for washing	Fair	Fair	Unfit	Fair	Fair	Fair	Fair	Fair	Fair

No. of Analysis	2075	2076	2077	2078	2117	2121	2122	2123	2124	2125	2126
Silica (SiO_2)	49.6	73.6	67.2	60.0	50.0	45.6	58.8	58.4	49.2	42.4	33.2
Aluminum (Al)	1.7	3.7	1.9	7.0	6.3	6.3	0.4	4.2	6.3	3.2	5.9
Iron (Fe)	0.5	0.4	0.4	0.6	0.1	0.0	Tr	Tr	0.0	0.0	0.1
Calcium (Ca)	73.4	62.1	64.3	70.0	85.3	42.9	50.8	57.6	83.5	60.9	39.5
Magnesium (Mg)	69.9	25.3	38.3	16.7	32.6	33.9	24.5	26.2	34.9	28.3	35.5
Sodium (Na) + Potassium (K)	4.7	25.9	27.4	71.9	60.0	84.0	77.4	52.5	17.8	44.9	49.3
Carbonate radicle (CO_3)	19.2	21.6	21.0	66.0	12.0	24.0	21.6	134.4	16.4	45.6	21.6
Bicarbonate radicle (HCO_3)	358.7	231.8	302.6	173.2	305.0	273.3	327.0	85.4	268.4	200.1	289.9
Sulphate radicle (SO_4)	95.5	41.2	30.5	82.3	84.2	61.9	31.9	26.3	65.8	65.8	24.7
Nitrate radicle (NO_3)	0.9	1.3	0.9	0.9	2.8	1.4	1.4	1.4	1.4	1.0	1.4
Chlorine (Cl)	46.0	32.0	30.0	44.0	68.0	70.0	30.0	36.0	52.0	40.0	36.0
Total dissolved solids	470.0	370.0	400.0	480.0	480.0	460.0	380.0	350.0	410.0	430.0	315.0
Hardness (parts per million):											
Temporary	358.7	231.8	320.6	173.2	305.0	273.3	327.0	85.4	268.4	200.1	289.9
Permanent	219.0	129.1	153.8	125.8	171.7	116.9	111.9	124.3	175.1	128.5	110.7
Total	577.9	360.9	456.4	299.0	476.7	390.2	438.9	209.7	443.5	325.9	400.6
Mineral content	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Suitability for irrigation	Good	Good	Good	Good	Good	Good	Fair	Good	Good	Good	Fair
Suitability for domestic use	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Scale forming ingredients	Poor-385	Poor-306	Poor-295	Poor-307	Poor-370	Poor-240	Poor-260	Poor-280	Poor-365	Poor-195	Poor-220
Alkali coefficient (K)	44.3	60.7	62.8	29.5	28	18.9	12.2	21.8	39.2	43.2	17.6
Suitability for drinking	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Corrosion	+.67	-2.91	-.66	-3.6	-3.14	-2.94	-4.048	-3.27	-1.382	-2.124	-1.86
Foaming coefficient	Very good 12.7	Good 70	Good 74	Fair 194	Fair 162	Fair 227	Fair 209	Good 142	Very good 48	Good 121	Good 133
Suitability for washing	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair

Location of wells represented by samples analyzed under numbers given in above table:

1988......Miss Mayhew's well, corner Restriction and Archer Sts., Plainview.
1989......H. L. King well, corner 3rd and Jones Sts., southwest part of Plainview. Water reported extra hard.
1990......Courthouse well, center of town of Plainview.
1991......Bowlin well, corner Sterling and East Sixth Sts., southeast part of Plainview.
1992......Knight well, 3rd and East Sts., northeast part of Plainview.
1993......Town well, Hale Center.
1994......Dr. Sanders' well, 1 mile southwest of Hale Center.
2000......Moore well, near northeast corner of Hale County.
2001...... A. B. Rosser well, Sec. 114, Blk. D2, northeast part of Hale County.
2058......Pearson irrigation well No. 2, near east line of Hale County.
2059......Dan Gray well, about ¼ mile north of S. W. corner Sec. 4, Blk. JK4, on east side of Running Water road near its junction with Olton road.
2060......Tarwater well, at Running Water postoffice.
2061......H. D. Witte well, near northwest corner Sec. 6, Blk. G, 3¾ miles north of Running Water postoffice.
2062......Olsen well, northwest corner of Hale County.
2063......Malone City Waterworks well, Plainview.
2072......Well 2½ miles N. 55° E. of Plainview courthouse.
2073......E. Dowden well, northeast quarter Sec. 54, Blk. JK2.
2074......E. A. Cragin well, 4½ miles due north of center of Hale Center town section.
2075......S. S. Howard well, near southwest corner Sec. 23, Blk. JK3.
2076......Morgan windmill well, 200 yds. north of irrigation well and 10 miles west of Plainview.
2077......Dr. R. R. White windmill well, southeast of his two irrigation wells.
2078......H. H. O'Brien well, 1½ miles north-northwest of Aiken, 200 yds. south of Floydada branch railroad, and 100 yds. northwest of Texas Land and Development Company's irrigation well.
2117......Benson well, 9 miles southwest of Hale Center.
2121......F. H. Hildebrand well near northwest corner Sec. 6, Blk. K, Floyd County, near Hale County line.
2122......Well in southwest corner Sec. 10, Blk. A4.
2123......F. H. Springer well, northeast quarter Sec. 11, Blk. A2. Water encrusts iron pipes.
2124......Peterson well, 10 miles northwest of Hale Center.
2125......J. B. Ross well, northeast corner Sec. 20, Blk. A4.
2126......Town well, Petersburg.

Rainfall at Nazareth, Castro County, Texas, in inches.

Year				Crop-growing Season									
	Jan.	Feb.	Mar.	Apr	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann
1906	0.41	0.28	0.73	2.06	0.95	0.99	4.23	3.33	2.88	1.22	2.29	0.14	20.41
1907	1.31	T	0.10	1.06	2.13	2.30	5.12	7.66	1.25	4.68	0.59	0.70	26.90
1908	0.49	0.26	0.01	1.01	5.54	2.25	3.88	1.59	4.82	0.52	0.60	0.00	20.97
1909	T	0.10	1.38	0.10	1.75	3.57	3.18	0.18	1.16	1.00	3.92	0.56	16.90
1910	0.06	T	----	1.69	1.03	1.72	1 66	2.77	T	0.33	0.44	----	----
1911	----	3.60	0.25	----	----	----	----	----	----	----	----	----	----
Monthly Average	0.36	0.71	0.41	1.34	2.28	2.17	3.61	3.11	2.02	1.55	1.57	0.35	21.29

Rainfall at Plainview, Hale County, Texas, in inches. Elevation, 3,325 feet.

Year				Crop-growing Season										
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.	Departure from normal
1889	----	----	----	----	----	----	----	----	0.45	1.89	1.24	----	----	--------
1890	1.17	0.62	0.00	5.37	0.95	2.37	2.32	2.25	0.34	1.36	2.20	0.00	18.95	—1.98
1891	0.70	0.26	0.58	2.27	3.10	4.31	2.41	----	----	----	----	----	----	--------
1892	----	----	----	----	----	----	----	----	----	----	----	----	----	--------
1893	----	----	----	----	----	----	----	----	----	----	----	----	----	--------
1894	0.05	0.62	0.00	T	2.90	2.50	2 25	4.00	1.75	1.00	0.00	0.50	15.57	—5.36
1895	0.35	0.50	T	0.50	0.75	8.51	7.12	2.34	0.20	3.40	0.80	0.17	24.64	+3.71
1896	0.80	0.28	0.12	1.55	0.80	3.65	6.85	6.50	3.00	5.00	0.45	2.00	25.00	+4.07
1897	1 29	T	0.60	1.65	5.26	1.41	3.72	3.07	1.25	0.80	T	0.08	17.97	—2.96
1898	0.30	0.20	T	0.95	2.54	4.91	2.33	3.07	1.31	0.10	0.75	1.22	17.68	—3.21
1899	0.15	T	0.15	0.25	2.53	6.64	6.13	0.00	1.35	1.41	3.05	1.20	23.16	+2.23
1900	0.10	0.52	0.80	5.01	3.40	3.19	4.71	2.13	9.45	3.21	1.16	0.00	34.72	+13.79
1901	0.20	0.95	T	3.56	0.95	T	3.23	1.75	3.14	0.50	3.25	0.35	17.78	—3.15
1902	0.10	T	0.50	0.30	2.00	T	4.70	T	2.50	1.35	1.25	1.25	13.95	—6.98
1903	0.12	2.30	T	2.35	0 35	3 58	0.84	3.88	0.80	0.05	0.00	0.00	13.97	—6.96
1904	0.00	0.20	0.00	0.14	4.27	4.73	2.75	3.55	5.10	0.40	0.15	0.05	21.34	+0.41
1905	0.27	1.52	3.80	3.40	2.53	3.14	5.77	2.36	4.37	0.00	2.93	0.92	32.01	+11.08
1906	0.18	0.15	0.30	2.50	2.28	1.78	1.63	2.12	4.80	1.13	2.23	0.30	19.50	—1.43
1907	1.47	T	0.16	0.62	2.16	1.38	4.18	4.99	0.15	5.21	0.84	0.74	21.93	+1.00
1908	0.72	0.72	0.16	1.96	4.70	1.70	3.19	1.32	0.70	1.00	1.39	T	20.56	—0.39
1909	T	T	0.97	T	2.18	5.09	3.37	1.15	0.37	0.98	1.52	0.27	18 90	—2.03
1910	0.30	T	0.23	1.00	1.93	0.61	3.16	2.67	1.06	0.71	0.35	0.18	12.05	—8.88
1911	0.38	5.83	0.43	4.80	1.92	0.03	10.06	1.03	2.40	2.47	1.35	1.34	32.04	+11.11
1912	T	1.35	0.63	1.39	1.50	0.75	3.60	2.94	5.75	0.63	0.00	0.40	18.99	—1.94
1913	0.16	0.40	0.32	1.67	0.50	4.30	2.89	2.03	3.33	1.24	----	1.76	----	--------
1914	0.30	T	0.10	1.30	1.98	----	----	----	----	----	0.32	0.57	----	--------
Monthly Average	0.39	0.70	0.48	1.47	2.28	2.97	3.98	2.72	2.44	1.54	0.28	0.60	----	--------

Normal for 21 years..............................20.93 inches
Number of years with rainfall above normal.............. 8
Number of years with rainfall below normal..............13

Rainfall at Portales, Roosevelt County, New Mexico, in inches. Elevation, 4,006 feet.

Year				Crop-growing Season									
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
1911	----	----	----	----	----	----	----	----	----	2 06	0.59	3.77	----
1912	0.00	1.45	0.12	0.69	1.35	1.76	0.92	3.66	3.95	0.31	0.00	0.40	14.61
1913	0.25	0.86	0.15	2.09	0.91	7.55	1.00	1.00	1.75	1.21	2.26	2.20	21.29

Rainfall at Post City, Garza County, Texas, in inches.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1911	0.43	5.68	0.49	2.62	0.04	0.21	3.19	1.56	0.27	0.72	0.12	2.40	18.73
1912	----	----	----	----	----	----	----	----	----	----	----	----	----
1913	0.03	0.59	1.11	1.66	0.18	8.22	1.72	0.54	3.48	1.92	2.59	1.66	23.70
1914	0.22	0.29	0.32	1.22	9.64	3.25	4.54	4.18	0.09	6.54	0.67	2.21	33.17
Monthly Average	0.23	0.52	0.31	1.83	3.29	3.89	3.15	2.09	1.28	3.06	1.13	2.09	25.20

Rainfall at Tahoka, Lynn County, Texas, in inches. Elevation, 3,050 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1914	0.02	0.37	T	2.06	4.79	2.64	4.24	3.11	1.12	7.12	1.38	1.22	28.07

Rainfall at Tucumcari, Quay County, New Mexico, in inches. Elevation, 4,194 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept.				
1905	0.53	1.15	2.96	2.10	2.25	2.50	4.07	1.01	2.50	T	4.00	1.00	24.07
1906	0.70	0.70	0.04	1.79	1.00	0.45	4.21	2.92	0.33	0.62	1.66	1.61	16.05
1907	0.24	0.00	0.00	2.31	2.30	3.36	2.56	3.92	0.08	1.43	0.75	0.80	17.75
1908	0.20	0.90	0.00	1.60	0.21	0.44	3.45	1.78	1.03	0.93	0.98	T	11.55
1909	T	T	1.72	0.48	0.97	2.42	2.03	1.04	0.85	1.90	1.59	0.20	13.20
1910	0.09	0.04	0.09	0.76	0.16	0.26	1.77	5.88	0.49	0.45	0.22	0.15	10.36
1911	0.13	1.70	0.17	0.68	0.92	1.13	2.90	5.01	2.75	1.89	0.40	0.74	18.42
1912	0.00	2.40	0.15	1.01	1.50	1.57	3.11	3.74	1.16	0.10	0.00	0.13	14.87
1913	0.28	0.64	0.16	4.00	1.21	3.05	0.56	1.97	1.58	0.08	2.09	2.62	18.24
1914	0.16	0.32	0.32	2.18	9.36	1.30	4.46	1.02	1.31	3.75	0.00	0.86	25.04
Monthly Average	0.23	0.78	0.56	1.69	1.90	1.65	2.91	2.83	1.21	1.11	1.17	0.80	-----

Normal for 10 years---------------------------------16.95 inches

SANTA FE RAILROAD ANALYSES. (Expressed as parts per million.)

Number of Analysis	1	2	3	4	5	6	7	8	9	10	11	12
Calcium Sulphate (Ca SO_4)	Tr	123.4	0.0	208.0	31.0	14.0	267.0	12.0	38.0			
Magnesium Sulphate (Mg SO_4)	0.0	696.0	0.0	302.0			1010.0		34.3	Tr	7.0	5.3
Magnesium Chloride (Mg Cl_2)	84.0											
Magnesium and Calcium Carbonate (Mg CO_3+$CaCo_3$)	213.0	283.0	77.2	77.2	122.0	140.0	55.0	134.0	302.0	219.0	267.0	263.0
Sodium Chloride (Na Cl)	51.4	604.0	85.7	984.0	115.0	35.0	3960.0	26.0	201.0	164.0	180.0	180.0
Sodium (Na)	20.4	371.0	171.6	523.0	98.4	46.9	1725.8	45.3	155.2	235.0	192.9	192.3
Chlorine (Cl)	31.0	364.0	51.7	594.0	69.5	21.1	2392.0	15.7	121.0	99.0	108.7	108.5
Sulphate radicle (SO_4)		911.0	88.8	658.4	79.5	80.8	1263.5	101.6	212.1	189.5	177.0	176.0
Sodium Sulphate (Na_2 SO_4)		407.0	135.0	414.0	80.8	103.0	502.0	108.0	223.0	280.0	254.0	254.0
Sodium Carbonate (Na_2 CO_3)		216.0			65.4					183.0	89.2	89.2
Alkali coefficient	25.2	5.0	5.7	3.2	15.7	11.1	0.1	76.9	14.1	26.4	9.0	8.2
Mineral contents	Moderate	Very high	High						High	High	High	High
Suitability for drinking	Good	Fair	Good	Fair	Good	Good	Unfit	Good	Good	Good	Good	Good
	Good	Very bad	Very bad	Very bad	Bad	Good	Very bad	Good	Very bad	Very bad	Very bad	Very bad
Foaming coefficient	56.2	1000.0	463.5	1410.0	266.0	126.7	4660.0	122.0	420.0	635.0	521.0	520.0
Suitability for irrigation	Good	* Poor	Poor	Poor	Fair	Fair	Bad	Good	Fair	Good	Fair	Fair
Inconstants	295.0	1102.0	77.2						374.0	219.0	268.0	267.0
Solids	346.0	2117.0	515.0						797.0	847.0	790.0	790.0
Alkalinity	206.0	283.0	294.0	56.5	187.0	202.0	57.2	204.0	309.0	403.0	352.0	352.0

Number of Analysis	13	14	15	16	17	18	19	20	21	22	23	24
Calcium Sulphate (Ca SO_4)	24.0	10.3	Tr	5.0				288.0	34.0	73.8		8.6
Magnesium Sulphate (Mg SO_4)	19.0	8.7	12.0	10.4	12.0					310.0		25.7
Magnesium Chloride (Mg Cl_2)												
Magnesium and Calcium Carbonate (Mg CO_3+$CaCo_3$)	261.0	268.0	218.0	242.0	283.0			261.0	26[illegible].0	253.0	262.0	281.0
Sodium Chloride (Na Cl)	55.0	43.0	50.0	48.0	35.0		1920.0	245.0	201.0	232.0	89.0	76.3
Sodium (Na)	36.4	38.0	47.4	36.3	27.8			164.0	182.2	115.0	89.8	58.5
Chlorine (Cl)	33.1	25.9	30.2	28.9	21.1			142.0	121.0	140.0	51.0	27.7
Sulphate radicle (SO_4)	63.5	562.4	23.8	47.9	38.7				238.0	181.0	49.6	59.3
Sodium Sulphate (Na_2 SO_4)	45.0	65.2	21.0	53.3	43.0			219.0	317.0	161.0	75.5	49.7
Sodium Carbonate (Na_2 CO_3)			48.0									68.7
Alkali coefficient	54.0	62.8	24.2	59.4	80.2				13.3	16.2	13.0	27.4
Mineral contents	Moderate	Moderate	Moderate	Moderate	Moderate		High	High	High	High	Moderate	Moderate
Suitability for drinking	Good	Fair	Good	Good	Good		Bad	Good	Good	Good	Good	Good
	Good	Good	Good	Good	Good			Very bad	Very bad	Bad	Fair	Fair
Foaming coefficient	98.2	102.5	128.0	98.0	75.0			443.0	492.0	392.0	234.0	178.0
Suitability for irrigation	Good	Good	Good	Good	Good		Bad	Bad	Fair	Fair	Fair	Good
Inconstants	304.0	288.0	230.0	257.0	235.0	446.0		549.0	405.0	657.0	262.0	315.0
Solids	395.0	394.0	348.0	359.0	272.0	871.0		1000.0	922.0	1063.0	195.0	435.0
Alkalinity	257.0	264.0	266.0	246.0	283.0		329.0	261.0	252.0	254.0	331.0	283.0

Number of Analysis	25	26	27	28	29	30	31	32	33	34	35	36	37
Calcium Sulphate (Ca SO_4)	91.4	92.7	44.8	38.0	65.2	18.0	14.0	8.8	10.3	125.0		199.0	206.0
Magnesium Sulphate (Mg SO_4)	365.0	98.0	79.0	96.0	54.0	19.0	108.0	116.6	58.3	81.0		316.0	317.0
Magnesium Chloride (Mg Cl_2)													
Magnesium and Calcium Carbonate (Mg CO_3+$CaCo_3$)	292.0	251.0	273.0	269.0	282.0	300.0	283.0	290.0	288.3	247.0		220.0	221.0
Sodium Chloride (Na Cl)	529.0	151.0	142.5	145.0	110.0	123.0	201.0	128.7	130.0	146.0	197.0	421.0	415.0
Sodium (Na)	234.0	81.7	94.9	94.8	90.2	110.7	116.3	78.8	108.3	69.5		169.8	165.1
Chlorine (Cl)	198.0	93.0	86.0	87.5	66.4	74.1	126.5	77.5	78.4	88.1		254.0	250.0
Sulphate radicle (SO_4)	1175.0	186.9	174.5	201.7	186.4	156.9	172.8	73.5	172.5	177.7		399.4	401.0
Sodium Sulphate (Na_2 SO_4)	321.0	63.5	118.5	115.0	141.0	191.0	113.0	86.0	175.0	36.0		8.7	3.5
Sodium Carbonate (Na_2 CO_3)													
Alkali coefficient	7.8	19.1	20.7	20.6	25.2	21.8	14.9	23.6	21.2	22.2		8.0	8.6
Mineral contents	High	High	High	High	High	High	High	High	High	High		High	High
Suitability for drinking	Fair	Good	Good	Good	Good	Good	Good	Good	Good	Good		Fair	Fair
	Very bad	Fair	Bad	Bad	Fair	Bad	Bad	Fair	Bad	Fair		Very bad	Very bad
Foaming coefficient	632.0	221.0	256.0	256.0	243.0	299.0	314.0	213.0	392.0	187.5		458.0	446.0
Suitability for irrigation	Fair	Good	Good	Good	Good	Good	Fair	Good	Good	Good		Fair	Fair
Inconstants	752.0	415.0	396.0	403.0	400.0	336.0	405.0	415.0	355.0	453.0		722.0	744.0
Solids	1400.0	662.0	656.0	664.0	654.0	670.0	720.0	629.0	660.0	635.0	331.0	1162.0	1164.0
Alkalinity	254.0	240.0	266.0	264.0	276.0	293.0	293.0	290.0	288.0	249.0		220.0	219.0

Location of wells represented by above numbers:

1------Bailey County. Well near Janes, at mile post 628.
2------Bailey County. East well at Muleshoe.
3------Bailey County. West well at Muleshoe, water at 190 ft.
4------Curry County, N. M. Clovis well No. 3, water at 476 ft.
5------Curry County, N. M. Clovis well No. 3, water at 523 ft.
6------Curry County, N. M. Clovis well No. 3, water at 360 ft.
7------Curry County, N. M. Clovis well No. 3, water at 586 ft.
8------Curry County, N. M. Clovis well No. 3, water at 353 ft.
9------Dawson County. Lamesa well No. 1, first water at 104 ft.
10------Dawson County. Lamesa well No. 1, second water at 182 ft.
11------Dawson County. Lamesa well No. 1, mixture of above waters.
12------Dawson County. Lamesa well No. 2.
13------Floyd County. Floydada well No. 1.
14------Floyd County. Lockney well No. 2.
15------Hale County. Abernathy well No. 1.
16------Hale County. Abernathy well No. 1.
17------Hale County. Hale Center well No. 1.
18------Hockley County. Roundup well opposite station 1280, water at 75 ft.
19------Same, water at 175 ft.
20------Hockley County. Roundup sectionhouse well.
21------Hockley County. Roundup yard well opposite station 1272.
22------Hockley County, well opposite station 1576, west well.
23------Lamb County, well at north edge of lagoon at Littlefield.
24------Lamb County, well at south end of Wye at Littlefield.
25------Lubbock County, well opposite station 120.
26------Lubbock County. Lubbock well No. 1.
27------Same
28------Lubbock County. Lubbock well No. 2.
29------Lubbock County. Posey well No. 1.
30------Lubbock County. Slaton well No. 1.
31------Lubbock County. Slaton well No. 2.
32------Lubbock County. Slaton well No. 3.
33------Lubbock County. Slaton well No. 4.
34------Lubbock County. Slaton well No. 5.
35------Lynn County. Tahoka well No. 1.
36------Lynn County. Tahoka well No. 2.
37------Lynn County. Tahoka well No. 3.

Rainfall at Tulia, Swisher County, Texas, in inches. Elevation, 3,501 feet.

Year	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.
				Apr.	May	June	July	Aug.	Sept				
1894	----	----	----	----	----	1.40	3.23	3.63	2.26	1.33	T	0.20	-----
1895	0.51	1.90	0.20	0.24	1.27	3.88	4.94	5.03	0.60	3.85	0.77	0.25	23.44
1896	1.35	0.15	0.15	2.46	0.95	0.90	4.36	0.75	2.24	4.01	0.55	1.93	19.81
1897	1.76	T	0.75	1.08	2.78	----	----	----	----	----	0.00	----	-----
1898	0.50	0.18	T	0.95	3.36	5.55	4.67	3.07	1.31	0.10	0.75	1.70	22.14
1899	0.55	0.10	0.30	0.25	5.17	4.44	10.84	0.00	2.90	0.65	2.40	----	-----
1900	0.10	0.52	0.80	6.60	3.77	3.25	4.40	2.30	6.83	7.80	2.25	T	38.62
1901	0.10	----	----	----	----	----	----	0.70	2.50	1.05	2.80	0.20	-----
1902	0.20	T	0.65	1.35	7.47	0.87	2.20	0.00	2.05	1.35	1.85	0.70	18.69
1903	0.40	1.60	T	2.35	0.35	3.58	0.81	3.88	4.25	1.92	0.00	0.00	19.17
1904	0.00	0.00	0.00	0.95	2.86	3.42	3.78	3.07	3.35	1.18	0.15	0.55	19.31
1905	0.68	1.95	1.65	7.60	2.48	0.11	----	----	----	----	----	----	-----
1907	1.98	T	0.05	0.93	2.34	2.15	4.30	3.85	1.25	5.25	1.00	1.25	29.35
1908	0.95	1.20	0.32	0.85	4.08	1.80	4.09	6.67	1.85	1.85	1.70	T	25.16
1909	0.10	0.07	1.83	T	1.55	8.02	3.17	0.64	0.60	1.65	4.39	0.58	22.60
1910	0.33	T	1.06	1.91	2.65	1.25	2.55	3.75	T	0.70	0.51	0.36	15.07
1911	0.32	5.43	0.77	3.81	1.75	T	6.60	1.32	3.05	3.24	1.36	2.12	29.77
1912	T	3.19	1.15	1.06	1.95	1.03	1.58	3.97	4.10	0.65	T	1.07	19.75
1913	0.40	0.91	0.64	2.82	0.84	4.18	3.85	1.95	6.53	1.16	2.15	4.12	29.55
1914	0.35	0.00	0.37	2.06	6.30	0.62	6.06	4.50	0.74	5.25	0.15	2.00	28.90
Monthly Average	0.56	0.96	0.59	2.07	2.80	2.58	1.18	3.00	2.58	2.39	1.19	1.00	-----

Normal for 15 years ---------- 24.09 inches
Number of years below normal ---------- 9
Number of years above normal ---------- 6

Mean relative humidity (percentage) at Amarillo for 18 years.

Time	Jan.	Feb.	Mar.	Crop-growing Season						Oct.	Nov.	Dec.	Ann.	Avg.
				Apr.	May	June	July	Aug.	Sept.					
8 A. M.	.74	.78	.68	.70	.73	.78	.79	.80	.80	.77	.74	.74	.76	
8 P. M.	.53	.54	.38	.37	.42	.44	.45	.47	.46	.51	.51	.57	.47	.615

Average evaporation for the six months of the growing season at Amarillo.

Year	April	May	June	July	August	Sept.	Average	Rainfall
1907	-------	-------	-------	-------	-------	-------	51.98	19.99
1908	-------	-------	-------	-------	-------	-------	50.38	16.56
1909	-------	-------	-------	-------	-------	-------	56.55	12.78
1910	-------	-------	-------	-------	-------	-------	58.61	9.74
1911	-------	-------	-------	-------	-------	-------	52.59	20.75
1912	-------	-------	-------	-------	-------	-------	52.87	11.04
1913	7.75	9.81	7.07	12.74	10.45	6.00	53.79	13.16
1914	6.69	6.74	10.12	8.75	8.93	8.04	49.27	11.27
Average	7.39	8.98	9.99	10.09	9.26	7.49	53.25	14.41

Relative humidity, Lubbock, Texas, October, 1913–June, 1914.

October	November	December	January	February	March	April	May	June
52.2	68.0	74.0	45.4	45.6	32.2	41.9	69.0	53.5

CHAPTER IV

Underground Waters

Introduction

All underground water may be included under two heads: surface or non-artesian water, and artesian water, or water under hydrostatic pressure. Artesian wells that flow at the surface are known as flowing wells and artesian wells that do not flow are known as non-flowing wells. The essential difference between artesian and other wells is that the water in the artesian well will rise to a higher level when the bed rock containing it is penetrated by the drill. Originally the terms artesian wells and flowing wells were synonymous, and any notably deep well is often called artesian: but in this report the term "artesian" will be restricted to water under hydrostatic pressure which will rise in a well when first encountered by the drill. Often the deeper waters are more thoroughly filtered and more highly mineralized than the shallower waters. All underground water has its source in rainfall. That portion of the rainfall which sinks into the ground and is neither taken up by plants nor combined with rocks and minerals, constitutes the supply of underground water. The underground water of a given locality may either be derived from the rain falling on the land surface in the vicinity, or may be partly or wholly derived from a considerable distance away. More water seeps into the ground during a slow rain than during a violent one: on a flat area than on one of greater relief, where the drainage is greater and more rapid; in a forested country than in one not forested; and in a porous soil, such as sand and gravel, than in a more impervious soil, such as clay.

