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UNITED STATES GEOLOGICAL SURVEY

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TWENTY-FIRST ANNUAL REPORT

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UNITED STATES GEOLOGICAL SURVEY

PART VII—TEXAS

GEOGRAPHY AND GEOLOGY

OF THE

BLACK AND GRAND PRAIRIES, TEXAS

WITH

DETAILED DESCRIPTIONS OF THE CRETACEOUS FORMATIONS AND SPECIAL REFERENCE TO ARTESIAN WATERS

BY

ROBERT T. HILL

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GEOGRAPHY AND GEOLOGY OF THE BLACK AND GRAND PRAIRIES, TEXAS.

By Robert T. Hill.

INTRODUCTION.

Area treated.—The Black and Grand prairies of Texas and southern Indian Territory comprise about 50,000 square miles (see Pl. LXV, in pocket)—an area equal to that of fifty of the quadrangles mapped and described by the United States Geological Survey in its Geologic Atlas of the United States. The accompanying general geologic map (Pl. LXVI, in pocket) is a condensed presentation of the geology usually shown on that number of atlas sheets as published in folio form. Most of these quadrangles have been studied by the writer and his former assistants.

Sources of data.—An entirely satisfactory presentation of these results is still impossible by reason of the lack of adequate maps. The topographic maps of the United States Geological Survey, which cover 24 of the 50 units of area, were made in the earlier years of the Survey and with a contour interval insufficient for the expression of the geology. For the remaining portion of the area it was necessary to use as a base the Land Office maps of the State of Texas.

The conclusions herein presented, often condensed in a short paragraph, are founded upon a large amount of paleontologic, stratigraphic, and topographic data. The results, so far as they refer to the Black and Grand prairies, are the outcome of studies made by the writer since 1882, sometimes independently, sometimes with the assistance of the United States Geological Survey, and during two years in connection with the Texas Geological Survey. In times past he has been assisted in this work by his former students, C. C. McCulloch, now captain, U. S. A.; Messrs. Wilson T. Davidson and L. T. Dashiel; Mr. Joseph A. Taff, now of the United States Geological Survey; Dr. J. W. Stone, Mr. N. F. Drake, and Mr. G. H. Ragsdale. Inasmuch as the details which these gentlemem worked out were problems of the writer's suggestion, he has incorporated them into this paper, and here acknowledges indebtedness therefor. Upon the writer's retirement from the Texas Survey, Mr. Taff continued the work of mapping the region. He published two reports,[1] which have been freely used and which have been of great assistance in the preparation of this paper.

Importance of paleontology.—In addition to the collection of the data which appear in the text and illustrations, much paleontologic research has been necessary in order to classify the formations. Paleontology is the most reliable guide in determining the position of any bed in the geologic series with a view to ascertaining the depth, from any particular portion of the surface, of the underground waters in the Cretaceous regions of Texas. If a few species of fossils, such as can be found in any locality, be sent to one familiar with the sequence of the beds, he can predict within a few feet the depth below the surface of any particular water-bearing stratum in the series. It was a labor of years to disentangle the preexisting confusion concerning the occurrence and succession of these fossils and their bearings upon the determination and definition of the strata. Their further consideration has been left to Mr. T. W. Stanton, who, it is presumed, will make final publication of the descriptions and the scientific results.

This is not a final and complete report. Detailed field work is desirable in many localities. Chemical analyses of water and illustrations of typical scenery should be more complete, but these were not obtainable with the means and time at the writer's disposal. When appreciation of geologic investigation shall have been awakened in Texas and the region under discussion shall have been studied more closely by resident students, in the manner now common in other parts of the United States, the data here presented will be largely increased and refined, and the conclusions will doubtless be correspondingly amended and rectified.

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[1] See Third and Fourth Annual Reports Geol. Survey of Texas.

PART I.

GEOGRAPHY OF THE TEXAS REGION.

In a recent paper[1] the author endeavored to present an outline of the physiographic features of the Texas region, as shown on a new map therewith, and to define its salient primary natural subdivisions, as a basis for more detailed discussion and differentiation of the various phenomena. The limits and plan of that paper forbade extended discussion or description of specific local features. The present paper will be devoted to a minute description of one of the provinces of the greater region as outlined in the paper mentioned. Before beginning this description, however, it will be well to give a brief résumé of the region as a whole.

The Greater Texas region includes practically all the country east of the Rio Grande south of the northern boundary of New Mexico. The region thus defined is not a physical unit, but rather an area which includes a peculiar group of physiographic units, composed of mountains and plains belonging to the four greater natural provinces of the United States, to wit: the Cordilleran region, the Great Plains region, the Appalachian region, and the Atlantic Coastal Plain. The characteristic features of these regions as they extend into the State present local modifications. There are also extensive stretches of country in the central portion of the State which have no counterpart elsewhere.

Before the individual physiographic features of the Greater Texas region are described the area, relations, and subdivisions of the State will be noticed.

THE STATE OF TEXAS.

Area, Relations, and Subdivisions.

The area of the State of Texas is 265,780 square miles, or about one-twelfth that of the entire United States. Its magnitude will be better appreciated when it is remembered that to the combined area of the New England States, New York, New Jersey, Pennsylvania, Delaware, Maryland, and the District of Columbia the areas of Ohio and Kentucky must be added to equal it. Its extent is about that of

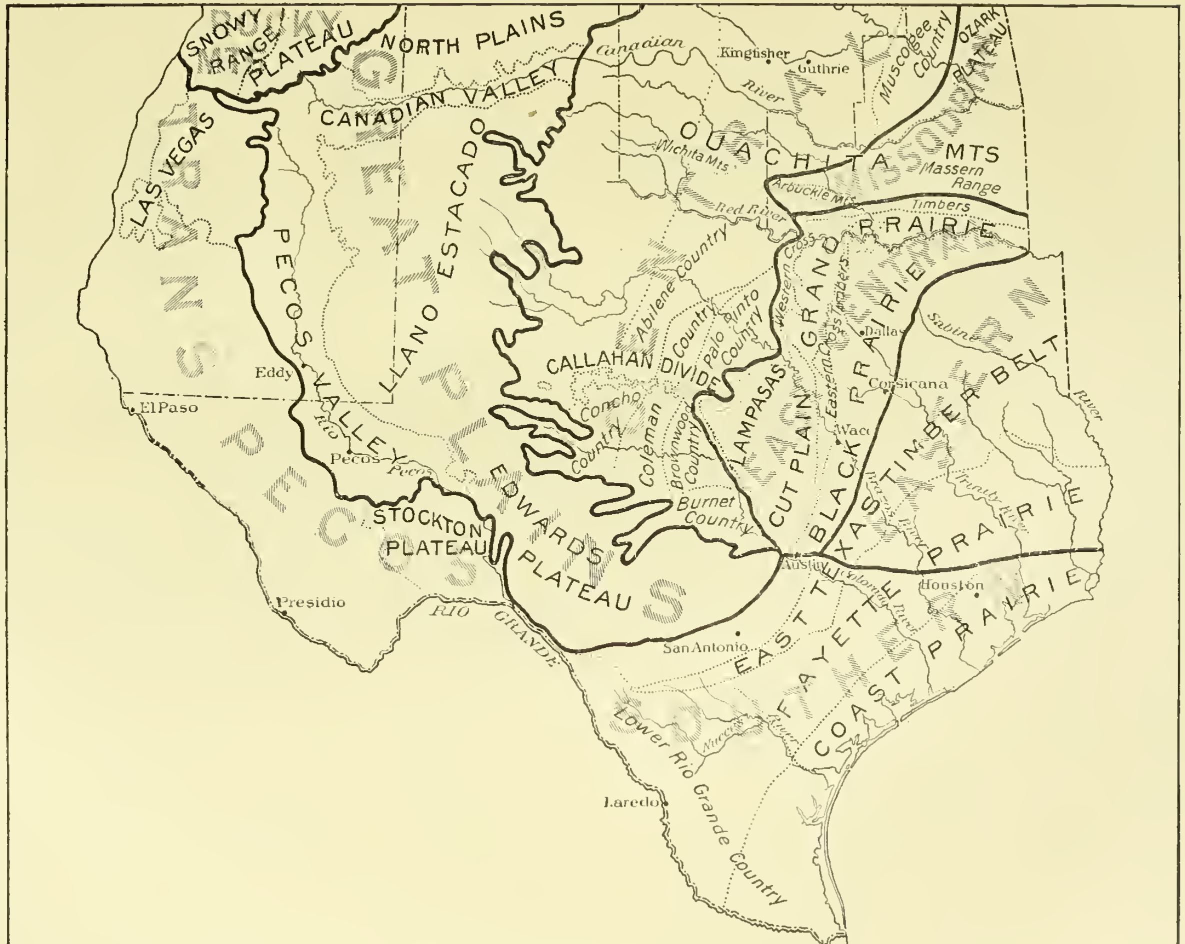
[1] Physical geography of the Texas region: Topographic Atlas U. S., folio 3, U. S. Geol. Survey, 1900.

France. Its length and breadth are nearly the same. The former is 760 miles, and the latter, along the thirty-second parallel, is about 740 miles. By rail these distances are 900 miles, or the same as from New York to Savannah, Atlanta, Chattanooga, Evansville (Indiana), Chicago, or Labrador. Its length is one-half that of our country from north to south. Its width is more than one-half the southern border of the United States between the Atlantic and the Pacific. This width is equal to one-third the distance across the widest portion of the country, from Cape Hatteras to Cape Mendocino.

In respect to location and natural conditions Texas does not fit exactly into any one of the ordinary classifications of States. It is southern—Florida excepted, it is the most southern of all States in geographic position. It is central, for it is one of the great tier that exactly forms the central strip of the Union. It is a Gulf State, and has one-fourth the shore line of the Gulf of Mexico. It is a western State, large areas of both the Great Plains and the Cordilleran regions being included in it, while its far western corner is nearer the Pacific than the Atlantic, and has the climatic features of the former rather than of the latter. Not only do its parts present the geographic features of the larger divisions of the United States already mentioned, but there are areas typical of the adjacent Republic of Mexico, such as the northern end of the Tierra Caliente at the mouth of the Rio Grande. Hence it may be said that Texas is both southern, central, and western in relative position and interests.

Neither the State of Texas nor the adjacent territories within the Greater Texas region have well-defined or officially recognized subdivisions. In Texas vague subdivisional terms have grown into popular use, but these have not been recorded or defined. Personal observation of this local usage shows that it includes two classes of terms: first, terms of direction, vaguely applied without definite reference to natural subdivisions; second, names based on specific natural features and applied to local districts, colloquially called "countries."

The directional names in general use in Texas are as follows: East Texas, Southwest Texas, Central Texas, Northwest Texas, North Texas, and West Texas. The bounds of the areas which these terms are intended to designate have never been defined, and it is doubtful whether they are well formulated in the public mind. They were not originally used with reference to the geographic center of the State, but were and still are employed with reference to the early American centers of population in the extreme eastern part. Thus all the areas to which these names are applied lie east of the central meridian of the State. Southwest Texas, for instance, according to this older nomenclature, embraces the country between the Balcones scarp line, the Rio Grande, and the coast. This region, relative to the geographic center



NATURAL PROVINCES OF THE TEXAS REGION.

of the State, is really Southern Texas, as it will be called in this report. Central Texas was the region traversed by the Houston and Texas Central Railway, and included a country (the east half of the East-Central Province of nomenclature) more than 100 miles east of the true Central Province as defined in this paper. North Texas was the tier of black-land counties adjacent to Red River, and included only the eastern third of the northern border. Northwest Texas was almost the exact geographic center of the State. The term West Texas was applied to the region immediately beyond the westwardly migrating line of frontier settlement.

No set of directional terms coincides exactly with the natural subdivisions of the State; nevertheless, such terms are convenient and often unavoidable in description. The use made of them in this report, however, is quite different from that which is customary, and results from a new classification of the region into provinces, based on physical characters and relations. The parts of the Greater Texas region which, by reason of natural features—characteristics of soil, climate, geologic structure, drainage, underground water conditions, and environment for human culture—constitute geographic units for discussion, or provinces, are six in number. (See Pl. I.) These provinces may be briefly outlined as follows:

DEFINITION OF THE PROVINCES.

Eastern Province.—This consists of the northern half of the Texas Coastal Plain, and includes the forest country east of the Black Prairie and north of the thirtieth parallel, which corresponds approximately to the latitude of Austin. It represents the continuation into Texas from Arkansas and Louisiana of the Atlantic Timber Belt of the interior portion of the Southern Coastal Plain. In Texas it embraces 33,000 square miles.

Southern Province.—This is the southern half of the Coastal Plain in Texas and the modified southern extension of the Eastern Province. It includes the area between the thirtieth parallel on the north, the Balcones scarp line on the west, and the Rio Grande on the south as far west as Del Rio. It contains a diverse group of countries, such as the Coast Prairie, the Fayette Prairie, the Carrizo Country (an attenuated southwestern extension of the Atlantic Timber Belt), the Comal Country (the southern continuation of the Black Prairie), and the Rio Grande embayment. Its area aggregates 52,000 square miles.

East-Central Province.—This includes the portion of Texas north of the Colorado between the Eastern Province and the Central Province proper, and the portion of southern Indian Territory south of the Ouachita Mountains and east of the ninety-seventh meridian. It includes the Black and Grand prairies and the two belts of timber known as the Western and Eastern cross timbers. Its area is about 31,000 square miles.

Central Province.—There is a vast area of diversified prairie plains in southern Kansas, Oklahoma, Indian Territory, and Texas, lying between the Plateau of the Plains and the western border of the Ozark Plateau and the East-Central Province. This is the Central Denuded region of the writer's previous papers, and consists of a number of diverse prairie features occurring in more or less regular north-south belts succeeding one another to the west, including those established upon the Red Beds, the Carboniferous, and the older Paleozoic rocks, each of which will be described under its appropriate head. The area of its southern portion which lies in Texas is 37,000 square miles.

Great Plains Province.—This includes the Great Plains proper, which extend eastward from the Rocky Mountain front to the prairie plains of the Central Province and southward to the Southern Province.

Plateau Subprovince of the Great Plains.—This is the modified southern extension of the Great Plains Province of the United States. In Texas it is an extensive oblong plateau south of Canadian River, comprising the Llano Estacado and the Edwards Plateau—60,000 square miles. The Stockton Plateau, between the Pecos and the Rio Grande and the eastern front of the mountains, which may be included in the Plateau Province, has an area of about 15,000 square miles.

Trans-Pecos Province.—This represents the continuation of the eastern ranges, plateau plains, and interior basins of the great Cordilleran region of western United States west of the Pecos and southward from northern New Mexico, through Texas, into the eastern Sierra Madre of Mexico. The portion in Texas embraces 35,000 square miles.

Provisional subdivisions into "countries."—In Texas the name "country" is used locally for more limited districts (subdivisions of the provinces) which have some peculiar or specific natural unity of soil, flora, or topography. Thus we have the Coast and the Pine Woods countries for certain subdivisions of the Eastern Province of the State; the Abilene, Wichita, Brownwood, San Angelo, San Saba, and Llano countries for subdivisions of the Central Province; the Uvalde, Laredo, Carrizo, and Brownsville countries for subdivisions of the Southern Province; the Plains, Panhandle, and Pecos Valley countries for subdivisions of the Great Plains Province; and the Big Bend; El Paso, Marathon, Fort Davis, and other names for the countries of the Trans-Pecos Province. No definite bounds of these can be fixed without good surveys and maps, which have not been completed, and hence exact definitions or descriptions of the countries are not attempted in this paper. Each forms a unit worthy of separate treatment in a special paper.

THE RELIEF.

The relief features of the Greater Texas region range from vast stretches of apparently level country, like the Llano Estacado and Coast Prairie, presenting no visible breaks in their plain-like extent, to the rugged mountains of the Trans-Pecos Province, marked in places along the Rio Grande by abrupt canyons and declivities.

This relief, as a whole, may be classified as that of the mountains and that of the plains. The altitudes of the region vary from sea level to 13,000 feet (see Pl. II).

Broader features of the relief.—In a broad sense the Greater Texas region consists of a vast and diversified plain bordered on the west and north by mountains. That portion between the eastern front of the Cordilleras and the sea may be primarily conceived as an elongated plain. This plain inclines gently from the Cordilleras toward the sea. The inclination from the foot of the Cordilleras to the Gulf is generally in an easterly direction, but there are slight variations of direction. The area having this general inclination may be specifically called the Regional Coastward Slope, and its variation in gradient and direction, as will be explained later, has an important relation to the physiographic history. Except in the extreme northwest corner of Texas, where the Great Plains continue north unbroken, and on the east, where the Coastal Plain borders the sea or continues into Louisiana, the Regional Coastward Slope is terminated by the Cordilleran and the Ouachitan mountain systems, which extend at approximately right angles to each other, diverging so as to inclose the plain in a triangle having its wider base toward the sea. The plain is rudely comparable to a wide, low stairway, leading upward from the sea to the Cordilleras, in which the various subdivisions of the plain represent the treads, local escarpments the risers, and the limiting mountains the balustrades. This analogy can not be carried far, for great irregularities occur in the width and tread of the steps, and the wear and tear of time has scarred and disfigured their relief, etched valleys where the drainage depressions have crossed the plains, and lowered the mountain walls. Some escarpment steps in exceptional instances face westward, or upstairs, while other subdivisions of the plain succeed one another without any well-defined feature of relief. Furthermore, the structure of the inclosing mountain systems is of two entirely different types and periods of architecture. The formations which underlie some of the plains are crumpled up in the Cordilleras and are deposited against the Ouachitas. Hence, parts of the plains are older than the Rocky Mountains and younger than the Ouachita uplifts.

Specific features of the relief.—The chief specific features of the relief may be enumerated as follows:

- Mountains:
  - Ouachita Mountains.
  - Trans-Pecos Mountains.
- Plains:
  - Plains of the Regional Coastward Slope.
    - The Great Plains.
      - North Plains.
      - Llano Estacado.
      - Edwards Plateau.
      - Stockton Plateau.
      - Pecos Valley.
      - Canadian Valley.
    - Prairie plains.
      - Muscogee Prairies.
      - Oklahoma Prairies.
      - Grand Prairie.
        - Western Cross Timbers.
      - Black Prairie.
        - Eastern Cross Timbers.
    - Coastal Plain.
      - East-Texas Timber Belt.
      - Coast Prairie.
      - Rio Grande embayment.
  - Plains of the Trans-Pecos Province.
    - Bolson plains.
    - Plateau plains.

Each of the diverse features alluded to has an area equivalent to that of an average State of the Union; each is distinguished from the others by different types of soil, rocks, and drainage, and by different agricultural and industrial possibilities.

Before describing these features in detail it is essential to state briefly the salient geologic conditions upon which their existence is dependent.

Relation of Formation to Relief.

Nowhere is there a more intimate relation between geologic formation and physiography than in the Texas region. Nearly all conditions which influence human environment, except climate, depend on the composition and arrangement of the various rock sheets. Each formation has peculiarities of stratification, consolidation, cohesion, friability, and porosity, which, when the formation is acted upon by climatic agents, result in various relief forms.

The induration, or hardness, of the rock sheet is the chief factor influencing the character of the relief. All hills, scarps, plateaus, mountains, and other relief features of Texas are illustrations of the survival of the hardest in the denuding processes of land degrada-

A HYPSOMETRIC MAP OF THE TEXAS REGION.

1, 1,000 feet; 2, 2,000 feet; 3, 3,000 feet; 4, 4,000 feet; 5, 5,000 feet; 6, over 6,000 feet

B GEOLOGIC MAP OF THE TEXAS REGION.

1, Older granite; 2, Paleozoic and Mesozoic; 3, Cambrian-Silurian; 4, Carboniferous; 5, Permian; 6, Jurassic; 7, Lower Cretaceous; 8, Upper Cretaceous; 9, Nonmarine Tertiary; 10, Marine Eocene; 11, Coast Neocene; 12, later igneous.

tion; correspondingly, the minute configuration of the stream valleys, valley plains, escarpments, and many of the level prairies bordered or surrounded by scarps also depends upon the relative hardness of the rocks.

The inclination of the rock sheets is an important factor in producing relief. Where these are horizontal or but gently inclined the tendency is toward plane surfaces with vertical cliffs bordering the drainage grooves; where steeply inclined, rugged mountainous forms result.

Consolidation, friability, cohesion, solubility, and porosity modify the relief in various ways. Loose sands are heaped by the wind into low hills or dunes; unconsolidated clays weather into rounded hills and flat surfaces; soluble rocks produce sink holes and other irregular surfaces with caverns and bluffs; and the degree of porosity facilitates or retards decay.

Especially in the nonmountainous part of Texas, each formation produces a characteristic relief and weathers into its own distinctive type of soil, the color of which—white, red, black, brown, or yellow—gives a peculiar tone to the resulting landscape, accompanied by floral individualities resulting from its texture and composition. Sometimes a simple group of strata, like the Plains formation, which extends over 40,000 square miles, produces an extensive uniform region, with less differentiation in physical features than is found elsewhere within the area of an ordinary township.

In general, as has already been explained, the relief of the Greater Texas region resolves itself into two broad types: (1) True mountainous areas (the Trans-Pecos and Ouachitan), in which the rock sheets are comparatively more tilted or otherwise deformed; and (2) a greater plains region, that of the Regional Coastward Slope, in which the rock sheets, largely the same as those which make the mountains, are but slightly inclined and form vast extents of sublevel surfaces rather than eminences. The area of Oklahoma, Indian Territory, and southern Kansas, north of the Ouachita Mountains, is included under this general head, though its slope is not strictly coastward but toward the Mississippi.

KINDS OF RELIEF-MAKING ROCKS IN TEXAS REGION.

Most of the surface of Texas is formed of sedimentary rocks, igneous formations covering a much smaller area. There are also extensive formations composed of wind-blown débris, chemical precipitates, and upland drift.

The sedimentary rocks, superposed one above another in more or less orderly succession, are of two general classes: (1) Marine formations, originally laid down upon the marginal bottoms of the sea; and

(2) surficial formations, deposited upon the slopes of the land or at local deposition levels, as in lakes, rivers, or other bodies of water which have existed within the land areas.

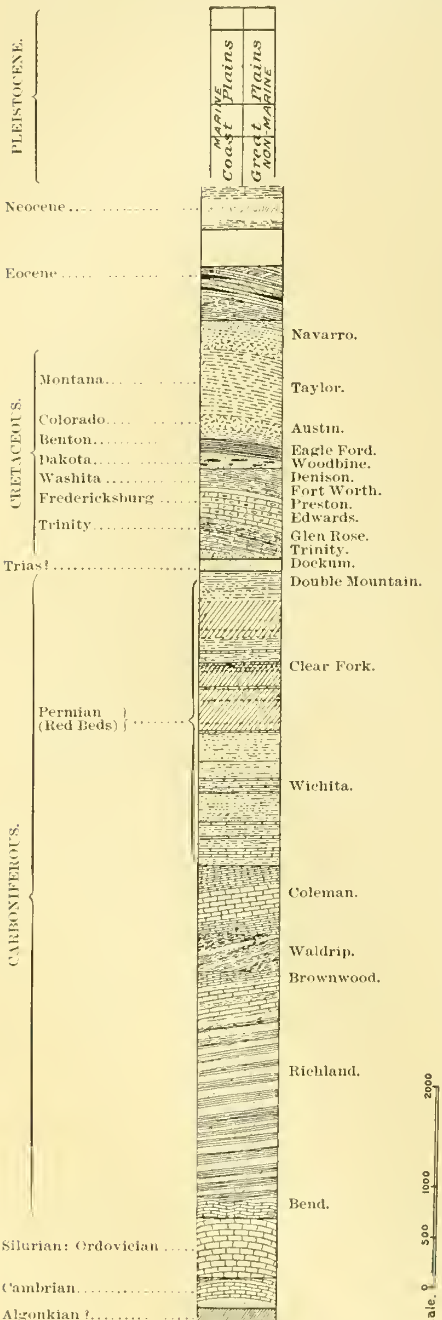


FIG. 1.—Geologic formations of Texas.

INFLUENCE OF THE MARINE SEDIMENTARIES.

The sedimentary rocks laid down on the sea bottom are of all ages from Cambrian to Recent, with the possible exception of Devonian. They aggregate about 25,000 feet in thickness, as is shown in the accompanying vertical section (fig. 1; see also Pl. II, *B*). These rocks occur as strata of different hardness, tilted at steep angles in the mountainous areas, and nearly horizontal in the plains region (see fig. 11). They are of two general classes, differing in occurrence and relative importance, viz:

1. An older or fundamental series of pre-Cretaceous formations. The structural arrangement of these formations, in anticlines and synclines, is discordant with that of the later formations of the Coastward Slope. The series represents the remains of an ancient topography which was base-leveled during Jurassic and Cretaceous time, prior to the invasion of the Cretaceous seas, which completely buried it with later sediments. These older rocks, except in the mountains, are now seen only where areas of the later strata have been worn away. In the structure of this group is written an interesting pre-Cretaceous history,

involving the growth and decay of relief features quite different in detail from those of the present time, which is described more fully in later pages.

2. Formations of the Coastward Slope, from Cretaceous to Recent age. Most of these rocks were once marginal deposits of the Gulf of Mexico, laid down when it extended much farther inland than it does to-day; and as they were elevated the Gulf receded from the Rocky Mountains front to its present position. All these strata now incline toward the sea. In some instances the inclination coincides with the surface slope, while in others it is slightly greater.

Relief expression of the older or Paleozoic sedimentaries.—Classified according to geographic importance the older rocks may be divided into two groups—the earlier and the later Paleozoic. The first includes the Algonkian and Cambro-Ordovician; the second, the Carboniferous, with the Permian. They may be divided into four greater lithologic subdivisions—the pre-Cambrian, the Cambro-Ordovician, the Carboniferous, and the Permo-Triassic Red Beds. Of these the first two are usually more or less associated in geographic occurrence in limited areas, and by reason of their hardness produce allied features of topographic relief. The third and fourth, forming the surfaces of large areas, have each individual features.

Pre-Cambrian and older Paleozoic rocks are the foundation upon which all the other rocks were laid down, and are still in the main covered by them. Their outcrops are exceptional and restricted in area; they occur in small districts in the Wichita Range of the Ouachita Mountain system, in some of the Trans-Pecos Mountains, especially the district between the thirty-first and thirty-second parallels, and in a limited territory in the southern end of the Central Province known as the Burnet Country.

The pre-Cambrian rocks are mostly schists and granites; the former are greatly disturbed and weather into angular vertical knife-edges of projecting hard strata or low mammillary hills. The Cambro-Silurian rocks are indurated sandstones and limestones which weather into rounded hills with steep slopes. They usually occur in geographic association with the pre-Cambrian rocks.

The Carboniferous rocks are the chief formations of eastern or Massern Ranges of the Ouachita Mountains, the eastern border of the Central Province in Indian Territory and Texas, and the Diablo, Guadalupe, and Caballos Mountains of Trans-Pecos Texas. The Permian Red Beds prevail in the greater part of the Central Province and in the Pecos and Canadian valleys. Both Carboniferous and Permian formations occupy an old synclinal trough between the Grand Prairie and Ozark Plateau on the east and the Cordilleras on the west, which was buried by the Cretaceous formations. The Carboniferous and Permian rocks produce somewhat allied but different topographic forms. The Carboniferous, largely made up of soft, impure shales alternating with harder, coarse, brown sandstones and conglomerates, produces ridge-like mountains and a broken belt of country along the eastern margin of the Central Province, composed of rough-scarped and flat-topped sandstone plains and hills of circumdenudation, surrounded by and overlooking wide clay valleys called "flats." The Permian Red Beds aggregate some 7,000 feet in thickness and consist largely of unindurated arenaceous clays, with only a few hard strata. They weather into extensive flat regions with occasional scarp lines attended by "bad-land" slopes. They occupy the western and greater part of the Central Province and extend beneath the Plateau of the Plains and outcrop in Pecos Valley against the eastern front of the Cordilleras.

Relief expression of the Mesozoic and later rocks.—The existence of the early Mesozoic (Triassic) is doubtful, although possible. Rocks referred to this period overlie the Permian along the western part of the Central Province and appear in small areas around the border of the Plateau of the Plains, but are of no topographic significance. Jurassic limestone strata of the Mexican type have been found in only a limited area in the barren ranges west of the Cordilleran front and are not known on the Atlantic slope or the east front ranges.

The later group of formations of the Coastward Slope consists of vast sheets of sea-made sediments, from Cretaceous to Pleistocene age, inclusive, and of aggradational deposits of upland wash and stream and lacustral alluvium of Tertiary and later age, all of which, except the Lower Cretaceous, are mostly unconsolidated terranes of clay, sand, marl, and loam. Of this later group, the marine Cretaceous, Tertiary, and Pleistocene rocks are the chief formations, especially east and south of the Central Province. They were unconformably deposited across the upturned edges of the older formations above described. They may be subdivided into two general series, producing two broad variations of low relief: (1) The older Cretaceous formations; and (2) the newer Cretaceous, Tertiary, and Pleistocene formations. These rocks occur in belts, each underlying a broad strip of country.

The Cretaceous rocks, divisible into an older or lower and a newer or upper series, occur in the Trans-Pecos Mountains and in the Coastward Slope plain. The older formations consist of hard limestones alternating with clays, and are underlain by sands; they produce dip plains, cut plains, and low scarps. The Upper Cretaceous strata consists largely of unindurated clay marls, with a few indurated scarp-making strata, all underlain by sands and weathering into low, undulating areas.

Of all the Texas formations influencing the relief the Upper and Lower Cretaceous rocks have the largest areal development. They extend from southern Indian Territory, where their horizontal strata abruptly end against the upturned Paleozoic strata of the Ouachita Mountains, southwest toward the Trans-Pecos and Mexican Cordilleras, which are largely composed of their crumpled sheets. The upper and younger Cretaceous rocks, being softer and yielding more readily to disintegration, usually underlie level plains. The lower and older Cretaceous formations, composed of hard, resisting limestones, weather into sharp relief features—scarps, plateaus, and mountains—and, with the exception of the high volcanoes of southern Mexico, compose most of the high relief of Texas and Mexico. They are also cavernous. The newer Cretaceous rocks form the Black Prairie of the East-Central Province and the interior portion of the Southern Province. The older Cretaceous rocks form the southern part of the Plateau Province, the Callahan Divide, the Lampasas Cut Plain, and many of the Trans-Pecos Mountains.

The marine Tertiary and Pleistocene sediments are found only to the coastward of the later Cretaceous formations in the Eastern and Southern provinces, making, with portions of the later Cretaceous, the formations of the Coastal Plain. The Eocene strata are mostly unconsolidated alternations of sand and clay, with exceptional local indurations of ferruginous sandstone. The later marine sedimentaries of the Coast Prairie district (Miocene to Recent) have not been classified by age, but collectively they make a great thickness of unconsolidated sands and clays of late Tertiary and Pleistocene age. According to well borings at Galveston, they are over 3,000 feet thick. They produce a remarkably level topography—apparently a new plain lately reclaimed from the sea.

INFLUENCE OF THE NONMARINE SEDIMENTARIES.

The nonmarine deposits of Texas are lacustral deposits, sheets of upland gravel, and alluvial wash, "tepetate,"[1] and wind-made formations, all of which are laid down at local deposition levels. Of these formations the alluvium is found throughout the whole region, in the valleys of all streamways, and even over the uplands of much of the Southern and East-Central provinces. The lacustral deposits are found in valleys of the Cordilleran region, partially filling the desert basins. The upland formations (the "wash,"[2]) are flood sheets of gravel, sand, and marl, sometimes consolidated in the calcareous matrix known as "tepetate." They cap the Llano Estacado and occur along the interior margin of the Southern Province at the foot of the Balcones escarp-

[1] The word "tepetate," also spelled "telpetate," is a term used throughout Mexico and Central America for secondary nonmarine deposits, either chemical or volcanic, forming a superficial coating over the country rock, or impregnating the regolith. In Texas and northern Mexico the tepetate is always a chemical precipitate of lime, formed on calcareous soils, or transported in solution and deposited through evaporation around the margins of desert basins.

[2] For a description of the process of distribution of the wash see Nueces folio, U. S. Geological Survey.

ment, consisting of the worked-over talus of the mountains and the débris of the Edwards Cut Plain. These deposits, begun in Tertiary time, are in constant process of formation. The wash and tepetate occur on most of the slopes of the semi-arid and arid regions, where streams evaporate and sink into the plains, in the wind-made formations on the Llano Estacado, and in the valleys of the Great Plains and Central provinces.

INFLUENCE OF THE IGNEOUS ROCKS.

The igneous rocks in respect of occurrence are of three classes: (1) The older granites accompanying the pre-Cambrian or fundamental rocks, upon which the whole superstructure of fossiliferous rocks may have been laid down, (2) intrusive rocks, pushed up through and between the other rock sheets and necessarily of later age than the rocks which they intrude; and (3) extrusive rocks, which have flowed or fallen over the surface. The oldest igneous rocks of Texas, included in class 1, above, and herein called fundamental, strictly speaking are not such, inasmuch as some of them at least are intruded into schists which are the lowest of this portion of the earths's crust visible to our inspection.

The old granites outcrop in the Llano Country (see Pl. XV) of the Central Province, in the Franklin, Hueco, and Cornudas mountains of the Trans-Pecos Province, and in the central and western half of the Ouachita Mountains. They are not of extensive topographic occurrence.

The intrusive rocks occur extensively in the Trans-Pecos Province, and exceptionally along the interior border of the Rio Grande embayment.

Extruded rocks of Cretaceous and Tertiary age occur chiefly in the Cordilleran region, as necks, dikes, flows, and cones. Volcanic necks of rhyolite form the extensive mountain groups known as the Chisos, Corazones, and Davis in part. Extensive flows of basalt and rhyolite make the indurated cap rocks of such features as the scarp-cut plains of the Davis Mountains and the Mesa de Maya. Extrusive sheets of lava known as "malpais" are also found in the floor of the Hueco Basin of the Trans-Pecos Province. Volcanic craters, or cinder cones, which are exceptional features, occur in northeast New Mexico east of the Rocky Mountain front and in central New Mexico.

The marine sedimentary rocks of the Cordilleran region are of various ages prior to the Tertiary, representing in part the survival of structural features of pre-Cretaceous time, mostly buried by later deposits of Cretaceous rocks.

The Ouachita group is made up of the same Paleozoic beds that form the foundations of the nonmountainous regions, where they are buried beneath the later rock sheets. In the mountains the Algonkian, Cambro-Silurian, and Carboniferous rocks are the survivals of ancient land masses that were not base-leveled in pre-Cretaceous time. Their arrangement in long anticlinal folds more or less influences the present relief, and, assisted by erosion, produces a type of configuration quite different from that of the mountains of the Cordilleras.

The mountains of the Trans-Pecos Province are composed not only of the older sedimentary rocks found in the Ouachita uplift and the floor of the Coastward Slope plain, but also of the Cretaceous rocks which make much of the surface of the latter region. Here they are folded and tilted into mountain structure, while sheets and necks of hard eruptive rock, produced in Mesozoic and Cenozoic time, furnish further relief-making elements. The marine Tertiary and Pleistocene formations of the Coastal Plain are missing, but in the flats and basins between the mountains are extensive unconsolidated nonmarine deposits, probably of synchronous age.

The Mountains.

Within the Greater Texas region are two mountain systems—the Ouachita system of Arkansas and Indian Territory, and the Trans-Pecos Mountains. These systems are of different structural types, ages, and configuration, and trend approximately at right angles to each other. The Ouachita system is Appalachian in structure and general resemblance, and is thereby related to the mountains of the eastern half of the United States. The Trans-Pecos Mountains are a part of the great Cordilleran systems which dominate the western half of the continent between the Great Plains and the Pacific.

OUACHITA SYSTEM.

This system extends east and west between the ninety-third and one hundredth meridians, from the Mississippi embayment of the Coastal Plain to the plateau of the Great Plains, through western Arkansas, Indian Territory, and Oklahoma. The system as a whole is a narrow line of old mountains, whose summit nowhere exceeds 3,000 feet. It is composed of three principal groups, of different types of relief and rock composition. These are the Massern Ranges on the east, the Arbuckle Hills in the center, and the Wichita Mountains on the west.

The Massern Ranges were so named by Thomas Nuttall on a map accompanying his book entitled A Journey of Travels into the Arkansas Territory during the Year 1819: Philadelphia, 1820. These consist of elongated ridges of vertically folded clays and sandstones with some limestone, mostly of Carboniferous age. They extend east and west to longitude 95° 30′, where they take a southerly direction, ending in a manner as yet not satisfactorily explained at the northern edge of the Grand Prairie and against the eastern end of the Arbuckle Hills.

The southward continuation of these folds was planed off and buried beneath the Cretaceous rocks of the Grand Prairie of Texas.

The Arbuckle Ranges extend from the ninety-sixth to the ninety-eighth meridian, in a series of low limestone ridges and granitic hills which strike in a direction north of west. These are old mountains composed of vertically folded limestone strata with a granitic base, exposed toward their eastern end, in the vicinity of Tishomingo. They have been so degraded that they have lost that magnitude which is usually associated with mountains.

The Wichita Range is the western end of the Ouachita system and forms a rugged sierra between longitudes 98° 30′ and 100°. The highest peak, Mount Sheridan, rises 2,800 feet—about 1,300 feet above the surrounding plains, which are composed of old granitic and volcanic rocks projecting through flanks of Silurian limestone.

The mountains of this system in general are old, and represent the remnants of once more lofty and extensive ranges which have undergone degradation since early Mesozoic time.

MOUNTAINS OF TRANS-PECOS PROVINCE.

The Trans-Pecos Province is a peculiar combination of mountains and stretches of plateau, plain, and bolsons surrounding, bordering, and lying between mountain ranges. The plains will be discussed later under a separate head.

The Trans-Pecos Mountains of Texas and New Mexico lie between the Pecos and the Rio Grande south of latitude 35° 30′. They represent the eastern front ranges of that portion of the North American Cordilleras lying between the southern end of the Rocky Mountains in northern New Mexico and the northern end of the eastern sierras of Mexico. These mountains are called by some the Continental Divide, but erroneously, for the Cordilleran region has no single dividing ridge in this latitude, but is a canoe-shaped area, bordered toward the Pacific and the Great Plains by broken crests, between which are large basin plains and low, disconnected mountain ridges.

By origin these mountains are of three distinct types, as follows:

1. True mountains of deformation, composed of structural folds or tilted fault blocks of sedimentary rocks, the mountain forms corresponding in trend to the strike of the structure.

2. Plateau mountains, consisting of high subhorizontal plateaus void of serious deformation, occurring either as summits or as shoulders attending higher relief features.

3. Mountains of igneous material, of three subtypes—old igneous vents (such as dikes and necks), craters, and summits of circumdenudation capped by sheets of ejecta.

The highest altitudes attained are in the mountains of the eastern front ranges. Sierra Blanca, of the Sacramento Range in southern

New Mexico, reported to be 13,000 feet high, is the highest summit. The highest mountain of the system in Texas is Guadalupe Peak, near the New Mexican line—9,000 feet, or 5,000 feet above the interior margin of the Coastward Slope plain. Southward the mountains do not attain high altitudes until they cross the Rio Grande in Mexico. Livermore Peak (8,500 feet) and Mount Emory (8,500 feet) are the highest summits south of Guadalupe Peak. Immediately upon crossing into Mexico the ranges again rise to higher altitudes—10,000 feet or more.

The Trans-Pecos Mountains lack continuity and exhibit many irregular and eccentric forms of relief. In general the individual mountains present sharp and rugged outlines. They are usually barren of timber, except a few summits of the Sacramento, Davis, and Chisos mountains that rise above the base of the timber zone, which is about 6,000 feet along the Rio Grande.

The individual mountains may be primarily classified as sierras, disconnected peaks, and groups of peaks. The various mountain forms, whose lineaments are so clear in the arid atmosphere, have generally been given individual and descriptive names by the former explorers and inhabitants, who were of Spanish speech. Thus we find the various eminences called by such names as cabezas (heads), cornudas (horns), chisos (ghosts), corazones (hearts), sandias (watermelons), sillas (saddles), cuchillas (knife edges), etc. The term "cuesta" is also extensively used adjectively for the surface of a limited plain, plateau, or mountain which has a distinctly visible slope or tilt—a tilted mesa.

Front ranges.—The east front of the Cordilleras, as the parting between the mountains and plains may be called, has a southerly trend from Colorado to the thirty-first parallel. From the latter line it curves southeast through Trans-Pecos Texas and northern Mexico, closely following in direction the general course of the Rio Grande toward the Gulf, which it reaches in Mexico near the northern tropic. This change in direction of Cordilleran trend is due to certain orogenic processes which can not here be set forth, but it has an important bearing on the geography of the west Texas and north Mexican regions.

The Plains.

By far the larger portion of the Greater Texas region is occupied by plains, and, as these are diverse in structure and relations, their character may best be explained by a few preliminary words on the nature and origin of plains in general.

CLASSIFICATION OF PLAINS BY ORIGIN.

The term "plain," while applied to a region which is dominated by a conspicuous and persistent subhorizontal surface, is not always intended to signify an unbroken monotonous physiographic feature, absolutely without relief. It is true that some of the districts in the Texas region to which the term is applied are vast level stretches approximating as nearly as is found in nature a theoretical plane. But every plain, however level it may appear, presents within its area or as bordering phenomena some inequalities of configuration, such as valleys and rises, while some of the plains to be described are so rugged as to be locally classified as mountainous. The plains herein described are, by origin, of two broad types—constructional and destructional.

Constructional plains.—Constructional plains owe their origin and present surface features principally to the distribution and deposition of earth material in sublevel sheets along the streamways or at the margin of the ocean, or to the distribution of lava sheets or other volcanic ejecta over the surface. Destructional plains originate in the degradation (or planation) of older and higher surfaces down to a lower level.

Destructional plains are sometimes evolved constructional plains; the latter, after elevation and long erosion, are reduced in old age to the former. On the other hand, constructional plains are usually established upon areas which were once destructional plains. Ancient buried destructional plains thus veneered by constructional plains might be appropriately termed *paleoplains*.

Constructional plains may be either sea-made or land-made. In the former case, with certain minor exceptions, like the platforms of coral reefs, they are land-derived sediments which were once distributed and deposited in the littoral and sublittoral waters around the margins of the land. In the latter case they are composed of lake and river sediments or débris brought down by freshets and distributed over the surface of a preexisting older plain at the foot of higher regions, such as mountains and escarpments.[1]

There is one great sea-made constructional plain in the Coastward Slope region of Texas. This is the Coast Prairie, which borders the present Gulf shore. It is a young plain, and represents the old deposition surface, which has been but slightly elevated above the sea.

Of land-made constructional plains there are many examples in the Texas region, two of which—the Llano Estacado and the Rio Grande embayment—are conspicuous. Both of these are imposed upon old destructional plains, to which condition they are again being reduced by erosion. Many of the bolson plains of the Trans-Pecos Province are constructional plains.

The Llano Estacado is a constructional plain veneering an old destructional plain. The surface formation is land-made and is composed of talus and wash derived in Tertiary and later time from the higher Cordilleran regions to the west; it has been redistributed over

[1] See description of the wash in the Nueces folio, No. 42, Geologic Atlas of the United States, 1898.

and over again by the process of sheet-flood and wind erosion. On the west, north, and east margins this plain has been eroded so that it now stands above lower-lying destructional plains situated in those directions. Southward it merges into the destructional plain of the Edwards Plateau, which is a reexposure of the old destructional plain that makes the foundation of the Llano Estacado to the north.

The plain of the Rio Grande embayment occupies a low synclinal trough between the Balcones escarpment and the east front of the Mexican extension of the American Cordilleras. Its constructed surface consists of the sheet-flood débris (wash) of the two border regions—the Edwards Plateau on the north and the Mexican Cordilleras on the south. The surface of the Rio Grande Plain is now dissected into low summit areas occurring as wide divides between the streams. By destruction it is being graded down toward the level of the Coast Prairie.

There are also many notable constructional plains in the Trans-Pecos region, which will be more fully described later.

Destructional plains.—Other extensive plains of the Texas region, such as the Edwards Plateau, the Central Province, and the East-Central Province, are destructional plains and are the result of leveling by erosion processes, by which an older relief is reduced toward a lower horizon or plain, upheld by the resistance of a relatively more durable stratum. These destructional plains may again be classified into several minor types of stratum plains.

Stratum plains are level or sublevel surfaces the configuration of which is conformable to a rock sheet which is relatively hard and therefore more resistant to erosion than are the adjacent rock sheets. There are three well-marked varieties of stratum plains, viz, mesa plains, dip plains, and cut plains.

A mesa plain is the flat summit of a hilly mountain or plateau of circumdenudation or of a mesa bench. Such phenomena are elements of a cut plain.

A dip plain is an inclined stratum plain, the surface slope of which coincides with the dip of the upholding stratum.

Mesas are either the horizontal summits of plateau plains completely circumdenuded or benches of level plain abutting against a background of higher relief. The term "mesa," meaning a "flat surface on the top of hills or mountains," signifies a quality of a relief feature rather than the whole feature. Thus a flat-topped butte is often called a mesa, when in fact the mesa may be only a feature of the butte as a whole.

The term "cuesta," meaning a slope, is used similarly to the word mesa, as an attribute of a relief form, signifying a flat summit surface which is tilted rather than horizontal.

A cut plain (dissected plain) is a stratum plain of any kind which has been so dissected into remnants by erosion that the level of the original stratum plain is still recognizable in the summits of the dissected members.

The term "rolling prairies" is well established by popular usage in Texas for plains of undulating or rounded hilly relief, as distinguished from flat plains. Such plains are usually built upon unconsolidated strata of clays or sand.

The plains of the Texas region may be geographically classified into two groups: The plains of the Regional Coastward Slope and those of the Trans-Pecos Province.

PLAINS OF THE REGIONAL COASTWARD SLOPE.

The term Regional Coastward Slope is here used for all the non-mountainous portions of the Greater Texas region, including the Great Plains, the Central, East-Central, and Southern provinces.

Before the individual plains of the Regional Coastward Slope are separately discussed its broader features will be considered. As a whole it has a general eastward slope from the foot of the Cordilleras to the coast, from an altitude of 4,000 feet or more to sea level. This slope is primarily caused by a tilt, or the sum of several tilts, which the region has received through uplifts of the Cordilleran region in Tertiary and later time. The slope of the Coastal Plain north of the twenty-ninth parallel is to the east, and in a direction at right angles to the east front line of the Cordilleras north of the thirty-second parallel. Between the twenty-ninth and thirty-third parallels the slope continues east as far as the interior borders of the Eastern and Southern provinces. Within these provinces the direction of the slope changes to the southeast. The first-mentioned direction of the slope pertains to the Great Plains region in general, and the second to the more restricted coast plains proper. South of the thirty-second parallel the gradient of the Regional Coastward Slope is adjusted to the curve of the mountain front in a peculiar manner. Normally it should change in direction sympathetically with the curve, but, instead, it continues east, in a direction no longer at right angles to the mountain front, until the twenty-ninth parallel is reached. At the latter parallel the uniformity of direction of slope is suddenly broken by the structural deformation of the Rio Grande syncline, making a low synclinal basin between the Balcones scarp and the Mexican Cordilleras.

The general average inclination of the Coastward Slope from the mountains to the sea is 8.7 feet per mile. It varies in the different provinces, being approximately 8.6 feet per mile across the Llano Estacado, 9 feet across the western part of the Central Province, 6.7 feet across the eastern part of the Central Province, 16 feet across the Grand Prairie, 2.5 feet across the Black Prairie and East-Texas Timber Belt, and 1.3 feet per mile across the Coast Prairie.

The chief relief feature of all the plains of the Coastward Slope is their general inclination toward the sea, in conformity with the tilt or dip of the underlying strata, away from the Cordilleran front, caused by the regional upward movements of the Cordilleran area as a whole, as mentioned elsewhere in this paper.

The relief of the individual plains is due to differences in origin, age, adjustment of erosion to the different geologic formations, climatic conditions (such as wind, humidity, precipitation, and evaporation), and gradient of the regional slope. Some plains, like the Coast Prairie, are so nearly flat and unbroken that undulations or elevations can hardly be detected; others, like some belts of the Central Province and the margin of the Edwards Plateau, are deeply and extensively dissected into high hills of uniform elevation separated by valleys, so that only small remnants of the former surface are here and there preserved; still others, like the eastern and southern extension of the Black Prairie, are eroded into low, rounded hills called rolling prairie.

The plains of the Regional Coastward Slope are of four general types, forming wide belts extending approximately north and south. These are the Great Plains proper, the Central Prairies, the plains of the East-Central Province (the Black and Grand prairies), the Atlantic Timber Belt, and the Coast Prairie. They may be classified by relationship into three major groups: The Great Plains, the prairie plains, and the Coastal Plain.

The Great Plains are a wide north-south belt of sublevel highland extending east from the Rocky Mountains to the prairie plains. The Coastal Plain, including the Coast Prairie and East-Texas Timber Belt, forms a wide stretch of lowland extending west from the Gulf. The prairie plains consist of the plains of the Central Province and the Grand and Black prairies of the East-Central Province. They occupy an intermediate position between the Coastal Plain and the Great Plains proper, and they differ from these in many respects, as will be shown later.

The most conspicuous relief features of the plains of the Coastward Slope are the Plateau of the Plains, the bordering Breaks of the Plains, the Valleys of the Plains, the Callahan Divide, the Balcones fault line, the Anacacho Hills, the Llano Hills, the Shumard Knobs, and the White Rock, Grand Prairie, Baird, and Seymour scarps, which will be described in the specific accounts of the plains to which they are related.

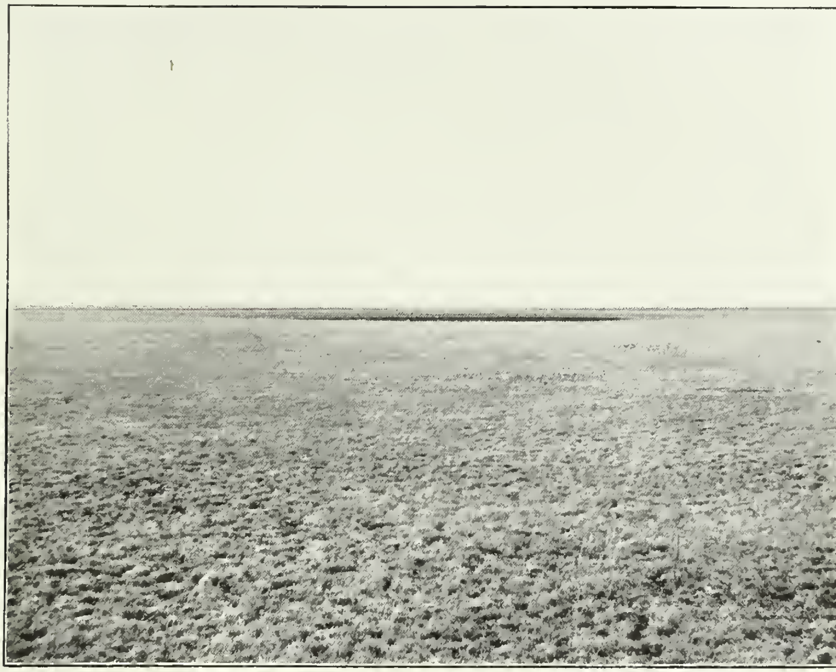
THE GREAT PLAINS.

The Great Plains Province within the area of our map includes a portion of the middle and all of the southern part of the Great Plains region. The middle division, which is locally known as the North Plains, lies between the Arkansas and the Canadian rivers. The southern division is the relief feature which we have described as the Southern Plateau of the Great Plains.

The Southern Plateau of the Plains (the combined Llano Estacado and Edwards Plateau) is the most extensive relief feature of the nonmountainous portion of Texas. It represents the continuation of the Great Plains proper south of the Canadian Valley, and is a vast subquadrangular, treeless table-land, about 60,000 square miles in area, slightly tilted toward the sea and surrounded on all sides by escarpments of erosion. (See Pl. III.) At one time it was a continuous plain which extended from the front of the mountain eastward far across the Central Province. Denudation of its margins has restricted the area to its present dimensions. It is surrounded by the escarpments of the deeply eroded Pecos Valley, separating it from the mountains on the west, the drainage groove of the Canadian on the north, and an escarpment of headwater recession on the east. Its southern margin is abruptly terminated by the Balcones fault escarpment, coastward of which the level of the country has dropped several hundred feet. In this manner the Plateau of the Plains has become a subquadrangular plateau surrounded by low escarpments, which are locally known as the Breaks of the Plains.

THE PRAIRIE PLAINS.

The prairie plains, which include the vast Central Province of southern Kansas, Oklahoma, Indian Territory, and Texas and the East-Central Province of Texas, consist primarily of destructional plains resulting from the wearing away of the formations of the Coastward Slope from higher to lower beds. The general type of relief is that of a greatly denuded prairie region in which the surfaces have been established upon many different planes of stratified rocks, some of which are very rugged, although extensive stretches of level prairie predominate. These stretches occur mostly in subparallel north-south belts of country, accompanied by scarp lines, isolated circular buttes and mesas, and deeply serrated cut plains. This relief is due to erosive sculpture resulting from the establishment of the natural drainage upon successively lower and lower stratum plains in the geologic series from the Plains (Tertiary) formation on the west to the Algonkian at the southeast, inclusive. In a broad way this relief may be looked upon as a great and deeply cut intaglio, in which the various surfaces, composed of layers of six groups of subhorizontal strata of different age, thickness, hardness, and color, have been successively exposed by erosion.



A. SUMMIT OF THE LLANO ESTACADO.

B. BREAKS OF THE LLANO ESTACADO.

PLAINS OF THE EAST-CENTRAL PROVINCE.

The East-Central Province is composed chiefly of the Black and Grand prairie belts of Texas and southern Indian Territory, each bordered on the west by a belt of upland timber known as "cross timbers." These are parallel north-south belts of dip plains developed upon the outcrops of the various Cretaceous formations. The latter are a series of marls, sands, and limestones, inclining to the east so gently that their dip is only slightly greater than the inclination of the Regional Coastward Slope. Such an arrangement produces broad areas of outcrop. The topography of the Black Prairie, established principally on the marls, is undulating. The topography of the Grand Prairie is established upon beds of firm subhorizontal limestone of vast areal extent. These limestone surfaces are mostly flat dip plains, passing into cut plains along their interior margins. They slope gently eastward, and are terminated coastward by low inward-facing escarpments composed of the strata of the next plain. The plains are faintly indented by drainways that are fed by longitudinal branches whose ultimate and active caletas rise along the inland-facing escarpments.

The interior of the Black Prairie is marked by a low inward-facing stratified escarpment which extends south from Sherman toward Austin. Although this does not exceed 200 feet in altitude, it is a marked break in the otherwise uniform surface of the adjacent areas. It is an outcrop of the Austin chalk, the only conspicuous semi-indurated bed between the interior margin of the Black Prairie and the sea. Its margin overlooks the narrow belt of the Eastern Cross Timbers.

The western or inland-facing escarpment of the Grand Prairie is a still more conspicuous feature in the Texas region, extending, as it does, from the boundary of Arkansas due west through Indian Territory to the ninety-eighth meridian, and thence south through Texas to the Colorado, in a much-lobed and crenulated line. From the Colorado it curves west around the southern edge of the Central Province, where it becomes the eastern escarpment of the Plateau of the Plains.

North of the Brazos the slopes of this escarpment, marked by many low stratified terraces, descend to the west at a low gradient and include the Glen Rose type of prairie, consisting of open stretches of country and the various upland belts of the Western Cross Timbers, which follow certain outcrops of sandy strata. The crests of this escarpment are produced by an outcrop of the Edwards limestone; its hardness relative to that of the underlying formations results in its preservation as the summit of the escarpments and as many circular outlying remnantal buttes, usually known as round mountains, along the western border of the Grand Prairie and at widely disconnected intervals over the Central Province, as described later. This limestone stratum caps also the southern (Edwards) portion of the Plateau of the Plains, into which the Grand Prairie merges south of the Colorado.

PLAINS OF THE CENTRAL PROVINCE.

The Central Province in its entirety includes the vast region between the Plateau of the Plains on the west and south and the Missouri, Ozark, and Grand Prairie countries on the east. It consists of two great divisions separated by the ranges of the Ouachita Mountain system—the northern or Kansan, and the southern or Texan. The northern area comprises various belts or prairie plains in Oklahoma, Indian Territory, and southern Kansas, closely allied in origin and nature and often continuous with those of the southern area. In this paper the latter only can be considered. This is bordered on all sides except the north by receding escarpments of erosion. On the west and south these are the eastern breaks of the Plateau of the Plains; on the east they are the western scarps of the Grand Prairie.

Callahan Divide.—The highest relief features of the Central Province in Texas are the numerous flat-topped, circular, remnantal hills (mesa buttes) which are outliers of the Plateau of the Plains and of the Grand Prairie. (See Pl. IV.) These are capped by the hard Edwards limestone. Upon some of the most western of these are found gravel and other remnants of the Plateau of the Plains. The altitude of these mesas averages 500 feet above the principal drainways, and about 250 feet above the highest of the several intervening plains.

The remnantal mesas occur at widely separated intervals over that portion of the Central Province which is south of the northern headwater forks of the Brazos. Although widely distributed, they form less than 10 per cent of the total area of the Central Province. The principal group, which may be termed the Callahan Divide, occupies the watersheds of the Brazos and Colorado, lying approximately along the thirty-first parallel, and extends, like thickly set bridge piers, from the western border of the Grand Prairie west to the Plateau of the Plains, through Comanche, Brown, Eastland, Callahan, Coleman, Taylor, Runnels, and Mitchell counties. North and south of this line, separated from one another by great areas of lower-lying plain, there are many similar isolated remnants, such as Double Mountain, in Stonewall County, and Santa Anna Mountain, in Coleman County.

Collectively the summits, escarpments, and plateaus thus composed of the horizontal Edwards limestone represent a wide topographic level which once extended over nearly the entire Coastward Slope, from the mountain front to the eastern edge of the Grand Prairie and

SIGNAL PEAK, A SUMMIT OF THE CALLAHAN DIVIDE, MITCHELL COUNTY, TEXAS.

Balcones scarp line. This was a plain (the Edwards Cut Plain) which occupied nearly 100,000 square miles of the Texas region. During long periods of degradation, the first of which was in early Tertiary time, prior to the deposition of the Plains formations, the continuity of this level was largely destroyed by erosion, especially in that portion which gently arched over the Central Province, resulting in its almost entire removal from that area, only the remnantal summits mentioned being preserved, and the establishment of the two opposing escarpments of the Plains and Grand Prairie, which have been gradually receding from each other over the Central Province.

By the establishment of a diversified drainage upon and below the ancient Edwards Cut Plain the main area of the Central Province has become a series of benches successively farther and farther below the general level of the former. These plains are classified into two distinct subgroups, those of the western portion and those of the eastern portion of the Central Province, each of which includes several minor groups.

Red Beds plains.—The relief of the western group of plains is that of a series of almost level plains of wide extent bordered by eastward-facing escarpments of erosion and established upon the Red Beds formations (Permian). The eastern portion, at least that part south of the Trinity River, consists of less extensive plains, which have been more completely broken by deep canyons and are composed of Carboniferous and older Paleozoic rocks. The plains of the western subprovince as above outlined, and of the eastern subprovince north of the Colorado, are mostly dip plains which incline to the west and are bordered on the east by long escarpments. These escarpments occur at wide intervals in parallel north-south directions and are so arranged as to impress the traveler who crosses them from east to west, from plain to plain, with a sensation of constantly ascending a series of steps. The apparent dip of the plains to the west at a very slight angle, in a direction contrary to that of the continental slope, is due to the fact that the region is the eastern limb of an old pre-Cretaceous syncline (the ancestral trough of the plains) which underlies all the Texas region between the Grand Prairie and the Rocky Mountains. This old structure has been reexposed by denudation of the Tertiary and Cretaceous strata which once covered it.

Palo Pinto Plain.—The eastern third of the Central Province is more rugged and varied in relief. This is due to the harder and more resistant nature of the older Paleozoic formations out of which it is carved and which are successively encountered by the denudation in progressing to lower and lower strata.

North of the Callahan Divide, in what is known as the Palo Pinto Country, this relief consists of a cut plain carved out of Carboniferous sandstone marked by scarps, mesas, and canyons, with occasional valley stretches of "mesquite flats," or level prairie where extensive beds of shale prevail. Country of this character also extends a short distance south of the Callahan Divide, where it is called the Brownwood Country.

The Burnet Country.—Still farther south, adjacent to the drainage basin of the Llano River, the so-called Burnet Country (see Pl. XIV) is found. This is so very rugged that it is considered mountainous by the inhabitants. It is composed of a series of erosion levels cut below the Edwards Plateau, imposed in succession first upon the Carboniferous and then upon the Silurian and Cambrian strata, and finally cut down to a basement plane of ancient granite and schists, upon which the drainage of the Llano and a section of the Colorado is now established. These various levels of the Burnet Country are often extensive features, such as the Backbone Plateau west of Burnet and the Packsaddle Mountains. Notwithstanding its rugosity, this area, which may have been a monadnock—or remnantal hill in a generally planated region—before Cretaceous times, is now a subcircular basin of erosion, below the general level of the Plateau of the Plains and the Grand Prairie, surrounded by overlooking scarps of their strata, which once completely buried it.

THE COASTAL PLAIN.

The Coastal Plain of Texas includes the area lying within the Eastern and Southern provinces, and consists of three broad types of country—the Coast Prairie, the East-Texas Timber Belt, and the Rio Grande embayment.

This plain is a continuation of the Atlantic Coastal Plain of the Eastern and Gulf States, yet is essentially different from that in many features. At the east line of Texas it has the general characters seen in the other Southern States, consisting of a gently sloping plain, extending from a mountainous background (the Ouachita Mountains) to the Gulf, its eastern border attaining an elevation of about 500 feet in southern Arkansas. As it bends to the southwest its features become gradually modified until they present several notable variations from the Coastal Plain to the east. The most notable differences are the absence of a well-defined interior border between the Ouachita Mountains and the Colorado River, the increasing proportion of prairie, the different adjustment of the fall line of the rivers, and a great embayment which the plain makes up the valley of the Rio Grande, somewhat analogous to that of the Mississippi.

Between the Ouachita Mountains and the Colorado River the Coastal Plain is so continuous with the Regional Coastward Slope, which extends westward to the Rocky Mountains, that its border in this region must be an arbitrarily assumed line practically coinciding with the coastward border of the Black Prairie as far south as the Brazos.

CORAZONES MOUNTAIN, IN THE TRANS-PECOS PROVINCE

South of the Brazos the Balcones scarp gradually develops and makes a well-defined interior limitation of the Coastal Plain toward the Rio Grande.

The Coast Prairie.—The Coast Prairie is a belt of prairie land not over 100 miles wide which borders the Gulf of Mexico in Louisiana and Texas. This is a grass-covered constructional plain, newly reclaimed from the Gulf of Mexico, whose interior margin rises scarcely 100 feet above the sea. It is marked by an exceedingly level surface, hardly broken except by a few low-drainage grooves, which become fewer and more faintly developed toward the Rio Grande. Upon it a youthful drainage system is being established, while the seaward extensions of the through-flowing streams cross it. These rivers have wide and deeply indented thalwegs, with gentle, terraced slopes filled with old alluvium.

The floor of the sea border of Texas is a submerged, gently sloping, sandy plain or shelf extending 50 miles seaward. By action of tide, wave, current, and wind this sand is piled into long island strips, which fringe the coast and stand almost at sea level. These are separated from the land by shallow lagoons, in which most of the sediments of the river are deposited. The building of the sand bars by wind and wave and the filling up of the lagoons between them by river sediments, in connection with gradual uplift, may possibly explain the origin of much of the adjacent Coast Prairie.

East-Texas Timber Belt.—North of the Colorado the Coast Prairie is practically succeeded on its interior margin by a hilly belt of sandy timber land, corresponding to the outcrop of the Eocene formations. This area is a dissected dip plain.

The substructure is sandy and unconsolidated and is occupied by a greatly branching drainage system, which results in low eminences with gentle slopes and without sharply marked scarp lines, except near the western border, where the dissection of an indurated stratum forms low summit mesas, such as the Iron Ore Knobs, occurring along a line between Rusk and Gonzales.

Plains of the Southern Province.—The Southern Province includes in its relief the major part of the Coast Prairie, together with the western prolongation of the modified southern continuation of the East-Texas Timber Belt and the Black Prairie up the Rio Grande into the district known as the Rio Grande embayment. Collectively, these features represent the southern attenuation of the greater Coastal Plain as modified by the geologic structure of the eastward deflection of the Cordilleran front in northeast Mexico and the increasing westward development of the Balcones escarpment. The influence of increasing aridity upon induration and erosion results in a slight variation in the relief.

In this province the country west of the Coast Prairie, with gradually increasing altitude and older and more fully developed drainage systems, becomes more undulating, and finally, toward its interior margin, consists of low, rolling hills, which increase in rugosity toward the Balcones scarp line. These hills are capped by the gravel wash from Edwards Plateau. West of a line from San Antonio to Laredo a low synclinal trough (the Rio Grande embayment), threaded by the Rio Grande, sets in and the slope changes from directly coastward toward the river, forming the north side of a trough between the Balcones and Mexican sierras, which inclose it on the north and south, respectively. The slopes in this district have a normal inclination of less than 8 feet to the mile. The Texas side of the Rio Grande embayment consists of a low broken plain abutting against the sharply defined interior Balcones escarpment of the Plateau of the Plains. Its surface includes long stretches of level country, presenting a few interesting features of minor relief, several solitary volcanic hills, hills of circumdenudation, and a low monoclinal mountain group known as the Anacacho Hills.

Some plains, as in the vicinity of Spofford and Del Rio, are of constructional origin and present the aspect of gravel-covered flats analogous to the Llano Estacado; they have been produced by the distribution of arid material by storm-wash deposition.

Rising out of the interior or northern margin of this plain, in Uvalde and Kinney counties, are a number of low, dome-shaped volcanic or laccolithic necks or stocks and monadnocks of horizontal strata, capped by sills of igneous rock. The Anacacho Hills, in Kinney County, form an exceptional feature of relief—a long cuesta or monoclinal mountain rising out of the plain, presenting a steep escarpment to the north and sloping toward the Rio Grande.

PLAINS OF THE TRANS-PECOS PROVINCE.

The Trans-Pecos Province, as previously stated, is a region of combined plain and mountain, the total area of which is about equally divided between these two forms of relief. (See Pl. VI.) The plains differ from those of the Regional Coastward Slope in origin, geologic formation, details of relief, and vegetation. The former are chiefly the result of the emergence and destructional base-leveling of the Coastal Slope, unaccompanied by structural deformation. The latter are largely structural valleys originated by the deformation that produced the mountains, which have been converted into constructional areas by accumulation of débris of the surrounding highland.

The plains of the Trans-Pecos Province are of two principal types, plateau plains and bolson plains, though, exceptionally, lava plains occur.

A DESERT PLAINS NEAR TORNILLO CREEK, TRANS-PECOS TEXAS.

B DESERT PLAINS NEAR TERLINGO CREEK, TRANS-PECOS TEXAS.

THE DRAINAGE.

The extensive region under discussion has a diverse drainage, its streams varying in origin, number, length, and volume with the topographic and structural conditions, rainfall, evaporation, slope, and porosity of the surface. Some parts have numerous streamways which drain the surface and lead the water to the sea. Others, like the great bolson deserts of the Trans-Pecos region and the Plateau of the Plains, are practically without surficial drainage, and the surface precipitation is disposed of by evaporation and imbibition.

There is little surficial obstruction to the direct run-off of the rainfall, whereby a constant supply of water to streamways may be regulated, except such as the forest growth of the Eastern Province, and the absorbent character of the dry soil and rocks in certain local areas—for example, in the Cross Timbers, the Llano Estacado, and the bolson deserts of the west. The Central Province and the Trans-Pecos Mountains are largely without either vegetal or structural obstruction to run-off, and hence they are rapidly drained after rainfall.

Types of Streams.

Some streamways, like those draining the Coast Prairie, are of a simple consequent type; they rise upon a slightly tilted plain and occupy one geographic province. Others of a similar character traverse two or more provinces, being prior relative to the one and consequent relative to the other. Still others are of a more complicated nature and origin and traverse all the provinces. (See Pl. VII.)

In the eastern portion of the State, owing to the large rainfall, streamways are numerous and continuously carry flowing water, while small streams which enter this region from the west become large within it through locally acquired laterals. Only in this and the Coastal Plain is navigation practicable, rapidity of fall and scarcity of water prohibiting it to the west.

In parts of the State, such as the summit of the Llano Estacado and the great bolson deserts of the Trans-Pecos Province, drainage channels of local origin are few in proportion to area, feebly etched, and normally without water except for a few hours after heavy rainfall. These areas consist of extensive plains of gentle slope underlain by pervious substructure, and the streamways are the products of the torrential rainfall, which is sporadic and less in quantity than the average rate of evaporation. In such runways as are developed water is normally absent, being intermittent in occurrence and consisting of occasional floods which temporarily (at rare intervals) occupy them. Furthermore, the temporary run-off is seldom of sufficient quantity to endure more than a few miles, owing to loss by imbibition in its normally dry and porous stream bed and by evaporation. Hence the water does not persist far enough to form outlets to the sea.

Streams of a third type are frequent in the Central Province and around the interior margin of the Southern Province, which derive their normal run-off from springs draining the substructure of the plateau (structurally impeded drainage). These streams, which are usually vigorous at their head, are often interrupted in their lower courses, presenting irregular alternate sections of dry and watered channels, the water disappearing by absorption in sands, gravel, or fissures and reappearing at other places. They may be called spring rivers, and are of two general types; the first, those which rise in the margins of the Llano Estacado and Edwards Plateau and receive their water from gravity springs; the second, those which originate in great fissure springs that rise by hydrostatic pressure, like those of the Balcones scarp line.

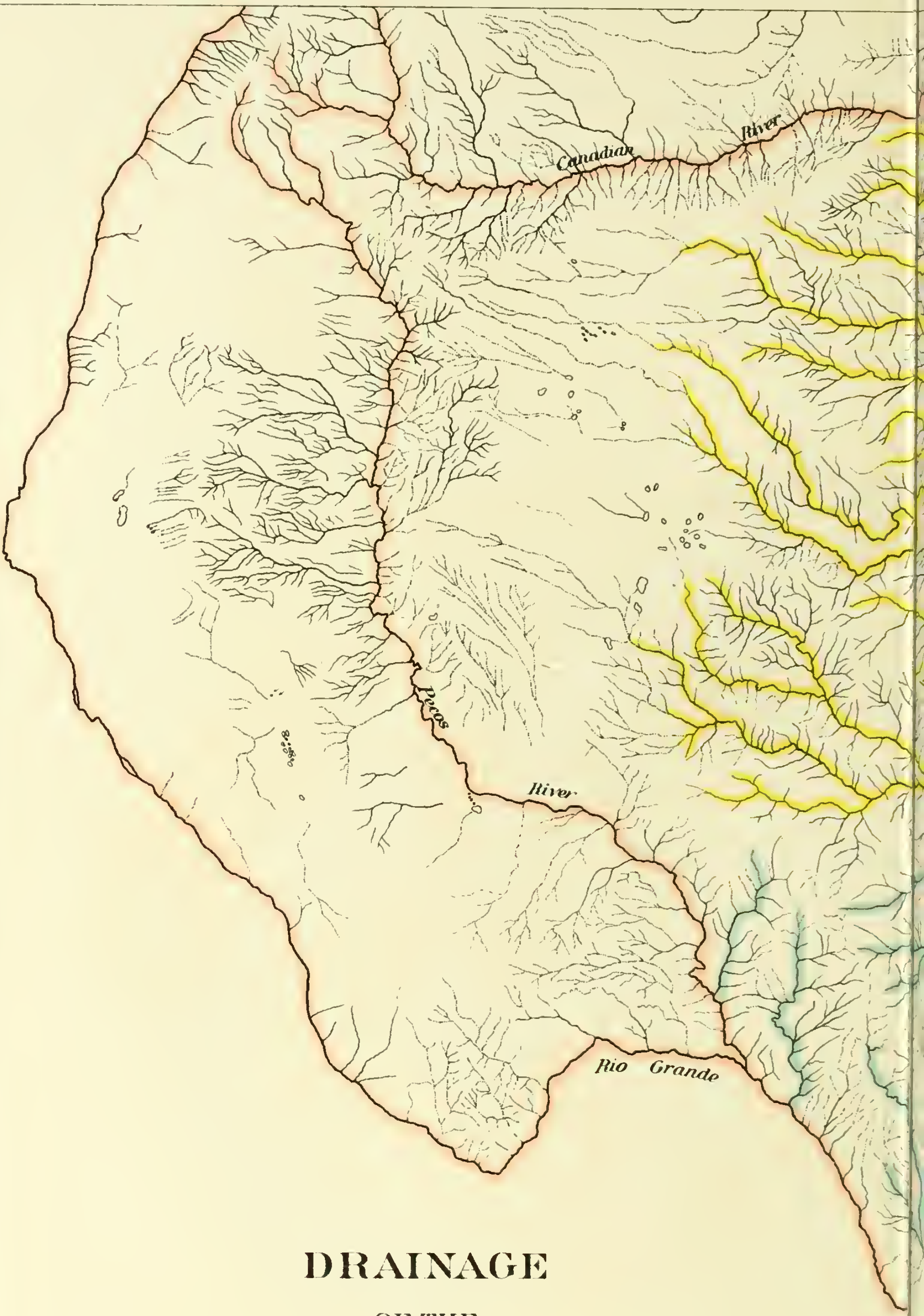
Drainways of a fourth type may be called through-flowing rivers; they derive their water from the snow-covered ranges of the Rocky Mountains of northern New Mexico and Colorado and traverse all the geographic provinces. These streams receive their principal volume from the Cordilleras and in their courses across the Regional Coastward Slope are practically great antecedent canals passing across the Greater Texas region without serious lateral reenforcement. Such streams are the Canadian, the Pecos, and, at certain seasons of the year, the Rio Grande.

Direction of Flow.

Most of the streams normally follow the continental slope toward the sea across the various provinces and are of the kind called consequent streams. Others, which are exceptional, flow at right angles to that of the normal regional slope, following parting valleys. The Pecos west of the Plateau of the Plains is the most conspicuous type of the latter class. The Clear Fork of the Brazos, Hubbard Creek, and Jim Ned Creek, of the Central Province, and certain forks of the Trinity in the East-Central Province are minor examples. The Rio Grande, in portions of its course through the Trans-Pecos Mountains and the Rio Grande Plain, follows great structural troughs.

Still another class of streams consist of headwater ramifications (caletas) of the longitudinal streams which drain the inland-facing scarps. These are called obsequent streams. They are usually short obsequent headwaters, and flow in a direction the reverse of that of the consequent streams, which follow the continental slope. They are found along the north-south scarp lines of the Central and East-Central provinces and along the western breaks of the Llano Estacado.

Some streams are of one of these types throughout, and may be called simple in character. Others present in different portions of



DRAINAGE

OF THE

TEXAS REGION

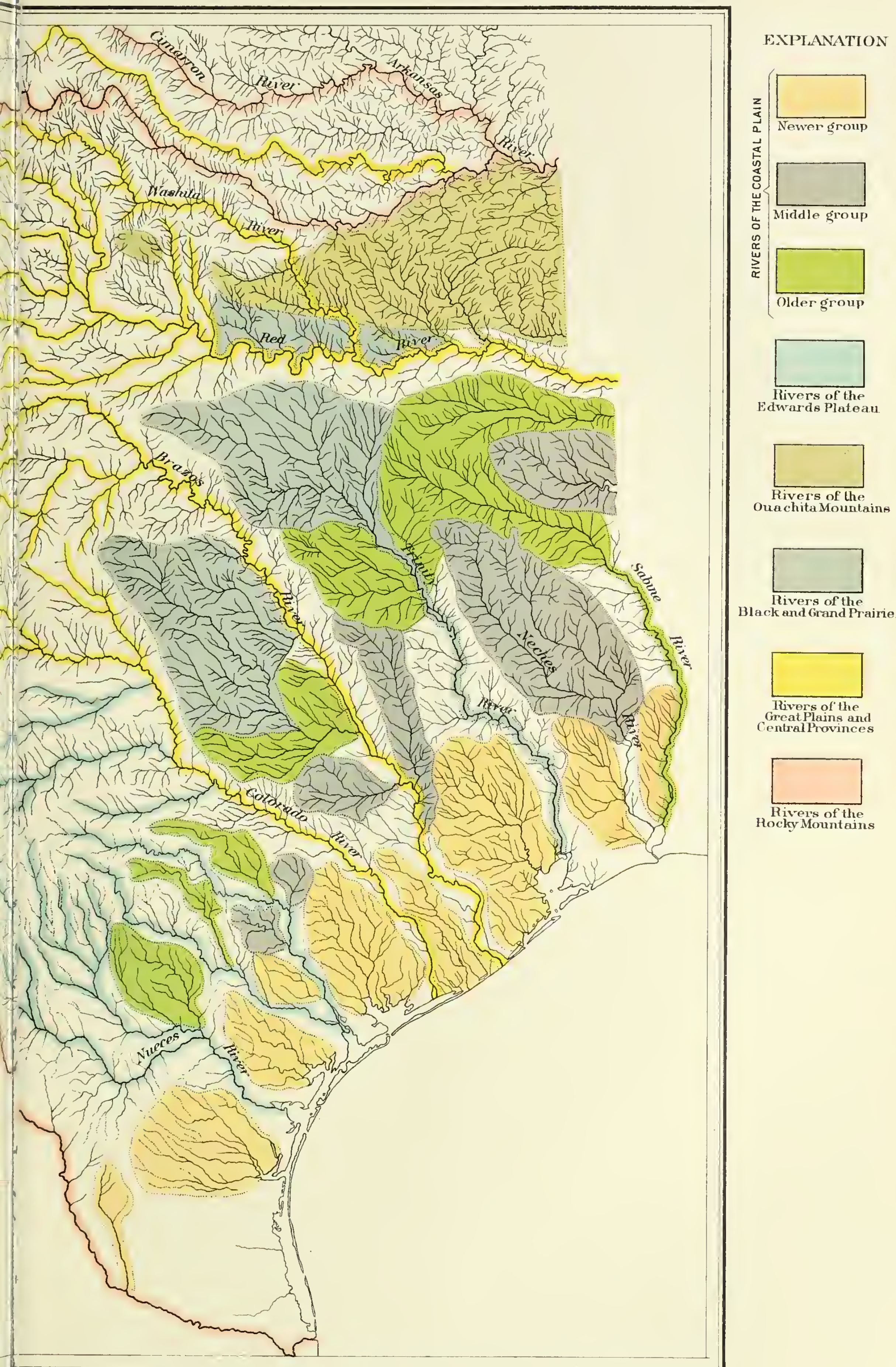
BY

ROBERT T. HILL

Scale

50 40 30 20 10 0 50 100 150 200 MILES

1900



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their course several of the types described, and may be called compound.

The topography of each stream valley varies throughout its course with the structure of the country upon which it is established. Hence the members of a series of long, parallel streams flowing across different belts of country locally resemble one another in each belt.

The run-off in the streamways in the Texas region is of three kinds—intermittent, interrupted, and continuous. Intermittent run-off is sporadic in character, occurs only after rainfall, and soon ceases. Most of the drainageways of the western half of the State are of this character. Drainways of this type are termed arroyos. Interrupted drainage is that in which the continuity of the permanent flowing stream is broken by alternate stretches of dry streamway. Rivers of this character abound in the East-Central and Central provinces and are indicated by alternations of continuous lines and dots. Continuous streams are those which flow continuously from the head of permanent water to their mouths.

Classification of the Drainage.

While some of the larger streams flow across all the different types of country and are prior thereto, each of the greater provinces we have mentioned has a distinct group of local rivers, forming a drainage system which finds outlet directly to the sea or is gathered into the larger lateral trunks. The different members of each system possess similar characteristics of origin, slope, length, and valley topography.

When a streamway gathers its drainage from one province it is of a provincial type. On the other hand, when it flows through two or more provinces, diverting a number of local drainage systems, it becomes composite. The rivers of the Coast Prairie system are of the simple type; those of the Central Province are composite.

Geographically the drainage of the Greater Texas region as a whole may be classified generically as follows: Rivers of the Cordilleras, rivers of the Great Plains, rivers of the Central Province, rivers of the East-Central Province, rivers of the Edwards Plateau, and rivers of the Coastal Plain.

Rivers of the Cordilleras.—The rivers of the Cordilleras are the Arkansas, Canadian, Pecos, and Rio Grande. They receive most of their volume from the precipitation on the Colorado group of the Rocky Mountains, and gather little or no drainage from the provinces of the Texas region as they cross it. They are normally flooded in May and June, at the time the snow melts in the mountains at their headwaters.

Rivers of the Great Plains.—There are no true rivers of the Great Plains in the general region under discussion. The few faint drainageways that exist upon the plains consist of draws, shallow basin-like depressions ordinarily without water, leading into the head canyons of the streams of the Central and Southern provinces. It is a misnomer to call these streamways true rivers, for they are shallow. hardly traceable, seldom contain water, and never present a continuous flow. In time of rainfall they form wide, shallow, slothful, turbid floods, which serve only to distribute the loose débris of the surface to a slightly lower level. To this class belong certain long draws, such as the Paloduro, Tule, and Castro creeks, leading into the canyon of Red River; the Catfish and Amarillo, leading into the Brazos; and the Sulphur and similar drainways, leading into the Colorado. It is true that these draws are literally the headwater drains of the rivers of the Central Province, and that these streams, which were inherited in past geologic time from the Plateau of the Plains, when it extended far east of its present border over the western part of the Central Province, were once rivers of the Plains, but it is here preferable to treat them as rivers of the Central Province. The Llano, Guadalupe, Frio, Nueces, and Devils rivers, which are principally established upon the Coastal Plain, have similar headwater draws passing back upon the Edwards Plateau.

Rivers of the Central Province.—The rivers of the Central Province are the Cimarron, North Canadian, Washita, Red, Brazos, and Colorado, with large and important tributaries, including the North Fork, South Fork, Pease, and Wichita, belonging to the Red River; the Salt and Double Mountain Forks, belonging to the Brazos; and the North Fork, Concho, and Llano, belonging to the Colorado. The constant portions of these streams rise along the eastern margin of the plains, either in the front scarps or in the deep canyons which incise them, like Red River. Normally these are continuous streams (interrupted in some instances) of small volume, deriving a constant headwater supply from the structural drainage of the Plateau of the Plains through the medium of numerous gravity springs. In months of maximum rainfall they become excessively flooded with red sediment, which is carried to the lower countries. They are long, continuous-slope streams, which have their principal and widely branching ramifications developed in the Central Province, and which gather little or no local drainage as they pass the lower-lying provinces.

The gradients of these streams across the Central Province become greatly flattened below their sources, and are farther below the general summit levels of the regional slope than any others in Texas. In fact, Red River cuts nearly 900 feet below the level of the Plateau of the Plains before it emerges from it. The Colorado, from the Plateau of the Plains to the East-Central Province, is cut 500 feet below the regional summit as preserved in the Callahan Divide. (See Pl. VIII.) Such facts indicate the great antiquity of these streams rela-

COLORADO RIVER. LOOKING WEST FROM MOUNT BONNEL, TEXAS.

tive to the age of some other systems to be described. These streamways were originally established upon the older and higher plateau level, and by inheritance have approximately maintained their original locations as they cut deeper and deeper into the floor of unconsolidated Red Beds and Paleozoic rocks. The upper waters of such of these streams as cross the gypsum beds of the western part of the Central Province are often brackish. In the lower portions of their courses, through the East-Central, Eastern, and Coastal provinces, these valleys are marked by wide bottoms, rising in several terraces, which are veneered with old alluvium derived from prehistoric denudation of the Central Province.

Rivers of the East-Central Province.—Still another category of streams is composed of rivers which rise upon and drain the prairies of the East-Central Province. The through-flowing rivers of the Central Province cross the East-Central Province through grooves deeply indented below the general level of the flat upland plains of which the latter is composed. Upon the upland plains intervening between the older streams has been developed the newer system which comprises the rivers of the East-Central Province. These include the Trinity group, between the Brazos and Red rivers, and the Paluxy, Leon, and San Gabriel groups, between the Brazos and the Colorado. The many ramifying branches of the Trinity gather all the drainage north of the Colorado, even taking it from the very margins of the valleys of the greater through-flowing Central streams, and carry the water, through the Eastern Province, directly to the sea. The branches of the Paluxy, Bosque, Leon, and San Gabriel similarly drain the upland portion of the Grand Prairie between the Brazos and the Colorado, but deliver their water to the Brazos at the edge of the Eastern Province. These are simple consequent slope streams, and are usually interrupted in character, the water sometimes running into deep pools and again disappearing in dry, stony channels. They all rise close to the western margin of the Grand Prairie plain, but by rapid descent of their streamways soon become so deeply indented that their paths are much lower than the surface of the upland prairies. Their permanent water is largely derived from the drainage of the sands of the Cretaceous beds. Some of them, as the Leon and San Gabriel systems, are also largely reenforced, as they cross the Balcones fault zone at the border of the Grand and Black prairies, by springs rising under hydrostatic pressure through fissures. (See Pl. IX.)

Rivers of the Edwards Plateau.—The rivers which rise within the Edwards Plateau somewhat resemble both the rivers of the plains and those of the East-Central Province, and yet present variations sufficient to justify their consideration in a special category. These streams, such as the Blanco, San Marcos, Guadalupe, Medina, Frio, Nueces, and Devils rivers, which pass from the Plateau Province directly across the Balcones scarp line into the Coastal Plain, are complex, presenting entirely distinct topographic characters in the two provinces. On the plateau summit their ultimate heads are gentle, waterless draws, like those of the Llano Estacado. These lead suddenly down into the deep, wide-bottomed box canyons indenting the margin of the plateau, also similar to those of the eastern border of the Llano Estacado, and at the bottom of which water begins to flow from gravity springs. The permanently flowing water of these canyons makes streams of great beauty. The headwater streams continue only short distances, and are succeeded by waterless gravel. On passing the Balcones scarp line into the lower-lying country of the Rio Grande embayment the character of the streamways entirely changes. Here the beds are only slightly indented below the general level of the country and have no steep canyon walls. Furthermore, in this portion of their courses some of them, like the Frio and Nueces, except in time of flood, are normally dry gravel beds without water. Lower down in their courses, however, permanent water again appears.

Rivers of the Southern and Eastern provinces.—Within the Southern and Eastern provinces, which collectively make the Coastal Plain, two distinct systems of streams have originated and occupy the relatively higher surfaces between the through-flowing streams. The longest and oldest rivers of these systems rise along the eastern margin of the Black Prairie Subprovince and at the Balcones scarp line; those of the second begin at the western margin of the Coast Prairie, upon which they are established. To the first class belong the Sabine, Sulphur, Neches, and Angelina. The second includes a number of short streams (creeks and bayous) which in their coastal extent are sluggish and brackish. In that portion of the Coastal Plain south of the Colorado there are streams of another category, which have their origin in remarkable fissure springs that break out at the foot of the Balcones escarpment. Among these spring rivers may be mentioned the San Marcos, Comal, San Antonio, Las Moras, and San Pedro.

Résumé of the Drainage System.

In résumé it may be said that the rivers of the mountains are complex, composite streams. The rivers of the Coastward Slope plain consist of four distinct systems of consequent streams which have developed during different epochs of geologic history, each recording distinct changes of level, accompanied by a migration of the coast line back and forth.

By provinces it may be said the drainage of the Trans-Pecos Country

FISSURE SPRING, BARTON CREEK, AUSTIN, TEXAS

is of a nascent type, being practically nil on the bolson plains. This is partially due to lack of slope, but chiefly to meteorologic and structural conditions, the evaporation and absorption being so much in excess of the rainfall that there is not sufficient run-off to develop streams on these desert plains. The minor drainage of the mountains is also faintly developed in comparison with that of other regions, owing to the lack of sufficient rainfall. The through-flowing river of this region (the Rio Grande) gathers no local drainage from it.

On the Great Plains, also, the drainage is undeveloped, and for the same reason as in the case of the bolson deserts. Its summit run-off is deficient in quantity and of the flood-sheet type, which tends to destroy rather than to establish surface drainways. The real drainage of this province is underground. Such water as is not evaporated sinks through the superficial strata until it is retarded by the impervious embed of older rocks, upon which it flows laterally by percolation to the incised marginal scarps, where it furnishes the headwater gravity spring drainage of the Central Province.

The drainage of the Central Province is mature or old, the headwaters of its streams having etched away the surface upon which it was established down to lower and lower levels, until it is now superimposed upon the lower-lying Paleozoic beds. This drainage has been inherited.

The drainage of the East-Central Province is adolescent, having passed its period of youthful development. It has not yet completely occupied all the areas of the plain upon which it is established, except along the eastern margin of the region. Those portions of the streams of the Central Province which continue into the East-Central Province are inherited and revived in the latter portion of their course, having been at base-level or estuarine here when the sea bathed the eastern border of the East-Central Province and when the latter was a newly made coastal plain. The older drainage system of the East-Central Province is adolescent, but younger. The newer drainage of the Coastal Plain is in its youth, and illustrates most completely the development of simple drainage upon a newly reclaimed and gently tilted coastal plain.

The sediments of all these streams testify to the work which they perform in lowering the general surface level. The Rio Grande in New Mexico, flowing through the unconsolidated and heterogeneous formations of the ancient bolsons, is noted for its dull-yellow sediments and silts. On the other hand, all the streams draining the Red Beds of the Central Province are famous for their vermilion floods. Other streams rising in the calcareous and argillaceous Cretaceous rocks of the Edwards Plateau and Grand Prairie have a slightly whitish color. The Colorado, before reaching Austin, receives tributaries from both the Cretaceous and the Red Bed areas, and hence, in the lower portion of its course, its floods are known as "red rises" and "white rises," those coming from the Llano and San Saba tributaries being of the latter color, while those from the northern laterals are of the former.

These stream valleys as a whole record a remarkable geologic history from the close of Cretaceous time to the present, which can not yet be fully interpreted.

PART II.

GEOGRAPHY OF THE BLACK AND GRAND PRAIRIES AND CROSS TIMBERS (EAST-CENTRAL PROVINCE).

RELATIONS AND SOILS.