The downward limit of the penetration of ground water is that place in the body of the earth, generally considered to be not more than five or six miles beneath the earth's surface, below which the pressure of the overlying mass of rocks becomes so great that pores, crevices, and caverns in the rocks can no longer exist. Notable caverns are found only in porous rock, such as limestone. Crevices are formed, more notably in hard rocks, by forces which break and shatter the rocks, and generally take the form of joints or faults. But most of the underground water is to be found in the pore spaces of such rocks as sand, sandstone, conglomerate, and some limestones. Most clays and shales have very little pore space or larger openings, except in the case of joints and faults in the more compact and harder shales, and consequently are relatively impervious to the passage of water in any direction. Consequently it sometimes happens that the presence of a bed of clay or shale underneath the more porous beds lying at or near the surface in certain regions effectively prevents the downward passage of surface water or the upward passage of artesian waters present in more porous beds underneath the clay or shale. Such we shall find to be the case in the northern Llano Estacado.

Water which has sunk into the ground lies in a saturated zone in the rocks, the upper surface or limit of which is known as the groundwater table or ground water level. This surface is constantly fluctuating, rising during the rainy season and sinking during times of drought. In hilly countries the ground water table or level is deeper beneath the hills, but higher in absolute altitude than it is underneath the valleys. An exception to this rule occurs in the case of a stream flowing through a porous bed in an arid country and contributing to the underground supply by seepage, for then the ground water level is both closer to the surface and higher in absolute elevation underneath the stream valley than underneath the neighboring highlands.

Underground water is only stagnant or at an absolute standstill when it is confined in a porous bed, cavity, or crevice in the midst of impervious rocks (and in this case the opening or porous rock which originally admitted the water, being already full or saturated with water, is impervious to its further passage) or when it strongly adheres to the surfaces of the rock or of the particules which compose the rock. Ordinarily, underground water has a slow, but definite and continuous movement through the rock and is always progressing or in a state of potential progression from a higher level to a lower. So, in a region of heavy rainfall, the underground water is moving from a region of higher elevation underneath the hills to a lower elevation in the valleys and is always seeking, just like the water of streams, lower and lower levels, until it reaches its final resting place, the ocean.

Artesian Waters

For artesian waters it is necessary to have (1) a continuous porous bed of rock which has a higher elevation in the region of its outcrop or catchment area than in the region where it is tapped by a well or spring, and (2) an impervious bed overlying the porous, saturated, water-bearing bed so as to prevent the upward escape of the water. If the elevation of the outcrop or catchment area be sufficiently above the elevation of the surface at the site of a well which penetrates the water-bearing bed the water will rise in the well and flow out at the surface. The water in the well will never rise as high in elevation as the upper surface of the saturated zone at the catchment area because adhesion of the water to the particles of the rock and the friction of flow through the rock decrease the hydrostatic head, generally at the rate of about one foot for every mile of distance between the catchment area and the site of the well. The more porous the rock the less is the reduction of the head by friction. Five different structural conditions in the rocks favorable for artesian wells are shown in Figure 1.

Artesian Waters of the Northern Llano Estacado

1. The Permian Artesian Basin

Of the various deposits of the northern Llano Estacado, only the lower portion of the oldest, the Permian Redbeds, has any continuous connection with strata of the New Mexico mountains. It is true that the Triassic on the northwest side of the Llano has a partial connection with beds outcropping on the southeastern flanks of the Rocky Mountains in the vicinity of Las Vegas, New Mexico, but this connection is more or less broken and it is extremely probable that there is absolutely no artesian flow of any value entering the Triassic beds of the Plains from this direction.

The structure of the Permian rocks underneath the Llano is that of a broad and gentle downfold or syncline. Strata hundreds or thousands of feet beneath the Llano's surface outcrop east of the Llano on the lower eroded plains of north-central Texas, or west of the Llano on the lower eroded plains between the western escarpment of the Llano and the Pecos River or still farther west and at an higher elevation between the Pecos River and the summits of the New Mexico mountains. Water derived from rainfall which percolates into porous strata of the Permian, which outcrop in the region between the Pecos River and the eastern New Mexico mountains, is under head sufficient to rise and flow out to the surface when the containing strata are penetrated by a deep drilling on the Llano Estacado. In Fig. 1, a, is a sketch showing the general conditions giving artesian waters in the Permian rocks underneath the Llano Estacado. The lower bed of water-bearing sand is represented as being continuous from its outcrop in the New Mexican foothills underneath the Llano Estacado to its outcrop on the east in the lower eroded plains. Other beds are represented which are not continuous. Fig. 1, b and c, show two conditions of non-continuous porous beds containing artesian water. In the first case the porous sand gradually passes into an impervious clay, in which case the horizon on passing into the clay is no longer water-bearing. In the second case the continuity of the water bearing horizon is broken by a displacement in the rocks, or a fault. In such a case the plane of the fault may be effectually sealed up and the fault then constitutes a dam preventing the further movement of water, which thereupon becomes stagnant, though under hydrostatic pressure with considerable potential head, which will cause the water to rise when an opening is made; or the water may be able to leak out along the fault plane, thus producing artesian springs where the fault appears at the surface.

Water percolating into porous strata which outcrop on the lower eroded plains of north-central Texas will be under hydrostatic head underneath the Llano Estacado, but such water will not rise to the surface because the altitude of the area of intake or catchment area is lower than the surface altitude of the Llano.

But artesian waters which will rise to the surface of the Llano and produce flowing wells are confined in strata so deep beneath the surface of the Llano that the cost of sinking wells

Fig. 1

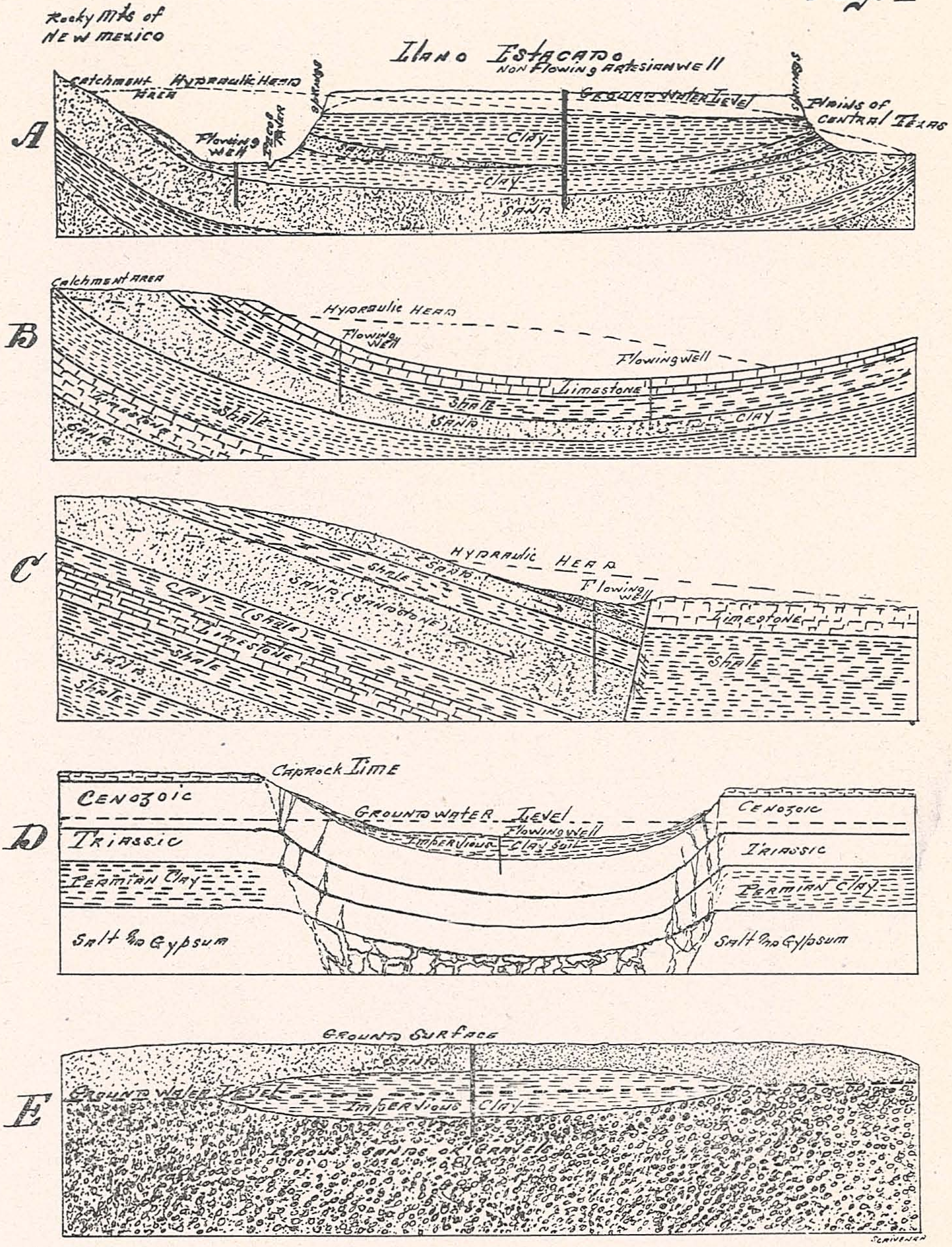

Fig. 1, Different Types of Artesian Conditions.

would be prohibitive. And even if these artesian waters could be reached and the cost of reaching them were not prohibitive, they would in any case be of absolutely no value, because in their passage through the Permian strata they would encounter and dissolve so much salt, gypsum, and alkali that they would be totally unfit for use. A number of deep borings on the Llano Estacado have already demonstrated that these waters are too highly mineralized to be usable. In the third place, most of the artesian supply from the New Mexico mountains is already almost entirely used in the Pecos Valley of New Mexico where it is less highly mineralized than it becomes during its longer journey eastwards to a site underneath the Llano Estacado. There is consequently no hope of obtaining a usable supply of artesian water from the Permian artesian basin underneath the Llano.

2. Artesian Supply in "Alkali Lake" Areas of Ground Settlement

In certain of the "alkali lake" depressions comprising the lower-lying areas about "Great" Salt Lake (Laguna Salada) in the Portales Valley of eastern Roosevelt County, New Mexico, near the Texas line; about White Lake in Bailey County, Texas; and in Yellowhouse Canyon in northwestern Hockley County, Texas, south of Yellow and Illusion lakes, shallow wells yield a feeble flow of brackish water. These depressions are caused by the removal by solution of underlying beds of salt and gypsum and the caving-in of underlying rocks, as has already been considered in the chapter on Physiography. When the bottom of the caved-in depression is lower than the ground water level under the surrounding highlands, one of two things will occur. If the movement of the ground water is not greatly inhibited or checked by impervious clays, the water will fill the bottom with a perpetual lake, the top surface of which will be at the level of the ground water table. But if it should so chance that impervious clays form the top strata of the portion which settles, or if deposition of clay takes place on the bottoms of these depressions subsequent to their formation by stream wash from the surrounding highlands, the water cannot rise through the impervious material to its normal level of hydrostatic equilibrium. In such a case the water immediately beneath the area, the surface of which is depressed below the normal ground water level, is under sufficient artesian pressure to cause it to flow out at the surface when the impervious cover is pierced in a well. Springs in the bottoms of some of these depressions represent sites of the escape of the waters to the surface. Fig. 1, d, shows the conditions under which a flowing well is obtained in the three "alkali lakes" noted above. The flow from wells in all three of these depressions is feeble, the water is too brackish to be of any use in irrigation and is also of poor quality for stock-watering purposes, while the surrounding lower surfaces of the depressions have a soil too alkaline to be of agricultural value.

The Surface or Non-Artesian Waters of the Northern Llano Estacado

The surface or non-artesian waters of the Llano Estacado constitute the only usable supply. The Cenozoic and Triassic strata, in which is found the water now used on the Llano Estacado, are cut off by the Pecos and Canadian rivers from the mountains and can get no water from places other than the Llano itself. The deeper artesian waters do not rise through breaks or openings in the strata and add to the supply of surface waters. The upper Permian, underlying the whole of the Plains, is composed of a great thickness of clay which is impervious to the passage of water in any direction. If these lower, highly mineralized waters did so rise, their high mineral content would ruin for purposes of irrigation the comparatively pure surface water; hence it is a fortunate circumstance that they do not rise. The ground water of the Llano Estacado is underlain by the generally impervious red clay of the upper Permian, a fact generally recognized by well drillers, who cease drilling when they reach the bed of red clay. This impervious red clay serves to hold up the accumulated ground water which has no escape to lower levels downward and is consequently forced to flow outward in a nearly horizontal direction.

The available underground water is therefore confined to the Triassic and Cenozoic formations which nowhere have a thickness probably greater than 700 feet, and most generally less than that amount. Since the Triassic and Cenozoic water-bearing formations of the Llano Estacado are, with the sole unimportant exception already noted, entirely confined to the region, it is evident that the water they contain must have come exclusively from the region of the Llano itself. The source of the water is of course the rainfall on the Plains, and only that portion of the rainfall which is absorbed by the Llano's soils and strata can contribute to the underground supply. This can be for the Plains as a whole only a small percentage of the actual rainfall since the lion's share of the moisture absorbed by the surface soil is again brought to the surface by capillary action and evaporated. Probably not more than three or four inches of the yearly rainfall adds to the supply of ground water, the remainder of the rainfall being lost by surface run-off and evaporation.

For the Llano Estacado as a whole the water table or the surface of the upper limit of ground water slopes gently in a direction south of east in the same direction as and more or less parallel to the surface of the ground. From Olton, Lamb County, to Lockney, Floyd County, the east-southeast gradient of the water table is about 9 feet per mile. Between Melrose, Roosevelt County, New Mexico, and Southland, Garza County, Texas, the rather uniform gradient in a south 52° east direction is 8.5 feet per mile. As the water level approaches the "breaks of the plains" at the borders of the Llano in any direction, its gradient increases and the water-level becomes lower; near the west escarpment of the Llano the ground water table dips westward, near the north escarpment its dip is northward, and near the east escarpment, eastward. This is because the ground water escapes to the surface at the edge of the plateau in the form of springs and seepages which feed the various streams flowing from the escarpments. Springs and seepages are naturally more abundant along the eastern escarpment because the movement of the ground water from nearly the entire Llano is in an eastward direction. The movement of ground water is very slow, because the resistance to its passage through the beds is quite great. In general, the higher the gradient of the water table, the higher the rate of flow of the ground water. In fine sand, with the water table sloping ten feet to the mile, the velocity of the ground water has been reckoned at 52 feet in a year; in coarse sand, at 845 feet per year; and in fine gravel, at rather more than a mile per year. The underground flow below the Arkansas River, with a gradient of 7 feet per mile, was estimated to be from about 1/5 to about ¾ mile per year. It is probable that the velocity of flow of the underground water in the great interior body of the Llano Estacado would average only a fraction of a mile yer pear. Near the borders of the escarpment where the gradient is greater, the rate of flow is greater.

Now, the fact that the water level under the Llano Estacado fluctuates but very little from year to year, remaining practically stationary, means that the annual rate of supply is very nearly equal to the annual rate of wastage. This state of equilibrium between supply and wastage has doubtless existed for a long time. In years of greater rainfall over the Llano as a whole the water level probably rises a small amount temporarily and lowers a small amount during years of lesser rainfall. It may rise locally underneath a region experiencing heavy rainfall, or, conversely, it may fall locally under a region experiencing very light rainfall. But in the aggregate such fluctuation really amounts to very little and does not in itself permanently increase or diminish the supply of underground water, which supply remains fairly constant. There is just so much water stored up and the annual addition to that supply is counterbalanced by the annual wastage. This is a conclusion of the first importance in the matter of water supply.

The places of intake of the ground water are: (1) the stream valleys of the plains, including the old abandoned stream course known as the Portales Valley; (2) the areas of sand hills and of sandy loam soils; (3) the larger and deeper deposits known as the "alkali lakes" and the smaller and shallower depressions known as the "dry lakes"; and (4) the broad, flattish top surfaces of the remainder of the plains area—in short, almost the entire surface area contributes more or less. The silty clay loam soil of the northeastern portion of the Llano Estacado is relatively impervious to the downward percolation of water, as is shown by observations at the Amarillo Agricultural Experiment Station where practically none of the rainfall percolated more than three feet beneath the surface. It may be objected that the sandhills are only a thin veneer covering a relatively impervious soil, and this is in some places true, but is not usually the case. The sandhill areas are the best collecting areas for underground water which the region affords. In many places the sand hills cover surfaces of the very porous "cap rock" lime through which water passes readily. And when the sand hills do cover a relatively impervious soil the water is only inhibited in its downward passage, the sand of the sand hills area preventing to a large extent its evaporation, which, in regions of impervious soil not covered by sand hills, is rapid and great. The sand hills area is one of the important places of supply of the underground water. In places where the "cap rock" lime is exposed on the surface or is only a foot or two below the surface soil, much water is absorbed by the porous limestone. The "cap rock" lime is at or close to the surface over an extensive area southwest of the sand hills region. A large amount of water is absorbed by the stream valleys of the plains, as shown by the fact that generally during and after a hard rain these streams flow only a few miles and disappear, largely because of absorption of the water by their beds.

The water in the underlying Triassic beds is more highly mineralized than that from the Cenozoic. This can be readily seen at places in the "breaks of the plains", where springs issue from the Triassic strata, the sites of their emergence being incrusted with white salts and the waters having a distinct taste given them by their contained mineral matter. Such springs. with their incrustations and tastes of mineral matter, are very common in Tule and Palo Duro canyons, particularly at or near the Triassic-Permian contact. The flowing wells of brackish water in the "alkali lakes" apparently derive their supply from the Triassic. In southwestern Lamb County, Texas. the water obtained under the Comanchean clays comes from the Triassic beds and is rather highly mineralized. Salty water was found in Triassic strata in the Santa Fe flowing well at Roundup, in northeastern Hockley County, and also in the deepest railroad well at Slaton, Lubbock County. Highly mineralized water was obtained from Triassic strata under the Portales Valley in Roosevelt County, New Mexico.

Water from the Triassic strata is, therefore. apparently not usable for irrigation purposes. It can be used in many cases for stock-watering, where water of better quality is not available. The driller of irrigation wells should have thoroughly in mind the characteristics of the Triassic strata given in the chapter on geologic history and should cease drilling when the undoubted Triassic is reached.

We are therefore justified in making a further restriction as to where water for irrigation purposes should be sought. Water for irrigation is apparently in general limited to the Cenozoic or uppermost strata of the Llano. These Cenozoic beds do not average over 300 feet in thickness; seldom, if ever, do they reach a thickness of more than 350 feet, and in many places they are less than 300 feet thick. Under present development the thickness of the Cenezoic beds is greater than the profitable height for the lifting of irrigation water, and this will probably be the case for a long time to come. Therefore, the only possible object in penetrating the Triassic beds in irrigation wells would be to secure a larger area from which to draw water. If a sufficient drawing area is not afforded in the Cenozoic water-bearing beds, it will be of no avail, and in fact a positive detriment, to drill deeper. In order to get a sufficient supply of usable water from the Cenozoic in such a case, either a battery of wells should be provided, or horizontal tunnels should be run out from the main well in water-bearing strata below the water level, or wells of large diameter should be constructed.

During the wet year of 1914, the ground-water level rose 3 to 4 feet in the Portales Valley of New Mexico and 3 feet in the Muleshoe district of Bailey County, Texas. In the autumn of 1914 the ground-water table at Muleshoe had returned to the normal. Both these districts are contiguous to the sand hill areas, which are probably the catchment areas *par excellence* of the ground waters of the plains. P. E. Fuller, irrigation engineer of the U. S. Department of Agriculture, estimates that there are 200,000 acres of sandhills in the region north and south of the Portales Valley. The reason that the ground-water level rose here so quickly after the rainy season began, is because the catchment area of the water is so close at hand.

Why should the ground-water table be closer to the surface in some localities than in others? (1) Near the regions where the greater part of the water is collected from the rainfall, the supply is of course greater and a greater thickness of porous beds will be saturated. Hence, in the midst of, and in the area contiguous to, the large sandhill areas, the water-table will be near the surface. (2) The upper surface of the plains does not have an absolutely uniform slope but is gently undulating in the inter-stream areas and is also broken by shallow "draws" and "dry" and "alkali lake" depressions. It is apparent that in the lower places the water will be nearer the ground surface than in the higher places. For this reason, the water-table is so near the surface in the valleys of some of the "draws", as for instance, in the Blanco near Running Water postoffice, Hale County, and along the Double Mountain Fork in southwestern Hale County, that the valley is sub-irrigated for alfalfa. Similarly, the valley of the "draws" may locally be cut below the general ground-water level and give rise to springs, such as are found in both of the stream valleys in the places just mentioned. (3) A predominant thickness of impervious strata may take the place of water-bearing strata and locally force the ground-water level higher, either by displacing water-bearing strata underneath or by forming a partial dam in the path of the flow of the ground-water. In such cases the flow of ground-water is inhibited and the water accumulates behind or on top of the barrier until a plane of equilibrium is reached at which the outflow again equals the inflow. At Clegg's Ranch, Sec. 16, Twp. 5N., R. 29 E, Quay County, New Mexico, the water-level in the Allimaso Draw is but 16.5 feet beneath the surface. Below a depth of 29.5 feet in this well the strata are impervious Triassic, which here serve to hold up the water-level. A clay dam on the southeast side of the Portales Valley in the region of Laguna Salada (near the Texas line) aids in holding up the water-level in the Portales Valley. A similar clay dam to the southeast of Hereford is apparently responsible for the shallow water in that district. In the Plainview district there is an impervious clay dam of a similar nature a short distance east of Lockney, Floyd County, and apparently near this dam and to the west of it, the porous strata thin to such an extent that the head of ground-water is unable to get through the region at what would be the normal water-level and hence is forced to rise over the barrier. Probably a similar state of affairs is responsible for the shallow water north of the line of the Santa

Fe Railroad between Littlefield and Yellowhouse, in Lamb County.

In the Hurley-Muleshoe district the surface level is lower than in contiguous areas and the sandhills catchment area is close at hand. The Portales Valley possesses the combination of lower surface level than the surrounding regions, very close proximity to the source of the water, and a clay dam.

Very often water-bearing formations are separated by impervious beds, generally composed of clays. On this account the different water-bearing strata are sometimes thought to have a body of water separate from that of a stratum above or below. In reality, the water in all these porous beds is more or less closely connected and belongs to the same body of ground water.

Occasionally the ground water will rise a few feet when the bed containing it is entered by the drill. In Fig. 1, *e* is given an explanation of this. It so happens that an impervious bed may occupy the position of the ground-water table and thus locally prevent the water from rising to its normal level. When the porous bed underneath is reached by the drill the water will rise in the drill hole to its normal level.

As should be expected to be the case in such markedly lenticular and locally distributed beds as those making up the body of the Plains Cenozoic, there are places where nearly or all the entire thickness of the Cenozoic is occupied by clays impervious to the passage of water. In some such spots not even a supply of water adequate for stock-watering purposes can be obtained. In other localities a supply sufficient for a windmill well may be obtained but not enough water for purposes of irrigation. The supply of water in such places can generally be increased by running horizontal tunnels through the water-bearing beds in various directions from the well or by drilling several wells close together and connecting them by tunnels driven beneath the water level. The upper surface of the underlying Triassic formation is locally irregular and hilly and in some localities approaches closely to the plains surface and of course lies nearer the surface of the ground under the bottoms of depressions in the general surface.

Only a few of these localities in which water is scarce have come to the notice of the writer and these will be briefly noted.

In northern Castro, southern Randall, and northeastern Swisher counties, Texas, there is a narrow belt of country beginning about 12 miles southeast of Hereford and running to the south of the Tierra Blanca Draw as far east as the mouth of the South Canyon Cita, in which the water is deep and the supply uncertain. In this belt little gravel is encountered in drilling, water is sometimes found in local sand beds, but the bulk of the beds encountered are clay. Western Lamb County, Texas, is another region where the water supply is uncertain. Very little water is to be had in a strip south of the line of the Santa Fe Railroad in the vicinity of Littlefield, Lamb County. In Deaf Smith County, Texas, north of Tierra Blanca Creek, and as far north as the cap rock escarpment, the water supply is uncertain. The top of the Triassic(?) red clay here seems to have considerable relief, it being reached in wells two miles apart at the depths of 80 and 200 feet. Southwest of Brownfield, Terry County, Texas, is a strip of country elongated in a northwest-southeast direction, in which water is scarce. Between Tatum and Ranger Lake in eastern Chaves County, New Mexico some wells have failed to find water, although when water is secured here it is at a shallow depth.

In Hale County, Texas, there is a locality of probably rather small extent (northeast corner Sec. 44, Blk. A4) southeast of Swastika spur in which water was not obtained in sufficient quantity for an irrigation well. There is also a strip of country barren of water ranging from one-half to two miles in width and six to eight miles long about two miles east of Lockney, Floyd County, Texas, in which little or no water can be obtained. East of this belt the water level is two to three times as deep beneath the surface as it is west of the barren belt. In the northeastern portion of Hale County, Texas, and near the east line of the county, there are large bodies of clays in the upper levels of the wells with most of the water-bearing strata near a depth of 200 feet or more. It is obvious that in a locality like this no accurate test of the water supply can be made from wells less than 200 feet in depth, and no territory surrounded by shallow water can be really condemned for irrigation purposes until all the strata lying above undoubted Triassic are known to be comparatively barren. If water were obtained in the deeper Cenozoic strata in such a locality, the upper beds being impervious to water, the water in most cases will rise to the general level of the ground-water in contiguous localities.

What is known as a "perched water table" may sometimes be found. Along the Blanco Draw near the east line of Twp. 35 E, Range 5N, Quay County, New Mexico, water is encountered at a depth of 7 feet, while under the creek valley two miles on either side the water level lies at a depth of 140 feet. The shallow water here is apparently held up locally by an underlying impervious bed. The real ground water level is at the lower (140 foot) depth.

Water Storage

The amount of water stored up in the pore spaces of the Cenozoic rocks constitutes the water storage. Not all of this water can ever be removed from the strata, because a large proportion will always adhere to the individual rock particles. The porosity of a number of water-bearing sands from Hale County were tested and the average percentage of pore space was determined as 38.4. The thickness of the water-bearing formations in 40 wells in Hale County 275 feet or more in depth, was computed and averaged, and from these figures it was computed that there was an average of 60 acre-feet of water stored in the upper 300 feet of the Cenozoic underlying the Plainview shallow water district. Mr. D. L. McDonald, of Hereford, using a porosity percentage of 37.5, estimated a water storage of 60 acre-feet beneath the Hereford shallow water area. For both these districts these figures must be regarded merely as estimates based on the data now available.

Since the ground water of the Llano Estacado is everywhere one practically continuous body of water moving slowly from a higher level on the west to a lower level on the east, the withdrawal of large supplies of water from a higher level to the west will in time decrease the supply of lower levels to the east. Thus the pumping of large quantities of water in the Portales and Muleshoe districts will diminish the supply available in the Plainview district, because a considerable portion of the water in the Plainview district comes from the general region of the Portales and Muleshoe districts. As the water level in any one of the shallow water districts is lowered, the gradient of the water table southeast of that district is diminished and consequently the amount of wastage will be decreased, for lower gradient means lower velocity of water through porous strata. The amount of decrease in wastage will be the greater the more the water level is lowered. The decrease in wastage will, however, not be considerable until the water level is lowered to quite an extent.

It is fortunate for the shallow water districts that the ground water level of so much the greater portion of the Llano Estacado lies too deep to be used for profitable irrigation. Those areas where the water level lies 100 feet or more beneath the surface become feeding areas for the shallower water belts.

The error should not be made of thinking that all the annual increase to the ground water supply can be withdrawn for irrigation without lowering the ground water level. As has already been emphasized, the annual increment is equal to the annual wastage, otherwise the water level would not remain stationary. Pumping all or most of the annual increment from any shallow water district would affect the amount of wastage comparatively very little, and the water level would accordingly become lowered by wastage. More water can be pumped without seriously affecting the water level from the higher-lying western districts, such as the Portales Valley and the Muleshoe-Hurley districts, than from the lower-lying eastern districts, for these western districts lie contiguous to one of the very most important sources of the water, the annual increment here is greater in amount, and there are no higher-lying shallow water areas to draw off a portion of the supply. The aggregate amount of water already drawn off by windmill wells all over the Llano Estacado and by irrigation wells in the shallow water districts has not yet been great enough to appreciably lower the water level, but it is only a question of time, if development is continued, until the water level will become lowered. For, obviously, there is by no means sufficient water supply to irrigate all of the land underlain by shallow water.

Finally, it must be emphasized that there is absolutely no such a thing as an inexhaustible supply of underground water. Even in such a well-watered country as central England, the ground water has been wellnigh exhausted by the demands made on it for industrial and domestic purposes. Similarly, artesian basins are not inexhaustible, for the limit of development has already been reached and many times surpassed in such artesian basins as that of the Dakotas, the Yakima Valley of Washington, the Pecos Valley, or the artesian belt of central Texas.

Notes on Some Shallow Water Districts.

The following notes on the Hereford, Muleshoe-Hurley, and Portales Valley districts have mainly been compiled from information given by prominent irrigators of the districts, although the writer has personally visited all these districts. The Plainview district has been rather fully discussed in the previous portion of this report and a considerable body of information has been embodied in the map of that district; hence it will not be further discussed. So little is yet known of both the Littlefield district and the Lovington district of Eddy and Chaves counties, New Mexico, that further discussion of these two districts is not warranted. Logs of wells in the various districts will be found in Appendices Nos. 1 and 2.

Hereford District

The writer is indebted to Mr. J. L. McDonald for most of the following information.

Mr. McDonald estimates that the southeastern quarter of Deaf Smith County, or an area of 250,000 acres, is underlain by water at a depth not greater than 100 feet. There were 27 irrigation wells of large capacity in the Hereford district at the end of the year 1914. The wells are of larger diameter and of lesser depth than those in the Plainview district.* There is a great deal of sand in this district, the porosity of which is said by Mr. McDonald to average 37.5 per cent. Seepage of water through the bottoms of the draws of Tierra Blanca, Frio, and Palo Duro creeks probably contributes notably to the shalllow water supply of this district.

*Drilling 30-inch wells for irrigation, Engineering News, Vol. 73, No. 19, May 13, 1915.

Muleshoe-Hurley District

The shallow water belt here is confined to the territory along the Double Mountain Fork (Blackwater Draw) in a belt something like 6 miles in width. Water near the draw is close to the surface (3′–10′) and the depth of the water level gradually increases northward under the gradually rising land surface. At Hurley the water-level is 22 feet beneath the surface, at Muleshoe, 18-25 feet, and gradually increases in depth northward, being about 200 feet beneath the surface 20 miles north of Hurley. In the spring of 1914 the water level raised 3 feet but fell the same amount by autumn.

A large shallow water area, extending southeastward into Lamb County, underlies the sandhills area, which is probably worthless for agriculture. At Hurley and Muleshoe the sandhills lie south of the Blackwater Draw. The wells are 120-150 feet in total depth. One well is said to have yielded 4,000 gallons per minute, but soon sanded up and was ruined. Probably in all cases such sanding up can be prevented by proper well construction.

Salt grass in the bottom of the Blackwater Draw denotes the presence of alkali. The water 5-6 feet beneath the bottom of the draw is said to be somewhat alkaline. The few Santa Fe railroad water analyses available indicate, so far as they go, that the water is less suitable for irrigation than in the other shallow water districts. This is probably because of the alkali lakes in the nearby sandhill areas. The suggestion is advanced, but not strongly urged, that the water in its course eastward to Hale, Swisher, Floyd, and other counties, undergoes a natural process of self-purification.

Portales Valley District

Most of the following information on the Portales Valley district has been kindly furnished by Mr. A. A. Rogers. This is supplemented by some observations by the author.

The Portales Valley is 4-6 miles wide and 60 miles long. There is an average of 40 feet of water-bearing strata in the first 100 feet below which red clay, probably Triassic, is reached. The red clay lies at 107 feet beneath the surface of the south side of the valley, near Portales, and at 50 feet on the north side of the valley. There is generally a layer of water-bearing gravel from 6 inches to 12 feet in thickness immediately above the red clay. At Pleasant Valley, south of the Portales Draw, red clay was reached at 40 feet, and was not yet drilled through at a depth of 400 feet. The flowing and artesian water from the Triassic strata beneath the valley is rather highly mineralized. The average depth to water in the vicinity of Portales is 20 feet. An average of 4,000 acre-feet per annum was pumped during the four years from 1910 to 1914. Pumping is done almost all together by electric motors, with a central power plant at Portales. Reservoirs are used and water is pumped both night and day.

The Portales Valley affords the following advantages: (1) a low lift for pumping; (2) a large supply of water drawn from sandhills and the Portales Valley above the town of Portales which cannot be drawn off by other localities in which the water-level is higher; (3) a porous soil more easily worked when wet and difficult to water-log by over-irrigation; and (4) pumping by electric power, which means at the least a saving in the cost of care and attention given to the operations of pumping.

There is alkali in the lower portion of the valley near the Texas line. In this district, also, there is a considerable area of shallow water overlain by sandhills.

CHAPTER V

Costs of Irrigation.

The following tables gives the cost of some of the complete wells, pumps, and engines. This information was in nearly every case furnished by the owner of the well:

Name of Well	Depth to water	Drawdown	Horse-power	Capacity, in gals., per min.	Cost
Hereford District		Average drawdown 22′	30	900	$3,500
			40	1200	4,500
		Avg. total head, 65′	50	1200–1800	5,000
		Heaviest lift, 115′	60		5,500
		26″ diam. casing.	70		6,000
Linville's, Lamb County	63′		50	1000	3,500
Warren Ranch, Muleshoe, 12 wells			22		2,000 ea.
Fairview Land and Cattle Co		8′	11	400	400
Plainview District—					
Alley, at Hale Center			50	1250	4,000
Dr. Anderson	20′		Electric-motor	1550	2,954
Branson	73′		25	500	1,500
Dowden	47.5′		25		1,250
Eiring			40	1300	2,350
Garrison			40	950	
Dr. Gidney	19′	22′+	30	1000	2,600
Judge Graham	15′	30′+*	40	1200	2,500
Harp	36.7′		50	2000	5,000
Hickman	55′		60	1200	2,800
Hollman (2 wells)	37-38′			1200	4,800 ea.
Howell	23.5′		40	1500	3,000
Hubbard	39′		40	1500	2,000
Leach	46′		60	1500	4,000 +
Perry (home place)			75	1400–1500	5,000
Perry (near Slaton's)			40	900–1000	2,650
Dr. Scott	39′	20′	100	2000–3000	4,300
Shire, at Hale Center			50		3,500
Snyder	57.5′		75	1500	4,000
Slaton	20′	15′	32	1500	2,350
Dr. Wayland		30′+	50	900–1000	3,400

The average drawdown of the Texas Land and Development Company wells in the Plainview district is 25 feet, which is attained in about 30 minutes after the pump is started. Under test, 2350 gallons per minute was pumped from the Dr. Pearson No. 2 well with a maximum drawdown of 39 feet. In the Hereford district, a 24-hour run on a 40-horsepower pump tested 1184 gallons per minute, on a 50-horsepower outfit, 1320 gallons per minute, and on a 70-horsepower outfit, 1605 gallons per minute.

In figuring actual cost of pumping, both fixed charges and operating expenses must be included. Fixed charges consist of interest on the capital cost, insurance, taxes, and depreciation. Operating expenses include labor, fuel, supplies, lubricant, and repair. Figuring interest and depreciation both at 10 per cent., the average cost per acre-foot for pumping in the Hereford and Plainview districts is about $5.00. Probably, on the average, it will require about two and one-half acre-feet per year for alfalfa. The cost varies greatly, depending on a number of factors, but the above figure represents the writer's estimate, as well as that of two of the most well-informed men in the Plainview and Hereford districts.

For other and more detailed information concerning costs and pumping appliances, the reader is referred to the following publications:

REPORTS ON PUMPING APPLIANCES PUBLISHED BY THE UNITED STATES GEOLOGICAL SURVEY*

Wilson, H. M.—Pumping for irrigation: Water-Supply Paper 1, 1896.

Murphy, E. C.—Windmills for irrigation: Water-Supply Paper 8, 1897.

Hood, O. P.—New tests of certain pumps and water lifts used in irrigation: Water-Supply Paper 14, 1898.

Perry, T. O.—Experiments with windmills: Water-Supply Paper 20, 1899.

Barbour, E. H.—Wells and windmills in Nebraska: Water-Supply Paper 29, 1899.

Murphy, E. C.—The windmill; its efficiency and economic use, Part I: Water-Supply Paper 41, 1901.

Murphy, E. C.—The windmill; its efficiency and economic use, Part II: Water-Supply Paper 42, 1901.

Slichter, C. S.—Field measurements of the rate of movement of underground waters: Water-Supply Paper 140, 1905.

Slichter, C. S.—Observations on the ground waters of Rio Grande Valley: Water-Supply Paper 141, 1905.

Slichter, C. S.—The underflow in Arkansas Valley in western Kansas: Water-Supply Paper 153, 1906.

Slichter, C. S.—The underflow of the South Platte Valley: Water-Supply Paper 184, 1906.

Meinzer, O. E., Kelton, F. C., and Forbes, R. H.—Geology and water resources of Sulphur Spring Valley, Arizona: Water-Supply Paper 320, 1913. Also published as a bulletin of the Arizona Agricultural Experiment Station.

Darton, N. H., Schwennesen A. T.—Underground water of Luna County, New Mexico, with results of pumping tests: Water-Supply Paper 345-C, 1914.

*Nos. 1, 8, 14, 20, 29, 41, and 42 are out of stock. Most of the rest are no longer available for free distribution but can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

Schwennesen, A. T., Meinzer, O. E.—Ground water for irrigation in the vicinity of Enid, Oklahoma, with a note on ground water for irrigation on the Great Plains: Water-Supply Paper 345-B, 1914.

Schwennesen, A. T.—Ground water for irrigation in the Valley of North Fork of Canadian River near Oklahoma City, Oklahoma: Water-Supply Paper 345-D, 1914.

Meinzer, O. E., and Hare, R. F.—Geology and water resources of Tularosa Basin, New Mexico: Water-Supply Paper 343, 1915.

REPORTS ON PUMPING APPLIANCES PUBLISHED BY THE UNITED STATES DEPARTMENT OF AGRICULTURE

Mead, Elwood—The relation of irrigation to dry farming: Yearbook for 1905, pp. 423-438.

LeConte, J. N., and Tait, C. E.—Mechanical tests of pumping plants in California: Bull. 181, 1907.

Gregory, W. B.—Cost of pumping from wells for the irrigation of rice in Louisiana and Arkansas: Bull. 201, 1908.

Gregory, W. B.—The selection and installation of machinery for small pumping plants: Cir. 101, 1910.

Fuller, P. E.—The use of Windmills in irrigation in the semi-arid West: Farmers' Bull. 394, 1910.

Elliott, C. G.—Development of methods of draining irrigated lands: Reprint, 1911, from Annual Report of Office of Experiment Stations for year ended June 30, 1910.

REPORTS ON PUMPING APPLIANCES PUBLISHED BY THE NEW MEXICO AGRICULTURAL EXPERIMENT STATION

Vernon, J. J., and Lester, F. E.—Pumping for irrigation from wells: Bull. 45, 1903.

Vernon, J. J., Lester, F. E., and McLallen, H. C.—Pumping for irrigation: Bull. 53, 1904.

Vernon, J. J., Lovett, A. E., and Scott, J. M.—The duty of well water and the cost and profit on irrigated crops in the Rio Grande Valley: Bull. 56, 1905.

Fleming, B. P.—Small irrigation pumping plants: Bull. 71, 1909.

Fleming, B. P., and Stoneking, J. B.—Tests of pumping plants in New Mexico, 1908-1909: Bull. 73, 1909.

Fleming, B. P., and Stoneking, J. B.—Tests of centrifugal pumps: Bull. 77, 1911.

REPORTS ON PUMPING APPLIANCES PUBLISHED BY THE ARIZONA AGRICULTURAL EXPERIMENT STATION

Smith, G. E. P.—Ground-water supply and irrigation in the Rillito Valley: Bull. 64, 1910.

Meinzer, O. E., Kelton, F. C., and Forbes, R. H.—Geology and water resources of Sulphur Spring Valley, Arizona. (See above.)

A large amount of accurate and helpful information can also be obtained from two free trade bulletins published by the American Well Works, Aurora, Illinois: Bulletin 127, Economical Irrigation by Pumping; and Bulletin 141, Methods of Constructing Large Capacity Deep Wells for Irrigation Pumping in the Great Plains.

CHAPTER VI

Some Problems of Future Development

Irrigation

Since the supply of shallow water is limited and there is certainly not enough of it to irrigate all the land underlain by shallow water, the problem of the utmost conservation of water supply becomes of first importance. Fortunately, the cost of pumping serves as a preventative of great wastage of water. The problem therefore largely narrows itself to the best possible utilization of the water after it has been pumped to the surface. In the Plainview district especially, and only to a slightly less degree in the other districts, much can be done by deep plowing (to a depth of 16 or 18 inches) and thorough cultivation. Such deep plowing and thorough tillage will tend to decrease soil evaporation, increase the amount of rainfall stored in the soil, give a better seed bed for crops, bring up some of the lower lime into the surface soil, thus increasing the yield of alfalfa, and tend to decrease the danger of the surface soil becoming water-logged and being ruined by the deposition of the deleterious alkaline salts contained in the ground water.

The salts most injurious to cultivated crops are those of sodium and potassium. Of the various salts of sodium and potassium the carbonates are the most injurious and the sulphates are the least injurious to plants; the chlorides holding an intermediate position. All ground water contains some mineral matter, and if large volumes are allowed to evaporate on the land, this matter will accumulate as "alkali" and finally render it unfit for plant growth. It is finally necessary, therefore, to resort to drainage or flushing out of the "alkali." Deep plowing, by increasing the seepage, will aid somewhat in flushing out of the alkali. Deep plowing and thorough cultivation, by decreasing the evaporation, not only will aid in increasing the amount of water available for plant uses, but will also aid to at least some extent in increasing that portion of the supply of ground water contributed by the area under cultivation and irrigation.

During the wet years less water will be necessary for agriculture than during the dry, and advantage will no doubt be taken of this fact. Irrigation of row crops and grains will be mainly useful during the droughty years, although for alfalfa some irrigation must be resorted to even in the wet years.

It is the writer's view that the best method of utilization of the shallow-water belts will be by the irrigation of not over 80 acres out of every 640, the remainder of the section being used for the producing of forage crops by dry-farming, and for grazing of cattle, horses, mules, and sheep.

Fruit-growing has not been a great success on the Llano Estacado because of the high winds and frequent hailstorms. The planting of windbrakes around orchards will lessen the deleterious effects of the wind and such windbreaks will also lessen somewhat the present excessive soil evaporation. Hardy trees for windbreaks will probably grow if their early growth is aided by watering.

The pumping lift with a water table not exceeding 50 feet has already been demonstrated to be profitable for irrigation. However, the cost of lifting water from depths of more than 100 feet (included in this figure is depth to the water table plus the drawdown) is generally prohibitive at the present time, except where the water is used for especially valuable crops. In all cases the less the depth to the water level, provided a sufficient supply can be gotten, the more the chances of profit. Generally speaking, horizontal centrifugal pumps are more advantageous for greater lifts, but if such pumps are not carefully installed and kept in first-class repair, they may develop great friction and consequently have low efficiency. One of the great losses of efficiency in centrifugal pumps is in the slipping of the belt connecting the pump with the engine. Some system of direct connection should be devised in order to get more efficiency. The chances of reducing the cost of pumping in the future lie in increasing the efficiency of the pumping plant and in improved methods of cultivation. All wells should be thoroughly tested out first in order to determine the best type of pump and plant. Pumps and plants should always be installed by expert mechanics.

The efficiency of deep-well cylinder pumps is rather high if they are kept in repair, but very low if their valves leak. They are better adapted for pumping small amounts of water than large amounts, and are especially useful where a part or all of the water is pumped by windmills into a reservoir. Where deep-well cylinder pumps are operated by engines or electric motors, they should be of the double-acting type. The efficiency of air lifts is too low for purposes of irrigation.

In experiments made by P. E. Fuller, of the United States Department of Agriculture, it was found that with a lift of 56 feet a 12-foot windmill would pump 1½ gallons a minute when the velocity of the wind was 6 miles per hour; 4½ gallons with a wind velocity of 8 miles; 8⅓ gallons when the velocity was 10 miles; 12 gallons with 12 miles per hour wind velocity; and 22½ gallons when the wind velocity was 18 miles. In one and one-half months, with an average wind velocity of about 13 miles per hour, and a lift of 56 feet, a 12-foot back-geared windmill pumped 1¼ acre feet, a 14-foot-geared mill pumped a little over 2 acre-feet, and a 16-foot direct-stroke mill pumped about 2½ acre-feet. In records obtained by the Office of Experiment Stations, United States Department of Agriculture, in 1904, of 72 windmills at Garden City, Kansas, it was found that these windmills pumped sufficient water to irrigate from one-fourth to seven acres each, at a cost of 75 cents to $6 per acre. The crops were worth $12 to $500 per acre, and included alfalfa, garden vegetables, fruit trees, sugar beets, corn, cane, and sweet potatoes.

The Llano Estacado is handicapped by the lack of cheap electric power and of fuel. Internal-combustion engines, burning crude oil or some one of its various derivatives, are now used almost everywhere except in the Portales Valley.

A drawback to the raising of alfalfa for market on the Plains is the liability to damage because of summer rains. For this reason irrigators are beginning to pasture hogs on their alfalfa, or else use it for the feeding of their own stock, or sell it to nearby stock-growers. The great stock-growing industry of the Llano Estacado can use all the forage crops raised there. Obviously, the irrigator who raises crops for market will profit most in the dry years when local feed is scarce and prices are high.

Reservoirs for storing water should always be used where the flow is less than 600 gallons per minute. The reason for this is that with small streams used directly from the pumps, the loss in conveying water in ditches is excessive and loss in application of water to land is large, since a small stream will saturate a spot and a large amount of water will sink into the soil in one place instead of moistening the surface of a large area.

Dry-farming

Dry-farming may be successfully pursued in connection with irrigation and may perhaps be a success under thoroughly up-to-date methods when engaged in without irrigation, but the dry-farmer who is also a stock-farmer, with a considerable area of grazing land, stands the best chance of success. The sorghums (milo maize, kaffir corn, feterita, etc.) will be more successful dry-farm crops here than will wheat. A silo is advisable for the dry-farmer.

Stock-raising

The Llano Estacado is a good stock country. The great bulk of the Llano Estacado will in all probability always be a grazing region. Particularly successful has been the raising of high grade cattle, horses, mules, and hogs. Sheep-grazing will probably be largely confined to the rougher lands about the border of the plains, although with shelter and food for the sheep in winter, sheep-growing may become an important industry of the future. The best hopes for better future utilization of the High Plains appear to lie in an improvement of the range, the growing of a better grade of stock, and the cultivation by dry-farming methods of forage for winter feed. Past experience has shown that forage plants, and especially the sorghums, produce better yields in this region of great evaporation than does the great staple crop, wheat, of most dry-farming districts. The feedstuffs raised both by irrigation and dry-farming should be fed to stock on the plains. If the supply of these in the years of more favorable rainfall should be greater than the local demand, the excess should be held over to help supply the deficiency in years of drought. Silos will be a great aid to the combination stock and dry-farmer.

Probably the best size for a ranch for stock-raising, supplemented by enough dry-farming to supply winter feed, is about 4,000 acres collected into a body 2½ miles square with a windmill well in the center. A cow, when thirsty, should not be obliged to travel too far to water, and 1½ to 1¾ miles is far enough at the most. It has been demonstrated that in a pasture of this size very little or no grass will go to waste as is the case in larger pastures. Furthermore, some of the land should be fenced off and not grazed each year in order that the grass may come to seed, the pasture thereby being improved. On a ranch of this size and shape, it seems possible to so improve the grazing that 10 acres will be sufficient for a cow. The great present problem of the stock-grower is conservation and betterment of his range.

In conclusion, the author wishes to point a moral. What these High Plains need is developers and not speculators. Over-inflation of land values by real-estate speculators is doing a vast amount of harm in the American West, and is hindering, not aiding, the ultimate development of many districts. The great need of the country is for thoroughly industrious and intelligent farmers and stock-raisers who are capable of developing and using thoroughly scientific methods. It is evident that the price per acre of grazing and dry-farming land must ever remain low. Even with raw grazing land selling at a low figure per acre, the investment in land, stock, improvements and machinery on a 4,000-acre ranch is very nearly the same as that of a 160-acre improved and stocked farm, supplied with tools and machinery, in the great agricultural region of the upper Mississippi Valley.

MISCELLANEOUS WATER ANALYSES. (Expressed in parts per million.)

Number of Analysis.	1	2	3	4	5	6	7	8	9	10	11	12
Silica (SiO_2)	49.5						40.0	20.0			45.6	
Aluminum (Al)	9.0						0.0	0.0			21.6	
Iron (Fe)							0.0	0.0			Tr	
Calcium (Ca)	39.4	48.0	40.0	47.0	40.0	50.0	71.4	122.8	42.3		152.4	26.8
Magnesium (Mg)	31.5	42.0	47.0	53.0	42.0	67.0	28.8	26.9	29.0		62.9	45.7
Sodium and Potassium (Na+K)	52.0	36.0	42.0	41.0	41.0	44.0	77.3	48.7	46.8	46.4	131.8	47.1
Carbonate radicle (CO_3)	160.4	343.0	310.0	320.0	338.0	358.0			153.5	89.4	88.8	110.9
Bicarbonate radicle (HCO_3)	162.5	349.0	315.0	325.0	344.0	364.0	115.0	125.0	157.1	91.0	75.6	123.3
Sulphate radicle (SO_4)	35.1	35.3	76.4	62.7	40.2	89.0	145.5	209.6	33.2	26.5	274.6	85.6
Nitrate radicle (NO_3)											0.7	
Chlorine (Cl)	27.8	32.1	30.0	51.5	24.0	71.0	40.0	65.0	26.3	20.0	308.0	60.4
Total dissolved solids							620.0	720.0			1070.0	
Fixed solids							490.0	620.0				
Organic and Volatile matter							130.0	100.0				
Hardness:												
Temporary											75.6	
Permanent											317.8	
Mineral contents		Moderate	Moderate	Moderate	Moderate	High	High	High	Moderate	Moderate	High	Moderate
Suitability for irrigation	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Poor	Good
Scale-forming ingredients	Poor-226.8						Poor-298	Poor-426.7			Bad-640	
Alkali coefficient (K)	23.9	59.0	55.0	37.9	63.0	28.0	36.5	30.5	22.5	23.0	6.6	32.4
Suitability for drinking	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Fair	Good
Corrosion	-3.11						+0.47	+2.0			+3.4	
Foaming coefficient	Good--140	Good--97.2	Good--113.5	Good--110.7	Good--111	Good--118.7	Fair-207.6	Good-131.5	Good--112	Good-128	356	Good--127
Suitability for washing											Fair	
Suitability for domestic use											Fair	

Location of wells represented by samples numbered as follows:

1------Well 3 miles southeast of Hereford, Deaf Smith County.
2------Texas Land and Development Company Lake Plainview well, Hale County.
3------Texas Land and Development Company well No. 2, Hale County.
4------Texas Land and Development Company well No. 11, Hale County.
5------Texas Land and Development Company well No. 43 (Pioneer farm), Hale County.
6------Texas Land and Development Company windmill well No. 11, File 72, Hale County.
7------Portales Valley, New Mexico, well No. C. I., analysis by H. T. deBerard, chemist, Denver Union Water Company.
8------Portales Valley, New Mexico, well No. P. H., analysis by H. T. deBerard, chemist, Denver Union Water Company.
9------City well, Plainview, Hale County.
10------Col. Smythe irrigation well, Plainview, Hale County.
11------Herring well, Taboka, Lynn County. Analysis No. 2127, by J. E. Stullken, chemist, Bureau of Economic Geology and Technology.
12------Lubbock State Experiment Farm well, Lubbock, Lubbock County, Texas. Analysis by State Chemist.

SANTA FE RAILROAD ANALYSES FOR BOILER PURPOSES ONLY.
(Expressed as parts per million.)

County	Water Station	Calcium sulphate $CaSo_4$	Magnesium sulphate $MgSo_4$	Calcium and magnesium carbonate $CaCo_3 + MgCo_3$	Incrustants	Solids
Carson	Panhandle (deep well)	-------	21.7	225	245	398
Carson	White Deer	12.0	87.0	185	209	252
Carson	White Deep No. 1	-------	-------	197	197	310
Carson	White Deep No. 2	-------	-------	170	170	324
Dawson	Lamesa (104 ft.)	24.2	37.2	302	374	797
Dawson	Lamesa (114 ft.)	27.5	34.2	385	350	760
Dawson	Lamesa (182 ft.)	-------	-------	219	219	846
Deaf Smith	Dawn	8.7	46.3	266	322	364
Deaf Smith	Hereford	-------	8.7	249	259	376
Deaf Smith	Hereford	-------	-------	304	304	475
Deaf Smith	Hereford (deep well)	8.8	34.2	276	319	448
Deaf Smith	Hereford Sulphur Spring	-------	-------	335	335	530
Floyd	Floydada (153 ft.)	24.0	19.0	261	304	404
Floyd	Lockney (84 ft.)	10.4	8.8	268	286	395
Gray	Hoover (new well)	18.0	24.0	278	321	350
Gray	Hoover No. 1	7.0	15.5	206	235	257
Gray	Pampa (new well)	24.0	84.0	176	285	975
Gray	Pampa (new well)	41.2	70.3	171.5	283	948
Gray	Pampa	24.0	101.0	201	325	630
Hale	Abernathy (175 ft.)	-------	12.0	218	230	548
Hale	Abernathy (200 ft.)	5.2	10.4	242	257	358
Hale	Hale Center (120 ft.)	-------	12.0	283	295	372
Hale	Plainview	27.5	51.5	309	387	521
Hale	Plainview	46.3	86.0	237	369	494
Hale	Plainview (40 ft.)	-------	56.7	280	336	439
Hale	Plainview (72 ft.)	-------	22.3	271	294	383
Lipscomb	Higgins (deep well)	7.0	8.8	228	244	334
Lubbock	Lubbock (C. & S. P. Ry.)	60.0	51.5	269	379	552
Lubbock	Lubbock No. 1	44.7	79.0	273	396	657
Lubbock	Lubbock No. 2	38.0	96.0	269	396	669
Lubbock	Lubbock No. 3	92.7	98.0	254	445	662
Lubbock	Lubbock No. 4	-------	55.0	304	368	624
Lubbock	Lubbock No. 5	-------	39.5	257	297	584
Lubbock	Slaton No. 2 (141 ft.)	17.2	19.0	300	336	650
Lubbock	Slaton No. 4	10.3	58.3	287	355	660
Lubbock	Slaton No. 5	125.0	80.6	247	267	835
Lubbock	Slaton No. 12	48.0	29.2	300	378	700
Lubbock	Yellowhouse Cr. at Slaton	15.5	82.3	698	795	4680
Lynn	Tahoka (Chambers)	230.0	266.0	206	701	1105
Lynn	Tahoka (85 ft.)	304.0	430.0	322	1055	1670
Lynn	Tahoka (200 ft.)	-------	-------	166	166	321
Lynn	Tahoka No. 2 (105 ft.)	199.0	316.0	220	735	1160
Lynn	Tahoka No. 3 (110 ft.)	206.0	317.0	221	745	1163
Lynn	Tahoka	-------	-------	166	166	3220
Lynn	Tahoka (H. G. Code)	-------	-------	166	166	3217
Lynn	Tahoka, 1½ mi. W. (H. G. Code)	304.0	431.0	323	1056	1675
Parmer	Black	-------	12.0	209	221	314
Parmer	Black No. 2 (217 ft.)	27.5	65.2	187	280	383
Parmer	Bovina	8.7	12.0	183.5	204	279
Parmer	Bovina	-------	-------	226	228	333
Potter	Amarillo W. N. W. well	-------	5.2	247	252	384
Potter	Amarillo S. E. well	22.3	14.0	240	274.6	372
Potter	St. Francis (305 ft.)	12.0	14.0	214	240	314
Potter	St. Francis (658 ft.)	852.0	399.0	101	1550	2960
Randall	Canyon City (creek)	-------	12.0	256	268	400
Randall	Canyon City (deep well)	24.0	-------	60	67	451
Randall	Canyon City (new well)	-------	-------	48	48	396
Randall	Canyon City (new well, 408 ft.)	-------	-------	43	438	377
Randall	Canyon City (shallow well)	45.0	22.2	216	283	1030
Randall	Canyon City No. 1 (80 ft.)	24.0	12.0	219	255	374
Roberts	Miami (surface)	29.2	17.2	199	245	269
Roosevelt	Portales, New Mexico	82.3	19.5	205	305	410
Swisher	Tulia	22.3	56.8	280	359	426
Texas-New Mexico	Texico (deep)	-------	10.3	127	168	257

APPENDIX NO. 1.