Collectively these features cover an area about 275 miles in length and having an average width of 65 miles. They extend south from the Ouachita Mountains of Indian Territory to the Colorado River of Texas. (See Pl. X.) There are also a few inliers of the Cretaceous prairies within the Tertiary area of the southwest corner of Arkansas and northwest Texas, and some outliers over the Central Province, as will be further explained.

These prairies are bordered on the north by the east-west line of the Ouachita Mountains of Indian Territory; on the east approximately by the western border of the Atlantic Timber Belt; on the west by the Central Province; and on the south, where they merge into the Rio Grande Plain and Edwards Plateau, arbitrarily by the Colorado River.[1] These borders are sharply defined on all sides, but least regularly on the west.

On the east the Cretaceous prairies are overlapped by the low forest-covered plain of the East-Texas Timber Belt. Although there is no topographic change at their border, the forest country is different from the Cretaceous prairie in all other natural aspects. It is the

[1] Geologically speaking the Black and Grand prairies are the northern area of the great belts of Cretaceous strata which extend across the State from the Ouachita Mountains north of Red River to the east front of the Cordilleras of western Texas and northern Mexico, across the East-Central, Southern, and a portion of the Plateau provinces.

The broader areas thus underlain are, in general, distinguished by the calcareous (exceptionally arenaceous) soils, the white or chalk-colored character of the outcropping rocks, and certain peculiarities of vegetation. The whole is almost severed into two great north and south bodies by the Colorado River, which cuts across its most narrow portion. These two are still further differentiated by climatic, structural, and hypsometric differences.

Of these two principal subdivisions of the Cretaceous prairies, the one lying south of the Colorado is the larger, embracing about two-thirds the total area. This includes two belts of country—the most eastern of which is the interior margin of the lower-lying Rio Grande Plain and the southern end of the Plateau of the Plains, known east and west of the Pecos as the Edwards and Stockton plateaus. This subdivision, situated largely in the semiarid region, is relatively less adapted to agriculture and a dense population except along its eastern margin. In general it is a pastoral country. The subdivision north of the Colorado includes the Black and Grand prairies with their accompanying belts of cross timbers. This is better situated climatically for agricultural pursuits and presents more extensive bodies of arable land.

In a previous paper (Geology of portions of the Edwards Plateau and Rio Grande Plain, etc.: Eighteenth Ann. Rept. U.S. Geol. Survey, Part II, 1898, pp. 193–322) Mr. Vaughan and the author have discussed the Cretaceous prairies south of the Colorado. The present paper will be restricted to those lying north of that stream.

western termination of the great forest mantle which covers the Appalachian region and its coastal plains. This forest ends abruptly with the commencement of the Black Prairie.[1] The timbered region is one of red clay and sandy soils, deficient or lacking in lime, which is everywhere the chief constituent of the Black Prairie lands.

The border of the Central Province immediately adjacent to the Black and Grand prairies on the west, consists of broken areas of prairie and timber land composed mostly of Carboniferous rocks nearly similar in composition to those of the Ouachita Mountains to the north, but less broken and tilted in arrangement. This too, in soils and economic conditions, is entirely different from the Cretaceous prairies.

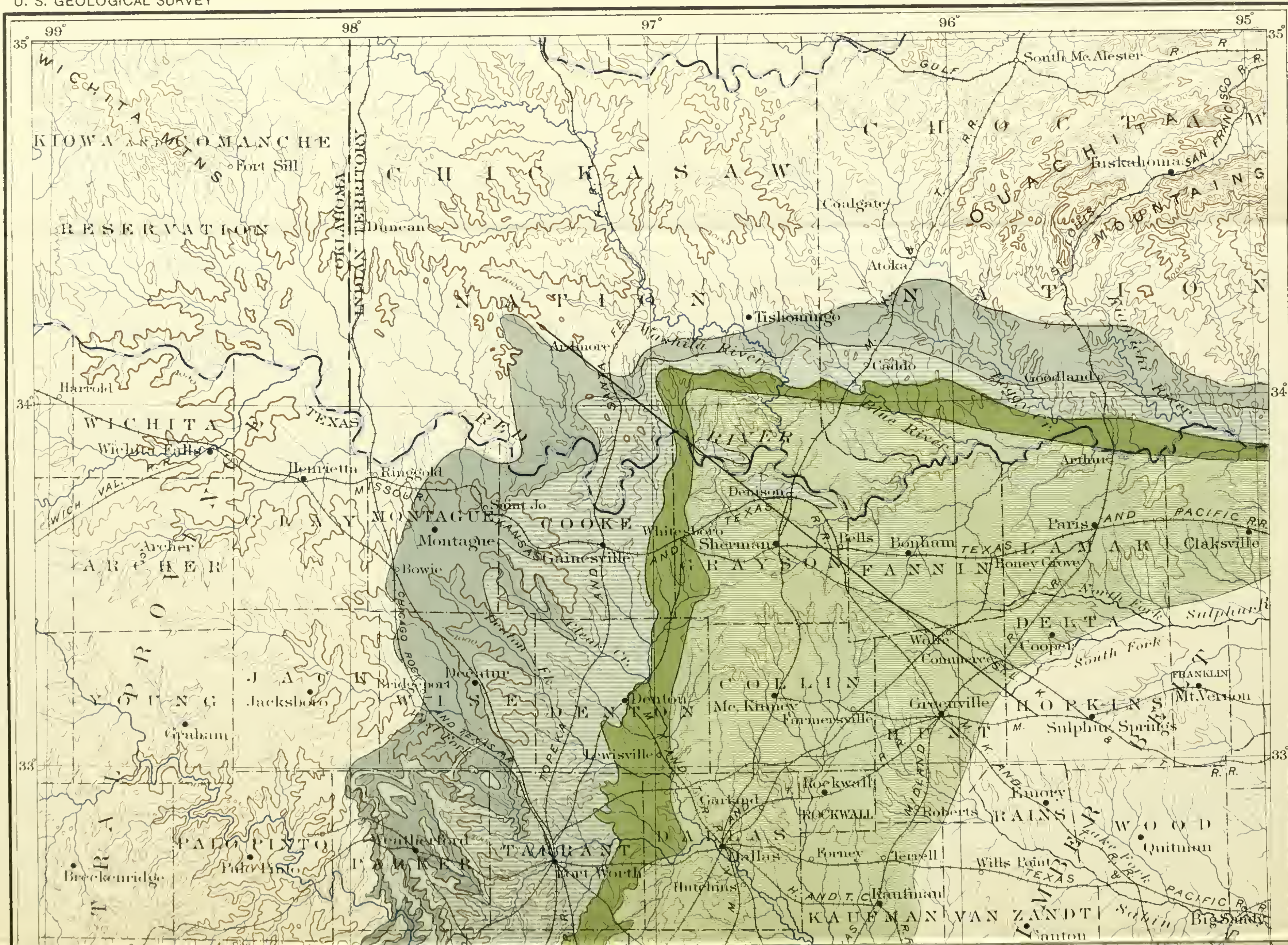
On the south and southwest, across the Colorado, the continuation of the Black and Grand prairies is the interior margin of the Rio Grande Plain and the coastward margin of the Edwards Plateau, respectively, consisting of a lower and higher plain separated by the structural feature known as the Balcones scarp line. The Rio Grande Plain is the interior margin of the great Atlantic Coastal Plain; the Edwards Plateau is the southern termination of the Plateau of the Plains.

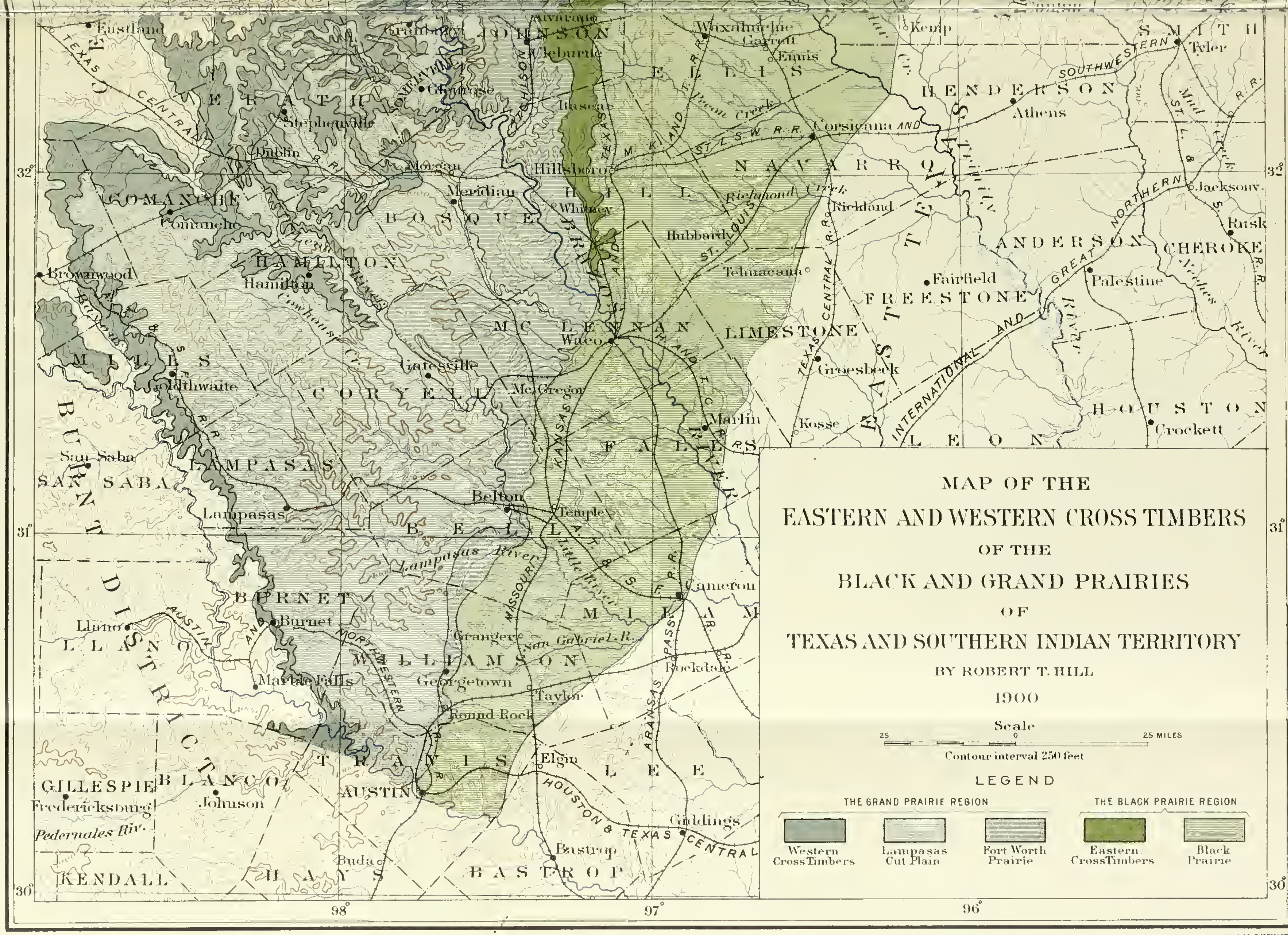
Vast treeless plains on which the eye finds no break to the monotony of the relief, such as characterize the Great Plains, are not found in the East-Central Province. On the other hand, while treeless surfaces abound and are sometimes extensive, they are relieved here and there by indentations of stratified scarps and by occasional stream valleys, usually more or less accompanied by trees, shrubs, or clumps of upland timber, the whole presenting several distinct minor types of relief and configuration.

The surfaces of the prairies are ordinarily clad with thick mantles of grass, liberally sprinkled with many-colored flowers, broken here and there by low growths of mesquite trees, or in exceptional places by "mottes" or clumps of live oak on the uplands, pecan, bois d'arc, walnut, and oaks in the stream bottoms; juniper and sumac where stony slopes exist, and post oak and black-jack in the sandy belts. These vegetal features are all adapted to the physical and chemical character of the outcrops of the formations upon which they grow.

The prairies are characterized by black or dark-colored soils derived from a substructure of calcareous marls or chalky limestones, which, compared with the less calcareous lands of the bordering regions, are unusually fertile, and are marked by an entirely different flora. In fact, these calcareous soils, especially those of the Black Prairie, are the most fertile of the whole trans-Mississippi region. This fact, together with the comparative scarcity of untillable lands, such as stony

[1] A very small margin of prairie along the western edge of the timber is in places underlain by Tertiary formations, and in some exceptional places along the eastern edge of the Black Prairie the Cretaceous outcrops are timbered.


99°
98°
97°
96°
95°
35°
34°
33°
WICHITA MTNS
KIOWA AND COMANCHE
RESERVATION
Fort Sill
OKLAHOMA
INDIAN TERRITORY
Duncan
CHICKASAW
NATION
CHOCTAW
NATION
OUACHITA MOUNTAINS
South McAlester
Tuskahoma
Coalgate
Atoka
Tishomingo
Ardmore
Caddo
Goodland
Arthur
Harrold
WICHITA
Wichita Falls
Henrietta
Ringgold
TEXAS
RED RIVER
Washita River
Blue River
Kiamichi River
CLAY
MONTAGUE
Montague
Saint Jo
Bowie
COOKE
Gainesville
Whitesboro
Denison
Sherman
GRAYSON
Bells
Bonham
FANNIN
Honey Grove
LAMAR
Paris
Claksville
DELTA
Cooper
North Fork
South Fork
Sulphur R.
FRANKLIN
Mt. Vernon
HOPKINS
Sulphur Springs
ARCHER
Archer
YOUNG
Graham
JACK
Jacksboro
WISE
Decatur
Bridgeport
DENTON
Denton
Lewisville
COLLIN
Mc. Kinney
Farmersville
HUNT
Greenville
Commerce
Wolfe
ROCKWALL
Rockwall
Garland
DALLAS
Dallas
Forney
Terrell
Roberts
RAINS
Emory
WOOD
Quitman
Wills Point
Big Sandy
PALO PINTO
Palo Pinto
PARKER
Weatherford
TARRANT
Fort Worth
Breckenridge
Hutchins
KAUFMAN
Kaufman
VAN ZANDT
Canton
GULF
SAN FRANCISCO R.R.
SANTA FE
MISSOURI
KANSAS AND TEXAS
CHICAGO ROCK ISLAND AND TEXAS R.R.
TEXAS AND PACIFIC R.R.
MIDLAND
WICH. VAL. R.R.
H. AND T. C.



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hills, bluffs, etc., except in the western portion of the area, enables it to support the densest agricultural population of Texas, relative to area (see fig. 2), and makes it the seat of the most important inland cities, such as Paris, Bonham, Denison, Sherman, Gainesville, Fort Worth, Waco, Weatherford, Taylor, Belton, Temple, Austin, New Braunfels, San Marcos, and San Antonio. To these soils the State owes a large part of her general prosperity.

In addition to the agricultural features the underlying rock sheets embrace a series of water-bearing strata whose artesian-well conditions

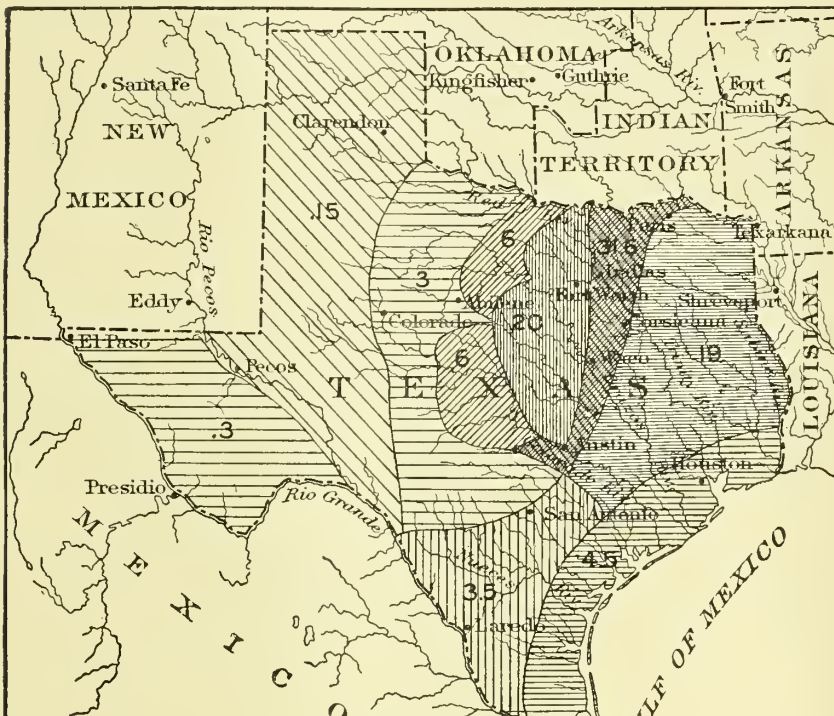


FIG. 2.—Density of population proportionate to geographic and geologic features, shown in percentages (Census of 1890). (Compare Pl. I, p. 26.)

are the immediate occasion of this paper. All the factors, agricultural, hydrographic, physiographic, and vegetal, however, which determine human habitation, are the direct result of the composition, arrangement, and weathering of the system of chalky rocks (chalky sands, marls, clays, and limestones) which underlie the surface and which must necessarily be understood, as described on a later page, before one can gain a correct knowledge of the resources.

Altogether these prairies are more comparable in some parts to the downs of England, and in others to the hills of France than to other regions. So far as the United States is concerned, this country is unique, without analogy or counterpart. In topographic, economic, and cultural aspects it is a distinct geographic region.

BELTS OF COUNTRY.

Not all the Cretaceous prairies are alike in physiographic, geologic, vegetal, and cultural features, but they are divisible into several distinct and strongly contrasting types of country arranged in irregular parallel belts. These belts of country are due to the varying composition and degrees of hardness of the Cretaceous strata upon which they are developed and which are minutely described on later pages.

The belts of prairie extend in an approximately north-south direction for 250 miles, from the Colorado to the vicinity of Red River. Here, in southern Indian Territory, and in Grayson and Fannin counties, Texas, they change in direction from north-south to due east-west. This radical change takes place at the point where the prairies cross a fault line, elsewhere described as the Red River fault zone, which extends in a northwest southeast direction from the vicinity of Marietta, Indian Territory, to near Cooper, in Delta County (see geologic map, Pl. LXVI, A). The Black and Grand prairies, with the belts of Cross Timbers, are separated by this fault line into two great subdistricts, which may be termed the Main Texas and the Red River areas, and the ends of the two subdivisions meet along this line like the bands of molding at the corner of a picture frame.

Collectively the Cretaceous prairies consist of gently tilted dip plains, those of the Main Texas area comprising a portion of the continental slope from the Rocky Mountains to the sea, which has an average gradient of about 40 feet to the mile. This gradient varies in places, as will be shown. The plains of the group vary in altitude from 1,500 feet above sea level at the western edge to about 400 feet on the eastern edge. The dip plains of the Red River area incline southward from the Ouachita Mountains. Because of the difference in slope, strike, and direction between these two subareas, the writer frequently throughout this paper uses the general term "coastward" instead of east in discussing the directions of dip and slope. When the wide extent of the prairies as a whole is considered, the general slope is remarkably uniform—more so than in any other large area in our country; but even in this slope there are certain important variations, which are elsewhere discussed.

From the profiles on Pl. LXVII it will be seen that a slight change in rate of slope apparently takes place in the Main Texas area along a north-south line from Red River to the Colorado via Bowie, Decatur, and Weatherford, the rate of slope increasing east of the line. This change is in the nature of an almost imperceptible monoclinal fold, with a steeper grade on the east and a flattening profile to the west. This trivial difference of slope, which increases south as the Balcones fault zone develops, and which is reflected in the dip of the underlying strata, has an important effect upon the topography, drainage, and conditions of distribution of underground water.

THE RELIEF.

The belts of Cretaceous prairie are, as a rule, of low relief, increasing in rugosity from east to west. The belts of faintest relief are on the east and those of more pronounced relief on the west, where they consist of flat-topped buttes, mesas, and widely terraced slopes and scarp lines.

The several belts also present contrasting minor variations of relief according to their structure. Those composed of the harder formations are usually flat in their coastward extension and are sometimes dissected into cut plains along their inland margin. Certain prairie belts in which the underlying formation consists of less consolidated terranes are eroded into a mammillary or hilly topography of the type known as rolling prairie.

The gently sloping dip plains of the various belts are accompanied by low interior-facing stratified escarpments, escarpment troughs, and drainage valleys. The escarpments are the outcrops or exposed edges of the beds of strata underlying the dip plains (see fig. 3). Escarpment troughs (parting valleys) are valleys occurring where the lower margin of a dip plain abuts against the base of the inward-facing escarpment of the succeeding plain.

While the dip plains incline coastward the accompanying escarpments always face in the opposite direction. There are two low inward-facing stratified escarpments near the interior borders of the Black and Grand prairies, whcih are specially conspicuous features of relief, constituting marked breaks in the otherwise monotonous surface of the adjacent areas. That of the Black Prairie, known as the White Rock scarp, extends through the Main Texas area southward from Sherman toward Austin. Its margin overlooks the narrow belt of the Eagle Ford Prairie. This feature is lacking in the Red River subdivision. The western and northern escarpment of the Grand Prairie—a more conspicuous feature—extends from the boundary of Arkansas due west through Indian Territory to the ninety-eighth meridian and thence south through Texas, in a much lobed and crenulated line, to the Colorado.

Fig. 3.—Ideal section of Grand Prairie, showing dip plains.

THE DRAINAGE.

The drainage of the Cretaceous prairies is of two general types: (1) Through-flowing rivers—the Red, Brazos, and Colorado, which enter the region from the west and cross it—and (2) a system of less copious locally developed autogenous streams.

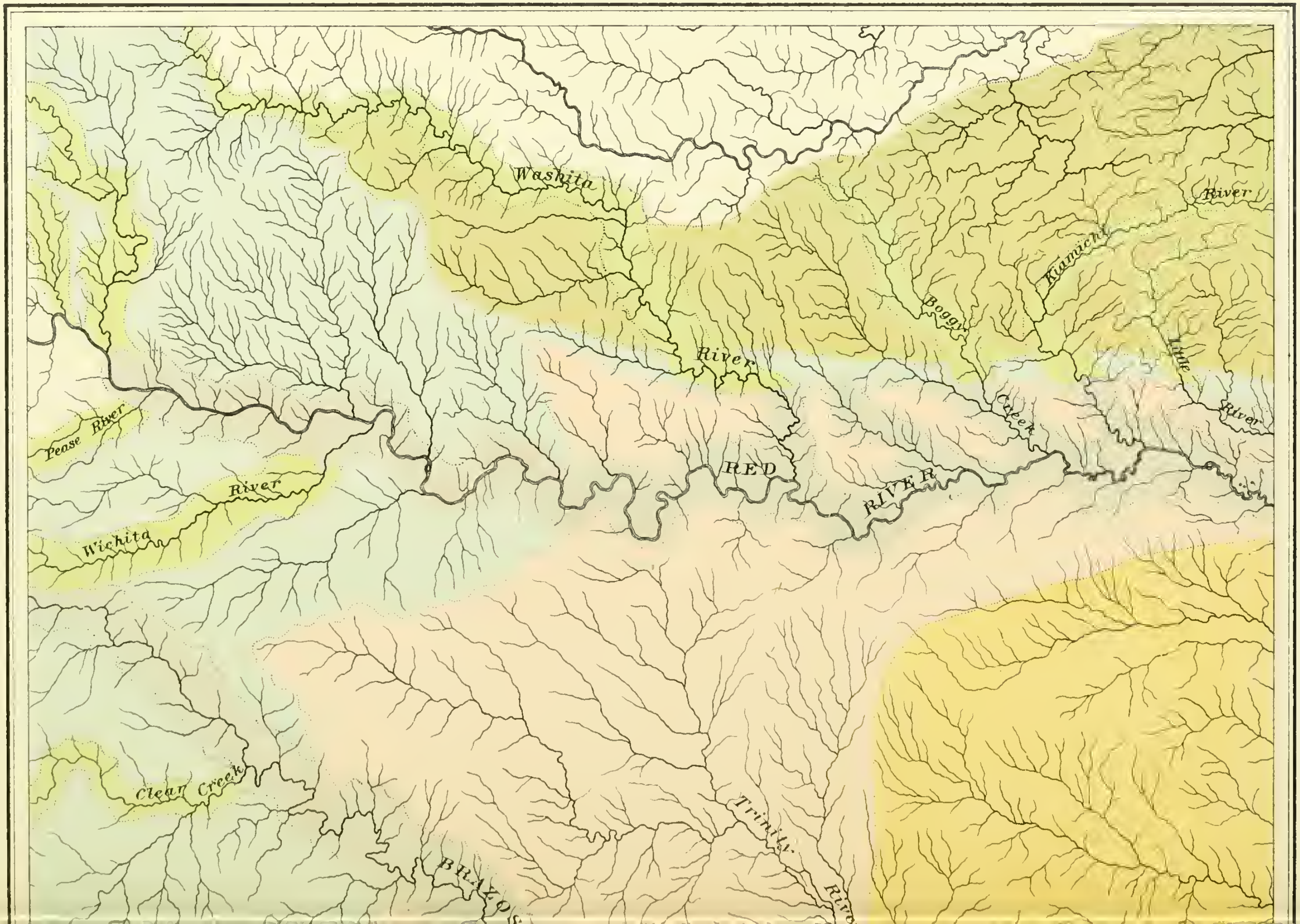
The through-flowing rivers, descending from the Central Province, cross the Black and Grand prairies in deeply indented grooves or valleys cut far below the general upland level, and are established upon a lower profile and have a more flattened gradient than the streams of the second class mentioned. They are practically great canals passing across the region without drawing much lateral drainage directly from it.

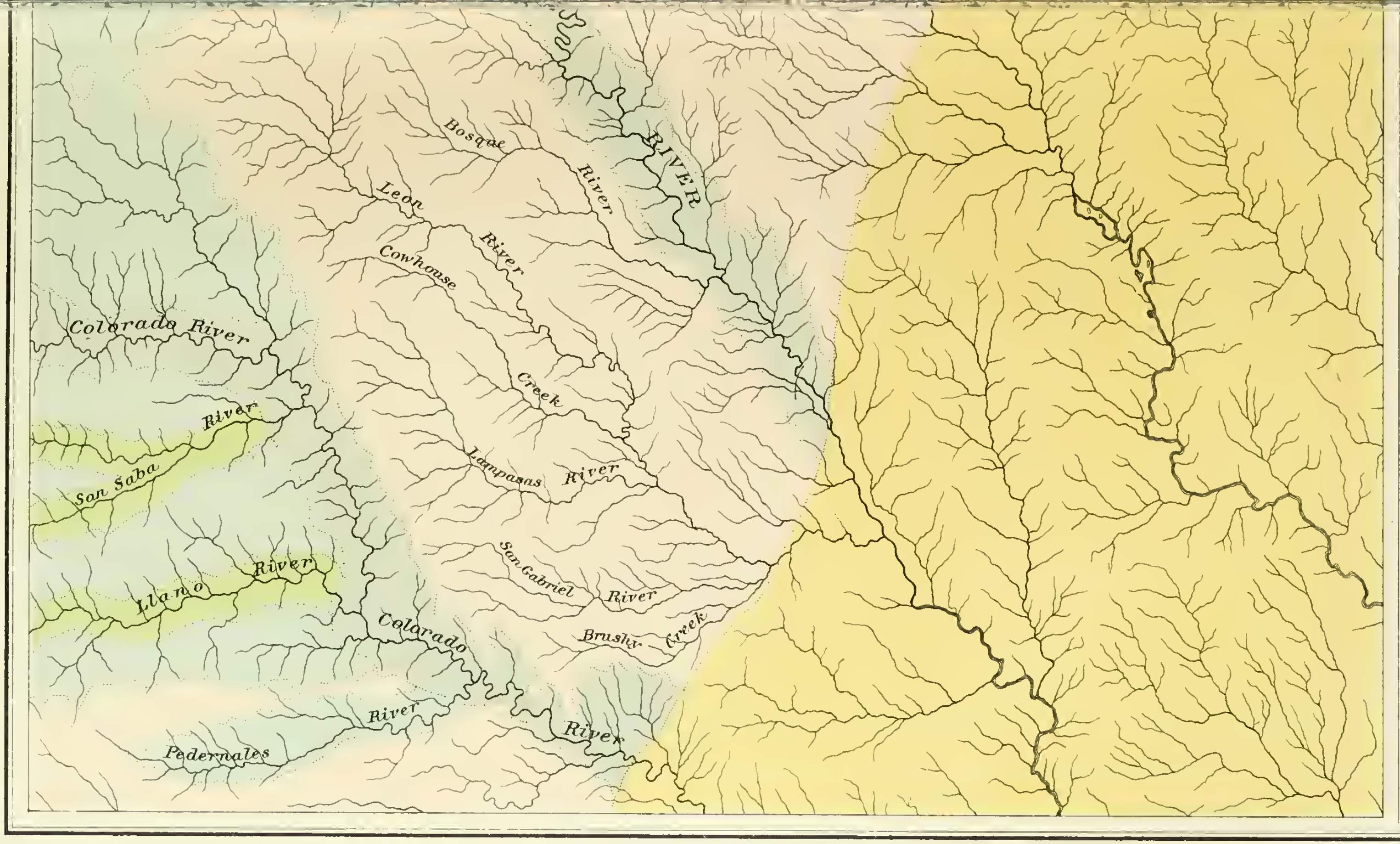
The Trinity, between Brazos and Red rivers, and the Paluxy, Leon, and San Gabriel, between the Brazos and the Colorado, are rivers of the second class. These are developed upon upland stretches of plain which separate the stream valleys of the older class of streams. (See Pl. XI.) The many ramifying branches of this second group gather all the upland drainage of the prairies between older rivers, taking it even from the very scarps of the valleys of the greater through-flowing rivers.

The trunks of these secondary rivers are primarily autogenous slope streams which were originally established upon higher surfaces, now stripped away; they have maintained their location by inheritance as the general region was degraded by erosion. These rivers mostly rise close to the western margin of the Grand Prairie plain, but by rapid descent of their streamways soon become so deeply indented that their paths are much lower than the regional surface of the upland prairies, which are flat-topped divides between them. Their permanent water is largely derived from the structural drainage of the sands of the Cretaceous beds. Some of them, like the Leon and San Gabriel, are also largely reenforced as they cross the Balcones fault zone, at the border of the Black and Grand prairies, by springs rising under hydrostatic pressure through fissures.

The laterals and sublaterals of these streams do the principal work of gradation and are of a peculiar type. The principal laterals tend to parallel the escarpment troughs in a north-south direction at right angles to the main trunks. The sublaterals flowing into the laterals gather their drainage on the east by short ravines from the inward-facing escarpments and from the west by long drains developed on the surface of the dip plains, as shown in Pl. XI.

The main trunks of the streams of the second class are usually interrupted in flow, the water running in deep pools for some stretches of their courses and again disappearing in dry stony channels. The


Washita
River
Kiamichi
River
Boggy
Creek
Little
River
RED RIVER
River
Pease River
Wichita River
Clear Creek
BRAZOS
Trinity
Rive



DRAINAGE OF BLACK AND GRAND PRAIRIES

BY ROBERT T. HILL

DRAINAGE OF THE BLACK AND GRAND PRAIRIES	OLDER THROUGH FLOWING DRAINAGE	DRAINAGE OF THE REVIVED WICHITA PALEOPLAIN (Older catagory)	DRAINAGE OF THE REVIVED WICHITA PALEOPLAIN (Later catagory)	DRAINAGE OF THE COASTAL PLAIN (Late)	DRAINAGE OF THE OUACHITA MOUNTAINS

Scale of miles

25 20 15 10 5 0 25 50

1900

laterals and sublaterals are dry except in times of rainfall, when they carry off the surface water.

The stream valleys of the through-flowing rivers and of the main trunks of the prairie rivers in their lower portion are accompanied by old alluvial formations, often of considerable width and extent, as more fully discussed in the geologic part of this paper.

In addition to the types of streams mentioned, the Indian Territory extension of the Red River subdivision of the Cretaceous prairies is crossed from north to south by a number of deep and copious laterals of Red River, which originate in the Ouachita Mountains, including the Little, Kiamitia, Boggy, Blue, and Washita rivers. Furthermore, Red River itself, instead of flowing across the strike of the different belts, as do the Brazos and the Colorado, first follows the Red River fault zone to the east edge of Grayson County and then practically follows the strike of the Eastern Cross Timber belt until it leaves the region.

THE BLACK PRAIRIE SUBPROVINCE.

Relations, Soils, and Drainage.

The various belts of Cretaceous prairies under discussion, both of the Main Texas and of the Red River subdivision, may be broadly grouped into two major types of country of about equal area, differing from each other in certain physical, cultural, and geologic conditions, known as the Black and Grand prairies, each of which is accompanied at its interior border by a belt of forested country, known as the Eastern and Western cross timbers, respectively.

The Black Prairie Country embraces all the area between Red River on the north, the Eastern Cross Timbers, the East-Texas Timber Belt, and the Colorado. The Missouri, Kansas and Texas Railway from Denison to Austin marks approximately the western edge of the Black Prairie belts. The Eastern Cross Timbers clearly define this border as far south as the Brazos, but between the latter river and the Colorado the line of demarcation is geologic rather than topographic. The broadest portion of the Black Prairie is to the north, in the counties between Trinity and Red rivers. Southward the width of the Black Prairie is restricted to its narrowest limits, about 20 miles, along the Colorado River, between Austin and Elgin.

The Black Prairie owes its name to the deep regolith of black calcareous clay soils which covers it. When wet these assume an excessively plastic and tenacious character, which is locally called "black waxy." These soils are the residua of the underlying marls and chalks, or local surficial deposits derived from them, and hence are rich in lime. Complicated chemical changes, probably due to humic acid acting upon vegetable roots, are believed to cause the black color. The region is exceedingly productive, and nearly every foot of its area is susceptible of high cultivation. In fact, the prairies are the richest and largest body of agricultural land in Texas, constituting a practically continuous area of cultivated soil extending from Red River to the Comal. Large quantities of cotton, corn, and minor crops are annually raised upon these fertile lands.

Except the streams which rise in other regions to the west and cut through it, the Black Prairie region has few running water courses, while the substructure is not favorable to securing surface wells, so that for domestic purposes its inhabitants depend largely upon cisterns or ponds, the water from both of which is unwholesome.

The configuration of the Black Prairie was well characterized some forty years ago by Dr. Ferdinand Roemer as the "sanftwellige Hügelland," or "gently undulating regions," inasmuch as its relief consists of gently rolling prairie lands, as distinguished from the sharper, more angular topography of the Grand Prairie belts to the west. In general the Black Prairie region is a slightly tilted plain sloping almost imperceptibly coastward, generally with numerous low mammillary hills having gently rounded slopes. The drainageways are void of scarps or other sharp lines of relief, and are so interlaced in their headwater portion as usually to produce the low type of mammillary relief above mentioned, although the general level of the divides is in some cases extensively maintained. The through-flowing streams which rise to the west make wide, shallow indentations below the summit slope, varying from 250 feet in depth at the western margin to 100 feet on the east, accompanied by considerable breadth of alluvial valleys. Short laterals fringe these valleys, but they have not made sufficient headwater progress across the divides of the original plain completely to destroy the old topographic summit level. The altitude of the plain is between 750 feet above sea level on the west and 400 feet on the east.

The Black Prairie of the Red River subdivision, with the exception of a small area of the Eagle Ford Prairie in the Chickasaw Nation, known as Carriage Point Prairie north of Denison, does not appear in Indian Territory, but has extensive development in the Red River tier of counties on the Texas side.

Subdivisions of the Black Prairie.

The Black Prairie is subdivisible longitudinally into four parallel north-south strips of country, differing slightly from one another and distinguishable by minor differences in topography and in the composition of the underlying rocks. Besides these there are small spots of Black Prairie occurring as inliers in the timbered area of southwest

Arkansas, as described in the writer's previous report on that region.[1] These subdivisions are as follows:

Black Prairie inliers within the Atlantic Timber Belt.
Eastern Marginal Prairie.
Taylor Prairie.
White Rock Prairie.
Eagle Ford Prairie.

Inliers of the Black Prairie within the Atlantic Timber Belt.—In the southwest counties of Arkansas and in east Texas and Louisiana occasional open glades of rich, black, calcareous soil are found in the midst of the great forests of the Atlantic Timber Belt. These are noted for the fertility of their soils relative to the surrounding country, producing much larger crops of cotton and corn. They occur in Clark, Hempstead, and Howard counties, in Arkansas; in Bowie (at the Freese place), Smith, and other counties of Texas; and in Louisiana. These prairies are never of great extent, and their occurrence is supposedly attributable to the local eroding away of the once overlying covering of the Tertiary formations. Such aberrant outcrops of a lower-lying formation within the general area of an overlying one are geologically known as "inliers."

Eastern marginal prairies.—The easternmost subdivision of the Black Prairie is a narrow belt of land occurring in Red River, Hunt, Delta, Kaufman, Falls, McLennan, Bell, Williamson, Navarro, and Travis counties, which is characterized by a black, sandy, calcareous soil derived from underlying beds of glauconitic sands and clays. These lands represent the surface residuum of the uppermost beds of the Cretaceous formations and are comparable in character to the sandy Cretaceous soils of Arkansas, Alabama, and New Jersey, and are an exceptional feature in the Texas region. In fact, they might be more appropriately classified, geographically, as a western marginal fringe of the Atlantic Timber Belt, inasmuch as, in places at least, especially to the north, they are covered with a growth of hardwood timber.

Taylor Prairie.—This is the largest and most characteristic subdivision of the Black Prairie region, occupying a wide belt south of the Red River counties, between the eastern marginal Black Prairie and the White Rock scarp, to be described. It is characterized by stiff, black, waxy, calcareous clay soils and a substructure of light-blue marl, called by the residents "soapstone" and "joint clay," from its jointed and laminated structure. The surface, composed of gently rolling uplands, is covered in places by a growth of mesquite shrubs. Some of the more extensive and poorly drained divides are accompanied in many places by small depressions known as "hog wallows," produced by the unequal drying and shrinkage of the calcareous clays

[1] Neozoic geology of southwestern Arkansas: Rept. State Geologist, Vol, II, Little Rock, 1888.

in such places. This, the main portion of the Black Prairie, forms fully two-thirds of its total area. The cities of Greenville, Terrell, Corsicana, and Kaufman are situated near its eastern border, near the junction of the sandy and main black waxy strips. Waxahachie, Taylor. Temple, and Manor are situated in the main black waxy belt.

White Rock Prairie.—A formation of harder rock, known as the "White rock" or "Austin chalk" outcrops along the interior margin of the Taylor Prairie from Sherman to Austin. The surface of this forms a narrow strip of dip plains averaging a few miles in width. The topography of this belt is more rugged and sharply incised than the main Black Prairie, but the relief is still low and devoid of the steeper bluffs and scarps that characterize the Grand Prairie region. It is dotted by clumps of handsome evergreens and oaks, and its soil, while black, is shallower than that of the adjacent belts. Where gullied and cut by the streams the exposed substructure of chalky rocks gives a light tone to the landscape.

The western edge of the White Rock Prairie as seen at Oak Cliffs, near Sherman, Dallas, Waco, Hillsboro, and other places is an inward-facing escarpment which overlooks to the west the Eagle Ford Prairie and Eastern Cross Timber strips. This feature is continuous from Sherman to Temple, some 250 miles, and intermittently from Temple to Austin. Except where cut by rivers this low-sloping escarpment seldom exceeds 100 feet. In a level region of low relief the breaks of this scarp are conspicuous objects, and in some places are called "mountains." The escarpment can be distinguished upon even ordinary maps by the small fringework of minor drainage heads which rise near its summit and lead to the west, emptying into a class of lateral streams which follow the escarpment trough along its base in a north-south direction before finally reaching the major drainageways. The east forks of the Trinity, Mountain Creek, Tehuacana Creek, and Bosque River are all streams of this character. The chalk or white rock forming the summit of this scarp is the immediate geologic antecedent of the marly clays underlying the Taylor or main black waxy area, and the one succeeds the other by easy transition. The eastern parting between the White Rock and Taylor prairies is usually indefinite.

An interesting cultural feature of this narrow strip of white-rock country is the fact that the tier of larger cities of central Texas, with the exception of Fort Worth, are built upon it. Sherman, Dallas, Waco, Austin, and San Antonio are all located along its narrow outcrop.

Eagle Ford Prairie.—Immediately west of the White Rock scarp and situated between it and the eastern border of the Eastern Cross Timbers is another long, narrow belt of black, waxy country very much resembling the Taylor or main Black Prairie. From the Brazos to within 10 miles of Red River this feature is especially conspicuous in eastern Hill, eastern Johnson, western Dallas, western Collin, and western Grayson counties, to the Red River. This portion of the belt is 180 miles long and averages 10 miles in width.

South of the Brazos this belt is of varying width and is intermittent in character, gradually narrowing and dying out as a distinct topographic feature at the Colorado. The last typical appearance of this subdivision of the Black Prairie north of the Colorado is in the Sixth Ward of Austin. The Red River area begins in eastern Grayson County, and continues down the valley of Red River through Grayson, Fannin, and Lamar counties to the eastern edge of Red River County, where it ends. The southern margin of the Red River belt is approximately marked by the transcontinental branch of the Texas Pacific Railway from east of Sherman, near Bells, to a few miles east of Paris, Lamar County. The southern border of this Red River belt is not marked by an escarpment of white rock as is the eastern border of the Main Texas belt.

The soil of the Eagle Ford Prairie, like that of the Taylor Prairie, is the residuum of marly clays, and in places is, if possible, even more productive and fertile than the latter. Along the western border of the belts this soil becomes slightly sandy as the substructure grades down into that of the Eastern Cross Timbers. Some of the richest agricultural lands in Texas, notably in Johnson County, are located upon this Eagle Ford division of the Black Prairie region.

THE EASTERN CROSS TIMBERS.

Character, Relations, and Extent.

The western border of the Main Texas area north of the Brazos and the northern border of the Red River area of the Black Prairie are terminated abruptly by a peculiar narrow ribbon of upland forest known as the Lower or Eastern Cross Timbers. This forest is largely composed of black-jack and post-oak trees, which grow in a deep, sandy soil. This is the most eastern of two similar belts which occur in the East-Central Province, a region of prairie plains, and which extend in a north-south direction, opposite to the prevalent courses of the streams.

The cause of these peculiar ribbons of upland timber between vast stretches of treeless prairie had long been a subject of inquiry before the writer, in 1887,[1] showed that the forest growth was adapted to the geologic formations, the two belts of cross timbers being upon outcrops of certain arenaceous formations at the base of the Upper and Lower Cretaceous series of rocks respectively, the deep permeable

[1] See Geology and geography of the Cross Timbers of Texas: Am. Jour. Sci., 3d ser., Vol. XXXIII, April, 1887.

regolith and sandy soils of which favored forest growth. These conditions are lacking in the close-textured calcareous soils of the intervening prairie regions. The formations upon which are found the Western and Eastern cross timbers are minutely described elsewhere.

The Eastern Cross Timbers proper consist of a belt of timber land in the Main Texas area which extends from the Brazos north of Waco to where Red River is intercepted by the boundary line between Cooke and Grayson counties. Besides this belt there are several extensive patches of similar forest lying within the Red River area which will here be included under this general name. The belt approximately follows the ninety-seventh meridian, extending through western Grayson, eastern Cooke, Denton, Tarrant, Johnson, Hill, and McLennan counties. This belt gradually diminishes in width from north to south.

The main body of the Eastern Cross Timbers and the outcrop of the formations on which they grow—the Woodbine, Pawpaw, and Denison beds—are nearly 180 miles in length from south to north, and seldom exceeds 10 miles in width. Their area and course are well shown on the map forming Pl. X.

The relief of the Eastern Cross Timbers is that of a greatly dissected dip plain which is sublevel to the east and becomes broken into many low hills toward its western border. In the local language it would be called a "rolling, hilly country."

When viewed from the White rock scarp, looking west, the Eastern Cross Timbers appear to occupy a low valley plain, but when observed from the west, looking east, as from Fort Worth or any point on the eastern margin of the Grand Prairie region, they appear as a range of low but sharply rounded, wooded, mammillary hills, which in places, as in Grayson, Denton, Tarrant, and Johnson counties, make conspicuous knobs capped by dark-brown arenaceous ironstone.

Within the Cross Timbers there are many spots of prairie, or "glades," as they are termed. These abound especially toward the eastern and western border. Those of the latter are an almost continuous body of narrow prairie land separating a fringe or ribbon of forest from the main body of timber.

The same character of timber growth also has extensive development in the Red River area, both in Indian Territory and down the valley of Red River nearly to the Arkansas line. There are three distinct areas of forested country of the Eastern Cross Timbers type within the Red River district. These are the Iron Ore Knobs of north-central Grayson County, the Caddo Knobs of southern Indian Territory, and the valley of Red River east of Grayson County. The areal extent of these northern representatives of the Eastern Cross Timbers can best be understood by examining the distribution of the formations upon which they grow, as shown on the geologic map, Pl. LXVI.

Iron Ore Knobs.

The Iron Ore Knobs of Grayson County extend east and west from Alchire switch, 7 miles west of Denison, to Red River. These knobs as seen between Sherman and Denison consist of low, rough, sandy hills densely clad with black-jack and post oak.

From the summit of the Iron Ore Knobs an exactly similar and parallel row of hills—the Caddo Knobs—can be seen some 30 miles northward, across the valley of Red River, in southern Indian Territory. This row of knobs, which is the interior margin of an extensive prairie dip plain sloping toward Red River, extends from the Washita River a few miles south of old Fort Washita eastward for 15 miles to the Missouri, Kansas and Texas Railway, beyond which it has not been explored.

Both of these parallel east-west belts are ultimately occupied by the valley of Red River, which intercepts that of the Iron Ore Knobs at the northwest corner of Fannin County and that of the Caddo Hills some distance eastward, in Lamar County. Where so followed by the rivers the cross timbers and the formations upon which they grow are so associated with the undergrowth and recent and old alluvial soils that it would be impossible to map them until minute studies are made.

Economic Features.

The Eastern Cross Timbers are admirably adapted to fruit growing, and the strata upon which they are established are of great importance to the question of artesian water. To appreciate the water conditions of this region it is necessary for the reader to know the sequence of the great rock sheets of the Black Prairie and the Eastern Cross Timbers, their water-bearing and water-transmitting capacity and their topographic lay, as given in subsequent pages.

THE GRAND PRAIRIE SUBPROVINCE.

General Character and Relations.

The Grand Prairie includes the portion of the East-Central Province situated west of the Eastern Cross Timbers in Indian Territory and Texas. It has an area of about 20,000 square miles and presents within itself many diverse features.

Although often confounded with the Black Prairie, the Grand Prairie differs from it in many minor physical features. In general the surfaces are flat rather than undulating, and the valley slopes are angular (scarped or terraced) rather than rounded. The residual soils and regolith are shallow in comparison with those of the Black Prairie belts, and are of chocolate or brown colors instead of black. although in at least one belt (the Del Rio) the latter color prevails. Owing to the more shallow soil and the decreased rainfall many of the upland areas of the western part of the Grand Prairie are not so well adapted to agriculture, other than grazing, as are those of the Black Prairie, but the valley lands are very fertile and are extensively utilized.

The chief difference between the two regions is that the Grand Prairie is established upon firm, persistent bands of limestones, which are harder than the underlying clay substructure of the Black Prairie region, and which, under erosion, result in more extensive stratum plains and more angular cliffs and slopes. These limestone sheets of the Grand Prairie belts also alternate with marls and chalky strata of varying degrees of induration and thickness, and at the base of the whole are unconsolidated sands. The rock sheets of the Grand Prairie are so much harder than those underlying the Black Prairie region and are so conspicuous features in the landscape that, in distinction, the Grand Prairie country has been appropriately called "the hard lime rock region."

In general the surface of the Grand Prairie, especially north of the Brazos, is composed of gently sloping, almost level, and usually treeless dip plains, broken only by the valleys of the transecting drainage. These prairies are more continuous and comparatively void of inequalities of erosion along the eastern portion of the area. In the western half, especially south of the Brazos, their surfaces are broken into cut plains, buttes, mesas, and flat-topped divides and are etched by deeply eroded valleys.

The Main Texas portion of the Grand Prairie, so much as is embraced within the subdivision described on a later page as the Lampasas Cut Plain, is the modified northern continuation of the Edwards Plateau and the surface outcrop of the eastwardly receding limestone sheets that once stretched over the Central Province to the Llano Estacado. In fact, it is the continuation of the great belt of Lower Cretaceous formations extending across the State, elsewhere represented by the Edwards Plateau southwest of the Colorado and east of the Pecos, the Stockton Plateau between the latter river and the Cordilleran front, the Callahan Divide throughout the Central Province, and a narrow belt of country immediately at the foot of the Balcones scarp from Austin westward. To the composition, stratification, and methods of disintegration of the different rock sheets is due the individuality of the topography of the Grand Prairie and its minor subdivisions.

The coastward border of the Grand Prairie Subprovince, with exceptions to be noted between the ninety-fifth and ninety-seventh meridians in the Red River district, is the valley of Red River; between Red River and the Brazos it is the Eastern Cross Timbers, and from the Brazos to the Colorado the Balcones fault zone.

The relief features of the coastward border are elsewhere described under the heads of the Black Prairie, the Eastern Cross Timbers, and the Balcones scarp. The northern and irregular western borders of the Grand Prairie terminate in the low inward-facing escarpment previously mentioned which overlooks the valley of the Western Cross Timbers. These features extend west through Indian Territory to Duncan and thence south through Texas, following an irregular line through the counties of Cooke, Wise, Parker, Hood, Erath, Comanche, Brown, Mills, San Saba, Lampasas, and Burnet.

This escarpment is an interesting feature, from both a geologic and a geographic point of view, inasmuch as it marks the eastwardly receding western edge of the Cretaceous prairie, which has been gradually withdrawing from the Central Province and the south front of the Ouachita Mountains. North and east of Trinity River the escarpment does not exceed 100 feet in height, but consists of a low simple cliff of the Goodland (Edwards) limestone surmounted by the dip plains which slope away from its margin. South of Trinity River, owing to increase in thickness of the Goodland limestone and to interpolation of numerous alternations of hard and soft layers as lower formations in the geologic sections, the escarpment feature becomes more complex or compound in character, and consists of a number of benches and scarps, the latter usually being low and inconspicuous, while the former spread out into belts, in places of considerable width. These alternate benches and terraces of stratification often continue long distances. Upon these benches are established many minor types of country, like the Walnut and Glen Rose prairies, consisting of open stretches of land, and the two belts of upland forest composing the Western Cross Timbers, which follow certain outcrops of sandy strata.

The escarpment line also becomes more irregular to the south and is crenulated and cut into innumerable hills and points. Sometimes the scarps bend down the valleys of the transecting rivers, which cut across the Grand Prairie until they almost reach the eastern margin of the region, as in valleys of the Brazos and the Colorado near Austin. The entire length of this scarp, with its principal meanderings across Texas, is little less than 2,000 miles.

This scarp topography is due to the presence of the hard cap rock of Edwards limestone previously mentioned in the descriptions of the Edwards Plateau and Callahan Divide and more fully described on later pages, which, owing to its superior hardness relative to the adjacent formations, resists erosion more stubbornly.

The drainage of the Grand Prairie has been described in the introductory portion of this paper (p. 55).

Subdivisions of the Grand Prairie.

The Grand Prairie, like the Black Prairie, is divided into two conspicuous general areas: (1) The northern or Red River district, in southern Indian Territory, lying along Red River with east-west trend; (2) the Main Texas district, between Red and Colorado rivers, with north-south trend. The combined outline of these constitutes an irregular area, one part of which, principally north of Red River, extends east and west, while the other, between Red and Colorado rivers, extends north and south.

RED RIVER SUBDIVISION.

The Red River subdivision of the Grand Prairie, except a small area in northern Grayson County, is situated in southern Indian Territory, between the eastern extension of the Western Cross Timbers, which occupies a parting valley along the southern side of the Ouachita Mountains, and Red River. It consists of a narrow east-west belt of upland prairie, transected at intervals by low timber-covered stream bottoms which cross it from north to south. This belt as a whole is a dip plain which slopes south toward Red River and scarps to the north toward the mountains. The surface consists of black calcareous lands with a shallow regolith of dirty yellow subsoils, underlain by the alternating limestones and marls of the Washita division of the Comanche series.[1] These prairies in Indian Territory increase in area from east to west. They are seldom over 5 or 6 miles wide from north to south and are bordered on the south by the Eastern Cross Timber belt, in which Red River flows.

The northern border, like the western border of their continuation in Texas, is the eastward continuation of the inward-facing escarpment making the general interior border of the Grand Prairie. In this portion of its course this escarpment is very low and overlooks a long and narrow timbered parting valley which lies between it and the Ouachita Mountains—a valley underlain by similar geologic formations and analogous in character to the Western Cross Timber valley of Texas. This east-west timbered belt on the north of the prairies parallels the forest belt of the Red River Valley, so that the prairies are included between them.

The streams of the north-south drainage, like the Boggy and Kiamitia, which flow from the mountains across these prairies, have cut deep and wide forested bottoms below the general prairie level, which extend from the timbered valleys on the north to those on the south. In this manner the continuity of the prairie belt is broken into a series of blocks separated by lower-lying forested stream bottoms.

These prairies begin on the east at the Arkansas-Choctaw line, just west of Little River. Here small spots of limestone prairie, covered with the rich, luxuriant grass and flowers peculiar to the Grand Prairie, begin to appear as islands amidst the dense forests of the

[1] The Denison beds in part, Fort Worth, Duck Creek, and Goodland beds in Indian Territory. See Geologic description, pp. 266 et seq.

great Atlantic Timber Belt. Westward the patches of Grand Prairie increase in area as the forests diminish, and occupy the flattened divides between the numerous streams flowing into Red River from the north. The plains of the Kiamitia (between the Kiamitia and Little River), the Goodland Prairie (between the Kiamitia and the Boggy), the Caddo Prairie (between the Boggy and the Blue), the Washita Prairie (between the Blue and the Washita), and the Marietta Prairie, west of the Washita, are the chief examples of this class.

An interesting feature of the Red River district is the fact that it is mostly of lower altitude than the prairies on the south side of the Red River fault line. This is largely because it occurs on the downthrow side of the Red River fault zone. As shown later, this feature has a most important bearing upon the artesian water question.

Grayson district.—In northern Grayson County there is a small disconnected body of Grand Prairie belonging to the Red River area which occurs as an inlier within the Eastern Cross Timbers and the Black Prairie. This occupies about 20 square miles to the north and northwest of Denison. Its isolated occurrence in this locality is due to the peculiar faulting elsewhere explained.

THE MAIN TEXAS SUBDIVISION.

GENERAL CHARACTER AND EXTENT.

West of the Red River fault zone, between Marietta, Preston, Denison, and Bells, Texas, the east-west trend of the Grand Prairie and the strike of its underlying formations which mark their occurrence in the Indian Territory change to the north-south direction which prevails in the Main Texas area, a district embracing all the belts of Grand Prairie Country between the Western and Eastern cross timbers and between Red River and the Colorado. The Missouri, Kansas and Texas Railway from Denison to Austin almost follows the eastern border of the Main Texas area. The valley of the Western Cross Timbers forms the western margin.

This portion of the Grand Prairie as a whole is a vast dip plain, which becomes more dissected and diversified to the southwest, finally passing southward into the sublevel dissected Edwards Plateau. The surface slope, with slight variations, is generally east. That portion of the Grand Prairie north of Trinity River and the eastern border in general, as far south as the Colorado, like the Indian Territory area, consists of comparatively flat and unbroken dip plains. To the west, especially south of the Trinity, the flat surfaces of the dip plains are more scarped and dissected into numerous low buttes and mesas constituting the Lampasas Cut Plain.

The prairies of the Main Texas belt are cross grooved by deeply scored valleys of numerous streamways with many branching laterals.

These stream valleys are deeply indented, wide, and flat in places, and sometimes bordered by limestone cliffs leading up to the more extensive intervening flat divides. The divides have undergone so much dissection in some places that they are preserved only as flat-topped buttes of the Comanche Peak type, occurring either isolated or as elongated chains—as seen in Hood, Bosque, Erath, Comanche, Hamilton, Bell, Williamson, Coryell, and Lampasas counties—which are more fully described on a later page as the Lampasas Cut Plain.

NORTH-SOUTH BELTS.

The Grand Prairie, like the Black Prairie, is subdivisible into several subparallel north-south belts of country, differing from one another in natural aspects and economic features as well as in underlying geologic formations. These subdivisions are as follows:

- Prairies of the Fort Worth type:
  - Gainesville Prairie.
  - Bosqueville Prairie.
  - Fort Worth Prairie.
- Prairies and forest belts of the Lampasas Cut Plain:
  - Lampasas Cut Plain.
    - Walnut Prairie.
    - Western Cross Timbers.
      - Paluxy Timbers.
      - Glen Rose Prairie.

Of the above subdivisions the first three are regular dip plains, of which the Fort Worth Prairie may be considered the type. The remainder are subdivisions of the Lampasas Cut Plain.

Gainesville Prairie.—The most eastern belt of the Grand Prairie of the Fort Worth type is a narrow north-south strip of land immediately west of the Eastern Cross Timbers, extending from Red River to the Brazos in Cooke, Denison, Tarrant, and Johnson counties, as may be seen east of Gainesville and Fort Worth. This is a dip plain, or series of minor dip plains, of low relief, characterized by the presence of shallow reddish-brown or chocolate soils and subsoils of rusty iron tints, derived from an underlying structure of ferruginous clays, with occasional thin bands of impure ferruginous limestones. The surfaces, while flat, are not so extensive as those of the other Grand Prairie belts. In Cooke County and across Red River in the vicinity of Overbrook and Marietta, Indian Territory, a few low tepee-shaped buttes, of which Comanche Peak,[1] 6 miles southeast of Marietta, may be taken as a type, outlie the marginal scarps of the dip plains.

Bosqueville Prairie.—South of the Brazos the position of the Gainesville Prairie relative to the other divisions of the Grand Prairie is rep-

[1] This is not to be confused with Comanche Peak of Hood County, Texas, a noted geologic and geographic landmark.

resented by a long, narrow strip of prairie country, seldom more than a mile in width, extending through McLennan, Bell, Williamson, and Travis counties, between the Balcones scarp and the western edge of the Black Prairie. The soil of this belt is different from that of the Gainesville Prairie, being black in color and of a sticky nature, instead of brown, and is underlain by the yellowish clay subsoil of the Del Rio (*Exogyra arietina*) formation. This black soil is an exceptional feature in the Grand Prairie and resembles more the prevalent character of the soil and joint clays of the Black Prairie. The surface of the Bosqueville Prairie can hardly be called a dip plain in the true sense of that word. It is marked by "hog wallow" depressions, and usually supports a dense growth of mesquite trees and mesquite grass, constituting a character of country known in Texas as "mesquite flats."

Fort Worth Prairie.—Immediately west of the Gainesville Prairie, north of the Brazos, and the Bosqueville Prairie to the south, a belt of more extensive and open prairie sets in, underlain by white and yellowish bands of limestone and clay, which outcrop in roads and streamways and weather into grayish soils, giving to the landscape a lighter and more glaring tone than that of the prairies above described. These prairies are superb illustrations of typical dip plains, the gently sloping flat surfaces being established for miles at a stretch upon single beds of strata, making grass-covered uplands resembling the boundless views of the Great Plains proper.

This prairie region, which is best seen around Fort Worth, in the western half of Tarrant County, occupies most of the uplands north of the Brazos west of the Missouri, Kansas and Texas Railway and east of the Western Cross Timbers, including the greater part of western Cooke, Tarrant, and Denton counties, and the eastern portion of Wise County. It also occurs in limited spots in the northern part of Grayson, and nearly all the Indian Territory division of the Grand Prairie region belongs to it. The Fort Worth Prairie is more rolling along its interior margin, which extends to the western escarpment, and is there usually accompanied by a fringing belt of stiff clay lands, the outcrop of the Preston beds below the Fort Worth limestones. South of the Brazos the Fort Worth Prairie contracts in width and becomes a secondary feature in comparison to the belts of the Lampasas Plain next to be described. In this general region it is a narrowing belt—often a mere ribbon—passing through McLennan, Bell, and Williamson counties, where it is found only on the downthrown side of the Balcones fault zone.

LAMPASAS CUT PLAIN.

CHARACTER AND RELATIONS.

As the more unbroken dip plains of the Gainesville and Fort Worth type which occupy nearly all the width of the Grand Prairie north of

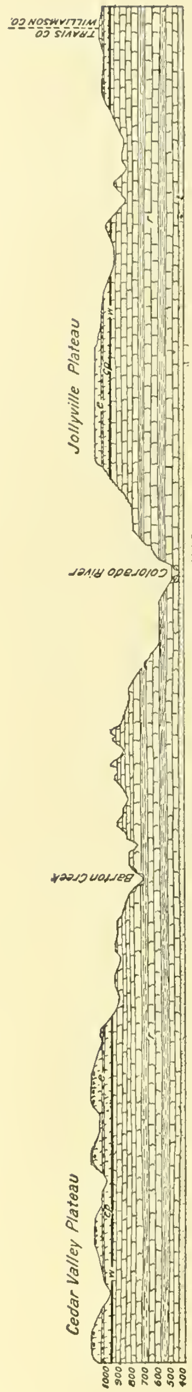


FIG. 4.—Cross section of the Lampasas Cut Plain, Travis County, Texas.

the Brazos decrease in area southward, another important topographic feature begins to develop along the western border. This feature. which has been named the Lampasas Cut Plain, is not represented north of Parker County. It increases in area southward as the Fort Worth Prairie decreases, so that the general width of the Grand Prairie as a whole is more than maintained.

This feature is so intimately related to and dependent upon the occurrence and erosion of one geologic formation—the Edwards limestone—that it is difficult to describe it without constantly bearing in mind the vast extent of this formation as previously stated and more fully described on a later page. South of the Brazos (see fig. 4) the outcrop of this limestone, which is found only in the western scarps north of that stream, becomes a subhorizontal plain-making formation and forms the summit level of all the vast country embraced within the limits of the Edwards Plateau, the Lampasas Plain, and the Callahan Divide.

The Lampasas Cut Plain is the modified northern extension of the great Edwards Plateau, previously described. It is a greatly dissected dip plain, now recognizable by the general level of its many remnantal summits, which dominate all the country south of the Brazos between the Western Cross Timbers and the Balcones fault zone. These summits, which are called mountains by the inhabitants, are numerous remnantal circular flat-topped buttes crowning the divides between the drainage valleys. Life and industry are mostly found in the valleys scored below the summit levels.

In general, these fragments have flat table tops and are bordered by glaring white cliffs above, leading down to gentler slopes below (see Pl. XIII). The tops consist of weathered surfaces of the Edwards limestone, sometimes bare of soil and in other places covered with rich but shallow black or chocolate residual soil supporting grasses and timber growth. Where barren the surfaces of

SCARPS OF THE LAMPASAS CUT PLAIN, BURNET COUNTY, TEXAS.

the massive limestone weather into many minutely sculptured ridges and depressions, produced by the solvent effect of the rainfall upon the hot limestones. Such forms are geologically known as "karrenfelder."[1] In places thick superficial coatings of residual flints occur, resembling beds of waterworn gravel. These have been left behind as the limestone, which originally contained them, was slowly carried away by superficial or underground solution. Some of these flints, through processes of decay, develop a peculiar scoriaceous texture, the cavities of which are filled with drusy quartz which sparkles in the sunshine.

The interior border of the Edwards Cut Plain forms the general western escarpment of the Grand Prairie region south of the Brazos. On the east the plain is less dissected and ends abruptly at the Balcones fault zone, which is a low escarpment hardly noticeable at the Brazos, but which gradually increases in altitude southward until it is a strongly marked feature at the Colorado.

The plain is first recognizable just south of Trinity River, in northern Johnson and Parker counties. East of the Brazos it occurs as a narrow belt of dip plain, surmounting and paralleling the western scarp along the interior margin of the Fort Worth Prairie. It widens rapidly south of the Brazos, so that, with its western continuation across the central region (the Callahan Divide), it is the dominating topographic feature from the eastern breaks of the plains to the Balcones fault zone. It narrows again along the Colorado in Travis County, where the deep canyon of that stream separates it from the Edwards Plateau to the south.

Southward from the Brazos the first characteristic remnant of this old plain is the flat-topped summit known as Comanche Peak, a noted landmark in Hood County, which occurs as an isolated flat-topped summit capping the high denuded divide between the Brazos and the Paluxy. Thence south to the Edwards Plateau and west far over the Central Province flat-topped hills of this character surmounting the drainage divides are conspicuous relief features. Of this description is a vast stretch of country which extends through western Travis, Williamson, and Bell counties, and occupies the divides of Lampasas, Mills, Comanche, Coryell, Bosque, and other counties.

The largest continuous area of the Lampasas Cut Plain is a much lobed and crenulated divide along the western border of the Grand Prairie, extending from the Colorado in western Travis County to the northeast corner of Comanche County, a distance of 115 miles. This in places is several miles wide, and separates the Colorado drainage of the western escarpment from the long prairie streams flowing eastward into

[1] See Illustration on Pl. L of the geology of the Edwards Plateau and Rio Grande Plain: Eighteenth Ann. Rept. U. S. Geol. Survey, Part II, 1898.

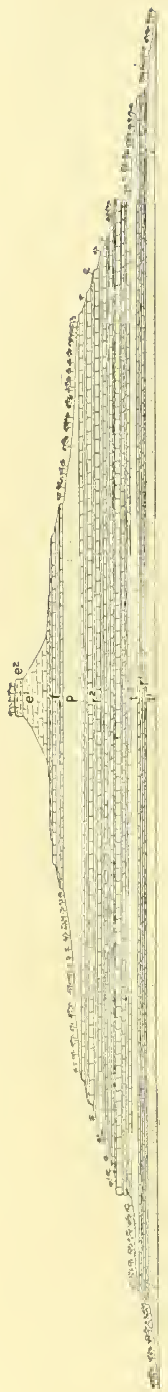
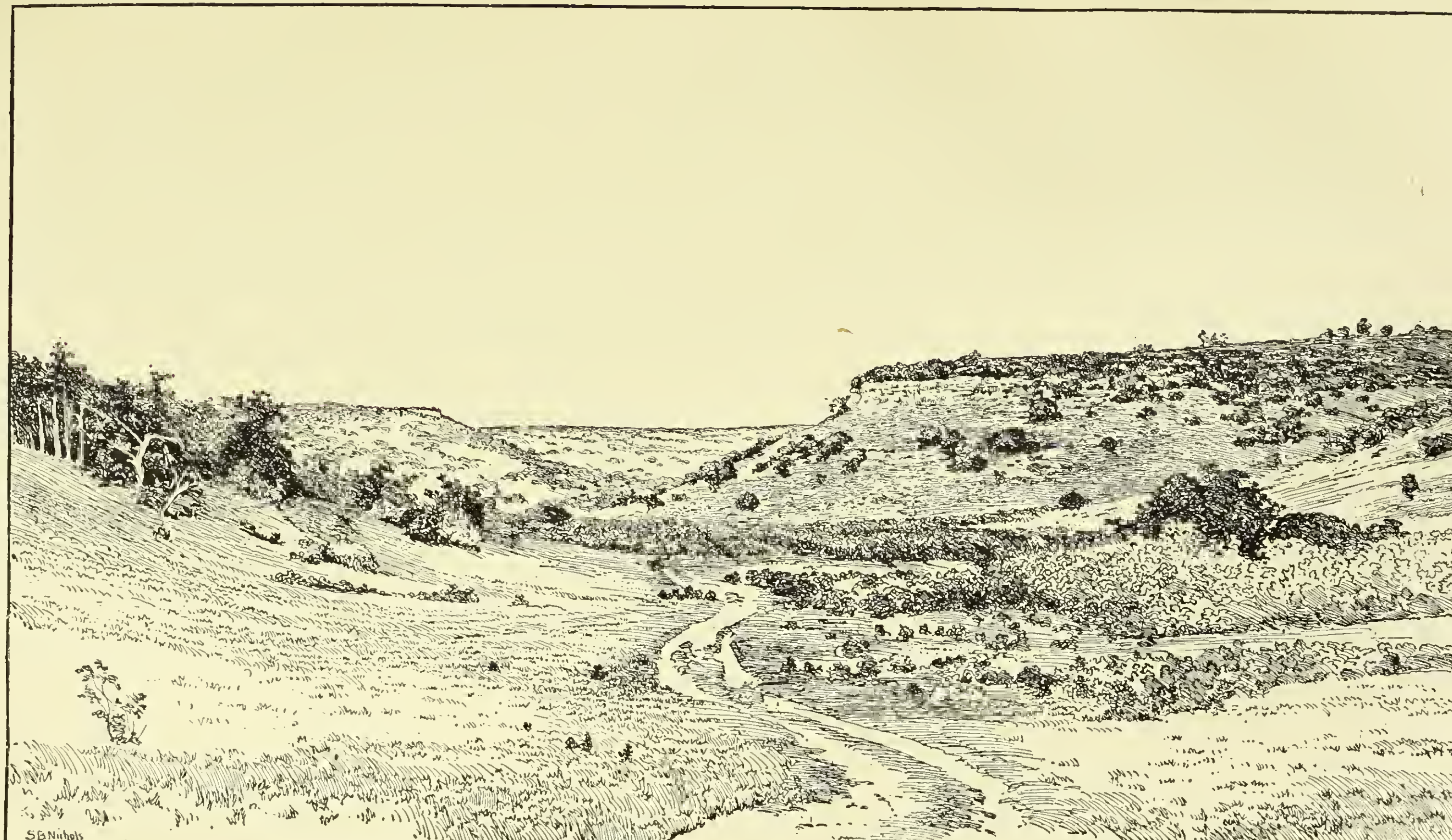


Fig. 5.—Diagrammatic representation of a divide of the Lampasas Cut Plain, showing relation of agriculture, forestry, topography, and underground water to the geology. e², Caprina limestone; summit divide of Lampasas Cut Plain; soilless except in large areas; growth of scrub oak, live oak, and post oak. e¹, Comanche Peak limestone; chalky, soilless slopes; growth of shin oak. f, Walnut formation, Walnut Prairie; rich, fertile land in many places. p, Paluxy sand; Eastern and Western Cross Timbers, forested with post oak and black-jack; fair cotton and good fruit land; water bearing. r², Barren limestone slopes with growth of juniper, live oak, and sumac; occasional fertile soils from interbedded marly layers; water bearing. t², Trinity sands; Western Cross Timbers; same forest growth as p. r¹, small prairie spots; good soil. t¹, Trinity sands; Western Cross Timbers; same forest growth as p.

the Brazos, which have their headwaters along the eastern scarps of the divide.

The more important rivers, such as the Colorado, Leon, Brazos, and Trinity, which rise west of the Grand Prairie area and cross it, as well as the eastward-flowing rivers and creeks of the Grand Prairie proper, having their source against the eastern border of this main western divide, flow in valleys which are deeply incised below the cap rock of the Lampasas Cut Plain. These valleys are separated from one another by long divides composed of eastward-extending remnants of the cut plain.

The principal ramifications of this character extending southeast from the main western border of the Grand Prairie are as follows: The Comanche Peak divide, between the Brazos and Paluxy in Hood and Erath counties, about 22 miles in length; the Chalk Mountain divide, between the Paluxy and Bosque in Erath, Somervell, and Bosque counties, about 45 miles in length; the Dublin divide, between Paluxy and Leon rivers in Erath, Bosque, and Hamilton counties, about 50 miles in length; the Hamilton divide, lying between Cow House and the Lampasas, which extends from eastern Mills County nearly to Belton, a distance of 65 miles; the Lampasas-San Gabriel divide, extending from west of Strickland, Burnet County, to Florence, Williamson County, 22 miles in length; the Bertram divide, in Burnet and Williamson counties, between the north and south forks of the San Gabriel, some 20 miles in length; the Bagdad divide (or Post Oak Ridge), between the south fork of the San Gabriel and the Colorado in Williamson and Travis counties, about 20 miles in length. Shorter secondary arms extend southeastward from these main divides between the principal creeks, such as Bennett, Sims, Big Lucy, Donaldson, Mesquite, North Rocky, South Rocky, and Miller creeks.



SUMMITS OF THE LAMPASAS CUT PLAIN, LAMPASAS COUNTY, TEXAS.

SUBDIVISIONS OF LAMPASAS CUT PLAIN.

The vast surface of the Lampasas Cut Plain is scored by the drainways arising near the western border into many valleys, which are cut below the old level of the plain into older and older belts of strata. These valleys within the area are bordered by escarpments like those found along its western margin. The wide slopes of these valley escarpments descend in series of benches based upon various formations underlying the cap rock of the cut plain, each of which produces a soil and vegetation characteristic of a peculiar type of country. (See fig. 5.) These intaglioed belts will now be described in descending series.

Walnut Prairie.—The first of the types of country resulting from the dissection of the cap rock of the Lampasas Cut Plain has been named the Walnut Prairie, after its typical development in the vicinity of Walnut, Bosque County. This has a shallow, black soil with a yellow-clay foundation, which is the outcrop of the Walnut formation elsewhere described. This formation occurs immediately below the Edwards limestone south of the Leon, and above the Paluxy sands north of that stream.

The Walnut Prairie usually occurs as benches, forming a shoulder immediately below the scarp rock of the summits of the Lampasas Plain, or as the surface of uplands, from which the summit rock has been eroded. The latter type of country is exceptional, but forms extensive areas of upland prairie, notably in Hamilton County. Toward the east this prairie occurs as belts along the stream valleys, between the remnantal mesa divides of the plain.

The Walnut Prairie first appears in Parker County, and is met with in the valleys of all the streams south to the Colorado in Hood, Bosque, Coryell, Lampasas, Bell, and Williamson counties, where it makes large areas of fertile land. The details of the occurrence of this prairie are more fully explained in the description of the Walnut formation, with the outcrop of which it is coincident. At and south of the Colorado the Walnut Prairie diminishes in significance.

Western Cross Timbers.—The Western Cross Timbers are a narrow forest belt or belts which attend the interior margin of the Grand Prairie, being established upon outcrops of formations below the cap rock of the Lampasas Cut Plain. Like the Eastern Cross Timbers, these consists of an upland forest growth of post oak and black-jack growing on sandy soils. These sandy soils are often so deep that wheels sink far into them and make wagon transportation very laborious. There is sufficient clay in the sand, occurring as occasional layers, to make it of considerable agricultural value. These forests and soils, as more fully shown in the geologic discussion, follow the outcrop of unconsolidated sandy strata lying at and near the base of the Cretaceous system and are exposed by erosion of the overlying strata of the Lampasas Cut Plain. These formations, which are discussed in detail on another page, have important relations to the artesian water question, inasmuch as they are the catchment area of the best artesian wells.

The topographic position of the Western Cross Timbers is always relatively lower than the summit of the western scarp of the Grand Prairie, and hence the regions of their occurrence are sometimes spoken of as the valley of the Western Cross Timbers.

The main belt of the Western Cross Timbers is of varying width, from a half mile to 10 miles or more. It is a gently rolling region—almost level—the configuration being largely adapted to and dependent upon the character of the rocks lying immediately beneath the surface. Where these are soft and easily denuded the cross timbers topography is rolling; where hard, at least patches of the sand are preserved over level areas of varying size.

In Indian Territory the Western Cross Timbers occur in an inward-facing valley which has developed along the parting between the Cretaceous prairies and the southern flank of the Ouachita Mountains, and between the receding scarps of the former and the elevated ridges of the latter. This valley is made by the interlacing lateral erosion of the minor tributaries of the main drainage that flows from the mountains to the plain.

In Texas the chief valley of the Western Cross Timbers is the base of the western escarpment of the Grand Prairie at the junction of the latter and the countries of the Central Province. There are ramifying branches of the cross timbers in this region which will presently be described.

Both in Indian Territory and Arkansas the Western Cross Timbers belt is narrow, averaging less than 10 miles in width. This belt approximately follows the thirty-fourth parallel, from Murfreesboro via Ultima Thule, Arkansas, into the Territory, and thence via Antlers, Tishomingo, and Old Boggy Depot nearly to the ninety-eighth meridian. In this portion of their course they are bordered on the north by the Ouachita Mountains. From the last-mentioned point they deflect south, approximately between the ninety-seventh and ninety-eighth meridians to Brazos River in Texas.

In the vicinity of the Brazos south of Decatur the Western Cross Timbers bifurcate into two distinct belts separated by strips of prairies. The most eastern of these belts may be termed the Paluxy Cross Timbers to distinguish it from the main western belt. South of the Brazos the main or western belt continues to follow the foot of the western escarpment of the Grand Prairie southwest through Parker and Erath counties into Comanche County. From this point, like the Lampasas Plain, it sends a long and narrow extension westward, approximately along the thirty-second parallel, around the Callahan Divide, where the cross timbers occur as bodies of timber fringing the base of the limestone buttes, in parts of Eastland, Callahan, Taylor, Coleman, Brown, and other western counties. South of this divide in Brown County the main Western Cross Timbers country continues to form a narrow belt at the foot of the western escarpment of the Grand Prairie, along the eastern slope of the Colorado, southward to Burnet County. In the northern part of the latter county there is a break in the belt for a few miles, but it reappears at the county seat and continues until it crosses the Colorado. South of the Colorado the timber follows the breaks of the Edwards Plateau in their irregular meanderings around the southern perimeter of the Central Denuded region.

The Western Cross Timbers sometimes extend down the valleys of the streams which transect the Grand Prairie, especially the Leon. There are also small inliers of them well within the Grand Prairie, notably along the heads of Bosque and Paluxy rivers. The details are further amplified on the map and in the geologic description of the Trinity division.

The western or interior border of the main belt of the Western Cross Timbers is not so regular or so distinct as is the eastern. Sometimes it is very sharp and definite, while again it merges into local forest areas occupying other arenaceous formations than those of the Cretaceous. Besides, there are many outliers of the cross timbers within the Central Province, a fact which will be better appreciated after reading the discussion of the general geology.

Paluxy Cross Timbers.—The eastern belt of the Western Cross Timbers may for convenience be called the Paluxy Cross Timbers. (See Pl. LXXI.) This belt south of Wise County is separated from the main belt of the Western Cross Timbers by the Glen Rose Prairie (next to be described), and follows the outcrop of a higher and later geologic formation than that occupied by the main belt. Like the latter, this belt is characterized by deep, sandy soils accompanied by red clays, thin limestone flags, fossil wood, and a stunted forest of post-oak and black-jack timber. It begins in southern Wise County as a narrow belt of post-oak timber, following the complicated contours of the upper slopes of the western escarpment of the Grand Prairie just below the summit. Along the eastern margin of the Brazos Valley, Parker County, it follows a contour of from 250 to 300 feet above the main belt of the Western Cross Timbers. Southward the Paluxy timbers are a feature of the incised topography of the Lampasas Plain. In Hood, Erath, Comanche, and Bosque counties, where the stratum benches have been partially denuded, these forests occupy platforms just below the belts of Walnut Prairie, or in cases where the summit plain has been entirely denuded they occur as extensive patches of upland forest country. These belts of timber usually follow the direction of the stream divides, or sometimes appear in the valleys of the streams themselves, according to the depth of erosion of the latter.

North of Parker County, owing to the dying out of the Glen Rose Prairie in that direction, the Paluxy Cross Timbers merge into the main cross timbers, so that from there northward they form a continuous belt. The Paluxy Cross Timbers cease to be a conspicuous feature south of Leon River, coincident with the cessation (as a stratigraphic feature) in that direction of the sand bed in which they grow.

Glen Rose Prairie.—We have mentioned the appearance south of Wise County of an intermediate belt of prairie between the two belts of forest which form the Western Cross Timbers. This prairie assumes increasing areal importance south, and forms an important accompaniment of the general region of the Lampasas Plain. Like the Walnut Prairie and the Western Cross Timbers, it is developed on the slopes of the western escarpment and in the streamway indentations of the Lampasas Plain, occupying large areas in Parker, Hood, Somervell, Erath, Comanche, Mills, Lampasas, Burnet, and Travis counties, and is seen typically around the towns of Granbury, Glen Rose, Stephenville, Comanche, and Lampasas.

The regolith is usually thin and shallow and the general tone of the landscape of a brownish-yellow color. The surfaces are usually stony, owing to the breaking down of the many thin ledges of limestone, which, in alternation with marly clays, compose their substructure. The Glen Rose Prairie is covered with a thin growth of short grasses. Thickets of sumac and occasional mottes of live oaks grow along the rocky ledges, and mesquite trees in the flattened areas. In places, for example the breaks of the Colorado, dense forests of juniper, locally called cedar, inhabit the rocky ledges. These vegetal features give to the country a diversified and picturesque aspect.

The minor configuration of the Glen Rose Prairie is broken by low relief features, consisting of low terraces and stratified benches resulting from the persistence of certain harder strata in alternation with beds of softer material. Low, circular buttes, seldom over 50 feet in height, consisting of alternations of thin beds of indurated arenaceous limestone and clay, are also frequent. These are seen near Lambeth and Stringtown, Parker County, and thence southward at many points on the eastern border of the Western Cross Timbers. They are especially well developed west of Lampasas and on the margins of the Colorado near the corners of Burnet, Blanco, and Travis counties.

RÉSUMÉ.

From the foregoing brief description of the Black and Grand prairie regions of Texas north of the Colorado, it must be apparent that all the diverse features thereof result from the composition, degree of induration, and arrangement of the underlying rocks. A stratum of unindurated marl, clay, or sand yields more readily to the attacks of erosion than the beds of harder material. Thus the outcrop of the Austin chalk produces the only sharply defined scarp or line of prominent hills in the Black Prairie region, while the Edwards limestone makes the most conspicuous and rugged topography of the Grand Prairie. Compact and excessively calcareous marls and clays seem unpropitious for forest growth, and hence wherever these form the surface there is an absence of forest, except in some cases where the mesquite grows. On the other hand, porous, unconsolidated sands, such as make the cross-timber regions, present ideal conditions for forest growth and are covered with trees. The outcrops of harder limestone, such as are found in the escarpments, are often fissured, shattered, and broken, and hence offer a propitious environment for the growth of hardy live oaks and other trees.

PART III.

GEOLOGY OF THE BLACK AND GRAND PRAIRIES.[1]

The formations which relate to the Black Prairie and Grand Prairie subprovinces belong to three categories, as follows: (1) The Azoic and Paleozoic rocks, making the basement or foundation; (2) the Cretaceous rocks, which are the chief formations of the Black and Grand prairies proper; (3) the surficial post-Cretaceous formations which in places veneer the surface.

BASEMENT ROCKS OF THE BLACK AND GRAND PRAIRIES.

The subhorizontal Cretaceous rocks which make the chief formations of the Black Prairie and Grand Prairie regions overlie an older floor or substructure of Azoic and Paleozoic rocks. The composition and structure of the latter rocks have an important bearing upon the conditions of underground water, for they are frequently penetrated by the artesian drills.

The interior edges of the subhorizontal sheets of Cretaceous rocks of the prairies under discussion everywhere rest unconformably upon and against the Paleozoic rocks. (See Pl. XIV.) These older rocks of the Paleozoic floor constitute a plexus of formations ranging in age from Algonkian to Permian, inclusive; they are entirely different in stratigraphic arrangement from the overlying Cretaceous and dip at different angles and in different directions.

From Arkansas west to the Missouri, Kansas and Texas Railway near Boggy Depot, a distance of 200 miles, the rocks are Carboniferous, or older Paleozoic. From Atoka westward toward Duncan, in the Chickasaw Nation, they are granites, Silurian limestones, and Carboniferous strata. From Duncan, following the western border southward, the Cretaceous rocks overlie the Permian Red Beds as far south as Chico, Wise County, Texas. From the latter point they overlie Carboniferous rocks to Burnet County, where Cambrian and Silurian rocks again form the floor for a short distance. Near the Colorado they rest upon the Carboniferous, while west of that stream they overlap Cambrian formations and granite. The northern border region, in Indian Territory, composed of the Ouachita Mountains, has been a land area since early Mesozoic time, and probably was never completely overlapped by the Cretaceous rocks.

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[1] See pocket maps, Pls. LXIII, LXIV.

The western border region, in Texas, on the other hand, was completely submerged by the Cretaceous seas and is now reexposed by the denudation of the Cretaceous rocks which once overlay it.

Azoic Rocks.[1]

The oldest known rocks of the plexus are schists, granites, and crystalline limestones. Some of these may be Archean; others are Algonkian. They are certainly pre-Cambrian. Studies so far made have not been sufficient to differentiate the rocks or to determine finally their exact age and origin. They are now exposed in comparatively limited areas at a few widely separated intervals in Texas and Indian Territory, between which no relation has been established.

The old granitic outcrops adjacent to the borders of the Black and Grand prairies are seen in limited localities in Burnet County, Texas, the Wichita Mountains of Oklahoma, the Chickasaw Nation of Indian Territory, and the Ozark Country of Missouri.

In the drainage valleys of the Llano and Colorado,[1] in Llano, Mason, Gillespie, and Burnet counties (the Burnet Country of the Central Province), erosion has stripped away layer after layer of the once overlying sediments and exposed older granitic rocks.[2] These consist of protrusions into a series of pre-Cambrian metamorphic strata to which Walcott, who first pointed out their relations, gave the name of the Llano group, which is unconformably overlain by the Cambrian.[3] The Llano group is composed of layers of schists, quartzite, and other rocks tilted almost vertically and overlain by subhorizontal strata of Cambrian sedimentary rocks. The Llano group is of Algonkian age and probably includes the oldest sedimentary rocks of the Texas region, which have been so altered and metamorphosed that remains of life have not as yet been found in them. The Burnet granites are clearly intruded into the Llano group and hence are of later age. They are also overlain by the Cambrian strata, and therefore are pre-Cambrian. There may be other granites of post-Cambrian age in the Burnet region, as has been asserted by Comstock, but their existence has not been demonstrated. The Llano schists and the Burnet granites are so intimately associated that for present purposes they will be considered collectively.

Southward, in Gillespie County, the granites are overlain by the Cretaceous rocks of the Edwards Plateau and are reexposed in small areas by the incisions of the Pedernales drainage. They are also penetrated by well drills beneath the surface of the Cretaceous lime-

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[1] See Pl. LXVI.

[2] Some have treated this Burnet granite outcrop—the survival of an ancient configuration—as the remnant of primeval mountains which have stood since the earliest days of geologic time, above the seas which subsequently surrrounded them. This is a mistaken hypothesis, however, for these rocks were completely buried beneath the sediments of the Cretaceous ocean which covered them, and are now exposed only where drainage has cut down to them through the overlying layers of later rocks.

[3] Am. Jour. Sci., 3d series, Vol. XXVIII, 1884, p. 431.

stones at Kerrville and 12 miles northward, showing that the granites are buried for a considerable distance to the south of their present outcrop. No hypothesis can be formed concerning their extent to the north, west, and east.

The next outcrops of supposedly fundamental granite are in Indian Territory and Oklahoma, some 250 miles north of the Burnet locality. These occur in two general localities within the Ouachita uplift, one of which is in the Chickasaw Nation of Indian Territory around Tishomingo, and the other in the Wichita Mountains on the Comanche Reservation of Oklahoma.

The Tishomingo locality is composed of old granites, exposed in a low, flat, or gently arched area by the stripping away of the Silurian and Carboniferous strata of the Ouachita plexus which once covered it. They are muscovite-biotite granites, overlapped on the north and west by Lower Silurian (Ordovician) rocks. Further study is needed before any final conclusions as to age can be reached.[1] The Cretaceous rocks of the northern edge of the Grand Prairie rest upon these granites between Boggy depot and Tishomingo.

The granites of the Wichita Mountains, which begin 75 miles westward, are quite different in occurrence and composition. They are the sharp central cores of an east-west range, flanked on either side by Ordovician and Permian rocks, the latter made up of granitic débris. Whether the Wichita granites are pre- or post-Ordovician is unsettled, but there is a modicum of evidence in favor of the latter supposition.[2]

The strike of the Wichita outcrop is east and west—a little north of west, or directly at right angles to the north-south trend of the supposed fundamental northeast-southwest axial trend, as generally believed. There is also a solitary granitic dike in the Cherokee Nation to the north of the Ouachita uplift, near Spavinaw Creek, recently reported by Drake.[3] This is a small dike cutting the Silurian strata.

Still to the northeast granites occur at the base of the Ozark plexus in Missouri. The Ozark granites of the Ozark uplift, which occupy nearly all of southern Missouri and northwestern Arkansas, occur as an island in a vast area of Paleozoic rocks. These granites, which have

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[1] Mr. J. A. Taff, of the United States Geological Survey, is now making detailed studies of southern Indian Territory, and his results will probably add much to our present incomplete knowledge of the region.

[2] Since this was written a valuable paper entitled Geology of the Wichita Mountains, by H. Foster Bain, has appeared. (See Bull. Geol. Soc. America, Vol. II, pp. 127–144, Rochester, March, 1900.) Mr. Bain's conclusions concerning the age of these mountains are as follows:

"It is evident that there was a pre-Cambrian land mass of igneous rocks, and that over this was laid down an undisturbed sequence stretching from the Cambrian up to and including the Trenton. Then came the main upheaval and the intrusion of the granite. Around the edge of the new mountains the Geronimo series was laid down. The shearing and faulting of the granite and the presence of greenstone dikes cutting it, with the true though slight dip of the Geronimo beds, indicate later disturbances of lesser degree. Since the intrusion of the granite, however, the main history of the region has been one of vigorous and long-continued erosion, through which the mechanical sediments of the Red Beds and later deposits were prepared and distributed."

[3] Proc. Am. Philos. Soc., Vol. XXXVI, 1898, p. 338.

VIEW OF THE BURNET DISTRICT, SHOWING THE MARGIN OF THE EDWARDS PLATEAU IN THE DISTANCE.

been frequently considered an Archean nucleus, have been shown to be of Algonkian age. It has been generally thought that the Ozark uplift represented the survival of an ancient upland, but Marbut, Davis, Griswold, Keyes, and others who have recently given the region special study from both the geographic and the geologic standpoint, agree in regarding the uplift as it now stands as a very modern feature of relief, not earlier than middle or late Tertiary.[1]

Paleozoic Sedimentary Rocks.

The sedimentary Paleozoic rocks of the Texas region, constituting the floor of the Cretaceous formations, belong to five great systems, the Cambrian, Ordovician or Lower Silurian, Upper or true Silurian, Carboniferous, and Permo-Triassic. The Devonian may also have inconspicuous representation in the complex of the Ouachita Mountains of Indian Territory, but need not be considered at present.

CAMBRIAN ROCKS.

The oldest of these systems of formations, the Cambrian, and the overlying Ordovician, which, so far as known, succeed each other

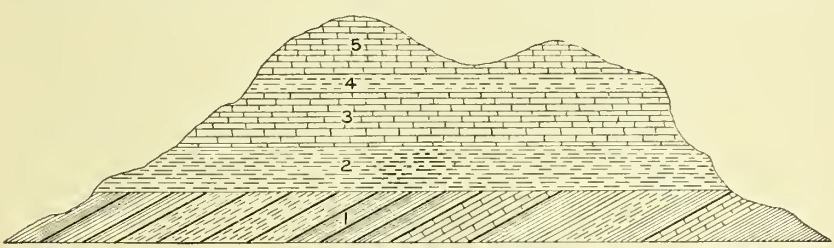

FIG. 6.—Walcott's figure of Packsaddle Mountain.

	Feet.
1. Llano group.	
2. Massive Potsdam sandstone	205
3. Potsdam limestone	310
4. Potsdam sandstone	30
5. Potsdam sandstone	60
	605

without break, may, for the purposes of this paper, be considered as a unit. These accompany and overlap the borders of the fundamental granite outcrops of the limited Burnet locality. The lowest and oldest of these is chiefly a sandstone of Middle Cambrian age with alternations of limestones. The second and overlying member, the Ordovician, is composed of firm limestone of close texture and great hardness.

The Cambrian formations, which are the oldest known fossiliferous sedimentary rocks, occur as the summits of buttes within the general area of the Azoic rocks of the Burnet basin and as a rim of outcrops

[1] Charles R. Keyes, in Science, April 29, 1898, pp. 588–589.

surrounding it. (See Pls. XIV and LXVI.) They consist of ferruginous brown sandstones alternating with limestone, as shown in the following section, made in Llano County by Walcott.[1]

These rocks were originally reconnoitered by Roemer,[2] and were further studied by Shumard,[3] but Walcott[4] presented the first classification, showing their unconformity upon the underlying Algonkian, giving measurements of their thickness, and demonstrating that they represent only the Middle and Upper Cambrian stages. Comstock[5] has later given much detail of the distribution of these rocks, but has erroneously assigned their basal portion to the Lower Cambrian.

Rocks of Cambrian age may also occur in the Wichita Mountains (Bain) and in the Arbuckle Hills of the Ouachita system, as exposed in Washita Canyon between Dougherty and Berwin, Indian Territory. The details of this latter section have not been minutely studied,[6] but from fossils collected by the writer, Prof. H. S. Williams determined some of probable Trenton age.

SILURIAN ROCKS.

ORDOVICIAN OR LOWER SILURIAN ROCKS.

Ordovician or Lower Silurian rocks, composed of massive limestones and dolomite accompanied by cherts, occur in the Burnet, Wichita, Tishomingo, and Ozark regions. These have been studied in the Burnet district by Roemer, Shumard, Walcott, Comstock, and the writer. These limestones occur principally around the peripheral portion of the Burnet basin, in Burnet, Blanco, Gillespie, Mason, Kimball, McCulloch, and San Saba counties. Their contacts with the overlying Carboniferous and underlying Cambrian are well shown. The only estimate of thickness is the section measured by Walcott,[7] who gives 1,145 feet.

Ordovician rocks also occur, as has been shown by the writer[8] and by Vaughan,[9] in the east-west folds in the Arbuckle and Wichita ranges of the Ouachita system, situated west of the Missouri, Kansas and Texas Railway, where they supplant as the chief mountain-making material the Carboniferous, which predominates to the eastward.

UPPER SILURIAN ROCKS.

True Silurian (Upper Silurian) rocks have not been recognized in the substructure of the region south of the Ouachita Mountains, although

[1] Am. Jour. Sci., 3d ser., Vol. XXVIII, December, 1884, p. 432.

[2] Texas, etc., Bonn, 1849; Die Kreidebildungen von Texas, etc., Bonn, 1852.

[3] Trans. Acad. Sci., St. Louis, Vol. I, 1860, pp. 672, 673; Am. Jour. Sci., 3d ser., Vol. XXXII, 1861, p. 213.

[4] Am. Jour. Sci., 2d ser., Vol. XXVIII, December, 1884, pp. 432–433.

[5] First and Second Reports of the Texas Geological Survey, Austin, Texas, 1890 and 1891.

[6] Am. Jour. Sci., 3d series, Vol. XLII, August, 1891, p. 121.

[7] Id., Vol. XXVIII, December, 1884, p. 433.

[8] Id., Vol. XLII, August, 1891, p. 121.

[9] MSS.

they may appear. They occur in the latter, however, in the Chickasaw Nation, as has been shown by the writer,[1] where they consist of limestones. Certain limestones in the Burnet plexus, called Burnet marble by the writer,[2] may ultimately prove to be of this age.

CARBONIFEROUS AND PERMO-TRIASSIC ROCKS.

EXTENT, SUBDIVISIONS, AND GENERAL RELATIONS.

The Carboniferous and Permo-Triassic rocks of the Central Province of Texas and Indian Territory are of great areal extent and importance.[3] They are the principal strata adjacent to the interior borders of the Grand Prairie and are the buried floor upon which the Cretaceous rocks of the latter are laid down, as shown in many of the geologic sections in this paper.

The maximum thickness of the Carboniferous and Permo-Triassic rocks aggregates nearly 30,000 feet, and for convenience of discussion they may be for the present divided into three great provincial groups, as follows:

3. Permo-Triassic	Red Beds of southern Kansas, Oklahoma, and Texas.
2. Permo-Carboniferous	Neosho-Chase formation of Kansas and Oklahoma and Coleman beds of Texas.
1. Carboniferous	5. Wabaunsee and Cottonwood formations (Kansas), Poteau (Arkansas, Indian Territory), Cisco, and Waldrip (Texas). 4. Cavanal (Indian Territory, Missouri, Kansas). 3. McAlester (Indian Territory), Richland and Strawn (Texas). 2. Marble Falls formation (Texas). 1. Wapanucka limestone (Indian Territory).

The uppermost of these grand divisions, the Permo-Triassic, which is more fully discussed on a later page, consists of beds of red clays, sands, and impure limestone. The Permo-Carboniferous is largely made up of alternations of evenly bedded yellowish limestone, shales, sandstones, and conglomerates, and, as indicated by its name, is a transitional formation connecting the Carboniferous and the Permian. The Carboniferous proper is composed almost entirely of impure shales and sandstones with coal beds, with a thick bed of limestone near its base in the Indian Territory and Texas. These beds will not be discussed in detail, but some generalizations concerning their occurrence as a whole will be presented.

These formations are sediments wholly or in part derived from an old pre-Carboniferous Appalachian land, situated eastward of

[1] Am. Jour. Sci., 3d series, Vol. XLII, August, 1891, p. 121.

[2] Am. Geologist, May, 1889, p. 3.

[3] Since this chapter was written Mr. J. A. Taff, of the United States Geological Survey, has begun a thorough survey of the Indian Territory field, and his results will materially refine and complete the fragmentary knowledge we now possess of that interesting region.

their present outcrop,[1] which occupied the present site of the East-Central and Eastern provinces, as is more fully set forth in the section on the geologic structure.

The Carboniferous portion of these rocks at least has been considered to represent the southwestern continuation of the Missouri and Arkansas strata of the Mississippian field, for the rocks disappear westward beneath later formations of the Central and Plateau provinces. Their buried westward continuation supposedly occupies a great synclinal trough beneath the provinces last mentioned, the western limb of which reappears in the upturned flanks of the Cordilleras.[2]

OCCURRENCE IN PARALLEL BELTS.

The Carboniferous and Permian formations occur in a series of parallel belts of outcrop one succeeding another to the northwest in ascending series. The belts extend from southern Kansas and eastern Indian Territory toward south-central Texas, occupying the Central Province of the Greater Plains region. The plications of the eastern or Massern Ranges of the Ouachita system are the most eastern belt, while the Arbuckle and Wichita ranges are plications directly across the strike of the more westerly belts, which are separated by them into northern and southern areas.

Although the general features of some of these belts of outcrop may be traced from Kansas River in Kansas to the Colorado in Texas, a distance of over 500 miles, except where they cross the Ouachita trends, no attempt has been made to outline them as a whole, and the classification herein used must be considered temporary and provisional. In general, their occurrence by districts may be stated as follows:

Ouachita belt.—The most eastern belt may be termed the Ouachita. This comprises the outcrop of the lower rocks of the Carboniferous, principally sandstones and shales, which compose the Massern Ranges of Arkansas and Indian Territory. Similar rocks outcrop at intervals in the Palo Pinto, Brownwood, and Smithwick districts of Texas, along the interior margin of the Grand Prairie.

Muscogee belt.—Succeeding the Ouachita belt to the northwest there is usually a region of prairie underlain largely by arenaceous shales of the Coal Measures. This constitutes the prairies of eastern Kansas and north-central Indian Territory. In Texas the rocks of this district are represented along a belt through Cisco and west of Brownwood.

Neosho belt.—This is a narrow strip of prairie country, underlain by yellowish limestones and shales of the Permo-Carboniferous, which extends from Kansas River at Fort Riley southward via Arkansas City

[1] This fact is developed by J. C. Branner in Am. Jour. Sci., 4th series, Vol. IV, 1897, pp. 357-371.

[2] Carboniferous rocks also occur in the Guadalupe and other ranges of the Trans-Pecos Mountains. These belong to a distinct province from that of the phenomena discussed in the present paper, being separated from the latter by the Great Plains and the Central Province.

nearly to the Ouachita Mountains, by which it is interrupted. It reappears in Texas, near Albany, and extends southward via Putnam and Coleman to the Colorado.

Arapaho belt.—This succeeds the Neosho belt to the westward and is characterized by its vermilion-red soils and substructure of red sandstones and clays. It extends from southern Kansas near Medicine Lodge (on its western edge) through Oklahoma, via Kingfisher (at its eastern border) and El Reno, and through a gap between the Wichita and Arbuckle ranges, into Texas, where it is known in its different parts as the Wichita, the Abilene, and the Tom Green countries.

Canadian belt.—This succeeds the Arapaho belt to the westward, and is also composed of red soils, but is marked by the occurrence of thick beds of massive white gypsum. It extends west of Medicine Lodge, Kansas, southward through western Oklahoma, around the western edge of the Wichita Mountains, into Texas via Vernon, Haskell, and Sweetwater.

These belts and districts, established upon certain geologic formations for which the foregoing generic names are suggested, are largely known by different names in their different parts, as has already been indicated.

The rock sheets of the Ouachita district are intensely folded and plicated into the east-west ranges of the Ouachita system, extending from Arkansas into Indian Territory. The southward continuation of these folds toward Red River was planed away by the erosion preceding the Cretaceous period and buried by the Cretaceous formations in a manner which separates the outcrops of the Carboniferous areas of Texas from those of Indian Territory.

The rock sheets of the other belts have a general inclination westward and regularly succeed one another in that direction.

The outcrops of the Red Beds proper, which are of undoubted Permian age in Texas, and the Permo-Carboniferous groups do not touch the Grand Prairie and Black Prairie regions except in the area immediately adjacent to the valley of Red River, being confined to the Arapaho, Haskell, and Abilene districts. Everywhere else the Carboniferous rocks are in close proximity to the interior borders of the Grand Prairie.

CARBONIFEROUS FORMATIONS.

In Texas the belts of Carboniferous rocks may be subdivided into three local districts along the eastern half of the Central Province, separated from one another by overlap of the Cretaceous formations. These are the Palo Pinto, Colorado, and Smithwick districts. The Palo Pinto and Colorado districts are stratigraphically the same, their geographic continuity being partially broken by the overlap of the narrow Callahan Divide. The small Smithwick district is in the Colorado River Valley, near the corner of Burnet, Travis, and Hays counties, and is cut off from the Colorado district by the intervention of eminences of the older Paleozoic rocks and the Cretaceous overlap in Burnet County. These districts are all southern analogues of the belts of Indian Territory.

SMITHWICK DISTRICT.

The southernmost area of the Carboniferous exposures in the Central Province is found in the southeastern part of the Burnet Country, southeastward of Burnet, along the Colorado, between Marble Falls and Travis Peak post-offices. This outcrop is separated from the Colorado district to the north by the Burnet granite and older Paleozoic rocks and overlap of the Cretaceous in northern Burnet County.

A good section of the typical locality of these rocks is exposed on a line along the Colorado River from Marble Falls east, the rocks dipping beneath the Cretaceous southeastward. The beds consist of about 300 feet of shaly fossiliferous limestone (the Marble Falls limestone of the writer).[1] This occupies the stratigraphic position of, and is probably the same as, the formation of the Colorado district to which the name "Bend division" was later given by Cummins.[2] The limestone passes upward into shales and sandstones equivalent to the basal portion of the Richmond beds of the Colorado section.

Marble Falls limestone.—The basement limestone over which the river falls at Marble Falls, a short distance down the stream, rests upon the Ordovician. Its upper contact with the basal shales of the Richland division is seen in the river banks at the falls and in the bluffs of Backbone Creek in the town of Marble Falls. The lake above the natural dam of the Colorado at Marble Falls is formed by the erosion of the shales down to a floor of the shaly limestones, which here dip up the stream. This limestone outcrops elsewhere on the southern and eastern sides of the Burnet Country at various places below the Cretaceous scarp, between Colorado River and the town of Burnet. It largely forms the topographic feature in the region known as the Shinbone Ridge, extending from Marble Falls on the Colorado northward toward Burnet. Patches are found at several places elsewhere in the general Burnet district, notably near Packsaddle Mountain.

At Marble Falls and at a point about 5 miles east of that town, the lower limestones are overlain by shales and sandstones equivalent to the Richland formation of the Colorado district. The upward continuation of the Richland formation, or that portion in which we should expect to find the coal beds, is concealed in the Smithwick district by the unconformable overlap of the Cretaceous. Borings, if made in the valley of the Colorado, in western Travis County, would probably strike the buried coal beds.

[1] Am. Geologist, May, 1889, p. 3.
[2] See First Ann. Rept. Geol. Survey of Texas, 1889, Pl. III.

The Marble Falls limestone of this district is of historic interest, inasmuch as it is the same that Dr. B. F. Shumard stated might prove upon further research to be Devonian,[1] thereby suggesting the possibility of the existence of Devonian formations in the Texas region.

In 1889 the writer visited this locality in order to ascertain the age of these beds. He found that the same limestone was again exposed 2 miles northward, in Shinbone Ridge, resting against the granite. Between the two localities was a synclinal depression covered with shales and river alluvium. Collections were made at both localities and the opinion was expressed that the rocks were of Carboniferous age.[2]

Later Dr. Comstock[3] disagreed with the writer, in respect both to age determination and to stratigraphy of the rocks, apparently treating the two outcrops of the limestone at Marble Falls and Shinbone as distinct formations, calling it Devonian at the former locality and Silurian at the latter. Subsequent studies and collections in 1895, 1897, and 1898 fully verified the conclusion that the rocks are of Carboniferous age. Fossils collected from these beds were determined by the best specialists to be of Carboniferous age. A report from the Assistant Secretary of the Smithsonian Institution in charge of the National Museum, made in 1891, reads as follows:

The fossils from Marble Falls represent the Lower Carboniferous fauna and include: *Productus semireticulatus*, *Productus*, sp.?, *Spirifera striata*, *Spirifera rockymontana*, *Terebratula*, *Aviculopecten* sp.?, *Bellerophon* sp.?. Those from Shinbone Ridge are very imperfect, but they indicate the presence of the Carboniferous fauna. The genera *Fenestella* and *Productus* are represented.

The following report by Dr. George H. Girty, dated November 24, 1896, is self-explanatory:

At the request of Mr. R. T. Hill, geologist, I have the honor of making the following report upon a collection of fossils from Marble Falls, Texas. The specimens in question were derived from a limestone at Marble Falls, and are of especial interest as bearing upon the question whether Devonian time is represented in the rocks of Texas.

The following species have been identified:

Campophyllum torquium.	Streblopteria herzeri?
Chætetes radians?	Aviculopecten cf. whitei.
Productus semireticulatus.	Aviculopecten sp.
Productus costatus?	Myalina perniformis.
Productus prattenianus.	Pleurophorus occidentalis.
Spirifer rockymontanus.	Conocardium sp.
Spirifer condor.	Euomphalus subrugosus.
Seminula sp.	Phanerotrema grayvillensis?
Dielasma? sp.	Phillipsia missouriensis?

[1] Trans. St. Louis Acad. Sci., Vol. I, 1860, p. 673.
[2] Quoted in First Ann. Rept. Geol. Survey of Texas, Austin, 1890, p. 250.
[3] First Ann. Rept. Geol. Survey of Texas, 1890, pp. 311-315.

Productus semireticulatus, *P. costatus?*, and *Campophyllum torquium* are by far the most abundant, while *P. prattenianus*, *Spirifer condor*, and *Conocardium* sp. are also represented by several individuals. The remaining forms, including nearly all the lamellibranchs, are, for the most part, single specimens, and have not been determined with certainty. Nevertheless, the fauna represented in the collection presents an assemblage of types scarcely to be mistaken. It is clearly a Carboniferous fauna.

The Smithwick district is also interesting from the fact that it is the only exposure in the whole general region in which the Carboniferous rocks dip seaward, and may represent the coastward slope of the old post-Carboniferous land areas.

COLORADO DISTRICT.

The Colorado district of the Central Province as exposed in sections adjacent to the Colorado River in Brown, Lampasas, and San Saba counties, south of the Callahan Divide, is the typical district of Carboniferous rocks of the Central Province in Texas, to which those of

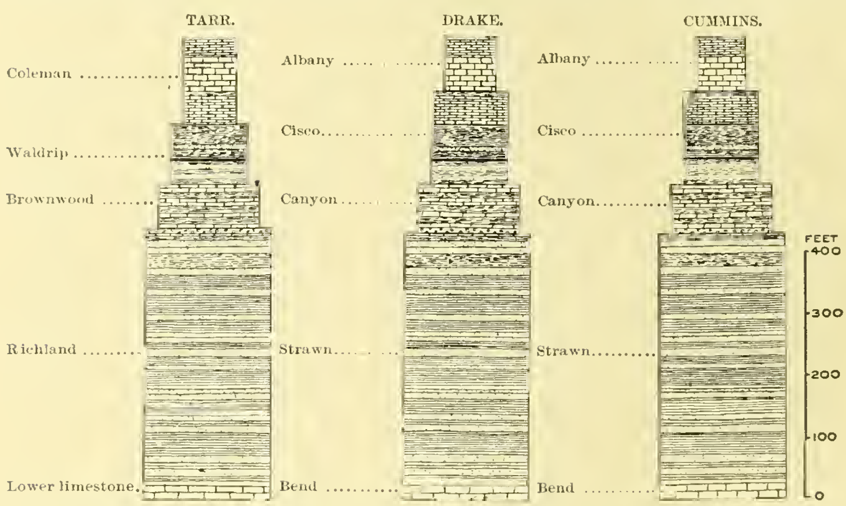

FIG. 7.—Comparison of the Colorado River sections of the Carboniferous as determined by Tarr, Drake, and Cummins.

the other districts may be compared. In this region there is exposed a continuous section from the Silurian rocks below, on the east, to the Permian above, on the west. The Carboniferous portion of this section has been described in its entirety by three authors—Tarr,[1] Cummins,[2] and Drake[3]—successively. (See fig. 7.)

The Carboniferous rocks of Texas were first reconnoitered by Roemer and subsequently in part by Shumard, Ashburner, and others, but their details and classification as a whole have been brought out more fully by the publications of Tarr, Cummins, and Drake.

[1] First Ann. Rept. Geol. Survey of Texas, Austin, 1890, pp. 201–203.

[2] Loc. cit.; also Second Ann. Rept. Geol. Survey of Texas, 1891.

[3] Fourth Ann. Rept. Geol. Survey of Texas.

The entire series of the Carboniferous and Permo-Carboniferous beds of this section, from the underlying Silurian to the overlying Permian, was divided by Tarr into six formations, called "divisions," based upon lithologic and stratigraphic characters,[1] as follows:

	Thickness in feet.
Coleman	1,200
Waldrip	800
Brownwood	800
Milburn	125
Richland	4,000
Basal limestone.	

Tarr[2] first observed the broad fact that the rocks comprising these divisions were groupable into three great lithologic categories, a lower group of more massive limestones, a middle group of sand and shale, sandstones, conglomerates, etc., and an upper group of limestones.

Basal limestone.—This division, which Tarr recognized but did not name, consists for the most part of massive, hard limestone, but at the top there is usually a bed of black clay shale. This rests upon the Ordovician rocks, forming a narrow belt on the north and northeast of the Burnet area.

Tarr gave no name to this lower formation, but it may probably be the same as that of the Smithwick Country which had been previously called the Marble Falls limestone[3] and which was later called by Cummins[4] the "Bend division." Tarr referred this lower limestone group to the "sub-Carboniferous" period upon the evidence of a fossil goniatite determined by Prof. Alpheus Hyatt. He stated that it consisted almost entirely of crystalline limestone with beds of calcareous shales occurring beneath the Upper Carboniferous beds and resting uncomformably upon the older Silurian rocks. In the later Texas reports[5] the thickness of this limestone is placed at 360 feet.

The strata of the overlying divisions are said to be unconformable with this, but conformable to one another, which conditions are shown in the map and sections accompanying Drake's report. According to the last-mentioned authority, the strike of the basal limestone is nearly at right angles to that of the overlying beds. More field work is necessary, however, to fully establish this conclusion.

The Richland, Milburn, Brownwood, Waldrip, and Coleman divisions of Tarr[6] (later called the Strawn, Canyon, Cisco, and Albany divisions by Cummins) constitute the plexus overlying the Marble Falls lime-

[1] The thicknesses cited are those given by Drake: Report on the Colorado coal field of Texas, by N. F. Drake and R. A. Thompson, Austin, Texas, September, 1893.

[2] A preliminary report on the coal fields of the Colorado River, by Ralph S. Tarr: First Ann. Rept. Geol. Survey of Texas, 1889, Austin, 1890, pp. 201–233.

[3] See Geological story of the Colorado River: Am. Geologist, May, 1889.

[4] First Ann. Rept. Geol. Survey of Texas, 1890.

[5] Second Ann. Rept. Geol. Survey of Texas, Austin, 1891, table on page 361.

[6] Second and Third Ann. Repts. Geol. Survey of Texas, 1891.

stones, and are distinguishable from one another by lithologic and faunal characteristics, as follows:

Richland division.—Beds of sharp-grained, moderately hard, even-textured sandstone, alternating with beds of blue clay. Conglomerates and shales are not abundant, and limestones are of rare occurrence. Thickness, 4,000 feet.

Milburn beds.—The Milburn division, as originally defined by Tarr, consisted of local impure deposits which are now included with the Brownwood division. At the close of the Richland subepoch, as shown by the clays of the Milburn beds, there was a slight subsidence of the sea floor, so that deeper sea deposits were laid down.

Brownwood division (Canyon division of Cummins).—Alternating beds of rather rough, even-textured, bluish limestone, blue clay, some sandstone and conglomerate. Thickness, 800 feet.

Waldrip division.—Beds of blue clay which are shaly at some localities, and of sandstone, usually conglomeratic and often a pure conglomerate. In the Waldrip division there is a commingling of material, indicating varying conditions of deposition. Accumulated vegetation, clay, sandstone, and conglomerate of coast deposits in quiet and turbulent waters, grading upward into deeper deposits of limestones, all enter into the general make-up of this division, and record it as a time of many changes. The irregular eroding and overlapping of some of the included beds also mark sudden and irregular changes. Thin-bedded limestone and some coal. Thickness, 800 feet.

Coleman division.—Massive beds of blue, gray, and yellowish colored limestone, alternating with beds of blue clay and black or gray shale. Sandstones and conglomerates are almost entirely lacking. The beds of the Coleman division are more regular and persistent than those of the preceding divisions. The limestones are thicker and the marine fauna is more abundant, indicating a deeper sea and more regular conditions of deposition. In this part of the field the limestone beds regularly thin to the north and seemingly to the south from the Colorado River, clay or marls sometimes replacing them. Thickness, 1,200 feet.

PALO PINTO DISTRICT.

The Carboniferous rocks of Texas lying north of the Callahan Divide, as previously stated, are a continuation of strata of the Colorado section, differing from them chiefly in variations in thickness of the strata and by the fact that the basal portion of the section is concealed by a greater overlap of the Cretaceous formations to the eastward. The rocks of this district were described, defined, and classified into divisions synonymous with those of the Central Province by Cummins. According to him[1] the thickness of the beds in this province is "three thousand seven hundred and forty feet, by actual

[1] Second Ann. Rept. Geol. Survey of Texas, Austin, 1890, p. 369.

measurement on a line run from the upper part of the measures at the northeast corner of Throckmorton County to the west line of Hood County." The section as thus stated is given from above downward and against the dip, which is to the west. The lower beds of the section are at the west line of Hood County and the upper beds at the northeast corner of Throckmorton County.

This section by Cummins does not represent the entire thickness of the Carboniferous series, for these continue downward from 1,500 to 3,000 feet lower than the base of Cummins's section, beneath the overlap of the Cretaceous formation of the Grand Prairie region to the eastward. The deep artesian well at Fort Worth, 40 miles from the nearest Carboniferous outcrop, after passing through 1,200 to 1,400 feet of Cretaceous, penetrated nearly 1,500 feet of Carboniferous strata.

CARBONIFEROUS ROCKS OF THE NORTHERN BORDER REGION.

In the Ouachita and Muscogee districts the relations of the beds which initiate the Carboniferous proper to the Marble Falls and Bend limestones of the base of the Texas sections can not be stated at present. The basal Carboniferous of the Ouachita and Muscogee districts is succeeded by shales and sandstones, which in a general way are the equivalent of the Richland formation of Texas. In the Ouachita district the beds are intensely folded. The chief characteristic of the Indian Territory section of the districts mentioned is its tremendous thickness in comparison with that of Texas, which leads to the belief that a previous and at present inexplicable pre-Carboniferous topographic barrier in some manner separated or partially separated the deposition areas of Texas from those of northern Indian Territory in Carboniferous time.

The Eocarboniferous, which may be absent in Texas, is well represented at the base of the series in Indian Territory, although, so far as the writer is aware, it has not been detected in the Ouachita district. No strong line of demarcation is found between the Eocarboniferous and the Carboniferous. According to Drake the latter in its entirety consists of shales, grits, and sandstones, attaining the enormous thickness of 24,500 feet.

The Muskogee section is divided by Drake[1] into the Lower and Upper Coal Measures, but to all intents and purposes it is practically a continuous formation. These beds homotaxially are equivalent to the Richland, Brownwood, and Waldrip divisions of the Texas section.

PERMO-CARBONIFEROUS STRATA.

Throughout their extent in Kansas, Indian Territory, and Texas the western outcrops of the Coal Measures proper grade up without

[1] Proc. Am. Philos. Soc., Vol. XXXVI, 1898, p. 361.

break, so far as is known, into beds marked by the appearance of considerable thicknesses of limestone and of certain species associated with the Carboniferous fauna which have been referred to the Permian. These beds are shales, massive sandstones, conglomerates, and limestones, aggregating 1,500 feet (more or less) in thickness, of the type of those of the Neosho-Chase section of Kansas. These beds have been well studied in Kansas by Prosser, but little investigation has been made of their continuation south into Indian Territory. They are homotaxially the equivalent of the Coleman formation of Texas. In Texas the sedimental change indicating this formation is noted in the beds at the base of Tarr's Coleman division, which are included in the top of the Cisco division of Cummins and Drake. These transitional beds, for which, in the absence of a more satisfactory classification, the name Permo-Carboniferous may be provisionally retained, have a thickness of 1,500 feet in Kansas at the northern end of their strike, and 1,200 feet along the Colorado River of Texas. Their relation to the Ouachita uplift has not been studied or made out.

They uniformly occur in a belt along the western margin of the main bodies of the Carboniferous formation of the Muscogee, Palo Pinto, and Colorado districts, but do not occur in the Smithwick and Ouachita districts. They grade, so far as known without break, into the true Red Beds.

No Upper Carboniferous or later Paleozoic rocks have yet been discovered on the coastward (eastern and southern) side of the general Carboniferous area.

PERMO-TRIASSIC RED BEDS

EXTENT AND SUBDIVISIONS.

So far as known, the Permo-Carboniferous formations of the Central region, in southern Kansas, Indian Territory, and Texas grade upward without break into a series of sediments which have been spoken of throughout this report as the Red Beds, but which, in order that they may have a definite geographic name, might be defined as the Brazos series.[1] This embraces all those rocks of Texas, Oklahoma, Kansas, and eastern New Mexico between the top of the conformable Coleman division of the Carboniferous beds below to the base of the unconformable Cretaceous above. The beds of this series have been called by various names in literature, such as Jura-Trias,[2] Permian, etc.

These rocks underlie all the western half of the Central Province

[1] This name is selected on account of the development of these beds along the course of the Brazos River.

[2] Inasmuch as in the whole of the Texas-New Mexican region east of the Rocky Mountains no evidence has been found that any of these beds are of Jurassic age the term Juratrias is not only inappropriate but misleading. It has been shown that by far the greater part of these beds is of undoubted Permian age, possibly succeeded by a thin Triassic formation. The term Permo-Trias is far more appropriate therefor if a compound name in necessary.

west of the Neosho belt, approximately the ninety-ninth meridian, from its northern boundary in southern Kansas to its southern border near the thirty-first parallel in southern Texas, where it is overlapped by the southern scarp of Edwards Plateau. They also underlie the Plateau of the Plains, forming beneath its cap a foundation of older rocks, and are reexposed in the valleys of the Canadian and Pecos of New Mexico. They likewise occur in the perimeters of the bolsons of Trans-Pecos Texas and New Mexico.

In general, the Red Beds consist of red clays, sandstones, occasional impure limestone, some conglomerate, and great beds of gypsum, occurring both in strata and as impregnations. Above all, they are distinguished by the flaring red tones which give to the rocks, soil, and topography of the region in which they occur a peculiar vermilion color.

The Red Beds of the Central Province have been noted and commented upon since the earliest days of exploration, and many descriptions of them are found in literature. The writer has passed over them many times and has always insisted that their ultimate classification would depend upon a special series of studies accompanied by detailed stratigraphic work. He has not time in the preparation of this volume to go into extensive historic researches concerning the evolution of knowledge on this subject. It can be stated in a general way that the Red Beds of Texas were, so far as the writer is informed, first mentioned by Falconer,[1] and that their Triassic age, based upon the former's observations, was first suggested by Roemer;[2] that details of the stratigraphy and subdivisions were first given by Stolley,[3] and that their undoubted Permian age was proved by Boll,[4] Cope,[5] and White.[6] Prof. Jules Marcou[7] described these formations in Indian Territory (Oklahoma) and the Canadian Valley of the Pan Handle of Texas, but his observations never extended south of the Canadian Valley.

The work of the late Texas Geological Survey, especially the carefully detailed sections by Cummins and Drake,[8] is the final step by which we are permitted to form an idea of the stratigraphy of the beds as a whole. The previous condition of knowledge concerning them, with the exception of the observations of Falconer and Stolley, are set forth in Bulletin No. 45 of this Survey.

The Red Beds as a whole are divided by the Texas survey[9] into two age groups alleged to be separated by an unconformity, the lower of

[1] Jour. Royal Geog. Soc. of London, Vol. XIII, 1843, pp. 199-226. [2] Texas, etc., Bonn.

[3] The Texas Immigrant and Travelers' Guide Book, by J. de Cordova, Austin, 1856, pp. 49-58.

[4] Am. Naturalist, Vol. XIV, 1880, p. 684.

[5] Prof. E. D. Cope published many papers on the vertebrate fossils of the Permian beds of Texas, and sent out the early expeditions of Boll and Cummins.

[6] The Texas Permian and its Mesozoic type of fossils: Bull. U. S. Geol. Survey No. 77, 1891.

[7] Geology of North America, Zurich, 1858.

[8] Second Ann. Rept. Geol. Survey of Texas, 1890, pp. 350-436. [9] Loc. cit., pp. 350-436.

which is called the Permian and the upper the Triassic. The former (which constitute an overwhelming proportion of the whole) is subdivided by Cummins into three divisions—Wichita, Clear Fork, and Double Mountain, in ascending series—while the few feet of strata of the alleged Triassic are called the Dockum formation.

THE PERMIAN.

Wichita formation.—This is described as being composed of sandstones, clays, and a peculiar conglomerate. There are no limestones in it from bottom to top. The sandstones are of various colors. The clays are red and bluish. Red clays or iron concretions exist in great abundance. The peculiar conglomerate is composed of clay or clay ironstone in a ferruginous matrix. The Wichita formation does not extend south of the Brazos, and its thickness is placed at 2,000 feet.

Clear Fork formation.—This is the name given to the middle division of the Permian strata. It is composed of limestones, clays, shale beds, and sandstones. The limestones are mostly magnesian and carbonaceous. The sandstones are not so abundant as in the Wichita beds and are not so massive, but are generally thin bedded. The clays are blue or red, the red occurring in thick, heavy beds. The conglomerate is similar to that found in the Wichita formation, but not so abundant. Toward the top the sandstones become more shaly and the clays more sandy. There are also some beds of gypsum, but not in so great abundance as found in the Double Mountain formation. The formation occurs immediately west of the Wichita formation as far south as the Brazos, and is then found resting upon the Coleman or Permo-Carboniferous throughout its continuation to the south of the latter stream.

Double Mountain formation.—The Double Mountain formation is composed of sandstones, limestones, sandy shales, red and bluish clays, and thick beds of gypsum. The limestones are generally of an earthy variety, containing casts of fossils. The gypsum beds are numerous, and many of them are very thick. All the clays and shales are impregnated with gypsum, and many of them carry a large percentage of the sandstones, and are generally very friable and of various colors—red, white, and spotted. These beds have a thickness of about 1,900 feet.

These divisions do not appear to be clearly marked stratigraphically, and probably represent continuous sedimentation. The Double Mountain beds are preeminently the great gypsum formation, although this mineral appears in the underlying divisions.

These beds cross Red River into southern Indian Territory, where they surround the Wichita Range. In this vicinity they are composed of the débris of the rocks of the Wichita Mountains, as shown by Mr. Vaughan. They pass north around the western and eastern termini of these mountains into the Oklahoma and southern Kansas districts, being well exposed in the Medicine Lodge region of Kansas. In this region the Red Beds conform lithologically with the Double Mountain divisions of Texas, and considerable doubt has been expressed as to their age, many authorities considering them Triassic.[1]

It is not within the writer's province to harmonize the diverse opinions whereby these beds are considered Triassic in Kansas and Permian in Texas. It is sufficient to say that the formations are identical and continuous between the two localities, and that they are Permian in Texas.

THE ALLEGED TRIASSIC.

The overlying Dockum beds,[2] occurring as thin, fragmentary remnants of a formation between the Permian and Cretaceous and the Permian and Plains Tertiaries, along the eastern breaks of the Llano Estacado, have been described in detail by N. F. Drake[3] as consisting of sandstones, conglomerate, and clays. This material varies in lithologic characters at different localities, and is so different from the underlying Permian and overlying Cretaceous or Tertiary that it is usually easily recognized.

The writer must confess, after much observation and careful perusal of the descriptions of others, that the Red Beds of the Texas region still require extensive study before they can be fully interpreted.

SUMMARY OF THE HISTORY OF THE PALEOZOIC ERA.

From the foregoing data it is evident that the underlying floor of the Cretaceous formations is a vast group of strata which record an interesting geologic history involving long periods of sedimentation and many changes in the configuration of the land.

Concerning the earlier Archean, Algonkian, and Cambrian history but little is known. The Cambrian sandstones of the Burnet region were derived from an old Algonkian near-by land. Its extent, however, is completely veiled by the overlying formations. The history of the Cambrian and Ordovician sea areas is likewise obscured, although we know that this sea did exist in central Texas and Oklahoma and Missouri, to the east and south. The probable absence of the uppermost Silurian, Devonian, and Eocarboniferous in the Texas districts, especially the Burnet district, strongly suggests that after Ordovician time there was a continued and increased land area in that region.

The Carboniferous formations, composed of land-derived sediments, attest the existence of great land areas in their proximity, from which

[1] These opinions are summarized by Prosser in the Kansas University Quarterly, Vol. VI, No. 4, October, 1897, p. 150.

[2] Named in the First Ann. Rept. Geol. Survey of Texas, Austin, 1890, pp. 189, 190.

[3] Third Ann. Rept. Geol. Survey of Texas, Austin, 1891.

these sediments came, and it is evident that this land lay largely to the south of the Ouachita Mountains, toward the Gulf of Mexico, in the direction of the present Coastal Plain. There are certain peculiarities in the thickness and attitude of these rocks which are difficult to interpret with our present knowledge, especially the great variations of thickness and composition of the formations in the Indian Territory and Texas provinces. The thickness decreases from 24,500 feet in the former to 5,411 feet in the latter. Furthermore, limestones, which are relatively few in the Indian Territory section, become abundant and conspicuous in Texas. These facts attest differences in the contemporaneous geography concerning which we have not as yet sufficient knowledge to make an intelligent interpretation. The belts of Permo-Carboniferous and Permian strata west of the main Carboniferous area and their lay relative to the latter suggest that geographic changes were going on even during the Carboniferous period, after the close of which the later uplifts of the Ouachita system of mountains were developed.

From known facts it is presumable that these mountains are but the later cumulative effects of certain orogenic action, which had previously given rise to similar mountain systems in approximately the same positions. There is some reason for suspecting that the western groups of the Ouachita system, the Wichita and Arbuckle ranges, existed as mountain systems previous to the Carboniferous epoch, and that during the Carboniferous epoch these were degraded, for the Permian sediments at least are composed of their débris.

The Massern or eastern division of the Ouachita system, including the ranges east of the Tishomingo granitic area, are apparently the most northern marginal folds of what was once a more extensive mountainous complex southward, the former extent of which in the latter direction had been planed away by marine base-leveling during Triassic and Jurassic time preparatory to the invasion of the Cretaceous seas which covered their former extent with oceanic sediments. The trend of the western end of the Massern Ranges is not east and west, conformable to the direction of the Ouachita system as a whole and to the western or Wichita division, but at the ninety-sixth meridian is deflected southwestward, in a direction which would carry its Texas extension beneath the Grand and Black prairies, and it may be possible that certain slight deformations in the surface of the latter, as explained on a later page, are due to the presence of this old orographic basement. The occurrence in the Smithwick district of the Carboniferous rocks, on the coastward side of the Burnet area, may or may not indicate a southward reexposure of this buried line of post-Carboniferous folding.

It is also probable that the Burnet district of Algonkian, granitic, Cambrian, and Ordovician rocks represents a buried pre-Cretaceous orogenic area or elongated dome which extends south and has an east-west trend toward the Balcones scarp line and west to the Pecos. The displacement along the Balcones fault may be due to the adjustment of the coastward load of sediments to this ancient fundamental feature.

A volume of unwritten and uninterrupted history presents itself when we consider the Permo-Carboniferous and Permian beds of the great Central Province. Their strike in a more uniformly north-south direction than the Carboniferous rocks which they border, their composition and occurrence in a great central basin entirely west of the main areas of the Coal Measures, and the absence of the Permian strata within the Carboniferous area indicate that the configuration to the east was changing by degradation during their deposition.

Paleozoic formations adjacent to the Black and Grand prairies region.

[Nmnbers indicate thickness of beds, in feet.]

Period.	Epoch.	Texas. Burnet area.	Texas. Colorado area.	Texas. Northern area.	Ouachita area.	Missouri. Kansan, Cherokeean. Massern areas.	Missouri. Ozark area.
Carboniferous.	Permian.	Buried by overlap of the Cretaceous.	Double Mountain. Clear Fork, 1,975. Wichita, 1,800.	Double Mountain. Clear Fork, 1,975. Wichita, 6.	Red Beds.	Medicine Lodge.	
	Permo-Carboniferous.		Coleman, 1,200.	Albany, 1,180.		Neosho-Chase.	
	Coal Measures.	Richland. Marble Falls.	Waldrip, 800. Brownwood, 800. Richland, 4,000. Marble Falls, 300.	Cisco, 670. Strawn, 3,740.	Poteau, 2,000. Cavanal, 5,500. Atoka (*a*). Wapanucka (*a*).	Wabaunsee Cottonwood. Missouri.	Coal Measures.
	Eocarboniferous.	Wanting?	Buried by overlap of the Cretaceous.		Caney (*a*).	Downward continuation to southward buried by overlap of the Cretaceous.	Boston, 200. Osage, 625.
Devonian.		Wanting?			(?)		Devonian.
Silurian.		Wanting?			Lower Helderberg.		Niagara, St.Clair, 75.
	Ordovician.	Ordovician, 1,145.			Trenton.		Ordovician.
Cambrian.		Upper, 605.					Cambrian.
Algonkian?		Llano.			Tishomingo.		Algonkian?

a Surveys in Indian Territory by Mr. J. A. Taff show the Atoka and Wapanucka formations to be lower Coal Measures, with a maximum thickness of about 6,000 feet. The lower part of the Caney formation is Mississippian.

CRETACEOUS ROCKS.

Introductory Statement.

The Cretaceous formations are by far the most important in Texas, both in area and in economic value. Their composition produces certain features of value to man. Their texture and stratigraphic arrangement in the Black and Grand prairies is conducive to transmission or retention of underground waters and results in most extensive and prolific artesian-well systems. They supply the most valuable soil, building material, stone, lime, and cement of all the formations, and in one instance are the source of valuable oil fields. It is therefore necessary to give a thorough description of these rocks, including their composition, texture, thickness, arrangement, distribution, and classification. They have been briefly and technically described in previous writings of the author[1] and others, but will now be treated in greater detail, in order that they may be more readily recognized and that a knowledge of them may be of service to the public.

The facts concerning the structure have an important economic application, for they enable one to predict to a degree of certainty within a few feet the depth of any water-bearing stratum. This knowledge is of incalculable financial value to all communities within the vast region under discussion. To make plain these facts certain illustrations are presented, which include a geologic map, vertical sections, cross sections, photographic reproductions of the rocks, and illustrations of fossils characteristic of certain beds.

The geologic map (Pl. LXVI), which is on a scale of 10 miles to the inch, shows the area of the outcrop of each formation, so far as known to the writer. The underground continuation, or embed, of the more important rock sheets, as made known by the records of the artesian wells, is indicated on the artesian-well maps (Pls. LXVII, LXVIII, LXIX). The records of the wells have proved invaluable as aids in the analysis of the general structure and sequence of the rock sheets in regions where they are not exposed at the surface.

Numerous local vertical sections convey exact information concerning the detailed character of the formations in particular localities. The cross sections (see Pl. LXIX) extend across the Black and Grand prairies from their interior Paleozoic border to the Eocene formations on the east. They reveal the entire sequence of the Cretaceous formations, their variations, and the outcrop or depth of embed of any particular formation at any point they touch. These sections are shown on Pl. LXVII.

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[1] See Am. Jour. Sci., April and October, 1887; Am. Geologist, January, February, 1890; Rept. Geol. Survey of Arkansas, Vol. II, 1888; Rept. Geologist of Texas, 1890; Bull. Geol. Soc. America, Vol. II, 1891; ibid., Vol. V, 1894; Report on the Artesian and Underground Waters of Texas, 1892; Geology of portions of the Edwards Plateau and Rio Grande Plain, etc.: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1898, pp. 193-322.

General Occurrence and Relations.

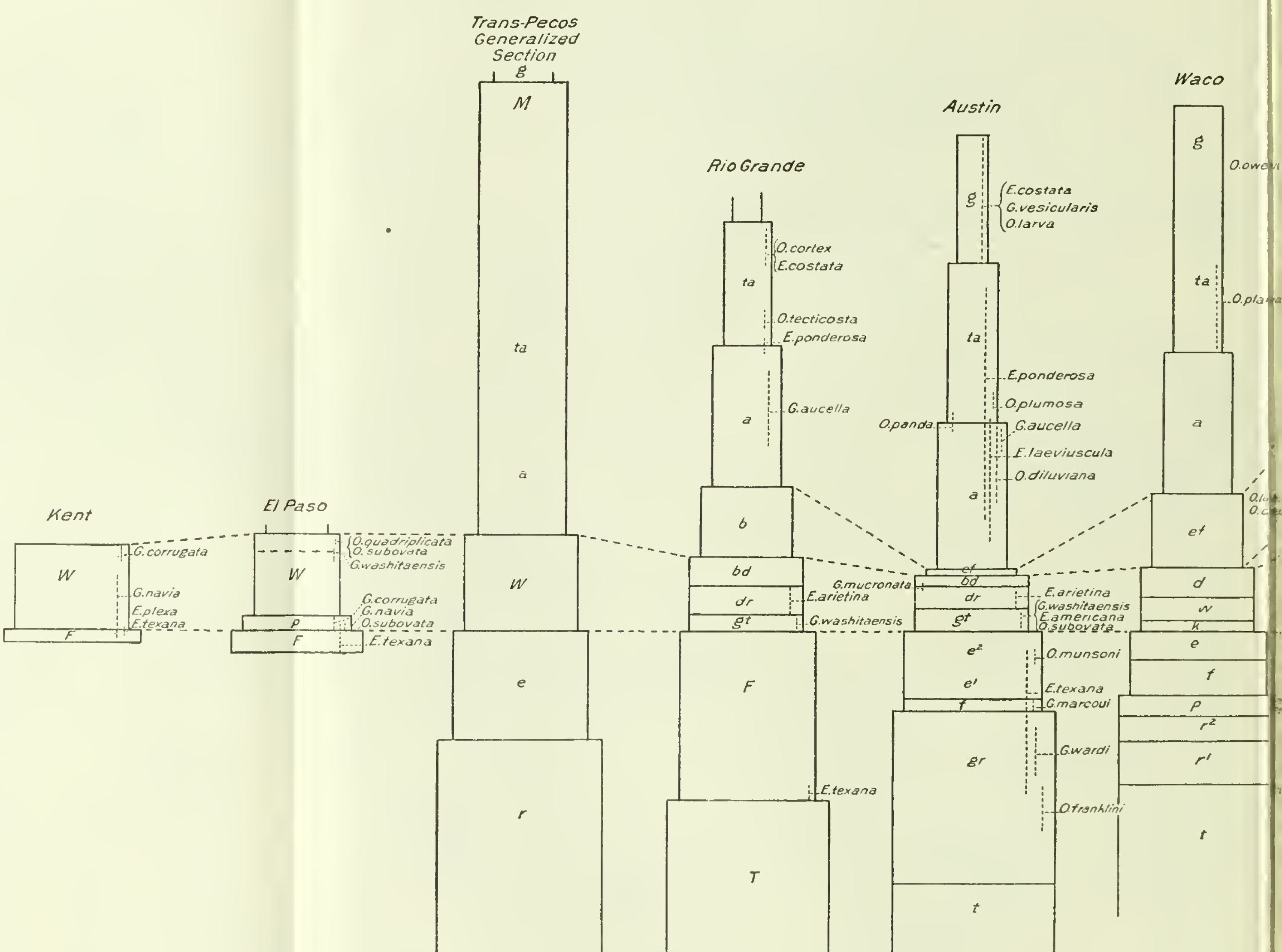
The Cretaceous rocks, except where locally veiled by alluvium, form the entire surface of the Black and Grand prairies, the Cross Timbers, Edwards Plateau, Stockton Plateau, and much of the interior portion of the Rio Grande Plain. (See Pl. II, *B*.) They also form a large part of the mountain masses of Trans-Pecos Texas. Remnants of these formations are scattered over the Central Province. The Tertiary formations of the plains and of the Fayette and Coast prairies are largely made up of their débris. The strata extend from Texas into Arkansas and continue east in the Atlantic Coastal Plain of the Eastern and Southern States and southward into Mexico. They formerly extended northwest and west into the Great Plains and Rocky Mountain regions.

The outcrops of the Cretaceous formations of the general Texas region, of which those of the Grand and Black prairie regions are a part, may be classified geographically into two general groups, viz: (1) Those of the main area, or central belt, which is a wide stretch across Texas from the Ouachita Mountains of southwestern Arkansas and Indian Territory south through central Texas to the Pecos and Rio Grande. This includes the Black and Grand prairies, the interior margin of the Rio Grande Plain, the Edwards and Stockton plateaus, the Callahan Divide, and the scarps of the plains northward to the head of Double Mountain Fork of Brazos River. (2) Those of the outlying areas[1] in the Great Plains and the Cordilleran Province. The present paper is concerned with only that portion of the main area which is north of the Colorado and within the Cross Timbers and the Grand and Black prairies of Texas and southern Indian Territory. In this Main Texas area a more complete sequence of the different beds of the Cretaceous section is exposed than elsewhere, and hence it may be regarded as a standard of comparison for the outlying provinces in New Mexico, Trans-Pecos Texas, Oklahoma, and Kansas, whose beds present variations therefrom.

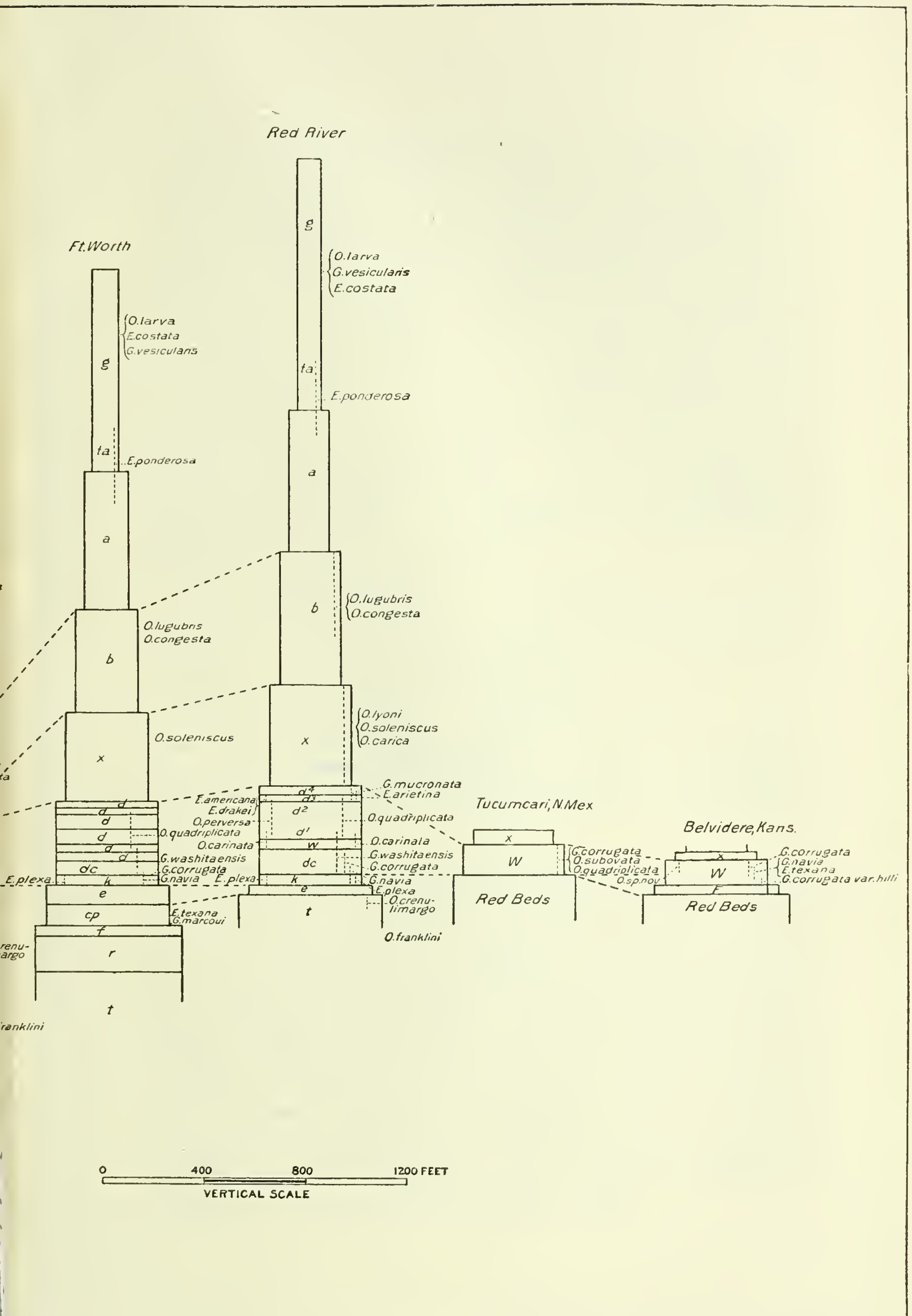
Character and Origin of the Rocks.

The Cretaceous rocks are of various kinds, but are chiefly limestones and marly clays. They include sands of all degrees of fineness, from small conglomerate to very fine particles; clays, which are sometimes arenaceous, and again calcareous; and limestones, which are either great agglomerates of shell or fine chalky material organically extracted from the sea water. The rocks are largely of whitish or chalky colors, although there are exceptional beds composed of ferruginous sands and bituminous clays.

[1] For a summary of the geology of these outlying areas, see Am. Jour. Sci., September, 1895, 3d series, Vol. L, pp. 205–234, and July, 1897, Vol. IV, pp. 43–50.



VARIATION IN THICKNESS OF THE CRETACEOUS FORMAT



IN THE TEXAS REGION.

All the Cretaceous rocks of the Texas region are old marginal sediments of the ocean deposited in the sea as it invaded a preexisting land from east to west across the entire Greater Texas region and extended from north and west over portions of the present Great Plains and Rocky Mountain region, from coastward of the present eastern border of the Black Prairie region north to the Ouachita Mountains in Indian Territory and around or through gaps in their western end as far north as southern Kansas and as far west as northeastern New Mexico, El Paso, and Sonora, in Mexico. Properly speaking, these rocks represent the sediments of two such invasions of the sea, the first in the Lower and the second in the Upper Cretaceous epoch. The rock sheets were thus spread over the entire region by the encroachment of the ocean upon the land, and some were once continuous from east of the present Black Prairie region northwest over the entire Central and Plains provinces. The present outcrops in the Grand and Black prairies represent remnants of rock sheets which once extended much farther west, where they have been largely eroded from the Central Province. Their eastward continuations are embedded by the successively later strata.

The different materials above mentioned composing the rocks do not succeed one another abruptly, but so grade into one another that the passage from a conglomerate to a sand, a sand to a silt, a silt to an arenaceous clay, an arenaceous clay to a calcareous clay, and a calcareous clay to a chalky limestone is gradual.

The material of these rocks is both land and sea derived. It represents ocean-deposited débris of lands which occupied the area during Jurassic time and were baseleveled by erosion and subsidence as the sea invaded them, and the débris of marine organisms, their skeletal parts, which were extracted by living animals from the sea water.

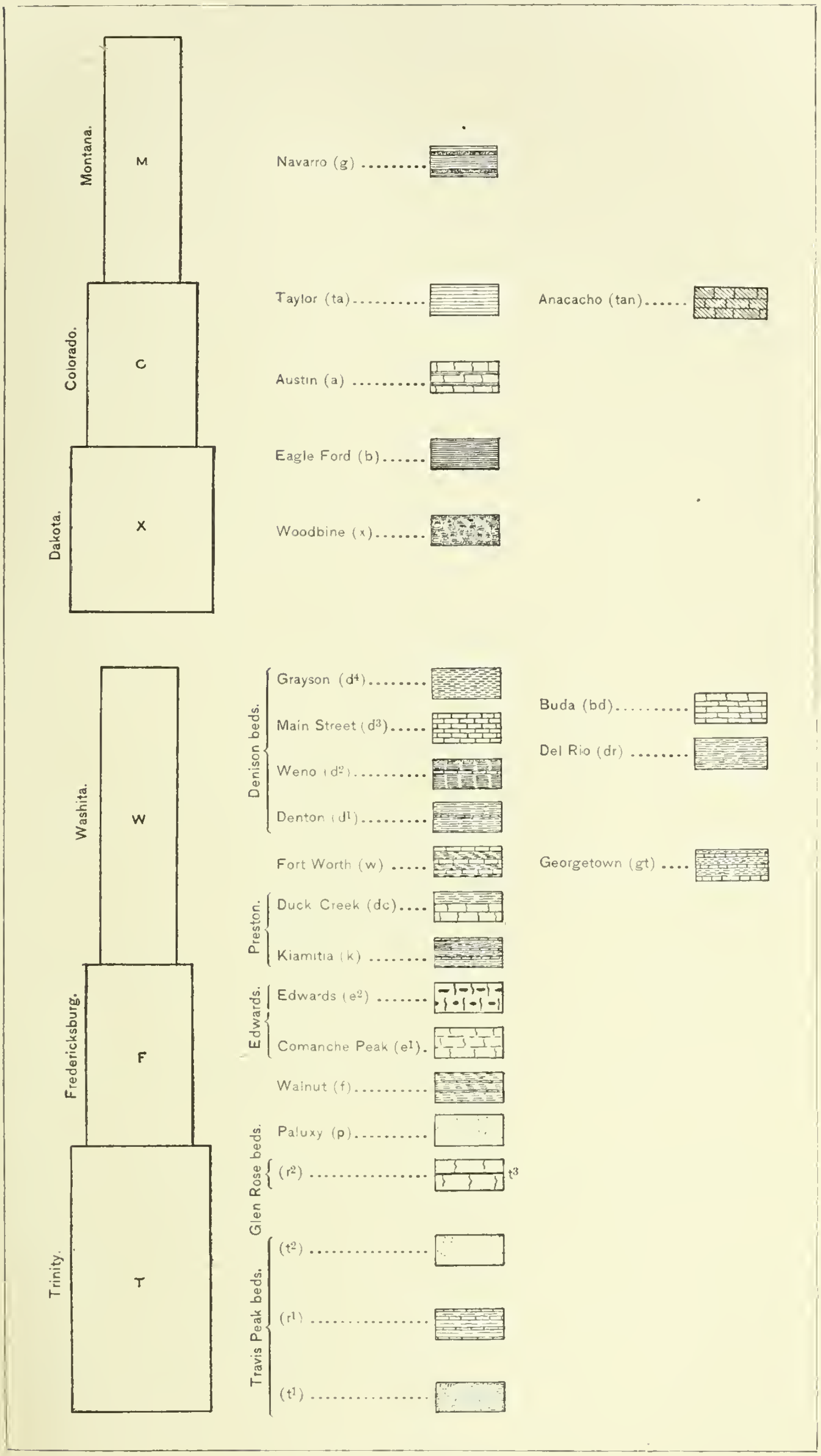
In general the sands are near-shore deposits, such as are seen to-day on most ocean beaches. The finer sands were carried a little farther seaward than the coarse material. The clays are the lighter débris of the land, which were laid down a little farther from the land border; and so on through the various gradations to the chalky limestones, which largely represent oceanic sediments deposited in relatively purer waters farthest away from the land. The limestones are not all chalky. Some are agglomerates of shells of animals which inhabited the sandy or muddy bottoms; others are old beach wash. The vast numbers of sea shells occurring upon the mountains and prairies of Texas have not been transported, as some people believe. Save that they have been subjected to general regional uplift whereby the sea bottom was converted into land, they are now in the exact locality where they lived and flourished, and the clays and limestones in which they are buried were once the muds of the old ocean bottom.

In the progress of the ocean's margin across the Texas region during the Cretaceous period the shore line moved in as the land subsided, and was not the same for any two subepochs of the Cretaceous period, as will be more fully set forth in the descriptions of the structure.

Succession of the Rocks.

The traveler across the Black and Grand prairies along the line of the cross sections (Pl. LXVII), starting at the interior or Paleozoic borders and passing eastward to the Tertiary border, encounters a definite sequence of strata in ascending series, which is more or less similar in all sections, although presenting minor variations, which will be further amplified in descriptions of the formations to be given later.

In general the following sequence occurs, as exemplified on Pl. XVI and in a section from western Parker County to east of Corsicana (see Pl. LXVII, section DD). The lowest Cretaceous formation (1) resting on the Paleozoic rocks and outcropping at the surface in the belt of Western Cross Timbers consists of loose beds of friable sand (locally called pack sand), with a few pebbles at its base (the Trinity sands). These sands pass upward into (2) light-colored arenaceous clays and marls in which alternating layers or beds of firm limestone of varying texture and thickness gradually appear. The marls and limestones are the Glen Rose beds. Another thick bed (3) of pack sand (the Paluxy sands) succeeds the Glen Rose beds. The outcrop of the Paluxy sands is covered with timber. Above the Paluxy sands are (4) clays alternating with thin limestones, usually accompanied by vast numbers of fossil oysters. These, the Walnut beds, pass upward into (5) white chalky limestones (the Comanche Peak beds), which are very fossiliferous and which usually constitute lower slopes of the escarpment of flat-topped mesas or plains. The Comanche Peak beds are distinguishable from the succeeding bed (6) of white chalky limestone (the Edwards limestone) only by the superior hardness of the latter, which is the rock of the numerous flat-topped buttes of the western border of the Grand Prairie and in which, at least south of the Brazos, are numerous beds of flint. The limestone, which is not very thick along the section under consideration, is succeeded to the east by another group of beds making the surface formations of the dip plains of the Grand Prairie between the western scarp rock and the Eastern Cross Timbers and consisting of alternations of marls and indurated layers of limestone. The lowest beds of this group consists of (7) darker-colored clays (the Kiamitia clays) containing great quantities of another fossil oyster. Above these appear more bands of limestone strata (8) of a chalky white color, alternating with clays (the Duck Creek formation) in which



FORMATION SYMBOLS.

huge ammonites a foot or more in diameter are found. Near the top of these alternations of marls is a group (9) of whitish limestone beds (the Fort Worth limestone) in which limestones and marls alternate with great regularity. Fort Worth is built on this formation. Above the Fort Worth limestone are beds (10) known as the Denison beds, which are mostly composed of clays, with frequent hard layers of impure limestone. These have ferruginous colors, such as chocolate, brown, and red, instead of the whitish lines which mark the preceding formations. The Denison beds pass into the western border of the Eastern Cross Timbers, where they are succeeded by another sandy timber-covered formation (11), the Woodbine, consisting of loose brown sand somewhat resembling the Trinity sands lying at the base of the whole section, but differing in particulars which are elsewhere described. In the upper part of these sands thin layers of blackish bituminous clay begin to alternate with the sand. Gradually the sand decreases and the clay increases until the latter makes the entire formation (12), the Eagle Ford. With the initiation of these black clays prairie lands again appear. The clays finally pass upward into a great formation of chalky limestone (13), the Austin chalk. This formation, upon which the city of Dallas is located, is some 500 feet thick. The chalk in turn passes upward into marly clays of great thickness, consisting in their lower part of unctuous, laminated, light-blue and yellow clays (14) which are known in Texas as "joint clays," and which we shall call the Taylor marl. These clays underlie the main Black Prairie for a distance east of the longitude of Dallas. The whole of the Black Prairie east of the Austin chalk is composed of soft, unconsolidated beds, but those above the Taylor marl are characterized by sandy layers, alternating with the clays, and especially by minute specks of glauconite. The sands and clays of this character, which constitute the final formations of the Cretaceous, are found along the eastern margin of the Black Prairie and may be called the Navarro beds (15). The Navarro beds are blacker and more arenaceous than the Taylor marl. The small laminæ of glauconitic sand in the Navarro beds give to them a greenish-yellow color in places. There are also some thin indurated bands of glauconitic sandstone and chalk marl in their upper portion.

The rock sheets along this section have an aggregate thickness of nearly 4,500 feet, but this thickness varies in different cross sections, owing to the thickening or thinning of the individual beds.

These rock sheets are apparently so flat and have such a superficial resemblance to one another that at first little difference is observed among them; all the clays may look alike, as well as the limestones and sands, but closer study shows that each particular stratum has many well-marked points of difference.

Fossiliferous zones.—The most conspicuously distinguishing features of the beds, especially of the limestones and clays, are the numerous fossil shells which weather out of them and lie strewn upon the surface. (See Pl. XVII.) Some of the shell beds are very conspicuous, making almost the entire material of the rock, such as those composing the oyster hill at Weatherford. Oysters of many species—coiled spirals of the ammonite family, many echinoids or fossil forms of the star-fish family, and numerous other forms—can nearly everywhere be found, except in the sandy beds, and in some places even in these. (See Pls. XXI, XXIV, XXV, XXVI, XXXIII, XXXIV, XXXV, XL, XLIV, XLVII, XLVIII.) The careful student, and especially the trained paleontologist, will find these fossils invaluable guides in determining the position of the formations in the general series, for they consist of many kinds or species, each of which is limited to some one particular formation or to a limited range in a series of strata.

Classification of the Rocks.

NOMENCLATURE.

Upon further consideration of these various beds or strata they are found to be divisible into two great groups or series (see Pl. XVI, p. 110), each of which in turn is composed of many beds of rock. The lower of these series begins with the Trinity sands and ends with the Denison beds, and has been named[1] the Comanche series, after the town of Comanche, where the writer, when a boy, first studied these formations. The upper series begins with the Woodbine formation and extends through the Navarro beds; this has been termed the Gulf series. Each of the series represents a complete cycle of sedimentation and is initiated by an arenaceous littoral terrane—the Comanche series by the Trinity sands, the Gulf series by the Woodbine sands. Each cycle of sediments is the result of continuous (unbroken) deposition during a time when the sea occupied the region.

Logically each series is one continuous formation in the broader sense of that word, which means the continuous product of one uninterrupted geologic event. The individual beds are the stratigraphic units which collectively compose these formations. Usage, however, has decreed that the term "formation" shall be employed otherwise than in its logical sense, and hence the term "formation" will be employed in this paper to designate a conspicuous subordinate stratum, or group of strata, of sufficient individuality to render it a mappable unit.

The beds and series are the only natural units and groups of strata. For convenience it is frequently necessary to discuss as a formation a

[1] See Am. Jour. Sci., 3d series, Vol. XXXI, April, 1886.

group of beds having allied relations, and sometimes to consider collectively a group of formations, in which case the term "division" will be employed. The sequence of the formations, their lithologic character, and the letter symbols used to designate the formations in all illustrations are shown on Pl. XVI.

In résumé, it may be said that each of the series is divided into three conspicuous divisions; each division is divisible into formations, and each formation into the individual beds which compose it. Again, finally, it may be said that, in continuous series of sediments like those under discussion, the individual strata or beds are the true units, and the grouping of these units into categories and the division of series into subdivisions is dependent solely upon the opinions of the individual.

The following table, and Pl. XVI, shows the sequence of the beds and their classification into formations, divisions, and series. The letter symbols on Pl. XVI are those used on the accompanying maps and illustrated sections throughout this report.

Nomenclature of the Texan Cretaceous area and its local sections from Arkansas to the Rio Grande.

Classification of formations.			Mappable lithologic formations in the local sections.						
Series.	Divisions.[a] (Groups.)	Major formations.	Arkansas-Choctaw section.	Denison section.	Fort Worth section.	Waco section.	Austin section.	Guadalupe section.	Uvalde section.
Gulf series.	Montana.	Navarro.	Arkadelphia. Washington. Anona (White Cliffs). Roxton.		Navarro.	Navarro.	Webberville.	Bexar.	Eagle Pass.
	Colorado.	Taylor.			Taylor.	Taylor.	Taylor.	Taylor.	Upson. Anacacho. Cline.
		Austin.	Austin.	Austin.	Austin.	Austin.	Austin.	Austin.	Austin.
		Eagle Ford.	Concealed.	Eagle Ford.	Eagle Ford.	Eagle Ford.	Eagle Ford.	Eagle Ford.	Eagle Ford.
	Dakota.	Woodbine.	Concealed. Morris Ferry.	Lewisville. Dexter.	Lewisville. Dexter.				

[a] Groups of formations. Divisions of series.

Nomenclature of the Texan Cretaceous area and its local sections from Arkansas to the Rio Grande—Continued.

Classification of formations.			Mappable lithologic formations in the local sections.						
Series.	Divisions. (Groups.)	Major formations.	Arkansas-Choctaw section.	Denison section.	Fort Worth section.	Waco section.	Austin section.	Guadalupe section.	Uvalde section.
Comanche series.	Washita.	Buda. *a*					Buda.	Buda.	Buda.
		Denison.		Grayson. Main Street. Paw Paw. Marietta. Denton.	Grayson. Main Street. Paw Paw. Marietta. Denton.	Del Rio.	Del Rio.	Del Rio.	Del Rio.
		Fort Worth.		Fort Worth.	Fort Worth.	Fort Worth.	Georgetown.	Georgetown.	Georgetown.
		Preston.		Duck Creek. Kiamitia.	Duck Creek. Kiamitia.				
	Fredericksburg.	Edwards.	Goodland.	Goodland.	Goodland.	Edwards.	Edwards.	Edwards.	Edwards.
		Comanche Peak.				Comanche Peak.	Comanche Peak.	Comanche Peak.	Comanche Peak.
		Walnut.		Walnut.	Walnut.	Walnut.	Walnut.		
	Trinity.	Paluxy.	Antlers.	Antlers.	Paluxy.	Paluxy.			
		Glen Rose.			Glen Rose.	Glen Rose.	Glen Rose.	Glen Rose.	Glen Rose.
		Travis Peak.			Basement sands, not named. *b*	Basement sands, not named. *b*	Travis Peak.		Concealed.

a The Buda formation of the southern section may be synchronous with the Grayson and Main Street of the northern section. *b* Not recognizable south of the Colorado Valley.

Inasmuch as the nomenclature in general use is largely of the writer's invention, he deems it proper to insert at this place a brief history of its origin and evolution, and to suggest certain necessary improvements.

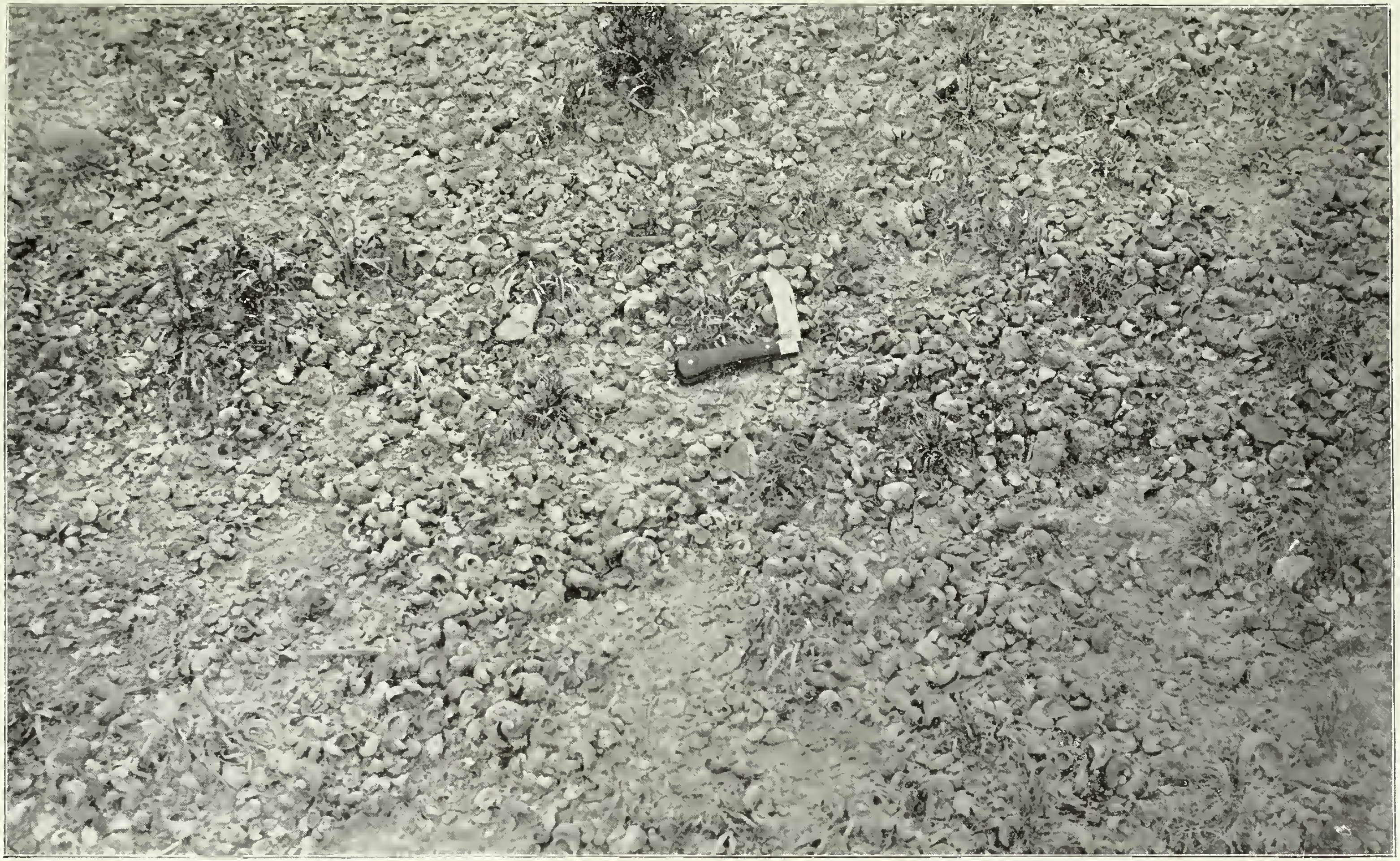
DEFECTS OF EARLY CLASSIFICATION.

Until the year 1886 little was known of the stratigraphy of the Cretaceous formations of Texas. Since 1819, beginning with the travels of Thomas Nuttall, fragmentary and disconnected observations had been made on the Cretaceous rocks and miscellaneous collections of fossils made, but no intelligible section of the rocks as a whole had been presented. The sequence of the formations was misunderstood and, in accordance with the classification of B. F. Shumard,[1] then accepted, the lower beds were erroneously considered to be the upper. It was generally believed that the whole group represented a synchronous and deeper-water facies of the Upper Cretaceous or Meek and Hayden section as developed in northwestern United States, the base of which was the Dakota (Woodbine) formation, and that the Lower Cretaceous was unrepresented.

In 1886 the writer presented[2] a section of the Cretaceous beds of Texas along the line of the Texas and Pacific Railway from Millsap to Terrell, through Weatherford, Fort Worth, and Dallas. This section brought out the fact that the Texas Cretaceous included not only the equivalents of the Meek and Hayden section but also another series of Cretaceous rocks of older age and equal import. At that time the writer commented upon the fact that the composition and arrangement of these beds presented peculiarly favorable conditions for furnishing artesian water to a large area of the Black and Grand prairies, and their adaptability to this end was constantly borne in mind and suggested as his studies progressed. It was then stated that it would be a labor of years to trace out the full extent and variation of the numerous Cretaceous strata of the section, in order that a final classification could be made. Since that time the writer has continued his investigations, studying the stratigraphic and paleontologic sequence along lines of typical cross sections from Arkansas to the Rio Grande and mapping the areal extent of the formations, but he has not been able to carry on the work continuously. Furthermore, large parts of the region are not yet topographically surveyed.

Thus it will be seen that the classification of the Cretaceous formations of Texas has been a subject of evolution. From time to time preliminary papers have been presented, but with no pretense to finality. The writer can not here detail the labors which he has devoted to the amplification of the early section and to tracing the variations of the Comanche series throughout the vast areas in which

[1] Trans. Acad. Sci., St. Louis, Vol. I, pp. 582–589, 1856–1860.
[2] Am. Jour. Sci., 3d series, Vol. XXXI, April, 1886.



AN OUTCROP OF THE DEL RIO CLAYS, SHOAL CREEK, AUSTIN, TEXAS, SHOWING EXOGYRA ARIETINA.

it is now known to occur. He may simply state that he has studied nearly every known locality where, from the early writings, he suspected that the Comanche series might occur: (1) The Plains of the Kiamitia of Morton; (2) the Preston, Fort Washita, and other Red River localities of G. G. Shumard, whose collections were described by Marcou; (3) the Fredericksburg locality of Roemer, and the Austin and Comanche Peak localities of B. F. Shumard; (4) the New Mexican (Tucumcari) region of Marcou, and, finally, (5) the outlying areas of Kansas which had been mentioned by Hay, Cragin, and others. He has reconnoitered and traced these formations through hundreds of miles of intermediate areas, from Arkansas on the northeast to El Paso and far into Mexico to the southwest, and has mapped and minutely studied many localities. He has also studied the collections of rocks and fossils preserved in the museums of Amherst, Philadelphia, Cambridge, New Haven, New York, and Washington, or in the possession of their original collectors, such as the collections of Prof. Jules Marcou in his residence at Cambridge, and the earlier collections of Professor Cragin at Washburn College. In addition, he has endeavored to encourage the investigations of others in this field, which still affords material for many workers for many years.

As the investigations progressed, in later years more minute data relating to the definition and development of the beds, their lithologic variation along long lines of outcrop, and the zones, hemeras, and faunal association of the fossil species, were secured, and opportunities to study the literature and nomenclature of the species were presented. These subsequent studies have not essentially changed the arrangement and sequence of the beds as defined in the original Fort Worth section, but they have resulted in a clearer definition of them. During these years the development of the details of the section was not only slow and progressive, but the investigator himself was constantly gaining knowledge.

The reader may well ask what are the logical criteria for the subdivision of the Cretaceous into the subordinate groups of divisions and formations. The paleontology would by some be considered sufficient, but, inasmuch as the paleontologic peculiarities themselves are the result of environment produced by physical conditions, there should be some accompanying correspondence in the physical character of the sediments. Unfortunately paleontologic research has not as yet progressed sufficiently far to give final conclusions, but there are some strong lithologic and paleontologic distinctions between the Trinity, Fredericksburg, and Washita divisions which can be presented. These paleontologic differences are not complete faunal breaks in the continuity of forms, but consist rather of the occurrence throughout the section of certain well-marked zones of particular species or groups of species.

Continued and minute research over the whole of the vast area shows that both the lithologic and the paleontologic criteria of the beds and divisions may change, so that the Red River section, for instance, may present rather strong variations in facies from the Colorado section, as will be shown; yet these changes are so gradual that they can not be noted in any small area, such as the ordinary quadrangle unit of the United States Geological Survey (one-quarter of a square degree of the earth's surface, about equal to the area of an average Texas county), but can be defined only by comparing sections hundreds of miles apart.

In the early classification the whole of the Texas Cretaceous was divided into two conspicuous categories, called "series," as previously set forth. The lower series was in turn subdivided into "divisions," having the equivalence of the term applied to the three groups of the Upper Cretaceous. This designation "division" was a comprehensive term of the writer, based upon the Fort Worth section, intended to include subgroups of paleontologically or lithologically allied beds of strata. The term is not quite satisfactory, but it has been impossible to devise a better one.

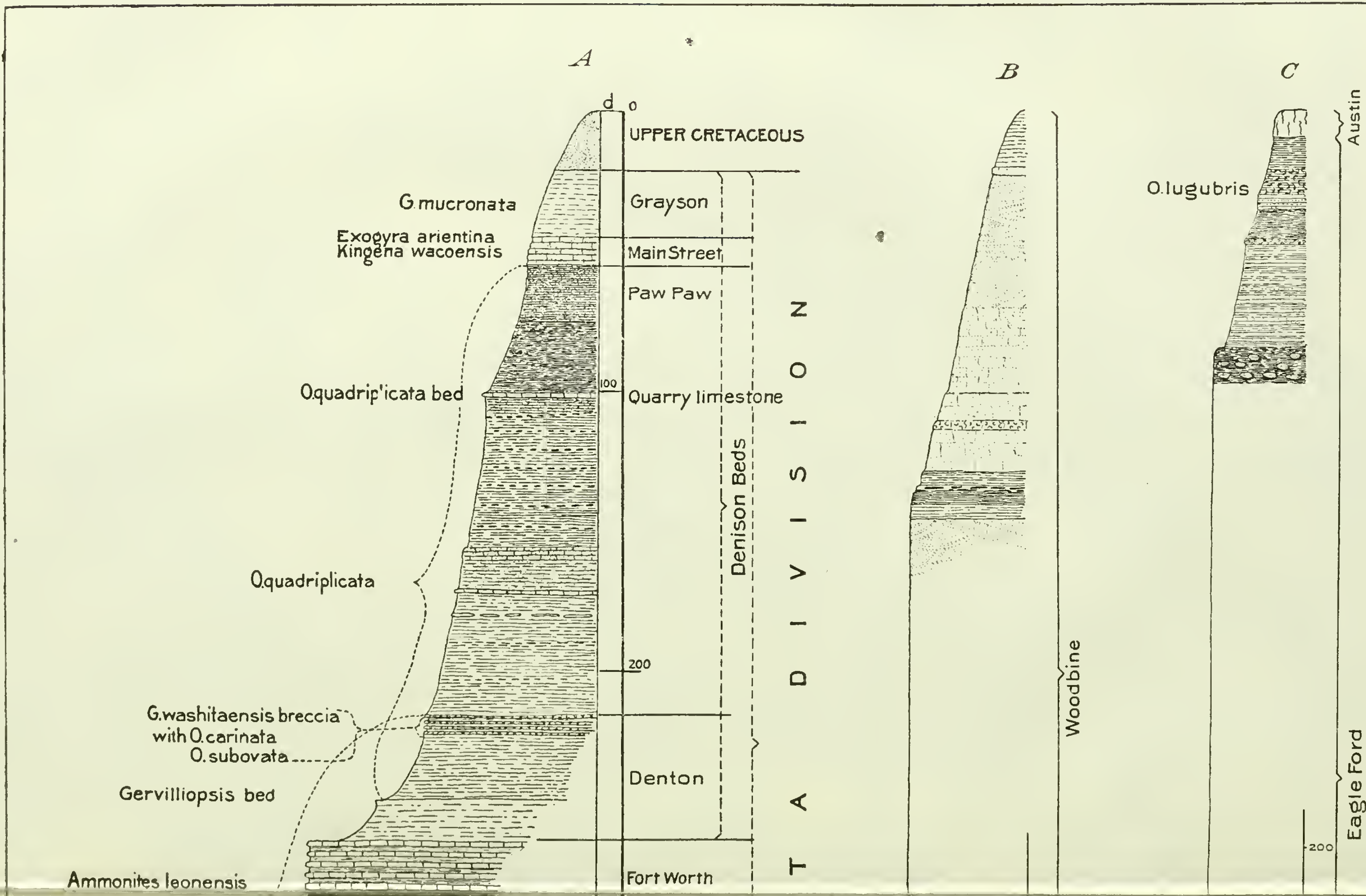
The lower Comanche series was at first made into two divisions, the lower of which was called the Fredericksburg division and the upper the Washita division.

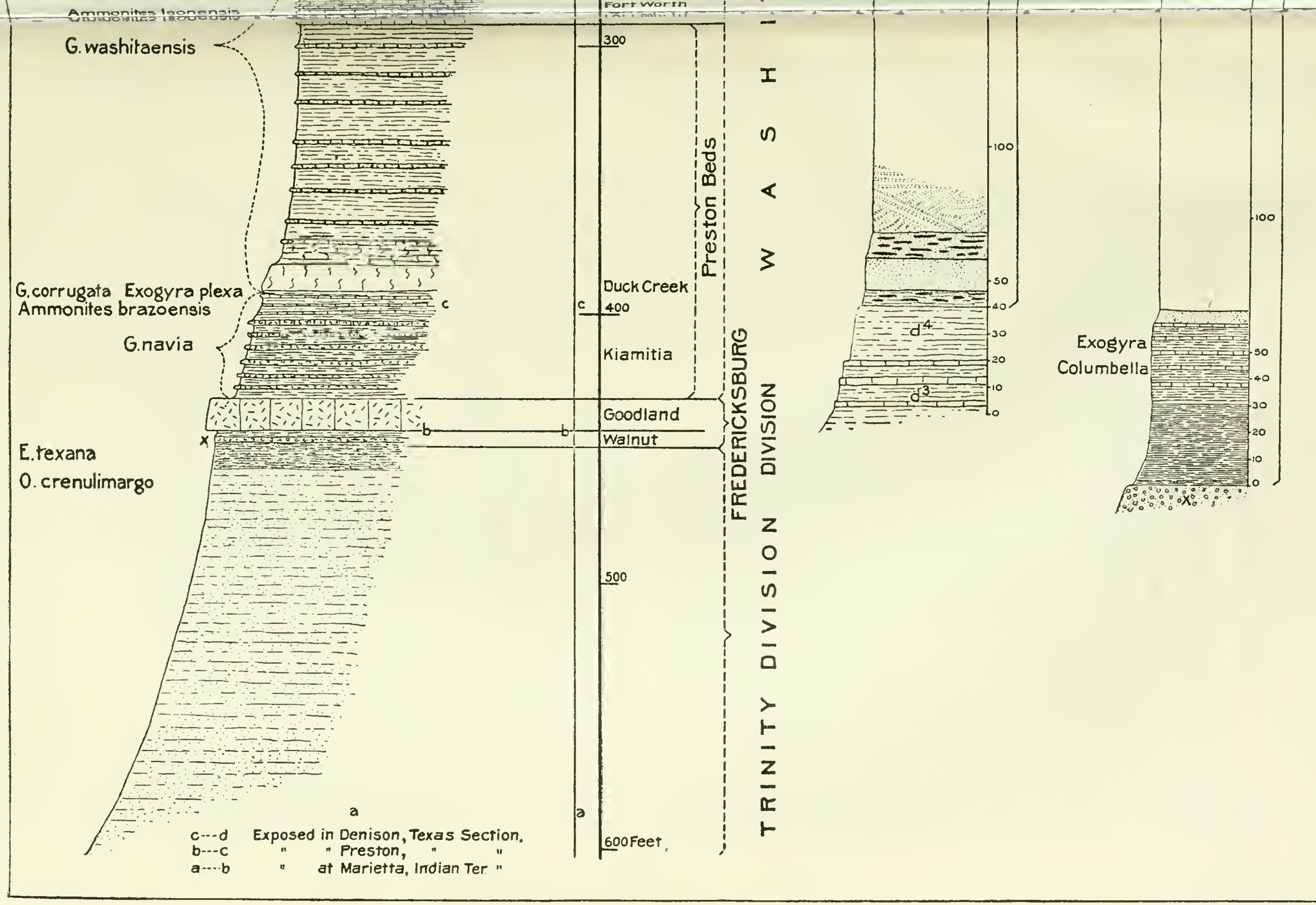
The Fredericksburg division was so named by the writer because its paleontologic features were those which had been originally published as the "Versteinerungen der Hügel bei Fredericksburg" by Roemer.[1]

The upper division of the Comanche series along the Fort Worth section contained fossils which had previously been collected from the vicinity of Preston, Texas, and old Fort Washita, Indian Territory, in the Red River region, by Dr. G. G. Shumard, and described by B. F. Shumard and Prof. Jules Marcou, to whom they were sent. This was named the Washita division, after the last-mentioned locality. When these terms were applied the writer had not visited either the Fredericksburg or the Fort Washita localities, but the classification was based upon the Fort Worth section, which occupies an intermediate geographic position between them, its features being correlated with the published data concerning the paleontology of the other localities.

In this preliminary classification, founded upon the Fort Worth section, the line between the Fredericksburg and Washita divisions was arbitrarily drawn above the zone of *Ammonites acutocarinatus* Shumard, which has been referred to *A. peruvianus* von Buch. This species, as shown in subsequent investigations, was found to have considerable vertical range, occurring throughout the Fredericksburg division and in the lower beds of the Washita division, especially in

[1] See Kreidebildungen von Texas, p. 17.


A
B
C
d
0
UPPER CRETACEOUS
Grayson
Main Street
Paw Paw
Quarry limestone
Denison Beds
Denton
Fort Worth
100
200
150
TA DIVISION
G. mucronata
Exogyra arientina
Kingena wacoensis
O. quadriplicata bed
O. quadriplicata
G. washitaensis breccia
with O. carinata
O. subovata
Gervilliopsis bed
Ammonites leonensis
Woodbine
O. lugubris
Austin
Eagle Ford



RED RIVER SECTION OF THE CRETACEOUS FORMATIONS, GRAYSON COUNTY TEXAS.

A, Washita, Fredericksburg, and Trinity divisions in the Denison section; *B*, Woodbine formation as seen between Denison and Sherman; *C*, Eagle Ford formation northwest of Sherman

the Walnut clay and the Comanche Peak beds, and hence was of indefinite value for correlation. The particular zone of *A. acutocarinatus* in the Fort Worth section, as originally described, was afterwards found to be the attenuated southern representative of a formation later termed the Kiamitia clay, which attains great and conspicuous development in Texas along Red River and in southern Indian Territory with an associated fauna.[1] This Kiamitia bed was also found to be Washitan in its lithologic and paleontologic affinities and geographic occurrence, as later set forth, and hence was included in the Washita instead of the Fredericksburg division in later writings.

Subsequent studies also showed that a group of limestones abounding in aberrant forms of *Chamidæ*, *Rudistes*, and *Nerinea*, which occurred below the Kiamitia clay, and to which Shumard had given the names "Caprina limestone" and "Hippurites limestone," and had placed at the top of all the Texas Cretaceous, both Upper and Lower, were the culminating beds of a progressive group of related sediments, and that with them ceased a majority of the peculiar lower-lying fossils. Only four or five species are known to persist into the overlying beds, where a new and different assemblage of molluscan remains is found. Owing to these facts, the line between the Fredericksburg and Washita divisions was, in all the writer's subsequent sections, drawn at the top of the Edwards limestone, including its northward extension along Red River and in Indian Territory known as the Goodland limestone, and below the base of the Kiamitia clay.

Still later, as research progressed, it was discovered that the Fredericksburg division as originally defined comprised two distinct groups of beds, the lower of which the writer later separated from the upper portion and gave to it the name Trinity division, retaining the term Fredericksburg for the higher strata comprising the Walnut clays, the Comanche Peak beds, and the Edwards limestone.