Logs of Shallow Water Wells arranged alphabetically by counties

BAILEY COUNTY.

Fairview Land & Cattle Co. well, 1 mile north of Hurley.

Depth	Thickness	
0	5	Sandy soil
5	16	White sandy rock
21	19	Fine red dry sand
40	47	Fine red water-bearing sand
87	2	Loose shale
89	13	Fine red water-sand
102	5	Hard red sandstone
107	16	Fine red water-sand
123	2	Hard red water-sand
125	35	Loose red quicksand
160	2	Hard red sand rock
162	19	Loose red fine sand
181	11	Hard fine pack sand
192	16	Coarse hard gravel
208	4	Coarse red sand
213	2	Red gumbo (Trias.)
215		

**This well was ruined by caving of sand.

Generalized log of Fairview Land & Cattle Co.'s wells at Hurley.

Thickness	
9	Soil and lime
6	Soft lime rock
8	Soft sand
4-6	Soft sand rock to water
10-15	Red clay, in which water is generally struck
50-75	Soft sand with water
2-3	Red clay
40-60	Soft sand
10-25	Flowing sand with third water
	Soft chippy red clay (Trias.?)

Judge J. C. Paul's well No. 1, north side of 160-acre tract, northeastern part of Hurley.

Struck gravel at 165 feet.

Well No. 2.

Struck coarse white sand in place of gravel, under third water stratum of flowing sand.

P. & N. T. Ry. well at mile post 628, near Janes.

Elevation, 3668.5′ Depth to water, 100′

Depth	Thickness	
0	35	Sandy clay
35	5	Light brown clay
40	15	Light red clay
55	20	Yellow clay
75	10	Red clay
85	8	"Gyp" and clay
93	17	Red clay
110	2	White water sand
112	8	Red sandy clay
120	10	White water-sand, second water at 120 ft.
130	12	Red clay
142		

**50 gallons per minute at 120 ft.

P. & N. T. Ry. well at Janes, near steel tank.

Elevation, 3705.9′ Depth to water, 120′

Depth	Thickness	
0	2	Soil
2	5	Dark red sandy clay
7	45	Light sandy clay
52	18	White marl
70	14	Light red sandy clay
84	35	Yellow clay
119	1	Brown shale
120	18	Yellow clay
138	10	Black clay (Comanchean?)
148	5	Sand and gravel
153	11	Blue clay (Triassic)
164	3	Hard gray sand rock
167	8	Light blue sandy clay
175	75	Red clay
250	45	Red rock
295	67	Red clay
362	....	Red sand—very salty water

**6 gallons per minute between 120 ft. and 167 ft.

P. & N. T. Ry. well at Janes, opposite station 2933+17.

Depth	Thickness	
0	2	Brown soil
2	6	"Gyp" and clay
8	52	Red sandy clay
60	45	Light red sandy clay
105	17	Yellow clay

Depth	Thickness	
122	2	Gravel with a little water
124	12	Yellow clay (possibly Comanchean)
136	11	Blue clay
147	5	Concrete gravel (Triassic)
162	16	Blue clay
168	10	Light blue sandy clay
181	....	Red clay

P. & N. T. Ry. well opposite west head block at Janes.

Depth to water, 98′

Depth	Thickness	
0	4	Soil
4	31	Light red sandy clay
35	17	Marl
52	36	Light red sandy clay
88	24	Yellow sandy clay
112	7	Conglomerate; first water at 112 ft.
119	14	Yellow clay
133	4	Dark gray clay
137	6	Sand and quartz gravel
143	3	Yellow clay (possibly Comanchean)
146	10	Blue clay
156	11	Light gray soft sand rock—water at 156 ft.
167	1.5	Gray clay
168.5	....	Red clay (probably Triassic)

**18 gals. per minute at 156 ft.

P. & N. T. Ry. east well at Muleshoe.

Elevation, 3748′ Depth to water, 20′

Depth	Thickness	
0	10	Brown clay
10	15	Marl
25	10	White sand; first water at 27 ft.; raised to 20 ft.
35	35	White clay
70	3	Blue clay
73	15	Brown clay; second water at 80 ft.; raised to 27 ft.
95	15	Fine red sand
110	5	Red clay
115	21	Soft sand rack; third water at 115 ft.; raised to 27 ft.
136	59	Brown clay
195	13	Brown sand; fourth water at 195 ft.; raised to 35 ft.

**30 gals. per minute at 157 ft.

P. & N. T. Ry. west well at Muleshoe.
Depth to water, 18′

Depth	Thickness	
0	3	Sandy clay
3	24	Marl
27	43	White clay; first water at 27 ft.; raised to 18 ft.
70	3	Blue clay
73	15	Brown clay; second water at 80 ft.; raised to 18 ft.
88	7	Red clay
95	15	Fine red sandy clay
110	5	Red clay
115	20	Soft sand rock; third water at 115 ft; raised to 18 ft.
135	7	Clay
142	19	Red sandy clay and gravel; fourth water at 142 ft.; raised to 35 ft.
161	29	Red clay
190	18	Sand and gravel; fifth water at 190 ft.; raised to 35 ft.

**38 gals. per minute at 171 ft.

Warren Ranch well No. 1, southwest quarter of Sec. 31.
Depth to water, 24′

Thickness	
5	Soil
15	"magnesia"
14	"magnesia" rock
6	Red sand
36	Yellow clay and sand with layer of rock
17	Red clay and sand
8	Red clay
3	Rock and boulders
22	Clay and rock mixed
6	Hard rock

Warren Ranch well No. 2, southwest quarter of Sec. 34.
Depth to water, 18′

Thickness	
4	Soil
15	"magnesia" and sand
14	Solid rock and "magnesia" rock
50	Red clay, sand, and boulders
23	Red sand rock
15	Red clay and sand
6	Quicksand

Thickness	
2	Clay
17	Sand rock
4	Shell rock and boulders

Warren Ranch well No. 3, northwest quarter of Sec. 47.
Depth to water, 14′

Thickness	
6	Soil
28	"magnesia" rock and boulders
14	"magnesia" rock and red sand
24	Red clay and sand
33	Red sand rock
23	Sand
22	Sand rock and gravel

Warren Ranch well No. 4, southwest quarter of Sec. 43.
Depth to water, 12.5′

Thickness	
3	Soil
9	Clay and "magnesia"
11	"magnesia" rock
20	Red sand rock
50	Yellow clay and sand
6	Red sand rock
4	Red sand
7	Red sand rock
30	Red sand rock and gravel

Warren Ranch well No. 5, southwest corner of S. E. ½, Sec. 36.
Depth to water, 18′

Thickness	
5	Soil
12	Clay
45	"magnesia" and clay
40	Hard gray clay and rock
56	Red sand rock

Warren Ranch well No. 6, southeast quarter, Sec. 79, Blk. Y.
Depth to water, 20′

Thickness	
9	Soil and clay
5	Clay and "magnesia"
40	Clay and sand
6	Red sand rock
20	Red sand and layer of shell rock
5	Yellow clay

Thickness	
11	Red clay and sand
6	Red clay
9	Sand and gravel

Warren Ranch well No. 7, southeast quarter of Sec. 43.
Depth to water, 18′

Thickness	
8	Soil and clay
8	Shell rock
35	"magnesia"
20	Clay and sand
5	Water-sand
50	Sand rock and clay
15	Sand and gravel

Warren Ranch well No. 8, N. W. quarter, Sec. 49, Warren Subdivision.
Depth to water, 18′

Thickness	
5	Soil
13	Rock
45	"magnesia"
15	Clay
7	Sand rock and gravel

Warren Ranch well No. 9, southeast quarter of Sec. 33.
Depth to water, 19′

Thickness	
8	Soil and clay
24	"magnesia" rock
42	Thin layer of rock, clay, and sand
8	Sand rock
12	Yellow sand
2	Hard rock
4	Red sand
6	Sand rock
36	Thin layer of rock and red sand

Warren Ranch well No. 10, northeast quarter of Sec. 43.
Depth to water, 15′

Thickness	
9	Soil and clay
53	"magnesia" rock
20	Sand
6	Rock
46	Thin layer of rock and red sand

Thickness	
3	Clay
11	Red sand and gravel

Warren Ranch well No. 11, southeast quarter of Sec. 43.

Depth to water, 18′

Thickness	
4	Soil
60	"magnesia" rock
6	Blue clay
10	Blue sand
25	Gray sand
36	Red sand and thin layer of rock

Warren Ranch well No. 12, south half of S. E. quarter of Sec. 34.

Depth to water, 19′

Thickness	
5	Soil
22	"magnesia" rock
40	Red clay and sand
12	Red sand
6	Sand rock
20	Red clay
39	Sand and gravel

CARSON COUNTY

P. & N. T. Ry. well No. 3, at Panhandle, south side of main line and east of boiler house.

Elevation, 3451′ Depth to water, 332′

Depth	Thickness	
0	5	Sandy loam
5	111	Yellow clay and sand
116	29	Fine dry sand
145	30	Clay
175	3	Clay and gravel
178	4	Sand and soapstone
182	18	Fine sand
200	4	Soft sand rock
204	19	Hard clay and sand
223	47	Dry sand
270	5	Clay
275	7	Clay with gravel
282	23	Yellow clay (Triassic)
305	16	Yellow sandstone
321	6	Magnesian limestone
327	22	Sandstone

Depth	Thickness	
349	16	Quicksand. Struck water, rose to 332 ft.
365	17	Brown sand
382	10	Fine brown sand
392		

P. & N. T. Ry. well No. 4 at Panhandle, west well, south side of main line.

Depth to water, 332′ (first struck at 349′)

Depth	Thickness	
0	5	Sandy loam
5	111	Yellow clay and sand
116	29	Fine dry sand
145	30	Clay
175	3	Clay and gravel
178	4	Sand and soapstone
182	18	Fine sand
200	4	Soft sand rock
204	19	Hard clay and sand
223	57	Dry sand
270	5	Clay
275	7	Clay with gravel
282	23	Yellow clay (Triassic)
305	5	Sand rock
310	17	Clay and magnesia
327	22	Sandstone
349	16	Quicksand
365	17	Packsand
382	32	Fine brown sand
		**Water from 406 ft. to 412 ft.

P. & N. T. Ry. well No. 1 at White Deer.

Elevation, 3338′ Depth to water, 328′

Depth	Thickness	
0	6	Soil
6	244	Red clay and sand
250	12	Brown caving clay
262	63	Light brown clay and sand
325	5	Gravel and clay
328	....	Some water
330	15	Gravel with clay; water, 328-345 ft.
345	41	Red clay and sand (Triassic)
386	4	Red sand
390	117	Red clay
507	8	Red water-sand
515	2	Red clay
517		

P. & N. T. Ry. well No. 2 at White Deer.
Depth to Water, 386′

Depth	Thickness	
0	6	Soil
6	244	Red clay and sand
250	12	Brown caving clay
262	28	Light clay and sand
290	10	Light clay
300	9	Bastard lime
309	16	Brown clay and sand
325	13	Gravel mixed with clay
328	....	Some water
338	7	Red clay and sand (Triassic?)
345	5	Brown clay
350	35	Red clay and sand
385	5	Sand; water at 386 ft.
390	116	Red clay and sand
506	10	Red sand; some water
516	55	Red clay
571		

P. & N. T. Ry. well No. 3, at White Deer (abandoned on account of bad water).

Depth	Thickness	
0	10	Surficial material
10	35	Yellow clay
45	51	Yellow clay
96	9	Brown caving sand
105	95	Yellow sandy clay
200	40	Yellow clay
240	56	Yellow sandy clay
296	10	Lime rock—base of Cenozoic
306	26	Red clay (Triassic)
332	3	Red sand rock—water
345	3	Water-gravel—5 gals. water per minute
335	10	Red sandy clay
348	2	Red sandy clay
350	12	Red clay
362	36	Red sandy clay
400	10	Red clay
410	85	Red clay
495	20	Red sand—water
515	5	Red clay
520	7	Red sand
527	6	Red sand
533	24	Red sand—bad water
557	5	Red clay
562		

P. & N. T. Ry. well No. 4, at White Deer.

Depth	Thickness	
0	4	Soil
4	22	Light brown clay
26	26	Light yellow clay
52	9	Red clay
61	14	Red sandy clay
75	15	Light yellow sandy clay
90	31	Light brown dry sand
21	79	White sandy caving clay—mostly sand
200	12	Light yellowish clay
212	4	Light brown sand
216	24	Light yellow clay
240	67	Light yellow sandy clay
307	20	Red sandy clay
327	4	Water gravel—4 gals. per minute
331	41	Red sandy clay (Triassic)
372	75	Red clay
447	73	Red sand—water at 510 ft.
520	....	
523	....	Red clay

CURRY COUNTY, NEW MEXICO.

A. T. & S. F. Ry. well No. 1, Clovis.

Elevation, 4218′ Depth to water, 256′

Depth	Thickness	
0	5	Clay
5	110	Brown sand with red clay streaks
115	15	Brown sand
130	125	Brown sand with red clay streaks
255	40	Brown sand
295	33	Fine sand
323	12	Coarser sand with small pebbles
340	6	Fine sand
346	3	Sandy red clay (Triassic)
349	4	Sand and fine gravel
353	4	Coarse sand
357	9	Red sandy clay
366	13	Red clay
379	6	Red and brown sand
385	66	Red clay
451	5	Brown sand
456	33	Fine gray sand
489	14	Dark gray coarse sand
503	7	Dark gray lime

Depth	Thickness	
510	45	Light red clay
555	12	Gray sand rock—salt water
567		

A. T. & S. F. Ry. wells No. 10 and No. 11; Clovis.

Elevation, 4216′ Depth to water, 260′

Depth	Thickness	
0	5	Soil
5	277	Brown sand
282	53	Brown sand
335	12	Red clay (Triassic)
347	28	Sand and gravel
375	85	Red clay
460	35	Sandy clay
495	12	Gray water-bearing sandstone
507	9	Red clay
516		

A. T. & S. F. Ry. well No. 1, at old roundhouse at Melrose, N. M.

Elevation, 4390′ Depth to water, 205′

Depth	Thickness	
0	6	Surface
6	19	Marl
25	40	Brown sand
65	10	Dry gravel
75	6	Yellow clay
81	34	Pink clay
115	15	Gray clay
130	30	Sandy clay
160	70	Gray sand
230	5	Light gray sand
235	25	Red clay (about 1½ gals. per min. of water at 255 ft.) (Triassic)
260	20	Red sand rock
280	15	Red clay
295	10	Gray sand rock
305	5	Soft gray sand rock
310	40	Soft red clay
350	20	Light gray sand rock
370	60	Red clay
430	20	Gray sand
450	260	Red clay (probably Permian)
710		**Abandoned

DAWSON COUNTY.

P. & N. T. Ry. well at Lamesa.
Elevation, 3634′

Depth	Thickness	
	35	Red sandy clay
	45	"gyp" rock (probably limestone)
	2	Limestone
	18	Red sandy clay
	3	Pack sand
	7	Coarse, water-bearing sand
	5	Red clay
115		

**5 gals. per min.

P. & N. T. Ry. well No. 1 at Lamesa.
Elevation, 3024′

Depth	Thickness	
	40	Red sandy clay
	40	"gyp" rock (probably limestone)
	5	Limestone
	15	Red sandy clay
	12	Water-bearing quicksand
	20	Red clay
185		

**17 gals. per min.

P. & N. T. Ry. well No. 2 at Lamesa.
Elevation, 3023′

Depth	Thickness	
	40	Red sandy clay
	35	"gyp" rock (probably limestone)
	5	Limestone
	20	Red sand clay
	5	Pack sand
	5	Coarse, water-bearing sand and gravel
	40	Red clay
	15	Quicksand with water
	1	Red clay
166		

**30 gals. per min.

DEAF SMITH COUNTY.

P. & N. T. Ry. well No. 1, at Dawn.

Elevation, 3758′ Depth to water, 68′ (first struck at 83′)

Depth	Thickness	
0	35	Reddish clay
35	25	Red sandy clay
60	10	Sand
70	10	Red sand with streaks of rock
80	14	Yellow sand
94	10	Fine sand
104	11	Pack sand—water
115		

**22 gals. per minute.

P. & N. T. Ry. well No. 2, at Dawn.

Depth to water, 68′

Depth	Thickness	
0	31	Yellow clay
31	5	Reddish sand
36	34	Lime rock and sand
70	3	White magnesian limestone
73	10	Red sand
83	22	White water-sand
105	10	Dirty, white, soft sand rock
115		

**25 gals. per minute at 108 ft.

Layne & Bowler, original MacDonald well, N. W. corner, N. W. quarter Sec. 65, Blk. K3.

Depth to water, 47′

Depth	Thickness	
0	47	Pit
47	17	Soft honeycombed limestone
64	79	Water-bearing sand
143	7	Grayish clay
150	15	Sand
165	98	Soft sand rock and sand
263		

Section of pit:

	5	Soil
	8	Grayish clay
	34	Red clay and lime

McDonald well No. 2, N. W. corner S. W. quarter Sec. 65, Blk. K3.
Depth to water, 46.5′

Depth	Thickness	
	126	Soft sand. (Limestone at 14 ft.)
	14	Grayish clay (most clay below water level in any Hereford well).
	96	Soft and hard sand rock
250		

FLOYD COUNTY.

P. & N. T. Ry. well No. 1, at Floydada.
Elevation, 3181′ Depth to water, 110′

Depth	Thickness	
	30	Light red clay
	10	"gyp" rock (limestone)
	30	Red clay
	10	"gyp" rock (limestone)
	30	Red clay
	15	Quicksand
	15	Water-bearing sand
	20	Light red clay
	5	Dry sand
165		

**50 gals. per minute.

P. & N. T. Ry. well No. 1, at Lockney.
Elevation, 3275′ Depth to water, 66′ (?)

Depth	Thickness	
	10	Soil and "gyp" (lime)
	10	Red clay
	5	Hard stone
	41	Soft sandstone with thin streaks of sand

P. & N. T. Ry. well No. 2, at Lockney.
Elevation, 3275′

Depth	Thickness	
	35	Soil and "gyp" (lime)
	49	Porous rock
84		

**30 gals. per minute.

GARZA COUNTY.

P. & N. T. Ry. well at Justiceburg (east of Llano Estacado).

Elevation, 2312′± Depth to water, 20′

Depth	Thickness	
0	2	Soil
	18	Red clay (Permian)
20	....	Struck salt water
	60	White shale (gypsum?)
	30	Red clay
	20	White clay (gypsum?)
130	....	Salt water
	80	Red clay
	5	White shale (gypsum?)
	190	Red shale—salt water
	6	White sand rock
	174	Red shale and beds of rock salt
	15	Rock salt, pure and clean
800	....	Well abandoned

P. & N. T. Ry. well No. 1, at Southland.

Elevation, 3070′± Depth to water, 102′

Depth	Thickness	
	3	Soil
	35	Gravel and dirt
	30	White rock and boulders
	34	Sand rock
	18	Water-bearing porous gray rock
120		

GRAY COUNTY.

P. & N. T. Ry. well No. 1, at Hoover.

Elevation, 3088′ Depth to water, 62′

Depth	Thickness	
	20	Surficial materials
	57	Sand, clay and pebbles; water rose to 62 ft.
77	6	Clay
83	37	Fine, buff, floury sand, very soft
120	8	Light yellow clay
128	49	Light brown sandy clay
173	24	Dark brown sand with a little clay—dry
197	3	Light brown sandy clay
200	21	Sand, clay and pebbles—dry
221	5	Yellow coarse sand
226	....	Struck water which rose to 210 ft.

Depth	Thickness	
226	31	Yellow, coarse, water-bearing sand
257	23	Yellow sandy clay
280		

P. & N. T. Ry. well No. 2, at Hoover.

Depth to water, 55′

Depth	Thickness	
0	20	Surficial material
20	57	Sand, clay and pebbles; first water
77	6	Clay
83	37	Fine buff sand
120	8	Fine yellow clay
128	45	Light brown sandy clay
173	24	Dark brown dry sand
197	3	Light brown sandy clay
200	21	Sand, clay and pebbles—dry
221	33	Yellow, coarse, water sand
254		

P. & N. T. Ry. well No. 3, at Hoover.

Depth	Thickness	
0	15	Surficial material
15	15	Red clay
30	20	White clay
50	25	White marl
75	30	Clay and sand
75	....	First water
105	95	Brown sand
200	7	Coarse dry sand
207	5	Quicksand
212	13	Brown sand
225	63.4	Brown water-bearing sand
288.4		

P. & N. T. Ry. well No. 4, at Hoover.

Depth	Thickness	
0	15	Surficial material
15	15	Red clay
30	20	White clay
50	25	White marl
75	....	First water
75	25	Clay and sand
100	100	Brown caving sand
200	7	Coarse dry sand
207	9.7	Quicksand

Depth	Thickness	
216.7	6.4	Brown sand; second water
223.1	61.9	Brown water-bearing sand
284		

P. & N. T. Ry. wells Nos. 1 and 2, at Pampa.

Elevation, 3234′ Depth to water, 355′

Depth	Thickness	
	4	Loam
4	16	Marl
20	82	Brown clay
102	45	Brown clay with streaks of sand
147	33	Dry pack sand
180	45	Brown clay
225	15	Pack sand
240	10	Yellow clay
250	60	Pack sand
310	63	Brown sand
355	....	First water
373	39	Brown water-sand
412		

HALE COUNTY.

P. & N. T. Ry. well No. 1, at Abernathy.

Elevation, 3361.5′

Depth	Thickness	
	75	Red clay
	2.5	Quicksand
	20	Red clay
	20	Red shale and soft sandstone
	5	Fine red sand, some water
	33	Water-bearing quicksand—10-15 gals. per min.
	17	"gyp" rock and limestone
	5	Soft sandstone
200		

**60 gals. per minute.

Alexander well.

Elevation, 3388.8′ Depth to water, 57′ (50′?)

Thickness	
50	Pit
20	Sand and boulders
10	Hard sand

Depth	Thickness	
	25	Soft sand
	10	Sand rock
	18	Soft sand

P. & N. T. Ry. well, at Alley.

Elevation, 3371.8′ Depth to water, 91′

Depth	Thickness	
	70	Red clay and limestone
	3.5	Rock, clay and some sand
	18	Red clay
	1.5	Red sandstone
	10.5	Clay
	2.5	Quicksand
106		

**10 gals. per minute

Dr. J. C. Anderson well (Layne & Bowler No. 5).

Elevation, 3382.4′ Depth to water, 20′

Depth	Thickness	
	16	Loam
	11.9	Soft rock
	16	Fine red sand
	1	Hard red sand
	1	Soft red sand
	3.2	Hard shale
	1	Soft shale
	7	Hard shale
	1	Soft shale
	13	Hard red sand
	31.5	Red sand
	3	Hard red sand
	128.5	Sand, becoming coarser
234		

J. Walter Day's well.

Elevation, 3417.5′ Depth to water, 56′?

Thickness	
56	Pit
6	Rock
24	Sand and boulders
25	Red clay
8	Sand
17	Red clay, sticky
2	Rock
20	Sand

Thickness	
2	Rock
20	Sand
6	Sand and gravel
1	Quicksand

**All strata Cenozoic

Ebeling well.

Elevation, 3424.2′ Depth to water, 25.7′

Thickness	
25	Pit
20	Rock
17	Soft red sand
43	Soft white sand
1	Rock
24	Pack sand

Eiring well.

Elevation, 3317.5′ Depth to water, 25′

Thickness	
25	Pit
5	Rock
10	Red sand
7	Clay
19	Sand and gravel
12	Clay
70	Pack sand
3	Coarse soft sand

Firth well No. 51.

Elevation, 3382.3′ Depth to water, 42′

Depth	Thickness	
	42	Pit
	17	Soft rock
	8	Sand and clay
	22	Red clay
	7	White clay
	8	Red clay
	20	Fine running sand
	10	Sand and boulders
	46	Yellow clay
	40	Yellow sand

P. & N. T. Ry. well No. 1, at Ferguson.
Elevation, 3394.5′

Depth	Thickness	
	30	Clay
	25	Rock
	18	Sand
73		

**10-12 gals. per minute

Garrison well.

Elevation, 3407.7′ Depth to water, 49.2′

Thickness	
47	Pit
20	White rock and gravel
25	Red clay
19	Sand
31	Sand rock
37	Gravel and sand
1	Red clay

Dr. Gidney well.

Elevation, 3375.1′ Depth to water, 19′

Thickness	
32	White chalk rock
23	Red clay
42	Sand and gravel
4	Clay
21	Water-bearing sand

**No. 5 Layne 16″ pump

P. & N. T. Ry. well No. 1, at Hale Center.
Elevation, 3424.3′

Depth	Thickness	
	60	Mixture of red and white clay (probably with some limestone)
	5	Quicksand
	5	Red clay
	10	Sandstone
	25	Red clay
	15	Soft red sandstone
	1	Red clay
121		

**60 gals. per minute

P. & N. T. Ry. well No. 2, Sectionhouse well at Hale Center.

Elevation, 3423′ Depth to water, 51′

Depth	Thickness	
	51	Mixture of red and white clay (probably with some limestone)
	9	Quicksand
	8	Red clay
	12	Porous, water-bearing, red sandstone
80		

**15 gals. per minute

A. E. Harp or Callahan well on Callahan County School Land.

Elevation, 3286.9′ Depth to water, 36.7′

Thickness	
36	Pit
5	White limestone
6	Red sand and gravel
20	Red clay
37	Fine sand
7	White clay
23	Red clay
19	Fine sand
4	Red clay
9	Coarse sand
13	White clay
24	Sand rock
31	Red clay

**Layne No. 6 pump. All strata Cenozoic.

H. E. Hollman well No. 1.

Elevation, 3348.1′ Depth to water, 37′

Depth	Thickness	
0	25	Soil and clay
25	3	"gyp" rock (probably limestone)
28	9	Red clay
37	2	Dry sand
39	1	"gyp" rock (probably limestone)
40	2	Sand
42	24	"gyp" rock (probably limestone)
66	9	Joint clay
75	20	"gyp" rock (probably limestone)
95	2	Clay
97	16	Sand and clay
113	119	Fine sand, becoming coarser
232		

H. E. Hollman well No. 2.

Elevation, 3347.1′ Depth to water, 38′

Depth	Thickness	
0	24	Soil and clay
24	4	Dry sand
28	2	"gyp" rock (probably limestone)
30	5	Dry sand
35	3	"gyp" rock (probably limestone)
38	3	Water-sand
41	27	"gyp" rock (probably limestone)
68	54	Fine red sand
122	4	"gyp" rock (probably limestone)
126	12	Sand
138	4	"gyp" rock and clay
142	66	Sand
208	2	Rock
210		

Howell well.

Elevation, 3324.4′ Depth to water, 26′

Thickness	
28	Pit
8	Rock
22	Clay
8	Red soft sand
4	Clay
48	Light pack sand
10	Soft sand
3	Hard sand
23	Red clay
10	Light sand
3	Red clay
6	Light sand
5	Gravel and sand
5	Coarse sand
13	Sand rock (probably Triassic)
1	Yellow clay
6	Rock

Hubbard well No. 53, N. E. corner, N. W. quarter, Sec. 110.