The beds of the Upper Cretaceous series can not be as readily grouped into divisions as those of the Comanche series, for the lithologic distinctions are not so varied. In his systematic arrangement the writer endeavored to adjust these beds to the three accepted divisions of the Upper Cretaceous of Atlantic sedimentation used in the nomenclature of the Survey—the Dakota, the Colorado, and the Montana—placing the Woodbine sands in the first (Dakota), the Eagle Ford, Austin, and Taylor in the second (Colorado), and the Navarro beds in the third (Montana). Inasmuch as the distinction between these divisions is largely paleontologic, especially between the Colorado and the Montana, and as other beds do not present strongly differing lithologic facies in Texas, the division names will not be used throughout this report, but the beds of this series when referred to will be called by

[1] See Bull. Geol. Soc. America, May, 1891, p. 515.

their formation designations, the Dakota, Eagle Ford, Austin, Taylor, and Navarro, respectively.

As the development progressed the writer used such temporary names for the beds as were convenient, changing them from time to time as was thought expedient. These names were often paleontologic terms and were applied with the intention of revising them for the final report upon the subject.

REFINEMENT OF THE NOMENCLATURE.

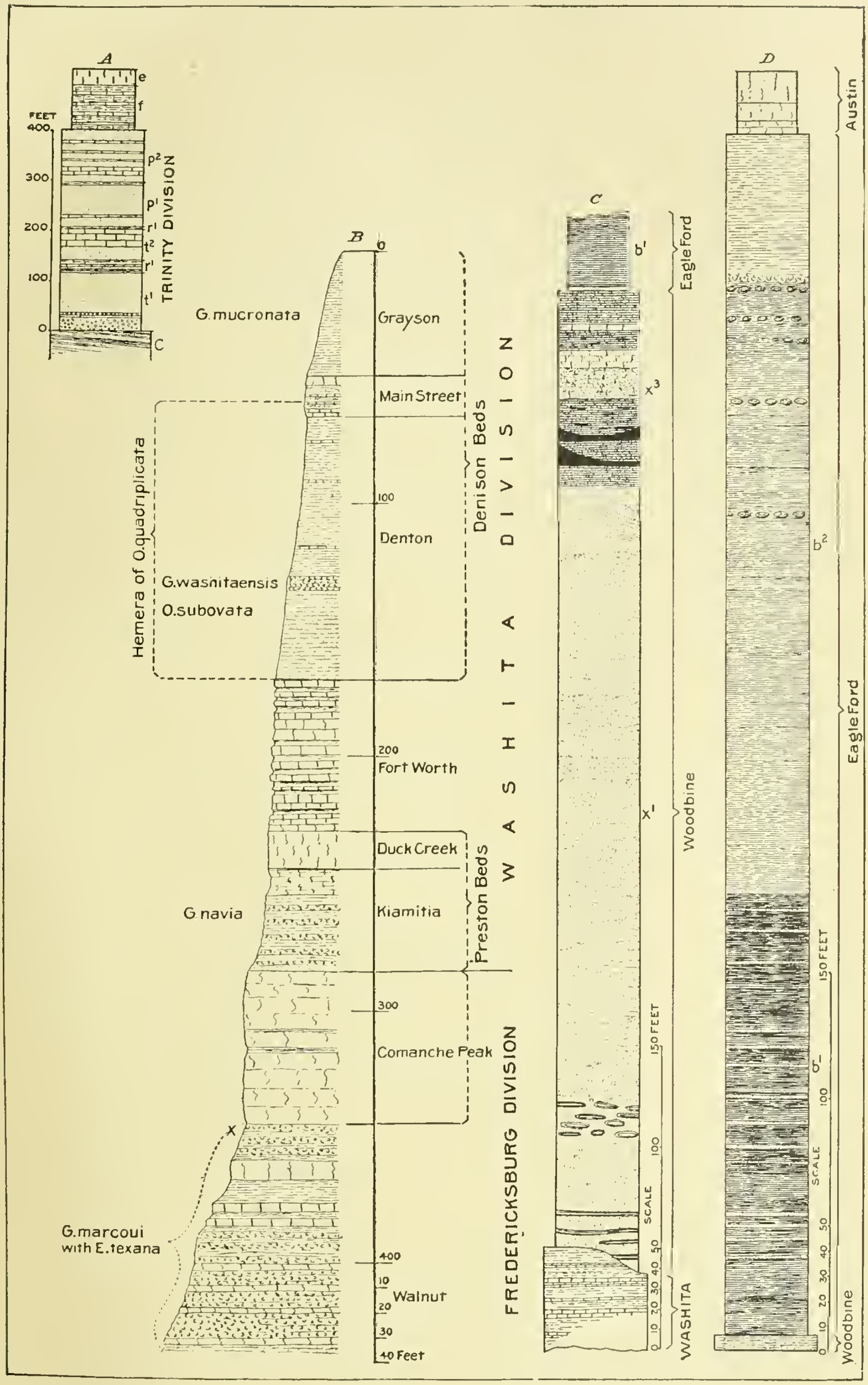
In the classification herein presented, the author has endeavored to refine this nomenclature by using appropriate geographic terms for all the beds. For this purpose, where possible, mononyms taken from recognizable localities have been employed, and the paleontologic and mineralogic names as hitherto used have been abandoned. Thus it is that the terms "Dinosaur sands," "Caprina limestone," "Exogyra texana[1] beds," "Exogyra arietina[1] clays," "Fish beds," "Exogyra ponderosa[1] marls," "Hippurites limestone," etc., of earlier writings have been replaced by appropriate geographic names. Even some geographic names originating in the author's earlier writings have been abandoned. For "Timber Creek beds," which had been previously used for a different horizon in New Jersey, Lewisville beds has been substituted, and for "Barton Creek limestone," which, besides being preoccupied, is not a good locality name, Edwards limestone has been substituted. Finally, as this work goes to press it is discovered that the name "Shoal Creek" must be abandoned because it has been previously applied to another formation in Indiana, and the term "Buda" is substituted therefor. While there has been an endeavor to use the same name for the same formation in different sections, in some cases it has been necessary to use purely local names for formations apparently synchronous with beds of other sections, because the beds, through gradual change along their strike, have become entirely different in composition.

Three Typical General Sections.

Section No. 1.—Denison or Red River section.

This section runs northward from Sherman through Denison to the vicinity of Nida, Indian Territory, across Red River. The sequence of the beds is partially duplicated north and south of Red River (see Pl. LII), owing to the downthrow of the Preston fault, which crosses the section approximately along the course of Red River. The Cooks Springs fault, south of Denison, cuts out much of the Upper Cretaceous strata.

[1] These terms have been wrongly abbreviated into the "Texana," "Arietina," and "Ponderosa" beds by certain writers.



SUCCESSIVE CRETACEOUS FORMATIONS OF THE DALLAS-WEATHERFORD SECTION.

A, Trinity division at Weatherford; *B*, Washita and Fredericksburg divisions in the Fort Worth section; *C*, Woodbine formation; *D*, Eagle Ford formation.

Upper Cretaceous.

	Feet.
Austin chalk: The northern limit of the Austin chalk is on a summit of a high hill 5 miles north of Sherman, where only a few feet are exposed (see Pl. XVIII, *C*)	±500
Eagle Ford formation: The Eagle Ford shales are largely cut out of this immediate Denison section by the Cooks Springs fault, although they are fully 500 feet thick in Grayson County. Their occurrence will be more fully discussed under the proper head. At Cooks Springs they consist of thick black shales weathering into light-brown colors like the Taylor marls, with fossiliferous sands at the base containing *Exogyra columbella* (see Pl. XVIII, *C*)	±600
Woodbine (Dakota) formation: The Woodbine formation occurs twice in the profile section. It occupies the portion of the section between Cooks Springs and the southern part of the city of Denison. Its occurrence here is described in detail upon a later page. The second locality is in Indian Territory, south of an east-west line drawn through old Fort Washita (see Pl. XVIII, *B*). Estimated thickness	±500

Lower Cretaceous.

WASHITA DIVISION (SEE PL. XVIII, A).

	Feet.	
Denison beds (see details on pp. 246, 266–280).		
Pottsboro subgroup:		
p. Grayson marls (see pp. 286–288 for details)	± 15	
o. Main Street limestone (see pp. 280–283 for details)	10	
		25
j, k, l, m, n. Weno subgroup (see details on pp. 280–286):		
n. Pawpaw formation. Impure clays and sands	55	
m. Quarry limestone. A conspicuous bed of yellow limestone	2	
j, k, l. Weno formation. Impure clays with occasional thin strata of sandstone and limestone	92	
		149
f, g, h, i. Denton subgroup:		
Breccia of *O. carinata* and *G. washitaensis*	2	
h. Brown clay marls, less calcareous	18	
f, g. Gervilliopsis beds, marls and fissile indurated layers	8	
		28
e. Fort Worth formation:		
White limestones in regular alternation with thin marls		20
c, d. Duck Creek formation (see details on p. 257):		
d. Chalky marls	128	
c. Chalky limestones	30	
		158

	Feet.
a. b. Kiamitia clays: As described within the body of this report (see pp. 252–257). Outcrop near Folsom, Chickasaw Nation, and in bed of Duck Creek north of Denison (estimated)	40

On the north side of Red River, between Colbert and Nida, all the foregoing beds from the Woodbine to the Kiamitia are repeated.

FREDERICKSBURG DIVISION.

	Feet.
6. Goodland limestone: A white-colored subcrystalline limestone about 20 feet thick, forming scarp lines. This occurs near Nida at the northern end of the section, but is cut out south of Red River by faulting along the immediate line of the section. It is seen at Marshalls Bluff, a few miles to the westward. Thickness, about	20

TRINITY DIVISION AND FREDERICKSBURG DIVISION IN PART (SEE PL. XVIII, A).

	Feet.
1, 2, 3, 4, 5. The equivalents of the whole of the Trinity division and the lower portion of the Fredericksburg division are represented in this section by pack sands, the Antlers sands, which occur along the northern end of the section. These sands are cut out of the section by downthrow where it crosses Red River, but their upper beds are exposed 4 or 5 miles to the westward, notably at Marshalls Bluff on Red River. No reliable data for ascertaining the thickness of these sands is obtainable. The thickness may be estimated at	400

Section of bluff at Marshalls Bluff of Red River south of the southeast angle of Prestons Bend of Red River, showing basal portion of section which is concealed between Denison and Red River.

		Feet.
Kiamitia clays, estimated		40
Goodland limestone:		
White friable limestone with *Dallioconcha stearnsii*	12	
Thin separation layers of clay	2	
White friable limestone with *Schloenbachia*	10	
Thin layers with *Gryphæa marcoui*	.5	
		24
Antlers sands:		
Pack sands with alternations of thin clay bands, more argillaceous at top and base, reddish clays in basal portion		+145

The top of the Goodland limestone is here 130–160 feet above the river at the base of the bluff.

SECTION NO. 2.—FORT WORTH OR TRINITY RIVER SECTION.

This section is carried through Terrell, Dallas, Fort Worth, and Weatherford, slightly diagonal to the dip.

Upper Cretaceous.

	Feet.
15. Navarro beds: Blue-black clays with occasional sandy laminæ and sometimes thin sandy strata, the whole characterized by the presence of grains of glauconite. Constitute the black and black and sandy prairies from Mesquite to 3 miles east of Terrell, Kaufman County. Estimated thickness from artesian well borings at Terrell	±1200
14. Taylor formation: Bluish joint clays weathering yellow, as at Austin; detail not as yet ascertained. Exposed in the eastern part of Dallas County between Rock Creek and the east fork of the Trinity. Thickness not positively known; estimated from artesian well at Terrell	±500
13. Austin chalk: Chalky white limestone with conchoidal fractures, occurring in thickish strata alternating with white chalky marls. Exposed from Oak Cliffs on Trinity River at Dallas eastward to the vicinity of Arnold. Thickness, estimated at	±500

	Feet.
12. Eagle Ford formation: Blue-black bituminous shales with occasional septaria, exposed between western edge of Dallas quadrangle near Grand Prairie and the Trinity at Dallas. Thickness	±500
11. Woodbine formation: Coarse sands and ferruginous clays covered by the growth of the Eastern Cross Timbers exposed between Handley and Arlington. For details see p. 309. Thickness (estimated)	±350

Lower Cretaceous.

WASHITA DIVISION, DENISON BEDS.

p. Grayson formation: East of Handley at a distance of 1 mile or more, there are grayish marls containing *Gryphæa mucronata* in great quantities, *Plicatula*, and other fossils of the Grayson beds of the Denison section. Fully 50 feet are exposed, but exact measurements were not obtained. The marls are very sandy at their basal contact with the Main Street limestone. From the regional dip across their outcrop they are fully 60 feet thick. These beds disappear beneath the Eastern Cross Timbers on the Trinity 9 miles east of Fort Worth	+60
o. Main Street limestone: Yellowish-white, crumbling limestone and marl layers, with *Kingena wacoensis* and *Exogyra arietina*. Exposed in bluffs of Trinity River, 6 miles east of Fort Worth, and in the town of Handley. (For details see section No. 39, p. 282)	22
j, k, l, m, n. Marls with alterations of thin limestone layers. (For details the see section No. 39)	105
f, g, h, i. Denton formation: *Gryphæa carinata* zone, composed of soft argillaceous and harder limestone layers, almost completely composed of *G. washitaensis* fossils, accompanied by *Plicatula*, and *O. carinata*.	10
A complete exposure was not seen. It occurs partially exposed in the railway cut south of the Union depot, Fort Worth; and at the Maddox residence, 2½ miles east of Fort Worth.	
f, g. h. Argillaceous sandy marl	25
Near the base the rock becomes more sandy, and is very fissile. This rock contains many specimens of *G. washitaensis*. There are good exposures between the Maddox residence and Trinity River; also in a bluff of Trinity River, 3½ miles east of Fort Worth.	
e. Fort Worth limestone:	
Regular alternations of bluish-white stratified limestone and soft friable marl; exposed	15
The upper portion is exposed in the bluff of Trinity River north of the court-house in Fort Worth, in street cuttings in the western part of the city, and in the quarries at the Union depot, and 3¼ miles north of the city, near Hodge.	
This horizon is marked by numerous fossils, especially *Ammonites leonensis* and the large variety of *Epiaster elegans* described as *Macraster elegans* Roemer. Other fossils are *Gryphæa washitaensis*, and *Neithea*. The limestones are slightly arenaceous and contain many fucoidal-like casts.	
At the top of the exposure the marly bands are a foot thick and the limestone layers are 6 to 8 inches thick, while at the base of the bluff the limestone is nearly a foot and the marl 3 inches thick.	
d, e. Continued compact and often shelly limestone, interstratified with friable argillaceous marl layers; estmiated 60	
	75

		Feet.
c, d. Duck Creek formation: The above limestones grade down into marls with occasional bands of limestone which contain *Pachydiscus brazoensis*. The exact thickness of the latter has not been ascertained, but they are in the neighborhood of 25 feet, and represent the upper part of the Duck Creek beds.		
d. 2 White, compact, chalky limestone, containing very many large specimens of *Pachydiscus brazoensis*, *Hamites fremonti* and *Inoceramus comancheanus*	15	
c. 1 Hard and marly limestone, in bands from a few inches to 1 foot in thickness	12	
		27
Kiamitia formation: Marly clays, with thin alternations of limestone. In the upper part of strata there are *Schloenbachia leonensis*, *Terebratula wacoensis*, *S. acuto-carinata*, and *Exogyra plexa*. The *Exogyra plexa* and *S. acuto-carinata* are found in the basal 4 or 5 feet of the rock		30

FREDERICKSBURG DIVISION.

Goodland limestone, as seen in the western part of Tarrant County:		
Crumbling chalky limestone, with characteristic fossils	18	
Alternate strata of soft, massive white limestone and shelly limestones	36	
		54
Walnut formation:		
Alternations of soft shelly limestone and argillaceous lime marl in strata of 5 to 6 inches each	14	
Massive limestone	8	
Alternations of compact and shaly limestone	68	
Agglomerates of *Gryphæa marcoui*, with thin separation layers of marl	50	
		130

TRINITY DIVISION.

(For minute details see Weatherford section, p. 190.)

3. Paluxy sands: Light-colored pack sands, with occasional thin clay laminæ and logs of silicified wood covered with a growth of post-oak forest, constituting the upper belt of the Upper Cross Timbers. Exposed in the western suburb of Weatherford	±110
2. Glen Rose beds: Alternations of limestone, marl, and sand, the limestone usually occurring in hard subcrystalline dimension layers, exposed between Lambert and a point 2 miles west of Weatherford	±300
1. Basement sands: Fine siliceous conglomerate and white pack sand, exposed in western Parker County, typical on the east side of Grindstone Creek. Thickness	115

SECTION NO. 3.—AUSTIN OR COLORADO RIVER SECTION.

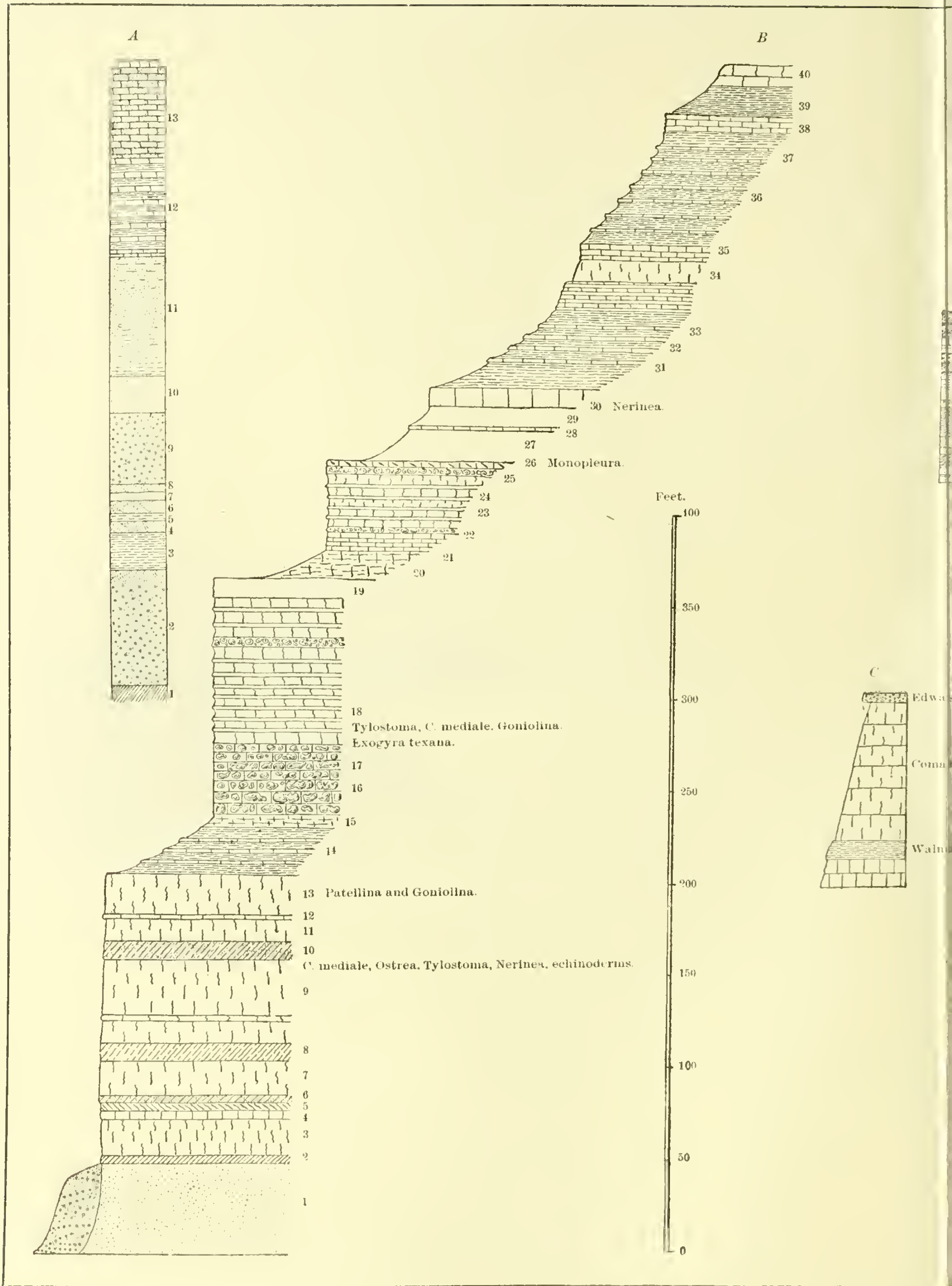
This section is exposed adjacent to the Colorado River in its course through eastern Burnet and Travis counties. It reveals the entire thickness of the Cretaceous, with the exception perhaps of a few feet of the uppermost beds, which are overlapped by the Eocene.

PLATE XX.

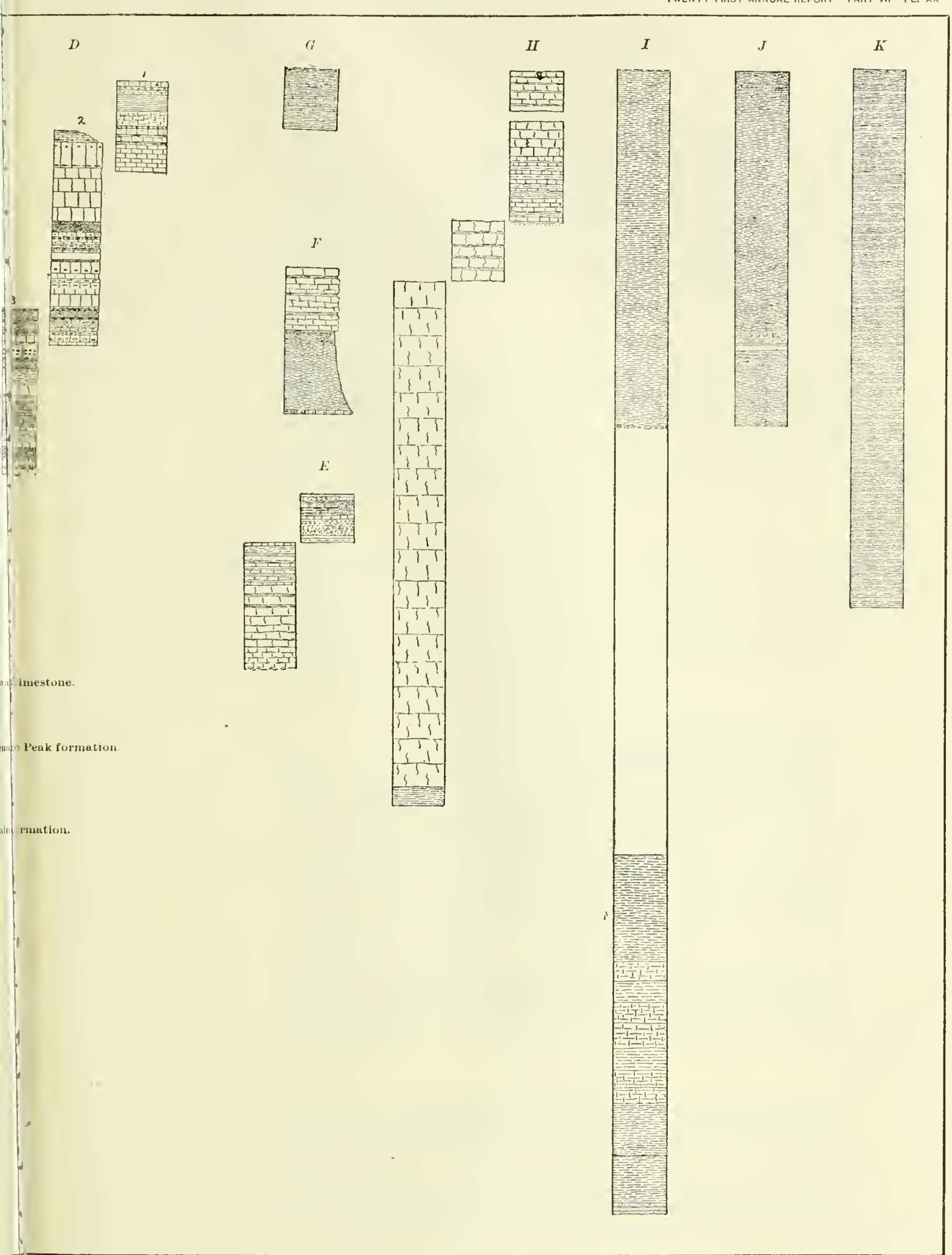
PLATE XX.

CONTINUOUS COLUMNAR SECTIONS OF THE CRETACEOUS FORMATIONS IN TRAVIS COUNTY, TEXAS.

A. Travis Peak formation, near mouth of Hickory Creek.
B. Glen Rose formation, south side of Colorado River, near Lomans Bend.
C. Basal portion of Edwards limestone capping Mount Barker.
D, 1, 2, 3. Caprina limestone as exposed in the south banks of the Colorado, east of the main Balcones fault line.
E, 1, 2. Georgetown formation, West Austin.
F. Buda and Del Rio formations, Shoal Creek.
G. Eagle Ford formation, Shoal Creek.
H. Austin chalk.
I. Taylor formation.
J, *K*. Webberville formation.



SUCCESSIVE COLUMNAR SECTIONS OF THE C



...ACEOUS FORMATIONS, TRAVIS COUNTY, TEXAS.

Upper Cretaceous.

MONTANA DIVISION.

		Feet.
XIII.	Webberville beds: Black clay shales with occasional arenaceous layers and indurations, and differing from the Taylor marls by the presence of many glauconite or greensand grains and by different fossils. (See Pl. XX, *J, K.*) Exposed in the eastern portion of Travis County, notably along Gilliland Creek and in the banks of the Colorado at Webberville. (For details see p. 344.) Thickness, estimated	±400
XII.	Taylor marls: Bluish unctuous clays which weather into a laminated subsoil. Exposed in the Black Prairie region to the east of the Austin chalk belt. Thickness	±540

COLORADO DIVISION.

XI.	Austin chalk: Glaring white chalky limestones and marls with conchoidal fracture, typically exposed in the city of Austin on both sides of Colorado River. East of Shoal and Bouldin creeks. (For details see XX, *H.*) Thickness	±410
X.	Eagle Ford beds: Laminated calcareous blue shales and flagstones characterized by remains of fish bones and teeth. (Pl. XX, *G.*)...	±30
IX.	The Dakota division is unrepresented in this section.	

WASHITA DIVISION.

VIII.	Buda limestone: Massive thick-bedded yellowish limestone. (For details see Pl. XX, *F*)	±45
VII.	Del Rio clays: Unctuous greenish clay, weathering light blue or yellow, with many fossil *Exogyra arietina.* (For details see Pl. XX, *F.*) Thickness	±80
VI.	Georgetown limestone: White limestone, slightly arenaceous, lumpy, and with frequent alternating strata of marls. Very fossiliferous. (For details see Pl. XX, *E*, 1, 2)	79

FREDERICKSBURG DIVISION.

V.	Edwards (Caprina) limestone: Massive white limestones with beds of flints. The lower portion only is preserved as a cap rock on the highest summits of the plateau between Burnet County and the Balcones fault line. The upper portion is exposed where the Colorado cuts through the downthrown area of the Balcones fault zone between Austin and 2 miles west. (For details see Pl. XX, *C*)	±300
IV.	Comanche Peak beds: Shattered, fossiliferous, chalky white limestone, which in this section is practically the base of the Edwards limestone exposed on the summits of the plateau above the Walnut clays. Concealed by downthrow east of the Balcones fault line. (For details see section No. 8, p. 154)	35
III.	Walnut beds: Yellowish gritty calcareous clays with large numbers of *Exogyra texana,* usually constituting a bench or crown just below the summit of the flat-topped mesas, crowning the hills composed of the Glen Rose beds, and coincident with them in extent. (For details see Pl. XX, *C*)	10

TRINITY DIVISION.

II.	Glen Rose beds: White and yellowish limestone and calcareous marls, sandy toward base and top; prevalent rocks from the western edge of Travis County to the Balcones fault line near Austin. (For details see Pl. XX, *B*)	±
I.	Travis Peak beds: Coarse conglomerates, grits, sands, clays, and calcareous layers exposed in the extreme western part of Travis and southeastern Burnet counties. (For details see Pl. XX, *A*)	±

Lower Cretaceous—Comanche Series.

DIVISIONS AND THEIR SALIENT FEATURES.

The strata of the Lower Cretaceous, or Comanche series, form the surface and underlying rocks of the Grand Prairie and Western Cross Timbers. The various beds belong to three divisions, as follows, beginning with the lowest: Trinity, Fredericksburg, and Washita. The general characteristics of these divisions are as follows:

The Trinity division is especially marked by strata of friable white packsands, which do not occur in the other divisions and which in places constitute nearly the entire rocks of the division. In some places, especially south of the Brazos, these sands alternate with marly clays and chalky and clastic limestones, the latter being composed of minute shells or fragmental particles of shells and sands having a lithologic and paleontologic individuality by which they can usually be readily distinguished. All the calcareous strata are white or yellowish and occur in numerous persistent alternations of hard and soft strata of various thicknesses.

The rocks of the Fredericksburg division in the typical area of occurrence are almost entirely chalky limestone, initiated by beds of marly clay, which grade into the limestone.

The rocks of the Washita division include the beds between the top of the Edwards limestone of the Fredericksburg division and the coarse sands of the Woodbine (Dakota).

The sediments of the Washita division, while generally light in color in their lower half, show darker tones and greater ferrugination of rocks toward the top. They are composed largely of alternations of marly clays and firmer layers of limestone. The limestones of this division, while slightly resembling others in the series, have a sufficient proportion of grit, and sometimes of iron, to make them relatively impure. The beds are successively shallower in origin in ascending series.

In general, rocks of the Trinity division were laid down upon a subsiding bottom of a former land surface; rocks of the Fredericksburg division (in this portion of Texas) upon a stationary offshore bottom of Trinity sediments; and rocks of the Washita division upon a shallowing bottom of Fredericksburg sediments.

All rocks of the Comanche series are sea sediments—deposits laid down in the ocean while it was invading a land area extending from east of the present Black Prairie north to the Ouachita uplifts and west to the Rocky Mountains, across the East-Central, Central, and Plains provinces of Texas. This invasion, first recognizable at the very beginning of the Comanche epoch, when the shore line was at or east of the eastern margin of the Black Prairie, ended at the close of the

Comanche epoch, when the shore line was hundreds of miles to the west.

As this invasion was progressing the highland of the interior area was being degraded by erosion, and its débris, carried to the shore line, became the marginal sediments of the advancing sea. Along the eastern margin of the Central Province and beneath the western margin of the Grand Prairie, as more fully explained later in the section on structure, there was a range of mountainous protuberances, or rather the seaward cliff edge of a great plateau, which sloped steeply to the east. The old land to the west was a more level plateau beneath the Central and Plains provinces. The migration of the shore line across this narrower belt of greater slope occupied as great an interval of time as that required for it to cross the entire plains region between the slope and the present east front of the Cordilleras.

The differences in the composition and stratigraphy of the beds of the three divisions of the Comanche series within the area of the Grand and Black prairies are due to the relations which the sediments of the old Cretaceous sea bore to this migrating shore line (see figs. 8, 11, 39, 40, 43). The varying composition and near-shore character of the sediments of the Trinity division are due to the fact that they were laid down against the near-by steep slope of the subsiding land from which the material was derived. This slope was an eastern scarp of the old post-Carboniferous surface, elsewhere described as the Washita paleoplain. These beds (of the Trinity division) are the only Cretaceous formations derived from a near-by shore line, or one which can be definitely located within the East-Central Province, and vary rapidly in composition and thickness proportionately to their proximity to or distance from it. On the other hand, most of the rocks of the Fredericksburg and succeeding divisions, within the Black and Grand prairies, were laid down within comparatively clear seas and at great distances from the land, long after the advancing littoral had conquered the barrier slope and while it was sweeping west across the wider regions of the Central and Great Plains provinces. Hence, relative to the deposits of the Trinity division, they are more uniform and calcareous in composition, less variable in thickness, and more widely distributed in areal extent.

TRINITY DIVISION.

This division includes the lower or initiatory beds of the Cretaceous formations of the Texas region, embracing all the rocks lying below the Walnut beds of the Fredericksburg division.

CHARACTER AND GENERAL OCCURRENCE.

The rocks of this division are among the greatest of the water-bearing formations of Texas, and are of utmost importance in the artesian discussion. Their outcrop (see Pl. LXIX) is the catchment area for the wells of the Trinity and Paluxy systems. Their embed, which is the most prolific source of artesian water in Texas, underlies the whole area of the Black and Grand prairies, increasing in depth from the western outcrop to over 3,000 feet at the eastern border of the Black Prairie. Certain stratigraphic peculiarities, especially the manner in which they rapidly thicken to the east, render their discussion somewhat more difficult and complicated than that of the other formations.

In general these strata consist of sands, clays, marls, and massive limestones (including in the latter shell breccias, agglomerates, and chalks), all of which grade imperceptibly into one another, both vertically and horizontally, according to their proximity to the shore line against which they were deposited. In the regions of their outcrop these beds more nearly resemble shallow-water deposits than do the rocks of the overlying Fredericksburg division, but in their seaward

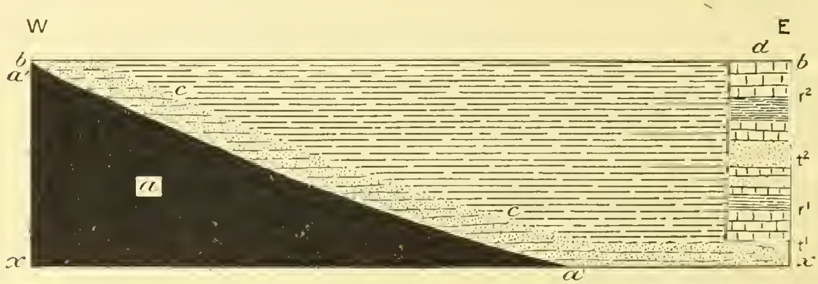


FIG. 8.—Diagram showing change in nature of sediments of Glen Rose beds. *a*, the Paleozoic floor; *a' a'*, the deposition surface; *c c*, the Basement sands; *d*, columnar section; *xx*, sea level at beginning of Cretaceous epoch; *b b*, sea level at close of Trinity stage. (For explanation of other symbols see Pl. XVI, p. 110.)

extension, now embedded beneath the rocks of the Black Prairie, they show a great thickness of massive oceanic limestones.

The rocks of the Trinity division are exposed in two well-defined areas of outcrop. The first, along the interior border of the Grand Prairie in Indian Territory and Texas, coincides in extent with the base of the western escarpment adjacent to and including the Western Cross Timbers. The second group of outcrops are in the incised stream valleys of the Lampasas Cut Plain, in Hood, Somervell, Erath, Bosque, Hamilton, Coryell, Bell, Lampasas, Williamson, Burnet, and Travis counties, where the rocks are exposed in narrow, ribbon-like belts along the valley slopes, separated from one another and the western belt by divides of the cut plain. Eastward they are embedded beneath the eastern part of the Grand Prairie, the Eastern Cross Timbers, and the Black Prairie, as shown by numerous artesian-well records.

Studies of these three areas, the western border, the incised sections of the Grand Prairie, and the embed beneath the Black Prairie, show great differences in thickness and composition of the rocks of the

Trinity division, indicating that they are thinner and more arenaceous along the western border region, where they are best exposed, and that they thicken and become calcareous to the east, being buried in the region of their greatest development beneath the Black and Grand prairies, where a knowledge of their nature can be obtained only by careful interpretation of the artesian drillings. From the western border of the Grand Prairie to an indefinite distance beyond the eastern margin of the Black Prairie the embedded portion extends fully 40,000 square miles.

As a result of these variations of thickness and composition the rocks of the Trinity division along the eastern portion of the general area of exposure within the incised valleys of the Edwards Cut Plain present the aspect of several well-defined and mappable lithologic units of various kinds of rock, which so coalesce along the western border exposures into a general basement formation of sands that they are there usually inseparable.

SUBDIVISIONS.

As a whole these strata of the Trinity division may be subdivided into the following conspicuous formations and beds:

Formations.	Beds.
Paluxy formation	Upper sands. Thin limestones. Lower sands.
Glen Rose formation.	
Travis Peak formation	Hensell sands. Cow Creek bed. Sycamore sands.

The term Basement sands will be used as the equivalent of any of the above formations where they rest upon the underlying Paleozoic floor.

The name Antlers sands will be applied to the equivalents of all these formations as they coalesce along the western border region north of Parker County.

The three subdivisions are nowhere exposed in complete series. The Travis Peak deposits are exposed in a small and irregular area in the valley of the Colorado in Blanco, Travis, and Burnet counties, between the mouths of Cypress Creek, Travis County, and Sycamore Creek, Burnet County. As elsewhere described in detail, they consist of coarse sands and conglomerates, beds of silicified shell breccia, and clays, probably the attenuated western representative of thicker limestone beds embedded eastward, above which is another group of sands and coarse grit, marked in places by ferruginous colors. In the author's opinion they represent the oldest of the Cretaceous formations exposed at the surface in the Texas section. They are possibly represented in the Brazos or Parker County section by the basal sands near Lambert and the Hiner and Bluffdale sands, which occupy analogous positions below the Glen Rose formation.

The Glen Rose beds in their broadest development, as shown in the bluffs of Colorado, Paluxy, and Lampasas rivers, are limestone beds with alternations of yellow and white marls and sandy marls. The beds are of various thickness, and sometimes make steep bluff formations. The Glen Rose beds are best exposed in the valley sections of the Lampasas Cut Plain between the Brazos and the Colorado. They do not outcrop north of Trinity River.

The Paluxy sands in their greatest development are thick beds of "pack sand." They are found in greatest extent between the thirty-first and thirty-third parallels, dying out in the southern counties of the Grand Prairie or changing in lithologic character to yellowish limestones and marls, there included in the Glen Rose beds.

In the Paluxy section the Paluxy sands and Glen Rose beds are well exposed in juxtaposition, but the equivalents of the Travis Peak beds are only partially if at all shown, being largely concealed by embedment. The details of these various beds will be brought out in the local descriptions of the sections. Explanation of certain conditions of the Trinity division as a whole is necessary to a clear understanding of the details of their occurrence, stratigraphic variation, and relations.

BASEMENT SANDS.

CHARACTER AND RELATIONS.

Whether along the western outcrop or where penetrated 2,000 feet or more beneath the surface the Basement beds of the Lower Cretaceous system adjacent to the underlying Paleozoic floor everywhere consist of friable conglomerate and sand sparsely accompanied by reddish and pale-green clays; these sands are next to and above the rocks of the Paleozoic floor upon which the Cretaceous rocks were deposited, and between the latter and overlying calcareous deposits.

These sands are more or less fine grained, very friable, and so slightly compact that they are readily cut with pick and spade; hence they are generally known throughout the region as "pack-sands." They are accompanied in places, usually at their base, by fine pebble conglomerate, locally varying according to the material of the adjacent preexisting rocks. Thin beds and laminæ of red and blue clay occur in the sands, and often the residual surface has a reddish color.

These Basement sands are undoubtedly of shallow-water or near-shore origin and represent the ancient marginal deposits of the sea as it encroached upon the land. Everywhere next to the Paleozoic floor and conformable to its slope, this bed of sand, which seldom reaches 200 feet in thickness, persists as an apparent formation, blanketed between the underlying Paleozoic floor and overlying calcareous beds, and inclines toward the sea at a slightly greater angle than the latter. (See figs. 8, 11, 40, 43.)

While these Basement sands of the Cretaceous, both in the area of outcrop and in that of the embed penetrated by the deepest wells, have the aspects of a continuous formation, they are in fact the interior margin of many formations, and were in process of deposition during a long period of time, and their successive layers are of later and later age as one descends the slope of the old Paleozoic floor. The embedded eastward portion beneath Waco, for instance, was deposited long before the portion now outcropping along the western margin.

Hence, while the Basement sands may be the local bottom of the Cretaceous beneath any particular area, they are not everywhere of synchronous age, but are newer and newer in age as one follows them interiorward in crossing the Texas region, so that, while beneath the Black Prairie they may be of the very oldest Cretaceous—i. e., the earliest beds of the Trinity division—their northwest extension into Kansas and New Mexico may represent the Fredericksburg and Washita divisions.

Therefore we may conclude that the Basement sands of the Trinity division and the Comanche series in general, representing the coalesced arenaceous interior margin of many seaward formations, may be treated as a continuous formation which traversed the geologic column of Lower Cretaceous formations diagonally as the Comanche sea invaded a subsiding land in its progress westward across the area beneath the Black and Grand prairies. The age of this sand varies in its different parts according to their location, and may represent at various points along the slope of the old Paleozoic floor the littoral beds of various formations, which are well-defined paleontologic and lithologic horizons in their seaward extension, collectively representing a long period of time.

We may further conclude, from data presented in full in later pages, that that portion of the Basement Trinity sands which is beneath the Black Prairie region is of the very oldest Cretaceous; that portion beneath the western border of the Grand Prairie, along the Colorado-Brazos divide, the age of the Glen Rose beds; that portion beneath the Callahan Divide of the Central Province, the age of the Paluxy sands; and that portion in southern Indian Territory (top of Antlers sands), southern Kansas (Cheyenne sands), and northeast New Mexico at Tucumcari Mesa, the age of the Fredericksburg and Washita subepochs.

In the beginning of Cretaceous time the shore line reached the eastern margin of the Black Prairie, and during the Trinity epoch the sea went westward as far as the present western border of the Grand Prairie.

An interesting illustration of the conquest of the old topographic irregularities of the Paleozoic floor by the Lower Cretaceous seas and the diagonal transgression of the Basement sands can be seen by tracing the relations of the formations between Colorado River near the

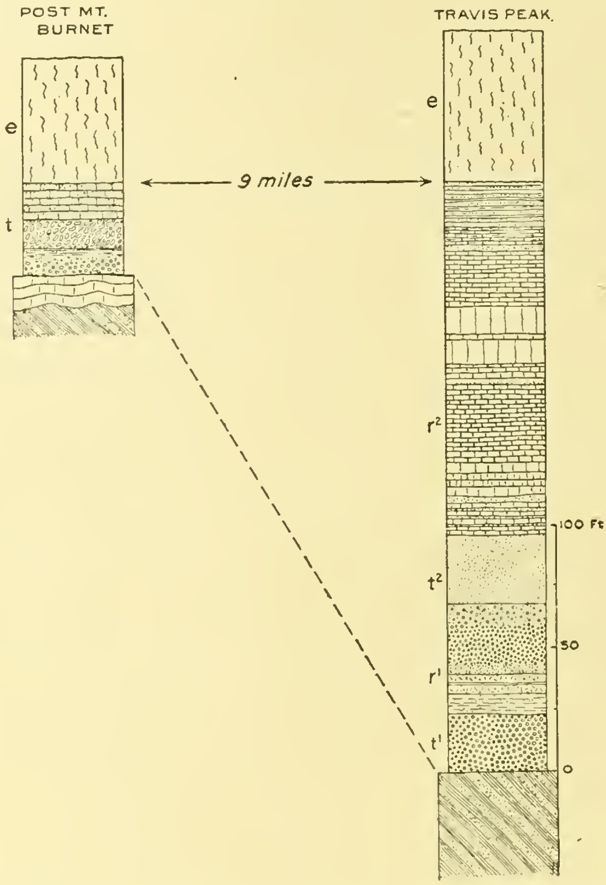


FIG. 9.—Transgressional Basement sands between Travis Peak and Post Mountain, Burnet County, Texas. (For explanation of symbols see Pl. XVI, p. 110.)

mouth of Sycamore Creek, in the southwest corner of Burnet County, and Post Mountain just west of Burnet (see fig. 9), some 15 miles west of north, along the foot of the escarpment of the Lampasas Plain. The Edwards limestone at the summit of this escarpment and of Post Mountain makes a subhorizontal datum plane, while the changing thickness of the rocks of the Trinity division in the slopes and the gradient of the old Paleozoic floor below are variables from the horizontal.

SECTIONS OF THE BASEMENT SANDS.

The most western outcrop of the Basement sands of the Trinity division in the Colorado Valley occurs just in the east bluffs of Sycamore Creek, 70 feet above its bed, at an altitude of about 750 feet. Here the beds of the Trinity division between the Paleozoic floor below and the Fredericksburg limestone at the top of the plateau have a total thickness of 498 feet, as shown in the following general section near the mouth of Hickory Creek. (See Pl. XX, *A*, and section No. 6, p. 141.)

SECTION NO. 4.—NEAR MOUTH OF HICKORY CREEK.

	Thickness.	Total depth to bottom of stratum.
Fredericksburg division:	*Feet.*	*Feet.*
Edwards limestone	70	
Walnut beds	10	
	80	80
Trinity division:		
Glen Rose beds.		
Alternations of thin limestones, clays, and sandy beds	235	
Travis Peak beds	263	
	498	578
Paleozoic:		
Carboniferous clays and sandstones	100	678

The town of Burnet is 15 miles west of north of the latter locality and is some 500 feet higher in altitude. Here, in the head of Hamilton

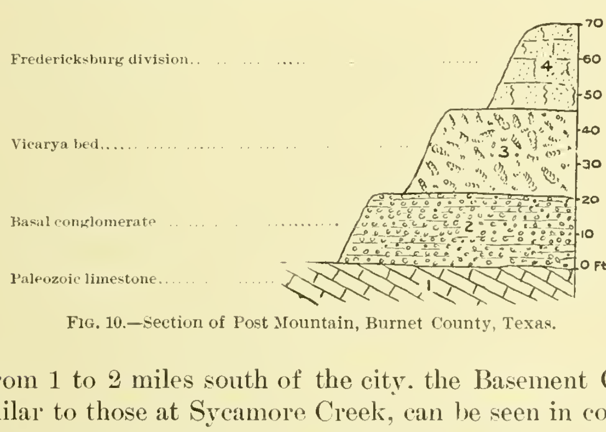


FIG. 10.—Section of Post Mountain, Burnet County, Texas.

Creek, from 1 to 2 miles south of the city, the Basement Cretaceous beds, similar to those at Sycamore Creek, can be seen in contact with limestones of supposed Silurian age (Burnet marble). These sands consist of a coarse grit or small conglomerate a few feet in thickness, surmounted by red arenaceous clays, and are covered by the typical Western Cross Timber forest. They occur at an altitude of 1,250 feet. Less than a mile to the west the Basement beds may be seen at an altitude of 1,400 feet, in the slopes of Post Mountain, resting upon the Burnet marble.

The following section shows the relations of the Cretaceous formations in this mountain:

SECTION NO. 5.—POST MOUNTAIN, 1 MILE WEST OF BURNET. (SEE FIG. 10.)

	Thickness.	Total depth to bottom of stratum.
Fredericksburg division:	*Feet.*	*Feet.*
5. Barren Edwards limestone and Comanche Peak limestone	95	
4. Walnut beds	10	
	105	105
Trinity division:		
3. Impure yellow arenaceous limestone and marl with aragonite crystals	25	
2. Limestone agglomerate of shells with asphaltum	25	
1. Reddish sandy clays and conglomerate	20	
	70	175
Paleozoic:		
Crystallized Silurian limestone.		

DIFFERENCE IN AGE OF PARTS OF BASEMENT SANDS.

The top of the underlying Paleozoic floor makes a steep ascent, 50 feet to the mile, between the two localities. The Fredericksburg cap rocks are practically of the same altitude at the two points. The beds of the Trinity division between the Paleozoic floor and the cap rock are limestones, except at their base, where they continue to be sands, which can be traced along the foot of this escarpment as they ascend the old Paleozoic slope. The Trinity division as a whole decreases in thickness along this line, from 498 feet near Sycamore Creek to 65 feet at Post Mountain, and this decrease is at the expense of the Glen Rose limestones. Between them and the Fredericksburg cap rock the escarpment gradually thins from 235 to 25 feet. There is no doubt that in the distance between the localities the Basement sands transgress nearly all the entire time interval occupied by the Glen Rose limestones in the sections to the east. Hence we may conclude that while the Basement sands at Sycamore Creek and Post Mountain represent a continuous formation, this formation is of the age of the Travis Peak (Sycamore sands) horizon at the former locality and of the upper beds of the Glen Rose at the latter; that in ascending the slope of the preexisting Paleozoic floor to the northward it traversed diagonally a vertical column of the Cretaceous formations representing a long period of time. In other words, the Basement Trinity beds exposed at the head of Hamilton Creek in the southern suburbs of Burnet County belong to a horizon 500 feet higher in the geologic series than the same sands at the base of the Travis Peak beds at the mouth of Sycamore Creek.

The progressive encroachment of the sea in a general westward direction resulted in a greater accumulation of sediments to the east during the Trinity subepoch, where nearly a thousand feet of strata had been deposited before the westwardly progressing shore line reached the Central Province in Fredericksburg time.

At Waco the Basement beds of the Trinity division resting upon the Paleozoic floor are estimated to be 1,250 feet below sea level. (See fig. 41.) At Lipan, Hood County, 85 miles northwest, they are 1,250 feet above sea level, or 2,500 feet higher. The present slope of the Paleozoic floor between these places is 29 feet to the mile. One thousand two hundred and fifty feet of this slope is due to tilt which the beds have undergone since they were deposited. This amount subtracted from the total slope of 2,500 feet shows that the Basement sands at Waco were deposited upon a point of the sloping continent 1,250 feet lower than at Lipan. In other words, the old pre-Cretaceous land had subsided 1,250 feet while the sea margin transgressed from Waco to Lipan and deposited the continuous bed of Basement sand. Hence the latter is much younger at Lipan than at Waco, the interval of time being indicated by the deposition of 1,250 vertical feet of sediments. Furthermore, when the sea margin reached Lipan the Basement beds at Waco were covered by at least 1,000 feet of calcareous limestone-making mud layers which passed horizontally westward into the transgressing bed of Basement sands.

THE BASEMENT SANDS A PSEUDO FORMATION.

Although the Basement sands considered as a formation were accumulated upon a surface diagonal in slope to the normal deposition plane of the more horizontal limestone strata, the individual laminæ of the sands were also deposited horizontally in the direction of the planes of the limestone. Hence the Basement sands as a whole have a slant diagonal to the planes of deposition of its integral parts. (See fig. 8.)

Beginning at any point along the outcrop of the Basement sands and tracing the sediments away from them coastward along the lines of original deposition, which were once subhorizontal, one will find that they usually pass east into clays and calcareous strata which constantly increase in aggregate thickness. Hence it is that the rocks of the Trinity division as a whole increase in thickness east of the old shore slope, and this increase consists of accretions of layers which pass westward into the mother bed of Basement sands. In other words, the Basement sands may in parts be the attenuated littoral portion of any of the well-defined synchronous beds to the coastward.

The strata which pass eastward from the transgressing Basement sands are of various kinds, increasing in calcareous material away from the shore. Occasionally thin sheets of sand are found intercalated between the calcareous layers like a plate or cardboard inserted between the leaves of a thick volume, and these sheets lead west into the transgressing Basement sands. These intercalated sands bed shaving the lithologic aspects of the Basement sands, of which the Paluxy formation is an example, are seen to best advantage in the sections farthest east of the western outcrop. The deep artesian-well section

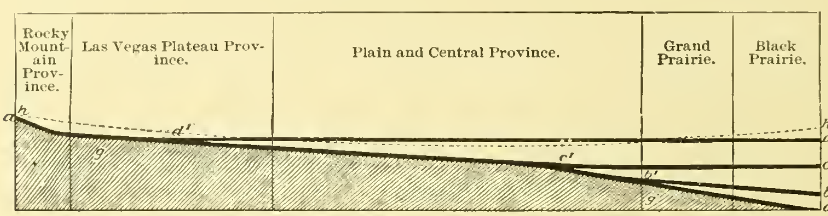


Fig. 11.—Section showing transgression of Basement Cretaceous sands westward and mergence of other Cretaceous sand beds into them. *aa*, Basement sands which traverse the geologic column diagonally from the Wealden to the Dakota; *b*, Hensell sands embedded beneath Grand and Black prairies; b^1, union of Hensell sands with *aa*; *cc*, Paluxy sand; *dd*, Dakota sand; *gg*, Paleozoic basement; *hh*, Erosion profile. Space between sands is occupied by calcareous beds.

on the east presents several thin beds of sands of this nature, separated by beds of limestone. Again, proceeding from the southeast to northwest on lines parallel with the dip, or across the strike, one finds the limestones between the sands, like those of the Glen Rose formations, decreasing in thickness and finally disappearing as the Basement sands of the western border are approached, while the sands continue until they merge into this mother bed. Thus the transgressing Basement sand beds, where they meet the Paleozoic floor on the west, represent the attenuated interior margins of horizons which in the sections coastward are well defined and differentiated formations of clays, limestones, and sands.

The sheets of sand projecting eastward from the transgressing mother bed are important horizons in the general Cretaceous section, their outcrops and embeds having vast subhorizontal extent. (See fig. 11.) Of this nature are Hensell and Paluxy sands of the Trinity division, elsewhere described in detail, which spread out from the Basement sands within the area discussed in this paper, as shown in the above figure. Possibly the Dakota and Navarro sands are of a similar nature.

As a result of the condition of origin, the aggregate thickness of rocks of the Trinity division throughout the Black and Grand Prairie regions, as shown by cross-cutting drainage and well drills, constantly increases to the east, as does also the calcareous element of the rocks. Hence the Trinity division as a whole is wedge shaped in cross section, thickening seaward between the diverging lines of the rapidly sloping Paleozoic floor and the more horizontal beds of the Fredericksburg division above it.[1]

This increment in the total thickness of the Trinity division beneath the Black and Grand prairies in their seaward extension away from the old Paleozoic shore line may be understood by examining the general cross sections throughout this paper and by comparison of the details of the vertical sections across the strike, such as the Decatur, Fort Worth, Glen Rose, Waco, Belton, Georgetown, and Austin cross sections. Some figures bearing upon the rate of increase are given on a later page.

In view of the facts presented, the term Trinity sands as heretofore used will be employed in a general sense only as a generic name for the transgressing Basement sands of the Trinity division. In other cases special locality formation names will be used for portions of the Basement sands or their ramifications where their exact relations to the other Cretaceous formations are known.

The details of the occurrence of the Basement sands will be given more fully at the end of this chapter, after describing the Glen Rose and Paluxy formations, which pass westward into them; the question of the diagonal transgression of the Basement sands and problems of stratification related to it are more fully discussed in the chapter on "Structure."

While attention has been called to the variation in thickness and material which the beds of different sections show, the reader must understand that these beds, when studied along their strike, exhibit remarkable persistence and extent. While the beds vary as above stated, along the dip, each has great persistence and lithologic uniformity along its strike, and can be traced for many miles in continu-

[1] Owing to the diverging angle between the limestones of the Fredericksburg division and the seaward slope of the Paleozoic basement the subhorizontal position of the former makes a better datum for measuring the thickness of the beds of the Trinity division at any known point. The reader can obtain a better conception of the horizon of any particular rock sheet of the Trinity division by measuring its distance downward from the Fredericksburg division rather than by estimating the distance above the slanting Paleozoic floor. This method will also be convenient because the greater thickness of the Trinity division is embedded and exposed only by the artesian-well drills. As the latter always proceed from above downward, the method is, after all, the rational one.

ous outcrop. The Texas region is one of magnificent distances, and individual strata often have a hundred miles or more of continuous outcrop. In fact, such uniformity and persistence can hardly be seen in any other region.

TRAVIS PEAK FORMATION.

OCCURRENCE AND COMPOSITION.

The Travis Peak beds are the lowest Cretaceous formations exposed within the Greater Texas region. They are revealed in only a limited area along the slopes of the deeply incised valley of Colorado River between the mouths of Sycamore and Cypress creeks, in Burnet, Blanco, and Travis counties, where they form the Basement sands. The name was given because they are seen in the vicinity of Travis Peak post-office, in the extreme western corner of Travis County, where they occur in a trough or irregular valley in the preexisting Paleozoic floor, now occupied by the Colorado River, some 500 feet below the base of the Walnut clays of the Fredericksburg division and 475 feet below the altitude of the Basement sands at Burnet northward, as we have shown. (See Pl. XX, *A*.) In general the Travis Peak beds at this locality consist of conglomerate, composed of coarse rounded pebbles of Silurian and Carboniferous limestones, granite, Llano schists, and quartz derived from the adjacent Paleozoic rocks; beds of finely cross-bedded pack sand, white siliceous shell breccia resembling the Florida coquina, and some bands of blue, reddish, and greenish-white clays, having much the characteristic colors of the Potomac beds of the Atlantic coast, and they are sometimes accompanied by lignite and fossil bones.

SECTION OF TRAVIS PEAK FORMATION.

The following section, by Mr. J. A. Taff,[1] will give an idea of the sequence and composition of the formation as a whole, as exposed in the valley of the Colorado, between Travis Peak post-office and Smithwick Mill, Burnet County. (See Pl. XX, *A*.)

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[1] The division and formation names at the left in this and other sections given are interpolated by the writer.

SECTION NO. 6.—HICKORY CREEK SECTION OF THE TRAVIS PEAK FORMATION, BEGINNING AT THE TOP OF THE DIVIDE BETWEEN HICKORY AND COW CREEKS AND CONTINUING TO THE COLORADO RIVER LEVEL AT THE MOUTH OF HICKORY CREEK BURNET COUNTY. (PL. XX, A.)

	Thickness.	Total depth to bottom of stratum.
GLEN ROSE FORMATION.		
TRAVIS PEAK FORMATION:	*Feet.*	*Feet*
12. Bands of conglomerate and calcareous sandstone, alternating with beds of arenaceous limestone, the arenaceous limestone predominating	40	40
Hensell sand:		
11. Marly magnesian limestone	40	80
10. Calcareous sand at base, grading upward to a siliceous limestone at the top, barren of fossils	55	135
9. Yellow calcareous sand, stratified	15	150
8. Conglomerate, similar in character to No. 2, with the exception that the pebbles are smaller and more worn, grading into sand below and into calcareous sand above	25	175
7. Red sand, unconsolidated	3	178
6. Friable yellow sand	5	183
Cow Creek beds:		
5. Cross-bedded shell breccia, containing many small rounded grains and pebbles of quartz flint and granite sand. Fossils: *Trigonia* and small bivalves and *Ammonites justinæ*	7	190
4. Ostrea beds, magnesian lime cement, fossils en masse	3	193
3. Brecciated grit, composed of worn fragments of oyster shells and shells of other Mollusca, with sand and fine pebbles stratified in false beds	5	198
2. Bands of friable bluish shale and calcareous sand, stratified. Fragments of oyster shells are common in the calcareous sandstone	15	213
Sycamore sands:		
1. Basal conglomerate of pebbles of limestone, quartz, chert, granite, and schist, well rounded, in a cement of ferruginous yellow and red gritty sand. Some of the pebbles at the base are from 4 to 6 inches in diameter. They decrease in size, however, upward from the base, until we obtain a false-bedded calcareous shell grit at the top	50	263
Total thickness of Travis Peak beds		263
CARBONIFEROUS:		
0. Laminated, flaggy, Carboniferous sandstones and friable light-blue clay of Carboniferous (Coal Measures) age, from the Colorado River level upward to the base of the Trinity conglomerate, the laminated sandstones containing prints of ferns, nearly	100	363

SUBDIVISIONS OF TRAVIS PEAK FORMATION.

The Travis Peak formation is subdivisible into three distinct lithologic beds, which may be termed the Sycamore sands, the Cow Creek beds, and the Hensell sands. While these beds are not of great thickness at this locality, they have more important development eastward, in the area of their embed, and hence must be differentiated.

Sycamore sands.—These consist of conglomerate and pack sand which form the basal 50 feet of the Colorado section as exposed in their typical locality along the slopes of the Colorado Valley from river level at the crossing of the Burnet-Travis county line to a point a mile or two back of Sycamore Creek. The pebbles at the base of the basal conglomerate, varying from 1 to 6 inches in diameter, consist of limestone, quartz, chert, granite, and schist derived from the adjacent Paleozoic rocks. They are well rounded and embedded in a cement of ferruginous yellow and red, gritty sand. They decrease in size from the base upward, passing gradually into a bed of coarse, angular cross-bedded sand which becomes finer and finer in ascending until it reaches the condition known in Texas as "pack sand"—i. e., a very fine-grained, loosely consolidated sand, cemented by chemically precipitated calcareous carbonate. The sandstone contains grains of silica varying from the size of a pea to the most minute particles, and small subangular fragments of clay in the cement of lime.

The Sycamore beds in this, their typical locality are undoubtedly the lowest outcropping beds of the Cretaceous of Texas east of the Pecos River and are typical Basement sands. They rest unconformably upon the disturbed Carboniferous shales and sandstones of the Richmond series. Their relations are shown in fig. 9 (p. 134). The Basement sands, of which they are a part, rise north toward Burnet, from which place their outcrop around the meandering westward projection of the Grand Prairie to the northwest represents higher geologic horizons.

Embedded Basement sands which are probably of the same age as the Sycamore sands, are encountered coastward in artesian wells, especially at Austin, Belton, Waco, and Fort Worth, where they make the lower and most copious water-bearing stratum, but are not positively known to outcrop elsewhere within the region under discussion. Where the Leon River in Comanche County crosses the Fort Worth and Rio Grande Railway adjacent to the Brazos at Powells Crossing, are Basement sands (the Leon sands), which future research may show to be a northern continuation of these sands. They may outcrop at other places along the western border region, but are not elsewhere separable into a distinct horizon.

Cow Creek beds.—Numbers 2, 3, 4, and 5 of the Travis Peak section (Pl. XX, *A*), aggregating 30 feet, are of an impervious calcareous and argillaceous nature, and represent the western thinning out of beds which in the Austin artesian wells have a greater thickness. These beds succeed the Sycamore sands in the region of their typical development along the Colorado between the Travis County line and Sycamore Creek, where they present the details shown on section No. 4.

Fossils occur in these beds, but they are neither plentiful nor distinct. The upper or coquina-like beds are full of casts and molds, among which are undetermined species of *Trigonia streeruwitzii* Cragin, *Pholadomya*, *Cyrena*, and *Ammonites justinæ* Hill. (See Pl. XXI.) In these beds also appears the first of the several oyster agglomerates of the Comanche series. This is composed of a solidified mass of large oyster shells forming a stratum 7 or 8 feet in thickness just below the junction of Post Oak and Cow creeks.

Accompanying the oyster breccia another noteworthy feature of the Trinity division appears—i. e., an excess of epsom salts, or magnesian sulphate. The oyster-shell bed effloresces into a powdered earthy substance accompanied by the epsom salts. Magnesian and pyritiferous layers occur in other horizons higher in the division, and their presence is no doubt in part the cause of the mineral character of some of the artesian waters, especially those wells which are not drilled into the Basement sands below these layers.

The Cow Creek bed has not been paleontologically identified elsewhere than in the Colorado section, and is the western attenuation of beds which attain their greatest thickness in the region of embed. There are certain thin bands of impure calcareous-argillaceous material occurring in the Weatherford section, which occupy an analogous position. The artesian wells at Glen Rose pass through a similar formation between the depths of 75 and 180 feet. The artesian wells at Austin, Waco, Belton, and elsewhere along the borders of the Black and Grand prairies, pass through a formation occupying an analogous position but of greater thickness, amounting to 200 feet at Austin.

Hensell sands.—Numbers 6, 7, 8, 9, 10, 11, and 12 of the Travis Peak section represent a second group of porous water-bearing pack sands. These are beautifully displayed in the banks of Cow Creek, in the neighborhood of Mr. Hensell's place at Travis Peak post-office. They are limited at the top by the basal limestone of the Glen Rose formation, bearing fossil monopleuras, and at the base by the Cow Creek beds.

The Hensell sands are probably represented in the Paluxy Valley by about 40 feet of fine pack sand, which is reached in the wells at Glen Rose at depths of from 70 to 110 feet below the Paluxy River. This sand may be represented in the Brazos section by No. II of the Weatherford section and by the sands which succeed the Lambert beds, encountered in the deep wells at the border of the Black and Grand prairies below the top of the Trinity division at San Marcos, Austin, Belton, Waco, Fort Worth, and other places.

They are the water-bearing horizon referred to throughout this paper as t[2]. These sands are easily recognizable in the drill sections, at least, in the samples from the San Marcos well, showing the typical red color of the clays that they exhibit at their outcrop at Travis Peak post-office. Westward the Hensell sands[1] lose their identity by merging into the general Basement sands of the western border.

The Travis Peak formation as a whole records a subsidence of the land during its deposition. As the waters deepened the deposits changed from coarser to finer material, becoming more comminuted and calcareous at the top of the beds, until the sand grains are so fine as to be almost imperceptible to the eye, the whole mass becoming chalky and "magnesian" in appearance.

At the top of the sandy beds (No. 1 of the Glen Rose section, Nos. 12 and 13 in the Colorado section) a yellow, arenaceous, fossiliferous limestone appears. This marks the first or lowest appearance of the peculiar fossils *Monopleura* and *Requienia* (*Caprotina*), and indicates the beginning of the Glen Rose formation.

GLEN ROSE FORMATION.

LITHOLOGIC AND STRATIGRAPHIC CHARACTERS.

The typical Glen Rose formation consists largely of even-bedded strata of argillaceous, arenaceous, chalky limestones, alternating with thin strata of marly, arenaceous clay. The beds are of different thicknesses. The thickness of each individual bed is remarkably uniform throughout its extent when traced along the outcrop. From the alternation of limestone and clay the beds were provisionally called the "Alternating beds" when first differentiated by the writer,[2] and were included in the Fredericksburg division.

The Basement beds of the Comanche series have been described as arenaceous in character. The Glen Rose formation, on the other hand, is calcareous, with clays and sand as accessory material. Each of these formations is accompanied by the material of the other as a minor accessory. Thus the calcareous rocks of the Glen Rose formation are partially arenaceous, especially at their base, the siliceous grains being so finely triturated that they are an almost impalpable powder. This siliceous material gradually diminishes upward in the beds, and the lime increases proportionately in both the indurated beds and the marls. Toward the top of the Glen Rose the limestones are again slightly arenaceous.

The indurated beds consist of strata of brecciated crystalline, arenaceous, magnesian, or chalky texture. They are white, yellow, and

[1] It is important to note that the Sycamore and Hensell sand beds are strikingly analogous to the water-bearing beds denominated t[1] and t[2] on the deep-well descriptions, and that the Cow Creek bed corresponds in position to great thicknesses of limestone between the sands in the Austin, Belton, and Waco wells.

[2] See Bull. No. 1, Geol. Survey of Texas, Austin, 1889, p. xiv.

CHARACTERISTIC FOSSILS OF THE TRAVIS PEAK AND GLEN ROSE FORMATIONS.

1. Ostrea ragsdalei Hill. 2. Pholadomya henselii Hill. 3. Trigonia lerchii Hill.
4, 5. Glauconia branneri Hill. 6. Ammonites justinæ Hill.

sometimes blue-gray on fresh fracture. Some are made up of minute fragments of shells, which give them a granular pseudo-oolitic structure. This is seen at Mount Bonnel, west of Austin, in many layers of indurated stones and marls. Others, like the Orbitulites bed, are chalky in character.

The stratification of these beds is conspicuous in the landscape on account of the manner of weathering. The alternating beds of soft marls and hard limestones weather into numerous small cliffs and stratum plains, resulting in a compound terrace effect along the slopes and the many round hills and incised canyons of the Lampasas Cut Plain and the Edwards Plateau southward. The softer strata between the indurated layers readily disintegrate into a marly earth, yellow to white in color, while the harder layers weather into vertical ledges, which break down into fragments as the softer bands fall away from beneath them.

Nearly all well-exposed sections of the Glen Rose formation show three marked subdivisions. The lower and upper thirds are thin-bedded alternations of marl and indurated strata, usually weathering into the terraced slopes above described, while the middle third is composed of thicker and more massive indurated beds, which make steep canyon bluffs when cut by streams.

The lowest Glen Rose beds are of a transitional character in the Glen Rose and other northern sections. The reddish sandy clay at the top of the Basement sands passes upward without stratigraphic break into calcareous fossiliferous strata of the Glen Rose formation. In the Colorado section it is impossible to draw a sharp line of demarcation between the lower beds of the Glen Rose formation and the upper beds of the Travis Peak formation, inasmuch as the one grades into the other. This is seen in the high bluffs of Cow Creek, immediately below Mr. Hensell's house at Travis Peak post-office, in the western part of Travis County, where the transition is gradual from the unconsolidated pack sands of the Hensell beds into semi-indurated calcareous sands, and finally into a firm band of magnesian arenaceous limestone containing fossil requienias—a horizon arbitrarily assumed as the base of the Glen Rose beds in this section. The name Requienia (Caprotina) horizon No. 1 has been applied to this bed because the fossil requienias, called *Caprotina* in earlier geologic literature, make their first known appearance in the section at this horizon.

ECONOMIC FEATURES OF GLEN ROSE FORMATION.

The agricultural possibilities of the Glen Rose beds are not great. The regolith is very shallow, although rich alluvial deposits derived from the adjacent Glen Rose beds are found in the local valleys. On the other hand, the beds are capable of producing valuable building stones and other material. Some have rich "magnesian"[1] (buff-yellow) colors, and other limestones resemble the stones of Caen, France, which are imported into this country. Some beds are valuable for the manufacture of hydraulic cements, although at present they are not utilized. These rocks contain undeveloped beds of epsom salts, strontianite, and other materials. The magnesian limestones are soft and of a rich cream or yellow color, and alternate with softer marls of similar composition, sometimes accompanied by pockets or crystalline nodules composed of calcite, aragonite, strontianite, and celestite. Epsomite is abundant in certain layers occurring about 90 feet below the summit of the formation at Mount Barker, west of Austin. These mineral deposits are well shown nearly 50 feet below the summit on Mount Bonnel, in beautiful wind-cut cliffs (see Pl. XXII). Here the surfaces of finely siliceous magnesian limestone are adorned with thick frost-like coasts of exquisite crystals of epsomite, apparently deposited from the solutions which exude from the rock. Pockets of these minerals occur in Williamson, Burnet, Lampasas, Bell, and Coryell counties, and apparently occupy a persistent horizon in the Glen Rose formation. The celestite has also been found by Taff in a marly bed below the heavy limestones in the bluffs along Rocky and South Rocky creeks, in northeast Burnet County. The same horizon occurs on South Rocky Creek near the Lampasas-Georgetown road and in a high bluff on the creek 3 miles below the same road crossing. On Donaldson Creek, due east of Nix, Lampasas County, beautiful blue crystals are found in large nodules in the yellow arenaceous limestone, and they also occur with calcite nodules around the face of the hills north of Nix. In the attenuated Glen Rose beds of the western border region there are small pockets of dog-tooth anhydrite, notably in Comanche, Lampasas, and in western Parker County.

LOCALITIES AND OCCURRENCE OF GLEN ROSE FORMATION.

The outcrops of the Glen Rose beds coincide with the extent of the Glen Rose prairies heretofore described. They occur along the western scarp and in separated areas in the incised valleys of the western half of the Lampasas Cut Plain west of a line drawn from Decatur, in Wise County, to the Colorado, which can be best appreciated by consulting the map. In general they occupy all the valley slopes of the Grand Prairie region west of the line above mentioned and east of the Western Cross Timbers as it meanders around the foot of the western escarpment.

These areas of outcrop, which are separated by drainage divides, surmounted by the later formations making the cap rock of the Lampasas Cut Plain, may be separated into two general groups, those

[1] The term "magnesian" has long been applied to certain yellow strata in these beds. Whether all of them are or are not magnesian in composition the writer can not state positively.

GLEN ROSE FORMATION BLUFFS OF MOUNT BONNEL, WEST OF AUSTIN, TEXAS.

of the western escarpment border and those of the incised valley slopes. These areas anastomose at places along some of the deeper drainage valleys which cut through the western escarpment, as along the Brazos, Leon, and Colorado.

The Glen Rose formations usually occupy irregular belts of prairie, either open or brush covered, varied by bosks and mottes of timber. These prairies are long, gentle slopes marked by small stratified terraces. (See Pl. XXIII.) Adjacent to the immediate streamway the beds often occur as steep vertical bluffs.

Back from the immediate streamway the unequal weathering of the alternately hard and soft layers produces steep slopes which are beautifully benched and terraced, so that they resemble ancient shore lines. This effect is due to the difference in hardness of the persistent horizontal layers, which consist of rapidly alternating soft clays or marls and indurated strata. The height of these terraces of stratification is governed by the distance apart of the indurated layers, and varies from 6 inches to 20 feet or more.

The terraced type of the typical Glen Rose topography is best shown around Lampasas and along the upper slopes of the Colorado Basin, west of Austin, and in the region northward, toward the sources of the San Gabriel and the tributaries of Lampasas River—areas where the former protective cap of Fredericksburg rocks has been completely removed. In these places the hills of Glen Rose rocks are usually conical knobs with persistent benches and terraces so symmetrical that they appear to have been cut by a turning lathe. The east slope of the summit of Mount Bonnell, northwest of Austin, is a familiar example of the terraced Glen Rose slopes, the different benches succeeding one another like the treads of an ordinary stairway. North of Leon River, where the Glen Rose limestones are included between the Trinity and Paluxy sands, the same terraced topography continues, but the benches are wider, and make extensive prairies, with fewer minor scarps. This type is well shown near Comanche and Glen Rose.

Where creeks or rivers in their winding courses cut rapidly against their banks the bluffs are precipitous, especially in those portions of the formation where the beds are thick and heavy. Bluffs of this character also occur where the Glen Rose beds are protected by a heavy capping of the Fredericksburg rocks, as in the headwater canyons of the streams south of Leon River. These bluffs are white or cream colored, and produce scenic features of remarkable beauty, notably along the banks of the Colorado adjacent to Lake McDonald, where they rise in exquisite lines 300 feet above the water. They also prevail along the San Gabriel and Lampasas rivers, and to some extent in the valleys of some smaller streams.

Wind has often been as important a factor as water in producing such bluffs. It blows away the dried, pulverulent material of the softer layers, thereby undermining the more indurated layers until they appear as projecting shelves, which later fall away by their own weight. The bluffs of Mount Bonnell are largely of this nature. (See Pl. XXII.)

The same individual strata may form either the slope or the bluff type of topography, although the terraced slopes are more often cut out of the thinner alternations of the upper part of the formation and the bluffs out of the more massive medial beds. The very steep and in places impassable bluffs of the western side of Mount Bonnell have been formed from the same beds which on the other side of the mountain weather into terraced slopes. It is necessary only to follow the terraced beds of the eastern face of this mountain around to the west side to observe the change from the bench and terrace to the bluff character.

Western border belt of outcrops.—The formation outcrops along the western escarpment slope through the whole extent of the Edwards Cut Plain from Colorado River northward as far as central Wise County, where it ceases. (See Pl. LXVI.) In this region the outcrops occur as a belt of prairie between the Western Cross Timber valley and the mesa cap of the western escarpment of the Grand Prairie. The eastern margin of the main belt of the Western Cross Timbers, which coincides with the outcrop of the Basement sands south of Wise County, marks precisely the interior and lower parting of the Glen Rose formation. This belt of outcrop accompanies the western escarpment in all its meanderings—slowly ascending toward the summits of the divides in westerly directions and descending toward the stream beds east, down the valleys of the through-flowing rivers, such as the Colorado, Leon, and Brazos.

Beginning at the foot of Mount Bonnell on the Colorado River northwest of Austin, one may follow this narrow and irregular belt of the Glen Rose formation continuously northwestward through Travis, Burnet, Lampasas, Mills, and Brown counties, passing 5 miles north of Smithwick Mills, through the eastern part of Burnet, near Naruna and Nix, Lampasas County, and through Goldthwaite, Zephyr, and May. The belt passes through a gap in the Callahan Divide between Clio and May, in northeast Brown County, and then turns southeast down the valley of the Leon for 35 miles, passing through the town of Comanche to near Hazledell, Comanche County; from the latter point the belt turns due north for 30 miles to near Desdimonia, Eastland County, constantly narrowing toward the latter point, from which it turns northeast for 45 miles until it intercepts the Brazos near Buckner, Hood County. From the Brazos it again turns west of north for 25 miles to Whitt, in northwestern Parker County, and finally disappears about 15 miles due northeast of the latter point, in central Wise County.

BUTTE OF THE GLEN ROSE FORMATION, TRAVIS COUNTY, TEXAS.

This western belt is mostly a bluff or steep slope from Mount Bonnell to Burnet, but sometimes occupies areas of considerable width along the Colorado. From the southeast corner of Burnet County to Senterfit, Lampasas County, the outcrop is a narrow calcareous belt, often merely a thin subvertical slope less than 100 feet in width.

Between Goldthwaite and Antelope Gap the Glen Rose prairies are wider and consist of gentle slopes marked by many small stratified benches bearing no timber. They are well displayed all the way to Copperas Cove. From Senterfit the belt gradually widens northward, being fully 3 miles wide at Goldthwaite, until along the line of Mills and Brown counties it forms an extensive prairie nearly 10 miles wide. Then it gradually diminishes in area toward Clio. From northwest Comanche County, where the prairie has almost vanished, or at least is the narrowest possible strip, it widens again to the southeast through Comanche County south of the Leon. North of the Leon and in eastern Comanche County and western Erath County, west of Dublin and near Mount Airy, the belt narrows toward Desdimonia, from which place to the Brazos its outcrop forms merely a narrow ribbon. The western border areas increase to a width of nearly 8 miles along the Texas Pacific Railway west of Weatherford and Lambert, but narrows again northward, finally dying out, as previously stated, in Wise County, where the most northern Texas outcrop representative of the Glen Rose beds may be seen in a narrow band of fossiliferous calcareous-argillaceous sandstone from 6 inches to 1 foot thick, in the muds of the less calcareous and argillaceous Antlers sands, as shown in section No. 10 (p. 157).

In Arkansas, from Ultima Thule eastward to Murfreesboro, limestone layers, as described in the writer's report on Arkansas[1] under the general classification of the Trinity formation, may represent the Glen Rose formation, but it is not possible at present to correlate them with certainty.

Throughout the extent of this western border belt of outcrops the Glen Rose formation is thin and composed of less calcareous material than is exhibited in the more eastern outcrops. In fact, there is but little doubt that much of the formation is there merged into the Basement sands.

Inliers of Lampasas Cut Plain.—The largest areas and best exposures of the Glen Rose formation are found within the main area of the Lampasas Cut Plain east of the western border belt above defined, in the slopes and bluffs of the drainage valleys which are cut below the fragmentary areas of the summit level of the cut plain, which now form divides that partially or completely separate the outcrops of the Glen Rose formation in the slopes of the various stream valleys. Outcrops of the Glen Rose formation occur in this manner throughout a

[1]Ann. Rept. Geol. Survey of Arkansas, 1888, Vol. II.

stretch of country extending from the Brazos to the Colorado in Erath, Somervell, western Bosque, western Coryell, eastern Hamilton, eastern Lampasas, and northern Williamson and Burnet counties and along the slopes of the Colorado in western Travis County.

In these areas the streams have cut down into and sometimes through the Glen Rose beds, and with some of their more important lateral creeks flow upon the Glen Rose rocks until they pass upon higher beds to the east. In this manner the Glen Rose formation (beneath the Paluxy sand in case it exists, and, if not, below the Walnut beds) occupies the wide slopes of the stream valleys until they dip beneath the newer rocks to the east. Thus the valley slopes of the western half of the Lampasas Cut Plain south of Wise County are occupied by areas of the Glen Rose limestone surmounted wholly or in part by higher beds. The rocks are more thoroughly exposed in those areas where the streams have cut deepest, and hence the beds are best seen along the valley slopes adjacent to the Colorado and the Brazos.

The valley exposures are usually of much wider area than the outcrops of the western border belt, and sometimes spread out so widely that they coalesce across the divides between the streams through gaps where the cap rock has been eroded. Wide valley areas of the Glen Rose formation are found east of the western escarpment along the Brazos, between Buckner and the northeast corner of Bosque County, for a distance of 25 miles; along the Paluxy from west of Morgans Mill to its mouth, 30 miles; along the Bosque from west of Stephenville to east of Iredell, 60 miles; along the Leon from the Savannah Mountains northwest of Comanche to near Gatesville, 66 miles; along the Cowhouse from the northeast corner of Hamilton County to below Pidcoke, Coryell County, 50 miles; along the Lampasas from northern Lampasas County to below Youngport, 60 miles, and along the breaks of the San Gabriel in Burnet and Williamson counties, 25 miles.

The eastern limit of the valley outcrops of the Glen Rose beds intersects the Colorado River at Mount Bonnell, 4 miles west of Austin, and crosses the principal river valleys as follows: San Gabriel River, 12 miles above Georgetown, Williamson County; Lampasas River, about 12 miles below Youngsport; Leon River, near the mouth of Plum Creek, in Coryell County; Bosque River Valley, on the Houston and Texas Central Railway, 4 miles southwest of Walnut, Bosque County; and Brazos River, at the mouth of Camp Creek in the southwest corner of Johnson County. East of this line the rocks disappear by dip, and are embedded beneath the eastern half of the Grand and Black prairies, where they are penetrated by numerous artesian wells, as shown later.

The coastward border of the Glen Rose outcrops is marked as far south as the Leon by a narrow ribbon of upland forest which grows upon the overlying Paluxy sands. This forest, which is a southward-

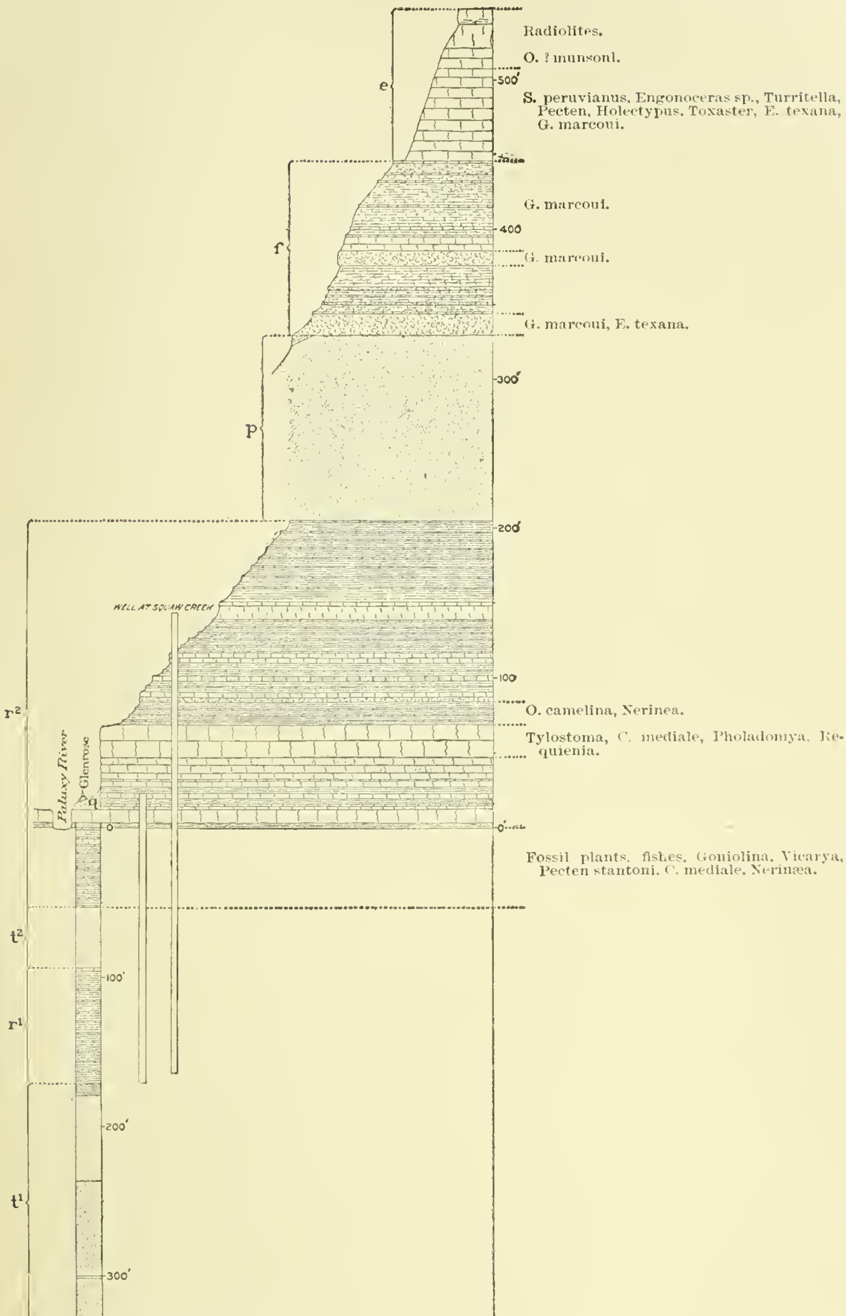


FIG. 12.—Section of slopes of Paluxy Valley from top of Comanche Peak, Hood County, to Glen Rose, Somervell County. (For explanation of lettering see Pl. XVI, p. 110.)

extending arm of the Western Cross Timbers, continues irregularly southward from its junction with the main belt of the Western Cross Timbers in Wise County, to the Leon. Hence in that portion of their extent where they are overlain by the Paluxy sands, the outcrops of the Glen Rose formation constitute prairie spots within the general area of the Western Cross Timbers, as seen between Weatherford and Millsap, on the Texas Pacific road, and in the slopes below the escarpment of Comanche Peak in Hood, Erath, and Somervell counties. South of the Cowhouse, where the Paluxy sands terminate, the outcrops of the Glen Rose beds are prairie lands continuous with those of the Walnut clays.

The inlying valley outcrops increase in area southward through Parker, Hood, Erath, Comanche, Lampasas, and Coryell counties. These rocks are well exposed along the valley of Lampasas River through Lampasas and Burnet counties, as well as along every creek valley tributary to this river. The confluents to these tributary creeks have also cut wide valleys into the rocks of the Glen Rose beds below the general level of the remnantal Edwards divides between Lampasas and Leon rivers along the east line of Lampasas County and between Lampasas and San Gabriel rivers.

The North Fork of San Gabriel River, with its main tributaries, Russell Fork and Bear Creek, runs in similar valleys for a great portion of its course in Burnet County. These valleys are narrow and contract continually as they pass southeast into Williamson County.

In the counties of southwestern Texas between the Pecos and the Colorado and south of the Burnet-Llano Paleozoic region these rocks form the basement of the Edwards Plateau. The canyons of Guadalupe, Comal, Nueces, Frio, Medina, and Devils rivers cut down into them.

DETAILED STRATIGRAPHIC SECTIONS OF GLEN ROSE FORMATION.

Typical sections of the formation, about 220 miles apart, near the northern and southern limits of the field of occurrence in the Grand Prairie region, illustrate the details of the formation. The more northern of these typical sections of the Glen Rose formation is seen in the lower part of the general Comanche Peak section (see fig. 12), in the slopes of the Paluxy Valley of Somervell County near Glen Rose, between the Paluxy sands above and the Bluffdale sands (the northern equivalent of the Hensell sands of the Colorado section) below.

SECTION NO. 7.—GLEN ROSE BEDS IN VALLEYS OF BRAZOS AND PALUXY RIVERS, ADJACENT TO GLEN ROSE AND GRANBURY, TEXAS.

	Feet.	
Paluxy sand (as described on page 167)		
Glen Rose beds:		
14. Thick, arenaceous marly limestone and thin, compact limestone in layers, the upper bands of which are sandy, the bands succeeding each other as follows:		
Limestone fossiliferous above, sandy below	4	
Marly layers	4	
Hard yellow limestone	1	
Marly layer	5	
Hard limestone flags, lower portions more fossiliferous and argillaceous and pervious to water	3	
	——	17
13. Marly limestone		12
12. Four marly layers, from 4 to 6 feet in thickness, separated by three thin compact bands of limestone, as follows:		
Marly layer	12	
Marly layer	3.5	
Limestone slabs	1	
Limestone slabs, compact and coarser	.5	
Marly layer	4	
Limestone slabs	2	
Marly layer	3	
Compact magnesian limestone slabs	1	
Marly layer	4	
	——	31
11. Hard, white crystalline limestone, which makes decided benches on the hillsides		4
10. Marly limestone		10
9. Thin alternations of marl and limestone, as follows:		
Gray, slightly argillaceous limestone	1	
Marly layer	4	
White broken limestone, fossiliferous	2	
Three soft limestone layers, with intervening marls	6	
White, evenly laminated limestone, with ferruginous segregations	1	
	——	14
8. Marly limestone, changing gradually upward into harder limestone		8
7. Soft argillaceous limestone, with thin indurated bands of limestone at the center and at the upper edge		8
6. Hard magnesian limestone; few fossils; small, ferruginous segregations		4
Soft yellow friable clay marls, with *Nerinea* and small fossils	10	
Yellowish clays with *O. camelina*	4	
Indurated limestone layers composed of shell débris	3	
	——	21
5. Chalky white limestone with numerous molds of *Lunatia* (*Tylostoma*), *Cardium*, *Trigonia*, and *Pholadomya*		10
4. Requienia (Caprotina) limestone. An agglomerate of fossil *Requienia* embedded in a firm chalky white matrix		20
3. Limestones and marls in alternation, the limestones forming thick massive layers, as exposed in the north bluffs of Paluxy Creek and Squaw Creek, between Glen Rose and Comanche Peak		130

Glen Rose beds—Continued.	Feet.	
2. Two miles west of Glen Rose a bluff in the creek shows a series of alternations of white quarry limestone, 10 feet of which presents the following section in descending order:		
Dimension layer of sandy yellow limestone with casts of fucoids	1	
Thin calcareous shales, with a layer of pyrites and epsomite; Thin laminated flags, containing gasteropods; Calcareous marly shales; Flaggy seams, from which the fossil fish shown in Pl. XXIV was procured	3.5	
Dark-blue calcareous shales	1	
Soft chalky white limestone, from which plants (Pl. XXVI) were collected	1.5	
Impure limestone, containing *Goniolina* at the top and made up below of an agglomerate of numerous fossils (see Pl. XXV)	3	
		10
1. Limestone in creek bed (estimated)		20
Total Glen Rose formation		315
Basement sands (penetrated by wells at Glen Rose):		
Bluff Dale sands	40	
Alternations of limestone and marl	67	
Basement sand	20	
		127

The thickest and most southern exposures of the Glen Rose beds in the Grand Prairie region are shown along the canyon of the Colorado west of Austin, in Travis County.[1] (See Pl. XX, *B*.)

The accompanying detailed section of the entire thickness of the beds of the bluffs of the south side of the Colorado in the vicinity of Round Mountain, Travis County, is typical of these beds. It coincides almost exactly with Mr. Taff's[2] Sandy Creek section, previously measured, on the opposite side of the river.

Section No. 8.—From top of high hill south of Round Mountain, east of road from Bee Caves to Lohmanns Crossing of the Colorado River.

	Feet.	Feet.
Comanche Peak limestone:		
40. Limestone breaking easily; some firm slabs at top	5	5
Walnut formation:		
39. Clays with large *Exogyra texana;* forms a shelf	10	15
Glen Rose formation:		
38. Shaly limestone; not very fossiliferous (*Tylostoma*)	10	25
37. Alternating harder and softer strata of limestone; some thin slabs about base; not fossiliferous	15	40
36. Alternating hard and soft yellowish limestone; not very fossiliferous	35	75
35. Shaly limestone, fossiliferous, contains a few individuals of *Cardium mediale* and a few other species	4	79

[1] In 1889 Mr. J. A. Taff was employed as the writer's assistant to make sections of these exposures in order to study the details and variations of the beds. These measurements and sections were later published in detail. (See R. T. Hill, Occurrence of artesian and other underground waters of Texas, etc., Senate Ex. Doc. 51, 52d Congress, 1st session, Washington, 1892; and second edition of same, Washington, 1893; also J. A. Taff, Third Ann. Rept. Geol. Survey of Texas, Austin, pp. 1892, 295–300.)

[2] Mr. Taff's section measured 447 feet, or 8 feet less than this: Third Ann. Rept. Geol. Survey Texas, 1891, Austin, 1892, pp. 298–299.

	Feet.	Feet.
Glen Rose formation—Continued.		
34. White limestone; breaks easily	15	94
33. Marly material, forming a terrace	10	104
32. Alternations of soft argillaceous or marly limestone with harder thin layers of purer limestone (four hard and three soft layers)	30	134
31. Slope and shelf; fossils at top	15	149
30. Hard, nodular limestone; contains *Nerinea* fragments	5	154
29. Slope and shelf	14	168
28. Thin, hard ledge	1	169
27. Slope; very gentle—rather a shelf	15	184
26. Bed of *Monopleura* in hard, yellowish limestone	2	186
25. Hard, perforated limestone	2	188
24. Alternating thin hard layers and soft thick layers; the thin layers 6 inches to one foot, the soft 3 to 4 feet	20	208
23. Soft, chalky, argillaceous stuff	2	210
22. Ledge of hard, yellowish, perforated limestone, 2 feet; hard ledges of limestone, 8 feet	10	220
21. Small hard ledge	2	222
20. Soft argillaceous limestone, marly; forms a slope	10	232
19. Shelf above, ledge below, rises	10	242
18. Soft, chalky (argillaceous) limestone with *Exogyra texana* at base, with harder layers that form shelves—eleven hard ledges. Twenty feet from the top of these beds the hard ledge is honeycombed by solution, and is arenaceous. In the lower 20 feet numerous fossils occur. *Lunatia* (*Tylostoma*) *pedernalis*, *Cardium mediale*, "*Goniolina*," etc.; also horizon of *E. texana*. Thickness of series	60	302
17. Hard ledges of honeycombed (perforated) limestone. The limestone, hard, yellowish, contains many poorly preserved calcitized fossil shells, largely the remains of *Nerinea*	30	332
16. Hard ledge of limestone; many *Cardium mediale*	5	337
15. Soft, argillaceous, chalky limestone	5	342
14. Ledges, 6 inches to 1 foot thick, with soft, shaly layers between	20	362
13. Soft limestone	20	382
12. Hard ledge	2	384
11. Soft, chalky, argillaceous layer	10	394
10. Ledge of hard brownish or yellowish limestone, containing embedded sand grains	5	399
9. Soft, chalky, argillaceous limestone, with an occasional hard ledge. Hard ledge 2 feet thick 15 feet above base. In the upper part of this marly bed fossils are very abundant. *Cardium mediale*, *Lunatia* (*Tylostoma*) *pedernalis*, many echinoderms, *Pseudodiadema texana*, *Nerinea*, *Ostrea*, etc	35	434
8. Ledge of hard yellowish limestone	5	439
7. Slope, underlain by soft, chalky limestone	25	464
6. Arenaceous ledge, a few feet	3	467
5. Soft ledge with many *Monopleura*	3	470
Travis Peak formation:		
4. Rather hard ledge, with poorly preserved fossils; appear to be oysters	2	472
3. Soft, chalky limestone	20	492
2. Ledge of yellowish limestone, 2 feet, and 40 feet of the section covered by river alluvium	42	534
1. Yellowish calcareous sandstone at river level; thickness not obtainable.		

Totals of foregoing section.

Comanche Peak (in part) and Walnut formation	15
Glen Rose formation (entire) about	455
Travis Peak formation, upper part	64
Total of section, about	534

In the foregoing section thin beds of calcareous packsand appear above the Caprotina bed, interstratified with the lower Glen Rose limestones; or the latter themselves are arenaceous in their basal layers, the clay and lime material increasing and the sands decreasing in ascending series. These impurities are increasingly noticeable westward, in which direction the limestone beds fray out into clays and sands. These partially arenaceous beds of the lower portion of the formation do not occur in as uniform alternations as those of the upper third. For instance, there may be 10 or 12 feet of soft, friable material, and then a thin layer of less than a foot of indurated stone. In weathering, this results in wide terraces with low but steep bluffs surmounted by flat-topped stratum benches, as seen in southeast Blanco County.

The yellow magnesian and lime strata increase in thickness in ascending series as the sands decrease, and become conspicuous in the middle portion, occuring in strata often 5 to 15 feet in thickness, as seen in the cliffs of Mount Bonnel, near Austin.

The upper third of the formation, as seen at the top of Mount Bonnel, presents thin alternations of friable, slightly arenaceous marls and hard limestone strata. The limestone strata usually average less than a foot in thickness. These alternations occur with great regularity and persistence. The marls are soft and laminated and are composed largely of minute shell fragments, giving the beds a distinctly granular oolitic character. They have little clay and imbibe the moisture very freely.

North of the Lampasas the Glen Rose formation is succeeded above by the Paluxy sands, which are believed to radically change southward into thin alternations of sandy marl and limestone, composing the upper 100 feet of the Glen Rose formation of the Colorado section, where the top of the Glen Rose formation is just below a bed of yellow marl (the Walnut formation), which is persistent over a great area in central Texas, and is the culminating horizon of the oyster *Exogyra texana*, after which the Walnut beds have at times been called.

In the northwest corner of Comanche County is a group of isolated limestone mesas representing the northwest extension of the Caprina-capped buttes of the Grand Prairie. The following is a section of Baker Mountain, at the southeast corner of these buttes, made by Mr. J. A. Taff:

SECTION NO. 9.—BAKER MOUNTAIN, COMANCHE COUNTY, TEXAS,[1] SHOWING THINNED-OUT WESTERN REPRESENTATIVE OF THE GLEN ROSE FORMATION NO. 2.

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
6. Comanche Peak limestone, with probably the basal portion of the Edwards limestone	110	110
5. Paluxy and Walnut formations. Calcareous, indurated sandstone, grading upward into marly or arenaceous, crumbling limestone, bearing small *Exogyra texana*, *Gryphæa pitcheri*, and associated fauna of the *Exogyra* bed, such as *Ammonites*, *Toxaster*, *Natica*, and *Cardium*	20	130
4, 3. Glen Rose formation (?). Red and purple clays, locally distributed. In some places it is 10 or more feet in thickness; at others it is absent. Stratified, partially indurated, calcareous sand, which weathers in rough, nodular, porous masses	210	340
2, 1. Trinity sands. Coarse, gritty sand. Porous homogeneous "pack sand"	110	450
0. Carboniferous sandstone.		

SECTION NO. 10.—SECTION SOUTH SIDE OF SALT CREEK, ONE MILE SOUTH OF COTTONDALE. (TAFF.)

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
5. Paluxy sand		
4. Arenaceous limestone with fossils	10	10
3. Calcareous layers, false bedded	10	20
2. Fossil leaves and wood in thin, irregular sheets	0.5	20.5
1. Basement or Trinity sand	+50	70.5

For 50 feet above the fossiliferous strata the sand layers show various degrees of compactness. They are interstratified with bands of lignite and lignitic sand and bear much silicified wood. Such exposures occur in a ravine near the Fort Worth and Denver Railway 5 miles northwest of Decatur.

The Glen Rose beds are not exposed along the western and northern border region from central Wise County to the Arkansas line. This is probably because the beds have lost their identity throughout this littoral area by having become merged into the Basement sands, and because a change in strike from a north-south to an east-west direction takes place in this vicinity. The typical limestone beds of the seaward

[1] Modified from a section by J. A. Taff: Third Ann. Rept., Texas Geol. Survey, Austin, 1891, p. 321.

extension are no doubt fully developed coastward beneath the Grand Prairie.

No outcrop of the Glen Rose beds is known in Indian Territory, where the entire Trinity division, so far as known, is made up of sand.

THICKNESS AND VARIATION OF GLEN ROSE BEDS.

The greatest thickness of the Glen Rose beds exposed in the Colorado section is about 435 feet, of which probably 100 feet at the top may be considered the equivalent of the Paluxy sands. The rocks are exposed in many sections from the Colorado northward about 130 miles to Glen Rose. Near the latter place, as shown in the Comanche Peak section, the Glen Rose beds have an exposure of 236 feet, which, together with the overlying Paluxy sands, show a thickness about equivalent to that of the Round Mountain section of the Colorado Valley.

The Glen Rose formation decreases in thickness from east to west, and passes from limestones into clays and sands toward the western border region, as is shown by various general and local sections and described in detail later under the head of Structure. (See figs. 8, 41, and 44.) Obversely stated, in going south-southeast, perpendicular to the strike, from any point on the western border of the Grand Prairie, the rocks of the Glen Rose rapidly increase in thickness along the line of dip and change from sands into clays and limestones, thus thickening coastward from the interior border region at a varying rate, to be explained later, but averaging 8 feet to the mile.

In the sections of the western border the Basement sands pass upward into reddish clays, sandy clays, and impure limestones; proceeding coastward, the limestones become more frequent and abundant and the sands and clays less important.

As shown in the discussion of the transgression of the beds of the Trinity division upon the Paleozoic rocks of the old Cretaceous shore line, the Glen Rose beds are largely represented along the western border by pack sands which herein have been included under the general name of the Basement or Trinity sands. There is little doubt that a large part of the Basement sands of the western border from Burnet to north of Nix, Lampasas County, as well as of the Antlers sands of the northwestern and northern border regions is synchronous with the lower portion of the Glen Rose formation. It is also certain that the uppermost calcareous Glen Rose beds of the southern sections represent the southern equivalent of the Paluxy sands of the northwest, as will be more fully set forth under the head of Paluxy sands.

There are but few places within the area of the Grand Prairie proper where the entire thickness of the Glen Rose beds is exposed, notably between the village of Paluxy, Erath County, and the higher slopes of Comanche Peak in Hood County, around Lampasas and in the Colorado section of Travis County. Even these sections thus exposed, owing to their proximity to the western border, do not represent the Glen Rose beds in their greatest thickness.

Eastward down the valleys of the streams incised below the level of the Lampasas Plain, which but seldom cut entirely through the Glen Rose, the streams become superimposed upon successively higher and higher beds. The lower beds become successively embedded as one proceeds down the streams, and the sections exposed in that direction are constantly being curtailed of their lower beds. Thus sections of the beds in regions of their greatest thickness to the east are only partial, as in the case of the Mount Bonnell section and the Rocky Creek section in Williamson County, where the lower part of the formation is concealed. Finally the streams, in their coastward journeys, completely surmount the Glen Rose beds, which become entirely embedded beneath the Black Prairie, so that beneath the latter area their thickness can be estimated only from the artesian-well drillings, which show them to be 600 feet at San Marcos, 600 feet at Austin, 400 feet at Belton, and 554 feet at Waco. (See chapter on Structure and various geological sections.)

PALEONTOLOGY OF GLEN ROSE BEDS.

The Glen Rose beds contain fossil remains of foraminifers, echinoids, mollusks, vertebrates, and plants. Corals, brachiopods, and ammonites are conspicuously lacking. The mollusks are the most abundant, but are rarely well preserved, usually occurring as casts and molds. Many layers are barren; others are made up almost entirely of organic remains. In general, the fossils occur in certain conspicuous fossiliferous zones, which have wide extent and are even more persistent than the lithologic matrix in which they are embedded.

In the typical Comanche Peak section the lower 30 feet is marked by numerous mollusks, forming a massive agglomerate, above which is a single stratum, from which one exceedingly rare fish, the only specimen of its genus hitherto found in America (see Pl. XXIV), *Macrepistius arenatus* Cope, has been procured. A list of the invertebrates of this horizon is given on page 161.

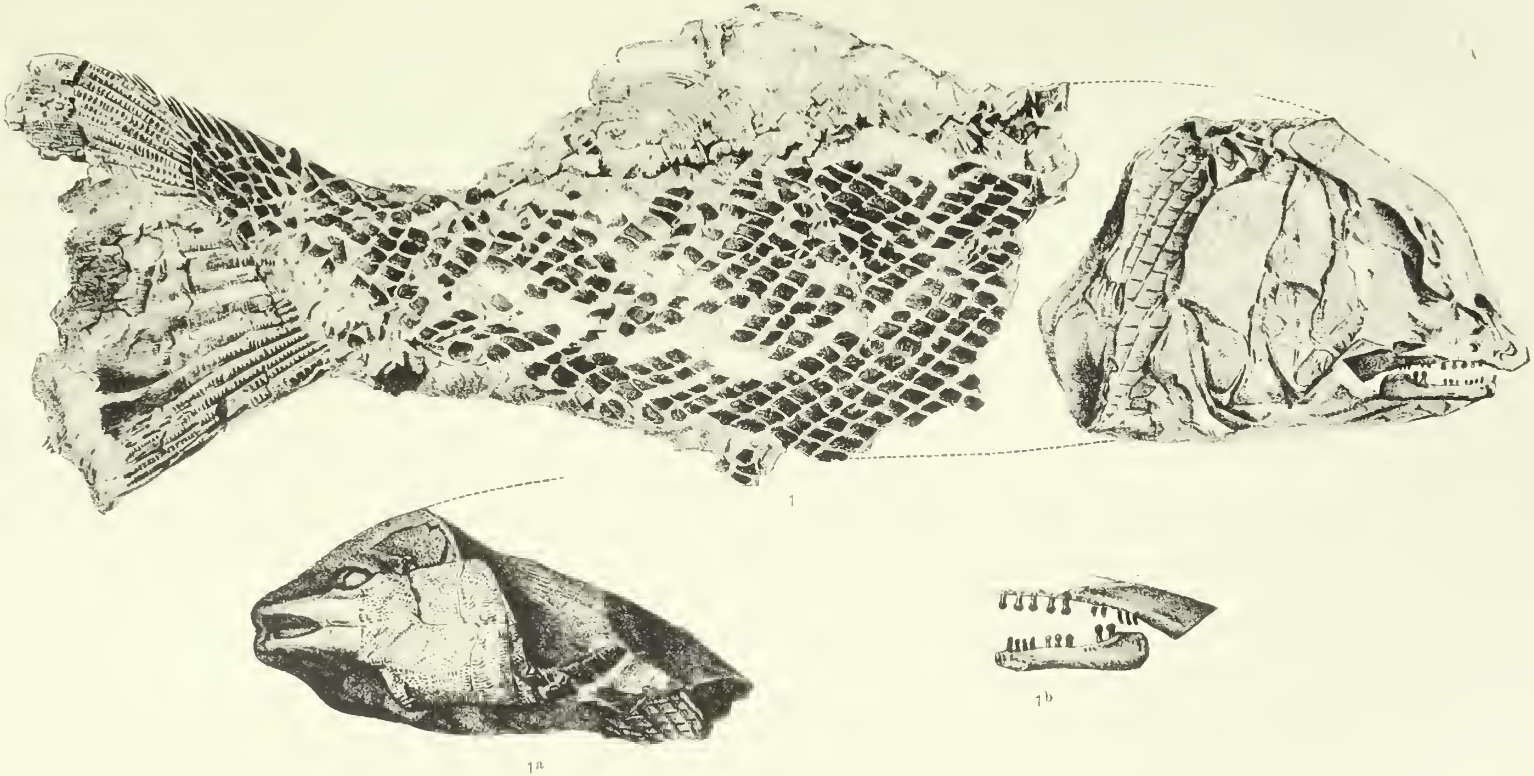
For an interval of from 80 to 100 feet above this lowest fossiliferous horizon the Glen Rose section is comparatively barren, but has not been carefully searched for fossil remains elsewhere. About 100 feet above the base of the section, 250 feet below the base of the Fredericksburg division, and 150 feet below the base of the Paluxy sands of the Comanche Peak section, are thick, white, chalky limestones aggregating about 36 feet, which are exposed in the banks of the Brazos east, north, and south of Granbury. The lower 20 feet of this limestone is a massive agglomerate of fossil requienias embedded in a firm semicrystalline matrix of white limestone. This requienia limestone is a most important paleontologic landmark. The 16 feet of limestone lying above this contains innumerable molds and casts of *Lunatia* (*Tylostoma*).[1] *Trigonia*, *Cardium*, and *Pholadomya*, some of which are of the same species as those found in the basal fossiliferous horizon. Fossils similar to those of this chalky bed range from the base to the top of the section, but this particular horizon is one of the most persistent in all sections of the Glen Rose formation. These beds are succeeded above by thin marly clays and impure, nonchalky limestone. In the clays are found large free specimens of *Ostrea camelina* Cragin. The thin crystalline limestone, from 1 to 3 feet thick, near the top of these clay beds, is composed almost entirely of shell débris. Plant remains and *Nerinea*, *Anomia*, and *Turritella* also occur in this group.

The upper 120 feet of the beds of the Comanche Peak section, consisting of thin alternations of impure clays and limestones, are largely made up of comminuted shell débris, but have not been searched minutely for fossils. The writer has observed in them numerous casts of *Lunatia* (*Tylostoma*) and *Cardium mediale*.

In the Colorado section, which is some 220 miles south of the Glen Rose section, the paleontologic horizons are somewhat different. The lowest fossiliferous horizons are marked by the fossils *Monopleura* and *Requienia* (see Pl. XXXIII). About 75 feet above this is a chalky horizon, 35 feet thick, which contains large casts of *Cardium mediale*, *Lunatia* (*Tylostoma*) *pedernalis*, and *Pholadomya* (see Pl. XXI). This is about 330 feet below the base of the Walnut formation in the Round Mountain section. About 275 feet below the base of the Fredericksburg division there is another hard layer characterized by *Lunatia* (*Tylostoma*) and *Cardium* fauna and a problematic form called "*Goniolina*." *Exogyra weatherfordensis* also occurs. This horizon corresponds closely with the *Lunatia* (*Tylostoma*) horizon above the *Requienia* horizon of the Glen Rose section, as is shown by its near proximity to the *Ostrea camelina* zone, which occurs above it, 206 feet from the top. *Nerinea* appears nearly a hundred feet above this bed, or 300 feet below the base of the Fredericksburg division, and ranges into it. One hundred and seventy-five feet below the base of the Fredericksburg division there is a second horizon of *Monopleura*, in a hard yellowish limestone, while 145 feet below is another zone of *Nerinea*.

In the upper 140 feet of the Colorado section, which homotaxially may represent the stratigraphic position of the lower Walnut and Paluxy beds of the northern sections, are numerous small fossils, including *Exogyra texana* (see Pl. XXVII), while *Cardium mediale* and *Lunatia* (*Tylostoma*) continue to the uppermost layers.

[1] Mr. Stanton has recently determined the generic name of this fossil to be Lunatia instead of Tylostoma.



A FOSSIL FISH OF THE TRINITY DIVISION

(MACREPISTIUS ARENATUS Cope)

THE MERIDEN GRAVURE

Foraminifera.—A peculiar fossil of the Glen Rose beds of the Colorado section is the large foraminifer *Orbitulina texana* of Roemer, which occurs in a thick, chalky stratum adjacent to the lower Lunatia (Tylostoma) beds, about 220 feet below the summit of the beds in the Colorado section. This fossil has not been noted north of the Colorado section, but is a very marked and abundant species southward. The chalky bed containing these shells was formerly exposed in the bed of Bull Creek west of Mount Barker, but has now been covered by the sediments from the Austin dam. Diller[1] has noted the occurrence of other species of *Foraminifera* in the matrix of the Orbitulina chalk, belonging to that genera.

Echinoids are very rare, so far as known, in the Comanche Peak section, and there are but few in the upper 100 feet of the Colorado section, where a small species of *Holectypus* abounds. The writer has collected a few specimens of an irregular Epiaster-like echinoid, from a horizon at about the level of the Colorado near the Chautauqua, west of Austin.

Mollusca.—Remains of marine mollusks abound in the Glen Rose formation. They occur abundantly in certain horizons, and as isolated specimens in other beds which are generally barren of fossils.

Following is an imperfect list of the *Mollusca* thus far reported from these beds:[2]

(*a*) *From the lower beds at Glen Rose.*

Anomia texana sp.	Trigonia stolleyi.
Ostrea ragsdalei.	Eriphyla pikensis Hill.
Pecten stantoni.	Protocardia sp. indet.
Modiola branneri.	Pleuromya (?) henselli.
Leda (?) harveyi.	Buccinopsis (?) parryi Conrad.
Cyprina medialis Con.	Lunatia (Tylostoma) pedernalis (Roemer).
Cucullæa gratiota Hill.	Glauconia (Vicarya) branneri.
Cucullæa terminalis Conrad.	Neritina sp. indet.

(*b*) *Additional species from various localities and horizons.*

Ostrea camelina Cragin.	Requienia sp.
Exogyra weatherfordensis Cragin.	Monopleura sp.

The only fossils which seem peculiar to the Glen Rose beds are the foraminifer *Orbitolina texana* and the mollusks *Glauconia branneri*, *Lunatia pedernalis*, and *Cyprina medialis*.

The most marked molluscan fauna seems to be an association of certain forms usually preserved as molds and casts, including large species of mollusks such as *Cyprina medialis*, *Lunatia* (*Tylostoma*) *pedernalis*, *Pleuromya henselli*, *Trigonia*, etc. These are found in nearly every

[1] Bull. U. S. Geol. Survey No. 150, 1898, p. 119.

[2] The writer has not access to his various collections whereby he could make a revised and final list of these species; and inasmuch as the study of the paleontology of the Cretaceous has been turned over to Mr. T. W. Stanton, it is not desirable to attempt such a list until the latter's researches are completed.

exposure of the formation, but seem to occur in several definite horizons separated by barren beds in the lower and middle portions of the formation. Beds of this nature will be referred to as the Lunatia or Tylostoma beds.

An extremely fossiliferous *Lunatia* (*Tylostoma*) horizon occurs about 200 feet below the upper edge of the Glen Rose beds in the valley sections. This horizon is also well exposed in the Colorado, Comanche Peak, Lampasas, Williamson, Comanche, and other sections.

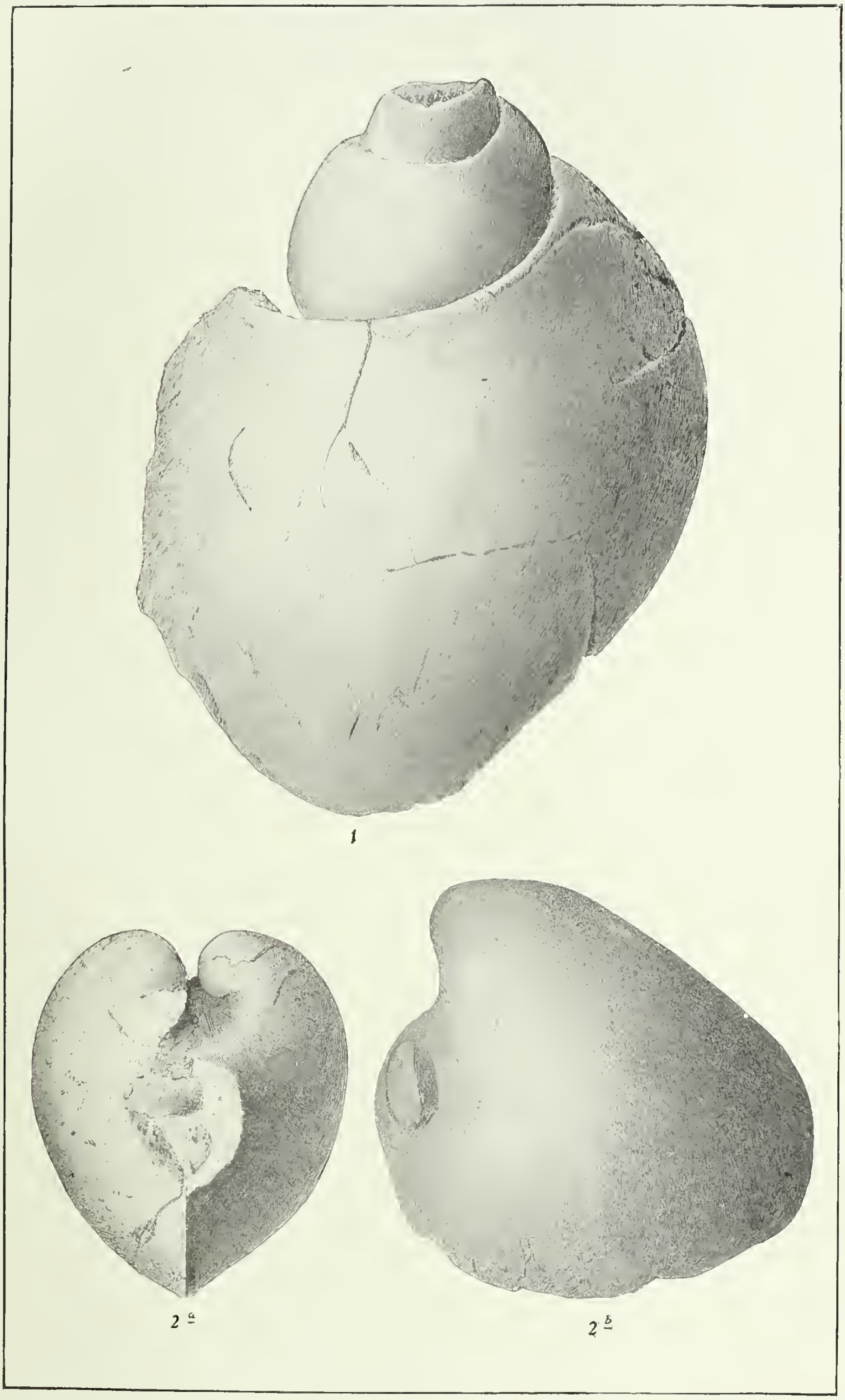
Glauconia branneri seems to be a species which ranges throughout the beds. It occurs at the base of the beds at Glen Rose and near their summit at Post Mountain, Burnet County, and in western Parker County.

Ostrea camelina Cragin, a normal ostrean form, apparently occupies a well-marked horizon about the middle of the beds. Small forms of *Exogyra texana* (var. *weatherfordensis*) Cragin are found more or less abundantly in the Glen Rose beds. This fossil occurs in the Twin Sisters Peak section, Lampasas County, 50 feet beneath the summit of the series. At Bachelor Peak it is 150 feet beneath. This same bed also occurs in the Colorado section, Bosque County, and in the Weatherford section. The writer has observed it also at the very base of the Glen Rose beds in the northeast quarter of the Blanco quadrangle. Concerning this species it can be said that it is always very small, seldom exceeding an inch in length, thereby differing from the large adult forms which so distinctly mark the Walnut beds.

The aberrant forms *Monopleura* and *Requienia*, which attain their greatest development in the upper layers of the Fredericksburg division (see Pl. XXXIII), first appear at the very base of the Glen Rose formation in the Colorado section, from 337 to 450 feet below its summit. Monopleuras have not as yet been detected in the northern sections, but in Comanche Peak around Granbury there is a remarkable agglomerate of requienias about 130 to 140 feet below the summit of the beds.

A *Requienia* horizon occurs in the Bachelor Peak section (Lampasas County), just below a Lunatia (Tylostoma) bed, in a band of hard, arenaceous limestone 10 feet thick, 185 feet below the Walnut beds. The rock weathers with a peculiar rough surface. This is probably the most southern outcrop of the Requienia bed of the Comanche Peak section. In the Colorado section there are three well-defined horizons of the fossil *Monopleura*, at the base and in the middle portions of the section.

In the more shallow beds of the upper 100 feet of the sections south of the Leon are found many small species which have a Fredericksburg affinity. These include *Exogyra weatherfordensis*, an antecedent of *E. texana*, a small echinoid, nerineas, and other species which are not found below the Paluxy sand in the Comanche Peak section. In



CHARACTERISTIC FOSSILS OF THE GLEN ROSE BEDS.

1, Lunatia (Tylostoma) pedernalis Roemer; 2*a*, 2*b*, Cyprina? mediale Conrad.

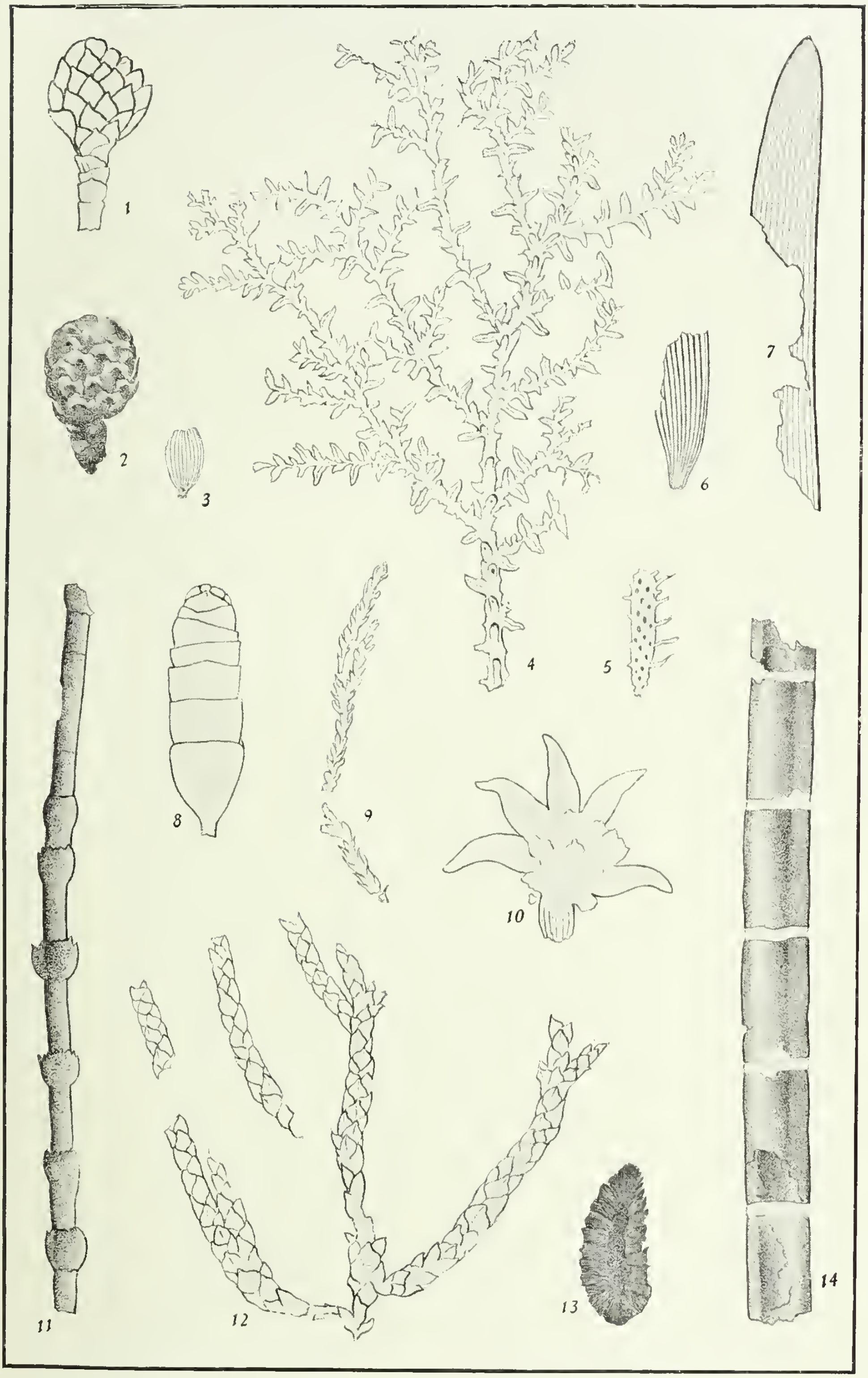
PLATE XXVI.

PLATE XXVI.

CHARACTERISTIC PLANTS OF THE TRINITY DIVISION.

Fig. 1. Pagiophyllum dubium sp. nov.
2. Pagiophyllum dubium sp. nov.
3. Podozamites acutifolius Font.?
4. Sequoia pagiophylloides sp. nov.
5. Laricopsis longifolia Font.
6. Podozamites sp.?
7. Zamites tenuinervis Font.
8. Frenelopsis varians sp. nov.

Fig. 9. Sphenolepidium sternbergianun var. densifolium Font.
10. Williamsonia texana sp. nov.
11. Equisetum texense sp. nov.
12. Brachyphyllum texeuse sp. nov.
13. Brachyphyllum texense sp. nov.
14. Frenelopsis varians sp. nov.



FOSSIL PLANTS FROM THE BASE OF THE GLEN ROSE FORMATION GLEN ROSE, TEXAS.

the upper beds of the Glen Rose at Lampasas there are many small bivalves of the form described as *Chione decepta* by the writer.

Nerineas especially abound in the upper part of the Glen Rose beds. These are first noted as a conspicuous zone in the Glen Rose section at Granbury. In the Colorado sections they are rather abundant as far down as 100 feet below the top.

Ammonites, which occur more or less frequently through all the other formations, are conspicuously absent, and gryphæate oysters, which commence in the beds above, are also notably lacking.

Fossil plants.—There are many silicified and lignitized trunks in the Basement sands of the western border region which have been but little examined by the paleontologists, some of which were deposited synchronously with the more calcareous beds of the valley sections. These are most probably the heavier parts of the same plants, the lighter débris of which—leaves, stems, and fruits—are occasionally found in the calcareous valley sections.

Traces of fossil plant remains, such as casts of stems and leaves of monocotyledonous plants, are found at various places in the calcareous beds of the valley sections; but the only locality which has yielded determinable specimens is at Glen Rose, at the base of the Comanche Peak section. The writer has seen at Granbury monocotyledonous leaves and stems and plants similar to those found at Glen Rose 100 feet above the base of the Glen Rose horizon, and at Austin in the gap between Mount Bonnel and Mount Barker, nearly 200 feet above the base of the section. The problematic fossil *Goniolina*, which has been referred to many classes of the animal and vegetable kingdom, and concerning which we as yet know but little, is found at the very base of the Glen Rose beds in the Comanche Peak section, and in the Colorado section it ranges from near the base upward, occurring in several horizons, into the base of the Fredericksburg division. The writer is of the opinion that this is the fruit of a conifer, but other authorities disagree with him. The question can not be finally determined until more perfect specimens are found.

The following species of plants are all that have been determined from the Glen Rose beds. These come from a single stratum west of Glen Rose, and were described by Prof. W. M. Fontaine.[1] (See Pl. XXVI.)

1. Equisetum texense Font.
2. Sphenopteris valdensis? Heer.
3. Dioonites buchianus var. rarinervis Font.
4. Dioonites buchianus Schimper.
5. Dioonites buchianus var. angustifolius Font.
6. Dioonites dunkerianus (Göpp.) Miguel.
7. Podozamites acutifolius Font.
8. Podozamites sp.?
9. Zamites tenuinervis Font.
10. Abietites linkii (Roem.) Dunk.
11. Laricopsis longifolia Font.

[1] Proc. U. S. Nat. Mus., Vol. XVI, 1893, pp. 261-282.

12. Sphenolepidium sternbergianum var. densifolium Font.
13. Pinus sp.? Font.
14. Brachyphyllum texense Font.
15. Pagiophyllum dubium Font.
16. Frenelopsis varians Font.
17. Frenelopsis hoheneggeri (Ett.) Schenk.
18. Sequoia pagiophylloides Font.
19. Abietites sp.?
20. Williamsonia texana.
21. Carpolithus obovatus Font.
22. Carpolithus harveyi Font.
23. Cycadeospermum rotundatum Font

According to Professor Fontaine,[1] the plants found at Glen Rose show, so far as can be judged from so imperfect a collection, that the Trinity flora finds its nearest analogue in the older portion of the lower Potomac. There is, however, this important difference: No trace of angiosperms, even the most archaic, has been found. We have only the four elements of the typical Jurassic flora. This, then, makes the Trinity flora somewhat older than that of the oldest Potomac. The absence of the angiosperms and the presence of the forms that are fonnd, indicate decidedly that the Trinity flora is not younger than the earliest stage of the Cretaceous.

PALUXY FORMATION.

CHARACTER AND OCCURRENCE.

The Palnxy sands (see Pls. LXVI and LXX), although of less areal extent than the lower sand beds, mark an important horizon, inasmuch as they are a valnable sonrce of artesian water in the region of their embed and of surface wells in the area of their ontcrop.

In Wise, Parker, Hood, Erath, Somervell, Bosque, Hamilton and Coryell counties the Glen Rose limestones grade up into a well-defined and mappable formation, which attains a maximum thickness of 100 feet, composed of fine white packsands closely resembling the Basement sands, of which they are a ramification, as is elsewhere shown, and the outcrop of which corresponds to the eastern limbs of the Western Cross Timbers, as shown on Pl. LXVI. When these sands outcrop on slopes or plains, or otherwise than in vertical exposures, they are marked by a growth of forest timber, largely post oak and black-jack.

As a whole, the Palnxy bed is a body of homogeneous, fine-grained, porous, compact, but not indurated sand, bearing numerous specimens of silicified and lignitized wood. In detail it is false bedded on an extensive scale, and often finely and beautifully laminated. Lenticular bands of impure clay occur, with lignitic sand in like form. The basal position of the sand becomes calcareous and flags of compact semicrystalline shell limestone sometimes occur in the marly sand. Near its upper limit the sand becomes argillaceous in some localities, and occasionally there are nearly pure clays. The sand is stratified

[1] Op. cit., p. 279.

and sometimes cross bedded, and there are local hardenings. The color changes from gray to yellowish, and the amount of ferrugination which is here found is variable. Southwest of Weatherford, along Sanchez Creek, the argillaceous bands are made up of thin agglomerates of calcified shells, mostly *Vicarya* and small species of bivalves. While similar to the Basement sands in many respects, the Paluxy sands are more calcareous and argillaceous in places, and possibly less ferruginous.

The general outcrop of this formation, except its extension westward around the Callahan Divide (see Pl. LIV), is well shown on the geologic and the artesian-well map (Pl. LXVI). The principal outcrops are found within the western portion of the Lampasas Cut Plain, between the Trinity and the Leon. It also occurs along the western border scarps, ultimately becoming the Basement sands along the Callahan Divide. It also extends northward from Decatur, but in this portion of its course it is so united with and inseparable from lower formations of the Basement sands that it is necessary to treat it under another head (see Antlers sands, p. 192).

The most typical exposures of the Paluxy formation lie within the northern portion of the Lampasas Cut Plain, in Parker, Hood, Somervell, Erath, Bosque, Comanche, Hamilton, and Coryell counties. (See Pls. LXIV, LXVI.) In this area the outcrops, like those of all the formations within the Lampasas Cut Plain, occur in numerous disconnected belts or ribbons running parallel to the drainage.

In the western portion of the area above mentioned, where the original Edwards cap rock of the plains has been denuded, the Paluxy sands form large districts of upland forested sandy land, notably along the divide of the Paluxy and the Brazos from Comanche County far west into Erath County, and along the divide of the Paluxy and Bosque in Erath County. To the east, as the preserved areas of limestone cap rock become more extensive, the outcrops of Paluxy sand gradually but slowly descend the slopes toward the rivers, in general occurring as narrow belts parallel with them, until they finally reach the streams and become embedded.

The Paluxy sands become separated from the Basement sands by the appearance of the Glen Rose formation between them in Wise County, at a point between Decatur and Alvord. At Decatur the beds are well developed. Here the formation merges into the overlying and underlying beds rather gradually and the Paluxy sands contain a very argillaceous bed of honeycombed limestone. The outcrop continues down the indentations of Trinity River to Azle, into western Tarrant County.

At Weatherford the outcrops turn southeast again, along the outer margin of the Brazos Valley, just below the crest line of the western escarpment of the Grand Prairie. This belt is many miles from the stream and some 500 feet above it, making a thin, narrow ribbon of forested land, bordered on both sides by wide areas of prairie established upon the overlying and underlying calcareous formations, and is seldom more than a mile wide. It extends from west of Weatherford to the Brazos, at the southeast corner of Hood County. It constitutes a conspicuous example of the relation of forests to formation.

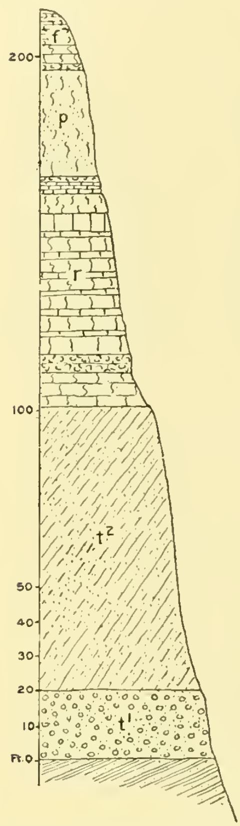


FIG. 13.—Walnut, Paluxy, Glen Rose, and Trinity formations, Dublin, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

After crossing the Brazos at the last-mentioned locality the outcrop again turns up that stream and follows its western valley slopes. Between the Brazos and the Paluxy, at the base of Comanche Peak, the sands form the plain of the wide plateau, making an elevated shoulder of forest region around the butte. Here the beds are 100 feet thick and in character similar to those at Decatur. This plateau, as seen along the line of railroad between Granbury and Stephenville, and Stephenville and Dublin, is especially conspicuous southwest of Granbury, forming a large upland timbered region, from which the Fredericksburg limestone cap has everywhere been degraded except at Comanche Peak.

The Glen Rose formation occupies a belt which extends many miles down the south side of the Paluxy, descending from the divides at the head of the Paluxy to the level of the river at its mouth, and finally disappearing by dip at Bluff Mills, near Kimball.

The sands are well exposed along the outer slopes of the Leon Valley, near Dublin. Two or three miles west of Dublin there is a very fine cut in the sand, some 50 feet in depth, which shows cross bedding to a remarkable degree, suggesting at first glance a wide unconformity.

The sands make similar belts up and down the valley slopes of the Bosque and the Leon, first occupying the high divides in Erath County and gradually descending the slopes until they cross the Bosque in the vicinity of Clifton and the Leon near Gatesville. East of Dublin and along the Bosque Valley toward Walnut, Bosque County, the formation is 50 feet thick.

Near the eastern limit of Comanche County, along the slopes of the Leon Valley, the sand is nearly 50 feet thick (see fig. 13), but on passing down the valley to its most easterly exposures near Jonesboro, Coryell County, it thins out to a narrower band, 15 feet thick. The sands extend for a considerable distance down the Leon Valley, although it is difficult to determine their exact eastern limit on account of confusion with the drift of Leon River, composed of this débris, in eastern Coryell County. Jonesboro, Coryell County, is situated directly on the outcrop of these sands, and the Lanham road northward from the town crosses it several times. A few miles north of Jonesboro the sands are only about 15 feet thick, showing a decrease to the south.

South of the Leon the Paluxy sands are exposed only in scattered spots in the western portion of the Lampasas Plain, where erosion has stripped away the overlying cap rocks. In this region they pass rapidly into limestones in the east. Thus east of Burnet on the Mahomet road they appear as occasional areas of reddish sandy lands, bearing a growth of post oak. At some places in this vicinity their outcrop is unmistakable, as near the junction of Northern and Russell forks of San Gabriel River. Elsewhere the localities are very small in area.

An argillaceous calcareous sand, 15 feet thick, in the base of Bachelor Peak, in the northeast corner of Burnet County, between the Glen Rose and Walnut beds, is a characteristic representative of the Paluxy sand bed in this region. This also outcrops around the head of North Rocky Creek south and east of Bachelor Peak. Where it occupies a level surface of a considerable extent marked by "skirts" and clumps of timber it is the source of many small springs. Wells sunk into it are abundantly supplied with water.

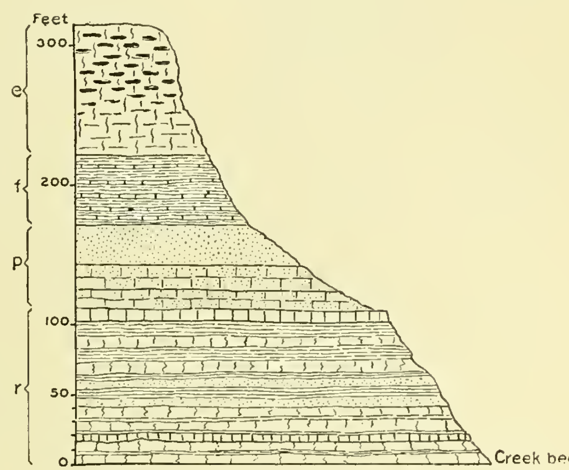


FIG. 14.—Section of Bachelor Peak, Burnet County, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

Another narrow belt of Paluxy sand appears near the source of Hickory Creek, Burnet County, just beneath the Walnut formation, but soon changes into an arenaceous limestone as it is traced toward the east, as do the outcrops in the vicinity of Bachelor Peak. (See fig. 14.)

The absence or sparse representation of the Paluxy sands south of the Colorado-Brazos divide may be explained by several hypotheses. One of these is that either the region was more remote from the preexisting land from which the sediments were derived, and hence the latter were of a calcareous offshore nature, or the preexisting lands of the Paleozoic limestones of the Burnet district, which probably persisted above the Trinity waters in the Burnet area until the Comanche Peak epoch, were of a nonsiliceous composition, resulting in a different character of synchronous sedimentation. It is the writer's opinion that these sands gradually change into the upper limestones of the Glen Rose beds of the southern sections.

In some places along the western border scarp of the Grand Prairie, dependent upon the persistence or resistance of the calcareous Glen Rose beds, the Paluxy formation can be differentiated from the Basement sands in general. In others its individuality is lost through mergence into the Basement sands.

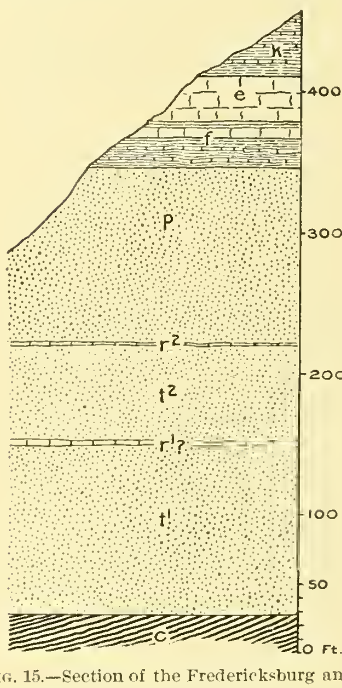


Fig. 15.—Section of the Fredericksburg and Trinity divisions, Decatur, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

Beginning near Decatur, its outcorps along the western border can be distinguished from the underlying Trinity sands as far southeast as the Leon by the occurrence of the merest trace of the Glen Rose beds between them (see fig. 15). Between the Leon and the Brazos, from near Desdimonia, Eastland County, to near Lipan, Erath County, the latter occurs as a thin, narrow bluff formation in the escarpment between the two sands.

Upon the western border, from the Leon to central Burnet County, the Paluxy formation is not definable, although arenaceous limestone or very calcareous sandstones occupy its position at the summit of the Glen Rose formation near Nix and Lampasas. In this locality the Paluxy formation is less apparent along the western border than it is just to the east of it on the coastward side of the remnant of the Lampasas Cut Plain, previously described as separating the Colorado drainage from that of the Lampasas and San Gabriel. The western and northern continuation of the Paluxy sands is further discussed in the sections on the Antlers and Basement sands.

Seven miles east of Decatur the upper part of the Antlers sands, which is equivalent to the Paluxy sand, is seen in contact with the Walnut beds, here consisting of a great development of *Gryphæa* rock, with *Exogyra texana*, showing about 30 feet of alternating layers of limestone and *Gryphæa* rock. A few miles northeast a zone of

Ostrea crenulimargo appears at the top of these sands, although not seen west of Hare Creek, and the *Gryphæa* breccia increases in thickness. This fossiliferous horizon continues through northeastern Wise County and southwestern Cooke County, being notably conspicuous at Blockers Creek.

In general the Paluxy sands thicken to the northwest, along the antidip, and thin with the dip to the south of east. The strike of the line of greatest thickness seems to be northeast and southwest from Decatur to the thirty-second parallel, and thence westward along the latter to the Llano Estacado. They are of greatest thickness along the western escarpment from Eastland County to Decatur, being 190 feet at Twin Mountain, Erath County, 120 feet at Weatherford, and 140 feet at Decatur, thinning to the southeast along the dip and to the south along the western border region (which is not coincident with the line of strike), finally playing out altogether as an arenaceous terrane in the latter direction.

An important stratigraphic feature of these sands is the fact that their embedded portion does not completely underlie the Black and Grand prairies, as do the Basement sands, but ultimately end coastward and south by changing into limestones and clays. The extent and limitations of this area of embed as determined from well drillings are more fully discussed elsewhere in this report.

Fossils.—The Paluxy sands are remarkably free from fossil remains other than logs of silicified wood, which occur in great abundance in Parker, Hood, Erath, Comanche, and Bosque counties. A few rare specimens of fish remains have been found, including the species of *Pycnodontidæ*, described by Cope,[1] which occur in these sands in the creek bed at Weatherford. In western Cooke and northwestern Wise counties the uppermost layers of the Paluxy sands contain the rare ostrean form, *Ostrea crenulimargo* Roemer, and in southern Indian Territory and along Red River *Exogyra texana* Roemer. The sands in these localities, however, are undoubtedly the homotaxial equivalents of the basal Fredericksburg division.

BASEMENT SANDS (REPRESENTING VARIOUS FORMATIONS) ALONG WESTERN BORDER REGION.

The chief exposures of the Basement sands are in the main belt of the Western Cross Timbers, at the base of the western border scarp of the Grand Prairie, extending from the Colorado River of Texas to Red River and eastward to Arkansas. (See Pls. LXVI, LXIX, LXVII.) Long, disconnected belts of these sands, from 10 to 30 miles in length, occur in the valleys of certain streams, like the Paluxy and Bosque, in the western portion of the main area of the Lampasas Cut Plain. West of the main belt along this border, within the Central

[1] Jour. Acad. Nat. Sci. Phila., Vol. IX, p. 443 et seq.

Province, are many fragmentary disconnected patches of the Basement sands resting upon the Paleozoic rocks, notably in San Saba, Brown, Coleman, Callahan, Taylor, and Jack counties and in the Chickasaw Nation.

EXTENT OF BASEMENT SANDS.

It having been shown that the Basement sands of the western border, which have the aspects of a mappable formation, are largely the attenuated interior margins of all the formations of the Trinity division, they will now be further described. They first reach northwest through Burnet, Lampasas, and Mills counties to Brown County, Texas, along the eastern slopes of the Colorado Valley. From Brown County the outcrop deflects west along the south side of the narrow Callahan Divide for many miles to the Llano Estacado, and thence back again on the north side. From northern Brown County on the north side of the divide, after a long indentation of 50 miles down the Leon Valley, the belt turns northeast through Comanche, Eastland, and Erath counties to the Brazos, and thence in zigzag lines through Hood, Parker, Wise, Montague, and Cooke counties in Texas northward to Healdton, Chickasaw Nation, and thence east to the Arkansas line at the crossing of Little River.

Roughly measured, and not including the minute meanderings, the length of the narrow belt of outcrop along the western border is estimated as follows: From the Colorado to the Callahan Divide in northern Brown County, 100 miles; west along the Callahan Divide, following the thirty-second parallel to the Colorado River and return, 300 miles; the indentation of the Leon Valley from May, Brown County, southeast to Hazledell, Comanche County, 35 miles, and north to Desdimonia, Eastland County, 35 miles; the main border from Desdimonia north of east to the Brazos, 45 miles; the zigzag meandering down and up the indenting valleys of the Brazos and Trinity to Decatur, 100 miles; from Decatur to Healdton, Indian Territory, 90 miles; from Healdton east to the Arkansas line, 175 miles; from the Arkansas line east to near Murfreesboro, Arkansas, where the sands finally disappear, 30 miles; a total of 910 miles.

The width of the belt of outcrop varies with the topography. It is governed by the degree of preservation of the rocks of the overlying slopes and scarps composed of beds of Glen Rose and Edwards limestones. The latter extends for the most part to within from one-fourth of a mile to 2 miles of the western crest of the Grand Prairie, forming low escarpments that overlook the slopes composed of the Glen Rose formation which lead down to the Basement sands. The belt of sands is usually upon a lower-lying plain extending from the base of the Glen Rose slopes to the outcrop of harder rocks of the Paleozoic border, which may vary in width according to the degree of erosion of the overlying beds.

Between the Colorado and Nix, Lampasas County, where the deep-cut river approaches close to the western escarpment line, the areal outcrop of the beds is a narrow belt seldom exceeding a mile in width. The width gradually increases from Lampasas County northward as the river and escarpment diverge.

In approaching the gap in the Callahan Divide near the north line of Brown County the width and thickness of the Basement sands greatly increase and the surmounting escarpment is reduced to a narrow remnant of the Glen Rose limestone. The area widens down the Leon Valley, and then narrows again where the rocks disappear with the dip.

From Lipan, in the northwest corner of Hood County, the outcrop of the Basement sands narrows as it turns down the Brazos Valley and back again through Parker County, on the west side of the Weatherford quadrangle. From Comanche County north to Red River the average width of the belt of Basement sands is from 3 to 10 miles; they attain their greatest width in Wise and Montague counties, where they spread over considerable areas. They seldom exceed 10 miles in width, being widest in that portion which extends irregularly northward from Parker County to the mountains of Indian Territory. The total areal extent of the Basement sands along the western border of the main Cretaceous and north of the Colorado River in Texas can not be less than 1,200 square miles by the lowest estimate. In Indian Territory these sands vary from 1 to 15 miles in width, being 14 miles wide between Antlers and a point just north of Goodland.

TOPOGRAPHIC ASPECTS OF THE BASEMENT SANDS.

Owing to the unconsolidated, pulverulent nature of these sands they are more rapidly eroded than the overlying limestone of the adjacent scarps or the underlying floor of older rock. Their outcrops therefore present no sharp or conspicuous features of relief, except when they form the base of a bluff supported by a protecting cap rock. There are three topographic phases of the Basement sands—vertical bluffs; wide, level, timber-covered flats overlooking the Paleozoic regions to the west; and wide valleys incised into the Glen Rose formation and bordered by sloping, terraced escarpments. The first is characteristic of both the Basement and the Paluxy sands, and depends upon the presence of an overlying cap rock of a more indurated character, while the second and third types depend upon the character of the foundation formation, which upholds the sands long after the cap rock has been removed.

The escarpment faces of sand are seen in steep westward-facing declivities wherever the upper limit of the sands are exposed south of Trinity River along the main western border. Most of the flats occur along the western border north of the Colorado and in the incised valleys.

These flats sometimes have a low, hilly relief, as seen in the rolling "sand roughs" found in northern Brown County, eastern Callahan, and Eastland counties, and throughout the area of the Antlers sands. A narrow belt of country of this character extends northward between Elm Fork of Brazos River and Hubbard Creek, west of the area of the map, Pl. LXVI, in an irregular zone from the Callahan Divide in the southeast corner of Taylor County. Here the sand forms low oval hills, everywhere covered by a dense growth of dwarf oaks. The surface is generally level and the hills are low and numerous. From these areas of sands the limestone that was once above them has been removed.

The escarpments which border the sands to the coastward turn down the through-cutting rivers from the west—the Leon, Brazos, and Trinity—and gradually widen out on each side of wide, flat valleys within the main area of the Lampasas Cut Plain. These valleys, each bordered by widely separated walls, through whose center flows a stream, small in proportion to the width of the valley, are also well developed just below the headwater portion of certain prairie streams, notably the Paluxy and the Bosque, where they form valuable agricultural lands.

The upper portion of the Basement sands and the overlying beds of limestone form a bluff with sloping base along the eastern summit of the Red River Valley in Montague and Clay counties. From this summit extensive views can be had across the thick forests of the cross timbers. Here the sands form the slope of a generally wide valley occupied by the Western Cross Timbers. Although the Cross Timbers occupy this valley, the Basement sands underlie only the coastward portion. From the interior margin of the sands at their contact with the Paleozoic a rolling country of wooded and prairie land begins rising gently toward the west. Near the coastward border bold, flat-topped, limestone-capped, timbered buttes—remains of the Grand Prairie—"are silent witnesses to the fact that they are remnants of beds that once extended over many thousand square miles of the 'Denuded Area' toward the Staked Plains." Rapid denudation of the sand (more rapid than that of the overlying limestone) undermines the limestone and maintains an ever present escarpment, which is gradually moving east.

In southern Indian Territory the sands make a wide valley belt between the mountain front and the Goodland scarp, and consist of very low mounds of timber-covered land. Here the interior margin of the sands occupies the lowland immediately along the south front of the Ouachita uplifts, resting upon a pre-Cretaceous base-level, at many places reexposed by denudation and composed of the upturned and planed-off rocks representing the former southward extension of the mountains.

THICKNESS OF BASEMENT SANDS.

The Basement sands, although varying in thickness, being a bed nearly 100 feet thick at Colorado River in the southeast corner of Burnet County and a comparatively thin band of limestone conglomerate where the contact crosses the north line of the county, average about 100 to 120 feet in thickness throughout their extent.

From the Burnet-Lampasas county line northward across Lampasas and Mills counties the conglomerate increases very gradually in thickness, from a thin band to a bed nearly 100 feet thick, surmounted by 100 feet of sand. Along the base of the Callahan Divide the sand varies in thickness from 60 to 160 feet. At Buffalo Gap it is 140 feet thick. On the west side of the valley of Bitter Creek in Nolan County, where it rests on the Permian, it is 120 feet thick, with a 10-foot band of conglomerate at the base. In Horse Mountain, nearly due south of Bitter Creek, it is 160 feet thick. In Church Mountain section, Runnels County, it is 90 feet thick. About 10 miles west of Horse Mountain there are only 50 feet. West of Weatherford the Basement sands are 115 feet thiek. Continuing northward across the State into the region where they represent the united Trinity and Paluxy sands, the formation becomes at least 300 feet thick, and is probably over 400 feet thick in Indian Territory.

CONTACTS OF BASEMENT SANDS.

On account of the irregular surface of the Paleozoic rocks upon which the Basement sands rest and the varied erosion of the many streams that pass across it with the dip of the rocks, the contact lines along the western border mark a eourse so tortuous that it is difficult to locate it by deseription. It is traced in detail on the map (Pl. LXVI) and is shown on the general map accompanying the First Annual Report of the Geological Survey of Texas, on which all the divisions of the Cretaceous traced out in the field by the writer and his assistants were mapped.

Wherever the Trinity sands are exposed they rest unconformably upon Paleozoie rocks. Above they come in contact in complete conformity with harder rocks. Where the superimposed strata are harder than the sands the contact of the sands and their overlying bed is clearly marked, and can be readily and accurately located. Such is not always the ease at the base of the sands, however. In the valleys of the larger streams crossing the Trinity, and toward the southeast, and where erosion is very rapid, the contact of the sands with the Paleozoic rocks is easily discerned; but where these conditions are not present the sands spread out over the edge of the irregular base-level in attenuated sheets and remnant areas, obscuring actual contacts.

The lower contact of the Basement sands of the Trinity division begins at the Colorado River, where it crosses the Travis-Burnet county line, 650 feet above the sea, and rests upon Carboniferous clays, shales, and flaggy sandstones of the Richland series of Tarr. The border follows the river, but gradually ascends from it nearly to the mouth of Sycamore Creek (altitude, 750 feet). At the last-mentioned point it deflects toward Burnet in a west-of-north direction. The Carboniferous rocks continue beneath the border nearly to the intersection of Hairston Creek and the Austin-Burnet road (altitude, 1,000 feet), where they give way to the pre-Carboniferous (Burnet) limestones. These limestones continue as the Paleozoic contact rock from Hairston Creek northeastward, by way of Burnet, to Spring Creek, about 4 miles west-northwest of Burnet. Just west of Burnet there is an isolated outlier of Cretaceous rocks known as Post Mountain.

From a point 4 miles west-northwest of Burnet the base of the sands rests upon the Cambrian sandstones, and so continues west of north for about 5 miles to the crossing of Morgans Creek, near Dobyville. North of Morgans Creek the Burnet limestone again makes the floor to a point nearly 4 miles south of Nix, where the Carboniferous sands and shales of the Richland series again form the basal rocks, extending northward for 200 miles to Chico, in Wise County, where the Permian rocks set in.

The beds rest upon the Carboniferous along the base of the escarpment at Nix, and between Nix and the south line of the county; at the base of Twin Sisters Peak and Montvale, along the western base of the high plateau; on the branches of Salt Creek, near the Gulf, Colorado and Santa Fe Railway; and at the base of the escarpment southwest and northwest of Antelope Gap, on the head branches of Antelope Creek.

From a point south of Nix, Carboniferous rocks persist beneath the Trinity sands across Lampasas County, a mile west of Nix, and thence the parting follows a line to the northward nearly parallel with the Gulf, Colorado and Santa Fe Railway, via Zephyr to very near Ricker, and thence nearly on a straight line to Clio, Brown County. Beyond Clio, through Brown County, where the Callahan Divide diverges westward from the main area of the Grand Prairie, in the southeastern portion of Callahan County and in northern Comanche County, are large undefined areas of Trinity sands.

From Clio, Brown County, the basal contact deflects westward around the Callahan Divide. Crossing the divide north of Clio, the sands are again encountered in the vicinity of May, from which point they make a southeastern indentation down the Leon, crossing that stream very near the Fort Worth and Rio Grande Railway bridge, about 10 miles east of Comanche, and returning northwest upon its north side through northern Comanche and southern Eastland counties. In the neighborhood of Rising Star, Sipe Springs, Desdimonia, Ranger, and southern Eastland County there are many scattered areas of the sand and fine conglomerate, whose exact parting with the Carboniferous has not been located. From the vicinity of Desdimonia the basal parting assumes a meandering northeasterly direction through northern Erath County, passing near Wylieville, 11 miles southeast of Gordon and north of Lipan, in the northeastern corner of Hood County, the area narrowing, and thence onward down the breaks of the Brazos, which it crosses at Powell's ferry, near Hiner. From the latter point the basal contact of the still narrow belt passes in a northwesterly direction, crossing the Texas and Pacific Railway about 4 miles east of Millsap. The sands continue northwestward into southeastern Jack County, around the Trinity-Brazos divide, and then make another southeastward meander down the Trinity Valley to the neighborhood of Bridgeport, Wise County. From this point, near which the Paluxy sands join the Trinity, the area broadens again, the western border passing northward toward Bowie and thence northeast between Belcherville and Nocona to near Zim, on the border of the Red River Valley, and then down that stream, principally as a narrow ribbon, crossing the river near Jimtown, in the northwestern portion of Cooke County. The sands are bordered by the Red River alluvium between Spanish Fort and Red River station.

In the area between Chico, Wise County, and Healdton, Indian Territory, much of the sands on the western border which have herein been classified with the Trinity may possibly belong to the upper beds of the underlying Paleozoic; they are much like those of the Trinity, and study of them has not been sufficient to justify their separation.

The western border as far north as Healdton is against the Red Beds and Carboniferous formations of the denuded plains of the Central Province. Thence east the interior bordering region becomes mountainous. East of Healdton the interior border of the sands passes near Loneoak, Overbrook, Tishomingo, Boggy Depot, south of Ardmore, Antlers, and Ultima Thule. Immediately southwest of Ardmore there are several hills of pre-Silurian limestone, disconnected southern outliers of the Arbuckle Range, which occur as islands in the Trinity sands. The sands rest upon Silurian, Carboniferous, and pre-Cambrian granite as far east as Boggy Depot; thence east they again rest upon the Carboniferous.

The Basement sands are bounded coastward by the various rock sheets comprising the western scarps of the Grand Prairie, consisting of the indurated clays and limestones of the Glen Rose beds south of Wise County and of the Fredericksburg division to the north. It should be borne in mind that the Basement sands along this border may be the attenuated western edges of any of the formations of the Comanche series below the Edwards limestone, all of which have their greatest known development coastward and which grade into the Basement sands along this border.

The upper limit or eastern border of the Basement sands, considered as a formation, runs nearly parallel with the basal or western line across Travis, Burnet, Lampasas, and Brown counties. From the northwest corner of Comanche County, which is also the northeast corner of Brown County, the eastern limit passes down the south side of the Leon River Valley, by Comanche, very nearly to the junction of the North and South forks of Leon River. It returns northwest along the northern side of the Leon, passes southwest of Desdimonia, Eastland County, west of Dublin, Erath County, and crosses the Houston and Texas Central Railway 4 miles west of De Leon. From Desdimonia this parting follows a northward course for 45 miles to the Brazos, near Powell's crossing. Twin Mountain, in northeastern Erath County, and Lipan and Buckner, in Hood County, are near this line. North of the Brazos the line of the upper contact turns west of north, passing near Hiner post-office, Parker County, and crosses the Texas and Pacific Railway nearly 4 miles east of Millsap. It continues 1½ miles west of Anthon, crossing the Whitt-Weatherford road 1½ miles from Whitt, Parker County; passing near Gibbtown, Jack County; Willow Point, Wise County, and 2 miles south of Bridgeport; crossing Trinity River at the mouth of Sandy Creek; Sandy Creek due west of Decatur; and the Fort Worth and Denver Railway 1 mile west of Alvord, Wise County; passing very near Denver, Montague, and Bonita, Montague County, and reaching the Red River Valley north of Belcher post-office, Cooke County.

This upper contact crosses the Fort Worth and Denver Railway 4 miles northwest of Decatur. At this point the basal Trinity and the upper or Paluxy sands blend and the summit of the Basement sands represents a higher geologic horizon than to the south. Opposite Decatur the parting between the two beds of sand is nearly midway between the base of the Fredericksburg division and the Trinity Paleozoic contact; it is believed to hold this relative position through the northern portion of Wise and Montague counties.

The eastern border of the sands forms a narrow belt down Red River from Belcher to the crossing of the river by the bridge of the Santa Fe Railway, and returns up the stream on the Territory side and thence north to a point northwest of Marietta 10 or 15 miles. From here their coastward border turns east, following the interior border of the Goodland limestone scarp, 6 miles northwest of Marietta, 2 miles north of Goodland, and crosses into Arkansas north of Cerro Gordo. The lower portion of Marshalls Bluff, Grayson County, is composed of the Basement sands surmounted at the top by the Goodland limestones.

VARIATIONS AND DETAILS OF COMPOSITION.

When their vast extent is considered, the composition of the Basement beds is remarkably uniform, although there are a few exceptional variations to be noted. Their general type consists of beds of conglomerate at the base, which grade up into packsands that become finer and more calcareous toward their summit, until they pass upward into arenaceous clays and limestones.

The character of the Basement conglomerate varies locally with the composition of the underlying beds, but the sands are remarkably similar and uniform in lithologic nature throughout their extent, and are mostly derived from the preexisting Carboniferous rocks, which make by far the greater portion of the underlying floor. It will be necessary at times to describe the occurrence of the conglomerate and sand separately.

Between the Burnet-Travis county line and Cypress Creek, Travis County, Colorado River cuts through the outcrop of the Basement beds of the Trinity division (previously described under the head of the Travis Peak beds) from their contact with the Carboniferous below to the bed of Monopleura limestone which marks the base of the Glen Rose division above.

The writer has shown that these beds in the basin of the Colorado, where it flows eastward across the Cretaceous formations, are deposited in a pre-Cretaceous trough in the Paleozoic rocks on the south side of a pre-Cretaceous uplift which has its summit in northern Lampasas and Burnet counties. The Basement Cretaceous beds are thinnest on the summit of this old land, and thicken as they descend its slopes to the south and the north. The Travis Peak formation represents the oldest and thickest formation upon the southern side of the old Paleozoic highland. The paragraphs on the diagonal transgression of the Basement beds (p. 137) showed how they ascend this divide from the river northward toward Burnet. Near the river the Basement beds consist of two thick beds, the Sycamore conglomerate and the Hensell sands, separated by a thin bed of argillaceous and brecciated material (the Cow Creek beds), representing the most western attenuation of thick limestones which are embedded to the east. The conglomerates are coarse pebbles of Paleozoic limestone, with a little granitic débris. Immediately upon turning north from the Colorado Valley the Hensell sands overlap the Cow Creek beds and coalesce with the Sycamore conglomerate, and this united Basement bed ascends the sloping Paleozoic floor as a deposit synchronous with the lower part of the Glen Rose beds and continues to represent the attenuated littoral of the latter to north of Nix. At Burnet the material consists of coarse conglomerate and grit embedded in a reddish clay matrix, as seen in Hamilton Creek and Post Mountain, south, west, and north of the town. In this area the Basement beds contain the débris of the granite, Algonkian, Cambrian, and Silurian rocks.

From Burnet northward to Nix the Basement sands are thin and represent the interior margin of the upper Glen Rose formation as far as the center of western Lampasas County, when they begin to descend and thicken at the northward slope of the Burnet highland of the Paleozoic floor. The following section at Twin Sisters Peak, Lampasas County, shows the nature of the Basement sands in this general locality. (See fig. 16.) The section includes Cretaceous rocks from

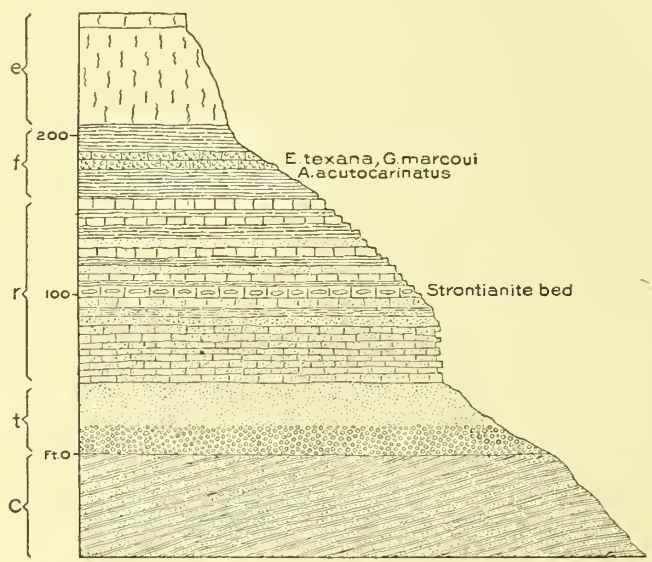


FIG. 16.—Section of Twin Sisters Peaks, Lampasas County, Texas. (For explanation of lettering see Pl. XVI, p. 110.)

the Carboniferous to the base of the Caprina limestone in Twin Sisters Peaks, and is given in descending order. The base of the Cretaceous is 160 feet below the Fredericksburg division.

SECTION No. 11.—TWIN SISTERS PEAKS, LAMPASAS COUNTY (TAFF).

	Feet.
5. Caprina limestone; indurated chalky limestone forming cap rock of the butte.	8
4. Comanche Peak limestone from below the cap of the peak to top of the Walnut bed. The rock is soft, white, heavily bedded, almost pure limestone. Numerous fossils of *Enallaster texanus*, *Diplopodia*, and gasteropods occur at base of bed. The lower 25 to 30 feet is a chalky limestone very like the above. *Schloenbachia acutocarinata*, *Cyprimeria texana*, *Arca*, *Enallaster texanus*, *Diplopodia texanum*, and gasteropods occur in the lower chalky limestone	67
3. Walnut formation, upper to lower limits of the occurrence of the fossil *Exogyra texana*. Below the Comanche Peak chalky white to yellow limestone alternates with a marly lime. *Exogyra texana* and *Gryphæa pitcheri* shells are very numerous and well preserved near the middle of the beds, but become smaller and less numerous below and above	55

	Feet.
2. Glen Rose formation: Limestone, lime marl, and calcareous sand alternating in layers from 2 to 3 feet to as many inches. Toward the base the rocks become more arenaceous until the sandy marl blends with the sand. Twenty feet above the base there are many large inclusions of calcite crystals in the marly lime. Fossils of a small variety of *Exogyra texana* occur about 15 feet above the base of the bed. *Cardium mediale*, many other bivalves, and gasteropods occur in the lower portion	90
1. Basement sands, resting upon Carboniferous sandstone. The bed forming the upper 20 feet is a stratified calcareous sandstone. Below this there are about 30 feet of loosely packed materials composed of typical "packsand" grit and calcareous sand, stratified and in part false bedded. The basal bed, 20 feet thick, is a conglomerate of limestone, quartz, and flint, cemented in an argillaceous calcareous sandy matrix, purple, yellow, brown, and red in color. Many of the cobblestones composing the conglomerates are but slightly worn	70
0. Carboniferous sandstone in thin beds. This sandstone is brown and false stratified, dipping 2 to 3 degrees northwest	

In the vicinity of Nix, Lampasas County, the basal beds are a conglomerate of Carboniferous and Silurian limestone, quartz, flint, and other Paleozoic material, cemented in a matrix of arenaceous and argillaceous lime. Small fragments of sand and gravel compose much of the matrix, which in some cases is iron stained and very hard. The whole mass has a mottled appearance from the variously colored materials composing it. The colors are pink, red, yellow, purple, brown, and several shades of blue. The materials of the conglomerate vary in size from fine pebbles to bowlders 8 inches in diameter. Their form indicates subjection to different degrees of abrasion. Some are subangular fragments, while others are smooth and well rounded. Between these varieties are fragments of rocks showing all kinds of form and smoothness of surface.

The packsand varies in texture from a compact, nonindurated, yellowish mass of coarse sand, quartz, and chert pebbles to a close-grained, stratified, calcareous sandstone, brown to whitish in color. Strata of limy sand occur in thin variable beds. There is a general stratification in these basal beds, but the materials composing them are not well sorted as to size. An examination of this heterogenous conglomerate creates immediately the impression that there was a commingling on the seashore of materials brought from a distance and local débris. This coarse material gradually becomes less conglomeratic higher in the beds, giving place to a mass of loosely bedded grits, packsands, lime marl, and calcareous sandstone. The whole grades imperceptibly into the more calcareous and marly strata of the upper beds of the Glen Rose formation, which persist to the western scarp in this vicinity.

From a stratigraphic point of view the parting line between the Basement sands and the Glen Rose beds is necessarily an arbitrary one here, and there is no other means of distinction. Yet in the more limy thin bands within the sands, near their upper limit, are casts of gasteropods and small bivalves not distinguishable from casts of like forms in the Glen Rose formation, facts which substantiate the conclusion that the sands at this locality are the attenuated edge of the lower part of the Glen Rose formation.

The whole of the Basement bed at Nix does not exceed 50 feet. From 20 to 25 feet of the basal portion includes the conglomerate. The pack sand, with associated material, is 30 feet thick. The upper half contains the more calcareous sandstone, lime, and marly material.

From Nix northward the conglomerate in the lower part of the Basement sands is conspicuous, and so distinct from the overlying pack sand that the two materials may be separately described. The basal conglomerate is extensively developed from just west of Nix northward to Clio, Brown County, on the east side of Colorado River and Pecan Bayou; also between the bayou and Colorado River south of Brownwood, at and around Bangs, east of San Saba, and between Colorado and San Saba rivers on some outliers of higher elevation within the Central Province. The details of these localities have been minutely described by Drake,[1] and the writer has drawn freely upon these data in the following account of the Basement sands between Nix and the Leon.

The basal conglomerate is composed principally of crystalline limestone pebbles 1 to 5 inches in diameter, with some chert, sandstone, and quartz pebbles. The matrix is sand or grit of quartz grains with a lime cement. The bedding is massive, and the change of material from one horizon to another is gradual and not marked by bedding planes. The limestone, chert, and sandstone pebbles are large and usually not well rounded, showing that they were derived from older beds near the place of deposition. The quartz pebbles are small and well rounded, showing a more distant origin. The prevailing color of the beds is pink, with patches of lighter or deeper red scattered through it. At places the lower beds lose their conglomeratic nature more or less and pass into a hard sandstone, compact sand, grit, clay, sandy clay, or more rarely into limestone. The above conditions are approximately true of the conglomerate bed wherever it is found in the Lampasas-Brownwood field. At San Saba Peak it is 175 feet or more thick, and the upper part grades through a decidedly hard, calcareous, crystalline, only slightly conglomeratic rock mass into the overlying Glen Rose formation.

From 5 to 6 miles east of San Saba, between Horse and Camp creeks, and at the head of China Creek, are small remnants of the conglomerate. At many other places the conglomerate has so lately been eroded that its most enduring pebbles remain scattered over the

[1] Report on the Colorado coal field of Texas, by N. F. Drake and R. A. Thompson; Fourth Ann. Rept. Geol. Survey of Texas. Austin, Sept., 1893.

surface, reminding one of the drift of the later geologic epochs. The conglomerate is thickest in the western part of Lampasas and Mills counties and thins out to the northwest, while the pack sand, almost lacking in the northwestern part of Lampasas and Mills counties, thickens rapidly to the north from about the locality of Brownwood.

Just west of Nix, at the head of Lynch Creek, the conglomerate is very thin, but thickens rapidly northward. West of Twin Sisters Peaks it is fully 50 feet thick. A considerable part of the bed from Nix to Senterfit consists of massive-bedded pink sands, usually calcareous and forming rather firm rock masses. In the bed of Salt Creek at Senterfit the conglomerate is well exposed and is composed of subangular pebbles of hard crystalline limestone embedded in a hard calcareous matrix; east and west of this point pink calcareous sands and clays are interstratified with the conglomerate. The stratification is local, however, and generally not well marked. At the head of Antelope Creek the conglomerate bed is more than 100 feet thick, and is mostly a hard mass with no bedding planes, though local and irregularly-marked horizons have different degrees of hardness, causing it to weather with a wavy or rough rounded surface. Most of the matrix is sand, but calcareous matter is present to a greater or less extent. At places the bed becomes almost or entirely pure sandstone and more rarely clay. The pebbles of the mass are usually from 1 to 5 inches in diameter, and some are even larger, though at places where the conglomerate grades into a sandstone they become very small and rare. Most of the pebbles are hard limestone, but many flint, chert, sandstone, and some quartz pebbles are present. The mass of the rock is usually pink, with small parts of lighter or deeper red scattered through it; other parts are almost white.

Between Zephyr and Goldthwaite much lime appears in the Basement beds, marked by open-timber prairie. The beds between Mullen and Ricker, and thence on to Clio, about 5 miles east of Brownwood, spread over a considerable area and consist of sands and conglomerates.

The Basement beds near Pecan Bayou west of Mullen are strongly conglomeratic. The pebbles are usually from 2 to 4 inches in diameter, with some angular hard sandstone bowlders 2 to 3 feet in diameter. This highly conglomeratic mass is 15 feet thick, and is overlain by friable sandstone, which shows some bedding planes; this sandstone is in turn overlain by calcareous, hard, light-pink, slightly conglomeratic rock. Bedding planes, which are ordinarily rare, and usually false, become more common. Most of the conglomerate bed up Pompey and Blanket creeks, Brown County, shows fine illustrations of false bedding, but it is generally a red and rather friable sandstone, instead of a regular conglomerate. Along Stepp Creek, in the vicinity of Ricker, the base of the conglomerate bed is red clay, varying in thickness in closely connected localities; along the branches of Delaware Creek it is missing, but on most of the eastern branches of Stepp Creek it is nearly 100 feet thick. Above the formation is a coarse grit or conglomerate, composed of white sand and rounded limestone and sandstone pebbles. The mass is slightly calcareous.

About 7 miles southeast of Brownwood, along Devils Branch, the Basement beds consist of 20 to 30 feet of characteristic conglomerate, overlain by 8 to 10 feet of red, tough, slightly calcareous sandstone, which contains only a few pebbles. South of Brownwood a rather friable arenaceous limestone overlies this sandstone and forms much of the present Cretaceous cap rock. Due south of Brownwood there is not much of the typical conglomerate, but, instead, pink or yellowish friable sandstone or grit, a compact yellowish sand, arenaceous limestone, and some white sandstone containing but little grit; and some outcrops show a number of variations in the material along the same stratum in closely contiguous places.

The conglomerate bed changes rapidly toward the north in Brown County. At the head of Stepp Creek it is about 125 feet thick, and is composed of white grit, conglomerate, and red clay. The clay usually lies at the base, makes the greater part of the bed, and is overlain by the sands. At Salt Creek the conglomerate is represented by a thickness of only 4 to 5 feet on either side of the creek; the sands have rapidly increased in thickness and replaced it.

In that portion of the western border region adjacent to Clio the area of outcrop broadens extensively and the red colors are much more prevalent. The materials throughout this region are red sandy clays with impure lumps of white material.

The basal Cretaceous as it extends down the Leon drainage north of Sidney and Comanche contains some conglomerate, but it is of a character slightly different from that along Colorado River and Pecan Bayou. About 1 mile below Sidney, in the banks of both Sweetwater and Jimmys creeks, is a bed of deep-red, slightly sandy clay, 30 to 40 feet thick, which is underlain by a hard conglomerate of small limestone, sandstone, and siliceous pebbles in a matrix of white sand, and under this is another bed of red clay. The stratification of these beds continues only a short distance northeast of Sidney; farther down the creek in a number of places the beds show a section of from 20 to 50 feet, and at nearly every place they vary in the proportion and relative position of their conglomerate and clay strata. Sometimes nearly pure sandstones appear, as at the top of the section at Cottonwood Springs on Sweetwater Creek. The beds also at places contain material very similar to the overlying pack sands, showing their close relation, or even the transition of one into the other. This relation may be seen about one-half mile down the creek from Cottonwood Springs, where the beds, composed principally of ferruginous, compact sand, contain also a great many red, pink, brown, or nearly black siliceous pebbles, and some hard sandstone pebbles, hard conglomerate layers, and a little blue or reddish clay. The basal Cretaceous strata farther down, on the southeast side of Sweetwater Creek, were found to have no continuity, and to change almost entirely into sandy material northwest of Comanche.

The 50 to 75 feet of basal Cretaceous along Rush Creek, north of Comanche, is composed largely of a conglomerate of siliceous pebbles and grit of white quartz grains, with occasional red ones. In places, as along Pettit Branch, this conglomerate is almost a mass of white and occasional pink pebbles, and it is all false bedded. The conglomerate is usually friable, though sometimes hard, as in Jimmys Creek. North of Rush Creek, on the divide between it and Leon River, are some remnants of a conglomerate which has more the appearance of that east of Pecan Bayou.

A peculiar conglomerate of small, waterworn siliceous pebbles, often occurring in a disintegrated and fragmentary condition, characterizes the bottom of the Basement sands in many places. This is especially characteristic of the western parting from Goldthwaite north to Red River, and as far west as Sweetwater, Nolan County. This pebble also has wide occurrence along the western

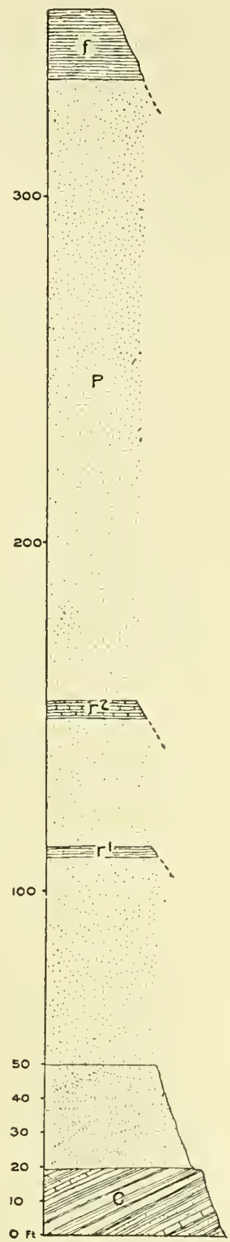


FIG. 17.—Section of Twin Mountain, Erath County, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

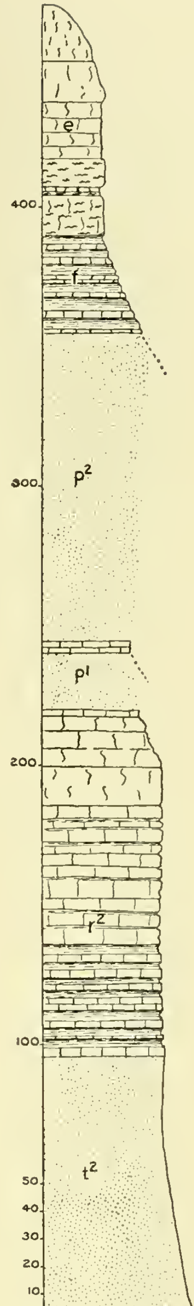


FIG. 18.—Section at Hiner, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

border of the Cretaceous in Eastland, Palo Pinto, Parker, Jack, and Montague counties, and while ultimate research may prove it to be of pre-Cretaceous age, investigation has not sufficiently progressed to differentiate it. The evidence that this conglomerate belongs with the sands is shown by the fact that, as in northern Montague County, it grades upward and downward into typical pack sand. In Eastland and Wise counties it rests on Carboniferous limestone. Its remnants occur in places within the Central Province far west of the line indicated on the map, and attest the vast denudation the Cretaceous has undergone.

FIG. 19.—Profile and section, Weatherford, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

A few additional notes on the pack sands which overlie the conglomerates in the area just described from Nix to Clio will now be given. On the east side of the Colorado River, from Nix northward to opposite Brownwood, the beds of pack sand succeeding the conglomerates are thin, irregular, and somewhat different from the normal pack sands in that they have more or less clay and lime. There are usually 20 to 30 feet of red sand and clay present. Northeast of Brownwood, at the head of Stepp Creek, there are 15 to 25 feet of the typical sands overlying the conglomerate, but these sands at places shows stratification beds of white compact sands, bluish clay, and, more rarely, red clay. At the head of Salt Creek, east of Salt Mountain, nearly the whole of the conglomerate bed has been replaced by sands 80 to 90 feet thick. The sand is compact and is composed principally of white grains, with some red grains scattered through it. There are layers of ferruginous sand which are a little firmer, and there is a very little bluish and red clay in the bed, especially toward the top.

West of Clio and May, along the headwaters of Salt, Elm, and Hog creeks, the pack sands have greater thickness and an outcrop from 1 to 3 miles wide, which supports a thick growth of small oaks. These sands are especially well shown around Sidney and Comanche, along Sweetwater, Little Jimmys, Duncan, and Indian creeks.

In Jimmys Creek at Sidney there is a rather firm, slightly ferruginous sandstone, bedded in layers from 1 to 18 inches thick, above which is a white compact sand containing some small, well-rounded siliceous pebbles partly interstratified with bluish sandy clay.

At the base of these beds, in the vicinity of Sidney, a deep-red, slightly sandy clay is common. Along Pettit Branch north of Comanche is a series of alternating bluish sandy clay beds and compact white sand, which at places shows a reddish cast on the weathered surface. Fossil wood is very common at the base of these sands. In the case of a large tree, the central portion was silicified to within a few inches of the circumference, where silicified wood gave place to silicified lignite, which continued to a narrow outside rim of lignite. Similar conditions of petrifaction have been observed in Hamilton County.

From Desdimonia eastward to the margin of the breaks of the Brazos Valley the Trinity Basement sands spread out as a thin mantle over the Carboniferous rocks at the foot of a low but well-marked escarpment of the Grand Prairie. The following is a typical section of this portion of the escarpment (see fig. 17, p. 185):

SECTION NO. 12.—TWIN MOUNTAIN,[1] ERATH COUNTY, TEXAS (TAFF).

	Thickness.	Total depth to bottom of stratum.
Walnut formation:	*Feet.*	*Feet.*
6. Sandy limestone, which contains *Exogyra texana*, *Gryphæa pitcheri*, and *Cardium hillanum*. This limestone, the base of the Walnut bed, forms the summit of the mountain	10	10
Paluxy formation:		
5. Paluxy sand. This sand is fine grained, yellow, and generally friable. It readily disintegrates. Occasional partially indurated ledges are seen, but they are not of sufficient firmness to form benches on the mountain sides	190	200
Glen Rose formation:		
4. Limestone, slightly arenaceous, in thin ledges	5	205
Basement sands:		
3. "Pack sand," exactly similar to upper portion of No. 2.	22	227
2. Arenaceous blue clay	3	230
1. Conglomerate, 20 feet; pack sand, 70 feet	90	320
Carboniferous sandstone resting uncomformably beneath the above.		

The following sections near Hiner and Weatherford give the nature of the sands in this vicinity (see figs. 18 and 19). Throughout this region the Basement sands are overlain by thin, indurated layers representing the western attenuation of the Glen Rose beds.

[1] The most eastern of the buttes of this name shown on the Stephenville atlas sheet of the United States Geological Survey.

SECTION NO. 13.—HINER, PARKER COUNTY, TEXAS (TAFF).

FREDERICKSBURG DIVISION.

	Feet.
Comanche Peak formation:	
16. Comanche Peak chalky limestone	40
15. Chalky limestone with large *Exogyra texana*, *Enallaster texanus*, *Lima*, and *Cyprimeria texana*	30
14. Hard chalky limestone	40
Walnut formation:	
13. Gryphæa shell limestone	10
12. Chalky limestone	1.66
11. Hard limestone, with many small *Gryphæa*	1.5
10. Chalky limestone, with few *Gryphæa*	15
9. Marly limestone, containing *Exogyra texana*, *Gryphæa pitcheri*, and *Ammonites*, all in great abundance	30

TRINITY DIVISION.