Elevation, 3338.5′ Depth to water, 39.5′

Thickness	
39.5	Pit
10	Limestone
12	Sand and clay
22	Red clay

Thickness	
8	Pack sand
23	Yellow clay
18	Red clay
8	Pack sand
18	Quicksand
46	White clay
12	Sand and gravel with rolled Cretaceous fossils

Morgan well, Sec. 8, Blk. J K 4.

Elevation, 3495.5′ Depth to water, 64′ (70′?)

Thickness	
64	Pit
6	Sand
12	Rock
25	Sand and boulders
31	Red clay
17	Soft sand
6	Hard sand
23	Soft sand
16	Coarse soft sand
1	Red clay

P. & N. T. Ry. well near Texas Land & Development Co. No. 1.

Thickness	
6	Soil
54	Red sandy clay
17	Coarse gravel, water-bearing
14	Red clay
2	White water-sand
16	Red clay
10	Brown water-bearing pack sand

**From 127-176 ft. fine sand and a wet hole. Seemed to be dry from 122-124 ft.

Perry's well at home place, south of Dowden's.

Elevation, 3401.8′ Depth to water, 47.7′

Thickness	
5.5	Soil
10	White clay
4	White and red clay, streaked
12.5	Red sand and clay
7	Light red sand
2	Rock
3	Red and white clay
5	Sand and clay

Thickness	
15	Sand and gravel; first water
12	Clay, shelly rock, and gravel
16	Red clay
9	Coarse water-sand
4	Sand and gravel
10	Quicksand
1	Red clay
12	Sand and gravel
11	White clay
3	Red clay
18	Sand and gravel
4	Quicksand

Perry well No. 1, southeast of Hale Center.

Depth to water, 78′

Thickness	
81	Pit
3	Light sand
2	Red clay
7	Red sand
8	Joint clay
4	Soft sand
2	Hard rock
25	Sand rock
23	Rocks and boulders
2	Blue clay
4	Joint clay
45	Red clay (perhaps Trias.)

**Very little water was ever developed in this well.

Dr. A. S. Scott well (Layne & Bowler No. 1).

Elevation, 3419.8′ Depth to water, 39′

Depth	Thickness		
0	13.3	Clay and gravel	
13.3	19	Sand	
32.4	7.7	Hard sand	
39	7	Rock	
46	2.9	Sand, spots of white rock	probably lime-
48.9	10.6	Pieces of white rock	stone concretions
59.5	0.5	Rock	
60	31	Sand	
91	4.5	Hard sand	
95.5	1.1	Hard rock	
96.6	2	Hard rock	
98.6	17.6	Fine red sand	

Depth	Thickness	
116.2	1	Hard sand
117.2	82.2	Sand
199.4	19.4	Sand with spots of shale
218.8	18.1	Coarse shale
238.9	11.6	Coarse sand
	2.	Boulders
	6	Clay
	9.6	Clay
	10	White rock
	18.8	Hard fine white rock
	5	Sand
	1	Rock
331.5		

Dr. Pearson well No. 3.

Elevation, 3318′

Depth	Thickness	
	25	Surface soil
	4.5	Clay and lime
	14	Clay
	10	Shale
	17	Lime rock
	8	Water-bearing sand and limestone
	10	Clay and sand
	5	Water-bearing sand
	13	Shale rock
	20	Shale
	5	Clay
	12	Water-bearing sand
	10	Water-bearing sandstone
	12	Shale
	16	Water-bearing sand
	3	Shale
	8	Water-bearing sandstone
	6	Clay
	13	Water-bearing sand
	19	Shale
	8	Clay
	4	Water-bearing sandstone
	8	Water-bearing sand
	5	Water-bearing sandstone
	23	Water-bearing sand and gravel
	5	Water-bearing sandstone
	15	Water-bearing sand and gravel
	13	Shale
289		

Dr. Pearson well No. 5.

Elevation, 3310.5′ Depth to water, 46′

Thickness	
3	Surface soil
9	Clay and lime
22	Sand
22	Lime and boulders, partly water-bearing
14	Sandstone
6	Clay
6	Hard sand with a little water
11	Shale
16	Soft water-bearing sandstone
7	Clay
13	Shale
18	Water-bearing sand
5	Water-bearing sandstone
6	Clay
19	Coarse water-bearing sand
7	Clay
23	Coarse water-bearing sand
14	Shale
7	Water-bearing sandstone
15	Water-bearing sand and gravel
8	Clay
13	Shale
22	Water-bearing sand and gravel
4	Clay
1	Hard sandstone

P. & N. T. Ry. sectionhouse well at Lider.

Elevation, 3334.6′ Depth to water, 40′

Depth	Thickness	
	20	Soil
	30	White rock (limestone)
	5	Hard sand
55		

Slaton well.

Elevation, 3402.1′ Depth to water, 20′

Thickness	
21	Pit
15	Water sand
6	White chalky rock
42	Red clay
32	Quicksand
2–	Hard flint rock
8	Quicksand

Snyder well.

Elevation, 3388.2′ Depth to water, 57.5′

Depth	Thickness	
		Pit
	23	Rock, gravel and sand
	20	Reddish clay
	4	Hard lime rock
	10	Clay
	36	Gravel, sand and second water
	6	Clay
	18	Colored gravels or waterworn igneous rocks and sand (base of Tertiary)
	37	Tough, dark red clay
	40	Colored gravel and sand
250		

Dr. Stewart (Sterrett?) well.

Elevation, 3341.3′ Depth to water, 42′

Thickness	
42	Pit
7	Soft sand
3	Hard rock
16	Soft sand
22	Red clay
21	Soft sand
12	White clay
12	Rock
3	White clay
14	Pack sand
7	Hard rock
20	Pack sand
21	Soft sand
8	Coarse soft sand
13	Gravel
1	Yellow clay

Van Howeling's well, 4 miles south of Plainview.

Depth to water, 45′

Thickness	
45	Pit
8	White sand
2	White clay
8	Red sand
22	Red clay
22	Fine sand
2	Sand and clay
31	Fine sand

**All strata Cenozoic

Dr. Wayland well, N. W. corner of northeast quarter, Sec. 24.
Elevation, 3487.9′ Depth to water, 62′

Depth	Thickness	
0	5	Soil
5	4	Light brown clay
9	2	White, decomposed rock
11	35	Red clay
46	4	Gray putty clay
50	45	Gray rock, first water at 62 ft.
96	30	Red shale
125	20	"conglomerate" red shale with seams of sand
145	4	Red sand
149	13	Flowing water-bearing sand
162	10	Sand rock
172	38	Clay with streaks of sand
210	5	Sand rock
215	2	Coarse water-bearing gravel
217	43	Fine, compact, water-bearing sand
260	16	Coarse, compact, water-bearing sand
276		

Dr. R. R. White well No. 1.
Elevation, 3348.1′

Depth	Thickness	
0	20	Soil and clay
20	2	"gyp" rock (probably limestone)
22	10	Red clay
32	2	Sand
34	3	"gyp" rock
37	3	Sand
40	14	"gyp" rock
54	2	Sand
56	6	Clay and "gyp"
62	6	"gyp" rock
68	1	Sand
69	3	"gyp" rock
72	118	Sand
190		

Dr. R. R. White well No. 2 (Layne & Bowler No. 4).
Elevation, 3347.4′

Depth	Thickness	
	33.8	Loam and sandy clay
	2	Clay
	1	Rock
	8	Sand rock
	1	Soft rock

Depth	Thickness	
	1	Sand
	1	Rock
	11.9	Sand
	7	Clay
	12.5	Soft rock
	0.5	White rock
	88.4	Red rock
	25.6	Sand, clay, and soft rock
	16	Clay
	33.8	Coarse sand
	17.8	Coarse sand and red clay
	32.7	Coarse sand
	17.8	Coarse sand and red clay
	32.7	Coarse sand
	31	Gumbo (perhaps Triassic)
325.9		

HEMPHILL COUNTY.

P. & T. Ry. east well, at Mendota.
Depth to water, 12′

Depth	Thickness	
0	5	Brown sand
5	7	Clay
12	6	Sand, gravel and water
18	42	Sand, gravel, clay and small amount of water
60	30	Sand, gravel, and water
90		

P. & N. T. Ry. west well, at Mendota.
Depth to water, 10.2′

Thickness	
5	Brown sand
5	Clay
31	Sand and gravel, water-bearing quicksand

HOCKLEY COUNTY.

P. & N. T. Ry. west well, opposite Station 1376.
Depth to water, 20′

Depth	Thickness	
0	15	Brown clay
15	27	Fine red sandy clay; struck first water at 25′
42	23	Light brown sand and gravel
65	5	Fine sandy clay

Depth	Thickness	
70	10	Brown sandy clay
80	20	Blue sandy clay
100		

**60 gals. per minute at 47 ft.

P. & N. T. Ry. well in Roundup yards opposite Station 1272.

Elevation, 3330′± Depth to water, 71′

Depth	Thickness	
0	50	Sandy clay
50	25	Red clay
75	7	Brown sand; struck water at 75 ft.
82	18	Yellow clay
100		

**20 gals. per minute at 85 ft.

P. & N. T. Ry. east well, at Roundup sectionhouse.

Elevation, 3330′± Depth to water, 74′

Depth	Thickness	
0	5	Light-colored clay
5	20	Marl
25	53	Red sandy clay
78	6	Brown water-sand; struck first water at 78 ft.
84	2	Red clay
86	4	Brown water-sand; struck second water at 86 ft.
90	12	Red clay
102		

**42 gals. per minute at 98 ft.

P. & N. T. Ry. west well, at Roundup sectionhouse.

Elevation, 3330′± Depth to water, 74′

Depth	Thickness	
0	6	Red clay
6	19	Marl
25	11	Red clay
36	14	Light-colored clay
50	28	Dark-colored clay
78	6	Brown water-sand; struck first water at 78 ft.
84	2	Red clay
86	4	Sand and gravel; struck second water at 86 ft.
90	8	Red clay

**42 gals. per minute at 90 ft.

P. & N. T. Ry. well, at Roundup station opposite Station 1280.

Elevation, 3330′ Depth to water, 75′

Depth	Thickness	
0	3	Sandy loam
3	30	White marl
33	47	Red sandy loam; 6 gals. per minute at 75 ft.
80	65	Yellow clay; 3 gals. per minute at 125 ft.
145	21	Blue clay (Comanchean?)
156	2	Gray sand rock
168	1	Blue clay
169	15	Gray sand rock; 3 gals. salty water per min. at 175 ft.
184	1	Blue clay
185	13	Gray sand rock (Triassic)
198	12	Blue clay
210	11	White sand rock
221	8	Coarse dry gravel
229	8	Red clay
237	11	Blue sandy clay
248	117	Red clay
365	8	Brown sandy clay
373	7	Blue-gray sand; flow of very salty water
380		

LAMB COUNTY.

Littlefield well just east of stockyards, at Littlefield, Labore 20.

Depth to water, 78′

Thickness	
78	Pit
8	Sand and some clay
9	Coarse red sand
13	Coarse gravel and sand, consolidated
4	Yellow clay
6	Red clay
20	Yellow clay

**Because well would not yield sufficient water, it was "shot" and therefore ruined.

Littlefield well, 2 miles north of Littlefield, Labore No. 10, League 64.

Depth to water, 69′

Depth	Thickness	
	78	Pit (water rose 9 ft. in this)
	8	Sand and clay
	9	Coarse red sand
	13	Coarse gravel and sand with worn Comanchean *Gryphaea* shells

Depth	Thickness	
	4	Yellow clay (Triassic?)
	6	Red sand
	20	Yellow clay
165		

Geo. W. Littlefield well No. 1, northeast portion of town of Littlefield.

Depth	Thickness	
0	30	Soil and clay
30	9	Dry red sand
39	7	Rock
46	8	Dry sand
54	14	Rock
68	10	Sand and clay
78	12	Water-bearing sand
90	35	Clay (Triassic?)
125	12	Rotten shale
137	3	Sand and rock
140	8	Gray sand
148	5	Flint rock
153	7	Hard sand rock
160	30	Loose sand
190		

**Very little water in this well.

Geo. W. Littlefield well No. 2, at Yellowhouse, 6 miles southeast of Littlefield.

Elevation, 3409′± Depth to water, 48′

Depth	Thickness	
0	3	Surface soil
3	32	Red clay
35	10	Soft "gyp" rock (probably limestone)
45	3	Joint clay
48	22	Fine red water-bearing sand
70	11	Fine gray water-bearing sand
81	24	Coarse gray water-bearing sand
105	1	Sand rock
106	14	Coarse gray sand
120	5	Fine gray pack sand
125	13	Coarse gray water-sand
138	1	Clear white sandstone
139	7	Gray water-bearing sand
146		

Littlefield well No. 2, near Yellowhouse railroad station, Labore 11, League 665. This well is the one farther away from the station.

Depth to water, 44′ (first water struck at 48′)

Depth	Thickness	
	48	Pit
	5	Red sand
	2	Soft limestone
	15	Dry white sand
	2	Soft lime rock
	36	Red sand
	12	Pale red clay
	6	Red sand
	4	Soft lime rock
	5	Red sand
	3	Sloping lime rock
	5	Red clay
	5	Yellow clay, probably succeeded by red beds of Triassic
148		

P. & N. T. Ry. east well, at Littlefield.

Elevation, 3515′ Depth to water, 72′

Depth	Thickness	
0	7	Soil
7	27	Light red clay
34	21	White marl
55	62	Yellow clay; first water struck at 80 ft.
117	8	Variegated clay
125	27	Blue clay
152	2	"cap rock"
154	16	White clay and gray sand; struck water at 154 ft., raised to 145 ft.
170	5	White sand
175	10	Coarse sand and pebbles
185	5	Fine sand
190	10	Fine sand
200	10	White sandy clay
210		

**25 gals. per min, at 160 ft., decreasing to 12 gals. per min.

P. & N. T. Ry. well at north edge of lagoon at Littlefield.

Elevation, 3515′ ± Depth to water, 81′ (?)

Depth	Thickness	
0	5	Adobe
5	13	Light brown clay

Depth	Thickness	
18	40	Red clay
58	2	Dark brown clay
60	5	Light yellow clay and gravel
65	5	Hard rock
70	5	Light yellow clay
75	5	Gravel
80	30	Yellow clay; first water at 81 ft.
110	7	Brown sand; second water at 111 ft.
117	5	Dark red clay
122	13	Light yellow clay
135	25	Blue clay
160	3	"cap rock"
163	10	Light yellow clay
173	1	Gravel; third water at 173 ft.
174	19	Light yellow clay
193	7	White water-sand; fourth water at 193 ft.

**42 gals. per minute at 171 ft.

Perhaps all Triassic below 120 ft.

P. & N. T. Ry. well at south end of Wye at Littlefield.

Elevation, 3315′± Depth to water, 81′ (?)

Depth	Thickness	
3	3	Adobe
3	39	Red sandy clay
42	18	Light-colored sandy clay
60	15	Hard rock
75	21	Light red sandy clay; struck first water at 81 ft.
96	18	Light yellow clay
114	6	Brown sand; struck second water at 114 ft.
120	18	Yellow clay
138	23	Blue clay
161	3	"cap rock"
164	3	Blue clay
167	3	Dark gray soft sand rock
170	9	White sandy clay
179	17	Coarse sand and gravel; third water at 179 ft.
196	4	Blue clay
200		

**33 gals. per minute at 179 ft.

P. & N. T. Ry. west well at Littlefield.

Elevation, 3315′± Depth to water, 72′

Depth	Thickness	
0	4	Brown sand
4	12	Brown sandy clay

Depth	Thickness	
16	36	Red sandy clay
52	16	White marl
68	12	Yellow clay
80	2	Clay and sand; 8 gals. per min. at 80 ft.
82	48	Yellow clay
130	20	Blue clay
150	2	"cap rock"
152	6	Blue sandy clay
158	12	White sandy clay
170	20	Coarse sand and gravel

**15 gals. per min. at 170 ft.

LUBBOCK COUNTY.

P. & N. T. Ry. wells Nos. 1 and 2, at Lubbock.

Elevation, 3241'± Depth to water, 80'

Depth	Thickness	
	63	Red clay and limestone
	3	Water-bearing gravel and sand
	12	Red clay
	4	Water-bearing gravel
	36	Red clay with some sand
	4	Quicksand
	9	Coarse water-sand
	7	Water gravel and sand
	3	Sandstone (probably)
143		

**65 gals. per minute.
Well No. 2 yielded 75 gals. per minute.

P. & N. T. Ry. sectionhouse well, at Lubbock Junction.

Elevation, 3207' Depth to water, 45'

Depth	Thickness	
	6	Red soil
	24	"Gyp" rock (probably limestone)
	15	Red clay
	15	Sandy clay
	6	Quicksand
	2	"gyp" rock (probably limestone)
	4	Sandy clay
72		

**10-15 gals. per minute

P. & N. T. Ry. well No. 1, at Posey.

Elevation, 3190'± Depth to water, 105'

Depth	Thickness	
	10	Red clay
	60	Lime rock
	20	White clay
	10	Quicksand
	30	Light gray clay
	15	Soft, yellow, water-bearing sandstone
	35	Limestone
	20	Blue sand and shale; caves badly
	20	White shale and sand
	10	Red clay; caves badly
	20	Red clay
250		

**Both wells abandoned.
No. 1 tested 20 gals. per min.; No. 2, 10 gals.

P. & N. T. Ry. well opposite Station 1120.

Depth to water, 22'

Depth	Thickness	
0	40	Yellow sandy clay
40	28	Fine yellow sand; first water at 40 ft.
68	12	Coarse sand and gravel
80	10	Yellow clay
90	10	Blue clay
100		

**At 70 ft. pumped 100 gals. per minute, which lowered water level to 30 ft.

P. & N. T. Ry. sectionhouse well, at Slaton.

Elevation, 3123' Depth to water, 86.5'

Thickness	
6	Soil
20	Chalk rock
32	Sandstone
34	Packsand
3	Quicksand
3	Clay
1	Gravel and sand

P. & N. T. Ry. water station well No. 1, at Slaton.

Elevation, 3152'

Thickness	
80	Lime rock
16	Red clay

Thickness	
30	Quicksand
10	Water sand and gravel
13	Red clay
2	Limestone

**Wells at Slaton from 50-63 gals. per min.
Water level in No. 2 is 95 ft.

P. & N. T. Ry. water station well No. 12, at Slaton.

Elevation, 3152′± Depth to water, 95′

Thickness	
10	Red clay
70	Gyp rock
20	Red sandy clay
20	Quicksand
7	Coarse water-sand with a little gravel
3	Coarse sand and gravel
10	Red sandy clay
10	Pack sand
5	Quicksand

P. & N. T. Ry. well No. 13, at Slaton (abandoned).

Elevation, 3127′±

Depth	Thickness	
	30	Light-colored clay
	10	Clay and boulders
	50	Red clay
	17	Quicksand—some water
	23	Clay and "gyp" rock
	35	Limestone
	3	Gray sand
	32	Blue shale
	5	Gray quicksand—some water
	35	Red clay (Triassic)
	15	Light gray clay
	10	Gray sandstone
	70	Red clay
	20	Brown sandstone—some water
	75	Red clay
	3	Shells—a little salt water
	87	Red clay
	35	Light reddish-gray sandstone
	10	Dark gray sandstone
600		

**Water in well is salty.

Scott test well No. 1, at Lubbock.

Depth to water, 60 ft.

Depth	Thickness	
0	4	Soil
4	8	Light clay
12	8	Red clay
20	15	Red compact sand
35	5	"gyp" rock (probably limestone)
40	12	Gray compact sand
52	14	Rock (struck first water at base, raised 5 ft)
65	23	Water-bearing rock, sand, and gravel
88	22	Yellow clay
110	38	Bluish clay
148	2	Hard sand rock with water underneath
150	30	Water-bearing gray sand and gravel
180	80	Red clay with blue streaks (probably Permian)
260		

**Second water rose to 85 ft. below surface.

Wortham test well on League No. 4, San Augustine County School Land.

Depth to water, 60′

Thickness	
8.5	Soil
11.5	Clay
10	Soft rock
15	Soft sandstone and boulders
22	Soft sandstone (first water at base)
3.5	Water-bearing sand
5	Sandy clay
9.5	Water-bearing gravel
3	Water-bearing quicksand
0.1	Sandstone
9.9	Water-bearing gravel
3	Sandy clay
7	Water-bearing quicksand
1	Water-bearing sand
21.5	Clay
6.5	Water-bearing sand
4	Clay
20	Sandy clay and magnesia
3	Water-bearing gravel
11	Water-bearing sand
1	Water-bearing pack sand
8	White sandy clay
4	Sand with clay pockets
8	Water-bearing sand

Thickness	
11	Sandy clay and magnesia mixed with water-worn gravel
4	Cemented gravel
20	Red clay
6	Sand
13	Clay

LYNN COUNTY.

P. & N. T. Ry. well No. 1, at Dune (abandoned).

Elevation, 3165′± Depth to water, 95′ and 200′

Depth	Thickness	
	35	Red clay
	10	Limestone
	25	"gyp" rock (probably limestone)
	25	Red clay
	8	Quicksand—5 gals. water per minute
	7	Yellow clay
	40	Blue clay
	50	Limestone
	25	White clay
	5	Limestone, shells
	15	Soft gray sand, shells; 5 gals, per min. (Triassic?)
	5	Blue clay
250		

P. & N. T. Ry. well No. 1, at O'Donnell (abandoned).

Elevation, 3096′±

Depth	Thickness	
	45	"gyp" rock (probably limestone)
	5	Limestone
	30	"gyp" rock (probably limestone)
	5	Limestone
	5	Soft yellow clay
	40	Limestone
	55	Blue clay (Triassic)
	15	Cemented red gravel
	30	Red clay
	20	Water-bearing gray sandstone
	3	White clay
253		

**10 gals. per min. of salty water, unfit for boiler use.

P. & N. T. Ry. well No. 1, at Skeen.
Elevation, 3070′±

Depth	Thickness	
	10	Red sandy clay
	10	"gyp" rock (probably limestone)
	48	Bluish yellow clay
	2	Small gravel
	20	"gyp" rock (probably limestone)
	2	Blue shale (probably Triassic)
	13	Gray limestone
	70	Blue shale
	5	Water-bearing gravel
180		

**Water extremely salty, and well abandoned.

P. & N. T. Ry. Tahoka well No. 1 (abandoned).
Elevation, 3137′±

Depth	Thickness	
	30	Red clay
	5	Limestone
	25	"gyp" rock (probably limestone)
	5	Limestone
	15	Red clay
	10	Quicksand
	10	Yellow clay
	40	Blue shale
	55	Limestone
	5	Coarse water-bearing sand
	10	Fine gray sandstone
	3	Coarse gray sand
	2	Blue shale
215		

**8-10 gals. per minute

P. & N. T. Ry. well No. 2, at Tahoka (abandoned).
Elevation, 3142′± Depth to water, 86′

Depth	Thickness	
	10	Sandy clay
	10	"gyp" rock (probably limestone)
	50	Red clay
	16	Pack sand
	19	Quicksand
105		

**20 gals. per minute at 101 ft.

P. & N. T. Ry. well No. 3, at Tahoka.

Elevation, 3143′ Depth to water, 85′

Depth	Thickness	
	10	Sandy clay
	10	"gyp" rock (probably limestone)
	50	Red clay
	16	Pack sand
	24	Quicksand
110	....	Yellow clay

**25 gals. per minute at 101 ft.

P. & N. T. Ry. sectionhouse well No. 4, at Tahoka.

Elevation, 3136′ Depth to water, 65′

Depth	Thickness	
	9	Sandy clay
	13	"gyp" rock
	43	Pack sand
	15	Quicksand
80		

**7 gals. per minute.

POTTER COUNTY.

P. & N. T. Ry. well No. 1, at Amarillo, S. W. corner of quadrangle.

Elevation, 3683′± Depth to water, 210′

Depth	Thickness	
5	5	Soil
5	60	Clay
65	73	Sand
138	92	Gray sand
230	54	White water-sand; water struck at 230 ft.; raised to 210 ft.
284	8	Red clay
292	13	Red and white clay
305		

**52 gals, per min. at 260 ft. in No. 2
50 gals. per min. at 256 ft. in No. 3
45 gals. per min. at 256 ft. in No. 4
52 gals. per min. at 263 ft. in No. 5
52 gals. per min. at 263 ft. in No. 6
52 gals. per min. at 261 ft. in No. 7
52 gals. per min. at 265 ft. in No. 8

In No. 9, water level at 244 ft.; pumped 45 gals. per min. at 306 ft.

In No. 10, struck water at 243 ft.; pumped 28 gals. per min. from 291 ft.

In No. 11, water level at 218 ft.; top of sand, 248 ft.; bottom of sand, 282 ft.

In No. 12, water level at 212 ft.; top of sand, 240 ft.; bottom of sand, 285 ft.

P. & N. T. Ry. well No. 8, at Amarillo.

Elevation, 3683′± Depth to water, 210′

Depth	Thickness	
0	5	Soil
5	60	Clay
65	73	Sand
138	92	Gray sand
230	....	Struck water which rose to 210 ft.
230	54	White water-sand
284	2	Red clay
286		

P. & N. T. Ry. well No. 1, at St. Francis, east well at Bridge 4; 7,300 ft. from St. Francis.

Depth	Thickness	
0	2	Black sand
2	5	White marl
7	43	Light-colored clay and sand
50	100	Red clay and caving sand
150	25	Light-colored clay and sand
175	25	Brown clay and sand
200	53	Caving dry sand and gravel
253	35	Red clay
288	21	Red water-bearing sand
309	5	Red clay
314		

**17 gals. per minute

P. & N. T. Ry. well No. 1-E, at St. Francis.

Elevation, 3581′ Depth to water, 299′

Depth	Thickness	
0	5	Clay
5	40	Marl
45	80	Sandy clay
125	20	Dry gray sand
145	30	Red sand
175	20	Dry, gray, coarse sand
195	31	Dry coarse gravel
226	15	Dry gray sand
241	58	Dry red clay
299	3	Coarse gravel—12 gals. per minute
302	17	White, water-bearing, pack sand

Depth	Thickness	
319	11	Red clay
330	35	Red clay
365	15	Sand rock
380	164	Dry red clay
544	5	Brown water-sand; water rose to 364 ft.
549	2	Red clay
551	7	White water, sand
558	18	Red clay
576		

**550 gals. per minute

QUAY COUNTY.

C. B. Clegg well, west side of Sec. 16, Twp. 5N, R29E.

Depth to water, 16.5′

Depth	Thickness	
0	6	Soil
6	6	Light soil
12	45	White shattered limestone
16.5	13	Water-bearing sand and gravel
29.5	9	Red clay (Triassic)
38.5	11	Hard gray sandstone
49.5	2	Blue clay
51.5	8.5	Red clay
60	27	Layers of red sandstone
87	2	Red clay
89	65	Layers of red sandstone
154	9	White pack sand with a little water
163	4	Sandstone
167	4.5	Gray sand; water first rose to 32 ft. and afterwards to 19 ft.
171.5	9.5	Pink sandy clay
181	7	Pink sandstone
188	....	Red clay

RANDALL COUNTY.

P. & N. T. Ry. well No. 1, at Canyon City (in draw).

Depth to water, 70′

Depth	Thickness	
0	3	Soil
3	37	White marl
40	30	Light clay
70	10	Light clay
80	3	Clay and sand; 3 gals. water per minute

Depth	Thickness	
83	5	White marl
88	32	Red clay (Triassic?)
120	10	White clay
130	10	Red clay
140	165	Red and white clay
305	....	Second water
305	35	White sand rock
340	5	Light brown sand rock
345	15	Red clay
360	5	Light brown sand rock
365	10	Red clay
375	55	Light brown sand
430		

**80 gals. per minute at 220 ft.

Miller well No. 1, Tyler Tap R. R. Co., Sec. 24, Blk. A, in bed of Palo Duro Canyon, 7 mi. above Canyon City, and 18 mi. S. W. of Amarillo.