	Feet.
Paluxy formation:	
8. Paluxy sand bed	110
7. Yellow crystalline limestone made up of shell fragments	5
6. Calcareous yellow sand, stratified	20
Glen Rose formation:	
5. Marly and shaly limestone capped by a ledge of hard crystalline limestone	20
4. Marly and shaly lime, containing *Cardium*, *Arca*, *Cyrena*, *Trigonia*, *Anomia*, and *Ammonites*	10–15
3. Alternating hard and crumbling limestone	50
2. Cardium bed	30
Basement sands:	
1. Trinity sand	100

Outcrops of the Trinity and Fredericksburg divisions are beautifully shown in the wide slopes of the Brazos Valley from the eastern edge of the Grand Prairie at Weatherford westward to Millsap. It is difficult to obtain the exact thickness of the formation in vertical series, owing to the fact that within this short distance along a profile of 14 miles the increment of the Glen Rose beds is very great. The following section, made by the writer in 1890, gives an idea of the sequence and thickness of the formations at their outcrop. This will be followed by a vertical section at Weatherford from an artesian well which penetrated the entire series here described and which gives a check on their thickness at that locality. The section extends from Millsap eastward to Weatherford along the lower Millsap road.

SECTION NO. 14.—PROFILE SECTION, MILLSAP TO WEATHERFORD, TEXAS.

(See Pl. XIX, *A*; also fig. 19.)

Distance in miles from Millsap.	Character of rocks.	Thickness in feet.
	CARBONIFEROUS.	
0	From Millsap east to Grindstone Creek the country consists of the sterile clay soils of the Carboniferous with outcrops of the harder rock layers. The surface is an arid flat covered with a growth of mesquite.	
1½	Grindstone Creek, laminated purple clays with a 6-inch band of sandstone; clays contain Carboniferous fossils: dip, 2° W	20
	TRINITY DIVISION.	
1⅝	I. Basement sands: Conglomerate, typical, very minute quartz and jasper pebbles with sandy matrix. Low eastward dips.	
2	East prong of Grindstone Creek. Purple red colors, so characteristic of the Trinity formation, appear in the creek bank, with (Ia) damp pack sands surmounted by conglomerate (Ic); thickness........................	5
	Presuming that the normal dip prevails from Grindstone Creek to the east fork, it is highly probable that the 5-foot bed of conglomerate above mentioned is not the lower basal one (Ia).	
	A minute section was made up the east bank of this creek to the scarp plain, 100 feet above it. This section shows conglomerate (Ic) at the base, coarser sands (Id) in the middle, and fine pack sand (Ie) at the summit. The pack sand is fine, pulverulent, faintly oxidizing to yellowish tints, cross bedded, and succeeded below by coarse-bedded layers. A few egg-shaped calcareous nodules, at first glance resembling remnants of decomposing bones, appear in upper part of these sands. Silicified fossil wood in large chunks occur near the base. The cross bedding is on a grand scale, resembling stratification. This steep sandy slope is surmounted by a bench consisting of a thin stratum of yellow arenaceous magnesian lime material accompanied by impure nodules..	100
	Total Basement sands..............................	105
	Glen Rose formation: This subdivision begins at the scarp line above mentioned, including the thin bench rocks. These beds constitute the little buttes so frequently shown on the topographic sheets by a single small circular contour.	
	II. Impure clay, pack sand with purple and green colors, yellow magnesian concretions, calciferous and gypsiferous .	1
	III. Slope of alternations of buff-colored sandy "magnesian" arenaceous-calcareous layers, alternately consolidated and unconsolidated, giving serrated profile to the bench, containing *Anomia* and fragments of an undetermined oyster..	20
	IV. Scarp bench of hardened layers of sandy material	10
	V. Slope like II, composed of fine arenaceous, pseudo-oolitic, buff-colored marl with imperfect shell fragments (*Anomia?*), and light buff yellow colored indurated layers..	5
	VI. Slope with thick, firmer layers containing *Glauconia* and oyster, surmounted by bench and dip plain............	20

SECTION No. 14.—PROFILE SECTION, MILLSAP TO WEATHERFORD, TEXAS—Continued.

Distance in miles from Millsap.	Character of rocks.	Thickness in feet.
	TRINITY DIVISION—continued.	
	VII. Slope consisting of strata 1 to 2 feet thick, alternating with sandstone, limy marls, and magnesian stuff, capped with an arenaceous shell breccia containing *Nerinea* and *Protocardia*. One massive stratum (1–2 feet) in this group of beds is made up of an angular crystalline breccia with *Glauconia* beautifully preserved; it contains also a *Lucina* and *O. franklini* var. *ragsdalei*. Thickness of this division not obtained	±20
	VIII. Stratum capping a butte and constituting a dip plain for 1½ miles, where it abuts against the foot of a scarp (AB) of XI	5
6	VIII. Alternating magnesian buff-colored unconsolidated material, constituting slope, thickness not obtained	±5
6	IX. Scarp of hard, white crystalline limestone bands dipping east. Numerous fossils: *Cyprina medialis*, *Cerithium*, *Glauconia*, etc	25
	X. Impure firm marly shale with *Arca*, *Venus*, and *Glauconia*	5
	Paluxy formation:	
	XI. Pack sand	±50
7	XII. White limestone flags composed entirely of cemented shell of littoral species	4
8	XIII. Millsap 8, Weatherford 7. Pack sand sets in, with forest growth; soil reddish	20
8¾–6¼	Descent into Patrick Creek (W. 6 m.), giving a check section on the preceding 75 feet.	
9–6	XIII. Pack sand	20
	XII. Brecciate slab beds	4
	XI. Pack sand slope	15
	X. Impure limestone shale, marly with *Arca*, *Venus*, *Glauconia*, etc	5
	IX. Massive limestone with *Cerithium*, making scarp rock	25
	VIII. Pack sand at base	5
9–6	Divide of Patrick Creek and next drainage, one-quarter mile east, consists of pack sand with hard sandstone layers. The slopes of Patrick Creek Valley form a typical example of the alternating terrace slope of the Glen Rose.	
11½–4½	XI. About 10 feet of hard shell breccia, containing *Glauconia*, *Protocardia*, etc. Quarried for use in city	10
	XII. Paluxy sands; at summit pack sand. The Walnut (*E. texana*) scarp at Weatherford is finely visible from this summit	40
12	The foregoing pack sand continues and contains fossil wood.	
12½	XIII. Down grade through limestone stratum with *Glauconia* and ascent again into sand (XV).	
13–2	A wide escarpment appears to left of road, which rises upon the bluish Walnut clays at base of Fredericksburg division.	

SECTION NO. 14.—PROFILE SECTION, MILLSAP TO WEATHERFORD, TEXAS—Continued.

Distance in miles from Millsap.	Character of rocks.	Thick-ness in feet.
	FREDERICKSBURG DIVISION.	
14½ 15–0	XIV. Walnut formation. Yellowish limestone, with *E. texana*, *Toxaster*, *Ammonites peruvianus*, *Gryphæa pitcheri*, and other fossils	±100
	Descend into the Paluxy sands (XVI). Weatherford, top of Paluxy sands (XV) at contact with Walnut clays (XVI).	

SECTION NO. 15.—WEATHERFORD, TEXAS.

Two wells, one 420 feet deep and one 440 feet deep. (See Pl. XIX, *A*.)

	Depth in drill hole in feet.
Walnut beds, constituting surface, 25 feet.	
Paluxy sands:	
Light-yellow sand	10
Light-yellow sand	20
Light-yellow sand	30
Mixture of calcareous clay in sand	40
Mixture of calcareous clay, gray-black specks	50
Lime with fine sand	60
White arenaceous rock alternating with drab, yellow, and some sand	70
White arenaceous rock alternating with drab, yellow, and some sand	75
Greenish marly stuff	80
Drab and white badly broken limestone	85
White sand with pyrites	90
White sand with pyrites, finer	100
Massive white calcareous shale	105
Sand with black specks	110
Sand with black specks, finer texture	120
Sand with black specks, finer texture	125
Fine sand	140
Fine sand	145
Fine sand	150
Fine sand	155
Marly sand	160
Gray sand	165
Glen Rose formation:	
Limestone and marl with some sand	170
Fine sand, light colored	180
Fine sand, dark colored	185
Coarse sand	195
Sand	200
Forty feet of limestone with marly alternations. Some of the limestone is coarsely crystallized	200–240
Basement beds:	
Marly calcareous layers, from 260 to	403
Sand with water, 403 to 407	403
Sandy shale, 407 to 417 feet	407
Red clay, 417 to 440 (bottom of well)	417
Bottom of second well, at 440 feet	440
In the other wells sandy shale was struck at 398 feet.	

The Basement sands are well exposed south of the railroad just east of Grindstone Creek and north near Lambert. Near the latter place bones of a dinosaur (as determined by Professor Cope) were found by the writer in 1886. It was on this account that the writer then temporarily designated the formation the "Dinosaur sands."[1]

The Basement sands have not been traced in detail across or around the divide between the Brazos and the Trinity in northwestern Parker, southeastern Jack, and southwestern Wise County. There are reasons for believing that they extend a considerable distance northwestward into Jack County, along the region between the drainage of the Trinity and the Brazos.

In the vicinity of Springtown, Parker County, only thin bands of clay and impure limestone, representing the Glen Rose formation, separate the Basement sands from the Paluxy sands. Crossing this divide from Whitt into Wise County, the Basement sands appear upon its northern side beneath less than 20 feet of thin indurated impure arenaceous limestone and clays containing the Glen Rose fauna, which are surmounted by another bed of thick sands of the supposed Paluxy formation.

Three miles southwest of Bridgeport, on the Willow Point and Bridgeport road, the Basement sands are well shown. At this place, at Willow Point, 1 mile west, at Holey, and at a point 7 miles north of Whitt are buttes capped by thin Glen Rose limestones. These buttes, locally known as East and West mounds, 3 miles south of Bridgeport, are very characteristic and marked. Beneath this cap rock are variegated clays from 40 to 50 feet thick. They are blue at the base and red, white, and other tints at the top. They have many calcareous concretions from the size of a walnut to that of a man's head. Below these clays is pack sand to the base of the Cretaceous, attaining a depth of over 60 feet.

ANTLERS SANDS.

RELATION TO PALUXY AND UNDERLYING SANDS.

In the cross timbers west of Decatur and thence north and east to the Arkansas line the Basement and Paluxy sands become a single undifferentiable formation, owing to a change in the lithologic character of the Glen Rose beds, which separate them southward. Near Decatur this thin parting of Glen Rose between the Basement and Paluxy sands becomes less appreciable and finally dies out, and northward the two sands unite into one great formation, to which the name Antlers sands (from Antlers, Indian Territory) has been given. West of Decatur these combined sands have an estimated thickness of 193 feet between the underlying Carboniferous and the Walnut beds at the

[1] Am. Jour. Sci., 3d series, Vol. XXXIII, April, 1887, p. 298.

base of the Fredericksburg at Decatur. In the sands at this point are thin indurations, often less than a foot thick, the last northward indication of the Glen Rose beds which to the southward are so well developed into great limestone formations.

The following composite section in the vicinity of Decatur will give a general idea of the formations in these regions (see fig. 15):

SECTION NO. 16.—SECTION AT DECATUR, WISE COUNTY, TEXAS (TAFF AND HILL).

	Thickness.	Total depth to bottom of stratum.
Kiamitia clays:		
10. Blackish clays alternating with thin limestone flags containing a great abundance of *Gryphæa corrugata*, exposed on the hills to the east and south of the city. Thickness estimated	*Feet.* 50	*Feet.* 50
Goodland limestone:		
9. Hard white limestone	33	83
8. Marly clay	2	85
7. Compact white limestone	9	94
Walnut formation:		
6. Alternations of calcareous marls and compact layers of limestone containing great numbers of *Gryphæa marcoui*	18	112
Antlers formation:		
5. Pack sand	140	252
4. A thin indurated layer containing *Anomia* and other fossils of the Sanchez horizon	1	253
Glen Rose (?):		
3. Pack sand. Five feet above the base of this sand there are thin arenaceous indurations in the sand containing casts of Glen Rose fossils	35	287
2. Thin indurated layers like those of the Lambert horizon of the Weatherford section	Trace.	
Basement sands:		
1. Pack sand, grading downward into a conglomerate at its base	120	408
CARBONIFEROUS.		
0. Sandstone and clays.		

CHARACTER OF ANTLERS SANDS NORTH OF DECATUR.

From Decatur northwestward to Bowie, 28 miles, the Basement sands have their greatest development. This includes a great thickness of pack sand, with a few bands of clay and pebbly conglomerate, which extends from the Upper Coal Measures near the Permian contact at Bowie to the Walnut beds at the base of the Fredericksburg division at Decatur. In every physical aspect the sands and conglomerates in this area are exclusively Basemental in character, but they are known to represent a union of the Basement and Paluxy sands, and may possibly include even lower formations of undetermined age. The only separation layers visible in the beds as a whole are a few bands of conglomerate. A conglomerate of pebbles and sand forms the basal zone of this region and of other localities cited above, but it is of very small pebbles. Beginning in northern Wise County, large masses of this indurated conglomerate appear at the base of the beds and continue through Montague County to Red River Valley. It is hardened into firm, resistant stone in places. The easily eroded pack sand which overlies the conglomerate, especially in outlying areas which have been detached by erosion from Wise County north, envelops large masses of this hard conglomerate, which may or may not be pre-Cretaceous. In compact masses of sand similar pebbles occur, mixed with the sand, associated with the erratic compact conglomerate. Above the pebbly zone, through a vertical distance of 320 feet to the Walnut limestone, there is no perceptible change in the sand. In the character of the material composing the sand and of the structure there is no indication of a change or cessation of deposits throughout the bed.

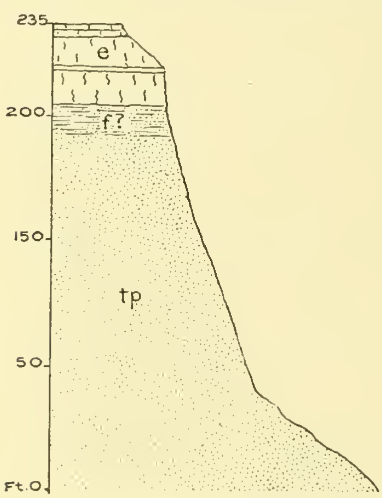


Fig. 20.—Section of western escarpment of Grand Prairie at St. Jo, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

As a whole the pack sands overlap the parting of the Carboniferous Coal Measures and Permian Red Beds in this region, and much of the pebble therein may be developed from a conglomerate which, according to J. S. Stone, may mark the contact between the Carboniferous and the Permian. This has little, rounded, white pebbles, which are also found in great abundance in the Basement sands. It is utterly impossible at present to differentiate this great thickness of sands, and for practical purposes they must be included in the basal Cretaceous.

From Bowie the Antlers sands continue north, being well displayed between Montague and St. Jo, the western parting passing between Nacona and St. Jo (see fig. 20). From these points the outcrop turns due east down Red River, gradually narrowing into a vertical bluff formation. The thickness of the sands between Bowie and Red River is indefinite, but Taff estimates 500 feet just west of St. Jo in Montague County.

It is an interesting fact that as these sands turn eastward down Red River their upper beds begin to encroach upon the stratigraphic position of the Walnut formation at the base of the Fredericksburg division. On both sides of Red River adjacent to Jimtown the upper limit of the sands passes into an impure sandy clay beneath the Goodland limestone, marked by the characteristic *Exogyra texana* fauna of the Walnut clays to the south. The same condition is seen in the bluff of Hickory Creek north of Marietta, Indian Territory.

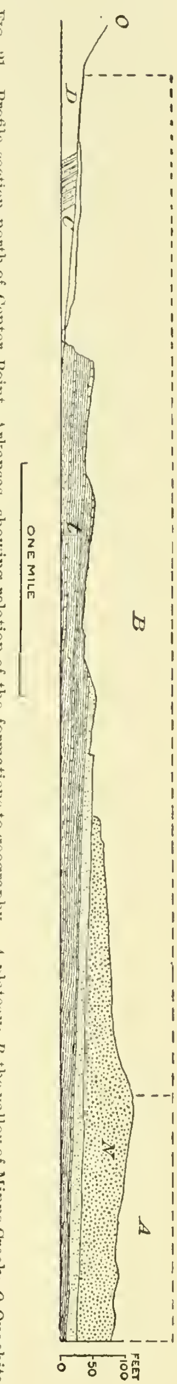


Fig. 21.—Profile section north of Center Point, Arkansas, showing relation of the formations to geography. *A*, plateau; *B*, the valley of Minns Creek; *O*, Ouachita Mountains; *D*, Wichita paleoplain; *N*, plateau gravel (Neocene); *T*, Trinity sands (Cretaceous); *C*, Carboniferous.

ANTLERS SANDS IN INDIAN TERRITORY.

There has been little study of the details of the Basement sands in Indian Territory. The writer has observed them only in rapid reconnaissances and noted points here and there along the boundaries of their outcrop. In general the formation, as in Texas, consists of loose, unconsolidated sands of undetermined thickness, with occasional laminæ of clay. The subsoil is usually red, from the oxidation of the contained iron, and the soil a leached, ashen gray.

From Healdton eastward to the Arkansas line they are better displayed and exhibit the general surface characters exposed in Texas. Débris of the Permian conglomerates also occurs between Trinity River and Woodford, Indian Territory, and Silurian limestone pebbles occur southwest of Ardmore. For a short distance between Tishomingo and Boggy Depot, Indian Territory, débris of granites and Paleozoic limestones is found in the Basement sands. Elsewhere the beds are composed of débris of the Carboniferous sandstones.

From Powell's crossing of the Brazos, west of north from Anthon and Whitt, in the northwest corner of Parker County, are excellent exposures of the Basement sands in contact with the underlying Carboniferous; good general sections of the entire Trinity division from the base of the Fredericksburg, which forms the escarpment of the Grand Prairie, are procurable.

The Basement sands, as noted by Taff, occur in good exposures along a run three-fourths of a mile southeast of Hiner just north of the Brazos. They are beautifully false bedded and false laminated, and show clearly the action of the waves and fluctuating currents. From the base upward about 20 feet worn siliceous pebbles of various sizes and colors make a great part of the material, as seen at the base of the Dublin and Twin Mountain sections. Near the upper portion of this gritty, pebbly bed are fragments of silicified wood, which is very common here near the middle of the sand. Above the zone of fossil wood the sand becomes argillaceous and calcareous, indurated in bands. Here are local deposits of purple and red sandy clay, and nodules of iron sandstone occur rather abundantly in the upper half of the sand. Fifty feet below the upper limit of the sand, in a gulch in Kidwell's pasture, near the Milligan ranch place, 2 miles east of Hiner, there is an exposure of sand, clay, lignite, and silicified wood. The lignite is local and appears to have occupied the bed of a lagoon. Limbs, fragments, and bodies of trees project from the bluff. lignitized and silicified. In some instances the lignite has been silicified.

In places along their northern margin the Basement sands have been almost denuded, sometimes entirely removed from the old level of the Wichita paleoplain. Above this the sand remains as a thin veneering. No contemporaneous limestones have yet been noted in the Basement sands in Indian Territory, although they, together with a considerable thickness of clay, occur in Arkansas just across the line (see fig. 21). It is difficult to estimate the thickness of these sands in the Territory, but the whole Trinity division, if the dips on the surface are maintained, must be nearly 1,500 feet thick along the line of the San Francisco road. The following section of the rocks beneath the Washita division in an artesian well dug at Denison shows the nature of the Antlers sands at that place (see fig. 78, *E*). The section shows the occurrence of only 20 feet of limestone near the top, the remainder being clay and sandstone.

SECTION NO. 17.—ANTLERS SANDS IN DENISON ARTESIAN WELL (RECORD BELOW GOODLAND LIMESTONE).

(See fig. 78, *E*.)

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
18. Blue clay interspersed with frequent strata of fine quicksand, water	90	90
17. Sand, fine and coarse gravel, and bowlders, water abundant.	10	100
16. Very hard blue limestone (fossiliferous)	20	120
15. Clean fine white sand (silica)	25	145
14. Tough white clay	3	148
13. Coarse sharp white sand, water under pressure, rose to within 100 feet of surface	7	155
12. Tough blue clay	50	205
11. Tough white clay, no grit	7	212
10. Fine white sand, water abundant	25	237
9. Yellowish white clay with streaks of sand (water?)	45	282
8. Loose bowlders	10	292
7. Hard gray limestone	8	300
6. About 2 feet apparent cavity, balance white sand with streaks of white clay toward bottom	25	325
5. Yellowish clay, greenish toward bottom, with small lumps of greenish sand rock	15	340
4. Variegated clay with reddish sand toward bottom	10	350
3. "Red rock," composed of red clay or chalk and sand with small quantity of black sand in upper part of strata	75	425
2. Bed of small shells	2.5	427.5
1. "Red rock," same as 75 feet, but no black sand	23	450.5

INLIERS OF LAMPASAS CUT PLAIN.

(See map, Pl. LXVI.)

Some of the creeks and rivers that have their source within the main Cretaceous area near the eastern boundary of the Trinity have cut down into the sand by their rapid erosion, yet they are not able to maintain their position, because of the steep dips of the rock, which carry them down to the stream beds again. By this process of erosion ribbons of the Basement sands are exposed in the deeper stream valleys in the western portion of the Lampasas Cut Plain. Such is the case in the region of Paluxy, Bosque, and Lampasas rivers and other small streams.

In some cases these streams have cut across the Trinity–Glen Rose border, stolen finally the drainage of other creeks, and still hold their sources in the Trinity sands. The valley of the Paluxy in Erath, Hood, and Somervell counties presents an excellent illustration of an inlying outcrop of the Basement sands. The Paluxy has its source upon the narrow plateau of the Glen Rose formation, which makes the western border of the cut plain, and by rapid erosion near its head has cut a deep valley, down to the Basement sands, for about 20 miles. from Morgans Mill, Erath County, to the Paluxy sands above.

In these outcrops occur immense quantities of silicified wood, especially between Bluffdale and Morgans Mill. These sands are reddish when weathered, are nearly pure white in places, and are often interstratified with thin seams of clay. Sometimes the clay is in lenticular layers, or even balls, and in all external aspects resembles that of the Potomac formation. The sands are sometimes consolidated into white rock that can not be distinguished from the Albirupean rocks of Uhler. Mottled and pink clays like those of the Potomac occasionally occur.

On Wolf Creek, 4½ miles north of Bluffdale, is a cliff about 60 feet high, with a fine exposure of the sands and clay layers. Near the top was a layer containing obscure vegetable remains, very scarce, with shells among them. Their position was peculiar. No plants could be found in the clay layers, although two of the sand beds had black carbonaceous seams at their base. In the creek bed the clays and sands often appeared below a considerable bluff of valley wash, but in no instance could plants be found. The clays are usually greenish, but in some places the pink, red, white, and mottled condition was very distinct. The lignite reported was far under water in a pool of the right fork. A mile below, on the right bank of Wolf Creek, in a gulch, there are a number of trunks and roots of silicified wood.

Along the greater part of the length of a canyon called Woodrock Hollow, on the Paluxy, 2 miles below Bluffdale, and its several branches, as well as up on the sides, there are vast quantities of silicified wood, some of it in good condition. Well down in the ravine are some rather high bluffs or exposures of Basement sands with clay seams. In one of these there is a dark seam in which Professor Ward found obscure vegetable remains, apparently leaves or pinnæ of *Zamites*. At another exposure lower down in the ravine bones were found projecting from the sands. They were very rotten and only a few could be collected without excavation.

Similar exposures of the Basement sands are made in the valley of the Bosque in eastern Erath County.

In one instance the Basement sands as exposed well within the main area of the Lampasas Cut Plain may be seen resting upon the Paleozoic floor. This notable example is a small district south of the town of Lampasas, as shown on the geologic map (Pl. LXVI). Here a belt of Basement beds, chiefly conglomerates, crops out around the perimeter of the Carboniferous rocks. Extending west from Lampasas, it occurs along the north side of Donaldson Creek Valley to the Lampasas and Nix road. From the Lampasas-Nix road it bears nearly south to the South Fork of Donaldson Creek, whence it bears southwest, passing along the south side of the creek valley and crossing Sulphur Creek about 2 miles below the town. From the point of crossing on Sulphur Creek it occurs along the hillsides east, north, and west of Lampasas. The Basement beds at this locality are apparently the margins of the lower portion of the Glen Rose formation, surrounding a local projection in the Paleozoic floor.

REMNANTAL AREAS IN THE CENTRAL PROVINCE.

In the Central Province, between the western border of the Grand Prairie in Comanche County and the eastern border of the Llano Estacado, are many remnantal areas of the Basement sands spreading out from the foot of the table-lands and buttes of the Callahan Divide and overlapping the edges of the lower-lying plains. These "sand-roughs," as they are locally termed, rest upon Carboniferous and Permian rocks. They stretch westward irregularly from northern Brown County along the southern side and between the various buttes of the Callahan Divide and in a northerly direction along their northern side from the northwestern portion of Comanche County across southern Eastland, northern Brown, and southeastern Callahan counties. The sand extends fully 200 square miles in the more western counties and is of the age of the Paluxy formation, the Glen Rose limestone no longer appearing.

FREDERICKSBURG DIVISION.

GENERAL CHARACTER AND RELATIONS.

It has already been shown that the Comanche sea at the close of the Trinity epoch had overcome the old Paleozoic barrier beneath the Grand Prairie, and how during the succeeding Fredericksburg epoch it swept gradually west and north over the vast areas of the Central and Plains provinces, reaching southern Kansas and northwestern New Mexico at its close. During the Fredericksburg subepoch the Cretaceous shore reached west and north approximately to a line extending from El Paso north into southwestern Kansas. The area lying south and east of this line, as far at least as the eastern border of the Black Prairie, as shown by the extent of the Edwards limestone, was a great arm of the sea, the bottom of which was covered with calcareous organisms as certain banks of the present West Indian seas are now covered. Over the entire area thus covered by the oceanic waters the sea deposited a mantle of arenaceous, argillaceous, and chalky sediments which now make the rocks of the Fredericksburg division. Not only were the sediments thus deposited over a far greater area than that previously occupied by the Trinity seas, but they were also laid down over the sediments deposited during the Trinity epoch. Hence, these rock sheets have much greater extent than do those of the Trinity division, not only occupying all the area underlain by the latter, but overlapping a vast region to the interior which was dry land during the Trinity deposition.

As a whole, these sediments thicken and become more calcareous seaward, away from the position of the old peripheral shore line at the close of the Fredericksburg epoch, as above outlined. This thickening took place by the accretion of calcareous layers offshore and horizontally away from the diagonal basement beds, after the same manner as the limestone layers previously described in the case of the Trinity division. The slope of the old bottom of deposition was so slight and its extent so vast that these changes in thickness were very gradual, and can only be noted by comparing widely separated local sections. Hence, the rocks of this division, as a whole, notwithstanding the variations to be noted, may be considered as presenting a remarkable example of uniformity of thickness and composition. In its entirety this division is composed of more calcareous rocks than the other divisions of the Comanche series. Although its interior margins ultimately pass into the Basement sands, this change mostly takes place beyond the borders of the East-Central Province, within which it is practically a great limestone formation (Edwards limestone), initiated by beds of clay (Walnut formation) at its base.

The Walnut clays pass horizontally into the Basement sands at the periphery of the East-Central Province. Within the area discussed in this paper this passage is seen only along the northern border regions and northwestward across the Central Province in the western buttes of the Callahan Divide. In some places, as in the Red River district, the lower-lying clays are thick relative to the limestones; in others they thin out, while the limestones are greatly increased, as on the Rio Grande.

As a whole, the limestones of the Fredericksburg division thin toward the Rocky Mountains and the Ouachita uplifts to the north, and thicken southward or toward the Rio Grande, being in the neighborhood of 700 feet in the latter region and less than 30 along the southern foot of the Ouachita Mountains of Indian Territory. They ultimately pass into clays and sands around the western ends of the Ouachitas in southern Kansas and west of Texas in eastern New Mexico.

SUBDIVISIONS OF FREDERICKSBURG GROUP.

Notwithstanding the uniformity and persistence of the beds and the manner in which they coalesce in certain marginal belts in different portions of the area of their occurrence notable variations may be observed, which in the regions of their greatest development are of sufficient importance to justify the subdivision of the series into several distinct stratigraphic and mappable units, to which local names must be given. Each of these extends over wide areas and they will presently be described in detail.

In the area of its most typical, if not greatest, development, in the Grand Prairie region between the Brazos and the Colorado, as will be more fully set forth later, the limestone is further differentiable into two well-marked mappable subdivisions (see fig. 12). In this region all sections of the Fredericksburg division present the following sequence, as shown in various figures:

1. At the base there are a few feet of calcareous clays intercalated with brecciated limestones, passing up into chalky layers, which become more numerous toward the top. These are the Walnut beds.

2. The chalky bands which begin to appear in the top of the Walnut clays are the beginning of a succeeding limestone formation (Comanche Peak limestone), which in this region is separated into two well-defined stratigraphic units. (*a*) The lowest of these is the Comanche Peak formation. This formation is composed of compact white rocks which on weathering shatter into numerous angular or conchoidal flakes, seldom weathering into ledges, and contain great numbers of casts of mollusks and echinoids. (*b*) Without break or apparent change in composition the rocks above the Comanche Peak begin to become harder, weathering into ledges often semicrystalline in character, and containing flint nodules and peculiar fossils of the types known as *Requienia* and *Rudistes*. These rocks form the Edwards limestone. The Comanche Peak beds are chiefly distinguishable from the succeeding Edwards limestone by the absence of flints and certain very peculiar fossils of the overlying beds, and by the fact that they weather into slopes instead of bluffs.

Stratigraphically there is no break between the various formations, and they pass upward or downward into one another by gradual transition. The marly lime of the upper portions of the Walnut formation grades into the chalky limestones at the base of the Edwards formation without demarcation.

The combined Comanche Peak and Edwards limestone thins out north of the Brazos, where it is no longer separable into individual beds. On the other hand, it thickens south of the Colorado, where several distinct subdivisions could be made.

NOMENCLATURE.

In view of these varied aspects and conditions of mapping in the different fields of occurrence, the nomenclature to be used for the limestones must be adapted to them.

The term Goodland limestone will be used in a general sense to designate the combined Comanche Peak and Edwards limestones—the entire limestone formation—south of the Colorado. The terms Comanche Peak and Edwards limestones will be used for the two mappable units into which the Goodland limestone is differentiable in the Lampasas Cut Plain between the Colorado and the Trinity, and the name Goodland limestone will be used for the combined attenuated northern continuation of the Edwards formation in Texas north of the Trinity and in southern Indian Territory.

VARIATIONS IN THICKNESS.

The general sections given in this paper will convey a clear idea of the varying thickness and relation of the beds of the Fredericksburg division throughout their extent from the Colorado to Red River.

To the south, as seen in the Nueces sections, and less conspicuously so in the Colorado sections, the Comanche Peak and Walnut formations thin out until each is less than 10 feet thick and is not capable of being separately mapped. The Edwards limestone is thicker, aggregating a greater number of feet than all the formations of the division in the Brazos sections, and making the only mappable formation.

Fig. 22.—Transgression of Walnut clays. *e*, Edwards limestone; *c*, Walnut formation; *r*, Glen Rose formation; *a*, Paleozoic floor; *b*, Basement sands.

Hence in this region the rocks of the aspect of the Edwards limestone are the correlatives of the various formations of the Brazos section.

To the north of the Brazos, on the other hand, the formations of the Fredericksburg division gradually thin out and, with the exception of a thin band of the limestone, pass into the Basement sands. (See fig. 22.)

TOPOGRAPHY.

Throughout the region south of the Brazos included within the Callahan Divide, the Lampasas Cut Plain, and the Edwards Plateau, where the Walnut, Comanche Peak, and Edwards formations are developed and where the topography has reached maturity, each formation constitutes a definite element of the peculiar topography. The Edwards limestone makes the cap rocks of the flat divides; the Comanche Peak chalk weathers into slopes leading down from the cap rock to a lower platform, from which the buttes arise. This platform is composed of the Walnut clays, the indurated layers of which produce terraces of stratification. (See fig. 5.)

There are antecedent conditions to this cut-plain topography which may be stated as follows: Where the streams cut only into the Edwards limestone simple vertical bluffs occur, as seen on the Colorado between west Austin and the city dam. (Pl. XX, *D*, 1, 2, 3.) Where the stream cuts into the Edwards and the Comanche Peak bed the latter undermines. Where the stream reaches the Walnut beds wide flat valleys ensue and the Comanche Peak slopes and Edwards limestones form receding margins of the valley.

The uniform dip of the rocks of the Fredericksburg division is no less notable than their vast extent and uniform lithologic and paleontologic characters. Approximately from the one hundred and fifth to the ninety-seventh meridian the coastward dip of these rocks coincides with the continental slope. This does not average over 10 feet to the mile west of where the Callahan Divide branches off from the western border of the Grand Prairie in northwest Comanche County. Across the Grand Prairie the dip slightly increases as the rock sheets approach the gentle monoclinal flexure (developing southward into the Balcones fault), where they suddenly bend into their embed beneath the Black Prairie. The rates of dip are given on a later page (see p. 376 et seq.).

GENERAL SECTIONS.

With these few preliminary statements we can now proceed to a more detailed description of these various beds.

North of the latitude of Decatur the rocks of the Fredericksburg division within the area of the Grand Prairie rest directly upon the Basement sands, which thence north to the Ouachita Mountains include in their upper layers the equivalents of the basal Fredericksburg to the south. Between the Lampasas and Decatur they rest upon the Paluxy sands; from the Lampasas southward they rest upon limestones there included in the upper part of the Glen Rose beds, the equivalent of the Paluxy sands to the north. Nowhere is there any break or recognizable unconformity between the underlying beds and the Fredericksburg, but they rather pass into each other by abrupt transition.

West of the Grand Prairie, across the Central Province, the rocks of the Fredericksburg division usually rest upon the transgressing Basement sands, which are the equivalent of the Trinity, Glen Rose, and Paluxy formations and the lower part of the Fredericksburg itself. In places, such as northern Gillespie, Llano, and San Saba counties, where inequalities exist in the Paleozoic floor, the Fredericksburg rests almost directly upon the Cambrian, Silurian, and Carboniferous rocks.

From the south front of the Ouachita Mountains to the San Gabriel, just north of the Colorado, the limestone rocks of the Fredericksburg division are covered by the Kiamitia clays, representing the base of the Washita division. To the south of the San Gabriel the limestones which make the top of the Fredericksburg division are covered by limestone of the Georgetown formation, from which they can be distinguished only by certain minute lithologic and paleontologic differences. To the south of the Colorado the Fredericksburg and Fort Worth limestones make a single great limestone group. (See fig. 12.)

SECTION NO. 18.—SECTION OF THE FREDERICKSBURG DIVISION OF THE COMANCHE SERIES FROM THE TOP OF COMANCHE PEAK (ALTITUDE 1,250 FEET) TO TOP OF PALUXY SANDS.[1] (See fig. 12.)

FREDERICKSBURG DIVISION.

	Feet.	
Edwards limestone:		
7. i. Hard, chalky limestone, character uniform throughout. Fossil *Radistes*, occurring very irregularly. Forms cap rock of mountain	33	
Comanche Peak beds:		
6. h. Slightly softer, chalky limestone. More variable in hardness than the Edwards (Caprina), thus forming slopes	66	
g. Hard limestone, which bears numerous small *Gryphæa* at the upper edge	3	
f. Friable, marly limestone, in which are *Gryphæa*	8	
e. Ledge of hard limestone	1	
d. Marly limestone, weathering easily; contains *Gryphæa*	5	
c. Harder limestone layer	1	
b. Marly lime, exhibiting chalky character in the upper portion	15	
a. Flaggy limestone, containing *Gryphæa*	1	
		133
Walnut formation:		
5. Arenaceous and argillaceous lime marl with layers of harder limestone:		
e. Argillaceous lime marl, grading downward into arenaceous laminated marl in the basal portion	20	
d. Compact, argillaceous limestone	2	
c. Argillaceous lime marl with *Gryphæa*	3	
b. Thin, compact limestone	1	
a. White marly limestone	5	
		31
4. Bedded *Gryphæa* breccia		10
		41
On the surface, after long weathering, this rock appears as a yellow or light-buff friable marl. In fresh exposures it is a compact light-blue limestone with softer thin layers of marly lime intervening between the harder and thicker strata.		
3. Yielding argillaceous lime marl, bearing numerous individuals of *G. pitcheri*		14
2. Marly and hard layers of limestone alternating:		
g. Hard *Gryphæa* limestone	2	
f. Marly lime on weathered surface	4	
e. Thin layer of compact limestone	1	
d. Marly limestone, friable on weathered surface	2	
c. Limestone ledges with *Gryphæa*	3	
b. Marly limestone with many *Gryphæa* and *Exogyra texana*; weathers readily into soft material	4	
a. Persistent layer of limestone	2	
		18
1. Arenaceous lime marls with *Gryphæa*		15
		88

[1] For downward continuation of this section see fig. 12, p. 151.

The basal portion is more arenaceous than the upper, and grades downward with increasing proportions of arenaceous material to its contact with the Paluxy sand.

SECTION NO. 19.—SECTION AT LOGANS GAP, COMANCHE COUNTY, TEXAS.

(See fig. 23.)

	Thickness.	Total depth to bottom of stratum.
Edwards limestone:	*Feet.*	*Feet.*
10. Soft, chalky limestone	10	10
9. Three strata of so-called magnesian limestone with cherty nodules between them containing *Requienia*	40	50
8. Hard, crystalline limestone with *Requienia* and *Radiolites*	30	80
7. Impure siliceous limestone containing coarse grains	3	83
Comanche Peak beds:		
6. Pure white, chalky limestone in thin friable layers, breaking on exposure and containing *Enallaster texana*, *Exogyra texana*, *Cardium*, *Natica*, etc	±40	123
5. Yellow impure limestone at base of above	± 3	126
Walnut formation:		
4. Calcareous clays with thin blocks containing *Gryphæa marcoui* and *Exogyra texana*	10	136
3. Blue clays	30	166
Paluxy formation:		
2. White and red clays	7	173
1. Paluxy sand, as seen in well (packsand)	100	273

WALNUT FORMATION.[1]

GENERAL CHARACTER AND COMPOSITION.

The Walnut formation comprises the beds of clay and nonchalky limestones at the base of the Fredericksburg division. They consist of alternations of calcareous laminated clays, weathering yellow on oxidation, semicrystalline limestone flags, and shell agglomerate, all of which grade upward without break into the more chalky beds of the Edwards limestone. In places they weather into rich black soils and make extensive agricultural belts.

Both limestones and clays are accompanied by large quantities of two species of fossil oyster which are always so abundant as to be of great value in determining the formation. These are *Exogyra texana* of Roemer and *Gryphæa marcoui* of Hill and Vaughan. *Gryphæa marcoui* occurs in thick beds of shell agglomerate from 1 to 20 feet thick, made up almost exclusively of this oyster. These are especially

[1] Exogyra texana beds of Hill, 1887; Walnut beds of Hill, 1890; Texana beds of Taff, 1892; this formation is shown on the geologic map, Pl. LXVI.

conspicuous from the Lampasas River northward, in Belle, Bosque, Hood, Parker, Wise, and Cooke counties.

The flaggy layers, when present, are usually beds of thin, hard crystalline limestone, composed of shells of *Exogyra texana* cemented by a crystallized matrix. These flags are steel blue in color interiorly, but oxidized to dull olives at the surface. The marls between the layers are very calcareous and in places make deep and valuable agricultural soils.

The details of the Walnut beds in the Comanche Peak section (Section No. 18, fig. 12), the Benbrook section (Pl. XIX, *B*), and the following section, based on observations on both sides of Bosque River Valley, will give an idea of the character of this formation in the region of its maximum development.

SECTION NO. 20.—BOSQUE RIVER VALLEY.

		Feet.
Comanche Peak formation:		
6. Calcareous and argillaceous, chalky, white and light-blue limestone, which contains, in its upper portion, *Exogyra texana*, in their greatest development in point of size, *Enallaster texanus*, *Epiaster elegans*, *Holectypus planatus*, *Sphenodiscus pedernalis*, *Gryphæa marcoui*, and casts of gasteropods		15
Walnut clays:		
5. Uppermost *Gryphæa marcoui* zone; compact thin layers of limestone. The fossils are small and are cemented in the hard limestone	3	
4. Marly white to buff limestone, bearing but few fossils	25	
Fragments of oyster shells and fossil casts occur. On weathering, the marly lime breaks up into soft marl and angular balls of marly lime.		
3. Middle *Gryphæa marcoui* zone; composed of layers of hard and semicrystalline lime, bearing numerous individuals of small *Gryphæa marcoui* fossils	3	
2. Marly limestone beds	30	
The limestone layers composing this bed are of varying thicknesses. Occasional hard bands project from the surface and leave fragments of limestone on the sloping hillsides.		
1. Soft marly and compact semicrystalline limestone in alternating layers, varying in thickness from very thin bands to beds 3 to 4 feet thick	35	
		96
0. Paluxy sand.		
Total		111

The upper portion of this section is composed of massive white limestone, differing little in character from the superimposed Comanche Peak limestone. Near the base the limestone is in the form of thin beds, blue in fresh exposures, turning to a cream or yellow color on long weathering. It contains considerable clay apparently, and in some instances small quantities of petroleum. The lower portion contains few fossils.

Many of the hard bands of limestone are agglomerates of *Gryphæa* *marcoui*, which, in some instances, compose almost the whole rock. The fossils *Exogyra texana* and *Gryphæa marcoui* (see Pl. XXVII) occur abundantly in this bed, but *Exogyra* is most numerous at and near the base, while *Gryphæa* is most abundant at the top.

RELATIONS AND AREAL DISTRIBUTION.

Although the Walnut formation does not anywhere aggregate 200 feet in thickness, it is very persistent in its extent and makes one of the most extensive and easily recognized of the geologic formations.

South of the Trinity this formation usually outcrops as a conspicuous flat bench or shoulder just below the scarp and upper slope of the Edwards and Comanche Peak limestones which cap the numerous buttes and divides of the Lampasas Cut Plain. Along the eastward marginal region of the Grand Prairie the outcrop of the formation descends toward the stream beds. As a consequence many of the streams in certain portions of their courses flow in wide and fertile valleys established upon the Walnut beds, between outer bluffs of the Edwards limestone. Of this nature are the valleys of the Trinity in western Tarrant County, the Bosque, in Bosque County, the Leon, east of Gatesville, and Nolands River, in southern Bell County.

From Wise County northward the Walnut formation rests upon and passes horizontally into the Basement (Antlers) sands, the upper part of which is no doubt the equivalent of the Walnut formation of the more southern sections. Between the Trinity and the Lampasas the Walnut formation rests upon the unconsolidated Paluxy sands. South of the Lampasas River the Walnut rests directly upon the consolidated layers of the upper Glen Rose beds.

The general areal distribution of this

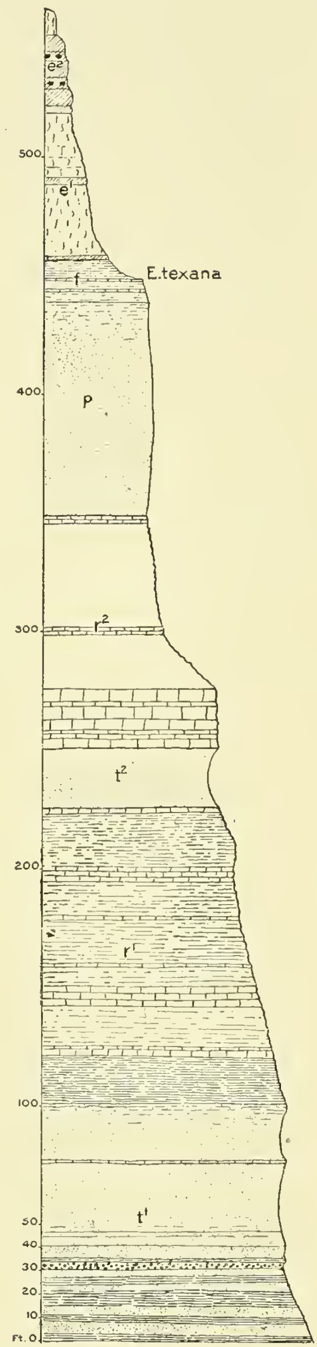


FIG. 23.—Section of Round Mountain, Comanche County, Texas. (For explanation of lettering, see Pl. XVI. p. 110).

formation within the area of the Grand Prairie may be said to be coincident with the base of the meandering cap rock of the western border and the incised valley scarps of the Lampasas Cut Plain. Through Indian Territory no well-marked lithologic representative of the Walnut clays is found, the Goodland limestone resting directly upon the Basement sands.

From Red River to the Clear Fork of the Trinity the Walnut formation rapidly thickens along the line of outcrop through Cooke, Wise, and Parker counties.

At Preston and Little Mineral Creek in northern Grayson County, and a few miles northwest of Marietta, Indian Territory, the Walnut formation is represented by a few clay layers bearing *Exogyra texana* in the Basement sands beneath the Goodland limestone. At Decatur, 27 miles north of Benbrook, the Walnut formation has thickened to 27 feet. In this region the formation is represented principally by vast agglomerates of *Gryphæa marcoui*, as conspicuously seen in the southern part of Weatherford, along the summit of the Grand Prairie east of Decatur, and along the eastward-extending valleys of the prairie streams. This agglomerate is 5 or 6 feet thick on Clear Fork of the Trinity, about 12 miles east of Weatherford.

In northeastern Wise County the formation occupies a narrow belt of prairie land seldom over a mile in width at or just below the edge of the western escarpment of the Grand Prairie and above the upland belt of timber established upon the Paluxy sands. This belt extends irregularly southward into the northwest corner of Tarrant County, following the slopes of the Trinity Valley, thence south nearly to Fort Worth, from which point it continues west of north up the south bank of that stream nearly to Jack County, where, turning around the northwest prolongation of the divide between the South Fork of the Trinity and the Brazos, it again continues southeastward through Weatherford and northeastern Hood County to the southwest corner of Johnson County, where it crosses the Brazos.

In the stream valleys of the Trinity drainage indenting the Grand Prairie in eastern Parker and western Tarrant counties the Walnut formation is well exposed, extending from the longitude of Weatherford to east of Benbrook, almost to Fort Worth. The Clear Fork of the Trinity cuts through the formation and finally flows across it. Nearly 6 miles northwest of Fort Worth the Walnut formation disappears in the bed of the river. Two miles east of Benbrook the Walnut clays, about 134 feet thick, are surmounted by 54.5 feet of Goodland limestone, as shown in section No. 23, p. 221.

South of the Brazos, beginning in northwestern Hood County, the beds outcrop along the western prairie border just above the Paluxy sands, coincident with its many meanderings through western Erath and Comanche counties, and from near Risingstar southeastward through Burnet County to the Colorado and down its valley to just west of Austin. In this portion of its extent the formation is not very thick, nor of important agricultural value. In some places its identity is almost lost. The beds thicken with the dip, as shown in the incised valley section within the Grand Prairie proper. The last-mentioned class of outcrops constitute exceedingly irregular areas. In central Erath County, north of Dublin and west of Morgan Mills and Stephenville, where these beds cap an extensive prairie plateau, they contain a larger proportion of consolidated limestone than the writer has noted elsewhere, and form open terrace prairies. In this area the original cap rock of Edwards limestone, if it ever existed, has been removed by erosion.

At Comanche Peak this formation encircles the base of the flat-topped summit, forming a well-marked bench or crown around it, and has a thickness of about 30 feet. (See fig. 12, p. 151.)

The Walnut beds are well exposed in the hillside south of Johnson Peak, on the southern margin of the Bosque Valley. They extend along the edge of the canyon of the river from a point west of Clifton to the mouth of the East Bosque. Still farther to the northeast, in the valley of Steele Creek, through which the Houston and Texas Central Railroad runs, there are on either side many buttes and mesas the slopes of which are made up of the Comanche Peak formation resting upon the Walnut clays. A section of the rocks in this vicinity has been already given. (See section No. 18, p. 204.)

Between the Brazos and the Leon there are long ribbons of this formation running in parallel directions along the slopes of the Paluxy and Bosque rivers, with their many headwater tributaries which rise along the eastern plateau above mentioned. These belts form extensive tracts of land in Somervell and Bosque counties, an especially notable belt extending from Kimball westward to Chalk Mountain. In the vicinity of Walnut Springs they constitute upland prairies. The greatest upland development of the Walnut beds is found in southern Comanche and Hamilton counties, where there are broad prairies of the Walnut formation from which the Edwards limestone has been eroded, traces of it remaining as occasional small knolls. Along the eastern tier of Grand Prairie counties, between the Brazos and the Colorado, there are wide, fertile valley plains between steep outer walls of the Edwards limestone which are composed largely of the Walnut formation. These are especially notable along the Bosque between Walnut Springs and western McLennan County; the Leon between Jonesboro and Leon Junction, Coryell County; the Cowhouse between Pidcoke, Coryell County, and Sparta, Bell County; and the South Fork of Noland River, between Copperas Cove and Belton, where there are extensive and fertile agricultural lands composed of this formation. In the cross sections afforded by Noland River and the Leon, the beds have considerable thickness and are beautifully exposed as wide and fertile areas of agricultural lands. No measurements have been made of their thickness within this region, however. Similar but less extensive areas occur in the valleys of the eastern portion of the Lampasas and at the falls of the San Gabriel River. The Walnut beds form agricultural lands as far south as Liberty Hill, Williamson County, and Bertram, Burnet County.

In northern Bell, southern Lampasas, Williamson, and Travis counties the Walnut beds have considerable exposure in fragmentary patches along the slopes of the various forks of the San Gabriel and Lampasas rivers. In the vicinity of Bertram and Bagdad the formation constitutes areas of agricultural land and has an estimated thickness of 30 or 40 feet. Along the Lampasas it shows greater thickness and its general thickness increases from east to west, being nearly 80

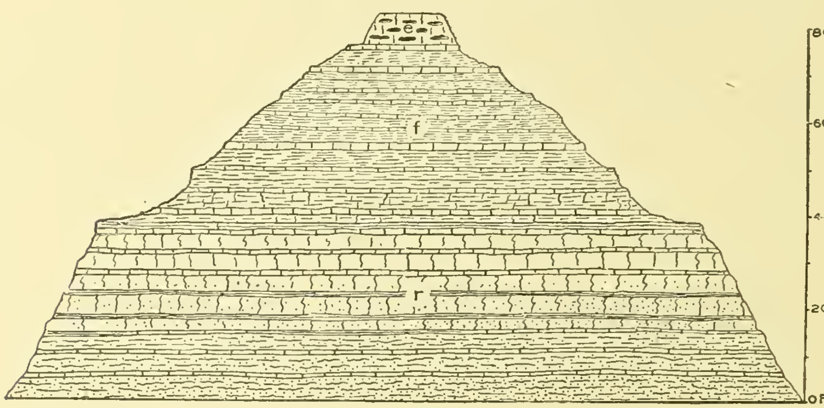


FIG. 24.—A butte near the Blanco-Travis county line, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

feet at Bachelors Peak and 55 feet at Twin Sisters Peak, in western Lampasas County. At Bachelors Peak it shows at the base bands of fossiliferous limestone containing great numbers of *Exogyra texana*, *Gryphæa marcoui*, and *Trigonia*, alternating with thick layers of yellow, argillaceous lime marl. Above this there are 15 feet of massive shell agglomerate composed almost exclusively of *Exogyra texana*, *Gryphæa marcoui*, and occasional specimens of *Schloenbachia acuto-carinata*. Above this to the top there is a zone of chalky stratified limestone, representing the base of the Comanche Peak beds.

The Walnut subdivision at the edge of the Colorado Valley west of Austin is from 10 to 15 feet thick. The formation is beautifully shown in the plateau region west of Austin. Here it makes a thin stratum of yellow, calcareous clay, lying below the cap rock of Edwards limestone and above the firm Glen Rose beds, and weathers into a flat crown-shaped terrace or shoulder just below the summits of the high buttes and mesas. Owing to the color and barrenness of these outcrops they may be distinguished for many miles in the landscape. Near the western border, to the south of the Colorado, on the Bee Caves–Burnet road, at the western border of the Austin quadrangle, there are fine exposures of the Walnut beds.

The following section was made at the summit of one of these buttes:

SECTION NO. 21.—SECTION AT BORDER OF BLANCO AND TRAVIS QUADRANGLES, 4 MILES SOUTH OF THE COLORADO RIVER.

(See fig. 24.)

	Thickness.	Total depth to bottom of stratum.
Edwards limestone (upward continuation eroded away):		
10. Firm white limestone containing flints 1 inch thick which have been worked by the Indians. This is the lower portion of the Edwards limestone, which is here preserved as a cap rock less than 100 square feet in area	*Feet.* 1	*Feet.* 1
Comanche Peak:		
9. White chalky limestone	15	16
8. Firm calcareo-siliceous clays containing great quantities of *Exogyra texana*	10	26
Walnut beds:		
7. Thin, indurated layer	.25	26.25
6. Calcareo-arenaceous clays containing great quantities of *Exogyra texana*	15	41.25
5. Yellow, rotten, honeycombed limestone	1	42.25
4. Yellow clay with abundance of *Exogyra texana*	10	52.25
3. White chalky limestone band with *Exogyra texana*	2	54.25
2. Firm limestone	2	56.25
1. Yellow arenaceous limestone, forming ledge	2	58.25
Glen Rose beds:		
0. Top of Glen Rose beds; firm, yellow arenaceous limestone weathering into ledges.		
Total Comanche Peak beds in section	25	
Total Walnut beds in section	32	
Total Glen Rose beds in section	280	

At Shovel Mountain, Blanco County (see section No. 22 and fig. 25), about 15 miles west of the above-mentioned locality, the Walnut beds are less than 20 feet thick, and thin out gradually if not completely as they pass over the axis of the Burnet uplift in northern Gillespie County.

In the Nueces section the bed is represented by only a few feet of clay between the top of the Glen Rose and the base of the Edwards limestone.

There can be but little doubt that the Walnut clays, in proceeding toward their original shore line, from the south northward in north Texas and from the east westward in central Texas, constantly transgress upon the higher and higher horizons at the expense of the basement occupied to the seaward by the limestones of the Edwards formation. Furthermore, they ultimately lose their identity interiorward by merging into the Basement sands, as shown in the figures on Pls. LIII and LIV.

SECTION NO. 22.—SECTION AT SHOVEL MOUNTAIN, BURNET COUNTY, TEXAS.[1]

(See fig. 25.)

	Thickness.	Total depth to bottom of stratum.
Fredericksburg division:	*Feet.*	*Feet.*
17. Edwards limestone	68	68
16. Buff calcareo-magnesian limestone	20	88
15. Soft, chalky limestone (Comanche Peak), abounding in *Exogyra texana*	20	108
Trinity division:		
14. Light-gray, hard, siliceous limestone	5	113
13. Light-yellow, earthy limestone of sandy texture	10	123
12. The same, but of a lighter color	10	133
11. The same, more compact in texture	19	152
10. Slope, with beds of yellowish, soft, coarse-grained limestone projecting at intervals. Some of the layers are more or less siliceous	77	229
9. Slope	10	239
8. Light-yellowish, earthy limestone appearing at intervals from slope	37.5	276.5
7. Light cream-colored subcrystalline limestone	3	279.5
6. Slope	15	294.5
5. Very similar to No. 11, but of a more granular texture	3	297.5
4. Light-yellow, soft, chalky limestone abounding in *Gryphæa*, *Rostellaria*, and *Arca*	44	341.5
3. Same as No. 13	.75	342.25
2. Light-yellowish, sandy, and compact limestone projecting in benches from slope	69	411.25
1. Rough, earthy, siliceous limestone	5	416.25

CHARACTER OUTSIDE THE BLACK AND GRAND PRAIRIES.

The argillaceous and calcareous Walnut beds gradually thin out north of the Trinity and south of Noland River and west of the Grand Prairie. To the north and west they pass into the Basement sands of

[1] B. F. Shumard, Trans. Acad. Sci. St. Louis, Vol. I, 1860, p. 585.

the Comanche series. To the south they decrease in thickness as the Edwards and Comanche Peak limestones increase.

To the west of the western border of the Grand Prairie, across the Central Province, as well as to the north, the Walnut beds pass gradually into the Basement sands, the upper part of which throughout the area of the Callahan Divide and in Indian Territory undoubtedly represents this horizon.

At Bakers Mountain, in northwestern Comanche County, the Walnut beds become arenaceous, consisting of 20 feet of indurated calcareous sandstone grading up into an impure arenaceous limestone bearing small *Exogyra texana*, *Gryphaea marcoui*, *Ammonites*, *Enallaster*, *Natica*, and *Cardium*. To the west, near Buffalo Gap, Taylor County, the Walnut clays are represented by less than 4 feet of an impure arenaceous limestone resting upon the Basement sands. In the bluffs of Bitter Creek Valley, Nolan County (see Pl. LIV, *E*), the Walnut clays are not lithologically represented at all, the Basement sands grading up into a limestone.

The Walnut beds are identified in the Castle Mountain section, Crockett County (see Pl. LIV, *G*), by their characteristic fossils, occurring in the upper 20 feet of the Basement sands. In the Horse Mountain section (see Pl. LIV, *F*) there is no lithologic equivalent of the Walnut clays, but the Edwards limestone, which here rests directly upon the Basement sands, includes its fauna at its base.

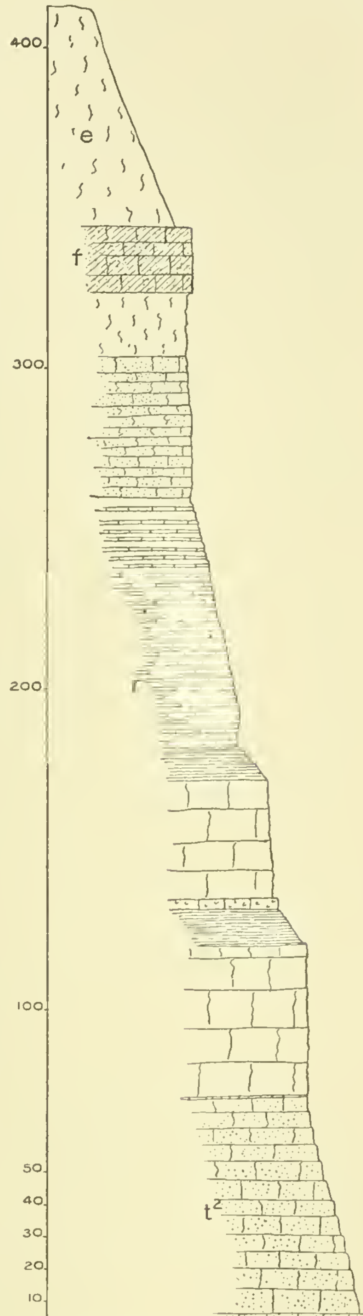


FIG. 25.—Section at Shovel Mountain, Burnet County, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

COMANCHE PEAK AND EDWARDS FORMATIONS.[1]

EXTENT, IMPORTANCE, AND THICKNESS.

The Walnut beds pass by insensible transition into more calcareous and chalky beds of the upper part of the Fredericksburg division, for which we shall use the general terms Comanche Peak formation and Edwards formation. These are the most calcareous beds in the Texas-Mexico region, and consist, with the exception of a few finely arenaceous layers, almost exclusively of white, chalky limestones of various degrees of induration and alteration, sometimes accompanied by flints.

The combined Comanche Peak and Edwards formations, while not everywhere the thickest, are the most conspicuous and extensive of all the Cretaceous rocks of the Texas region. The outcrop in its general area, as more fully detailed elsewhere, extends south from the Ouachita Mountain front across Texas into Mexico, and from the eastern edge of the Grand Prairie an indefinite distance westward until it is buried beneath the Llano Estacado and folded up in the trans-Pecos Mountains, which are in part composed of it. In the area of their embed the combined formations are easily recognizable strata in the artesian-well borings.

From a physiographic standpoint the combined Comanche Peak and Edwards are the most important formations in Texas, owing to the manner in which they dominate the configuration of an immense area. It is these formations which, owing to their superior hardness and resistance to erosion, give character to the topography of the vast areas of the Lampasas Cut Plain, the Edwards Plateau, and the scarps of the Grand Prairie and portions of the Llano Estacado.

As a whole these formations gradually increase in thickness from less than 20 feet on Red River to over 700 feet at the Rio Grande, and to still greater thicknesses in Mexico. This thickening, which is at the general rate of less than 2 feet to the mile, is so gradual and uniform that it is nowhere locally perceptible. They are nowhere more than 400 feet thick north of the Colorado.

In the extensive regions of the Edwards Plateau and Lampasas Cut Plain west of the Balcones fault and south of the Brazos, the dip of these combined formations is parallel to the surface, coincident with the continental slope, and they do not become embedded. Just east of the Balcones fault, by sudden displacement through faulting, they

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[1] In a previous paper the writer substituted the name Edwards formation for the paleontologic term "Caprina limestone" of Shumard. In casting up the knowledge of the limestone of the Fredericksburg division it has occurred to him that it might be better to extend the term Edwards to it as a whole, inasmuch as the other names used are but subdivisions of what practically constitutes an unbroken formation. It would be difficult, however, to find a proper substitute for the paleontologic name Caprina limestone, which Dr. Shumard used for a certain well-marked subdivision. In this paper the writer will continue to use the term Edwards limestone for the upper division of the great limestone formation succeeding the Walnut beds, and Comanche Peak for the lower subdivisions, where well defined. In the areas north of the Brazos the term Goodland limestone is used for their attenuated and consolidated continuation.

sink beneath the rocks of the western edge of the Black Prairie and are completely embedded beneath the latter region.

It is unfortunate that no complete sections of the outcrop of the Edwards limestone are obtainable within the area under discussion south of the Brazos, where it is thickest. This is owing to the fact that throughout the Lampasas Cut Plain and the regions to the west only the basal portion of the formation is preserved on the table-lands, the upward portion having been destroyed by erosion, while along the western margin of the Black Prairie, on the downthrown side of the fault, where the embedment takes place, only the upper beds are revealed. The latter are so broken by step faults that even their total thickness can be obtained only by a painstaking study involving the identification and correlation of ill-defined paleontologic horizons in the various outcrops. This has been attempted at only one locality, along the breaks of the Colorado and Barton Creek west of Austin, the result of which is shown in Pl. XX, *D*. Even this section is incomplete, inasmuch as it does not extend quite to the base of the Edwards limestone. Although the latter is preserved upon the upthrown side of the fault, within a short distance there is a hiatus, represented by erosion, which it is difficult to estimate with exactness.

The Comanche Peak and Edwards limestones undoubtedly represent a deposit formed farther offshore than the Walnut formation, and were laid down in oceanic water, free from land sediment, as is attested by the absence of land débris from them and by the character of the remains of oceanic life forms the skeletons of which largely make its rock material. At whatever depths they have been deposited their sediments represent the deposits of the deepest and most extensive submergence of the Comanche subepoch. It is true that in the Glen Rose formation occasional thin beds of chalk are met with, and that some of these are composed almost entirely of foraminifera; but such chalks usually contain a considerable percentage of clay, and relative to the Edwards formation the Glen Rose beds are a shallower formation.

The gradual thinning out to the north and northwest of the Edwards and Comanche Peak limestones is by the successive passage of the lower layers into clays and sands of the peripheral region, as seen in the sections of the outlying areas of northeast New Mexico and southern Kansas. Unfortunately the denudation of these formations from the Central Province of northern Texas and Oklahoma, and their concealment by overlap beneath the southern portion of the Llano Estacado, prevent the positive demonstration of this fact in those regions, but the transition is apparent along the Callahan Divide and to the south of the Ouachita Mountains in the Grand Prairie region.

The variations in thickness of the Comanche Peak and Edwards formations can be best understood by studying three groups of typical outcrops along the line of strike. The first of these is in the northern border section, extending from Little River, Arkansas, westward to north of Marietta, Indian Territory, and having outliers in the vicinity of old Preston, in northern Grayson County. The outcrops forming the second group are of what may be called the Fort Worth type, and are exposed in Cooke, Wise, and Tarrant counties, between Red River and the Brazos. The third group extends from Comanche Peak, just south of the Brazos, to the Rio Grande, west of the mouth of the Pecos. (See Pls. XVIII, XIX.)

In the northern border region and as far south as the Clear Fork of the Trinity these formations are only a comparatively thin and inconspicuous bed, increasing southward from 15 to 50 feet in thickness, and as yet presenting none of the well-defined differentiations which become such marked and conspicuous features for subdivisions southward. Owing to these peculiarities in the character of the formation north of the Trinity, the term Goodland limestone will be employed for it as the representative of Comanche Peak and Edwards limestones in that region. It is not until it passes south of the Brazos at Comanche Peak, Hood County, that the Goodland limestone begins to show two well-marked and persistent subdivisions, which may be termed the Comanche Peak and Edwards limestones, respectively.

The foregoing generalizations having been stated, the three aspects of this limestone known as the Goodland, Comanche Peak, and Edwards formations can now be more intelligently described.

GOODLAND LIMESTONE.

CHARACTER OF THE FORMATION.

At various places in southern Indian Territory, along the northern edge of the east-west belt of prairies extending from near where Little River crosses the Arkansas line 150 miles west to northwest of Marietta, Chickasaw Nation, there outcrops a thin bed of limestone, which, in this generally forested region of dark-colored soils and unindurated rocks, is conspicuous for its whiteness and firmness, and also from the fact that it usually makes low bluffs or interior-facing scarps overlooking the southern margin of the timber-covered Basement sands, which make a narrow strip between it and the adjacent Ouachita Mountains. These scarps bend down the lateral streams which cross the prairie stretches. This formation is particularly well displayed about 2 miles north of Goodland, on the St. Louis and San Francisco Railroad, from which it takes its name. About 5 miles east of the Territory line in Arkansas this limestone finally disappears by dip beneath the level of Little River.

In general, this formation consists of a white, pasty limestone, of dull or chalky texture and luster, certain layers of which crumble upon exposure into numerous fragments, generally broken in directions diagonal to the bedding planes. Sometimes the layers are firm and indurated or semicrystalline, a condition due to secondary alteration of its particles by percolation of water. These harder layers are susceptible of taking a high polish, under which conditions they are of a pearl-gray color, very similar to that of the shell marble which forms the entrance and stairway to the new Boston Public Library.

DETAILS OF OCCURRENCE.

At Goodland this limestone bed is less than 20 feet thick. It rests upon the top of the argillaceous Basement sands and is succeeded by the blue-black bituminous Kiamitia clays at the base of the Washita division. At this locality the rock contains many fossils, but most of them are so thoroughly crystallized that their identity is not easily determinable. Characteristic species are *Exogyra texana*, *Cerithium bosquense* Shumard, and a species of ammonite which is related to the form recently described by Dr. Joh. Boehm as *Engonoceras hilli*.[1]

The formation continues west across Indian Territory, everywhere marking the northern end of the Black Prairie. It is well exposed a few miles north of Caddo along the Missouri, Kansas and Texas Railway, near Emmet, north of Fort Washita, and 6 miles north of Marietta. Northwest of the latter place the formation turns southeast to Red River, crossing Red River into Texas near the Santa Fe Railway bridge north of Gainesville.

This limestone is well exposed on the Texas side of the Red River Valley from a point north of Reed and near St. Jo, Montague County (see fig. 20), to the crossing of the river at the point above mentioned, and in a small isolated area in northern Grayson County near Preston. In the vicinity of Elm Creek near St. Jo it is the outer scarp of the river valley, which is also the interior escarpment of the Grand Prairie, and is fully 300 feet above the river. From this point it follows the southern slope of Fish Creek, Cooke County, to the east, gradually dipping toward the alluvial bottom. Just above Jimtown are fine exposures of this limestone, which caps bluffs along the river and about 200 feet above it. About 3 miles east of Mossville the limestone begins to make a sharp bluff, which borders the old alluvial valley and extends up the various creeks, finally dipping beneath the alluvium a little west of north of Gainesville. The limestone in this region continues to be of the same general lithologic and paleontologic character as noted in Indian Territory, and is from 20 to 30 feet thick.

The erosion of Fish Creek has separated a remnant of Goodland limestone from the main body, which extends along the summit of the dividing ridge between Fish Creek and Red River, north of Marysville.

[1] Ueber *Ammonites pedernalis* v. Buch, von Dr. Joh. Böhm: Zeitsch. Deutsch. geol. Gesell., Berlin, 1898, p. 189.

The Goodland limestone is exposed in northern Grayson County on Little Mineral Creek, from the edge of Blood Basin, northwest of Denison, to Marshalls Bluff, a point 3¾ miles north of Pottsboro. The rocks cross Red River at the upper end of Preston Bend and extend nearly due east down the river valley, crossing again into Indian Territory northwest of Denison. This limestone is unusually well exposed at Marshalls Bluff (see fig. 26), about 2 miles south of Preston, forming the scarp rock of the Black Prairie of northern Grayson County and overlooking the lower-lying Indian Territory to the north (see Pl. XVIII, A). It consists of altered chalky rock of the same character as that previously described, occurring as a ledge about 15 to 20 feet thick, which is really separated in the middle by a thin clay seam. It is surmounted by the Kiamitia clays and underlain by over 100 feet of the Basement sands. In addition to the fossils previously enumerated, the bed here contains *Schloenbachia acutocarinata*, an irregular echinoid, *Remondia robbinsi*, *Turritella* (species), and *Gryphaea marcoui*, the latter appearing sparingly at its base. Fine bluffs of the Goodland limestone are also shown to the south in this vicinity, near the head of Little Mineral Creek.

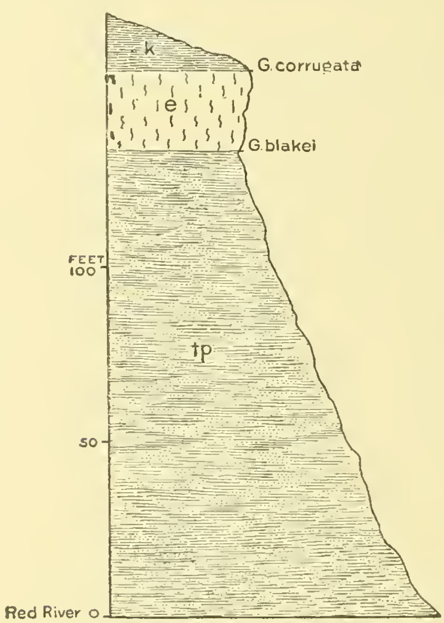

FIG. 26.—Section at Marshalls Bluff, on Red River, Texas. (For explanation of the lettering, see Pl. XVI, p. 110.)

From Red River Valley southward the Goodland limestone is exposed along the western border scarf of the Grand Prairie and in the numerous inlying areas of the valleys of the many tributaries of the Trinity which score its surface.

Each tributary flowing into the Trinity in the region of eastern Parker, Tarrant, Wise, and Cooke counties cuts below the Fort Worth limestones and Kiamitia clays, here forming the summit levels, and exposes the underlying Goodland limestone in low multilobed scarps. A clear idea of the form of these areas can be obtained only by a close study of the geologic map.

There are also several inliers of the Goodland limestone in southwestern Cooke and northwestern Wise counties. Sixteen miles west of Gainesville the Goodland limestone contains *Remondia robbinsi*; *Schloenbachia acutocarinata* (very abundant), *Cerithium bosquense*, and

Protocardium. The same rocks and fossils occur adjacent to the headwaters of Blocker, Wheat, Clear, and Denton creeks.

At Blocker Creek, in an incised valley within the Grand Prairie, the limestone is about 25 feet thick, and resembles lithologically the Comanche Peak beds of the more southern sections. The fossil *Gryphæa marcoui*, which occurred sparsely at St. Jo and Marshalls Bluff, and which continues to increase southward, is becoming abundant at this locality at the base of the bed, indicating the differentiation of the Walnut formation. A species of *Enallaster* and one of *Schloenbachia acutocarinata* range throughout the bed, and the peculiar species *Remondia robbinsi* occurs in its base. *Neithea* and *Turritella* also abound, as well as a species of *Pholadomya*. These limestones here rest upon sandy beds containing *G. marcoui* and *O. crenulimargo* of Roemer, which are slightly argillaceous at the contact. The Walnut clays and Gryphæa agglomerates, so fully developed west and south, do not occur as such in this section, but gradually appear in the sections toward Decatur.

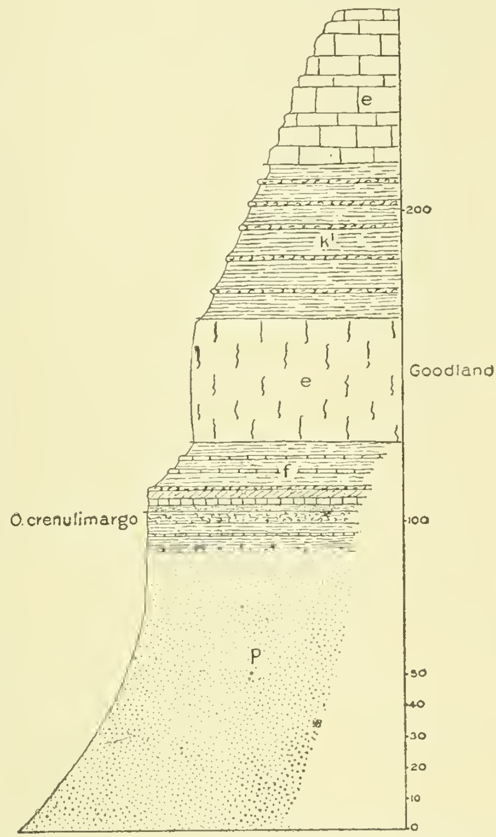

FIG. 27.—Section of Fredericksburg and Trinity divisions, Blocker Creek, Cooke County, Texas. (For explanation of lettering, see Pl. XVI, p. 110.)

Returning to the western border of the Grand Prairie near St. Jo, where it turns southeast from the Red River Valley, escarpments of the Goodland limestone may be traced in a meandering line through Cooke, Denton, Wise, and western Tarrant counties until it crosses the Trinity River a short distance northwest of Fort Worth. Wherever a creek or river valley indents the western escarpments and passes into the Grand Prairie the outcrops of the Goodland limestone facing the valley parallel the stream to the east until the dip (which in this region is nearly southeast and in the direction of the flow of the principal streams) gradually brings them down from the summit level to the stream bed. In this manner the outcrop of each rock sheet forms a V-shaped indentation into the western part of the Grand Prairie, the apex or point of which lies in the stream bed far east of the western border. The arms of the V rise to the west along the valley slopes until upon reaching the western border they occupy the divide between the valleys.

In this manner the Goodland limestone passes from near Reed post-office, on Big Elm Creek, Cooke County, northwest by Forestburg, thence southeastward to 1 mile below Bolivar, in the bed of Clear Creek; thence west around and across the arm of the Grand Prairie divide between Clear and Denton creeks; down Denton Creek nearly to the Gulf, Colorado and Santa Fe Railway; then northwestward again up the south side of Denton Creek until it crosses the divide between it and Oliver Creek; thence southeastward down the north side of Oliver Creek to a mile or two west of Justin, Denton County; thence up the south side of Oliver Creek to a point north of Decatur, and across the divide of Oliver Creek and the Clear Fork of the Trinity, which it follows to a point 3 or 4 miles west of Fort Worth, and thence up the south side of the fork into northern Parker County, near Agnes.

From St. Jo southward to Decatur the summit of the western escarpment of the Grand Prairie overlooking the Western Cross Timbers to the west is composed of the Goodland limestone. At a point due south of Decatur the outcrop turns southeast, down the edge of the valley of the West Fork of the Trinity, and forms a marked escarpment in Wise County. It descends with the dip until it crosses the river about 6 miles northwest of Fort Worth. Between the South and Clear forks and the Willow and South forks there are long, irregular, isolated remnants of the Walnut and Goodland beds.

From Agnes, in northern Parker County, to Carter, 6 miles southeast, Walnut and Goodland limestones cap the narrow remnants of the Grand Prairie forming the watershed between the drainage basins of the West and Clear forks of Trinity River, and are overlapped from a point 2 miles north of Carter to within 6 miles of Fort Worth by a very irregular belt of limestones of the Washita division, which crests the divide between the same two branches of Trinity River. The Goodland and Walnut rock sheets make the slopes on each side of this divide, extending in very irregular crenulated belts. Where the river on either side bears toward the watershed the slopes become more precipitous and the width of the rock exposures less, but where the river extends away from the divide the surface is gently sloping and occupies a wide area.

The Goodland and Walnut beds form a narrow and irregular border upon the south side of the valley of Clear Fork of Trinity River from the mouth of South Fork to within 6 miles of Fort Worth, which contracts from a width of about 2 miles at Anneta, in Parker County, to a point west of Fort Worth, where the rocks dip beneath the river bed.

From a point on the Clear Fork of the Trinity about 5 miles west of Fort Worth the main western border outcrops of the Goodland limestone follow the south side of the valley of that stream westward nearly to Weatherford; here they turn the angle of the Trinity-Brazos divide, and the formation becomes differentiable into the Comanche Peak and Caprina limestones, which follow the western escarpment of the Grand Prairie through Parker, Hood, and Johnson counties to the Brazos in Hill and McLennan counties.

The incised valleys of the streams of southeastern Parker and southwestern Tarrant counties, like Bear and Mary creeks, which lead into the South Fork of the Trinity from the south, also show fine exposures of the Goodland beds.

This limestone, from its first occurrence where it dips beneath the overlying formations in Little River, Arkansas, to the Hickory Creek locality northwest of Marietta, does not exceed 20 feet in thickness. Along Red River it is about the same; near Decatur it is 33 feet thick. Two miles east of Benbrook, on the Texas and Pacific Railway, and 8 miles west of Fort Worth, this limestone is 54 feet thick, and carries in greatest abundance the numerous and varied fauna of the Comanche Peak limestone of the sections farther south.

SECTION NO. 23.—FREDERICKSBURG DIVISION. DETAILS (AFTER J. A. TAFF) OF THE GOODLAND LIMESTONE AND THE UPPER PORTION OF THE WALNUT BEDS 2 MILES EAST OF BENBROOK AND ON MARYS CREEK 2 MILES NORTHWEST OF BENBROOK, IN DESCENDING ORDER. (SEE PL. XIX, AND FIG. 31.)

	Thickness.	Total depth to bottom of stratum.
Goodland formation:	*Feet.*	*Feet.*
16. Crumbling, chalky limestone, which contains *Cylindrites formosus* Crag.; *Enallaster texanus*, *Exogyra texana*, *Gryphæa marcoui*, *Diplopodia texanum*, *Epiaster whitei*, *Schloenbachia acutocarinata*, *S. pedernalis*, *Epiaster elegans* Crag., *Trichotropis shumardi* Crag.; *Cinulia tarrantensis* Crag., and *Turritella seriatim-granulata* in the upper part. *Caprina crassifibra* was found here 4 feet below the summit of the limestone	18.16	18.16
The upper portion of the above strata, above the occurrence of *Exogyra texana*, represents the whole of the Comanche Peak and Edwards limestones at this locality. Stratigraphically, the parting line between the Walnut and Comanche Peak limestones is difficult to draw.		
15. Blue, argillaceous lime marl	1	19.16
14. White, crumbling limestone, bearing *Enallaster texanus*, *G. pitcheri*, *Pecten texanus*, *Exogyra texana*, and *Exogyra plexa* Crag	4.33	23.49
13. Blue, argillaceous lime marl	1.5	24.99
12. Comparatively massive, soft, white limestone, the strata varying slightly in compactness	29.5	54.49

SECTION NO. 23.—FREDERICKSBURG DIVISION, ETC.—Continued.

	Thickness.	Total depth to bottom of stratum.
Walnut formation:	*Feet.*	*Feet.*
11. Soft, shelly limestone and blue argillaceous lime interstratified, each stratum being 5 to 6 inches thick	14	68.49
10. Massive limestone	8	76.49
9. Blue, laminated, argillaceous lime	10	86.49
8. Compact limestone	2.25	88.74
7. Shaly, argillaceous limestone	2.5	91.24
6. Compact limestone	2.5	93.74
5. Compact and shaly lime in thin layers	2	95.74
4. Concealed in this section and not examined	50	145.74
3. *Gryphæa marcoui* conglomerate, composed of layers of massive shell limestone and lime marl interbedded	15	160.74
2. Alternating chalky and *Gryphæa* limestone	32	192.74
1. Arenaceous marl, which contains *G. marcoui*, *Exogyra texana*, and *Sphenodiscus pedernalis*	3	195.74

SECTION NO. 24.—SECTION 2 MILES SOUTH OF PLEASANT POINT, JOHNSON COUNTY, TEXAS (TAFF).

	Thickness.	Total depth to bottom of stratum.
Goodland formation:	*Feet.*	*Feet.*
8. Chalky white to buff limestone, varying slightly in hardness, and bearing numerous large *Exogyra texana*, *Enallaster texanus*, *Lima wacoensis*, *Natica?*, *Turritella seriatim-granulata*, *Schloenbachia acutocarinata*, and *Sphenodiscus pedernalis*	30	30
Walnut formation:		
7. White to yellowish limestone, very much the same in character as that of No. 8, but no fossils found	40	70
6. Thin-bedded, compact, yellow limestone, bearing many small *G. marcoui*	10	80
5. Whitish limestone, similar to Nos. 7 and 8	15	95
4. Thin-bedded, hard, shaly limestone, bearing numerous small *G. pitcheri*	2	97
3. Limestone, similar to No. 5	18	115
2. Basal *Gryphæa* limestone, the upper 10 feet composed almost entirely of fossil *G. pitcheri* and containing many *Schloenbachia acutocarinata;* the portion below this is a crumbling limestone, which bears many *G. pitcheri* and associated forms	30	145
1. Arenaceous lime marl, which grades downward from the top with increasing proportions of sand to its contact with the Paluxy sand	15	160

COMANCHE PEAK LIMESTONE.

RELATION TO GOODLAND AND EDWARDS LIMESTONES.

From its outcrop in western Arkansas westward to Marietta, 150 miles, and south 100 miles to the Clear Fork of Trinity River, in the western part of Tarrant County, the Goodland limestone is practically a single indivisible formation. At and upon leaving the latter locality, however, it begins to differentiate into mappable formations which attain great conspicuity southward throughout the Texas region.

In the bed of the West Fork of Trinity River at Fort Worth, 5 miles west of Fort Worth, and at Benbrook Station, 10 miles west of Fort Worth, there is a chalky white limestone containing many of the typical Comanche Peak species, such as *Schloenbachia acutocarinata* and *Exogyra texana*, and also, as noted by the writer,[1] peculiar *Chemnitzia occidentale* of Gabb and *Remondia robbinsi*. Later studies and more exact measurements of the Benbrook locality by J. A. Taff give a section of the limestone bed aggregating 54.6 feet (see section, Pl. XIX, *B*). This section shows a total of 54.6 feet of chalky limestone resting upon 133 feet of the Walnut beds. Here the chalky limestones are separated into three beds by two thin layers of blue argillaceous marl about 1 foot thick. The uppermost bed is 18 feet, the middle one 4 feet, and the lower one 30 feet thick, and all are very fossiliferous.

In the upper bed were many other fossils characteristic of the Goodland limestone. The middle bed is marked by an abundance of *Enallaster texana*, *Gryphæa marcoui*, and *Exogyra texana*, making a paleontologic zone which is but faintly developed in the base of the Goodland and in the Blocker Creek section but which becomes very persistent across Texas to the south. The peculiar little fossil *Exogyra plexa* Cragin was found in this bed by Taff, although it had not been noted to the southward in Texas. The lower band of limestone also contains many fossils.

Within 4 feet of the top of the uppermost bed Taff found fossil *Rudistes*. This is the northernmost occurrence of these aberrant mollusks, which to the south are the distinguishing paleontologic feature of the Edwards limestone, which there has developed well-differentiated lithologic characters not observed in this section.

It can now be said that at Benbrook the 20 feet of Goodland limestone on Red River has developed into 54 feet of limestone, in which are seen indications of differentiation into two distinct groups of strata, the lower 50 feet of which represent the Comanche Peak chalk of the southern sections and the other 4 feet the Edwards limestone, both of which will be described.

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[1] Am. Jour. Sci., 3d series, Vol. XXXIII, April, 1887, pp. 298–299.

CHARACTER AND DETAILS OF OCCURRENCE.

The Comanche Peak limestone may, then, be defined as the lower portion of the Edwards limestone of the Texas region south of the West Fork of the Trinity, occurring above the Walnut clays and below the flint and Rudistes beds of the Edwards limestone. Although lithologically it might be considered the base of the Edwards limestone, it is one of the most persistent horizons of the Texas Cretaceous section within the area of the Grand Prairie south of parallel 30° 30′

In general it may be described as a persistent bed or beds of white, chalky, fossiliferous limestone, which seldom, if ever, exceeds 50 feet in thickness. In good exposures it consists of massive beds of white, chalky limestone from a few feet to as much as 20 feet thick, separated by faintly marked and widely separated planes of stratification, which are generally bordered by thin marly bands. On surfaces where it has undergone long disintegration it crumbles into subangular fragments and soft, limy masses, the more marly portions, as a rule, yielding more readily to erosion and forming slightly undulated surfaces. On weathering, the limestone adjacent to the planes of stratification decomposes more readily on account of water circulating more freely between the layers.

The overlying Edwards limestone, being more crystalline, is firmer, more persistent, and offers greater resistance to erosive agents, and therefore stands out as a shelf or bench on the hilltops where the strata have been exposed to weathering, while the underlying Comanche Peak limestone ordinarily weathers into steep slopes.

The Walnut beds grade up into the Comanche Peak limestone through a series of chalky layers, which increase in massiveness upward until they finally pass into a more indurated and persistent band of chalky limestone, making the base of the Comanche Peak, as above described. This transitional bed is about 20 feet thick, and is composed of strata 3 to 6 feet thick, in which the species *Exogyra texana* abound. Neither is the upper delimitation of the Comanche Peak clearly marked, except by the fact that it may be said to end where the firmer and more persistent bands of the Edwards limestone containing flints and Rudistes begin. In general the Comanche Peak formation is a more homogeneous bed of indurated chalky material than the underlying Walnut clays and a softer and more friable formation than the overlying Edwards limestone.

It is not necessary to attempt to describe all the occurrences of this formation, inasmuch as it is so intimately associated with the Edwards limestone that its general distribution, especially south of the Brazos, is almost coincident with the latter, outcropping in the slopes of all the scarps and mesas which it forms, as will be more fully described on a later page.

It is usually exposed along steep slopes, especially those of the numerous circular mesas of the western half of the Grand Prairie, and is only thinly covered by vegetation—an occasional stunted growth of scrub oak or scattering sedge tufts. In such cases it makes a conspicuous gray or white band in the landscape, which may be recognized miles away. Where it occupies a level plateau summit or bench, rich black residual soils are often found. A typical occurrence under this condition is upon a part of the high divide north of San Gabriel River in Burnet County; also upon the "flat" east of Pilot Knob, Burnet County.

Continuing southward east of the Brazos with the strike from Benbrook, 9 miles west of Fort Worth, to where the Brazos River crosses it near Greenock, Hill County, the Fredericksburg strata, which are here composed mostly of the Comanche Peak beds, with the thin but gradually thickening representatives of the Edwards at their top, increase rapidly in thickness until they measure 75 feet at the latter locality.

The formation has its greatest development and typical exposure in the western half of the Lampasas Cut Plain, between the Brazos and the Colorado, almost coincident with the outcrops of the Edwards limestone to be described.

This limestone is beautifully shown in the crown of Comanche Peak, Hood County (see fig. 12), where it is 30 feet thick and forms the steep slope leading up from a bench of the Walnut clays to the thin rock of Edwards limestone. This is the only remnant of this formation preserved north of the Paluxy.

At the south line of Hill County these rocks make the river bed and immediate valley of the Brazos. Northwestward to the northwest corner of Hill County each formation of the Fredericksburg division, from the top downward, rises successively from the river base. The Comanche Peak formation underlies the flood basin and forms the bluffs of the valley of Noland River from its mouth to very near the north line of Hill County. At many points below Blum beautiful bluffs of Comanche Peak and Edwards limestones rise above the river where it approaches the outer margin of the valley.

It is more extensively preserved along the Paluxy-Bosque divide from the east line of Erath County to the Brazos, being well shown in all the mesas of the type of Chalk Mountain and the Seven Knobs and in the eastern portions of the stream valleys. Similar belts are found along all the divides and eastern valleys southward to the Colorado. It also makes the slope of all the buttes forming the main divide between the Colorado and Grand Prairie drainage in Comanche, Brown, Hamilton, Mills, Lampasas, and Burnet counties.

Three miles northwest of Austin the Comanche Peak forms the summit slope of Mount Barker (see Pl. XX, *C*), the Edwards limestone having been almost completely eroded. It is exposed in many other localities near the summit of the Edwards Plateau in western Travis County.

West of the Grand Prairie region, in tracing the rocks of the Fredericksburg division along the Callahan Divide, of which it forms the upper slopes, across the Central Province toward the Llano Estacado, one finds that the Comanche Peak rocks gradually pass into the Basement sands, and that the lower portion of the Edwards limestone group is more or less arenaceous. (See Pl. LIV.)

The Comanche Peak limestone does not vary perceptibly, except in thickness, between the Colorado and Brazos rivers. In the Colorado Basin it is nearly 100 feet thick. On the Brazos River, as exposed in bluffs at the border of the river basin through Hill and Bosque counties and in Comanche Peak, the thickness of the Comanche Peak varies from 65 to 70 feet. North of the Brazos it begins to decrease, as previously described, as it passes into the Goodland limestone.

PALEONTOLOGY OF COMANCHE PEAK LIMESTONE.