Depth	Thickness	
0	7	Cellar
7	33	Red clay
40	15	Sand; heavy stream of fresh water rose within 8 ft. of surface
55	30	Red shale (Triassic)
85	40	Blue shale
125	195	Red and blue shale
320	40	Water sand
360	10	Red shale
370	65	Water sand
435	10	Red shale (Permian)
445	15	Yellow mud
460	5	Red shale
465	20	Yellow shale
485	25	Red shale
510	20	Gray shale
530	20	Red shale
550	15	Sand
565	20	Red shale
585	10	Sand
595	35	Red sand and shale
630	10	Salt water and sand
640	15	Red shale and sand
655	90	Light red mud
745	5	Sand
750	15	Hard limestone
765	175	Light red shale
940	230	Rock salt and red shale

Depth	Thickness	
1170	15	White limestone
1185	95	Red sand with gypsum water
1280	12	Limestone
1292	28	Red shale
1325	60	Brown sand
1385	5	Red shale
1390	40	Rock salt
1430	5	Dark gravel, shale
1435	65	Solid salt
1500	8	Limestone
1508	22	Rock salt
1530	14	White limestone
1544	20	Blue shale, sulphur
1565	5	Red shale and salt
1570	15	Salt; some shale
1585	25	Solid salt
1610	25	Hard limestone
1635	45	Salt
1680	15	White limestone
1695	5	Blue limestone
1700	10	Blue mud and salt
1710	10	Blue and brown salt
1720	20	Blue limestone and some water
1740	5	Blue shale
1745	80	Hard limestone
1825	5	Red mud
1830	120	Salt
1950	65	Blue limestone
2015	3	Blue shale
2018	7	Limestone
2025	180	Salt
2205	5	Brown shale
2210	2	Limestone and blue shale
2212	103	Salt
2315	125	Limestone
2440	40	Salt
2480	50	Limestone
2530	45	Red and blue shale
2575	....	Very sticky, dark shale

**Probably most of what is reported as limestone is really anhydrite.

ROBERTS COUNTY.

P. & N. T. Ry. well at Miami.

Elevation, 2802′ Depth to water, 38′

Depth	Thickness	
0	14	Dry clay
14	4	Dry sand
18	2	Dry gravel
20	14	Dry clay
34	17.6	Sand and small gravel
50	10	Tough dry yellow clay
	38	Sandy dry yellow clay
	9	Fine brown water-sand
	8	White clay
	5	Tough yellow clay
120		

**Normal water level when 50 ft. deep was 46 ft. After drilling to 120 ft., the water stood at 42 ft.

ROOSEVELT COUNTY, NEW MEXICO.

Portales Valley well No. A-0 (powerhouse well).

Elevation, 4006′± Depth to water, 22′

Depth	Thickness	
	20	Pit
	10	Gray clayey sand
	11	Light red pack sand
	5	White sand and gravel
	6	Dark red pack sand to 54 ft.
	9	Quicksand
	11	Coarse sand
	9	Sand rock
	7	Clayey sand
	6	Cemented sand
	11	Gravel
	8	Clay
115		

Portales Valley well No. A-2 (J. E. Morrison).

Depth to water, 18.5′

Depth	Thickness	
	17.5	Pit
	25	Clay and sand
	10	Sand and boulders
	11	Pack sand

Depth	Thickness	
	6	Reddish clay
	6	Gravel and sand
	4	Sticky clay
	7	Joint clay
	5	Sand and gravel
	11.5	Creek gravel
	14	Clay
78		

Portales Valley well No. A-4 (Lindsay).

Depth to water, 21.5′

Thickness	
21.5	Pit
23	Clayey loam
20	Flint clay
16	Quicksand
22	Gravel-bearing pack sand
6	?
0.7	Rock
3	Gravel
6	Clay-gravel
....	Clay

Portales Valley well No. A-5 (Heck) P. L. & D. Co.

Depth to water, 20′

Thickness	
19	Pit
36	Red sand and clay
13	Sand and gravel
9	Flint rock
6	Gravel
....	Red clay

Portales Valley well No. A-10 (Chas. Stimmett).

Depth to water, 18′

Depth	Thickness	
	17	Pit
	5	White sand and boulders
	3	Red sand
	20	Clay, boulders and sand
	13	Sand and boulders
	5	Red sand
	3	Clay and sand
	28	White gravel and sand
	7.5	Gravel
	5	Clay
107		

Portales Valley well No. A-11 (Moss).

Depth to water, 20.5′

Depth	Thickness	
	20.5	Pit
	20	Sticky red clay
	10	Yellow clay and sand
	11	Sand and boulders
	8	Clay and gravels
	5	Creek gravel
	5.5	Red clay
80		

Portales Valley well No. A-12 (Farnahan).

Depth to water, 19′

Depth	Thickness	
	18.5	Pit
	8	Sand and boulders
	14	Sand, clay and boulders
	10	Clay and gravel
	3	Pack sand
	9	Sand and gravel
	4	Black clay and sand
	6	Creek gravel
	1	Hard rock
	3	Red clay
	5	White clay and rock
	2	Sand and gravel
	7.5	Red clay
92		

Portales Valley well No. A-13 (Flue Anderson).

Thickness	
22?	Pit
12	Sand and gravel
14	Pack sand and gravel
2	Light sand rock
17	Sand and clay
10	Cement and boulders
2	Sand rock
4	Pack sand
8	Creek gravel
6	Red clay

Portales Valley well No. A-13 (S. & A., P. L. & D. Co.).

Depth to water, 23′

Thickness	
22	Pit
12	Sand and gravel

Thickness	
14	Pack sand
2	Light sand rock
17	Sand rock and clay
10	Cement and boulders
2	Sand rock
4	Pack sand
8	Creek gravel
6	Red clay

Portales Valley well No. A-14 (R. W. Jones).

Thickness	
21	Soil and pit
2	Sand
16	Gray sandy rock and sand
10	Light yellow clay and gravel—no water
12	Light sand rock
6	Sand and shell rock
5	Sand rock
	**Cemented sand and shells of sand rock of 97 ft.

Portales Valley well No. A-15 (Jim Green).

Depth to water, 25′

Depth	Thickness	
	24	Pit
	15	Red sand and boulders
	2	Gravel
	8	Clay and gravel
	5	Soft sand rock
	5	Joint clay
	3	Loose sand
	6	Clay and creek gravel to 68 ft.
	6	Sand rock
	3	Red clay
	12	Pack sand
	2	Clay and gravel
	3	Sand
	7	Creek gravel
	6	Clay
108		

Portales Valley well No. A-16 (O'Neil).

Depth	Thickness	
	31	Pit
	11	Pack sand and boulders
	4	Gravel and clay

Depth	Thickness	
	15	Red sand and boulders
	5	Clay
	15	Gravel, sand, and clay
	9	Sand and gravel
	4	Soft sand rock
	3	Clay and gravel
	2	Sand and gravel
	7	Creek gravel
	7	Clay
110		

Portales Valley well No. A-18 (Oldham east well).
Depth to water, 29.5′

Depth	Thickness	
	29	Pit
	12	Sand and boulders
	11	Red sand and gravel
	10	Gray sand and some gravel
	15	Soft sand rock
	1	Hard rock
	1	Sticky yellow clay
	1	Well worn white gravel
	1	Clay
	2	Water-worn white gravel
	1	Large sand boulders
	8	Creek gravel
	5	Clay
100		

Portales Valley well No. A-19 (Oldham south well).
Depth to water, 33′

Depth	Thickness	
	33.5	Pit
	15.5	Sand, clay and boulders
	10	Red sand
	6	Red clayey sand
	5	Soft sand rock
	1	Hard rock
	10	Gray clayey sand
	4	White sand and gravel
	4	Pack sand
	6	Water-worn gravel
	6	Clay
100		

Portales Valley well No. A-20 (Oldham west well).
Depth to water, 36.5′

Depth	Thickness	
	34.5	Pit
	30	Red sand
	4	Gray sand
	4	Flint rock
	6	Gray sand
	5	Pack sand
	1	Sand rock to 85 ft.
	1	Red clay
	5	Sand
	10	Creek gravel
	1	Yellow clay
	3	Clay and gravel
110	....	Reddish-gray clay

Portales Valley well No. A-21 (Sanders).
Depth to water, 29.5′

Thickness	
29	Pit
7	Lime rock
3	Water-worn gravel
5	Clay and gravel
3	Clay and gravel with water
2	Gravel
5	Red sand
15	Laminated sand
5	Pack sand
7	Clay and partly worn gravel
2	Sand
10	Gravel
5	Clay
15	Clay

Portales Valley well No. A-22 (Will Neil).
Depth to water, 28.5′

Depth	Thickness	
	28	Pit
	6	"gyp" (probably limestone)
	4	Red sand
	10	Clay and gravel
	6	Gray sand and gravel
	15	Rock, sand, and laminated sand
	5	Sand rock
	6	Sand

Depth	Thickness	
	3	Sand and clay
	11	Gravel
	7	Clay
100		

Portales Valley well No. B-1 (J. P. Stone).
Depth to water, 27′

Thickness	
23	Pit
4	Soft sand rock
3	Quicksand
5	Yellow and white sand
5	Light sand rock
21	Red sand and some gravel
8	Red sand and clay
9	Sand and gravel
17	Clay

Portales Valley well No. B-2 (Steed).
Depth to water, 40′

Thickness	
38	Pit
28	Quicksand
10	Pack sand
8	Creek gravel
2	Sand rock
4	Creek gravel
10	Red clay

Portales Valley well No. B-4 (Burke).
Depth to water, 49′

Depth	Thickness	
	46	Pit
	34	Red quicksand
81	15	Pack sand
	3	Yellow clay
	8	Clay and gravel
	3	Hard rock
	5	Red clay

Portales Valley well No. C-1 (Jackson and Merrill).

Depth	Thickness	
	16	Pit
	33	White sand
	10	Gravel and sand
	2	Block clay

Depth	Thickness	
	5	Gray sand and gravel
	3	Quicksand
	3	Gravel and sand
	8	White clay
	4	Blue "granite" (probably hard sandstone)
	4	Gray flint
	3	White gravel
	4	Creek gravel
	5	Red clay
100		

Portales Valley well No. C-2 (Reese west well).

Depth	Thickness	
	20	Pit
	20	Red sand and boulders
	15	Pack sand and clay
	5	Sand and boulders
	10	Sand and clay
	8	Creek gravel
	6	Red clay
	1	Rock
	6	Pack sand
103	....	Clay

Portales Valley well No. C-3 (Hicks).

Depth	Thickness	
	28	Pit
	10	Red sand and boulders
	8	Red clay
	8	Pack sand
	2	Creek gravel
	8	Creek gravel and red clay
	20	Stiff red clay
	6	Clay and gravel
	8	Red clay
	10	Creek gravel
	10	Red clay
	3	Quicksand
115		

Portales Valley well No. C-4 (Merrill, Rogers & Cave).

Depth	Thickness	
	30.7	Pit
	15	Red sand and boulders
	8	Pack sand
	17	Creek gravel

Depth	Thickness	
	2	Red clay
	4	Creek gravel and clay
	6	Gravel
	3	Red clay
	10	Gravel
	5	Large gravel
	5	Gravel and clay
	0.5	Clay
	4	Gravel
	5	Pack sand
125		

Portales Valley well No. C-6 (Carr).
Depth to water, 18.9′

Depth	Thickness	
	17.3	Pit
	30	Rock
	20	Red clay
	6.5	Clay and gravel
	4	Gravel and sand
	14	Red clay
	16	Creek gravel
	5	Clay
108		

Portales Valley well No. C-7 (Boyd).

Depth	Thickness	
	28	Pit
	17	Sand
	38	Sand and gravel
	10	Gravel
	18	Sand and gravel
	5	Clay
115		

Portales Valley well No. C-8 (Hopper, et al.).
Depth to water, 26.7′

Depth	Thickness	
	25	Pit
	15	Sand rock
	5	Chalk rock
	12	Gray sand rock
	10	Good gravel
	8	Sand rock
	8	Dark sand and gravel
	6	Coarse medium gravel
	6	Clay
95		

Portales Valley well No. C-9 (Coppage).

Depth	Thickness	
	39.3	Pit
	8	Sand rock
	5.	Gravel
	4	Hard rock
	5	Chalk rock
	8	White pack sand
	10	Gray sand
	8	Clay and sand
	5	Dark red sand
	42	Clay
	13	Clay
145		

Portales Valley well No. D-1 (Burgess Fisher).

Depth to water, 22.5′

Depth	Thickness	
	20.5	Pit
	14.5	"Gyp" (lime?)
	15	Sand and boulders
	5	Hard lime rock
	5	Red sand rock
	2	Flint boulders
	4	Red clay
	5	Creek gravel
	10	Yellow clay
	15	Blue clay with lime boulders
	7	Red clay
105		

Portales Valley well No. D-3 (Walter Morris).

Depth to water, 21′

Thickness	
18	Pit
5	White sand
14	Red sand and boulders
4	White sand and boulders
13	Quicksand
7	Pack sand
1	Red sand and boulders
4.5	Creek gravel
1.5	Gummy pack sand
4	Creek gravel
3	Red clay
27	Sand and clay

Portales Valley well No. D-4 (Stevenson).
Depth to water, 22′

Depth	Thickness	
	20	Pit
	17	Red sand and boulders
	10	"Gyp" (probably limestone)
	8	Clay and sand
	12	Pack sand
	10	Sand and boulders
	11	Pack sand
	2	Red clay to 90 ft.
	7	Creek gravel
105		

Portales Valley well No. D-6 (Holmes, P. L. & D. Co.).
Depth to water, 48′

Depth	Thickness	
	47	Pit
100	....	To bottom of 13″ hole

Portales Valley well No. D-8 (S. A. Morrison).
Depth to water, 22.2′

Depth	Thickness	
	23	Pit
	37	White sand and boulders
	5	Sand and gravel
	5	Sand and rock
	5.5	Creek gravel
	23.5	Yellow clay and sand
	9	Blue clay
85		

Portales Valley well No. D-9 (H. F. Jones).
Depth to water, 36′

Depth	Thickness	
	35	Pit
	12	Quicksand
	4	Sand and gravel
	14	Pack sand
	10	Sand and gravel
	2	Pack sand
	5	Sand and gravel
	7.5	Creek gravel
	6	Red clay
95		

Portales Valley well No. E-1 (Webber & Lykins).

Depth to water, 19′

Depth	Thickness	
	17.5	Pit
	20	Red sand and boulders
	0.4	Red sand
	30	White sand and clay
	7	Sandy clay to 80 ft.
	7	Coarse creek gravel
	7	Yellow clay
	2	Rock
	5	Clay
101		

Portales Valley well No. E-2 (Claud Anderson).

Depth to water, 22.7′

Depth	Thickness	
	22	Pit
	7	Yellow sand and boulders
	2	Yellow sand
	20	Sand, boulders, and gravel
	20	Pack sand
	10	Red pack sand
	8	Reddish clay and rock
	5	Creek gravel
	1	Rock
	5	Red clay
100		

Portales Valley well No. E-4 (Flue Anderson).

Depth	Thickness	
	23?	Pit
	2	Chalk rock
	20	Pack sand
	5	Grayish sand and gravel
	10	Pack sand
	5	Light sand rock
	4	Sand and gravel
	9	Pack sand
	7	Gravel
	13	Clay
95		

Portales Valley well No. F-2 (Pitts).
Depth to water, 30′

Thickness	
29	Pit
3	Quicksand
10	Pack sand
37	Blue, red, and white clayey sand
3	Sand rock
1.5	Cemented sand

Portales Valley well No. F-2 (Livingston et al.).
Depth to water, 21′

Depth	Thickness	
	20	Pit
	15	White rock
	5	Quicksand
	4	Yellow sand
	4	Reddish sand
	4	White sand
	5	Yellow sand
	29	Gray sand to 81 ft.
	7	Red sand and gravel
	7	Red clay and sand
	12	Good gravel
	5	Clay
115		

Portales Valley well No. F-3 (Murrel).
Depth to water, 50′

Depth	Thickness	
	48.5	Pit
	7	Sand rock
	13	White sand
	10	Quicksand
	10	Sandy clay
	3	Coarse sand and gravel
	21	Sandy clay
111	9	Sand rock
	3	Coarse sand
	10	Gravel

Portales Valley well No. F-4 (Pendergraft).
Depth to water, 36′

Depth	Thickness	
	35	Pit
	5	Sand rock
	41	Quicksand

Depth	Thickness	
	10	Sand and boulders
	20	Water sand; well ruined
	5	Pack sand
	5	Sand rock
	5	Sand and clay
	5	?
	6	Good gravel
	5	Clay
138		

Portales Valley well No. G-1 (Priddy & Sledge).

Depth to water, 18.5′

Depth	Thickness	
	17	Pit
	28	Sand
	7	Hard pan
	35	Pack sand
	5	Quicksand
	5	Sand
	3	Quicksand
	5	Sand
	3	Rock
	5	Clay
115		

**Log evidently incorrect as slush pile shows considerable gravel

Portales Valley well No. H-2 (Molinari).

Depth to water, 18′

Depth	Thickness	
	17	Pit
	15	Soft white rock
	50	Clay and pack sand
	10	Quicksand
	13	Clay and sand rock
	6	Gravel and sand
	1	Hard rock
117	30	Clay

Portales Valley well No. H-3 (Bounds east well).

Depth to water, 16.5′

Depth	Thickness	
	16	Pit
	5	White rock
	5	Red sand
	5	Sand and boulders

Depth	Thickness	
	10	Red sand
	27	Red sandy clay
	9	Red sand
	10	Sand and boulders
	10	Sandy clay and boulders
	3.5	Gravel
	3	White rock
	21	Red clay
125		

Portales Valley well No. H-4.

Depth to water, 20′

Depth	Thickness	
	19	Pit
	12	Lime rock and adobe
	30	Clay and sand
	13	Sand and boulders
	8	Sand and clay
	15	Quicksand
	18	Pack sand
110	9	Creek gravel
	9	
129		

Portales Valley well No. H-5 (Reese east well).

Depth to water, 21′

Depth	Thickness	
	20	Pit
	10	Lime and adobe dirt
	30	Clay and sand
	12	Quicksand to 70 ft.
	51	Pack sand with sandstone and clay
	2	Gravel
125		

Geo. W. Baker well in Portales Valley, N. M.

Depth	Thickness	
	27.	Pit
	3	Red sand
	3	Quicksand
	9	Caving quicksand and sand rock boulders
	7	Caving light gray sand
	9	Chalk
	3	Sand rock
	8	Medium gravel
	5	Clay
90		

Gregg well in Portales Valley, N. M.

Depth	Thickness	
	36	Soil, limestone, sand, and clay in descending order
	10	Quicksand
	2	Sand rock, boulders
	8	Yellow sand
	4	Sand and sand rock, boulders
	1	Sand rock
	3	Quicksand
	2	White sand
	5	White gummy gravel
	13	Pack sand
	4.5	Gravel
	0.7	Hard rock
	0.3	Sand pocket
	1.5	Rock
91		

Test well on Rittenhouse place, Portales Valley, N. M.

Depth to water, 31′

Thickness	
31	
3	Running sand
3	Adobe
6	Pack sand
28	Alternate layers of running sand and adobe or gummy soil
3	Reddish-pink clay
0.5	Gravel
1.5	Pack sand
1	Gravel and fine sand
3	Hard rock

Well on S. W. corner of Thompson 20-acre tract, Portales Valley, N. M.

Depth to water, 23′

Thickness	
23	Pit
2	Adobe
2	Running sand
6	Pack sand
20	Adobe
2	Red water sand
15	Adobe
2	Red clay
0.5	Gravel and sand
2.5	Hard rock

Well near S. E. corner of N. W. quarter Sec. 32, Twp. 1S, R.34 E about 3 miles west of Portales courthouse.

Depth	Thickness	
	2	Soil; disintegrated limestone
	12	Magnesian limestone
	2	Water gravel and sand
	10	Red clay
	6	Water gravel and sand (water raised to 12 ft. below the surface)
	12	Red clay
	8	Water gravel and sand
	32	Red clay, boulders, and some gravel
	16	Water gravel and sand
	4	Blue clay (Trias.)
	14	Red clay
	6	Water gravel and sand
		Red clay
	60	Red clay
	10	Blue shale
	50	Red clay and boulders
	10	Blue shale
	5	Blue water-bearing sandstone; water flowed 4 ft. above surface
	4	"asphalt" (lignite?)
	20	Red clay
	10	Sand and blue shale
	30	Red clay
	10	Blue shale, mucky
	40	Red clay and boulders
	6	Mineral water, with salt, iron and sulphur in a darker blue shale. Flowed out at surface
	8	"Oil sand", dark mulatto color
	40	Red clay and boulders
	10	Blue shale
	30	Red clay and boulders
	6	Blue shale
500	....	Dark heavy black shale to 500 ft.

**This log was given from memory.

Withroder well in Portales Valley.

Thickness	
23	Pit
20	Red adobe clay
4	Sand
16	White rock
3	Sand
4	Pack sand

Thickness	
10	White adobe
3	Soft sand
6	Red clay
6	Gravel
6	Clay

Well in Portales Valley (from Fisher, Water-Supply Paper 158, U. S. G. S.).

Depth	Thickness	
0	4	Soil
4	4	Gypsum (probably limestone)
8	12	Red sandy clay
20	12	White limestone
32	16	Red sandy clay
48	40	White limestone
88	100	Red clay (probably Triassic)
188	1	"Flint rock"
189	30	Coarse gravel and sand
219	78	Red clay
297	12	White sandstone
309	90	White sand and clay in alternate layers
399		

**This well flowed at about 400 ft.

SWISHER COUNTY.

D. D. Augspurger well, 1½ mi. west of Vigo Park.

Depth	Thickness	
0	71	Soil and clay
71	6	Hard rock
77	13	Hard sand
90	8	Soft rock
98	12	Sand
110	5	"Gyp" rock
115	12	Hard rock
127	23	Sand rock
150	11	Soft rock
161	8	Yellow clay
169	35	Coarse sand
204	6	Red clay
210		

Ira Cline well, northeast quarter Sec. 126, Blk. B2.
Depth to water, 50′

Thickness	
50	
22	Sand and boulders
43	Yellow clay
21	Sand
59	Yellow and white clay
9	Sand and gravel

Emmett well, about 15 miles northeast of Tulia.
Depth to water, 79.5′

Thickness	
14	Soil and white chalk
0.5	Rock
1	Clay
11.5	Sand rock
28	Sand
1	Rock
23.5	Sand
11.5	Sand and clay
47	Pack sand and gravel
7	Clay

L. Klaus & Sons well No. 1, 3 miles north of Tulia.
Depth to water, 59′

Depth	Thickness	
0	59	
59	41	Sand rock and shale
100	35	Fine hard sand
135	3	Hard rock
138	7	Pack sand
145	40	Moderately soft coarse sand
185	4	Shale
189	15	Hard sand
204	22	Shale and sand rock
226		

McGlasson well, 3 miles northeast of Kress.
Depth to water, 50′

Thickness	
50	Pit
12	Rock
4	Soft sand
29	Sand and rock
42	Soft sand
8	White clay

Thickness	
25	White sand
16	Gravel
50	Red clay (probably Trias.)

Price well, 19 mi. E. of Tulia and 6 mi. S. W. of Vigo Park.

Depth	Thickness	
0	5	Top soil
5	25	Red clay
30	2	Hard sand rock
32	15	Hard white rock
47	3	Soft white rock
50	4	Hard pack sand
54	6	Hard flint rock
60	4	Coarse, gray, water-bearing sand
64	11	Hard red sand rock
75	6	Coarse, gray, water-bearing sand
81	5	Loose, red, water-bearing sand
86	3	Hard gray sand
89	1	Soft white clay
90	5	Gray, water-bearing, pack sand
95	4	Loose, red, water-bearing sand
99	93	Hard, gray, sand rock
122	35	Loose, red, water-bearing sand
157	6	Hard, gray, sand rock (Triassic?)
163	7	Red clay
170	14	Hard, gray, water-bearing pack sand
184	2	Blue gumbo
186	12	Gray, coarse, water-bearing sand
198	2	Red clay
200	6	Coarse, gray, water-bearing sand
206	1	Hard sand rock
207	4	Coarse, gray, water-bearing sand
211	3	Blue gumbo
214	5	Coarse, gray, water-bearing sand
219	10	Hard, red, sand rock
229	31	Red clay
260		

**Very little water in this well.

Skipworth well, 1 mile north of Kress.

Depth to water, 64′

Thickness	
58	Pit
6	Dry sand
10	Fine sand and boulders
26	Soft sand

Thickness	
12	Sand and rock
9	Soft sand
62	Pack sand
7	Sand and gravel
4	Hard rock
1	Red clay

F. J. Vannerson well, 7 miles southeast of Tulia.

Depth	Thickness	
0	4	Soil
4	17	Red clay
21	35	Gray sand
56	4	Water sand
60	20	Coarse sand
80	20	Gray water sand
100	105	Hard pack sand
205		

Vaughn Bros. well No. 1, 1½ miles south of Tulia.

Depth	Thickness	
0	54	Pit
54	8	Hard rock
62	31	Yellow sand, moderately soft
93	3	Hard rock
96	69	Yellow sand, coarser than that above
165	7	Sand rock
172	5	Hard rock
177	56	Red clay
233		

(NEW MEXICO-TEXAS LINE.)

P. & N. T. Ry. well No. 1, Texico.

Elevation, 4095′ Depth to water, 193′

Thickness	
70	Red clay and sand
35	Lighter red clay
15	Darker red clay with pebbles
70	Lighter red clay
5	Soft sand rock
14	Fine sand
45	Quicksand

**Substantially same log as wells Nos. 2 and 3, except at bottom

P. & N. T. Ry well No. 2, Texico.

Elevation, 4095′ Depth to water, 186′

Thickness	
70	Red clay and sand
35	Light red clay
15	Dark red clay with pebbles
70	Light red clay
3	Soft sand rock
14	Fine sand
29	Quicksand
	Honeycomb rock
34	Quicksand
2	Red clay
13	Coarse gravel and water

**Substantially same log as wells Nos. 3 and 1, except at bottom. Same log as in well No. 3

P. & N. T. Ry. well No. 3, Texico.

Elevation, 4095′ Depth to water, 186′

Thickness	
70	Red clay and sand
35	Light red clay
15	Dark red clay and pebbles
70	Light red clay
3	Sand rock
14	Fine sand
	Streak honeycomb rock
34	Quicksand
2	Red clay
13	Coarse gravel

**Same log as in well No. 2.

APPENDIX NO. 2.

Logs of shallow water wells in the Plainview District, Hale, Floyd, and Swisher Counties, Texas.

TEXAS LAND & DEVELOPMENT CO. Wells.

District No. 1, well No. 10, northern part of S. E. quarter Survey 12, Blk. D5, Floyd County.

Elevation, 3310.2′ Depth to water, 51.5′

Depth	Thickness	
0	2	Top soil
2	5	Clay and lime
7	11	Clay
18	8	Shale
26	9	Clay
35	13	Shale
48	9	Clay
57	7	Lime rock
64	5	Lime rock and boulders
69	7	Sandstone (water)
76	5	Lime rock
81	15	Shale
96	7	Shale rock
103	14	Sand (water)
117	11	Clay
128	12	Sand (water)
140	38	Fine sand (water)
178	9	Sandstone (water)
187	22	Sand (water)
209	19	Coarse sand
228	11	Sand and gravel (water)
239	26	Sand (water)
265	9	Sandstone (water)
274		

*176 ft. water-bearing formation.

Well No. 75, 695 ft. S. and 75 ft. E. of N. W. corner of S. W. quarter Survey 13, Blk. D5, Floyd County.

Elevation, 3297.1′ Depth to water, 40′

Depth	Thickness	
0	3.5	Top soil
3.5	4.5	Clay and lime
8	11	Clay
19	11	Shale
30	6	Clay

Depth	Thickness	
36	4	Limestone
40	11	Sandstone (water)
51	6	Limestone
56	10	Sandstone (water)
51	6	Limestone
57	9	Shale rock
66	10	Sandstone (water)
76	13	Shale
89	9	Sand (water)
98	10	Shale
108	27	Sand (water)
135	2	Clay
137	7	Shale
144	24	Sand (water)
168	16	Sandstone (water)
184	14	Shale
198	14	Sand (water)
212	9	Clay
221	15	Sand (water)
236	11	Sand and gravel (water)
247	9	Sandstone (water)
256	5	Shale
261	8	Sand (water)
269	4	Sandstone (water)
273		

**158 ft. of water-bearing formation. 75 ft of 26″ pit.

Well No. 62.

Elevation, 3314.6′ Depth to water, 57′

Depth	Thickness	
0	3	Top soil
3	10	Clay and chalk
13	9	Sand
22	19	Shale
41	7	Lime rock and boulders
48	9	Clay
57	9	Sandstone (water)
66	4	Gumbo
70	18	Hard shale
88	21	Sand (water)
109	12	Shale
121	43	Sand (water)
164	7	Clay
171	7	Shale
178	45	Coarse sand (water)

Depth	Thickness	
223	35	Sand and gravel (water)
258		

**153 ft. of water-bearing formation. 77 ft. of 26″ pit.

Well No. 61, 232 ft. west and 75 ft. south of N. E. corner of S. W. quarter Survey 21, Block N, Hale County.

Elevation, 3314′ Depth to water, 48′

Depth	Thickness	
0	3	Top soil
3	9	Clay and lime
12	9	
23	11	Sand
34	11	Shale
45	10	Lime and boulders
51	7	Clay
58?	18	Sand rock (water)
76?	6	Gumbo
82?	16	Hard shale
98?	14	Sand (water)
105	14	Shale
119	40	Sand (water)
159	7	Clay
166	15	Shale
181	36	Coarse sand (water)
217	5	Clay
222	46	Sand and gravel (water)
268	5	Clay
273	5	Coarse sand (water)
278		

**159 ft. water-bearing formation.

Well No. 60. 1270.5 ft. east and 95.5 ft. south of N. W. corner of N. W. quarter Survey 21, Block N, Hale County.

Elevation, 3316.4′ Depth to water, 50′

Depth	Thickness	
0	3	Top soil
3	12	Clay and lime
15	13	Sand
28	6	Shale
34	11	Lime rock and boulders
45	5	Clay
50	21	Sand rock (water)
71	5	Gumbo
76	10	Hard shale
86	24	Fine sand (water)

Depth	Thickness	
110	11	Shale
121	6	Clay
127	41	Sand (water)
168	20	Shale
188	32	Coarse sand (water)
220	6	Sand rock (water)
226	47	Sand and gravel (water)
273	5	Gumbo
278		

**171 ft. of water-bearing formation. 77 ft. of 26″ pit

Well No. 59.

Elevation, 3316.4′ Depth to water, 47′ (?)

Depth	Thickness	
0	3	Top soil
3	9	Clay and chalk
12	9	Sand
21	36	Shale
37	14	Lime rock and boulders
51	5	Clay
56	13	Soft sand rock
69	4	Gumbo
73	18	Shale
91	16	Sand (water)
107	7	Clay
114	10	Shale
124	43	Sand (water)
167	11	Shale
178	4	Clay
182	45	Coarse sand (water)
227	28	Clay
255	19	Sand and gravel
274	2	Gumbo
276		

77 ft. 26″ pit
199 ft. 16″ hole

Well No. 58. S. W. corner of N. W. quarter Survey 15, Block D5. Floyd County.

Elevation, 3314.4′ Depth to water, 46′

Depth	Thickness	
0	3	Top soil
3	4	Clay and lime
7	7	Clay
14	7	Clay and sand

Depth	Thickness	
21	8	Shale
29	5	Clay
34	5	Limestone
39	7	Shale
46	11	Sandstone (water)
57	7	Limestone
64	15	Shale rock
79	7	Sandstone (water)
86	16	Clay
102	11	Sand (water)
113	16	Shale
129	9	Sand (water)
138	4	Limestone
142	9	Sand (water)
151	25	Shale
176	5	Shale rock
181	16	Clay
197	12	Sand (water)
209	11	Sandstone (water)
220	11	Shale
231	9	Sand and gravel (water)
240	14	Sandstone (water)
254	17	Sand (water)
271	4	Limestone
275		

**110 ft. water-bearing formation. 75 ft. of 26″ pit.

Well No. 52. 400 ft. south and 50 ft. west of N. W. corner of east half of N. E. quarter Survey 14, Blk. D5, Floyd County.

Elevation, 3311.6′ Depth to water, 48′ (?)

Depth	Thickness	
0	3	Top soil
3	7	Clay and chalk
10	8	Sand
18	5	Clay
23	14	Hard shale
37	4	Lime rock and boulders
41	7	Clay
48	14	Sand (water)
62	8	Clay
70	14	Hard shale
84	14	Sand (water)
98	8	Clay
106	6	Sand rock
112	24	Fine sand (water)
136	8	Clay

Depth	Thickness	
144	24	Shale
168	6	Gumbo
174	21	Shale
195	36	Coarse sand (water)
231	7	Clay
238	8	Shale
246	22	Sand and gravel (water)
268	5	Coarse sand rock (water)
273	5	Clay
278		

**77 ft. of 20″ pit.

Well No. 51. North half of N. W. quarter Surv. 24, Blk. N, Floyd County.

Elevation, 3297.4′ Depth to water, 47′ (?)

Depth	Thickness	
0	3.5	Top soil
3.5	5.5	Clay
9	9	Clay and sand
18	8	Shale
26	13	Clay and sand
39	8	Lime rock and boulders
47	7	Sand (little water)
54	7	Sand rock
61	11	Hard shale
72	8	Gumbo
80	11	Sandstone
91	12	Fine sand
103	12	Hard shale
115	13	Gumbo
128	6	Clay
134	8	Hard shale
142	7	Gumbo
149	14	Fine sand (water)
163	7	Clay
170	8	Sandstone (water)
178	3	Clay
181	5	Hard sand rock
186	11	Hard shale
197	9	Gumbo
206	12	Sand (water)
218	5	Clay
223	23	Coarse sand and fine gravel
246	5	Gumbo
251	7	Shale

Depth	Thickness	
258	12	Coarse sand
270	2	Gumbo
272		

**76.5 ft. of 20″ pit. 201.5 ft. of 16″ hole. 117 ft. of sand.

Well No. 50. West half of N. E. quarter, Surv. 15, Blk. D5, Floyd County.

Elevation, 3312.2′ Depth to water, 49′ (?)

Depth	Thickness	
0	3	Top soil
3	3	Clay and chalk
6	9	Clay
15	6	Shale
21	6	Clay and sand
27	9	Shale
36	5	Lime rock and boulders
41	8	Clay
49	8	Sand rock (water)
57	5	Clay
62	6	Hard sand rock
68	15	Hard shale
83	15	Medium coarse sand (water)
98	6	Clay
104	7	Shale
111	47	Fine sand (water)
158	6	Shale
164	7	Gumbo
171	17	Fine sand (water)
188	9	Sand rock (water)
197	8	Clay
205	7	Shale
212	11	Coarse sand (water)
223	11	Sandstone (water)
234	4	Clay
238	9	Sand and fine gravel (water)
247	21	Coarse sand (water)
268	10	Coarse sandstone (water)
278		

**76 ft. of 20″ pit. 162 ft. of water-bearing formation.

Well No. 49. Southwest quarter of S. W. quarter Surv. 65, Blk. D2, Floyd County.

Elevation, 3312.3′ Depth to water, 46′ (?)

Depth	Thickness	
0	2.5	Top soil
2.5	2.5	Clay and chalk
5	12	Clay
17	7	Shale
24	7	Clay
31	5	Shale
36	3	Shale rock
39	7	Lime rock and boulders
46	7	Sandstone and boulders (water)
53	8	Shale rock
61	11	Soft sandstone (water)
72	4	Shale
76	6	Soft sandstone (water)
82	6	Shale
88	6	Sandstone (water)
104	13	Shale
107	11	Fine sand (water)
118	12	Shale
130	5	Gumbo
135	44	Fine sand (water)
179	12	Sandstone (water)
191	18	Fine sand (water)
209	12	Sandstone (water)
221	9	Coarse sand (water)
230	9	Shale
239	14	Sandstone (water)
253	8	Coarse sand (water)
261	8	Coarse sand and gravel (water)
269	7	Coarse sand (water)
276	2	Shale
278		

**75 ft. 20″ pit. 175 ft. of water-bearing formation.

Well No. 48. Southeast quarter of S. W. quarter Survey 65, Block D2, Floyd County.

Elevation, 3313.1′ Depth to water, 47′ (?)

Depth	Thickness	
0	2	Top soil
2	3	Clay and chalk
5	14	Clay
19	7	Shale
26	9	Clay

Depth	Thickness	
35	12	Limestone and boulders
47	5	Sandstone (water)
52	9	Shale rock
61	8	Sandstone (water)
69	9	Shale rock
78	13	Clay
91	16	Fine sand (water)
107	4	Gumbo
111	51	Fine sand (water)
162	9	Shale
171	21	Fine sand (water)
192	6	Clay
198	11	Soft sandstone (water)
209	5	Fine sand (water)
214	7	Shale
221	9	Coarse sand (water)
230	11	Gravel (water)
241	11	Sandstone (water)
252	9	Coarse sand (water)
261	3	Sandstone (water)
264	13	Coarse sand (water)
277	4	Sandstone (water)
281		

**75 ft. of 20″ pit, 177 ft. water-bearing formation.

Well No. 47. West half of N. W. quarter, Survey 12, Blk. D3, Floyd County.

Elevation, 3311.5′ Depth to water, 48′ (?)

Depth	Thickness	
0	2	Top soil
2	3	Clay and chalk
5	9	Clay
14	5	Clay and sand
19	5	Shale
24	7	Clay
31	5	Shale
36	5	Shale rock
41	7	Lime rock and boulders
48	5	Sandstone and boulders (water)
53	6	Soft lime rock and boulders
59	8	Shale rock
67	4	Sandstone (water)
71	8	Fine sand
79	9	Clay
88	16	Shale

Depth	Thickness	
104	15	Fine sand (water)
114	13	Soft sandstone (water)
132	19	Clay
151	13	Fine sand (water)
164	7	Gumbo
171	18	Fine sand (water)
189	8	Sandstone (water)
197	12	Clay
209	8	Coarse sand (water)
217	15	Sandstone (water)
232	6	Shale
238	8	Coarse porous sand (water)
246	5	Clay
251	16	Coarse sand (water)
267	6	Fine gravel and coarse sand (water)
273	4	Coarse gravel (water)
277	2	Coarse sand
279	2	Clay
281		

**75 ft. of 20″ pit. 206 ft. of 16″ hole. 135 ft. of water-bearing formation.

Well No. 46. West half of N. W. quarter Survey 48, Blk. D6, Floyd County.

Elevation, 3298′ Depth to water, 50′ (?)

Depth	Thickness	
0	3	Top soil
3	13	Clay
16	5	Shale
21	7	Clay
28	8	Soft shale rock
36	13	Lime rock and boulders
49	8	Sandstone (water)
57	8	Shale
65	9	Sand (water)
74	7	Shale rock
81	15	Shale
96	11	Fine sand (water)
107	10	Sandstone (water)
117	19	Clay
136	16	Fine sand (water)
162	16	Sandstone (water)
168	14	Shale
182	8	Clay
190	11	Gumbo
201	30	Coarse sand (water)

Depth	Thickness	
231	21	Sandstone (water)
252	18	Coarse sand and fine gravel (water)
270	2	Shale
272	7	Coal formation
279	2	Shale
281		

**77 ft. of 26″ pit.

Well No. 45. North of P. & N. T. Ry., Floydada Branch, N. W. quarter Survey 46, Blk. D5, Floyd County.

Elevation, 3304.4′ Depth to water, 50′

Depth	Thickness	
0	3	Top soil
3	18	Clay
21	5	Clay and sand
26	10	Shale
36	13	Lime rock and boulders
49	7	Soft sandstone (water)
56	8	Shale
64	5	Clay
69	8	Fine sand (water)
77	14	Shale
91	11	Fine sand (water)
102	12	Clay
114	22	Shale
136	5	Shale rock
141	18	Fine sand (water)
159	3	Shale
162	5	Gumbo
167	19	Fine sand (water)
186	6	Sandstone (water)
192	14	Shale
206	5	Clay
211	10	Sandstone (water)
221	11	Coarse sand (water)
232	9	Sandstone (water)
241	20	Coarse sand (water)
261	17	Coarse sand and fine gravel (water)
278	4	Coarse sand (water)
282		

Lake Plainview well No. 44.

Elevation, 3362.2′ Depth to water, 27′ (?)

Depth	Thickness	
0	2	Top soil
2	9	Clay

Depth	Thickness	
11	10	Clay and chalk
21	4	Shale
25	7	Shale rock, water
32	11	Stone, lime boulders
43	6	Limestone
49	18	Shale rock
67	9	Hard shale
76	8	Fine sand
84	26	Shale
110	11	Fine sand
121	6	Shale
127	20	Fine sand
147	24	Shale
171	6	Clay and boulders
177	4	Medium coarse sand
181	24	Pack sand
205	22	Medium coarse sand
227	3	Gumbo
230	31	Coarse sand and gravel
261		

*Depth to pit, 71 ft.

Well "C", No. 43, Pioneer Park, drilled by Layne & Bowler.
Elevation, 3343.2′ Depth to water, 27′

Depth	Thickness	
0	25	Soil
25	16.7	Soft white sand, fine
41.7	7.5	Hard white sand, coarse
49.2	6	Sandy clay
55.1	16.5	Hard fine red sand
71.6	7	Soft white sand, fine
78.6	1	Hard rock
79.6	128	Soft sand
207.6	12	Shale and sand
219.6	60.4	Sand (66.4′?)
280		

*Depth to pit, 76 ft.

Well No. 42. (No. 2, Pioneer Park) S. W. quarter Sec. 14, Block D6, File 138, Hale County.
Elevation, 3357′

Depth	Thickness	
0	2.6	Top soil
2.6	1.4	Clay
4	3	Chalk and clay
7	11	Clay

Depth	Thickness	
18	10	Shale
28	8	Shale rock
36	5	Lime rock
41	3.5	Lime boulders
44.5	11.5	Hard stone
56	30	Hard shale
86	5	Hard sand
91	12	Clay
103	7	Shale
110	9	Fine sand
119	5	Shale
124	18	Fine sand
142	19	Medium hard sand
161	10	Gumbo
171	5	Shale
176	35	Fine sand
211	16	Coarse sand, medium
227	13	Soft sandstone
240	25	Coarse water-sand and fine gravel
265	2	Coarse sandstone
267		

**71 ft. of 29″ pit.

Well No. 41 (No. 1, Pioneer Park) S. E. quarter Sec. 14, Block D6, File 138, Hale County.

Elevation, 3357′

Depth	Thickness	
0	2.5	Top soil
2.5	15.5	Clay
18	4	Shale
22	5	Clay
27	8	Shale and chalk rock
35	11	Lime rock
46	11	Hard sand
57	6	Hard shale
63	13	Soft shale
76	5	Fine sand
81	12	Clay
93	19	Shale
112	9	Fine sand
121	11	Shale
132	17	Sand
149	20	Coarse sand
169	9	Shale
178	24	Medium sand
202	15	Coarse sand

Depth	Thickness	
217	14	Extra coarse sand and fine gravel
231	8	Fine sand
239		

**70.5 ft. of 29″ pit.

Well No. 40. N. E. corner of S. half of N. E. quarter, Survey 11, Block D5, Floyd County.

Elevation, 3307.5′ Depth to water, 46′ (?)

Depth	Thickness	
0	3	Top soil
3	18	Clay
21	6	Shale
27	7	Clay and sand (no water)
34	4	Shale
38	8	Shale rock
46	6	Pack sand (small amount of water)
52	6	Fine sand (small amount of water)
58	9	Shale
67	5	Fine sand (water)
72	19	Shale
91	16	Fine sand (water)
107	9	Clay
116	22	Fine sand (water)
138	14	Shale
152	5	Limestone
157	7	Clay
164	33	Medium coarse sand (water)
197	14	Soft sandstone (small amount water)
211	30	Coarse sand (water)
261	17	Coarse sand (water-bearing)
278	2	Clay
280		

**169 ft. of water-bearing formation
76 ft. of 20″ pit

Well No. 39. S. W. quarter Survey 12, Blk. D5, Floyd County.

Elevation, 3310.1′ Depth to water, 49′ (?)

Depth	Thickness	
0	3	Top soil
3	6	Clay
9	7	Clay and chalk
16	8	Clay
24	14	Shale
38	11	Shale rock
49	12	Fine sand (water)
61	11	Sandstone (little water)

Depth	Thickness	
72	14	Shale
86	18	Fine sand (water)
104	9	Clay
113	19	Gumbo
132	24	Fine sand (water)
156	12	Medium coarse sand (water)
168	14	Shale
182	24	Fine sand (water)
206	20	Coarse sand (water)
241	40	Sand and gravel (water)
281	10	Clay
291	11	Coarse sand (water)
302	3	Sand and gravel (water)
305		

**80 ft. of 26″ pit.
190 ft. of water-bearing formation.

Well No. 34. S. W. Hardy homestead, File 27, Floyd County.
Elevation, 3269′ Depth to water, 36′ (?)

Depth	Thickness	
0	3	Top soil
3	13	Clay
16	20	Shale rock
36	11	Soft sand, boulders (water)
47	19	Hard shale
56	6	Sandstone (water)
72	15	Clay
87	19	Shale
106	5	Sand, water
111	8	Gumbo
119	17	Shale
136	11	Pack sand, water
147	15	Clay
162	29	Fine sand—water
191	18	Shale
209	12	Fine sand—water
221	30	Coarse sand—water
251	5	Sandstone—water
256	10	Coarse sand—water
266		

**70 ft. pit.

Well No. 32. Floyd County.

Elevation, 3282.1′ Depth to water, 42.7′

Depth	Thickness	
0	48	Pit
48	8	Coarse sand and gravel
56	60	Clay and boulders
116	44	Coarse sand
160	6	Sticky clay
166	12	Coarse sand and gravel
178	11	Sticky clay
189	6	Sand
195	7	Clay
202	8	Rock
210		

**102 ft. of 16″ hole
100 ft. of 12½″ herringbone screen 74′-174′

Well No. 30. G. H. Todd tract, File 135, Floyd County.

Elevation, 3269.5′ Depth to water, 49′

Depth	Thickness	
0	2	Top soil
2	4	Clay
6	3	Joint clay
9	12	Clay
21	10	Shale rock
31	13	Lime rock and boulders
44	15	Sand—a little water
49	12	Shale
61	11	Soft sandstone—water
72	26	Shale
98	8	Fine sand—water
106	8	Shale
114	38	Shale rock
152	12	Fine sand—water
164	22	Shale
186	5	Fine sand—water
191	13	Gumbo
204	15	Shale
219	8	Sand—water
227	4	Sandstone—water
231	16	Sand—water
247	9	Sandstone—water
256	25	Coarse sand—water
281		

**70 ft. of 24″ pit.

Well No. 29. J. T. Livesay tract, File 18, Floyd County.
Elevation, 3279′ Depth to water, 49′ (?)

Depth	Thickness	
0	2.6	Top soil
2.6	2.4	Clay
5	4	Clay and chalk
9	7	Clay
16	11	Shale
27	8	Shale and rock
35	8	Lime rock and boulders
43	6	Sandstone—water
49	14	Shale
63	8	Soft sandstone—water
71	12	Clay
83	8	Soft sandstone—water
91	11	Shale
102	14	Clay
116	11	Pack sand—water
127	25	Shale
152	29	Fine sand—water
181	12	Shale
193	16	Sand
209	5	Coarse sandstone—water
214	16	Coarse sandstone and fine gravel—water
230	8	Sand rock—water
238	3	Coarse sand—water
241	27	Coarse sand—water
268	10	Gravel
278		

Well No. 28. J. K. Anderson homestead, File 18, Floyd County.
Elevation, 3279.7′

Depth	Thickness	
0	2.5	Top soil
2.5	2.5	Clay
5	2	Clay and chalk
7	10	Clay
17	4	Shale
21	5	Shale rock
26	6	Shale
32	10	Lime rock and boulders
42	7	Sand rock and boulders
49	7	Shale rock
56	11	Loose shale
67	5	Soft sandstone
72	24	Shale
96	12	Pack sand

Depth	Thickness	
108	6	Clay
114	17	Fine sand
131	6	Clay
137	9	Fine sand
146	2	Shale
148	28	Fine sand
176	10	Shale rock
185	11	Fine sand
197	12	Medium coarse sand
209	11	Fine sand
220	7	Shale rock
227	11	Coarse sand and gravel
238	2	Hard sand rock
240	30	Coarse sand
270	16	Gravel
286		

Well No. 26. Floyd County.

Elevation, 3285.4′ Depth to water, 43.2′

Depth	Thickness	
0	49	Pit
49	45	Red sandy clay
94	66	Pack sand
160	12	Sandstone
172	18	Sand and gravel
190	10	Clay
200		

**120 ft. of 12½″ pit.
15″ hole down 56 ft. below pit bottom.

Well No. 25. 200 ft. N. and 600 ft. W. of S. E. corner of S. W. quarter Survey 22, Blk. N, Floyd County.

Elevation, 3305.6′ Depth to water, 52′ (?)

Depth	Thickness	
0	3	Top soil
3	8	Clay and chalk
11	14	Sand
25	9	Shale
34	5	Lime rock and boulders
39	5	Lime rock
44	4	Lime rock and boulders
48	4	Clay
52	16	Soft sand rock—water
68	6	Gumbo
74	15	Shale
89	21	Sand—water

Depth	Thickness	
110	6	Clay
116	13	Shale
129	5	Clay
134	44	Sand—water
178	11	Shale
189	44	Coarse sand—water
233	5	Gumbo
238	41	Sand and gravel—water
279		

**79 ft. of 26″ pit.
200 ft, of 16″ hole

Pearson well No. 2, 95 ft. E. and 75 ft. W. of S. W. corner House lot, 395 ft. S. and 75 ft. E. of N. W. corner Survey 17, Blk. D5, Hale and Floyd counties.

Elevation, 3321.1′ Depth to water, 41′

Depth	Thickness	
0	3	Top soil
3	4	Clay and chalk
7	11	Clay
18	5	Shale
23	6	Clay and sand
29	7	Shale
36	5	Shale rock
41	8	Sandstone—water
49	7	Lime rock
56	7	Lime rock and boulders
63	4	Shale
67	9	Sandstone—water
76	8	Clay
84	13	Shale
97	12	Sand—water
109	12	Shale
121	9	Clay
130	19	Sandstone—water
149	19	Clay
168	10	Shale
178	29	Sand—water
207	12	Sandstone—water
219	28	Sand—water
247	7	Sand and gravel—water
254	7	Sandstone—water
261	7	Clay
268	8	Sandstone—water
276		

**75 ft. of 28″ pit.

Pearson Sec. Well No. 1.

Elevation, 3319′ Depth to water, 39′ (?)

Depth	Thickness	
0	3.5	Top soil
3.6	3.3	Clay
7	4	Clay and chalk
11	8	Shale
19	10	Shale rock
29	2	Clay
31	8	Soft sandstone and boulders—water
39	9	Shale
48	9	Fine sand—water
57	12	Shale
69	7	Shale, rock
76	7	Extra hard flint rock
83	18	Fine sand—water
101	12	Shale
113	35	Fine sand—water
148	4	Sandstone
152	9	Shale
161	7	Gumbo
168	19	Fine sand—water
187	7	Shale
194	9	Sandstone
203	18	Coarse sand—water
221	10	Sandstone—water
231	35	Coarse sand, water in abundance
266	15	Sand and gravel—water
281	13	Coarse sand, water in abundance
294	10	
304		

Well No. 24, 870 ft. N. and 75 ft. E. of S. W. corner of S. E. quarter Sec. 22, Blk. N, Floyd County.

Elevation, 3304.9′ Depth to water, 52′ (?)

Depth	Thickness	
	3	Top soil
3	12	Clay and chalk
15	12	Sand
27	4	Clay
31	16	Lime rock and boulders
47	5	Clay
52	18	Sandstone—water
70	8	Gumbo
78	14	Shale
92	17	Lime sand—water
109	8	Clay

Depth	Thickness	
117	15	Shale
132	41	Sand—water
173	11	Shale
184	44	Coarse sand
228	4	Gumbo
232	11	Shale
243	7	Clay and gravel
250	29	Sand and gravel—water
279		

**76 ft. of 26″ pit

Well No. 23. N. W. quarter Survey 22, Blk. N, Floyd County.

Elevation, 3310.7′ Depth to water, 43′ (?)

Depth	Thickness	
0	3	Top soil
3	9	Clay and chalk
12	9	Sand
21	13	Shale
34	5	Clay
39	4	Lime rock and boulders
43	8	Sand rock—water
51	4	Clay
55	9	Sand—water
64	7	Hard shale
71	7	Gumbo
78	6	Shale
84	17	Sand—water
101	8	Clay
109	17	Shale
126	39	Sand—water
165	6	Clay
171	26	Shale
197	47	Coarse sand—water
234	7	Gumbo
241	10	Shale
251	22	Sand and gravel—water
273	6	Gumbo
279		

**76 ft. of 26″ pit.
203 ft. of 16″ hole

Well No. 22, S. W. corner of N. E. quarter Surv. 3, Blk. D4, File 88.

Elevation, 3291.6′ Depth to water, 55′

Depth	Thickness	
0	3	Top soil
3	9	Red clay

Depth	Thickness	
12	6	Sandy clay
18	12	Clay and gravel
30	20	Soft rock
50	11	Rock
61	12	Rock and clay
73	8	Gravel and clay
81	10	Sandy clay
91	18	Red clay
109	11	Sand—water
120	23	Sandy clay
143	15	Sand—water
158	5	Gravel
163	12	Coarse sand—water
175	2	Gravel
177	7	Sand—water
184	5	Sandy clay
189	4	Fine sand—water
193	16	Sticky clay
209	4	Sand—water
213		

Well No. 21, S. W. quarter Surv. 2, Blk. D5, File 115, Floyd County.

Elevation, 3289.7′ Depth to water, 53′

Depth	Thickness	
0	53	Pit
53	8	Rock and clay
61	21	Sandy clay
82	10	Clay and boulders
92	21	Sand
113	32	Sandy clay
145	6	Soft sand and gravel
151	37	Sand and some gravel
188	5	Sticky clay
183	6	Sandy clay
199	8	Sticky clay
207	8	Sand
215	1	Clay
216		

Well No. 20, south side of N. E. quarter Surv. 2, Blk. D4, File 115, Floyd County.

Elevation, 3285.8′ Depth to water, 46.5′

Depth	Thickness	
0	50	Dug pit
50	2	Soft sandstone—little water
52	16	Shale

Depth	Thickness	
68	4	Soft sandstone—little water
72	26	Shale
98	34	Sandstone—little water
132	9	Shale
141	37	Fine sand—water fair
178	14	Shale
182	16	Clay
208	13	Fine sand—water
221	11	Sandstone—little water
232	9	Shale
241	26	Coarse sand—good water
267	9	Gumbo
276	11	Coarse sand—good water
287	5	Clay and gravel—some water
292		

**80 ft. of 20″ pit.

Well No. 19, N. E. quarter Surv. 8, Blk. D5, File 70, Floyd County.

Elevation, 3309.3′ Depth to water, 55′

Depth	Thickness	
0	61	Depth of pit
61	3.6	Pack sand
64.6	5	Sand and clay
69.6	1	Hard sand
70.6	2	Gravel
72.6	4	Soft rock
76.6	16	Sandy clay
92.6	31	Soft sand
123.6	5	Pack sand
128.6	15	Clay
143.6	33	Sandy clay
173.6	8	Sticky clay
184.6	15	Red, sandy clay
199.6	9	Gravel and sand
208.6	9	Soft river sand and gravel
217.6	1	Clay
218.6		

Well No. 18, S. W. corner of W. 200 acres of Surv. No. 4, Blk. D6, File 76, Floyd County.