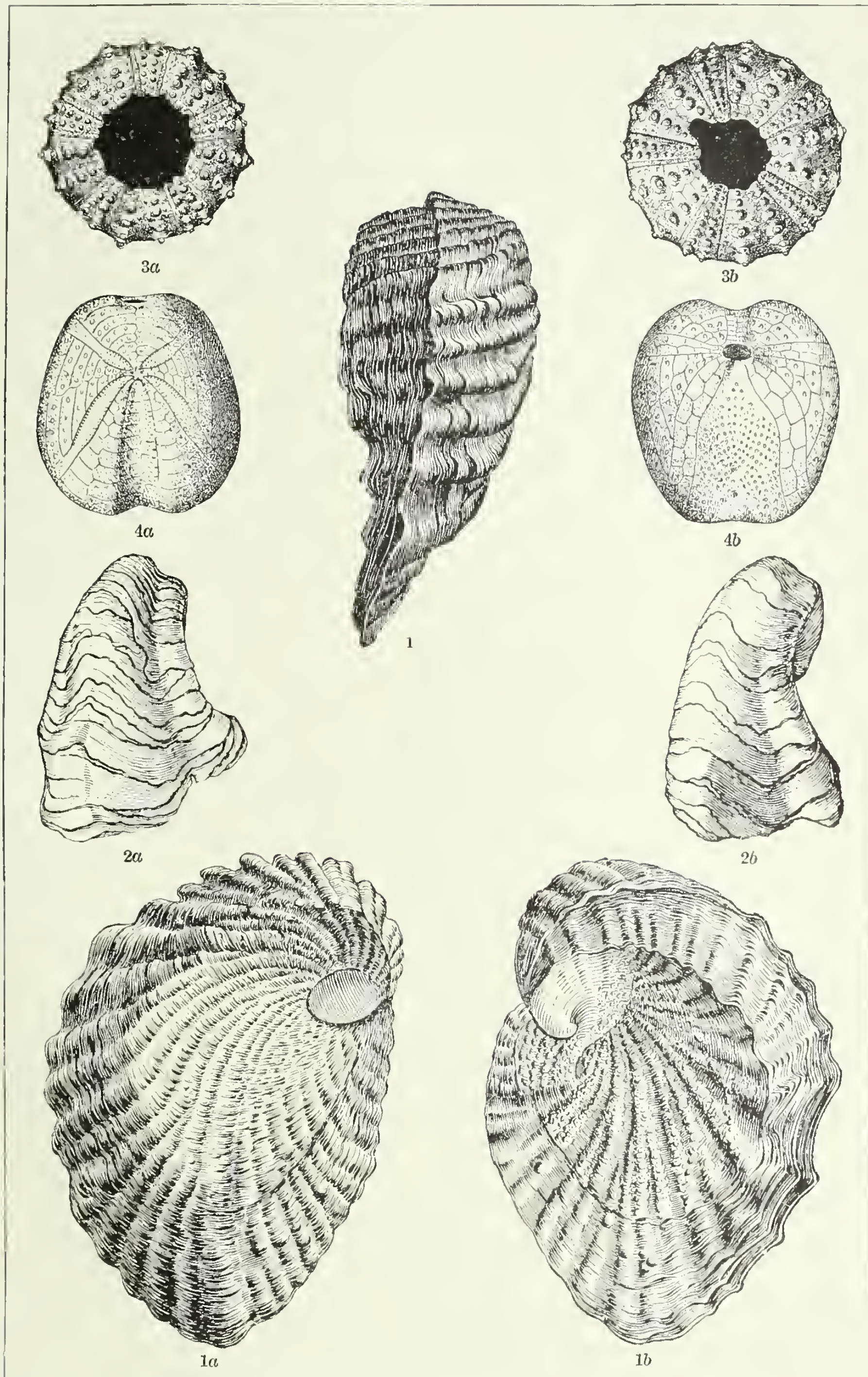
The Comanche Peak formation, especially in its lower part, is very rich in fossils, a feature which in a degree distinguishes it from the overlying Edwards limestone. (See Pl. XXVII.) Dr. B. F. Shumard noted[1] the following species as being those most frequently observed:

Exogyra texana.
Gryphæa marcoui.
Janira occidentalis.
Cardium multistriatum.
Cardium texanum.
Cardium coloradoense.
Pholadomya sancti-sabæ.
Lima wacoensis.
Arcopagia texana.
Trigonia crenulata.
Astarte lineolata.
Cardita eminula.
Corbula occidentalis.
Modiola concentrico-costellata.
Leda.
Thracia.
Ammonites acutocarinatus.
Ammonites pedernalis.
Scalaria texana.
Phasianella tumida.
Rostellaria (Eulima Sh.) subfusiformis.
Natica pedernalis.
Nerinea acus.
Avellana texana.
Turritella seriatim-granulata.
Cerithium bosquense.
Pleurotomaria (sp. undet.).
Solarium (sp. undet.).
Heteraster (Toxaster Roem.) texanus.
Holectypus planatus.
Cyphosoma texanum.
Diadema texanum.

These are the most conspicuous and abundant species south of the Brazos. Taff gives the following list from the limestones near Benbrook, Tarrant County, where a few species occur which have not been noted in the southern locality:

Cylindrites formosus Cragin.
Enallaster texanus.
Exogyra texana.
Gryphæa marcoui.
Diplopodia texanum.
Cyprimeria crassa, in the lower part.
Schloenbachia acutocarinata.
Schloenbachia pedernalis.
Epiaster elegans Cragin.
Epiaster whitei.
Trichotropis shumardi Cragin.
Cinulia tarrantensis Cragin.
Pecten texanus.
Exogyra plexa Cragin.

[1] Trans. Acad. Sci. St. Louis, Vol. 1, p. 585.



CHARACTERISTIC FOSSILS OF THE WALNUT CLAYS AND COMANCHE PEAK LIMESTONE.

1, 1*a*, 1*b*. Exogyra texana Roemer.
2*a* 2*b*. Gryphæa marcoui Hill and Vaughan.
3*a*, 3*b*. Pseudodiadema texanum Roemer.
4*a*, 4*b*. Enallaster texanus Roemer.

Exogyra texana and *Echinodermata* are especially abundant in the basal portion of the formation, which is marked by the absence of the *Rudistes* and *Requienia* species characterizing the overlying Edwards limestone.

EDWARDS LIMESTONE.

RELATIONS AND COMPOSITION.

The Comanche Peak formation passes up without break into the harder and more persistent Edwards limestone. In general the two formations can be distinguished by the fact that while the Comanche Peak strata are less consolidated, are slightly argillaceous, and possess a more marly texture, the Edwards limestone is largely a firm, white, ringing limestone of great hardness and durability. The Edwards also weathers into cliffs, while the Comanche Peak is wrought into lower-lying slopes. Finally, the Edwards limestone is distinguished from the Comanche Peak by the occurrence in it of great quantities of flint nodules and certain peculiar fossils—aberrant mollusks of the genera *Monopleura*, *Requienia*, and *Radiolites*—bivalve shells which have cornucopiate form, suggesting a resemblance in shape to the horns of cows, goats, and sheep. The line of separation must usually be drawn at the point of the lowest occurrence of flints and the rudistean and requienian forms which are so characteristic of the Edwards. The flints disappear from the Edwards formation near its passage across the Brazos River, as also do all the flaggy and siliceous layers.

Stratigraphically the Edwards limestone represents the culmination of the subsidence that progressed during the Comanche epoch, and while the beds may not represent deepest sea deposits they were laid down away from the shores and in clear oceanic waters, uncontaminated by land débris and where great colonies of animals, such as the sponges and rudistes, could thrive, the chief material of the rocks being organically derived lime and silica.

Where well developed, the Edwards formation shows slight variation in color, composition, texture, and mode of weathering. It is composed mostly of limestone, but there are some calcareous layers which are marly and arenaceous. Most of the beds are as nearly pure carbonate of lime as can be found in nature, but some have admixtures of silica, epsomite, chloride of sodium, and perhaps other salts as yet undetermined. Clay is absent except as a minor constituent in a few exceptional marly layers. Iron is sparingly present as pyrites, and is betrayed by the red color of the clay that remains after the solution of the limestone. Exceedingly fine siliceous particles occur in the so-called "magnesian beds"—light-brown, porous strata which appear in the formation southward from Comanche County—but no pebble, bowlder, lignite, or other undoubted piece of land-derived débris has ever been found.

The limestones vary in degree of induration from hard, ringing, durable strata to soft pulverulent chalk that crumbles in the fingers and resembles much the prepared article of commerce. Some of the beds are coarsely crystalline, with calcitized fossils, and are susceptible of high polish. The beds also vary in texture. Some are porous and pervious, while others are close-grained and impervious. Some are homogeneous throughout, others have hard and soft spots, the latter dissolving away in the percolation of underground water and producing what are popularly termed "honeycombed" rocks. The harder spots in some cases seem to be in process of induration, suggesting a step in the formation of flints. The holes in the honeycombed layers often represent what were once spots containing soluble salts of iron and other accessory minerals.

The formation is stratified into a succession of massive beds, accompanied by very few flaggy and marly layers. Some of the strata are harder than others and project beyond the softer layers in the profile of the hills as overhanging shelves; others are soft and erode rapidly.

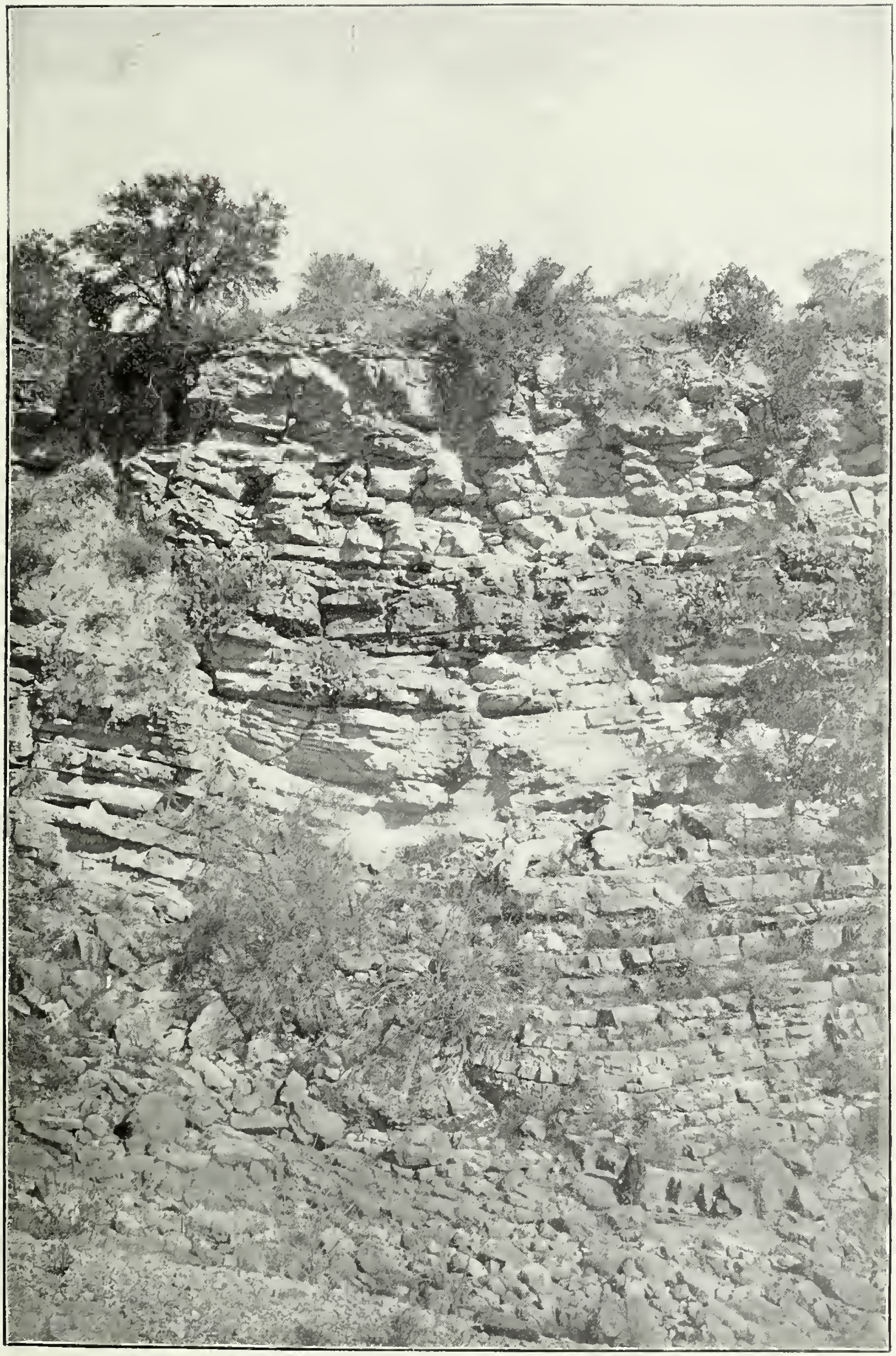
OCCURRENCE OF FLINTS IN EDWARDS LIMESTONE.

Accompanying these chalks and chalky limestones are well-defined layers of flint nodules occupying apparently persistent horizons. The flint nodules are flat, oval, cylindric, or kidney-shaped, ranging in size from that of a walnut to about 1 foot in diameter. Exteriorly they are chalky white, resembling in general character the flint nodules of the English chalk cliffs. Interiorly they are of various shades from light opalescent to black, sometimes showing a banded structure. These flint nodules are beautifully displayed in situ in the Deep Eddy Canyon of the Colorado, above Austin, where they can be seen occupying three distinct belts in the white, chalky limestones (see Pl. XXXI).

The partial decomposition of these flints and of the adjacent limestones has produced some striking effects in places, resulting in a peculiar red-colored cavernous rock composed of the siliceous pseudomorphs of fossil *Rudistes* and other shells, the interstitial spaces glittering with minute quartz crystals which line them.

Where the harder limestones form the summit of extensive plateaus, such as those of the Lampasas Cut Plain and Edwards Plateau southwest of Austin, the flints are sometimes left in great quantities as a residuum. These often cover large areas of country. The flints have also been transported in past geologic times by streams and are distributed over large areas along the margin of the Black Prairie as a part of the post-Cretaceous gravels of that region.

These are the only flint horizons, so far at least as is known to the writer, in the Cretaceous deposits of the United States. (See Pls. XXX and XXXI.) They occur about the middle of the Lower Cretaceous



EDWARDS LIMESTONE, BARTON CREEK, TEXAS.

series, instead of at the top of the upper series, as in England. It was from these flints that the ancient and modern Indians made their implements, and the ease of their lithologic identification will be of value to the anthropologist in tracing the extent of the intercourse and depredations of former Indian tribes inhabitating this region. Occasionally the flints, especially an opalescent variety in Comanche County, possess nuclei in the shape of fossils, usually *Requienia*. In going south the flints first appear in the vicinity of Meridian, but sparingly; they increase in number very rapidly to the south, being seen in great quantities about Belton. South of the Paluxy the formation can always be distinguished by the immense quantity of these flint nodules, which are embedded in and between the limestones, and which lie scattered everywhere over the surface.

PECULIAR ALTERATION.

Immediately west of Austin, along the downthrow of the great Bonnell fault in the bluffs of the Colorado, peculiar alteration takes place in the upper part of the Edwards formation. Occasional red blotches may be seen in the massive bluffs of white, chalky limestones. Upon closer examination the apparently nonfossiliferous limestone is seen to be undergoing decomposition, and as a residium there remains a dry, red, pulverulent dust containing exquisitely preserved calcite pseudomorphs of many rare fossils, such as have been recently described by Roemer [1] and White,[2] which occur in this horizon.[3] (See Pl. XXXII.)

ECONOMIC FEATURES.

The Edwards limestone affords fine building stone and road metal. Ornamental marbles like the fossiliferous pearl-gray marbles of France and the rich cream and yellow marbles of Portugal and Algiers occur in great abundance, but are as yet not utilized. Nearly all of the more compact marbles take a good polish. The following economic products have also been discovered: Potash, salt, strontianite, anhydrite, epsom salts, gypsum, and gold, but in quantities as yet unknown.

RELIEF FEATURES.

As a relief-making feature the limestone is one of the most important formations in Texas. In fact, it is the determining factor in the relief of the whole of the Grand Prairie and Edwards Plateau provinces. Its hardness being superior to that of the overlying and underlying beds, its consequent resistance to erosion has preserved it as the capstone of the innumerable round "mountains" (buttes) and mesas of the whole Edwards Plateau and Lampasas Cut Plain, and especially all the high summits of the divides and mesas of the Grand Prairie west of the Balcones fault line, near its eastern edge. On the

[1] Paleontologische Abhandlungen, Vol. IV, pt. 4, Berlin, 1888.

[2] Bull. U. S. Geol. Survey No. 4, 1884.

[3] Bull. Biol. Soc. Washington, Vol. VIII, 1893, p. 101.

downthrown side of the main or westernmost faults of the Balcones zone the latter becomes for a short distance the matrix of the streams, and in this portion of their courses, as seen at Austin, Georgetown, Belton, and east of Gatesville, the rocks form vertical canyons of great beauty.

In these canyons the limestones, which are generally higher beds in the series than those forming the cap rock of the mesas, show many types of weathering. Some of the strata make bold cliffs nearly 50 feet high, the faces of which, although apparently of homogeneous texture, weather into small, open caverns. This weathering sometimes brings out a thinly laminated structure associated with white efflorescence. The bottoms of caverns of this character are filled with a layer of white pulverulent earth. The residual products of other massive ledges weathering into caverns are vermilion-colored clays in which are beautiful fossils composed entirely of crystallized calcite. The hard limestones weather into vertical, square-cut bluffs, while the soft and more homogeneous beds of marly or chalky texture form slopes. Where these hard and soft beds occur in alternation there is a corresponding alternation of scarps and slopes in the topographic profile.

The level stretches of divide between the canyons of the downthrown belt are also stony—great jagged residual bowlders projecting through a black soil in places, while at other times the whole surface is made up of residual flints resembling transported gravel. This belt, as well as the summits of the mesas, is usually covered by an interesting and diversified hard-wood forest.

CONTACTS OF EDWARDS LIMESTONE.

North of the San Gabriel the top of the Edwards limestone is abruptly overlain by the Kiamitia clays, from which it is readily distinguishable. South of the San Gabriel the Edwards grades into the overlying Georgetown formation along the Colorado region, from which it is not separable except by paleontologic criteria. It is true that the Georgetown limestone is slightly more arenaceous than the Edwards, but the differences are so slight that it requires the trained eye of the geologist to detect them. As the overlying Georgetown formation in this region is less than 75 feet thick, the layman or well driller unversed in paleontology can nearly always be sure that any rock occurring 75 feet below the Del Rio clays belongs to the combined Comanche Peak and Edwards formations.

The eastern parting of the Edwards has not been traced from Oglesby in eastern Coryell County north to the Brazos. Near Oglesby the Fort Worth limestone is faulted down against the eastern margin of the Edwards. To the north it is overlapped by the Kiamitia clays of the Washita division.

On Coon Creek, a short tributary of the Brazos north of Greenock,

QUARRY IN THE EDWARDS LIMESTONE WEST OF AUSTIN, TEXAS.

Bosque County, the contact between the massive fossiliferous Edwards limestone and the Kiamitia clay may be seen where *Caprina crassifibra* and *Requienia* forms mingle with *Gryphæa corrugata* of the Kiamitia clays. The occurrence of the rudistes and requienias ceases at the Kiamitia clays.

OCCURRENCE AND DISTRIBUTION.

The Edwards limestone within the Grand Prairie north of the Colorado occurs in remnantal patches throughout the region between the Brazos and the Colorado. These occurrences are different in aspect east and west of the Balcones fault line.

On the downthrown side of the main fault line which runs just west of Austin, Roundrock, Georgetown, Belton, and McGregor, the upper strata are exposed in a narrow belt (which has been previously alluded to). This belt is also sheared by secondary faults on the east and is seldom more than 5 miles wide. Geographically this belt is the inner margin of the Black Prairie region. The rocks exposed in this downthrown belt (usually the upper part of the Edwards formation) belong stratigraphically above those found in the other area. This belt is followed by the north-south bend of the Leon for a considerable distance in eastern Bell County, and may be seen in the vicinity of Belton, where the bed carrying *O. ? munsoni* is downthrown to the level of Noland River and the Leon. The bluffs of the Colorado between Austin and the east foot of Mount Bonnel are also in this belt.

The second area of outcrop embraces all the summit region of the Lampasas Cut Plain, Edwards Plateau, and Callahan Divide west of the main Balcones fault, capping nearly all the eminences and making the flat-topped summits and vertical cornices of all the buttes and mesas, so frequently alluded to in this paper, in Travis, Bell, Burnet, Lampasas, Coryell, Mills, Bosque, Hamilton, Comanche, and Hood counties. It also makes the western scarp rock of the Grand Prairie from the Colorado to northern Brown County. In this relatively higher area only the middle and lower portions of the Edwards formation are preserved, the upper beds, which occur in the downthrown belt, having been generally removed by erosion.

DETAILS OF STRATIGRAPHY.

Owing to the faulting along the eastern margin of the Grand Prairie, complete sections of this limestone are rarely obtainable north of the Frio. Its basal portion only is preserved on the summits west of the fault line, while the upper portion is exposed along a narrow belt on the downthrown side of the Balcones fault zone between the Colorado and the Leon in the canyons of the streams.

The following composite section near Austin, made up from several localities on the downthrown side of the fault, is the most complete that has been obtainable within the area considered in this paper. (See Pl. XX, *D.*) Even this section does not reach to the base of the formation.

Section No. 25.—Composite section of the faulted Edwards limestone on south side of Colorado river, west of Austin, Texas. (See Pl. XX, *D.*)

[(*a*) Upper part of Edwards limestone exposed in bluffs of Barton Creek, about 1 mile above the bridge.]

Edwards limestone:	Ft.	In.
49. Nodular limestone full of requienias	3	0
48. Nodular limestone, nodules as large as one's head	2	0
47. Hard, chalky limestone	3	0
46. Thinly laminated limestone (the so-called "lithographic flags")	8	9
45. White, sublaminated, chalky limestone. The lower parts of Nos. 45 and 46 contain many fossils, *Exogyra texana*, *Pholadomya knowltoni*, etc	8	5
44. Nodular limestone, no requienias	1	0
43. [1] Nodular limestone with many requienias (second requienia bed)	3	9
e. Laminated limestone	1	0
d. A series of hard limestone ledges (eight in number) separated by thinly laminated layers. There are some flints, about as large as a man's fist—*Radiolites* and *O? munsoni*	45	8
c. Flaggy layer with discoidal flints	2	4
b. [2] Hard limestone, forming a shelf along this portion of Barton Creek and its bottom at the bridge below, eroded into deep pot-holes. The lower 2 feet of this layer contains very large blue flints, often 1 foot across. Some of them are oval, others flattened out and very irregular in outline. The upper part of bed contains small flints	12	8
a. Limestone ledges with some flattened flints. All of the flints in this section belong to the blue variety	11	0
Base of a is bed of Barton Creek.		
Total thickness of strata in bluff	171	11

[(*b*) Deep Eddy Bluff, south of the Colorado River, west of Austin, showing downward continuation of beds below 44 of (*a*).]

	Ft.	In.
43. Nodular limestone, with requienias at top (the second requienia bed of the Barton Creek section).		
42. Limestone ledges	5	0
41. Limestone ledges containing requienias. The three layers above described form a slope to the top of the hill (or bluff) above the face proper of the bluff	1	0
40. Ledge of hard limestone, 10 inches above basal sheet flint. The upper part of the ledge contains rather small nodular flints	15	0
39. Limestone weathering out and giving rise to a good deal of red clay, apparently representing the zone of calcitized fossils found in the high bluff above McGill's Ford	6	6
38. Massive thick ledges of limestone, detail not exposed	23	8
37. Soft, white, arenaceous limestone	2	2
36. Soft, arenaceous limestone	3	10
35. Ledge of limestone, rather soft, emitting odor of petroleum	2	10
34. Chalky limestone, forming little caves, composed of a good many small ledges; discoidal flints at top (just level with top of dam)	4	0

[1] Same bed as No. 43, section 25 b.

[2] Same bed as No. 29, section 25 b.

FLINT FROM THE EDWARDS LIMESTONE.

	Ft.	In.
33. Hard limestone, emitting odor of petroleum under blows of hammer. Texture of limestone rather mealy. Nodular flints, occasional discoidal flints in top	2	1
32. Two thin ledges of limestone; layer of sheet flint in top	1	2
31. Ledge of thick, massive limestone	5	0
30. Hard, yellowish limestone	2	0
29. Hard, thick, massive ledge of siliceous limestone, ringing under blows of hammer. At the base there is a layer about 9 inches thick of opalescent, pinkish, or browish flint. Apparently the limestone is being converted into flint by replacement, and the process has not yet been completed	6	0
28. Soft, chalky limestone, dissolving and forming small caves	3	0
27. Soft, chalky limestone with very large (may be 1 foot long), irregularly shaped blue flints at top	2	3
26. White chalky limestone, apparently siliceous; zone of flint near top. The flints blue, discoidal, and tending to form sheet	6	8
25. Massive ledge of hard, bluish limestone	7	0
24. Very hard limestone	0	6
23. A layer of enormous blue flints, in some places over 1 foot thick	1	0
22. Thick massive ledge of limestone, rather soft, yellow in color, and slightly arenaceous	5	5
21. Ledge of hard yellowish limestone, with a zone of flints tending to form a sheet at base	1	4
20. Soft, white, slightly arenaceous limestone, composed of three ledges; upper 2 feet, middle 4 feet, lower 1 foot	7	0
19. Soft yellowish or whitish limestone, with layer of flattish, bluish flints forming a sheet at top. This is really three ledges: Upper ledge, with flints at top, 2 feet; middle, containing concretions of calcite in lower part, 4 feet; lower ledge, exposed at low water, 1 foot	7	0
Total, Deep Eddy section	121	5

[(*c*) Bluff at the mouth of Bee Creek, showing downward continuation of (*a b*) below No. 22.]

	Ft.	In.
Limestone slope, detail not exposed	11	0
23. Layer of enormous blue flints	1	0
22. Arenaceous limestone	5	5
21. Hard yellowish limestone with sheet flint at base	1	4
20. Yellowish, rather hard limestone, somewhat siliceous; thin band of chalky limestone at top; calcite concretions near base	6	0
19. Sheet flint at top (sheet flint at top of lowest ledge of Deep Eddy Bluff); three ledges of limestone: upper, 1 foot; middle, 2 feet 6 inches; lower (containing calcite concretions), 3 feet	6	6
18. Sandy limestone, with two zones of nodular flint near middle; sheet flint at base; mass of requienias just above the sheet flint	10	0
17. Soft, yellow, calcareous sandstone, a part of the preceding ledge, about	3	0
16. Yellow cherty limestone, about	0	6
15. Three or four ledges of rather soft, whitish or yellowish limestone; the upper ledge containing a great mass of requienias, the others fewer	8	1
14. Solid white limestone, granular, not very hard; contains a great many requienias near top	6	11
13. Yellow arenaceous limestone	4	0
12. Blotched arenaceous limestone	3	8
11. Soft, yellow, arenaceous limestone	2	0

	Ft.	In.
10. Hard, yellowish, granular limestone, with shell fragments, gray on fresh exposure	1	6
9. Soft, yellow, arenaceous limestone or calcareous sandstone	2	4
8. Ledge of nonindurated granular limestone, with indurated blotches, which are structureless and flinty looking	1	0
7. Ledge of white, rather soft limestone, with many very irregularly shaped flints in a zone about the middle of the ledge. The flints are mostly small, bluish in color, and do not show concentric banding. About	3	0
6. Ledge of white, rather soft limestone; no flints; a few fragmentary fossils	2	6
5. A soft arenaceous ledge. The lower 1 foot 10 inches is a subledge. In the upper part (near top) are concretionary bodies that in their form resemble flints, but are not flints in texture. These bodies are hard, apparently siliceous, and contain white blotches, some of which appear to be of foraminiferal origin	5	5
4. Hard limestone, whitish or bluish, without flint; not fossiliferous	4	0
3. Arenaceous limestone; has a tendency to lamination, but in the ledge the laminated character is not always evident. The upper part of the ledge by solution becomes porous. The rock has a considerable absorbent power for water, and has a dark (wet) appearance, due to water contained	5	9
2. Thick ledge of white limestone, not very hard, oxidizing yellow from contained iron. Contains a large number of irregularly shaped flint nodules. These may be as much as 1 foot long, but usually are rather small—3 or 4 inches in length. They are bluish in color and have a concentrically grained structure, resembling the graining of pine wood. Their long axes are not always parallel to the bedding planes of the limestone, an important exception to the usual position of the flints relative to the stratification of the limestone	5	9
1. Ledge of yellowish or whitish limestone, without flints. In a thin layer about 6 inches thick at the top of this ledge there are an enormous number of *Requienia texana*	4	0
0. Base concealed by embed.		
Total, Bee Creek section	104	8

The total thickness of the partial section of the Edwards limestone on downthrown side of Balcones fault in the vicinity of Austin, as determined from the foregoing sections, is as follows:

	Ft.	In.
(a) Bluff on Barton Creek, beds 49 to 43	29	11
(b) Deep Eddy Bluff, beds 42 to 24	99	8
(c) Bluff at mouth of Bee Creek, beds 23 to 1	104	8
Grand total	234	3

The base of the limestone is exposed to the west of the fault line and on the upthrown side upon the summits of Mount Barker and other hills. (See Pl. XX, *C*.) Over 50 feet of this are seen on the divide to the west of Bull Creek. Inasmuch as this has probably been reduced in thickness by erosion, we can without exaggeration add 75 feet to the section above given, which would give a total of 300 feet of Edwards limestone beneath Austin.

Mr. J. A. Taff has presented a composite section of the Edwards

FLINTS IN THE EDWARDS LIMESTONE, BLUFF OF THE COLORADO, AUSTIN, TEXAS.

limestone on the downthrown side of the Balcones fault as exposed from the station at Georgetown to a point 6 miles northwest of the town, where it is abruptly cut off and concealed by the Balcones fault, and in the bluffs of Brushy Creek west of Round Rock. His observations are given below in full, with slight editorial changes, as they form an important contribution to the details of these beds.

COMPOSITE SECTION NEAR GEORGETOWN, TEXAS.

1. The massive layers of the Comanche Peak bed are succeeded by thick bands of limestone, varying but little from them in general appearance, except that some of them weather into a porous, honeycombed rock constituting what is locally known as the "bored limestone." Upon a close examination prints and casts of *Rudistes*, *Caprina crassifibra*, and *Caprina* sp. ind. may be seen in the limestone. This is the first appearance of the *Rudistes* and *Requienia* fauna. This horizon has a thickness of nearly 20 feet.
2. Succeeding these heavy bands of limestone are hard, siliceous limestone strata from 3 to 5 feet thick. Where this rock is freshly fractured it has the appearance of a hard, crystalline limestone; upon weathering, however, fine, clear grains of quartz sand appear on the surface. Intermediate between some of these layers of limestone are thin bands of fossiliferous, indurated, flinty limestone, resembling quartzite. These flinty layers contain many shell fragments, minute gasteropods, and öolitic grains. Upon weathering these fossils stand in relief on the face of the flagstone. This subdivision is 35 feet thick.
3. Next in order of succession are heavy strata of limestone. At the base and top of these beds are disconnected bands of large, oval, agaty flints, white to light blue in color. Some of these flints contain cavities lined with beautiful limpid quartz crystals. Some of the limestone layers are quite siliceous, especially those immediately surrounding the flints. These beds are about 25 feet thick.
4. A belt of limestone overlies the agaty flint zone. In this there is very much brown flint in nodular bands, which are not continuous. In one locality the flints may be observed in the form of a solid belt of flint-like flagstone, while in another place they are either absent or occur as nodules. A horizon of *Requienia texana* occurs in the upper portion of this flinty belt. The requienias may be seen upon the surface inclosed in the flint nodules. This subdivision is nearly 25 feet thick.
5. Chalky limestone in thick, massive strata next occurs. In the excellent exposures of the Edwards bed in the bluffs of Barton Creek south of Austin this limestone belt contains layers of decomposing limestone which are crowded with most beautiful translucent calcified fossils of Requienia corals, gasteropods, and bivalves. Their preservation is unique, showing every marking, and in beauty they equal living species. These fossils were not seen in the section on Brushy Creek near Round Rock. On Barton Creek a band of black flint nodules which is apparently absent here occurs immediately above this fossiliferous horizon. Thickness, 15 feet.
6. Dull-blue limestone follows upon the massive limestone. In this there are many *Caprina crassifibra* and *Requienia* sp. ind. Three feet.
7. The succeeding strata are of light-blue and white limestone, containing great numbers of the species termed *Ostrea munsoni* Hill, or *Hippurites flabellifera* Cragin. (This bed is No. 43 of the Austin section). The latter fossil is so abundant along the banks and bluffs of Barton Creek that it is not possible to collect a fragment of one fossil from the rock without the destruction of others. In the section on Brushy Creek black flints occur 27 feet below the summit of the

Edwards limestone. Where these appear the rock is chalky and in massive beds. The flints occur in the massive beds and between the strata, as broken bands and lens-like nodules. These black flints, from their lower to their upper limits, have a range of 23 feet. This limestone includes the base of the black-flint belt. As far as known there are about 13 feet of barren limestone above the *Ostrea ? munsoni* zone.

8. Indurated, hard, thick-bedded limestone, which contains *Requienia* fossils. This much resembles another Requienia limestone which occurs near the summit of the Edwards limestone. Seven feet.
9. Beds of yellow, chalky limestone (equivalent to No. 45 of the Austin section). *Exogyra texana* occurs in this limestone—a reappearance of this species, which has not been seen since its occurrence at the base of the Fredericksburg division, nearly 250 feet beneath this horizon. It is not known to exist in higher beds. As these beds are ascended from the medial portion the limestone is observed to become purer and more chalky in texture, until very near their summit strata are found which are almost pure lime, friable and of chalky whiteness. A specimen of a stratum of limestone 2 to 4 feet thick, just above the final occurrence of the black flint, showed upon analysis 98 per cent of carbonate of line. Eight feet.
10. The chalky layers grade up into the thinner dimension layers (No. 46 of the Austin section). In Brushy Creek at Round Rock, where a representative section is exposed, the bed begins at the base with a ledge of siliceous limestone 2 inches thick. This is succeeded by about 1 inch of semicrystalline, oölitic-like limestone. Above this ledge there occur flaggy layers some of which are almost chalky, while others are crystalline and finely oölitic (granular). From the middle to the top of the bed the rocks are more flaggy in nature. There are indications, almost throughout the bed, of shallow-water action, in the granular lime and in the wavy lines upon the laminated layers. Ripple marks occur upon some of the flagstones, though they are nearly pure lime. The nature of the flagstones in this respect points to a history of shallow water at sea beyond the reach of near-shore deposits. They are practically barren of fossils, small fragments of shells only having been seen in them. Their aggregate thickness at this locality and on the Colorado River west of Austin is nearly 10 feet.
11. The upper Requienia beds or Austin marble (No. 49 of the Austin section), as it occurs on Brushy Creek at Round Rock and at other points along the line of the great fault, is a white, nearly pure limestone composed almost wholly of a calcified agglomerate of *Rudistes* and *Requienias*. This is the final bed of *Caprina* and *Requienia*. They have not been observed above this zone of their greatest abundance in the Comanche series. The limits of *Requienia* are clearly defined by the occurrence of the fossils contained in it and by the character of the rock. Its chalky whiteness, as it occurs at Round Rock, is a contrast to the dull-blue flagstones below and to the Kiamitia and Fort Worth limestone above. This bed is about 6 feet thick. The rocks of this bed are involved in the disturbance incident to the great fault along the line of their outcrop. Hence in but few localities has it been possible to study them satisfactorily. In the valley of the San Gabriel they have been totally concealed by the downthrow of the fault.

The total thickness of the Edwards limestone described in this section by Mr. Taff is 188 feet. The writer is inclined to believe that, owing to difficulties in connecting the outcrops, this thickness is underestimated by at least 40 feet.

Northward from the Colorado River in Travis County the variable, arenaceous, flinty strata of the upper part of the Edwards limestone

WEATHERED EDWARDS LIMESTONE, WITH CHARACTERISTIC FOSSILS, AUSTIN, TEXAS.

thin out and become more chalky, and finally lose their hard and sandy character as the immediate valley of Brazos River is approached.

The Edwards limestone on Brazos River in McLennan, Hill, and Bosque counties is composed of homogeneous strata with little variation, ranging in thickness along the river basin from east to west from 10 to 33 feet. Fossil *Requienia* and *Rudistes* occur throughout, but are not very abundant. At the summit there is a narrow band of limestone bearing *Caprina crassifibra* and associated forms en masse. The horizon of Requienias crops out in the bluffs of the Brazos opposite Greenock, Bosque County, in the base of Coon Creek, in the bluffs of Rocky Creek north of Greenock, in the low bluffs at the edge of the Brazos River basin east of Towash, Hill County, and in the bluffs of Nolands River from its mouth to a point 4 miles above Blum, Johnson County.

In the valley of the Clear Fork of Trinity River, as seen 2 miles east of Benbrook in Tarrant County, and as described on a previous page, the whole of the Edwards (Goodland) limestone, representing the combined Comanche Peak and Edwards formations, is 54 feet thick. North of the Texas and Pacific Railway *Caprina* and *Requienia* do not occur in the limestone and the subdivisions lose their identity, merging into the consolidated and attenuated formation previously described as the Goodland limestone. No fossils, *Caprina* or *Requienia*, have been found north of the Trinity River Valley; yet there can be little doubt that the same strata as the Goodland limestone, though greatly diminished in thickness, extend even beyond Red River, passing into the basal clays and sands of southern Kansas.

THICKNESS, AND VARIATION THEREOF.

The Edwards limestone decreases from 600 feet on the Rio Grande to 4 feet on the Trinity. At Austin it is estimated to be 300 feet thick.

In the valley of the San Gabriel, in Williamson County, 186 feet of strata have been measured. On Brazos River its thickness is less than 30 feet, making a decrease of at least 130 feet in 100 miles. Continuing north, it grows still less, until at Trinity River it is not more than 4 feet thick.

The basal portions of the Edwards formation, which is preserved as the cap rock of the buttes throughout the Lampasas Cut Plain and Central Province (see Pls. LIII and LIV), are of remarkable similarity so far as studied. On some of these mesas the cap rock is thicker than on others.

In the double summits of Comanche Peak, Hood County, which is the type locality from which Shumard first described the Edwards and Comanche Peak formations (see section No. 18, and fig. 12), an excellent exposure of the Edwards limestone may be seen.

The summit of the smaller butte, which is a flat mesa a square mile in area, consists of about 35 feet of the Edwards limestone, composed of hard layers of white limestone from 3 inches to 10 feet thick. Within 3 feet of the exact summit the bed containing *Radiolites davidsoni* and *O. munsoni* occurs—apparently identical in composition and general character with the same bed exposed in Barton Creek at Austin, 160 miles south, and at Belton and other intervening points. Below this is a massive bed nearly 15 feet thick, which forms the scarp of the mountain. In the buttes to the south, as the formation thickens, the details of the beds vary considerably.

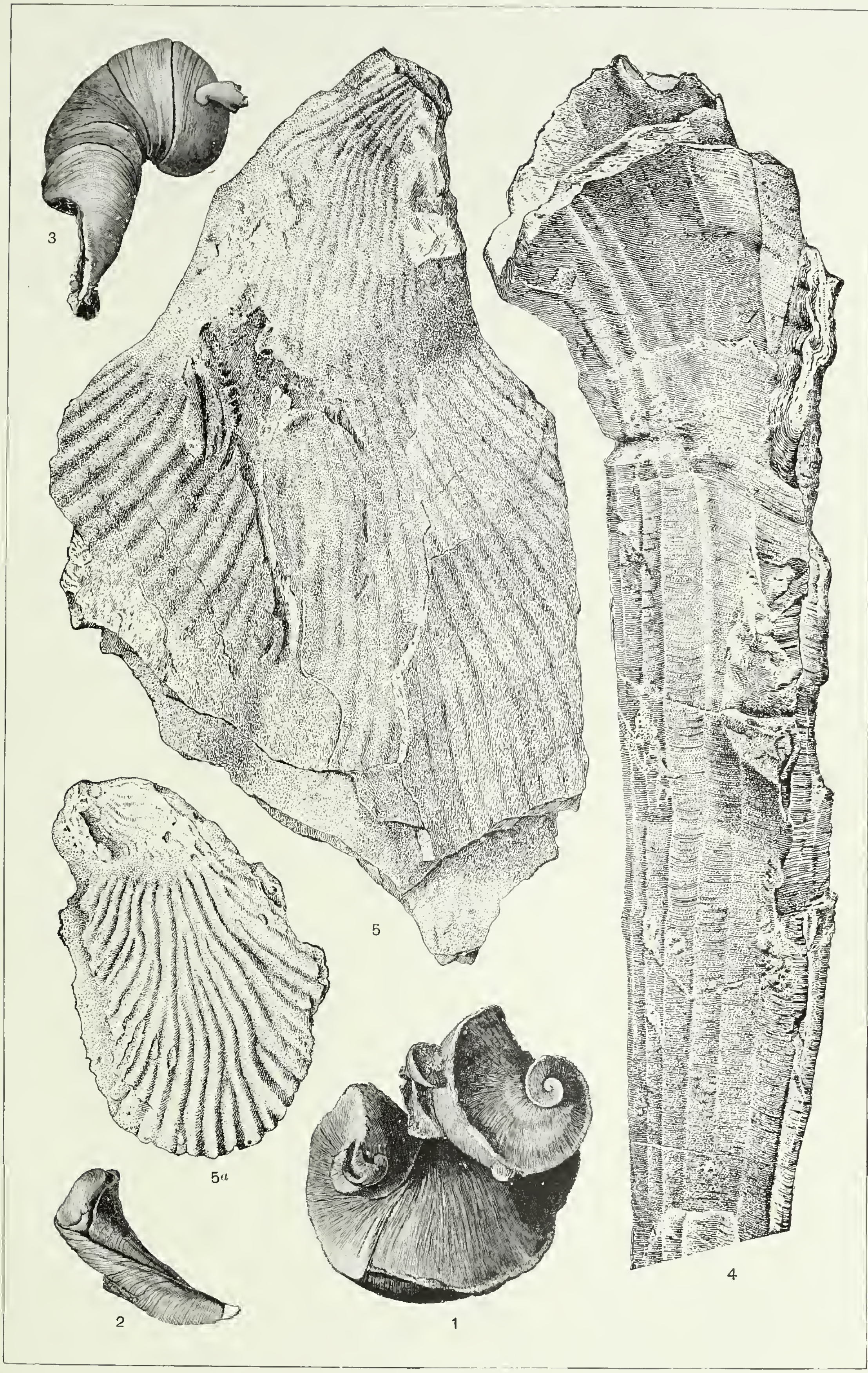
The following thicknesses of the undifferentiated Edwards cap rock (Comanche Peak and Caprina) upon some of the mesas of the Lampasas Cut Plain have been noted. One-half of this thickness may be of the Comanche Peak formation: West edge of Grand Prairie scarp and Callahan Divide, southeast Burnet County, 70 feet; Travis Peak, Burnet County, 20 feet (all Comanche Peak); western Lampasas County, Twin Sisters Peak, 60 feet; Round Mountain, 100 feet; Santa Anna Mountain, Coleman County, 50 feet. At Baker Mountain, in northwest Comanche County, the Edwards limestone is 110 feet thick. At Buffalo Gap, Taylor County, the Edwards and Comanche Peak formations are 130 feet thick, the upper 20 feet being Edwards. In the Horse Mountain section a lower subdivision of 100 feet of chalky limestone of the Comanche Peak character is capped by 60 feet of more massive limestone bearing bands of large flint nodules.

The bluffs of Bitter Creek Valley, Nolan County, are surmounted by 35 feet of limestone, the lower 20 feet of which are chalky. These are only the remnant of the base of the Edwards formation, for they are here overlain by the Plains formation of Tertiary or Pleistocene conglomerates and marls.

The Edwards formation is represented at Church Mountain, Runnels County (see Pl. LIII, *C*), by 155 feet of limestone, the lower 80 feet of which are of the chalky Comanche Peak character and the upper 25 feet of which contain flint nodules in great quantities.

At Castle Mountain, Crockett County (see Pl. LIII, *A*), the Edwards limestone makes a cap rock 40 feet thick, and this is arenaceous at the base.

Within the main area of the Lampasas Cut Plain some of the numerous summits show the following remnantal thicknesses: Divide of Bull and Sandy creeks, Travis County, 60 feet; Mount Barker, Travis County, 75 feet; Johnsons Peak, Bosque County (see fig. 48), 60 feet; divide south of Walnut, Bosque County (see fig. 12), Comanche Peak, 66, Edwards 33—total, 99 feet; Round Mountain, Comanche County (see fig. 23), 100 feet; Bachelors Peak, Lampasas County, 60 feet; Pilot Knob, Williamson County, 60 feet.



CHARACTERISTIC FOSSILS OF THE EDWARDS LIMESTONE.

1. Requienia patigiata White.
2. Monopleura marcida White.
3. Monopleura pinguiscula White
4. Radiolites davidsoni Hill.

5, 5*a*. Ostrea munsoni Hill.

PALEONTOLOGY.

Paleontologically the Edwards limestone presents many features of interest (see Pl. XXXIII). The abundant faunas of ordinary molluscan and oyster agglomerates which mark the base of the Fredericksburg division temporarily disappear at the base of the Edwards limestone, which is made up of oceanic débris, especially sponges, the remains of which are the flints, and colonies of *Requienia* and *Rudistes*, which must have thrived at times upon this sea floor as abundantly as do the reef-building corals which so thickly abound in certain parts of the ocean to-day. The *Requienia* and *Rudistes* in places form vast agglomerates, as seen in the two Requienia limestones, Nos. 43 and 49 of the Austin section (Pl. XX, *F*), which have thousands of square miles of extent.

In the more complete southern sections, notably at Austin, fossiliferous zones are more numerous in the beds, most of which are made up of the *Rudistes* and *Requienia* types. In the upper part of the beds is a conspicuous horizon of softer, chalky rock (No. 45 of the Austin section) bearing a varied molluscan fauna, including *Exogyra texana* and *Pholadomya knowltoni*, which indicates a slight change in environment and suggests a recurrence of the conditions that prevailed in the Comanche Peak subepoch. There is another conspicuous bed just below the above (No. 45 of the Austin section), which to all appearances is a thoroughly homogeneous chalky limestone, but which upon atmospheric alteration yields a most abundant fauna of small forms preserved as calcite pseudomorphs, a partial list of which will presently be given.

Near the top of the formation is a persistent fossiliferous bed composed of *Radiolites davidsoni* and a peculiar organism described by the writer as *Ostrea munsoni*, but which may prove to be some unexplained portion of the radiolitean anatomy. These fossils occur thickly together in a pure white limestone.

In Frio County agglomerates of *Gryphæa mucronata* occur in the lower part of the Edwards limestone, which may represent in that region the time represented farther north by the Walnut beds.

As a whole this fauna is an upward continuation of that of the Comanche Peak beds, many species of which continue with constant variation into the Washita division. It differs from it principally as the various faunas at greater or less depth or in water more or less turbid may be seen differing along the ocean slopes and sedimentary basins of to-day, in association or preponderance of particular species under certain conditions.

In these beds we have the best-known development of the aberrant *Chamidæ* and *Rudistes* of this country. They contain all the species of these families known to occur in the Cretaceous of the United

States, with two exceptions—*Coralliochama* of California and large forms like *Radiolites austinensis*, so common in the equivalents of the Colorado group of the Upper Cretaceous in the Alabama, Texas, and Colorado regions.

This group is in need of complete revision. The following species have been noted, many of which are synonyms:

Diceras (sp. undet.) Roemer.
Requienia bicornis Meek.
Requienia patagiata White.
Requienia texana Roemer.
Monopleura marcida White.
Monopleura subtriquetra Roemer.
Monopleura pinguiscula White.
Monopleura texana Roemer.
Ichthyosarcolithes anguis Roemer.
Caprina crassifibra Roemer.
Caprina guadalupæ Roemer.
Caprina planata Conrad.
Caprina occidentalis Conrad.
Caprina texana Roemer.
Plagioptychus (?) cordatus Roemer.
Radiolites (Hippurites) texanus Roemer.
Radiolites davidsoni Hill.

Like all the other faunas of the Texas region, that of the Edwards limestone needs careful revision and study. Following is a partial list of the species which have been observed from the upper part of the Edwards limestone beds at Austin, Texas:

Parasmilia austinensis Roemer.
Pleurocora texana Roemer.
Pleurocora coalescens Roemer.
Cladophyllia furcifera Roemer.
Coelosmilia americana Roemer.
Holectypus Roemer.
Pileolus.
Chrysostoma.
Helicocryptus or Adeorbis.
Ziziphinus (Calliostoma).
Nerinea austinensis Roemer.
Nerinea cultrispira Roemer.
Nerinea subula Roemer.
Glauconia (?).
Cerithium obliterato-granosum Roemer.
Cerithium austinense Roemer.
Trochus texanus Roemer.
Solarium planorbis Roemer.
Natica (Amauropsis) avellana Roemer.
Requienia patagiata C. A. White.
Monopleura marcida C. A. White.
Monopleura pinguiscula C. A. White.
Lucina acute-lineolata Roemer.
Requienia patagiata C. A. White.

The following forms are of more common occurrence:

Ostrea munsoni Hill.
Radiolites texana Roemer.
Radiolites davidsoni Hill.
Requienia texana Roemer.
Ichthyosarcolithes anguis Roemer.
Monopleura marcida C. A. White.
Ammonites (Buchiceras) pedernalis von Buch.
Ammonites (Schloenbachia) acutocarinatus Shumard.

WASHITA DIVISION.

GENERAL FEATURES AND RELATIONS.

The Washita division has been defined as the uppermost of the three stratigraphic groups of the Comanche series. It is composed essentially of sediments laid down in a shallowing sea accompanying a regional uplift which followed the subsidence of earlier Comanche time. The Fredericksburg division ceases everywhere throughout its extent with the purer limestones of the Edwards formation. These limestones represent the deposition of the deepest waters of the Comanche epoch and the culmination of the subsidence which had been progressing since the beginning of Cretaceous time. The succeeding sediments of the Washita division within the East-Central Province are all of a less purely calcareous, argillaceous, or arenaceous nature.

From the northern edge of the Grand Prairie in southern Indian Territory to the Rio Grande, 375 miles, the Edwards limestone is rather abruptly succeeded without stratigraphic break by the sediments of the Washita division, which includes laminated calcareous clays and alternations of stratified limestones which progressively become more mixed and impure in ascending series (see Pls. XVIII, XIX, and XX).

From Williamson County north for 250 miles the parting between the divisions is easily distinguishable, owing to the presence of a clay formation at the base of the Washita which abruptly succeeds the firm limestones of the Fredericksburg. South of Williamson County there is no easily recognizable parting between the two divisions, inasmuch as both the top of the Fredericksburg and the base of the Washita divisions are white limestone differing from each other only in minute details, such as the presence of slight impurities in the latter, consisting of an appreciable amount of sand in the limestone, a little pyrites, and a difference in the species of included fossils.

VARIATIONS IN THICKNESS AND IN SEDIMENTATION.

The beds of the Washita division in general are more varied in composition, of greater thickness, and more closely resemble shallow-water deposits toward the northern border region, extensive formations of ferruginous sands and bituminous clays occurring in that direction, which cease to the south. In general the strata of the Washita division, as a whole, become more calcareous to the south, but even this rule has its exceptions.

As a whole, the group decreases from about 400 feet in the Denison section on Red River to less than 175 feet in the Austin section, on the Colorado. This loss in thickness of the Washita division to the south is compensated for by a corresponding gain in that direction in the thickness of the Edwards limestone of the Fredericksburg division, so that the thickness of the Comanche series in its entirety is not impaired thereby.

The individual indurated beds of the Washita division seldom exceed a foot or two in thickness. The strata rarely extend through a hundred vertical feet without conspicuous lithologic or faunal changes. These individual beds are remarkably persistent in horizontal extension, especially when they are studied in large local areas, preserving their lithologic and paleontologic characters without any perceptible change for great distances. When the beds are traced through long distances, such as Texas provides, gradual important changes may be noted which can be appreciated only by comparison of widely separated minute local sections. What is a conspicuous clay formation in the Red River section may become a limestone when traced 300 miles south to the Colorado, or a formation which is a limestone upon Red River may be a clay on the Colorado.

Owing to these gradual changes in the character of the rocks the sections of the Washita division at the extreme ends of the area treated in this paper, as exemplified in the Denison and Austin sections, present entirely different lithological aspects and sequences, the relations of which would not be traceable were it not for the existence of certain well-determined paleontologic zones which persist regardless of the lithologic changes.

The beds of the Washita division are mostly impervious and non-water bearing, except a portion of its uppermost beds (the Denison beds), which for practical water purposes are classified with the Woodbine reservoir as reservoir x^1. (See explanation of artesian reservoirs, p. 420 et seq.) It is important to be able to recognize the rocks of this division, however, for by them the depth and flow can be estimated with certainty.

ORIGINAL SHORE LINE OF THE WASHITA SEDIMENTS.

The original limit of deposition, or ancient shore line, of the Washita division in the Red River region was undoubtedly the adjacent Ouachita Mountain system as far west as the ninety-ninth meridian. Outcrops of the beds in the outlying areas of southern Kansas, Oklahoma, and northeast New Mexico indicate that the sea in the Washita subepoch extended to those localities. The western shore line of the beds is as yet unknown, for over the Central Province they have been largely eroded away, and the eastern New Mexico region, where this boundary should be expected, has not been reconnoitered. Although in general stripped from above the remnantal summits of the Edwards peneplain, patches of the Washita rocks are preserved at places on the summit of the Edwards Plateau as far west as the Pecos at the northwest corner of the Llano Estacado in New Mexico, and in the mountainous areas of the trans-Pecos region as far west as northern Sonora.

GENERAL OCCURRENCE.

The Washita division has its typical and largest areal development within the East-Central Province, along the eastern margin of the Grand Prairie in southern Indian Territory and Texas north of the

Coloradó, in southern Choctaw and Chickasaw nations of Indian Territory, and in Grayson, Cooke, Tarrant, and Johnson counties of northern Texas, where it is the predominant formation, underlying wide areas of prairie land which have been described as dip plains. (See fig. 28.)

The extent of the beds of the Washita division within the immediate region of the East-Central Province is shown on the map. They commence exactly upon the boundary line of Choctaw Nation and Arkansas, where Little River crosses the line. Two or three miles west they occur as small spots of prairie in that densely forested region. These prairies of the Washita increase in area to the west, in southern Indian Territory, until north of Denison and Gainesville, Texas, they are the prevailing topographic feature. They then turn south through Texas and extend to the San Gabriel, near the Colorado. They make a large part of the prairie regions (the Fort Worth prairie) of Cooke, Denton, Wise, Tarrant, Johnson, Bosque, and Williamson counties. Southwestward from the San Gabriel to the Trans-Pecos Mountains the Washita beds do not form extensive areal outcrops, owing to the great Balcones fault, which has cut them off in that region. They appear in the Cordilleran region of Trans-Pecos Texas and Mexico, as has been previously shown.

North of the Brazos the outcrop of the rocks of the Washita division constitutes all the upland surface of the Grand Prairie between the Eastern Cross Timbers and the western escarpment. Their outcrop narrows somewhat in Johnson and McLennan counties, between the Brazos and the Eastern Cross Timbers, but widens again in western McLennan County over an irregular area, as shown on the map, in southern Bosque and northern Coryell counties. South of where the Leon makes the great southern bend in Coryell County to the Colorado, and on to the Pecos, the outcrop narrows again and occupies only a ribbon of country on the downthrown side of the Balcones fault, between it and the Eagle Ford prairies. In one place from just north of Austin to south of Round Rock it is entirely cut out by this faulting, the lower beds of

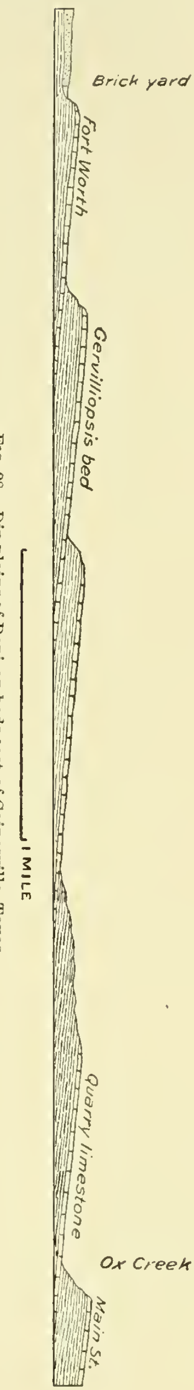


FIG. 28.—Dip plains of Denison beds east of Gainesville, Texas.

the Upper Cretaceous completely overlapping it and abutting against the Edwards limestone and Glen Rose beds of the Balcones escarpment.

These beds have been entirely stripped from the summit of the Lampasas Cut Plain, although fragments are preserved in small areas on the Edwards Plateau in Edwards County and to the west.

The details of the occurrence of the rocks of the Washita division in the regions to the west of the Grand Prairie and Edwards Plateau in Kansas, Trans-Pecos Texas, New Mexico, and Indian Territory, have been published by the writer and others in various papers upon the outlying areas of the Comanche series.[1]

CLASSIFICATION AND VARIATION OF THE FORMATIONS.

The Washita division presents several well-defined mappable units—eight, for instance, along Red River, and only three at Austin, on the Colorado.

In the region of its typical development as seen in the Red River section (see Pl. XVIII, *A*, and fig. 29) there are eight broad subdivisions: (1) Basement beds of bituminous clays rather abruptly succeeding the Edwards limestone; (2) beds of white, arenaceous, chalky limestone alternating with marls, which terminate with (3) a conspicuous limestone formation; (4) a group of beds of marls and shell conglomerates; (5 and 6) two groups of clays and sands separated by limestone, (7) an upper limestone, and (8) an uppermost lime marl.

These subdivisions, which are locally still further subdivided into conspicuous beds, may be named the Kiamitia, Duck Creek, Fort Worth, Denton, Weno, Pawpaw, Main Street, and Grayson beds. To the south, in the Colorado sections, only three lithologic members are recognizable—the Georgetown limestone, Del Rio clays, and Buda limestones. Each of these formations, although possessing very marked and important features in particular localities, loses its identity when traced through long distances, by coalescing with other formations. In order to preserve the affinities of these coalesced subdivisions and to avoid confusion that may arise in discussing the broader correlation features, the writer has used certain collective names, such as (beginning with the lowest) the Preston beds for the combined Kiamitia and Duck Creek formations, and the Denison beds for the Denton, Weno, Pawpaw, Main Street, and Grayson formations. Group names of this character are used merely as con-

[1] Outlying areas of the Comanche series, by R. T. Hill; Am. Jour. Sci., 3d ser., Vol. L, 1895, pp 205-234. Section of the Cretaceous at El Paso, Tex , by T. W. Stanton and T W. Vaughan; Am. Jour. Sci., 4th ser., Vol. I, 1896, pp. 21-26. Additional notes on the outlying areas of the Comanche series in Oklahoma and Kansas, by T. W. Vaughan; Am. Jour. Sci., 4th ser., Vol. IV, 1897 pp. 43-50. The Mesozoic section of Sierra Blanca, Texas, by T. W. Stanton; Science, 1898, p. 429. Geologic notes on the Wichita Mountains of Indian Territory, by T. W. Vaughan; Am. Geologist, Vol. XXXIV, 1899, pp. 41-55.

venient terms for a number of small beds which may best be discussed collectively. They are not intended to supplant the formation names in local sections, but are almost indispensable for purposes of general discussion and correlation. The value of such terms is illustrated by the fact that the two local formations, bracketed under the general term of Preston beds in the Denison section, coalesce to the south into one formation and are not recognized in the Austin section. The four or more distinct lithologic formations of the Denison beds of the Denison section, incident to the changes in character of the synchronous sedimentation within the limits of a large sea area, are represented in the Austin section by two stratigraphic units. In the outlying areas the Denison beds are represented paleontologically by characteristic fossil zones, but lithologic correlation is impossible.

The subdivisions and variations of the Washita division may best be presented by selecting two widely separated sections as types (see

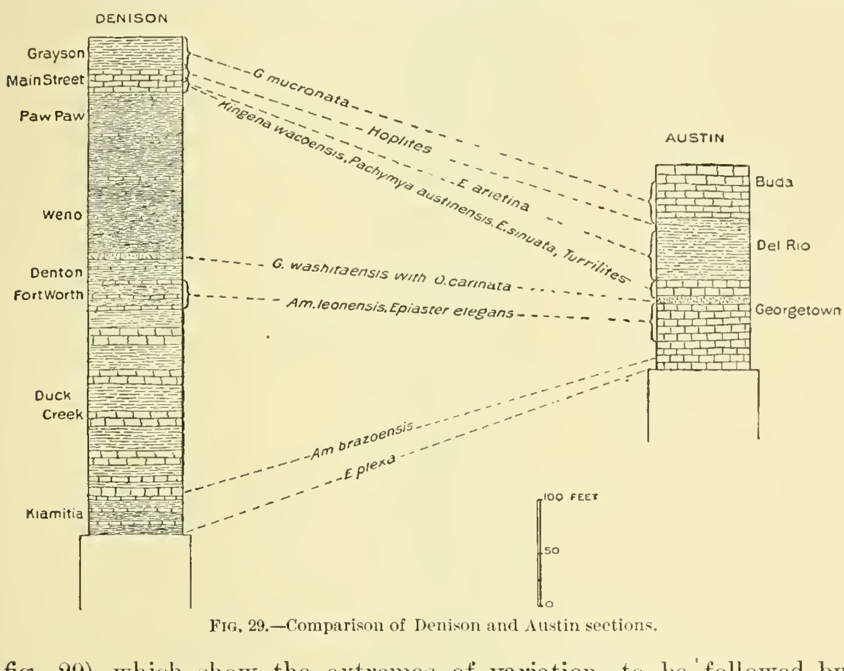


FIG. 29.—Comparison of Denison and Austin sections.

fig. 29), which show the extremes of variation, to be followed by descriptions of sections at intermediate points along the line of outcrop between these type sections. The Denison and Austin sections will be thus taken, the former as a representative of the Washita division in the Red River region and the latter as an example of the same as it occurs at the Colorado and to the south. In general, the nomenclature used in describing the sections is that given in the sections on Pl. XVI, p. 110.

RED RIVER SECTIONS.

In order to appreciate this division in the region of its typical development, we must first consider southern Indian Territory and northern Grayson County. In this region, south of and above the outcrop of Goodland limestone, may be found the best and most highly developed section of the Washita division. The Basement sands occupy the

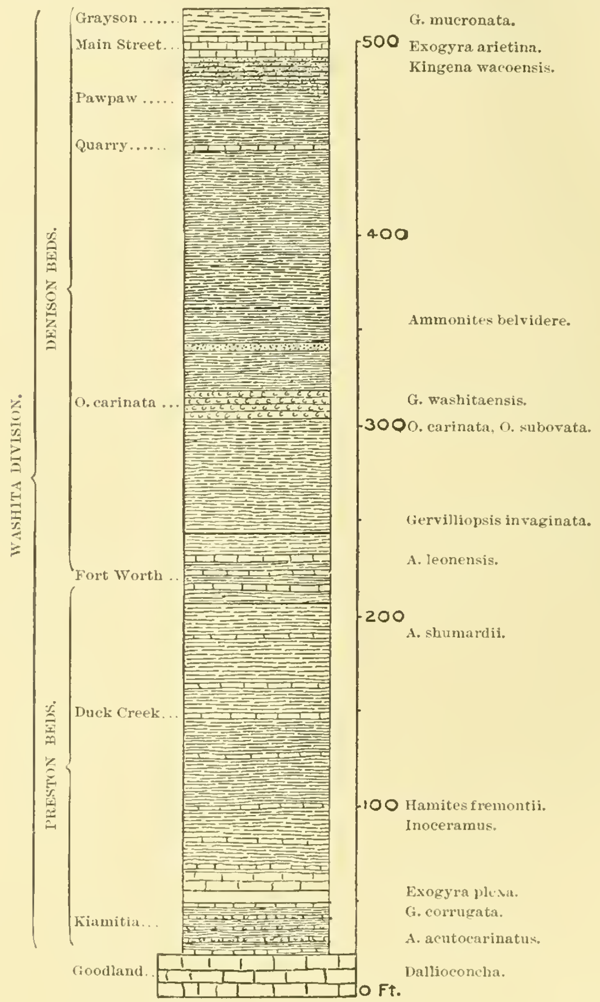


Fig. 30.—Section of Washita division, Denison, Texas.

parting valley between the southern flank of the mountains and the Goodland limestone escarpment. The beds of the Washita division lie immediately above the latter and form the upland prairies extending south from the Goodland scarp toward Red River. Fine sections are also exposed on Red River along the northern lines of Cooke and Grayson counties.

DENISON SECTION.

From the bed of Duck Creek, 4 miles north of Denison, to the southern suburbs of the city, at a point one-half mile southeast of the depot, almost the entire section of the Washita division, with the exception of its immediate basal contact with the Goodland limestone, is beautifully exposed in the drainage and railway cuts. The few feet of lower strata may be seen a few miles west of the section line, especially at Marshalls Bluff, Red River, where the highway descends from the edge of the Grand Prairie into the bottom at Preston. Continued southward from Denison toward Sherman, this section also gives a good exposure of the basal portion of the Upper Cretaceous, as will be more fully described later. This section is an important one and may well serve as a type of the development of the Washita division in the north Texas-Indian Territory region.

The thicknesses of the strata as given are approximate, and are not to be considered final. Some of them were measured, where possible, with level or tape line, but many of the unconsolidated beds do not permit of such measurements, and their thickness had to be determined by the dip, which is very near 2 feet in 100 (1.95). An artesian well in Denison gave a check upon the section measurement. Letters have been assigned to various beds and fossiliferous zones, for use in correlating the beds of other sections to be presented with those of the Denison section. The details of this section, so far as the writer is able to give them, are as follows:

SECTION No. 26.—BEDS OF THE WASHITA DIVISION BETWEEN DUCK CREEK AND DENISON. (SEE PL. XIX, A, AND TEXT FIGS. 30 AND 32.)

Washita Division.

DENISON BEDS.

POTTSBORO SUBGROUP.

	Feet.
p. Grayson marls:	
Greenish white, marly clays containing *Gryphæa mucronata*, *Turrilites brazoensis*, etc., exposed in the abandoned grade of the Denison and Bonham Railway south of Pawpaw Creek	±15
o. Main Street limestone:	
Ferruginous, arenaceous, white, coarse-grained limestone, turning yellow on exposure; more massive beds at base, with intervening layers of ferruginous sandy marl. *Terebratula wacoensis* are abundant in the lower strata (o^1), with *Exogyra arietina* above (o^2)	±12

WENO SUBGROUP.

n. Pawpaw beds:	
Impure laminated sandy clays, dark blue and bituminous in places. Very sandy in the upper 5 feet. The lower 12 feet contain an abundant fauna of many species. Near the base of the beds are numerous *O. quadriplicata*	45
m. Quarry limestone:	
A massive arenaceous limestone, blue interiorly, but oxidizing yellow; exposed in the quarries of East Denison	1.7

		Feet.
j, k, l:		
	Brown, ferruginous marls and sands with occasional indurated layers of hematite, impure limestone, sandstone, and flat, fissile lenses, called niggerheads. Some of the layers are very ferruginous and carry many fossils, including *Turritella*, *Ammonites* (*Engonoceras* of the Belvidere type), and other species. (k) is a crumbling, arenaceous limestone with a bed of sandstone, with *O. quadriplicata* and *G. washitaensis*, from 1 to 2 feet in thickness	94–124

No exact section of these strata has ever been made, but the following partial section of the well of T. V. Munson's old nursery will show the character of the beds j, k, and l in their medial portion:

Subsection No. 1, beds j, k, and l.

Yellow limestone, blue on fracture in bands of 1 foot, seen at the Munson mansion, 1 mile north of the city	0.5
Marly shales with alternate sands, plus	11
A band of brown, ferruginous, siliceous limestone with *Ostrea quadriplicata*	1
Marls, locally called soapstone, with thin, sandy interlayers	8
Beds of iron ore with nacreous casts of *Turritella*, *Nucula*, *Corbula*, etc	0.5
Hard, flinty limestone with nacreous shells (*Ammonites*, *Engonoceras*), etc	±3
Marls	10
Fissile lenses (niggerheads)	0

The base of marls (j) at the cemetery gate, Denison, is a black shaly material 10 to 12 feet thick, overlain by a heavy bed of limestone. Above this is the niggerhead horizon, consisting of large, round, lens-shaped blocks, like millstones.

DENTON SUBGROUP.

i.	*O. carinata* beds:	
	Thin beds of indurated *Gryphæa washitaensis* agglomerate, separated by a few inches of marl. The agglomerate is accompanied by occasional species of *Ostrea carinata*, *O. suborata* Shumard, Neithea, etc. This indurated zone forms a conspicuous dip plain from the cemetery gate northward	25
h.	Light-brown calcareous ferruginous marls, estimated at	65
g.	Gervilliopsis bed:	
	A very thin indurated layer of gray shell agglomerate weathering into fissile slabs and containing innumerable casts of small fossils, including *Gervilliopsis invaginata* White, *Remondia robinsi*, *Leiocidaris hemigranosus* Shumard,[1] *O. quadriplicata* Shumard, and other forms	0.5
f.	Whitish marls	5–10
e.	Fort Worth limestone:	
	A white, impure, chalky, slightly arenaceous limestone and marls, occurring in very persistent alternations of from 6 inches to 1 foot or more. Its outcrop weathers into low scarps and dip plains. This is well exposed on the highways and railroad 1½ miles north of the city. It is especially characterized by *Schloenbachia leonensis* Conrad, and *Epiaster elegans* Shumard var. *texana* of Roemer	25

[1] This is the lowest occurrence of this characteristic form of the Denison beds, which ranges up into the base of the Main Street limestone.

PRESTON BEDS.

	Feet.
d, c. Duck Creek formation: White massive and impure chalky beds at the base, with thin alternations of marl, grading up into beds in which the thickness of the marls gradually preponderates over that of the limestone. They are characterized by an ammonite fauna, including *Pachydiscus brazoensis* Shumard, *Schloenbachia belknapii* Marcou, and *Hamites fremonti* Marcou, and perhaps other undetermined species. They also contain near their base two species of Inoceramus—*I. munsoni* Cragin and *I. comancheanus* Cragin—the only forms of that genus as yet found in the Comanche series:	
d. Yellowish chalky clay marls, with occasional indurated layers, and containing the Duck Creek fauna to their top	130
c. Strata of homogeneous, crumbling, impure, chalky, white limestone, containing all the known species of the Duck Creek fauna	46
b. Transitional beds, which may be classified with either the Duck Creek or the Kiamitia.	
Thin alternations of marl and limestone in layers of less than 14 inches. *Schloenbachia belknapii*, *Schloenbachia acutocarinata*, *G. washitaensis*	10
Blue friable marl	3
Hard band of limestone, with *Kingena choctawensis*, *Exogyra plexa*, and fossils above mentioned	1
Blue, argillaceous, hard lime marl, with two indurated bands near center. *Schloenbachia acutocarinata*, *Gryphæa corrugata*, *G. washitaensis*, *Exogyra plexa*	4
a. Kiamitia clays:	
Only the top of the undoubted Kiamitia clays are exposed in this section in the bed of Duck Creek, consisting of alternations of black marl and flags, about 6 inches thick, of hard indurated *Gryphæa corrugata* breccia. (Base of Kiamitia clays not exposed)	4

SECTION NO. 27.—WASHITA DIVISION AT AUSTIN, TEXAS (SEE PL. XX, *E*).

	Feet.
4. Eagle Ford clays:	
Unconformity.	
3. Buda limestone:	
Yellowish and white limestone, lumpy in places, with many fossils, notably *Vola roemeri*, *Pholadomya*, *Pedinopsis pondii* Clark, a coral, and other species near top. A thin agglomerate (p) of *G. mucronata* at base	±45
2. Del Rio clays:	
Fossiliferous clays containing many loose specimens of *Gryphæa mucronata*	10
Thin, indurated, arenaceous layers in the clay, with casts of *Lima*, *Neithea*, *Turritella*, *Equisetum*, etc	05
Light greenish-blue laminated clays, with many specimens of *Exogyra arietina* throughout, but especially near upper portion (o²). *Kingena wacoensis* mixed with these at the base (o¹)[1]	70
1. Georgetown limestone:	
Firm and crumbling stratified impure white limestones with some beds of lime, marl, and shell agglomerate (for details see Section No. 29, p. 265 and Pl. XX, *E*). Total thickness	49.9
0. Edwards limestone:	
Nodular limestone full of *Requienia* (No. 49 of section No. 25, p. 233, Pl. XX, *D*	3

[1] Letters thus inserted indicate correlation of beds with those of Denison section (section No. 26).

BROADER PALEONTOLOGIC FEATURES.

The paleontologic characters of the beds of the Washita division are so well defined that they are valuable guides to the determination of its position regardless of lithologic changes over wide areas of country extending from Arkansas on the east to southern Kansas on the north, northeastern New Mexico and northwestern Mexico on the west, and beyond the Rio Grande on the south.

Many of the species have a single persistent definite zone of occurrence, extending throughout the areal extent of the formations, and are of the greatest value for correlation purposes. Others have a definite hemera or range, which is likewise of value for diagnostic purposes. In some of the beds the fauna is diversified and composed of many species. Other great beds are agglomerates or breccias composed largely of a single species.

As a whole the fauna of the Washita division is evolved from that of the fossiliferous beds of the Fredericksburg division and is a part of the general grand fauna of the Comanche series. While some of the fossils of the Fredericksburg division pass into the Washita division, there are many strongly marked paleontologic differences between them, notably the cessation of certain characteristic genera and species of the Fredericksburg division, such as the *Rudistes* and *Requienias*, and the appearance of many definite and peculiar species in the Washita division not found in the Fredericksburg. Furthermore, such species as extend from one division to the other show well marked varietal differences. Among the characteristic species are many ammonites and echinoids, and some brachiopods.

While much labor has been devoted to ascertaining the stratigraphic position, geographic distribution, and faunal association of the species of the Washita division, the time has not yet arrived to present a final discussion of these subjects. This task has been deferred to Mr. T. W. Stanton, whose special abilities in this line will no doubt result in an interesting presentation. At present we can only call attention to a few particular forms having definite horizons or hemera which will be of practical assistance to the layman in identifying the position of certain rock sheets in the geologic column. (See Pls. XXXIV, XXXV, XXXVI, XXXVII.)

Fossil remains of ammonites, oysters, and echinoids are especially abundant and well preserved. Among the fossil oysters there are several that are of great value in the determination of stratigraphic position. First among these are the gryphæas, of which there are three broadly differentiated varieties—*Gryphæa corrugata* (see Pl. XXXIV), *G. washitaensis* (see Pl. XXXVI, fig. 3), and *G. mucronata* (see Pl. XXXVII, fig. 1), which are peculiar to the lower, middle, and upper beds of the Washita division, respectively. There are also five other ostrean forms which are of value in this respect, known as *Exogyra* *plexa*.[1] *Exogyra arietina* (Pl. XXXVII, fig. 2), *Ostrea suborata*, *O. quadriplicata* (Pl. XXXVII, fig. 4), and *E. sinuata americana*. These forms are not so abundant as the gryphæas, but occur in definite zones which are of great value for correlation purposes.

Two species of the *Exogyra arietina* type have most definite stratigraphic significance. The first of these, an antecedent form, is the *Exogyra plexa* of Cragin. It occupies a definite zone, which may be considered the approximate boundary line of the top of the Kiamitia clays. The typical form of *Exogyra arietina* is the peculiar distinguishing fossil of the Del Rio formation and its correlatives.

Ostrea carinata Lamarck (see Pl. XXXVI, fig. 2) has a definite and persistent zone of occurrence and wide distribution. It generally accompanies *Gryphæa washitaensis*, which occurs in greater abundance.

Ostrea quadriplicata is a distinguishing fossil of the Denison beds of north Texas and outlying areas. It ranges from above the Fort Worth limestone to the top of the Washita division.

The ammonites are also of especial value for stratigraphic determination, but unfortunately the nomenclature and classification of this group of forms are unsatisfactory. In general we may remark that the forms known as *Ammonites acutocarinatus*, *Ammonites brazoensis*, *Ammonites leonensis*, and *Hamites fremonti* occur in persistent zones of stratigraphic value. *Ammonites acutocarinatus* does not range above the basal or Kiamitia beds of the Washita division. The large *Ammonites brazoensis* Shumard, and *Hamites fremonti* (see Pl. XXXV, fig. 3) distinguish and are peculiar to the Duck Creek horizon. *Ammonites leonensis* (see Pl. XXXVI, fig. 1) is the characteristic fossil of the Fort Worth beds.

In the Main Street and Buda limestones a rather smooth, square-keeled ammonite species, *Hoplites texanum* Cragin, is found. Throughout the Washita division, but especially abundant in the Denison beds, may be found peculiar ammonites of the *A. pedernalis* family, but inasmuch as these are also found in the Fredericksburg division, and their classification and specific differentiation is a problem which the most able students have not satisfactorily solved, their occurrence does not as yet possess any known stratigraphic value.[2] *Terebratula* (*Kingena*) *wacoensis* (see Pl. XXXVII, fig. 5) is another fossil which has a definite zone of occurrence, and is of great value for stratigraphic correlation. Its position is at the base of the Del Rio clays. An allied and perhaps antecedent form, *T. choctawensis*, occurs at the top of the Kiamitia clays in the Red River section.

The echinoids are also of value in stratigraphic determination, especially the large form of *Epiaster elegans* of Shumard (see Pl. XXXVI, fig. 4), which was described as *Macraster texana* Roemer. This, in

[1] A specimen of this species may be seen in the center of the mass of *Gryphæa corrugata* illustrated on Pl. XXXIV.

[2] This group of ammonites is now being checked for publication by Prof. Alpheus Hyatt.

association with *Ammonites leonensis*, is the characteristic fossil of the typical Fort Worth horizon.

There are many other rarer fossils of stratigraphic value, such as *Gervilliopsis invaginata* and *Leiocidaris hemigranosus*, which occupy a definite zone at the base of the Denison beds in the typical Denison section.[1] These fossil zones will be frequently alluded to in the stratigraphic descriptions.

PRESTON BEDS.

This name has been used by the writer as a collective term for the Kiamitia and Duck Creek formations at the base of the Washita division. Usually these formations are very distinct from each other, but in places may not be sufficiently differentiated for separate identification. This subgroup is developed in northern Texas and southern Indian Territory, decreasing in thickness to the south and not being represented beyond the Colorado. Its most characteristic development is near Red River, in Grayson County. (See Pl. XVIII, fig. 16.)

KIAMITIA CLAY.

CHARACTER AND EXTENT.

The Kiamitia clay is a conspicuous clay formation separating the Edwards formation of the Fredericksburg division below from the Duck Creek limestone of the Washita division above. This formation consists primarily of dark-blue, calcareous, carbonaceous, laminated clays containing many regular beds of impure limestones. The clays are rather bituminous to the north, but become more calcareous southward. The formation varies but little in character from the base to the top. Alternating with the clay are bands of indurated, thin, flaggy strata and dimension layers of clay limestone, which are sometimes slightly arenaceous. The shell agglomerate bands are conspicuous surface features at nearly every locality where Kiamitia clays crop out. On weathering the flagstones have a yellowish surface appearance, as does the clay, from the oxidation of the pyrites.

South of Brazos River limestone enters more largely into the rock material. Here, where the whole bed does not exceed 15 feet, the amounts of lime and clay are about equally represented. The limestone occurs as bands of shell rock 6 to 10 inches thick, rarely exceeding a foot in thickness, made up almost entirely of *Gryphæa corrugata* with clay beds between them.

The Kiamitia formation rests upon the compact Goodland limestone north of the Trinity abruptly and distinctly, without layers of transition rock. Southward from Trinity River the basal Kiamitia rests upon the same zone of Edwards limestone characterized by the fossil Requienia for more than 200 miles.

[1] The readers who may wish to make a further study of the fossil star-fishes of Texas are referred to Bulletin 97 of the United States Geological Survey.

The upper limitation of the formation is in general defined north of Brazos River by the occurrence of massive beds of chalkier Duck Creek limestone and by the Georgetown limestone south of that stream. This upper parting is paleontologically transitional, as will presently be shown.

This formation, being relatively softer and inclosed between firmer strata below and above, erodes rather rapidly at its outcrop. Its surface generally forms a gently inclined dip plain surmounting the Goodland scarp at its interior border and dipping into the base of interior-facing scarps to the coastward. Although this surface makes a rich, black, waxy soil, which supports a rank growth of grass for pastoral uses, its agricultural value is of secondary importance, owing to shallowness.

The thickness of the Kiamitia clay is difficult to ascertain with accuracy. It varies but slightly from point to point along the strike, in general decreasing from northeast to southwest. At Goodland, in the Choctaw Nation, the thickness is approximately 150 feet. On Red River west of Denison it is approximately 40 feet, decreasing to 30 feet at the Trinity and to 10 at the Brazos, and finally disappearing at the Colorado. The decrease in thickness measured along the outcrop from Red River to the Colorado is approximately at the rate of one-tenth of a foot per mile.

The Kiamitia clays outcrop in an elongated narrow belt along the interior border of the Grand Prairie, as has been approximately outlined upon the map. This belt of prairie attains a few miles in width in southern Indian Territory and Cooke and Grayson counties, but narrows toward the south until it is rarely more than a few hundred feet, and often but a few yards, wide.

This formation occupies extensive areas in the Goodland, Kiamitia, Boggy, Fort Washita, and other prairies of southern Indian Territory, where it weathers into a sticky black soil, through which projects an occasional stratum of gryphæa limestone. It also occurs in northern Grayson County, in the upland prairies south of Preston, and in the bed of Duck Creek north of Denison. At the last-mentioned locality, in the bed of Duck Creek, where the railroad crosses it, there is an interesting exposure revealing the upper beds of this formation and its relations to the overlying Duck Creek formation. Four or five feet of the Kiamitia consist of alternations of blue-black bituminous marl and hard, indurated, brecciated flags (see Pl. XXXIV) composed, in larger part at least, of *Gryphæa corrugata* Say[1] and *Gryphæa navia* Hall (*Exogyra forniculata* White). (See Pl. XXXV, fig. 1.)

Toward the upper border of the clay the layers of the gryphæa shell limestone become more abundant. At the top it grades into a

[1] The fossil gryphæas of the Texas region are described and figured in detail in Bulletin No. 151 of the United States Geological Survey.

more calcareous clay, with numerous limestone layers which contain *Terebratula choctawensis*, *G. washitaensis* Hill, and *Exogyra plexa* Cragin, and species peculiar to the succeeding beds of the Washita division. It also contains *G. corrugata* and *Schloenbachia belknapii* Marcou (see Pl. XXXV, fig. 2), species which survive from the Fredericksburg and here cease in their upward range.

SECTION NO. 28.—SECTION OF DUCK CREEK BLUFF AT MISSOURI, KANSAS AND TEXAS RAILWAY CROSSING NORTH OF DENISON, TEXAS (UPPER KIAMITIA AND LOWER DUCK CREEK).

	Thickness.	Total depth to bottom of stratum.
Duck Creek limestone:	*Feet.*	*Feet.*
(c) 6. Massive strata of chalky limestone, interstratified with very thin layers of marl in planes of stratification and containing the large *Pachydiscus graysonensis*, *S. geniculatus*, and *Inoceramus*, the basal portion of Fort Worth limestones as exposed in a bluff of Duck Creek one-third of a mile below the Missouri, Kansas and Texas Railway	10	10
(b) 5. Thin alternations of marl and limestone in layers of less than 14 inches. In these there are large numbers of *Schloenbachia belknapii*, *S. acutocarinata*,[1] and *G. washitaensis*	10	20
4. Blue friable marl	3	23
3. Hard limestone which bears *Kingena choctawensis?*, *S. acutocarinata*, *G. washitaensis*, and *Exogyra plexa* Cragin	1	24
Kiamitia clays:		
2. Blue argillaceous lime, with two thin indurated bands near the center; *S. acutocarinata*, *G. corrugata*, and *G. washitaensis*,[2] *Exogyra plexa*, and *Pholadomya*	4	28
(a) 1. Alternations of *G. corrugata* limestone and clay in the bed of Duck Creek at the base of the section	5	33

[1] This is the upper limit of this form in the Texas section.
[2] This is the lower limit of *G. washitaensis*, which extends upward to bed (k).

DETAILS OF OUTCROP OF KIAMITIA CLAY.

The Kiamitia clay occurs at the surface in numerous exposures in the bluffs of Little Mineral Creek from the border of Red River bottom to within 4 miles of Pottsboro. It is 33 feet thick, and in structure varies but little from that at localities in Tarrant, Wise, and Cooke counties. The indurated calcareous clay occurs interstratified in the dark-blue clay, and the laminated flags are numerous. In the middle and upper half gryphæa shell masses and limestone 2 to 6 inches thick largely replace the flags. These limestone layers are composed of fossil shells of *G. corrugata* en masse (see Pl. XXXIV), cemented into hard rock or in loose masses. In either case the shell beds are continuous from one locality to another, with little variation in thickness. As at other localities throughout the extent of the Kiamitia clay, the dark-blue clay rests directly upon the smooth surface of the solid white Goodland limestone. The base of the clays in contact with the underlying Goodland limestone is also well displayed at Marshalls Bluff, on Red River (see fig. 26, p. 218).

The clay with included gryphæa bands crops out along the valley of Red River northeast of Gainesville. At Brown and Sacres Ferry, Cooke County, the river cuts bluffs in the Kiamitia. At these places the contact between them and the overlying Duck Creek is 68 feet above water level.

In Cooke County very little variation is found in the structure and character of the clay from that in Wise and Denton counties. Near the northwest corner of the Charles Demorse survey, 2½ miles southwest of Era, Cooke County, a complete section shows the clay to be 30 feet thick. Here it is composed of laminated blue clays interstratified with indurated arenaceous calcareous flags, similar to the formation in Wise, Denton, and Tarrant counties. In the clay, 5 feet from the base, there is a band of gray, indurated, very limy clay, which is found in every good exposure in this region.

The Kiamitia clay occurs in each side of the valley of Denton Creek, very near the county line, west of Stony. As exposed in the bluffs of Denton Creek, it is a very finely stratified and laminated slaty blue clay, interstratified with bands of indurated calcareous-arenaceous flaggy layers 1 to 4 inches thick at intervals of 6 to 18 inches. These are finely laminated and, upon weathering, separate into thin sheets. The clay here is variably arenaceous in the basal portion. Some layers very near the base are sandy. The whole bed is 30 feet thick on Denton Creek.

The Kiamitia beds are well exposed along the upper margin of the breaks of the Trinity in Wise and Tarrant counties, especially west of Fort Worth, where the clays have a thickness of about 30 feet. Three miles east of Aledo, Parker County, the Kiamitia clay is exposed along the Texas and Pacific Railway. The rock is a blue laminated clay, with arenaceous flagstones nearly 2 inches thick at intervals of 1½ to 3 feet. The flags are bluish gray on fresh exposure and yellow after long surface weathering. The bands of indurated calcareous clay, in some instances 4 inches thick, occur at intervals of 3 to 4 feet.

At the base of the bed at this locality there is a layer of laminated, sandy, very calcareous and argillaceous material which contains large quantities of shell fragments. The Kiamitia bed is 30 feet thick at this locality.

The formation is well exposed in the bluffs of Brazos River north of Greenock, Bosque County, and in the bluffs of Coon and Rocky creeks. On the north side of the river good exposures are rare on account of the abundant river drift, gravel, and sand upon the surface. Kiamitia clay forms the banks and bluffs of Cook Creek for 2 miles above the edge of the river basin, while the Edwards limestone forms the bed of the creek. The more argillaceous lower portion of the Kiamitia bed here is not more than 5 feet thick. At the contact on the surface of the hard Edwards limestone the fossils *G. pitcheri* (Kiamitia phase), *Caprina crassifibra*, and *Caprina* sp. are commingled. The *Exogyra plexa* zone of lime and clay marl, 4 feet, occurs here at the upper part of the Kiamitia clay.

The most southern outcrop of the Kiamitia bed is at Round Rock. On the San Gabriel it is concealed by the downthrow of the fault. In this vicinity there is no clear line of demarcation between the Kiamitia and Georgetown formations, the Duck Creek not being differentiable here. The Kiamitia bed begins at the base in earthy, blue, marly, rather hard limestone, and grades up without perceptible change about 6 feet into the Fort Worth beds. The border line is drawn at the upper limit of the occurrence of *Gryphaea corrugata* and at the base of the *Exogyra plexa* horizon, which occurs at the border between the two beds north of Denison, in the banks of Duck Creek. The surface character of the rock of this bed here and its effect on the soil or surface conditions are not perceptibly different from the influence of the body of the Georgetown formations.

The formation gradually loses its bituminous character and becomes more and more calcareous with decreasing thickness southward from Red River, until, at the San Gabriel, it finally ceases to form a recognizable horizon.

PALEONTOLOGY OF THE KIAMITIA FORMATION.

Apparently there is no other bed of rocks in the Texas Cretaceous having the extent and thickness of the Kiamitia clays which contains so few species of fossils. *Gryphaea corrugata*, *G. navia* Hall (*Exogyra forniculata* White), *Schloenbachia belknapii* Marcou, and *Exogyra texana* are the only known fossil forms in the Kiamitia clay proper (see Pl. XXXV). *Gryphaea corrugata* is the principal and characteristic fossil of this formation, occurring in great numbers in the clay and forming the mass of the indurated layers. *Gryphaea corrugata* occurs in the lower portion, rarely ranging higher than 6 feet above the base. *Exogyra texana* (see Pl. XXVII, fig. 1) is rare,

GRYPHÆA CORRUGATA BRECCIA, KIAMITIA FORMATION, DENISON, TEXAS.

but its occurrence has been noticed in the bluffs of Brazos River north of Greenock, Bosque County.

Schloenbachia belknapii Marcou also occurs abundantly in the Kiamitia formation. This ammonite ranges up into it from the Fredericksburg division.

In the transition bed at the top there are, besides *S. belknapii* and *G. corrugata*, *Terebratula choctawensis*, *Exogyra plexa*, *G. washitaensis*, and *Avicula leveretti*.

In considering some of its fossil remains, like *Exogyra texana* and *Schloenbachia belknapii*, Taff has expressed doubts as to whether this formation in the areas of its marginal extension could be separated sufficiently from the Fredericksburg division to give it the status of a distinct formation, although throughout a large area of northern Texas and southern Indian Territory it is a well-defined, conspicuous, and mappable unit. He therefore included it in the Fredericksburg division. While it contains conspicuous fossil species which range up into it from the lower beds, there are also forms which are undoubtedly the initiatory species of the Washita faunas. Furthermore, the formation clearly belongs to the Washita division upon lithologic grounds, and was so placed by the writer, who originated the classification of the beds into divisions.

The following list of fossils collected from the Kiamitia beds on Duck Creek, and determined by Mr. T. W. Stanton, shows the character of the fauna:

Kingena choctawensis (?) Shumard.
Exogyra plexa Cragin.
Plicatula dentonensis Cragin?
Protocardia texana Conrad?
Pachydiscus brazoensis Shumard.
Schloenbachia belknapii Marcou.
Schloenbachia acutocarinata Shumard.