Elevation, 3298.3′ Depth to water, 40.2′

Depth	Thickness	
0	5	Top soil
5	17	Chalky clay
22	5	Rock
27	10	Sand and gravel

Depth	Thickness	
37	4	Solid rock
41	4	Sand and gravel
45	13	Shale
58	9	Soft sandstone—little water
67	16	Shale
83	14	Fine sand—little water
97	9	Clay
106	13	Fine sand—little water
119	13	Shale
132	17	Fine sand—small amount of water
149	3	Gumbo
152	30	Sand—water
182	14	Soft sandstone—little water
196	23	Sand—water fairly good
219	19	Coarse sand—good water
238	8	Shale—good water
246	22	Coarse sand—good water
268	15	Coarse sand and fine gravel—much water
283		

**45 ft. of 5′ pit.
20″ pit to 80 ft.

Well No. 17.

Elevation, 3305.7′ Depth to water, 47.8′

Depth	Thickness	
0	5	Top soil
5	20	Chalky clay
25	5	Rock
30	4	Sand and gravel
34	9	Solid rock
43	10	Sand and gravel
53	47	Red clay
100	25	Pack sand
125	21	Soft sand
146	26	Sand and gravel
172	3	Red clay
175	20	Coarse sand
195	11	White clay
206		

**Pit, 53 ft. 15″ hole, 118 ft. 11½″ hole, 35 ft 106 ft of 12½″ screen. 46 ft. of 10″ screen.

Well No. 16, S. W. quarter Surv. 46, Blk. D6, File 128, Floyd County.

Elevation, 3303.6′ Depth to water, 48.2′

Depth	Thickness	
0	5	Pit
55	15	Clay
70	45	Soft sand
115	34	Clay
149	12	Rock
161	35	Gravel and sand
186	17	Clay
203		

Well No. 15, N. W. quarter Surv. 46, Blk. D6, File 89, Floyd County.

Elevation, 3305.4′ Depth to water, 49.5′

Depth	Thickness	
0	3.2	Top soil
3.2	33	Clay
36.2	16.7	Rock
52.9	0.7	Flint boulders
53.4	22.8	Red clay
76	18	Pack sand
94	8	Clay
102	30	Pack sand and rock
132	19	Clay
151	8	Rock
159	18	Sand and gravel
177	30	Clay
207	18	Sand
225	2	Clay
227		

**54.6 ft. of pit.

Well No. 14, S. W. corner of N. E. quarter Surv. 10, Blk. D5, Floyd County.

Elevation, 3308.8′ Depth to water, 50′

Depth	Thickness	
0	2	Top soil
2	6	Clay and chalk boulders
8	6	Clay
14	12	Sand
26	5	Clay
31	12	Shale
43	7	Sand
50	4	Lime rock and boulders
54	8	Sand rock—water
62	4	Clay
66	13	Hard shale

Depth	Thickness	
79	14	Fine sand—water
93	5	Sand rock
98	22	Shale
120	8	Gumbo
128	15	Sand—water
143	8	Clay
151	42	Sand—water
193	9	Shale
202	35	Coarse sand—water
237	10	Clay
247	21	Sand and gravel—water
268	4	Clay
272	6	Coarse sand—water
278		

**76 ft. of 26″ pit.

Well No. 14 (filled up), N. E. quarter Surv. 10, Blk. D5, File 136, Floyd County.

Elevation, 3308.8′ Depth to water, 50′

Depth	Thickness	
0	1	Clay
1	26.3	Pack sand and gravel
27.3	14.6	Rock
41.9	7.2	Water rock
49	13	White rock
62	25	Red clay and boulders
87	5	Fine sand
92	7	Red clay
99	10	Soft sand
109	43	Fine sand
152	6	Hard rock
158	8	Red clay
166	4	Soft sand
170	12	Red clay
182	22	Sand and gravel
204	7	White clay
211	28	Sand rock and clay
239		

**53 ft. of pit.

Well No. 13, S. W. quarter Sec. 8, Blk. D5, File 74, Floyd County.

Elevation, 3308.5′ Depth to water, 51.2′

Depth	Thickness	
0	3.6	Top soil
3.6	8.6	Clay
12	10.4	Red clay

Depth	Thickness	
22.4	8.1	Clay
31.2	19.1	Rock
51	16.6	Water rock
67.6	5	Sand
72.6	12	Clay and boulders
84.6	14	Sand
98.6	15	Soft sand
113.6	16	Sand rock
129.6	2	Hard rock
131.6	14	Sand and boulders
145.6	14	Pack sand
159.6	10	Hard rock
169.6	4	Clay
173.6	10	Sand rock
183.6	12	Coarse sand
195.6	9	Gravel
204.6	1	Clay
205.6		

**57 ft. of pit.

Well No. 12, N. W. corner of N. W. quarter Sec. 8, Blk. D5, File 74, Floyd County.

Elevation, 3310.2′ Depth to water, 51′

Depth	Thickness	
0	2.6	Top soil
2.6	17.6	Clay
20	1.1	Rock
21.1	5.4	Clay
27.2	35.1	Rock
63	9	Red sand
72	19	Clay
91	16	Soft sand
107	18	Sand rock
125	6	Hard rock
131	2	Clay
133	10	Clay and boulders
143	8	Rock
151	12	Sand and boulders
163	7	Rock
170	5	Red clay
175	2	Rock
177	23	Clay and boulders
200	11	Gravel
211	1	Clay
212		

**57 ft. of pit

Well No. 11. Floyd County.

Elevation, 3308.9′ Depth to water, 49′

Depth	Thickness	
	54	Pit
	8	Rock
	2	Gravel
	12	Soft sand
	10	Red clay
	28	Hard sand
	10	Soft sand
	8	Red clay
	36	Hard sand
	4	Red clay
	6	Soft sand
	16	Sand and clay
	6	Hard rock
	1	Sticky clay
	4	Gravel
205		

**15″ hole 100 ft. below water. Old hole abandoned.

Pump= No. 6 L. & B. 2 stage.

Engine, 40 h. p. head.

Well No. 10, N. W. corner S. E. quarter Surv. 12, Blk. D5, Floyd County.

Elevation, 3310.2′ Depth to water, 51.5′

Depth	Thickness	
0	2.3	Top soil
2.3	6.2	Clay
8.6	3.4	Cemented boulders
12	7.4	Clay
19.4	42.6	Rock
62	8	Red sand—water
70	18	Red clay
88	6	Sand—water
94	16	Red clay and sand
110	14	Sandy clay
124	17	Sand—water
141	7	Sandstone
148	12	Clay
160	15	Rock
175	5	Gumbo
180	15	Rock
195	8	Gravel
203	17	Coarse sand

Depth	Thickness	
220	3	Rock
223		

**57 ft. of pit.

Well No. 9, N. E. quarter Surv. 12, Blk. D5, Floyd County.
Elevation, 3313′ Depth to water, 49.5′

Depth	Thickness	
0	3	Top soil
3	3	Clay and chalk
6	13	Clay
19	7	Shale
26	3	Clay
29	5	Shale
34	5	Shale rock
39	10	Lime rock
49	9	Soft sandstone and boulders—water
56	9	Shale
65	7	Sandstone—water
72	19	Shale
91	16	Fine sand—water
107	10	Clay
117	29	Fine sand—water
146	6	Sandstone—water
152	11	Shale
163	19	Fine sand—water
182	9	Shale rock
191	11	Clay
202	29	Medium coarse sand—water
231	10	Sandstone—water
241	21	Coarse sand—water
262	14	Coarse sand and fine gravel—water
276	5	Coarse sand—water
281		

**78 ft. of 20″ pit.

Well No. 9, N. E. quarter Section 12, Blk. D5, File 11, Floyd County.
Depth to water, 49′

Depth	Thickness	
0	3.8	Top soil
3.8	7.3	Clay
10.1	1.5	Boulders
12.4	16.3	Clay
28.7	23.1	Rock
51.8	12.4	Rock with water between beds
64	28	Red clay
92	5	Red sand

Depth	Thickness	
97	27	Red clay
124	22	Fine sand
146	36	Pack sand
182	18	Sand and gravel
200	19	Fine sand
219	3	White rock
222	6	Fine sand
228		

**54 ft. of pit.

Well No. 8, N. E. corner of N. E. quarter Sec. 12, Blk. D5, Floyd County.

Elevation, 3313′

Depth	Thickness	
0	3.5	Top soil
3.5	20.3	Clay
23.9	28.9	Rock
52.7	9.2	Rock
62	10	Red rock
72	20	Red clay
92	6	Red sand
98	19	Red clay
117	23	Fine sand
140	10	Red clay
150	6	Fine sand
156	3	Red clay
159	9	Pack sand
168	1	Sand and gravel
169	19	Pack sand
189	1	Red clay
189	18	Sand and gravel
207	9	Fine sand
216		

Well No. 7, N. E. quarter Surv. 65, Blk. D2, Floyd County.

Elevation, 3315′ Depth to water, 49′±

Depth	Thickness	
0	3.5	Top soil
3.5	14.5	Clay
18	3	Clay and chalk
21	6	Shale
27	7	Clay
34	7	Shale
41	8	Lime rock
49	5	Fine sand and boulders—water
54	14	Shale rock

Depth	Thickness	
68	8	Sandstone—water
76	5	Clay
81	13	Clay and sand
94	8	Fine sand—water
102	11	Shale
113	8	Shale rock
121	15 .	Fine sand—water
136	5	Gumbo
141	15	Fine sand—water
156	5	Clay
161	6	Sandstone—water
167	14	Clay
181	9	Soft limestone
190	17	Coarse sand—water
207	14	Fine sand—water
221	11	Shale
232	9	Coarse sand—water
241	15	Sandstone—water
256	6	Clay
262	11	Fine gravel—water
273	4	Coarse sand—water
277		

Well No. 7, N. E. quarter Surv. 65, Blk. D2, Floyd County.

Depth	Thickness	
0	3.6	Top soil
3.6	9.9	Clay
13.5	2.5	Cemented boulders
16	8.7	Gravel and clay
24.7	9.2	Rock
34	5	Clay
39	5.9	Rock
44.9	4.6	Clay
49.4	10.6	Rock and sand
60	18	Red clay
78	3	Soft sand
81	23	Red clay
104	1	Sand rock
105	10	Red clay
115	2	Sand
117	18	Red clay
135	17	Hard sand
152	3	Clay
155	28	Sand
183	3.5	Hard rock
186.5	24.5	Sand
211.5		

Well No. 5, S. E. quarter Surv. 65, Blk. D2, Floyd County.

Elevation, 3314.3′ Depth to water, 49.5′

Depth	Thickness	
0	3	Top soil
3	8	Clay
11	5	Clay and chalk
16	11	Clay
27	11	Shale
38	12	Shale rock
50	6	Sandstone—little water
56	8	Lime rock and boulders
64	7	Sandstone—water
71	15	Shale
86	5	Fine sand—water
91	11	Clay
102	22	Fine sand—water
124	10	Shale
134	8	Gumbo
142	19	Fine sand—water
161	11	Sandstone—water
172	11	Fine sand—little water
183	9	Shale
192	10	Medium coarse sand—water
202	20	Fine sand—water
222	9	Sandstone—water
231	10	Shale
241	6	Gumbo
247	14	Coarse sand and fine gravel—water
261	13	Coarse sand—water
274	4	Shale
278		

**76 ft. of 26″ pit.
202 ft. of 16″ hole.

Well No. 5, File 77, Clinkscales tract, Floyd County.

Depth to water, 47′

Depth	Thickness	
0	4	Top soil
4	32	Clay
36	17	Rock
53	5	White rock, soft
58	13	Red rock, hard
71	37	Fine sand
108	5	Red clay
113	31	Hard sand
144	23	Clay and gravel
167	19	Sand

Depth	Thickness	
186	2	Red clay
188	19	Coarse sand and gravel
207		

**53 ft. of pit.

Well No. 4, Merrill tract, File 133, Hale County.

Elevation, 3359.2′ Depth to water, 45′ (?)

Depth	Thickness	
0	3	Top soil
3	3	Mottled clay
6	26	Clay
32	6	Soft chalk and shale
38	7	Cemented boulders
45	12	Sandstone—water
57	33	Shale
90	17	Thin layers clay and sand—water
107	12	Pack sand
119	11	Shale
130	8	Fine sand—water
138	5	Pack sand
143	11	Gumbo
154	9	Sand—water
163	5	Shale
168	12	Fine sand—water
180	14	Coarse sand—water
194	3	Shale
197	18	Coarse sand—water
215	6	Gumbo
221	9	Medium coarse sand—water
230	14	Shale
244		

**70 ft. of 29″ pit.

Well No. 3, agricultural division of demonstration farm, Hale County.

Elevation, 3370.3′ Depth to water, 46.5′(?)

Depth	Thickness	
0	45	Top soil and clay
45	1.5	Gravel and sand—water
46.5	11.5	Hard lime rock with water between beds
58	13	Loose shale
71	25	Shale
96	9	Loose shale
105	9	Clay
114	5	Fine sand
119	3	Shale
122	23	Fine sand

Depth	Thickness	
145	20	Shale
165	7	Shale
172	9	Shale
181	13	Coarse sand
184	5	Soft sand rock
199	6	Coarse sand
205	4	Shale rock
209	4	Medium coarse sand
213	8	Water-bearing coarse sand rock
221	15	Medium sand
236	5	Soft sand rock
241	6	Red clay
247		

**73 ft. of 26″ pit.
All sands are water-bearing.

Well No. 2, 1100 ft. south of N. W. corner Sec. 16, D6, Hale County.
Elevation, 3373.3′ Depth to water, 46′ (?)

Depth	Thickness	
0	2.5	Top soil
2.5	33.5	Clay
36	4	Cement rock
40	1.5	Water sand
41.5	4.5	Cement rock
46	11	Sandstone—water
57	2	Shale
59	2	Sand—water
61	27	Pink shale
88	22	Clay
110	5	Pack sand
115	6	Clay and gravel
121	13	Pack sand
134	6	Soft sandstone
140	8	Clay and gravel
148	39	Fine sandstone and sand
187	5	Clay
192	17	Fine pack sand
209	21	Coarse sand and gravel—water
230	6	Coarse sand and gravel—water
236	2	Soft sandstone
238	8	Medium coarse sand
246	2	Sandstone
248	6	Medium coarse sand
254	7	Clay
261	7	Sandstone
268	7	Sand, with some water

Depth	Thickness	
275	14	Gumbo
289	20	Coarse sand—water
309	3	Gumbo
312		

Well No. 1, 890 ft. E. and 150 ft. N. of S. W. corner of Surv. 16, Blk D6, Demonstration farm.

Elevation, 3373.3′ Depth to water, 47′(?)

Depth	Thickness	
0	26	Top soil and clay
26	1	Hard cemented boulders
27	9	Clay
36	11	Hard lime rock and cemented boulders
47	12.5	Same, with water-bearing sand between layers
59.5	12.5	Pink shale
72	23	Hard-pan and pebbly clay
95	3	Coarse sand—water
98	9	Clay and hard-pan
107	3	Tight joint clay
110	3.5	Sand—water
113.5	23	Tight joint clay
136.5	34	Sand rock, breaks into white pebbles
170.5	8	Sand rock, red and white
178.5	1.5	Flowing sand
180	8	Compact sand
188	2	Clay and gravel
190	22	Sand rock
212	2	Flowing sand
214	1	Gravel pocket
215	15	Coarse sharp water—sand
230	....	Clay

DISTRICT NO. 2

Well No. 2-1, N. W. quarter Surv. 6, Blk. A1, Hale County.

Elevation, 3402.2′ Depth to water, 61′ (?)

Depth	Thickness	
0	3	Top soil
3	4	Clay and sand
7	10	Clay
17	9	Clay and sand
26	8	Shale
34	3	Clay
37	11	Hard shale
48	8	Shale
56	5	Lime rock

Depth	Thickness	
61	10	Sand—water
71	3	Lime rock and boulders
74	7	Lime rock
81	16	Hard shale
97	7	Clay
104	8	Sandstone—water
112	5	Shale
117	9	Sandstone—water
126	38	Sand—water
164	5	Sandstone—water
169	11	Sand—water
180	16	Sandstone—water
196	5	Shale
201	14	Coarse sand—water
242	9	Sandstone—water
251		

**90 ft. of 26″ pit.
161 ft. of 16″ hole.

THIRD DISTRICT.

Well No. 3-4, 75 ft. E. and 75 ft. N. of N. W. corner of 160-acre tract sold to H. J. Fair out of McVicker, Lattimore, and Sewell homesteads.

Elevation, 3432′ Depth to water, 51.5′

Depth	Thickness	
0	14.5	Soil and clay
14.5	32	"Gyp" of all colors, some clay
46.5	6	Sand—water
52.5	9	"Gyp" rock
61.5	9	Sand—water
70.5	1	Rock
71.5	15	Sand—water
86.5	2	Rock
88.5	7	Sand—water
95.5	11	Sand and "gyp"
106.5	15	Loose sand—water
121.5	47	"Gyp"
123.5	47	Loose sand—water
170.5		

**99 ft. of water-bearing formation.

Well No. 3-7, W. W. Snell homestead, Hale County.

Elevation, 3422′ Depth to water, 55′

Depth	Thickness	
	3	Soil
	29	Clay and limestone

Depth	Thickness	
	8	Dry sand
	19	White rock
	16	Water-sand
	6	Sandstone
	37	Water-sand
	8	Hard sand
	41	Water-sand
	7	White rock
	21	Water-sand
	10	Hard sand
	5	Water-sand
210		

Well No. 3-2, 75 ft. E. and 75 ft. S. of N. W. corner of D. R. McVicker homestead, File 105.

Elevation, 3446′

Depth	Thickness	
0	3	Top soil
3	9	Clay
12	5	Clay and sand
17	9	Clay
26	11	Shale
37	12	Clay
49	6	Clay and chalk
55	4	Lime rock and boulders
59	14	Sand
73	5	Shale rock
78	6	Lime rock
84	14	Shale
98	12	Sand—water
110	7	Clay
117	14	Sand—water
131	6	Sandstone—water
137	12	Shale
149	10	Sand
159	5	Sandstone—water
164	7	Lime rock
171	16	Sand—water
187	4	Soft sandstone—water
191	15	Sandstone and lime
206		

**90 ft. of 26″ pit.

Well No. 3-1, 50 ft. E. of fence of P. & N. T. Ry., and 50 ft. S. of north fence, L. B. White Purchase (File 106), Swisher County.

Elevation, 365.5′ Depth to water, 66′ (?)

Depth	Thickness	
0	2.5	Top soil
2.5	3.5	Clay and chalk
6	12	Clay
18	3	Shale rock
21	6	Shale
27	7	Clay
34	3	Shale
37	5	Shale rock
42	9	Clay
51	11	Shale
62	4	Clay
66	6	Sand—water
72	6	Lime rock and boulders
78	3	Lime rock
81	6	Shale
87	11	Clay
98	9	Shale
107	8	Soft sandstone—water
115	7	Shale
122	9	Shale rock
131	8	Sand—water
139	8	Sandstone—water
147	7	Shale
154	13	Sandstone—water
147	7	Shale
154	13	Sandstone—water
167	9	Shale
176	14	Sandstone—water
190	6	Lime rock, sandstone, and boulders
196	2	Sandstone and boulders
198	43	Shale
241	22	Shale rock
263	8	Clay
271	9	Shale rock
280	7	Shale
287	11	Shale rock
298	13	Shale
311	3	Shale rock
314	4	Lime rock
318	18	Shale rock
336	5	Shale

Depth	Thickness	
341	7	Shale rock
348		

**93 ft. of 26″ pit
102 ft. of 16″ hole
153 ft. of 8″ hole

HOUSE AND SUPPLY WELLS.

Supply well No. 67, 75 ft. E. and 75 ft. S. of N. W. corner of East half of S. E. quarter of Surv. 16, Block N.

Elevation, 3298.2′ Depth to water, 35.5′

Depth	Thickness	
0	5	Top soil
5	25	Clay
30	7	Rock
37	15	Water-sand
52	23	Clay
75	10	Water-sand
85		

Supply well No. 63, 75 ft. E. and 75 ft. S. of N. E. quarter of Surv. 16, Block N.

Elevation, 3303.5′ Depth to water, 37′

Depth	Thickness	
0	3	Top soil
3	31	Clay
34	4	Rock
38	15	Water-sand
53	20	Red clay
73	11	Water-sand
84		

Supply well No. 66, 650 ft. S. and 380 ft. E. of N. W. corner of S. E. quarter of Surv. 16, Block N.

Elevation, 3311.3′ Depth to water, 43′

Depth	Thickness	
0	8	Top soil
8	32	Clay
40	6	Rock
46	12	Water-sand
58	18	Red clay
76	10	Water-sand
86		

Supply well No. 68, 1260 ft. S. and 75 ft. W. of N. E. corner of S. W. quarter of Surv. 16, Blk. N.

Elevation, 3300′ Depth to water, 36.5′

Depth	Thickness	
0	5	Top soil
5	20	Clay
25	12	Rock
37	15	Water-sand
52	24	Clay
76	9	Water-sand
85		

Supply well No. 65, 1500 ft. S. and 75 ft. E. of N. W. corner of S. W. quarter of Survey 16, Blk. N.

Elevation, 3298.6′ Depth ta water, 32′

Depth	Thickness	
0	5	Top soil
5	21	Clay
26	8	Rock
34	18	Water-sand
52	20	Yellow clay
72	13	Water-sand
85		

Supply well No. 27, N. W. corner T. A. Cowart homestead.

Elevation, 3272.3′ Depth to warte, 35′

Depth	Thickness	
0	2	Top soil
2	3	Yellow clay
5	20	White dirt
25	5	White dirt and rock
30	5	White sand
35	24	Red clay
59	1	Rock
60	6	Sand
66		

Supply well No. 57, E. side T. A. Cowart homestead.

Elevation, 3272.3′ Depth to water, 35′

Depth	Thickness	
0	1.5	Top soil
1.5	7	White and yellow clay
8.5	18	Yellow clay
26.5	9	White dirt and rock
35.5	5	White sand
40.5	20	Red clay
60.5	25	Soft sand
85.5		

Supply well No. 56, S. half J. J. Roberts homestead.

Elevation, 3286.2′ Depth to water, 44′

Depth	Thickness	
0	3	Top soil
3	4	White and yellow clay
7	20	Yellow clay
27	10	White dirt
37	4	Hard rock
41	7	Red sand
48	20	Red clay
68	18	Sand
86		

Supply well No. 55, north half J. J. Roberts homestead.

Elevation, 3287.4′ Depth to water, 45′

Depth	Thickness	
0	3	Top soil
3	25	Yellow clay
20	14	White dirt and soft rock
42	5	Red sand
47	10	Red clay
57	8	Fine sand
65	10	Red clay
75	10	Sand
85		

Supply well No. 54, south half of S. W. quarter Surv. 48, Blk. D6.

Elevation, 3287.8′ Depth to water, 44′

Depth	Thickness	
0	2	Top soil
2	30	Yellow clay
32	16	White dirt and soft rock
48	7	Red sand
55	12	Red clay
67	17	Fine sand
84	1	Red clay
85		

House well No. 8 (see also Well No. 8). East half of N. W. quarter of Survey 12, Blk. D5, Floyd County.

Depth	Thickness	
0	2	Soil
2	24	Yellow clay
26	11	Pack sand
37	20	Pack sand
57	3	Rock and sand
60	18	Rock and sand
78		

Test well No. 53, north half of S. W. quarter Surv. 48, Blk D6, Floyd County.

Elevation, 3291.7′ Depth to water, 46′

Depth	Thickness	
0	2	Soil
2	35	Yellow clay
37	15	White dirt and rock
52	2	Sand
54	21	Red clay
75	7	Sand
82	4	Red clay
86		

Test well No. 52, east half of N. E. quarter Surv. 15, Blk. D5, Floyd County.

Elevationfi 3311.6′ Depth to water, 45′

Depth	Thickness	
0	2	Soil
2	1	White dirt
3	17	Yellow clay
20	12	White clay
32	23	White sand and rock
55	6	Red sand
61	29	Red clay
90	4	Sand
94	1	Red clay
95		

Test well No. 3-5, S. W. quarter Surv. 54, Blk. M14, Hale County.

Elevation, 3421.5′ Depth to water, 63′

Depth	Thickness	
0	3	Soil
3	1	White dirt
4	8	Yellow clay
12	5	Yellow clay and rock
17	25	Yellow clay
42	18	Loose sand
60	3	Sandstone
63	6	Clay
69	12	Sand
81	11	Red clay
92	6	Sand
98	2	Clay
100		

Test well No. 3-3, S. W. quarter Surv. 55, Blk. M14, Hale County.
Depth to water, 53′

Depth	Thickness	
0	3	Soil
3	1	White dirt
4	7	Yellow clay
11	3	White dirt
14	6	Yellow clay
20	2	Soft rock
22	18	Yellow clay
40	40	Soft sand
80		

Test well No. 23. (See Well No. 23.)
Depth to water, 43′

Depth	Thickness	
0	3	Soil
3	2	Yellow clay
23	9	Pack sand
32	7	White clay and rock
39	3	Hard rock
42	10	White sand
52	24	Red clay
76	10	Wet red sand
86		

Test well No. 24. (See Well No. 24.) West side of S. E. quarter of Surv. 22, Blk. N, Floyd County.
Depth to water, 44′

Depth	Thickness	
0	3	Top soil
3	24	Yellow clay
27	20	White clay and rock
47	5	Red sand
52	29	Red clay
81	9	Sand
90		

Test well No. 25. (See Well No. 25.) S. W. quarter Surv. 22, Blk. N., Floyd County.
Depth to water, 43′

Depth	Thickness	
0	3	Top soil
3	27	Yellow clay
30	10	White clay and rock
40	7	Hard rock
47	6	Red sand

Depth	Thickness	
53	25	Red clay
78	7	Sand
85	2	Red clay
87		

House well No. 51 (see well No. 51).
Depth to water, 44′

Depth	Thickness	
0	3	Soil
3	5	White dirt
8	8	White and yellow clay
16	12	Pack sand
28	7	White clay and rock
35	10	Rock
45	4	White sand
49	20	Red clay
69	6	Red sand
75		

House well at Aiken. Mr. H. I. Miller.
Depth to water, 48′

Depth	Thickness	
0	2	Top soil
2	5	Yellow clay
7	10	White clay
17	16	Yellow clay
33	12	White clay and rock
45	3	White sand
48	12	White clay
60	8	Red clay
68	7	Red sand
75		

Store well at Aiken.
Depth to water, 48′

Depth	Thickness	
0	3	Top soil
3	5	Yellow clay
8	10	White clay
18	16	Yellow clay
34	7	White clay and rock
41	12	White sand
53	1	Rock
54	23	Red sand
77		

House well No. 48 (see well No. 48).

Depth to water, 45′

Depth	Thickness	
0	2	Top soil
2	19	White dirt
21	1	Rock
22	7	White dirt
29	0.5	Rock
29.5	8	Red sand
37.5	15	Rock and white dirt
52.5	8	Rock and red sand
60.5	18	Red clay
78.5	2	Red sand
80.5		

Supply well No. 204.

Depth to water, 51′

Depth	Thickness	
0	3	Top soil
3	19	Red sand subsoil
22	8	Gray subsoil
30	11	Red clay
41	22	White clay
63	15	Red sand
78		

Supply well No. 203.

Depth to water, 54′

Depth	Thickness	
0	2	Top soil
2	10	Gray soil
12	15	Red sand and subsoil
27	17	White subsoil
44	10	Sand and rock
54	17	White rock
71	9	Red sand, clay and gravel
80		

Supply well No. 49 (see well No. 49).

Depth to water, 47

Depth	Thickness	
0	2	Top soil
2	26	Yellow clay
28	8	Soft rock
36	7	White dirt
43	22	Red clay
65	15	Red sand
80		

House well No. 15.

Depth to water, 51′

Depth	Thickness	
0	2	Top soil
2	8	White dirt
10	25	Yellow clay
35	10	Yellow clay and rock
45	4	White rock
49	6	White sand
55	16	Red clay
71	9	Fine sand
80		

Supply well No. 51 (see well No. 51).

Depth to water, 44′

Depth	Thickness	
0	3	Top soil
3	2	White dirt
5	15	White and yellow clay
20	14	Pack sand
34	3	Rock
37	7	Rock and white clay
44	18	Fine red sand
62	18	Red clay
80		

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