DUCK CREEK FORMATION.

GENERAL CHARACTER AND FEATURES.

The term Duck Creek formation was proposed by the author for a series of chalky limestones and marls situated between the Kiamitia clays and the Fort Worth limestone of the Red River section, making a distinct and mappable formation. (See Pl. XVIII, A.)

The typical exposure of this formation is seen in the Denison section, where it occurs on the south and east side of Duck Creek, along the Missouri, Kansas and Texas Railway. Here it consists at the base of (c) firm, white, impure, chalky limestone in persistent beds of varying thickness, from 6 inches to 10 feet, on exposure weathering with conchoidal fracture into scaly fragments. These grade upward into (d) chalky flocculent marls, blue before exposure but becoming yellowish-white on weathering.

The formation rests conformably upon the Kiamitia clays, without sedimental break, but lithologically presents a strong contrast with them, although the contact is somewhat transitional, as shown in section No. 28, p. 254. The Duck Creek formation is succeeded above by the Fort Worth limestone, with its distinct faunal characters and more regularly bedded alternations of marl and limestone. Lithologically the marly and calcareous aspects of this formation are allied to those of the overlying Fort Worth limestone, from which it could hardly be separated on other than paleontologic grounds, especially as one proceeds south.

PALEONTOLOGIC FEATURES OF DUCK CREEK FORMATION.

The beds are characterized by a conspicuous and peculiar fauna, especially marked by *Schloenbachia belknapii*, *Hamites fremonti* Marcou, and *I. comancheanus* Cragin. (See Pl. XXXV.) The fauna as a whole is in the hands of Mr. T. W. Stanton for final study. The following species have been collected from the type locality at Denison:

Fossils from the Duck Creek beds 4 miles north of Denison, Texas.

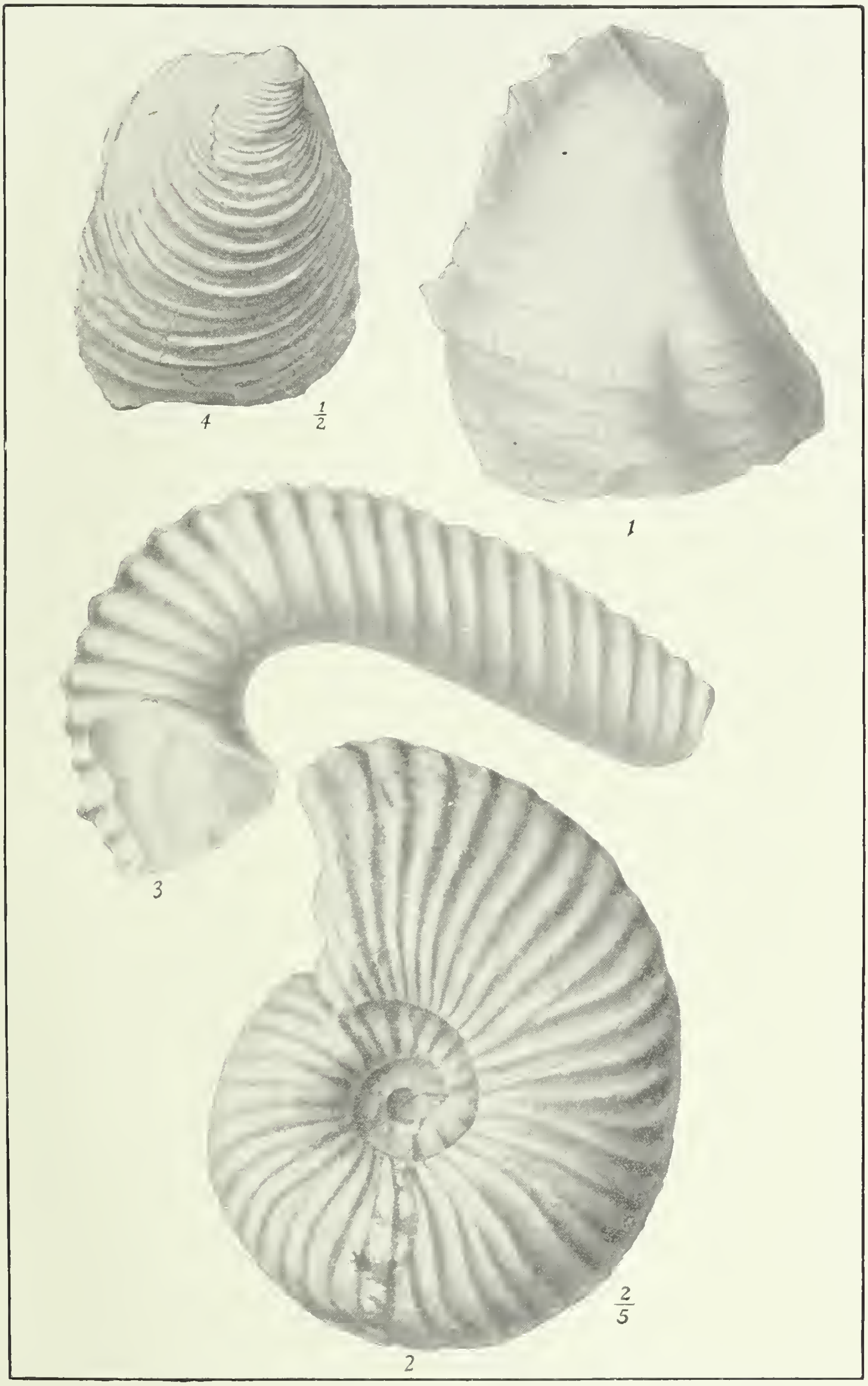
Kingena sp.	Pachydiscus brazoensis Shumard.
Ostrea sp.	Schloenbachia belknapii Marcou.
Plicatula dentonensis Cragin.	Schloenbachia acutocarinata Shumard.
Avicula sp.	Schloenbachia sp.
Inoceramus comancheanus.	Schloenbachia sp.
Inoceramus munsoni.	Hamites fremonti Marcou.
Pholadomya n. sp.	

OCCURRENCE.

This formation occupies extensive areas of prairie land in north-central Grayson County and western Cooke, and thence extends southward with decreasing thickness to Trinity River at Fort Worth. On the edge of Red River north of old Preston there is an outcrop of the formation on the downthrown side of the Preston fault.

The Duck Creek formation may be said to constitute a mappable unit in the counties of Grayson, Cooke, Denton, Tarrant, and Johnson only, and is therefore of less areal importance than other subdivisions of the Washita division. Its lithologic identity fades out to the northeast in Indian Territory, but is distinctly recognizable in the Chickasaw Nation northwest of Marietta. It continues as a recognizable formation as far south as the Brazos, being exposed 4 miles north of Blum and south of Rio Vista. South of the Brazos this formation loses its lithologic and paleontologic identity, its position being occupied on the Colorado by the lithologic phase of the Georgetown limestone in that direction. These beds have a total estimated thickness of about 194 feet at Denison and about 40 feet at Fort Worth.[1]

[1] The Duck Creek fossils occur in the base of a bluff north of the public square. This contains *Gryphæa navia*, *Hamites fremonti*, and *Pachydiscus brazoensis*.



FOSSILS OF THE WASHITA DIVISION, KIAMITIA AND DUCK CREEK FORMATIONS.

1, Gryphæa navia Hall; 2, Ammonites (Schloenbachia) belknapi Marcou; 3, Hamites fremonti Marcou; 4, Inoceramus comancheanus Cragin.

FORT WORTH FORMATION.

DEFINITION AND GENERAL CHARACTER.

The term Fort Worth formation as originally applied by the writer was used for a conspicuous white limestone and marl formation which may be traced almost entirely across Texas. For reasons which will be apparent in the following pages, this name will hereafter be used in a more restricted sense for that portion of the formation lying north of the Brazos, and the term Georgetown formation will be used for its modified continuation south of that stream.

The Fort Worth formation, as exposed in the railway cuts north of the Union Station at Fort Worth (see fig. 31), and underlying all the

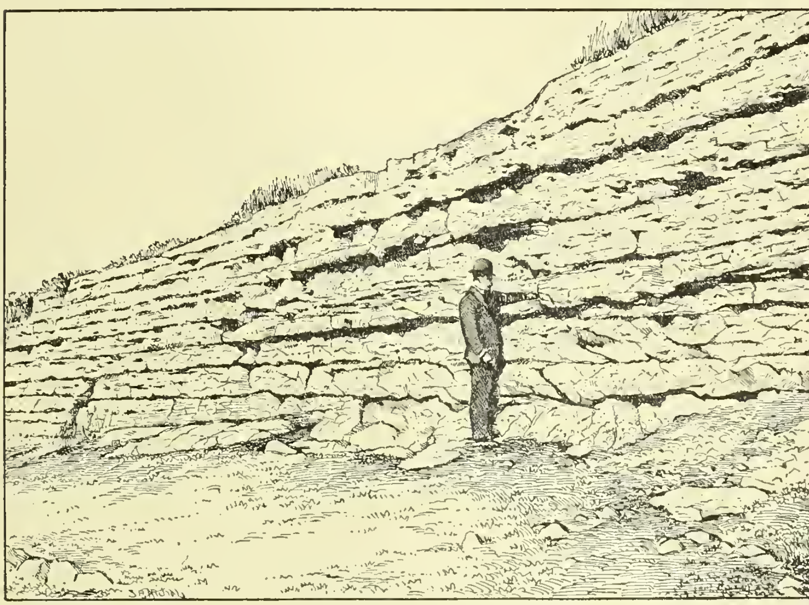


FIG. 31.—Fort Worth formation, Fort Worth, Texas.

business portion of that city, consists of a group of impure white limestones, very slightly arenaceous, regularly banded in persistent layers averaging nearly a foot in thickness, and alternating very regularly with similar layers of marly clay. The limestones and marls occur in strata 4 or 5 inches to 2 or more feet in thickness. The marly layers alternate with the hard limestones in bands ranging from thin laminæ to beds 6 inches or more thick. The gradation from hard marly lime bands to firm limestone is apparently sharp, but on close examination it is found to be very gradual, so that well-defined lines can not always be clearly drawn between them. Upon weathering in vertical bluffs the hard ledges become projecting shelves and the marls form recessions between them. Before exposure the rocks are dull blue, but when weathered they are glaring white, sometimes with a slightly yellowish tinge.

CHARACTERISTIC FOSSIL FORMS OF FORT WORTH FORMATION.

In portions of this formation fossils form the greater mass of the rock. Shells of *Turritella*, *Pecten*, *Gryphæa washitaensis* (see Pl. XXXVI, fig. 3), the large *Epiaster elegans* Shumard (see Pl. XXXVI, fig. 4), *Schloenbachia leonensis* (see Pl. XXXVI, fig. 1), and *Nautilus* sp., either as complete forms or as fragmentary casts, occur in every band from the base to the top. In some instances these shells are so numerous as to cover completely the surface of the degraded rock. Large fucoid-like masses also abound in many of the layers.

The following fossils, collected from the outcrop of these beds north of Denison and determined by Mr. Stanton, show the characteristic fauna of the Fort Worth limestone:

Fossils from Fort Worth limestone, $2\frac{1}{2}$ miles north of Dension, Texas.

Epiaster elegans (Shumard).	Schloenbachia leonensis Con.
Neithea sp. cf. N. texana Conrad.	Schloenbachia geniculata Con.
Exogyra sp.	Schloenbachia sp.

TYPE LOCALITY AT FORT WORTH.

At Fort Worth, the typical locality of occurrence, these beds, as seen in the railway cuts near the Union station, are limited above by brownish clay marls containing a great abundance of *G. washitaensis* Hill—the Denton beds of the Denison section. (See also Fort Worth general section, Pl. XIX, *B*.) Below they pass into marls and limestones of the Duck Creek formation, lithologically similar, but differing chiefly in fossil remains and in the less regular sequence of the alternations of lime and clay bands. Paleontologically the formation may be defined as the horizon of *Ammonites leonensis* and *Epiaster elegans*. (See Pl. XXXVI, figs. 1 and 4.)

The exact thickness of the Fort Worth limestone at Fort Worth has not been definitely ascertained. It is about 65 feet, and nowhere throughout its occurrence[1] does it exceed 100 feet, everywhere thinning northward.

EXTENT AND DISTRIBUTION.

The Fort Worth formation in its broader sense, whereby the Georgetown formation is included under this name as previously used by the writer, extends in almost continuous outcrop from Red River to the Rio Grande, occurring near the eastern margin of the

[1] Taff states (Third Ann. Rept. Texas Geol. Survey, p. 270) that the thickness of the Fort Worth limestone varies but little from 150 feet from central to northern Texas, but he includes under this name the Duck Creek and much of the Denison beds of the writer's nomenclature, and hence his measurements are greater than those here given.

Grand Prairie north of the Brazos and in a narrow strip at the foot of the Balcones from the Leon southward to the Rio Grande. Small remnants are also preserved upon the summits of the southwestern portion of the Edwards Plateau. At Denison the Fort Worth limestone does not exceed 25 feet, and at Austin, where other horizons of the north Texas sections (beds c and f to p) are included with it, it is only 75 feet. (See fig. 29, p. 245).

Regions underlain by this formation everywhere make open, grass-covered prairie dip plains, broken by the slight stratified terraces with glaring outcrops of white rock. The residual soils are usually very thin and of brown and black chocolate colors. Owing to the fact that the limestones are usually very near the surface, the prairies underlain by them suffer a comparative lack of cultivation, and are principally devoted to grazing. And to this same cause may be traced the general good quality of the roads, which have a good natural foundation.

The typical Fort Worth formation, in the restricted sense in which the name is now used, extends from the Brazos (or some point in Johnson County) north through Tarrant, Cooke, and Wise counties, and east through Grayson County, Texas, and the Chickasaw and Choctaw Nations of Indian Territory. Exposures along this belt are seen in the railway cuts 2 miles north of Denison, in the western suburbs of Gainesville, in the bluffs of the Trinity, and at the railway station in Fort Worth on the east side of Noland River.

The formation outcrops continuously across Indian Territory from Cerro Gordo, Arkansas, to northwest of Marietta, Chickasaw Nation. It is much more marly toward the east.

Near Marietta the limestone presents its typical facies, and is well developed thence south through Texas. It may be seen in the bluffs of Red River north of Gainesville and to the east toward the Grayson County line. It is well exposed east of the Eastern Cross Timbers in northern Grayson County, as shown on the map. From Gainesville, where it outcrops in the banks of the creek in the western part of the city, it extends in a narrow but continuous belt south through Cooke, Denton, and Grayson counties to Fort Worth. The latter city is located upon this formation, to which it has given its name, the rocks outcropping in every street, and many of the buildings being constructed of its layers. It is especially well shown in the railway cuts near Hodge, in the bluffs of the Trinity back of the court-house square, and in the railway cuts at the Union Station and westward along the Texas Pacific road. In Tarrant County its outcrop forms a vast extent of upland prairie land, making a gently sloping and much dissected dip plain, which gradually rises west of Fort Worth, extending into eastern Parker County, and is the true type of the Grand Prairie country.

From Tarrant County the outcrop of the formation narrows southward through western Parker and Johnson counties, but is well displayed along the line of the Santa Fe Railway north of Blum.

GEORGETOWN FORMATION.

LITHOLOGIC CHANGES IN FORT WORTH FORMATION SOUTHWARD.

Viewed as a lithologic unit the Fort Worth formation is apparently the most persistent formation of the Washita division, being traceable continuously across the State from north to south. But when the local sections of extreme regions are minutely compared, difficulties of correlation are encountered. South of the Brazos gradual variations in the paleontology from that of the typical Fort Worth section begin to be observed, until at the Colorado we find that the formation includes not only the direct continuation of the fossiliferous zones of the Fort Worth formation, but also has embraced, at the top and bottom, paleontologic horizons which, in the Red River sections, are characteristic of other formations of the general section. Hence we have at Georgetown and Austin a formation occupying an interval between the Edwards limestone and Del Rio clays, which, while having the lithologic aspect of the Fort Worth limestone of the northern sections, is also the paleontologic equivalent of the Preston, Fort Worth, and lower Denison beds of the Denison section. (See fig. 29.)

In view of these facts, it is obviously improper longer to call this consolidated formation in the southern sections the Fort Worth limestone, and hereafter it will be designated by the name Georgetown formation, after its occurrence at Georgetown on the San Gabriel, and for lack of suitable geographic name at Austin, where it has been most minutely studied. Furthermore, until more detailed research is made in the transitional counties of Johnson and McLennan, use of the terms Fort Worth and Georgetown will be arbitrarily limited to the allied formations north and south of the Brazos, respectively.

GENERAL OCCURRENCE OF GEORGETOWN LIMESTONE.

The upper part of the Georgetown limestone may be seen in McLennan County, 2 miles west of Ross Station, near Brazos River, surmounted by 60 feet of the Del Rio clay. Its chocolate-brown soil continues south as narrow strips of prairie land through western McLennan and eastern Coryell counties, notably in valley of the Bosque and near McGregor and Oglesby. It narrows until it is the merest line of outcrop in Bell County east of the Leon, 2 or 3 miles from Belton. It occurs in the angle between the Leon and Noland rivers, and thence continues south through Bell and Williamson counties. It is especially well exposed near Salado, Bell County; near Georgetown and Round Rock, Williamson County; at Austin near the State Encampment; in the railway cut at the west end of Sixth street; at the top of the bluffs of the Colorado; and in the bluffs of Bartons Creek, southwest of the city. Along this belt the areal outcrop of the Georgetown formation is limited to a narrow prairie lying between the western edge of the true Black Prairie and the eastern edge of the Balcones fault scarp.

The Balcones fault cuts the limestone on Brushy Creek at Round Rock, and conceals nearly 100 feet of its strata by downthrow on the east side of its fault line. The lower portion of the formation is well exposed along the banks of the creek. Portions of the belt outcrop in a similar manner along a narrow belt between Round Rock and Georgetown and west of Austin. In fact, narrow ribbons of the formation occur in the faulted zone along the foot of the Edwards Plateau in a similar manner as far southwest as Del Rio.

THE GEORGETOWN SECTION.

On San Gabriel River near Georgetown the formation is well exposed, but so broken by faulting that a good continuous section has not yet been obtained. Opposite Georgetown a few feet of the basal portion of the Georgetown limestone is concealed by the downthrow of the Balcones fault. Below the fault these rocks have many beautiful exposures for 2½ miles down the river. At Georgetown for nearly one-half mile along the river banks, and at the base of the high bluffs one-half mile below the water-power station, another portion of the formation, including a conspicuous ammonite zone, is exposed. The high bluff designated above exhibits the *Gryphæa washitaensis* horizon (bed i, Denison section) for many hundred feet along the north side of the river. Large bowlders and fragments of the rock lie in heaps at the base of the bluffs, displaying a rich fossil fauna. Extensive exposures of the upper division of the bed occur along the river from 2 to 3 miles below Georgetown, at the base of the high bluff of Del Rio clay and Buda limestone. Portions of the bed may be seen along Berrys Creek from 2 to 3 miles above its mouth.

PALEONTOLOGY OF GEORGETOWN LIMESTONE.

Exogyra plexa, which occupies a horizon (b) in the Denison section immediately above the final occurrence of *G. corrugata* var. *forniculata*, at the parting of the Kiamitia clay and Duck Creek limestone, occurs on Brushy Creek at the base of the Georgetown limestone. In its occurrence in Brushy Creek at Round Rock, *Exogyra plexa* bears the same relations to the Kiamitia and Georgetown beds as it does to the Kiamitia and Duck Creek at the Duck Creek locality near Denison. Small specimens of this species may be seen on Pl. XXXIV.

Through a range of about 50 feet above the *Exogyra plexa* horizon there occurs a very rich ammonite fauna. Different species of

Ammonites and *Nautilus* abound in a thick-bedded, hard limestone with narrow partitions of marly lime. *Pachydiscus brazoensis*, the distinguishing species of the Duck Creek beds (e) of the northern section, abounds in the lower portion of these beds, while *S. leonensis*, the characteristic species of the Fort Worth limestone, comes in above.

Above the beds containing *Pachydiscus brazoensis*, as may be observed in the bluffs of San Gabriel River one-half mile below the water power station at Georgetown, there is a narrow horizon of limestone a few feet thick containing echinoids, especially the large form *Epiaster elegans*, which is confined to the Fort Worth limestone of north Texas. Above the echinoid horizon is a zone of marly and thin-bedded limestone which contains numberless individuals of *Gryphæa washitaensis* and a few *Ostrea carinata*, the characteristic fossils of the Denton beds (f–i) of the north Texas section. There are also occasional echinoids, *Exogyra americana*, *Neithæa*, *Turritella*, etc., in the horizon. Many *Gryphæa washitaensis* may be found both above and below this horizon, but they occur here in greatest abundance. Ledges of rocks several inches thick are composed almost wholly of these fossil shells. As the upper portion of the bed is approached numerous *Exogyra sinuata americana* and *Ostrea carinata* appear. The echinoids and nautilus forms occurring in the horizons of the lower portions of the bed are rather numerous here also. An occasional *Ostrea suborata* is present in this horizon.

Within 4 to 6 feet of the summit of the Fort Worth limestone great numbers of *Kingena wacoensis* occur (o^1). The *Kingena* continues in profusion even through the transition argillaceous lime between the Fort Worth limestone and the Arietina clay. At the upper edge of this transition band of lime and clay *Kingena wacoensis* and *Exogyra arietina* fossils are intermingled in the rock. In the north Texas section these fossils distinguish the Main Street limestone (beds o^1 and o^2).

By comparing the stratigraphic positions of these fossil zones at Georgetown with their positions in the Denison section it will be seen that the Georgetown formation represents nearly the entire range of beds of the latter section, with the exception of the Weno subgroup, which has no equivalent south of the Brazos.

GEORGETOWN LIMESTONE AT AUSTIN.

The Georgetown formation is seen in the foothills west of Austin and between that city and the main escarpment of the Edwards Plateau, being especially well exposed in the railway cuts in the western part of the city, but in this vicinity no single exposure is found giving the formation in its entirety, owing to faulting. Hence the following section is a composite made up of several localities, the horizons of which have been carefully correlated.

SECTION No. 29.—DETAILED SECTION OF GEORGETOWN LIMESTONE AT AUSTIN, TEXAS.

[See Pl. XX, *E*.]

	Thickness.	Total depth to bottom of stratum.
o^2. Del Rio clays:		
b–o^1. Georgetown limestone:[1]		
o^1. 7. Massive brownish limestone studded with *Kingena wacoensis* (Terebratula bed)	*Feet.* 2	*Feet.* 2
6. Softer lime material (hard marl)	8.6	10.6
i. 5. Grayish limestone, irregular fracture, with *Alectryonia carinata* and *Gryphaea washitaensis*	1	11.6
4. Yellow or reddish calcareous shale	4.3	15.9
e. 3. Alternating layers of hard and soft limestone with *Alectryonia carinata*, *G. washitaensis*, *Exogyra americana*, *Lima wacoensis*, *Schloenbachia leonensis*, *Epiaster elegans*	18	33.9
b. 2. Hard, grayish limestone	33	66.9
1. Soft, chalky limestone with a saline taste and with fucoid layers at the base	13	79.9
Edwards limestone. (See section 25, on p. 232).		

Beds 1 to 5 are seen in continuous section at a bluff on Barton Creek about 1 mile above Barton Spring.

Beds 6 and 7 are displayed on Taylors Hill, at the railway cut in West Austin, and at various other localities north of the river and west of the city.

This section, it will be noted, is characterized by many fossils occurring in definite beds relative to one another and by several marked lithologic members. The fossils of this section occur throughout in definite zones and association, and some of the strata are composed almost entirely of them. At the top is a stratum of massive limestone less than 2 feet thick, consisting of a homogeneous calcareous matrix thickly studded with fossil *Kingena wacoensis*, characteristic of the Main Street limestone, or bed o^1 of the Denison section. Below this are alternations of bands of limestone and marls accompanied by *Ostrea sinuata*, *Turrilites*, and *Pachyma*, all of which occur in the uppermost or Pottsboro subdivision of the Denison beds of the northern sections. Below this is an agglomerate of *Gryphaea washitaensis*, associated with *Alectryonia carinata*. These forms are those which characterize bed i, the Denton beds of the northern section. In the medial

[1] Paleontologically, the term Georgetown (Fort Worth) limestone should be limited to the lowest member of this Austin section or to the thicker beds carrying *Epiaster elegans* and *Schloenbachia leonensis*, for the few feet of upper marls are probably the southern attenuation of the lowest Denison formation. The lowest Preston formation of the Washita division has not been found at Austin, or to the southward, although its equivalent has been reported by Taff at Georgetown, Williamson County, and is probably represented by a few feet of limestone below the Fort Worth limestone just south of Round Rock, in the same county.

portion of the section just below the foregoing, and perhaps associated with them, are *Schloenbachia leonensis* and *Epiaster elegans*, the typical Fort Worth fossils. The lower portion of the section as exposed at Austin is made up of thicker and more massive beds than the upper portion, and in the upper portion of these the writer once found a single specimen of *Leiocidaris hemigranosus* of the Denton beds, and below it large specimens of *Ammonites brazoensis*, the typical fossil of the Duck Creek limestone of the northern section.

The formation does not exceed 79 feet in thickness in the Colorado River section. Southwestward, toward Brackett, it becomes less and less distinguishable from the underlying Edwards limestone, and is recognizable at only a few places.

DENISON BEDS.[1]

CHARACTER AND NOMENCLATURE.

The Fort Worth limestone passes upward into a group of formations of various aspects, laid down in shallower waters and characterized by certain well-marked paleontologic zones, to which has been given the name Denison beds. These are mostly near-shore littoral formations, some of which have no traceable representation in the southern sections, while all of them completely change in lithologic character by almost imperceptible gradation into clear-water deposits in their horizontal extension southward across the State, so that arenaceous and argillaceous formations at Red River become limestones and marls at the Colorado.

This group is most highly developed in sections in northern Texas, as seen in Grayson, Cooke, and Denton counties, and in Indian Territory, as exemplified in the Denison section, where it presents at least five mappable units. In this region it consists of laminated ferruginous clays, sandy clays, impure limestones (littoral breccias), and sand. These beds are all characterized by the strong ferruginous colors peculiar to near-shore deposits, which appear only faintly, if at all, in the lower-lying Comanche series or the extension of the Denison beds south of the Brazos, while the white chalky element is entirely absent.

In the Denison section the Denison beds consist of about 300[2] feet of ferruginous, dark-colored clays and sands (fig. 32, beds f to n), free from the lighter-colored calcareous (chalky) element of the underlying beds, with occasional conspicuous indurated layers of impure lime-

[1] (See text fig. 30; Pl. XVIII, A, and text fig. 32.) This collective name, which originated with the writer, includes all the beds of the Washita division above the Fort Worth limestone (f to p inclusive). Paleontologically, they may be defined as the hemera of *O. quadriplicata*. They are generally composed of beds less pure and more ferruginous than any elsewhere encountered in the Comanche series. For definitions of Denison and Preston formations consult Bull. Geol. Soc. Am., March, 1894, Vol. V, pp. 303, 324–332.

[2] This thickness is calculated from distance and dip. It is impossible to measure accurately each individual bed, owing to the manner of outcrop.

stone, ferruginous sandstone, iron ore, and clays, which lie between the top of the Fort Worth limestone and the Grayson marls.

In previous papers the writer and others have given names to some of the various members of the Denison beds, but much confusion has resulted from misunderstanding the use of these terms, all of which were but temporary expedients. It will be best for the reader to discard any attempt to follow out these previous attempts at classification and to approach the whole subject de novo. In the descriptions and sections the letter symbols used for certain conspicuous paleontologic horizons will be of great service in enabling the reader to follow the correlation. (See section 26, p. 247, and fig. 32.)

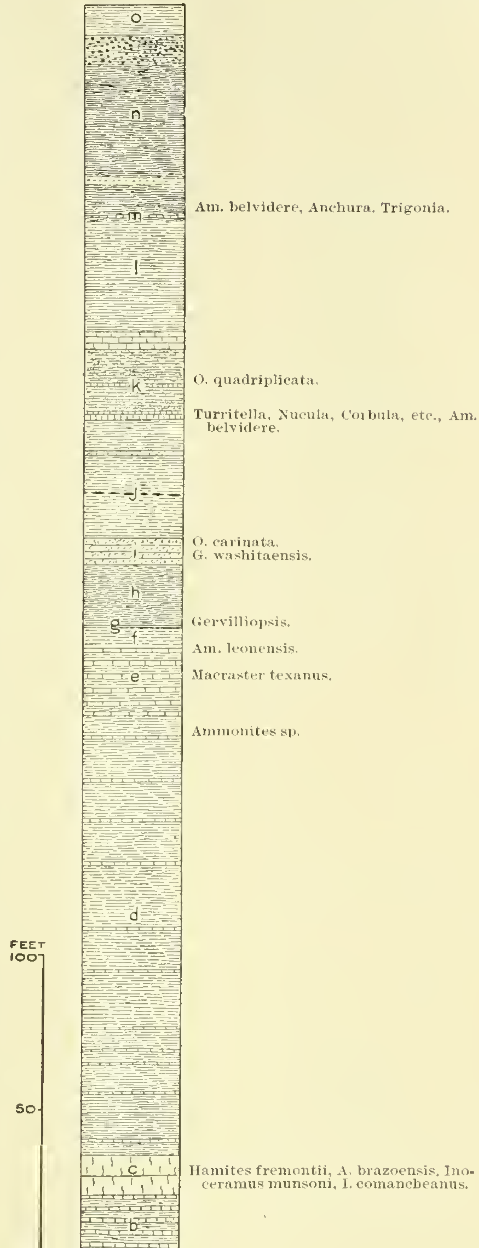


FIG. 32.—Geologic section, Denison, Texas.

THREE SUBGROUPS.

In a general manner the Denison beds may be subdivided into three conspicuous subgroups—the lower, middle, and upper. (See fig. 30.)

The lower subgroup of the Denison beds (beds f–i), including all that portion below the top of the *O. carinata* horizon, will be generally alluded to as the Denton beds.

The medial or Weno subgroup of the Denison beds (beds j–m), including all that portion above bed i (the *O. carinata* horizon) and beneath the Main Street limestone (bed o), for convenience may be divided into the Weno and Pawpaw formations. For the upper subgroup, consisting of the Main Street limestone and Grayson marl, the term Pottsboro may be used.

The lower part of the Denton subgroup consists of beds of blue marly clays, terminating above by conspicuous indurations of oyster breccia made up largely of *Gryphæa washitaensis* accompanied by *Ostrea carinata.* The Weno subgroup is characterized by black and brown ferruginous clays and sands. At the base this subgroup consists of laminated beds weathering brown, with occasional layers of immense rounded, fissile, lens-shaped indurations, generally brown in color. At the top of this subgroup is a conspicuous limestone bed known as the Quarry limestone, which in turn is succeeded by the Pawpaw beds, composed of dark clays and sandy ferruginous strata, oxidizing into ironstone which in places is almost indistinguishable from the Dakota sandstone.

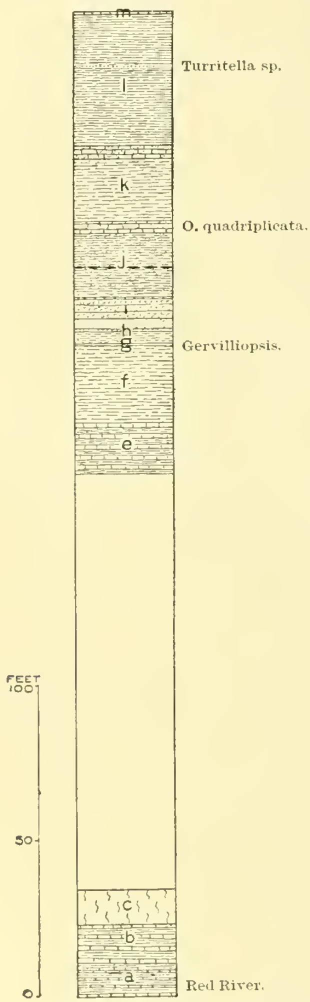


FIG. 33.—Section at Browns Ferry, Texas.

The uppermost or Pottsboro subgroup is characterized by beds of impure yellow limestone, which underlie Main street at Denison, and the lighter-colored Grayson marls which overlie them.

Southward from Red River through Texas the various beds gradually become purer and generally more calcareous sediments, and change in their lithologic character and arrangement, so that at the Colorado they are entirely different in grouping and composition. The ferruginous and sandy elements gradually disappear, becoming no longer perceptible when the Brazos is reached just west of Waco. There are many paleontologic horizons, the chief of which are very persistent, while others gradually cease in the extension of the beds.

In view of these facts, these beds can best be understood by first presenting sections of them in the north Texas region, where they are best developed, and then by comparing these with the typical Austin section at the extreme southern end of our area, which shows the maximum of variation. Between these two places the Denison beds gradually change from the aspects of one to those of the other. They present the following well-defined lithologic units at the two localities mentioned:

Comparison of Denison beds in northern Texas and at Austin.

DENISON SECTION.	AUSTIN SECTION.
Pottsboro subgroup:	
p. Grayson marl.	
o. Main Street limestone.	
Weno subgroup:	
n. Pawpaw beds.	
m. Quarry limestone.	p. Buda limestone.
l. Marl.	o. Del Rio clay.
k. Ammonite zone.	f, g, h, i, o. Georgetown limestone.
j. Niggerhead marl.	
Denton subgroup:	
i. O. carinata breccia.	
h. Marl.	
g. Gervilliopsis bed.	
f. Marl.	

A section of the Denison beds at Denison is included in the general section of the Washita division given on page 247. The Austin section is given on page 249. The following sections by Mr. J. A. Taff, made in northern Cooke County and in Denton County, are also typical of the Denison beds in northern Texas:

Section No. 30.—Section of bluffs of Red River at Browns Ferry, Cooke County, Texas (see fig. 33).

		Thickness.	Total depth to bottom of stratum.
	(n, o, p eroded. For details see fig. 33.)		
	WENO SUBGROUP.	*Feet.*	*Feet.*
m.	Quarry limestone	1.5	
l.	Blue laminated marl with *O. quadriplicata*	15	
	Arenaceous clay ironstone, a mass of *Turritella*	0.5	
	Laminated clay marl	24.5	
k.	Arenaceous yellow limestone (*O. quadriplicata*)	4	
	Friable arenaceous marl	20	
j.	Fissile flaggy sandstone	4	
	Laminated arenaceous clay with bands of clay ironstone nodules	20	
	Arenaceous limestone with *O. quadriplicata* and *G. washitaensis*	1	
			90.5

SECTION NO. 30.—SECTION OF BLUFFS OF RED RIVER AT BROWNS FERRY, COOKE COUNTY, TEXAS (SEE FIG. 33)—Continued.

	Thickness.	Total depth to bottom of stratum.
DENTON SUBGROUP.		
i. O. carinata beds.	*Feet.*	*Feet.*
Agglomerate of *G. washitaensis* with *O. carinata*, *Cardium*, *Trigonia*, and *Schloenbachia sp*	5	
h. Soft, argillaceous sand	3	
Laminated cross-bedded sandstone	1	
Friable laminated clay	2.5	
g. Gervilliopsis bed	11.5	
f. Marl, with *Gervilliopsis invaginata* and *G. washitaensis*	0.5	
f. Friable blue marl with *G. washitaensis* and *Trigonia*	25	
Total Denison beds		*a* 139
e. Fort Worth limestone; d. Upper Duck Creek	150	289
c. Duck Creek chalk	10	299
b. Ammonites beds	19	318
a. Kiamitia	4	322

a About 50 feet of the uppermost Denison beds as seen in near-by sections give a total of about 190 feet for the Denison beds.

SECTION NO. 31.—DENTON CREEK SECTION, IN DESCENDING SERIES. [TAFF.]

	Thickness.	Total depth to bottom of stratum.
POTTSBORO SUBGROUP.		
o[1]. Main Street limestone:	*Feet.*	*Feet.*
8. Terebratula wacoensis zone (o[1]). In the banks and bluffs of Marshall Branch, from 1 to 2 miles northeast of Roanoke, Denton County. The rock is made up of thin bands of hard limestone and thick (2 to 3 feet) beds of soft, argillaceous lime, which contain great numbers of *Terebratula wacoensis*, many *Turrilites brazoensis*, *Pecten texanus*, and a few *Ostrea subovata*. *Terebratula wacoensis* and *Exogyra arietina* are commingled in the upper layers	15	15
On the south side of Denton Creek 1½ miles west of the Missouri, Kansas and Texas Railway the basal 5 feet of the Terebratula zone are exposed in the top of creek bluff.		
WENO SUBGROUP.		
n. Pawpaw beds:		
7. Friable arenaceous clay, containing many thin, fissile, flaggy sandstone bands interstratified with clay	40	55

SECTION No. 31.—DENTON CREEK SECTION, IN DESCENDING SERIES—Continued.

	Thickness.	Total depth to bottom of stratum.
WENO SUBGROUP—continued.		
m. Quarry bed:	*Feet.*	*Feet.*
6. Light yellow, crumbling limestone, containing *O. quadriplicata*, *O. suborata*, *O. carinata*, and *Pecten*. Clay continues below to the edge of the creek basin (Quarry limestone)	5	60
The marls continue from the top of the bluff downward. Direct stratigraphic connection was not made with the preceding locality. The strata of this locality are below that of the former.		
j, k, l. 5. Weno formation. East side of Denton Creek, east of Justin. Friable bluish clay containing *O. quadriplicata* with thin fissile, flaggy sand interstratified from the top of the bluff downward	37	97
DENTON SUBGROUP:		
i. Ostrea carinata beds:		
4. Gryphæa washitaensis zone, with *O. quadriplicata* in the upper 2 feet of the bed and *O. carinata* in the lower layer, the *Gryphæa* fossils forming the mass of the rock	6	103
h. 3. Clay marl, dull blue, friable, and laminated, with a few bands of flaggy, fissile, calcareous sands and arenaceous shell limestone. These layers of marl range from fine shale to bands from 3 to 4 inches thick. The shell bands contain great numbers of small *Gryphæa washitaensis* and *Pecten*. On disintegrating the marl changes through purplish-blue hues to yellow	27	130
f, g. Gervilliopsis beds:		
2. Soft limestone. This rock is exceedingly fossiliferous. It contains innumerable *Plicatula dentonensis* Cragin, also *Ostrea perversa*, *Exogyra americana*, *Pecten texanus*, *Cyprimeria* sp.?	5	135
e. Fort Worth formation:		
1. Limestone and marl in alternating layers, exposed. The limestone bands vary in thickness from 2 inches to 1 foot, while the marly layers are 1 inch to 6 inches thick	23	158
d[2]. Duck Creek marl:		
The lower 50 feet of the Fort Worth limestone crops out in bluffs of Oliver Creek, on the Justin and Drop road	50	208
d. Duck Creek limestone:		
At the base of the bluff in the creek bed the heavy-bedded Duck Creek limestones occur, bearing *Pachydiscus brazoensis*, *S. leonensis*, *Hamites fremonti*, and *Inoceramus* sp.?		

THE INDIVIDUAL BEDS OR FORMATIONS.

The broader features of the Denison formation having been presented, the extent and variation of its several members will now be shown.

DENTON SUBGROUP.[1]

f, g. (Gervilliopsis beds.) The Fort Worth limestone is succeeded at Denison by light-colored calcareous marl from 5 to 10 feet thick, terminating with a laminated layer less than 1 inch thick, composed of a mass of small fossils, including *Gervilliopsis invaginata*, which occurs only in this horizon.

Mr. Stanton has identified the following fossils from this bed at Denison:

Fossils from the Gervilliopsis beds (f–g) 2, 2½, and 3 miles north of Denison, Texas.

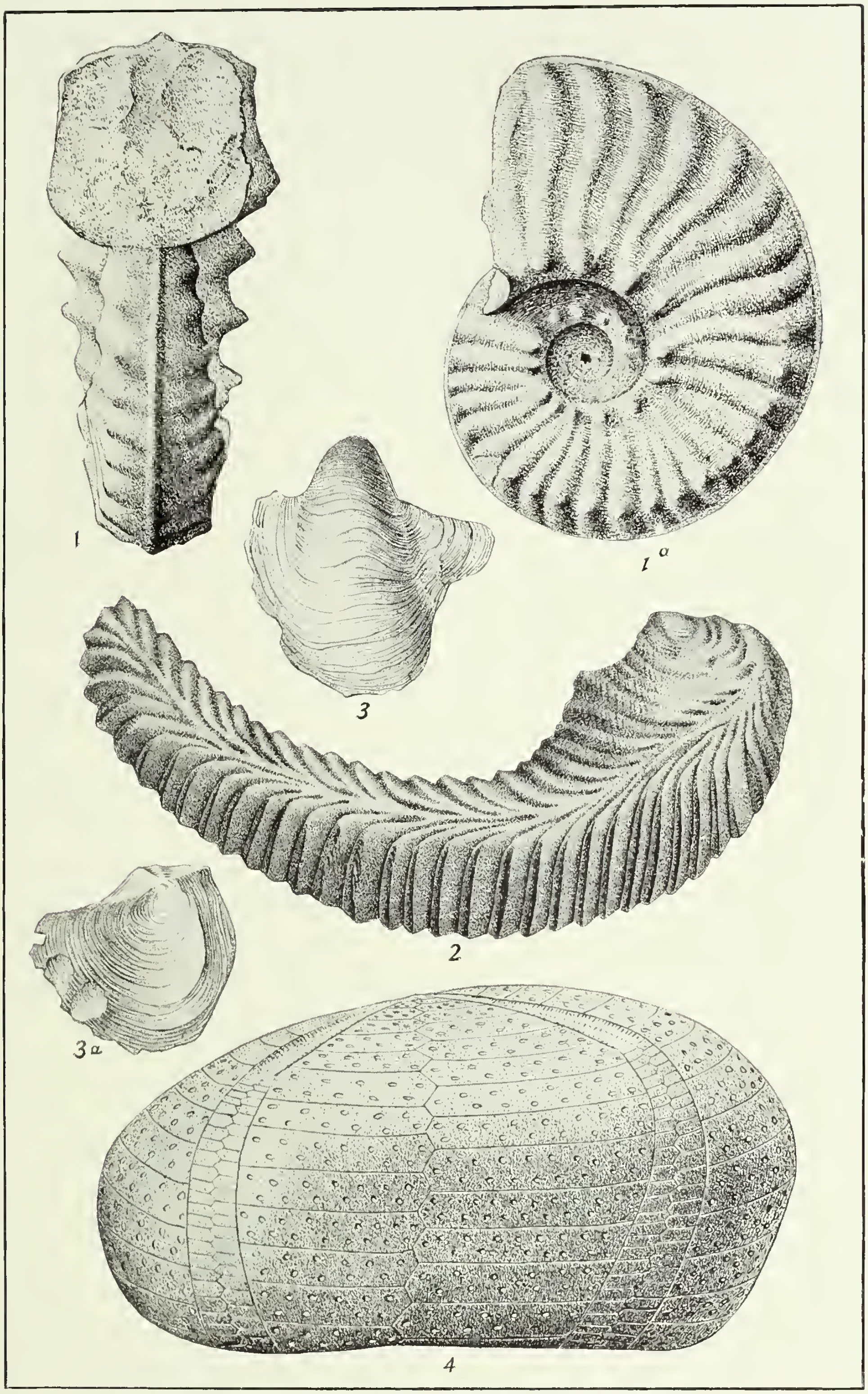
Serpula sp.
Epiaster sp. (probably young of E. elegans).
Leiocidaris hemigranosus Shumard.
Ostrea quadriplicata Shumard.
Ostrea diluviana Lamarck.
Ostrea carinata Lamarck.
Plicatula dentonensis Cragin.
Neithea texana Roemer.
Gervilliopsis invarginata White? (fragments).
Nucula sp.
Trigonia emoryi Conrad.
Ptychomya ragsdalei Cragin (same as in Main Street limestone).
Protocardia texana Conrad?.
Cyprimeria sp.
Tapes dentonensis Cragin.
Turritella marnochi (White).
Turritella sp.
Cinulia sp.
Schloenbachia sp. (fragment of young specimen).

The Gervilliopsis bed g forms a very persistent paleontologic horizon as far south as Fossil Creek, in Tarrant County.

. h. Above the Gervilliopsis bed in the Red River section there are a few feet of brownish, argillaceous, calcareous marls without any well-defined paleontologic characteristic. At Fort Worth, according to Taff's section, there are 25 feet of sandy clay marl between the Fort Worth limestone and the *Gryphæa washitaensis* agglomerate. This represents the thickness of beds f, g, and h in the Fort Worth section, but has not been recognized south of that locality.

i. (Horizon of Gryphæa washitaensis with O. carinata.) This is one of the most persistent and conspicuous horizons in the Washita division. In the Denison section it consists of a number of well-defined flag-like layers of a shell agglomerate, made up almost wholly of *G. washitaensis* in which *O. carinata* and *O. suborata* occur occasionally. This agglomerate is persistent throughout the Washita division in this relative position as far south as the Colorado. At Fort Worth it may be seen in the railway cuts in the southern part of the city. South of the Brazos it still persists, but is there included with the Georgetown

[1] Beds f, g, h, and i of this group correspond to the Denton marls of Taff.



CHARACTERISTIC FOSSILS OF THE LOWER DENISON BEDS.

1, Ammonites (Schloenbachia) leonensis Roemer; 1*a*, side view of 1; 2, Ostrea (Alectryonia) carinata Lamarck; 3, Gryphæa washitaensis Hill, 4, Epiaster elegans Shumard.

formation, being still recognizable at Austin as a conspicuous horizon composed of the characteristic shell breccia, as may be seen in the Sixth street cut of the International and Great Northern Railroad. Beds f, g, and h do not occur in the southern region.

Distribution and occurrence.—The Denton beds are well-defined only in the region north of Trinity River. They crop out in the bluffs of Red River from the upper end of Preston Bend, north of Martin Springs, in Grayson County, to Browns Ferry, in Cooke County. West of the latter place the Fort Worth formation also appears in the bluffs. They also have considerable development in the opposite side of Red River, in the Chickasaw Nation. At Browns Ferry, according to Mr. Taff's section, they have a thickness of 42 feet (see section No. 30, p. 269).

Turning southward with the strike through Cooke, Grayson, and Tarrant counties, these beds are exposed as far south as Trinity River, making the narrow strip of open prairie land, characterized by its ferruginous soils, immediately east of the narrow strip of Fort Worth limestone. On Denton Creek, in Denton County, according to Taff's section (see section No. 31, p. 270), they consist of 35 feet of strata maintaining the same general sequence as at Denison. In the Fort Worth section on the Trinity the ferruginous and sandy elements have greatly diminished, and the subgroup is represented by about 35 feet of sandy marl and shell breccia. Southward these beds continue to thin very gradually. At the Brazos, through decrease of ferruginous discoloration, they assume the lithologic facies of the Fort Worth limestone, until finally, in the Austin or Colorado section, they so completely coalesce lithologically with the Georgetown limestone that they are no longer identifiable or separate from it, the ferruginous and arenaceous elements having entirely disappeared, although the characteristic *G. washitaensis* breccia with *O. carinata* persists.

The last indication of differentiation of the Denison and Fort Worth beds of the northern section from the Georgetown beds of the southern section, as observed by Taff, is seen in the bluffs of Brazos River, between Cow and Little Rocky creeks, in Bosque County. Here a brown, ferruginous limestone layer 6 inches thick, associated with arenaceous and argillaceous marls, occurs at the top of the Fort Worth limestone. Above this zone there is a thickness of 30 feet of *Terebratula wacoensis* limestone (o^2), characteristic of the Main Street limestone formation. A similar ferruginous limestone was observed in the bluffs of Noland River, 3 miles south of Cleburne, Johnson County, in which *O. quadriplicata* of the Denison beds occurs. At Cleburne *Exogyra arietina* (o^2) occurs in clays and marls, overlying the *Terebratula limestone*. This is the most southerly known occurrence of the Denison beds in their characteristic aspect as seen in the north Texas section.

WENO SUBGROUP.

This subgroup attains its maximum development in the Denison section, where it includes all the beds between the top of the *G. washitaensis* agglomerate and the top of the Quarry limestone. It is well developed in the Red River region, where its several beds are important stratigraphic units, but these lose individuality southward across the State.

The Weno formation is characterized by a littoral fauna of many small species occurring in great quantities in certain horizons, notably *O. quadriplicata* and certain ammonitic forms of the *Engonoceras* type, which are now being studied by paleontologists.

Character of beds at Denison.—In the Denison section these beds embrace several well-defined members, j to m inclusive, consisting of very ferruginous brownish marls, with occasional persistent harder beds, such as large lens-shaped segregations, beds of ferruginous sandstone, impure limestone, etc., all of which are locally persistent and some very conspicuous. The indurated beds of the Denison section are interesting. One of these indurated layers (bed m), 80 feet below the summit (j), is especially noticeable, inasmuch as it consists of large lenticular indurations of a clay ironstone which are thinly laminated and break into sheets along the line of laminæ. These concretions are blue interiorly and brown exteriorly, and are often 4 or 5 feet in diameter. About 22 feet below the indurations, or 104 feet below the Quarry limestone (m), there is another indurated bed, consisting of sandstone as exposed near the cemetery gate north of Denison. Below this, extending down to the O. carinata beds (i), there are brown clay marls to a depth of about 22 feet.

In the Denison section the strata of the Weno subgroup are clearly defined and easily recognizable. Southward toward Fort Worth they lose their individuality, after the disappearance of the Quarry limestone in Denton County, which to the northward separates the Weno from the Pawpaw formation, as shown in the following section of Clear Creek, in Denton County (see section No. 32). Furthermore, the limestone element increases proportionately until the lithologic character so changes that along the banks of the Trinity the beds somewhat resemble the underlying Fort Worth beds (see Fort Worth section, p. 279).

In the bluffs of Clear Creek, north and northwest of Denton, only the beds k, l, m, and n are well exposed. In Denton Creek bluff, 1½ miles north of Denton and Gribble Springs road, the following section, given in descending order, is seen:

SECTION NO. 32.—WENO BEDS, CLEAR CREEK, DENTON COUNTY.

	Thickness.	Total depth to bottom of stratum.
Pawpaw:	*Feet.*	*Feet.*
n. 6. Arenaceous clay marl, estimated	35	35
5. Thin band of fossiliferous clay ironstone, not exceeding	.5	35.5
Weno:		
l, m. 4. Fissile, arenaceous clay marl, with thin laminated sandstone flags at intervals	60	95.5
3. White, arenaceous shell limestone	4	99.5
2. Marly clay with thin ferruginous sandy flags	15	114.5
l. 1. Friable, blue, argillaceous-arenaceous lime, containing very many foraminifers, *Nodosaria texana*, etc	2	116.5

SECTION NO. 33.—PARTIAL SECTION OF DENISON BEDS ON PILOT ROAD, EAST OF GAINESVILLE, TEXAS (BY G. H. RAGSDALE).

	Thickness.	Total depth to bottom of stratum.
o[1]. Main Street limestone (partial):	*Feet.*	*Feet.*
6. Yellowish limestone with numerous *Exogyra arietina* and *Kingena wacoensis*	4	4
n. Pawpaw formation:		
5. Laminated arenaceous and marly clays, yellow at top, blue below	35	39
j–m. Weno formation:		
4. Limestone with intercalated clay	35	74
Denton formation:		
i. 3. Agglomerate of *Gryphæa washitaensis* and *O. carinata*	4	78
h. 2. Indurated fossiliferous blue clay	15	93
g. 1. Flagstone (Gervilliopsis bed)	1.5	94.5

Quarry limestone (m).—This is a persistent band of siliceous limestone, which is notable in the series of otherwise unconsolidated beds and is the chief building stone in the country underlain by the Denison beds. Its interior portion is steel-blue in color, but it is oxidized for a depth of 2 or 3 inches from the surface into a chrome yellow. Its thickness at Denison is about 1.7 feet. This is an especially conspicuous formation within the relatively limited area of its occurrence, although at no place over 2 or 3 feet in thickness. It is very arenaceous, and might as well be considered a sandstone as a limestone. It is accompanied above by great quantities of the peculiar *Ostrea quadriplicata*.

This formation is practically limited to the Red River counties and southern Chickasaw Nation. It begins in Texas at Carpenters Bluff of Red River, 7½ miles east of Denison, where it makes the flat, rocky surface of the stream bed for nearly 700 feet. The western end of this outcrop is capped by alluvium. At the lower end are blue shales with large, fissile concretions. The dip here is southeast, 32 feet in 100. It outcrops along the bluff of Red River toward Denison and is extensively quarried in the eastern portion of that city. The outcrops also continue at many places west of that city until the Cook Springs fault is reached. It has not been particularly studied south of the Red River counties. It loses its stony character, but persists as a distinguishable paleontologic horizon as far south as Johnson County, where there is a bed, described by Taff, from the bluff of Noland River 3 miles south of Cleburne, consisting of a hard yellow limestone 10 inches thick, which resembles this stratum.

Pawpaw beds (n).—These include the strata between the Quarry and Main Street limestones. In the Denison section these are very impure laminated sandy clays and sands, dark blue and bituminous in places, oxidizing surficially into brown ferruginous colors, very much like the Woodbine (Dakota) formation. They are very sandy in the upper 5 feet at the crossing of Pawpaw Creek and the Texas Central Railway. This aspect is local, however. There are also small fragments of lignite in the sands, and the character of the sediments appears to be favorable to the preservation of leaf impressions, but careful search up to date has failed to discover these.

The Pawpaw is the most impure of all the Denison beds, and was apparently laid down near the shore, being accompanied by beds of ferruginous sand, which are not elsewhere found in the Washita division. The total thickness at Denison is 45 feet.

At the base of the Pawpaw, just above the Quarry limestone, are lead-colored clay shales with sandy alternations containing innumerable well-preserved nacreous shells, which in some places are replaced by pseudomorphs of iron ore. One band, just above the Quarry limestone, consists of 1 foot or more of impure, friable, ferruginous material, containing beautifully preserved fossils. These fossils are especially abundant in the lower 12 feet and consist of littoral Mollusca of many species.

In certain clay layers the nacreous shells are preserved with all their pearly luster. In sandy layers where ferruginous percolation has taken place the shell substance is dissolved and they are preserved as casts and molds in an arenaceous matrix of limonitic ironstone. Although the writer has several times collected this fauna, he has not as yet been able to secure a final study or enumeration thereof. Many of the species have not been described. At present he can only recall from memory some of the most typical fossils. Among these may be mentioned *Ostrea quadriplicata* Shumard, *Anchura mudgeana* White, *Trigonia emoryi*. *Protocardia texana* Conrad, together with undetermined species of *Corbula* sp., *Axinæa* sp., *Volsella* sp., *Tapes* sp., *Cytherea* sp., *Tellina* sp., *Pholadomya* (?) *postextenta* Cragin, *Cyprimera* sp., *Turritella* sp., and *Ammonites* (?) *emarginatus* Cragin.

Mr. Stanton also gives the following list of fossils:

Fossils from the Pawpaw beds.

Ostrea quadriplicata Shumard.
Pecten sp. small, smooth form, resembling one from Blue Cut Mound, Kansas).
Avicula sp.
Gervilliopsis or Gervillia (fragments).
Arca sp.
Nucula sp.
Leda sp.
Leda sp. (another form).
Astarte sp.
Protocardia texana Conrad.
Tapes (?) sp.
Cyprimeria sp. (large specimen).
Mactra sp.
Corbula sp.
Dentalium sp.
Anchura mudgeana White.
Sphenodiscus sp. (apparently same form that occurs in southern Kansas).

Most of the species are evidently undescribed.

Where the Pawpaw beds occur over horizontal surfaces the sandy clays weather into a loose brownish sand, which. as in north Denison, is covered by forest similar to the main forest belt of the Eastern Cross Timbers. This strip of supplemental forest along the western margin of the Eastern Cross Timbers, growing upon the Pawpaw sands and separated from the main body by the narrow prairie outcrops of the Grayson marls, is a phenomenon observable in places as far south as Fort Worth and to the northward in Indian Territory.

At Cold Springs, 4 miles west of Denison, the Pawpaw sands are faulted down opposite the Duck Creek limestone. A bed of lignite in bands from 1 to 10 inches thick, a few inches apart, occurs in this formation 1½ miles west of Martin Springs. This dips south nearly 80 feet per mile. The thickness from the upper to the lower limit is about 40 inches.

SECTION NO. 34.—SECTION OF THE MAIN STREET LIMESTONE AND PAWPAW FORMATION ON BIG MINERAL CREEK, 1½ MILES EAST OF CEDAR MILLS. (TAFF.)

	Feet.	Feet.
o.[2] Main Street limestone, partially concealed here, but fully exposed at Cedar Mills, where it contains *Exogyra arietina*, *Ostrea perversa*, *Holectypus charltoni*, *Holaster completus*, and small *G. pitcheri*...		
o.[1] Limestone:		
Terebratula zone, which includes the upper part of the *O. quadriplicata* and the basal portion of the *Exogyra arietina* beds		3

	Feet.	Feet.
n. Pawpaw beds:		
Culminating *O. quadriplicata* bed	5	
Blue, laminated, arenaceous clay marl, containing lenses and nodules of clay ironstone occurring in disconnected layers and *Pachydiscus* sp. and *Protocardia*	35	
		40
m. Quarry limestone:		
Band of *O. quadriplicata* in ferruginous limestone	1	
j, k, l. Weno formation (upper part):		
Blue laminated marl	1	
Arenaceous, lignitic clay	1	
Blue laminated marl	1	
i. Limestone, the *Alectryonia* fossils forming the mass of the rock	1.5	
h. Blue marl, extending to base of creek	5	
		10.5
Total thickness		53.5

The Pawpaw beds occur rather extensively in the southern part of the Chickasaw Nation as a narrow belt just to the north of the Eastern Cross Timbers hills, north of old Fort Washita. They also occupy a considerable area between Marietta and Red River.

These beds occur in a narrow north-south strip from Red River to the Trinity, which is first encountered about 8 miles east of Gainesville. At this locality there are many ferruginous slabs, made up of exquisite casts of the characteristic fossils. Southward these beds gradually lose their sandy nature.

The following section, by Taff, in Denton County, shows their modified character in that region:

SECTION NO. 35.—SECTION OF PAWPAW FORMATION AT CLEAR CREEK, DENTON COUNTY, TEXAS.

Denton and Pilot Point road, in descending order.	Thickness.	Total depth to bottom of stratum.
o. Main street formation:	*Feet.*	*Feet.*
6. Terebratula zone (o^1), partially concealed by broken débris and soil, *Exogyra arietina* and *Terebratula wacoensis* associated at the upper border of the limestone, estimated	5	5
n. Pawpaw formation:		
5. Marly clay, partially concealed	25	30
4. Thin bands of arenaceous fissile clay and layers of laminated friable brown sand, 6 to 10 inches thick	4	34
3. Friable laminated blue clay with numerous layers of soft sandstone	5	39
m. Weno formation:		
2. Ferruginous shelly clay, composed of fragments of *Ostrea quadriplicata* shells and casts of small bivalves in a ferruginous clay-lime cement (quarry limestone horizon)	1	40
l. 1. Blue, fissile, arenaceous clay, with occasional thin bands of ferruginous sandstones and seams of clay ironstone nodules extending to the base of the creek.	22	62

SECTION NO. 36.—EQUIVALENTS OF THE WENO SUBGROUP IN THE FORT WORTH SECTION; DENISON BEDS BELOW MAIN STREET LIMESTONE AND ABOVE THE DENTON FORMATION; BLUFFS OF TRINITY RIVER 4 MILES EAST OF FORT WORTH.

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
19. A space of a few feet concealed between Nos. 18 and 20		
18. Yellowish-white limestone	1	1
17. Dull reddish-blue, very argillaceous marl, a few feet thick.	6	7
16. Yellowish-white limestone in layers	1	8
15. Dull-blue to reddish-blue argillaceous marl, finely laminated; on decomposing it turns a deeper red color	25	33
14. Marly lime and harder limestone in thin sheets	1	34
13. Bluish marl, partially concealed near the center	8	42
12. Hard, white limestone	1	43
11. Marly lime and hard, buff-colored limestone, alternating	10	53
10. White, hard limestone	1	54
9. Blue, soft, limy marl	5	59
8. Compact, white limestone, single layer	1	60
7. Friable, argillaceous limestone	25	85
Denton formation.		

In the Clear Creek section, Denton County, there are about 52 feet of impure strata with a strong arenaceous element, which represent the Weno and Pawpaw beds. In this section the arenaceous character is also preserved.

In the Fort Worth section this formation has almost entirely lost its excessively arenaceous character, and is represented by about 85 feet of yellowish marls alternating with thin limestone. The beds continue to thin and lose their older littoral aspect southward toward the Brazos, the *Ostrea carinata* horizon of the underlying Denton beds and the *Kingena* and *Exogyra arietina* horizons of the overlying Main street beds constantly but gradually converging until they meet southward, where they are in close proximity at the Brazos.

The Weno and Pawpaw beds have not been specifically separated by surveys south of Red River. Their consolidated representative preserves its identity as far south as the southern edge of Tarrant County, but in this region they lose the sandy element, as will be seen by the Fort Worth section (section No. 36). Their outcrops are characterized by a narrow outlying belt of the Eastern Cross Timbers, which grow upon them, as seen just east of Handley Station on the Texas and Pacific Railway, 7 miles east of Fort Worth. The formation completely loses its identity south of the Brazos, being no longer distinguishable paleontologically or lithologically in that direction. The

Weno subgroup as a whole loses its thickness and individuality to the south.

In the Austin section there is no member corresponding either lithologically or paleontologically with these beds, the position of which is there occupied by the entirely different Del Rio clays, which carry the fossil fauna of the overlying Pottsboro group.

POTTSBORO SUBGROUP.

Divisions, character, and occurrence.—This subgroup of the Denison beds presents two conspicuous members which grade into each other. The lowest of these, the Main Street,[1] is a hard limestone formation; the upper, the Grayson marl, is mostly marl, with an occasional and exceptional limestone layer.

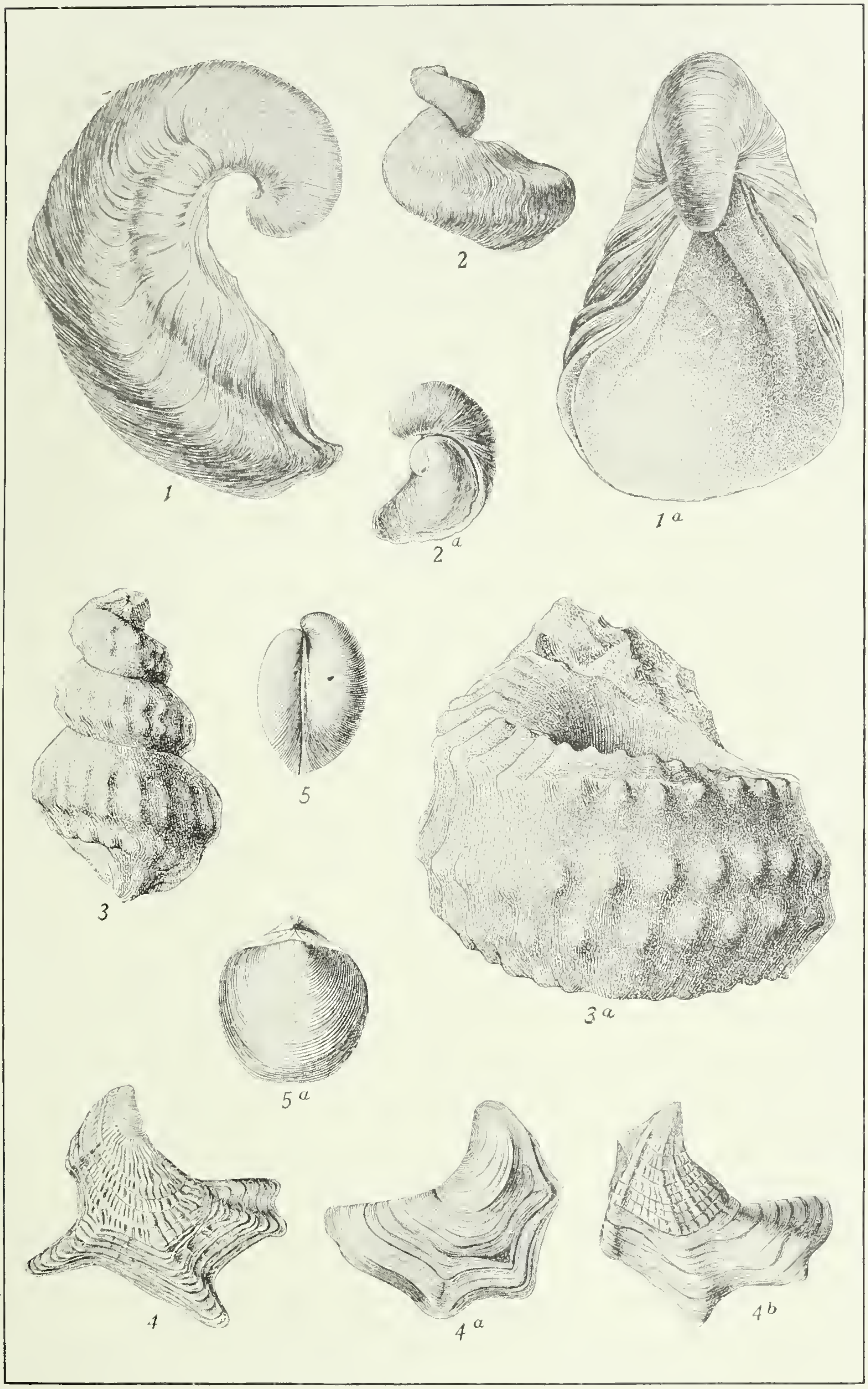
A marked lithologic change occurs in the Denison beds of the Red River sections above the Pawpaw formation. The dark ferruginous-arenaceous clays give way to the lighter-colored and more calcareous limestones and marls of the Main Street and Grayson formations, while paleontologic differences also occur.

These beds are typically developed along Red River in Grayson and Cooke counties, where they constitute well-defined, mappable units, but gradually change in lithologic nature to the south. Finally, when the Colorado section is reached, their positions are occupied by formations which are directly opposite in nature to them, as they are on Red River. The place of the lower or limestone member of the Red River group is there occupied by an unctuous clay formation, while the place of the overlying Grayson marl is there represented by a limestone. This peculiar phenomenon will be further explained in the detailed descriptions of the members of the section.

Main Street limestone (o).—In the Red River sections the Main Street limestone constitutes a very conspicuous formation, not only on account of the hardness of the strata, but because of its effect as a topographic factor. It consists of coarsely crystalline, bedded, brecciated white limestone, which, on oxidation, turns deep yellow, showing much more ferruginous coloring than any of the other limestones of the Comanche series. It occurs in strata of various thicknesses. Usually there are more massive beds at the base and thinner strata at the top, with occasional sandy marl layers. The formation nowhere aggregates more than 25 feet. Taff notes a thickness of 23 feet at Rock Creek, Grayson County. At Denison 15 feet have been noted.

This limestone has its typical and characteristic outcrop along Main street, Denison, the principal highway of that city, which runs in an east-west direction. It is beautifully exposed also in the extreme eastern suburb, in the cuts of the road and in the bluffs of the tributaries

[1] So called from Main street, Denison, Texas, which thoroughfare follows the outcrop of this formation.



CHARACTERISTIC FOSSILS OF THE UPPER PORTIONS OF THE DENISON BEDS.

1, Gryphæa mucronata Roemer; 2, Exogyra arietina Roemer; 3, Turrilites brazoensis Roemer; 4, Ostrea quadriplicata Shumard; 5, Terebratula (Kingena) wacoensis Roemer

of Pawpaw Creek. The Main Street limestone in western Denison may be seen in the vicinity of the limekilns near the end of Tone avenue, where it is nearly 10 feet thick.

SECTION NO. 37.—SECTION OF MAIN STREET LIMESTONE AND GRAYSON MARL AT BRIDGE ON CHOCTAW CREEK NEAR DENISON, ON DENISON AND BONHAM ROAD.

	Feet.
p. Grayson marl: Yellow marl and limestone in alternate strata, containing *Turrilites brazoensis?*, *Gryphæa mucronata*, *O. subovata*, *Cyprimeria* sp.?, echinoids, *Cardium hillanum*, *Ostrea* sp.?, and *Nautilus* sp.?	5
o. Main Street limestone: Limestone with *Exogyra arietina* (o^2), which grades upward into white limestone and marl	12
Limestone with *Terebratula wacoensis* (o^1)	4 or 5
n. Pawpaw beds: (See sections.)	

West of Denison the Main Street limestone outcrops in several places north of the Missouri, Kansas and Texas Railway from Denison to within 2½ miles east of Pottsboro. It is exposed at old Georgetown, Grayson County, on a branch of Little Mineral Creek and one-fourth of a mile northwest and south of Cedar Mills. Taff gives the following section of the Main Street limestone on Rock Creek in northwest Grayson County:

SECTION NO. 38.—SECTION ON ROCK CREEK, GRAYSON COUNTY, TEXAS.

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
p. Grayson marl: Light-yellow marl, with bands of limestone and great numbers of *G. mucronata*, the upper portion concealed	15	15
o^2. Main Street limestone: Beginning at the base with compact yellow shell limestone and grading upward into friable marl. *Kingena wacoensis* occurs in the lower portion, while *Exogyra arietina* ranges throughout	18	33
o^1. Arenaceous shell limestone with *O. quadriplicata* and *O. subovata* at the base, and *Exogyra arietina* and *Kingena wacoensis* succeeding	5	38
n. Pawpaw formation:		

In southern Indian Territory and from Red River southward the outcrop of the Main Street limestone (characterized by the fossils *Exogyra arietina* and *Kingena wacoensis*) occurs well within the western margin of the Eastern Cross Timbers. It is met with in the belt of the Denison beds extending across southern Indian Territory, notably along the northern edge of the timbered hills of Fort Washita.

The exposure of the Main Street beds can be followed southward from Red River, through Cooke, Denton, and Tarrant counties, as a belt of outcrops just within the western margin of the Eastern Cross Timbers. Along this line the percentage of the limestone constantly decreases and the marls correspondingly increase.

The Main Street limestone is exposed at various places in Cooke County, notably capping the bluffs of Red River, 6 to 12 miles east of Gainesville and 2 miles west of Dexter, in Cooke County, where the lower 15 feet of the bed is usually a friable and semicrystalline limestone. It is seen in a bluff of Ox Creek on the Gainesville and Pilot Point road. It occurs in the western edge of the Eastern Cross Timbers 2 miles west of Dexter, in the extreme northeast corner of Cooke County, as a bed of light-blue limestone 10 or 15 feet thick. *Exogyra arietina* composes the mass of the rock. With it occur *Terebratula* (*Kingena*) *wacoensis*, *Ostrea* sp., and *Ammonites*.

The Main Street limestone is exposed on Marshall Branch northeast of Roanoke, Denton County, beneath about 50 feet of the Grayson marls. It is 15 feet thick at this locality. Nearly 4 miles east of Birdville there is an outcrop of crumbling stratified limestone belonging to the Main Street subdivision. At Handley, 7 miles east of Fort Worth, the surface wells penetrate the formation, which is about 25 feet thick.

SECTION NO. 39.—MAIN STREET LIMESTONE IN BLUFFS OF THE TRINITY RIVER 6 MILES EAST OF FORT WORTH. *a*

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
23. Yellowish-white, crumbling limestone, with *Terebratula wacoensis* and *Exogyra arietina* commingled	3.5	3.5
22. Compact yellowish-white limestone, with *Terebratula wacoensis*	3	6.5
21. Blue, laminated, friable, argillaceous marl	1	7.5
20. White, compact limestone, bearing *Terebratula wacoensis* and *Turrilites brazoensis*	15	22.5
A few feet at the base not exposed.		

a These limestones are only a few feet beneath the town of Handley, as shown in a well at that place.

This limestone is near the surface at Handley Station, and is well exposed in a railroad cut three-quarters of a mile to the east.

The whole thickness of the Main Street bed is exposed in the bluff of Village Creek south and east of Burleson, in northern Johnson and southern Tarrant counties. Here the rocks containing *Exogyra arietina* are quite compact, with thin layers of limestone at the base. The central layers are stratified, yellow, friable, argillaceous limestone, while the upper portion is composed of friable and very argillaceous lime or calcareous clay containing *Gryphaea mucronata*, etc. North of Cleburne the Main Street horizon is represented by 5 or 6 feet of limestone. *Terebratula wacoensis* and *Exogyra arietina* occur together. In a branch of Noland River on the east side of Cleburne the basal layers of the Main Street beds are exposed, showing arenaceous and argillaceous lime in hard and soft layers. Only a few feet at the base can be seen. South of the Brazos, however, the limestone element entirely disappears and the Del Rio clays ensue.

Paleontologic features.—The limestone contains many large casts of unstudied Mollusca. Casts of a very large *Cerithium* are found. Among other species may be mentioned a large *Turritella*, *Pachymya austinensis* Shumard, *Ptychomya ragsdalei* Cragin, *Exogyra sinuata americana* Marcou, *Ostrea quadriplicata* Shumard, *Terebratula wacoensis*, and *Exogyra arietina*.

The thin bands of the upper part of the formation contain *Neithea*, echinoids, an alectryonate oyster, *Ostrea quadriplicata*, and *Exogyra arietina*. Below this are thin bands of harder limestone, yellow on surface, blue interiorly. Still below the latter there is a thicker band of yellow limestone, 4 or 5 feet thick, which contains *Kingena wacoensis*, *Neithea*, *Exogyra arietina*, echinoids, and *Ostrea quadriplicata*. This lower band may be designated the zone of *Kingena wacoensis*. *Kingena wacoensis* is always found in these lower, thicker limestones, while *Exogyra arietina*, as will be noted, occurs in the higher strata. The forms are associated in the medial beds. These two fossiliferous zones are important bench marks for correlation purposes, as will be shown later. Mr. Stanton has kindly identified the following forms from the beds at Denison:

List of fossils from the Main Street limestone.

Cyphosoma volanum Cragin. (Identified by Prof. W. B. Clark.
Enallaster sp. (Closely related to E. obliquatur.)
Kingena wacoensis (Roemer).
Ostrea quadriplicata Shumard.
Exogyra drakei Cragin.
Exogyra arietina Roemer.
Plicatula sp.
Neithea texana Roemer.
Cucullæa sp.
Trigonia emoryi Conrad.
Ptychomya ragsdalei (Cragin).
Protocardia texana Con.?
Cyprimeria sp. Large species.
Pholadomya sp. (Related to P. sanctisabæ Roemer.)
Turritella sp. (Related to T. leonensis Con.)
Turrilites brazoensis Roemer.
Nautilus sp.

Del Rio clay.—Before discussing its relations to the Main Street formation it may be well to describe the Del Rio clay as it occurs at Austin, where it is typically exposed. This formation, which occurs south of Brazos River, may be considered as the southern extension of the Main Street limestone of the northern section, into which it passes by gradual and horizontal transition. It is an especially important landmark in the southern sections, marking a break in a monotonous sequence of limestone beds, and possessing lithologic and paleontologic characters which render it easily recognizable.

It occurs in a narrow strip of prairie belt directly east of the Georgetown limestone and west of the Eagle Ford Prairie, the Western Cross Timbers having disappeared as a topographic landmark south of the Brazos in the region of the occurrence of this clay.

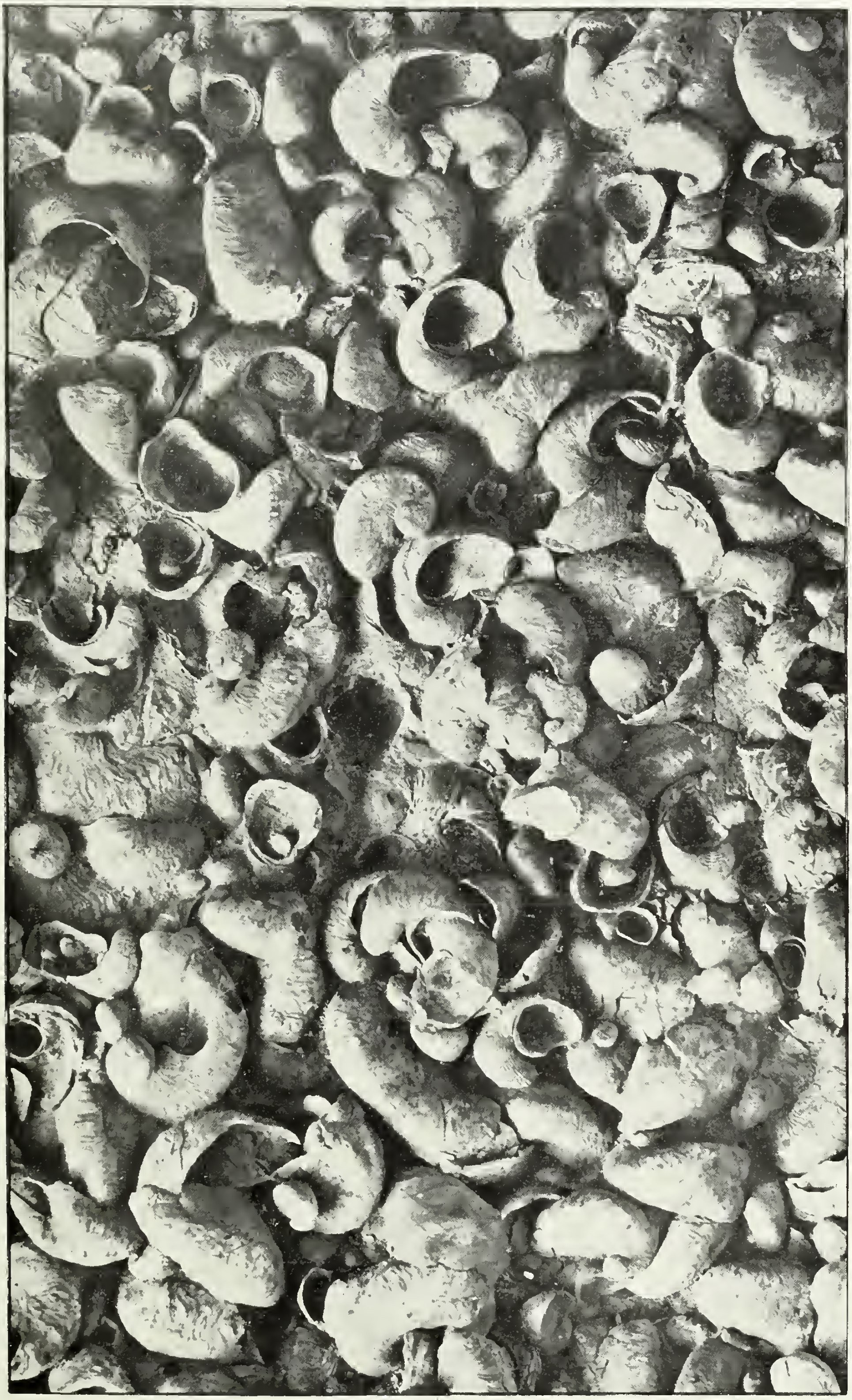
In general the prairie strip occupied by the Del Rio clay is characterized by superficial irregularities known as "hog wallows," and is covered by a dense growth of shrubby mesquite trees. The soil is also deeper and of a blacker color than that of the stony and more chocolate-colored surface of the Fort Worth limestone.

At Austin the clay is some 80 feet thick in the west bluffs of Shoal Creek in the northwest part of the city, and at Fish Pond Bluff on the south side of the river just above the mouth of Barton Creek.

The formation is composed almost entirely of a peculiar greenish-blue, unctuous, laminated clay, gypsiferous in places, but apparently freer from carbonaceous matter such as characterizes the Denison beds of the northern section. When freshly exposed these clays are of a light bluish-gray color. They lose their original character very rapidly upon exposure, becoming dull yellow and making a black soil. They are accompanied in places by thin slabs of shell breccia composed of *Exogyra arietina*, forming massive agglomerates seldom over 6 inches in thickness. (See Pl. XXXVIII.) Thin laminations of impure ferruginous, sandy limestone also occur occasionally near the top of the formation. The clay carries iron pyrites in places. When the clay disintegrates these particles of pyrites oxidize and decompose, and the iron rust gives the dry surface of the clay beds a dull yellowish color. At the same time the sulphur component of the pyrites combines with the lime of the fossil shells and forms gypsum. Crystals of selenite from this source occur in abundance on the surface and are disseminated in the clay and in joints and small fissures at a certain stage in the disintegration of the clay into soil. Laminations also show in the clay on freshly weathered surfaces. These are especially apparent in the upper portion of the clay, where the flaggy layers occur.

The chief and most readily distinguishable feature of the clay, whereby it may always be easily identified, is the presence in enormous quantities of the unique and easily recognizable fossil known as *Exogyra arietina* Roemer. This little oyster occurs by the millions in certain portions of the clay, either as consolidated sheets of agglomerate or as separate individuals, which often weather out so abundantly as to cover the entire surface of the exposure. (See Pls. XVII and XXXVIII.) Attached to these shells, especially to the umbonal region, are small cubes of iron pyrites, the decomposition of which has been described.

Paleontology and fossil horizons.—This clay is abruptly limited above and below by limestone formations. The limestone upon which



EXOGYRA ARIETINA AGGLOMERATE NEAR ROUND ROCK, TEXAS.

it rests is usually a massive stratum largely made up of the fossil *Kingena wacoensis*. This limestone is stratigraphically the top of the Georgetown limestone, but the fossil zone which it represents is the base of the Main Street limestone of the Red River section.

The Kingena limestone horizon is compact, while the clay is friable in structure and disintegrates readily when exposed. The fossils of the limestone extend for several feet up into the clay, mingling freely with *Exogyra arietina*. The characteristic *Exogyra arietina* occurs wherever the bed is found and throughout the clay, but its zone of greatest prevalence is near the center of the bed. Through a range of nearly 15 feet from the center of the bed upward this beautiful fossil is found in countless numbers in the clay and forms masses of rock.

Above the culminating zone of *Exogyra arietina* the clays are somewhat barren of fossils until near their summit, where they become slightly arenaceous and contain impure limestone slabs bearing other fossils, such as *Turritella*, *Lima*, and *Neithea*. Among these there are occasionally found casts of the stem of a fossil plant (*Equisetum*).

In the uppermost layers of the clay are many specimens of *Gryphæa mucronata* with *Pecten* and *Ostrea* sp. ind. These weather out of the clay. The gryphæas increase in numbers upward to the parting between the clay and Buda limestone, where they form a coating on the base of the limestone and extend up into it.

The formation outcrops at many places from the Colorado northward to the Brazos, being exposed along a narrow belt on the downthrown side of the Balcones fault zone. North of the Brazos, in Johnson County, it begins to assume the character of the Main Street limestone, and until further investigation the writer could not apply the name Del Rio to any beds north of McLennan County.

Nine miles west of Ross Station the Del Rio clay and shale occur in perfect contact with the Fort Worth limestone. The section here, according to Taff, is as follows:

SECTION NO. 40.—DEL RIO CLAY WEST OF ROSS STATION, TEXAS.

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
Alluvium	10	10
Del Rio clay containing abundance of *Exogyra arietina*	60	70
Basal third of this clay is marked by ammonites, with oysters in the upper beds.		
Fort Worth limestone	70	140

The base of this section is the level of Brazos River. The upper edge of the clay is lithologically the same as at Austin, but as one descends it gradually changes from a stratified clay to persistent fissile clay containing agglomerates of the oyster. This shale gradually passes upward into thinly stratified limestone.

Details of occurrence.—Two miles north of the mouth of Childress Creek, McLennan County, the Del Rio clay is 60 feet thick. The formation outcrops between the forks of the Bosque, where it occupies a large, flat prairie area upon which the growth of mesquite bushes is very thick. Probably a more characteristic outcrop of this clay is that seen farther to the south, about Moody and east of Belton. Here the beds outcrop along a considerable scarp which overlooks the Fort Worth limestone to the West.

The Del Rio clay forms the bluffs of the south bank of San Gabriel River, two or three miles below Georgetown. Its occurrence in the base of the river is concealed by the lake formed by the dam of Town's mill. It is about 75 feet thick at this locality. The bed is also well exposed south of Round Rock, in the northern part of the Austin quadrangle. It is then cut out by faulting, reappearing at the Colorado as described at Austin. The clay crops out in the escarpment slopes 2 miles east, southeast, and south of Georgetown. It approaches the Georgetown and Round Rock road 3 miles south of Georgetown, and continues in a narrow belt of exposure nearly due south to Brushy Creek at Round Rock. At this point it is nearly concealed by the downthrow of the Balcones fault, only about 10 feet of the upper edge of the clay remaining at the surface.

Grayson marl.—The Main Street limestone is succeeded in the Denison section by the Grayson marls. (See Pl. XVIII, *A*.) These are light-colored fossiliferous clays with many small lumps of lime and much iron pyrites. The outcrops of these marls are usually covered by ferruginous sandstone and other débris of the overlying Woodbine formation, and their contact with that formation and relations to it throughout have not been satisfactorily ascertained. It is still a question whether there is unconformity between them or whether the one passes into the other. The writer has tentatively maintained the first hypothesis, and a section published by Taff is somewhat confirmatory of this conclusion.[1] The débris of the Woodbine is scattered over the parting so completely in most places that the contacts can not be seen. Furthermore, the Grayson marl is usually so concealed by this débris that it outcrops only in a few disconnected places where erosion has cut through the veil.

Wherever the Grayson bed is exposed it forms spots of prairie land

[1] Fourth Ann. Rept. Geol. Survey of Texas, Austin, 1892, p. 282.

within the western margin of the Eastern Cross Timbers. The typical exposure of the Grayson formation is in an abandoned cutting of an old unused railway grade in the southeastern portion of Denison, discovered by Prof. F. W. Cragin, who first named this formation.[1] Here it is very fossiliferous, being characterized especially by *Gryphæa mucronata* and a form of *Turrilites* (see Pl. XX, fig. 3).

One and one-half miles north of Pottsboro there is a good exposure of the Grayson marl containing *Hoplites texanum* of Cragin, *Nautilus*, and *G. mucronata*. Two and one-half miles north of Pottsboro branch of Little Mineral Creek 35 feet of Grayson marl upon the Main Street limestone are shown.

One-fourth of a mile northwest of Cedar Mills the Woodbine is seen in contact with Grayson marl and Main Street limestone. Fifteen feet of the Grayson marl are also exposed on Rock Creek in northwest Grayson County.

The following section by Taff, made at Elm Creek, at the crossing of the Missouri, Kansas and Texas Railway in Denton County, is an excellent example of the character of the Grayson marl:

Section No. 41.—Grayson marl, on Elm Creek, at the Missouri, Kansas and Texas Railway crossing (Taff).

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
8. The creek drift on eroded surface of limestone at top of bluff	10	10
7. Limestone and marl, in layers varying in thickness from 3 inches to 1 foot, with *Pecten*, *G. mucronata*, *Cyphosoma volanum*	.5	10.5
6. Marly limestone, with *Hoplites texanus*	.5	11
5. Friable light-blue marl	2	13
4. Limestone	.25	13.25
3. Friable marl, with *G. mucronata*	2	15.25
2. Alternating limestone and marl, in twelve layers of equal thickness, containing *Turrilites brazoensis*, *Gryphæa pitcheri* (Vola phase), *Nautilus* sp.?, *Hoplites texanus*, *Trigonia emoryi*, and *Pecten*	6	21.25
1. Friable blue marl, containing *G. mucronata* to water level	8	29.25

Turrilites brazoensis ?, *Pecten texanus ?*, and *G. mucronata* occur throughout the section.

On Marshall Branch, northeast of Roanoke, the débris of the Woodbine formation conceals the upper border of the Grayson formation.

[1] Colorado College Studies, Colorado Springs, Colorado, 1894, p. 43.

Below this there are from 45 to 50 feet of yellow clay and blue clay marls containing *Turrilites*, *Gryphæa mucronata*, *Ostrea*, *Pecten*, etc. This rests on 15 feet of the Main Street limestone. In the bluffs of Denton Creek, 2 miles below the Missouri, Kansas and Texas Railway, 38.5 feet of the Grayson marls are shown above the uppermost limit of the *Exogyra arietina* zone of the Main Street limestone. The same character of Main Street beds, with little variation from that above, is maintained in the bluffs of Trinity River from a point 6 miles east of Fort Worth to Randall. East of Handley Station about 1 mile these marls occupy a prairie area well within the western margin of the Eastern Cross Timbers. They are 50 feet or more in thickness and very fossiliferous.

BUDA LIMESTONE[1] OF SOUTHERN SECTION.

RELATIONS, STRATIFICATION, AND MICROSCOPIC STRUCTURE.

The Grayson marl ceases to be recognizable by lithologic character south of the Brazos. Thence south its position is occupied by a limestone formation which progressively becomes more and more clearly defined and of more marked individuality in that direction. For this the name Buda limestone is used. (See Pl. XVIII, *A*, and Pl. XX, *F*.) This formation for many years has been known in Texas as the Shoal Creek limestone, as originally named by the writer. Recently it was ascertained that this name was preoccupied. Hence a new name for the formation became necessary and the term Buda was selected, as the formation is well displayed in the vicinity of the town of that name.

The Buda limestone may be defined as the uppermost of the three formations of the Washita division throughout southern Texas, where it is also the final bed of the Lower Cretaceous, occupying the same position in the southern section relative to the series as do the Grayson marls of the northern section, the one probably being the seaward extension of the other.

The chief exposures of the Buda limestone are in the steep scarps of Shoal Creek, in the city of Austin, and in the bluffs of Bouldin Creek and the outer borders of Barton Creek Valley, on the south side of the river. At these localities it forms picturesque precipitous bluffs with toppling projectings, owing to its jointed structure and the undermining of the clays of the underlying Del Rio formation. As the clay beneath gives way the bowlders, fragments of the Buda limestone, fall down and often veneer the bluff or escarpment face of the clay. The débris often remains on the surface of level areas of the Del Rio clay in places where the cliffs have long been receding.

This limestone is stratified in massive layers 2 to 6 feet or more in thickness. The strata are of varying hardness and consistency, some of them weathering into smooth-faced, regular beds, while others

[1] Formerly called Shoal Creek limestone.

weather into shattered, lumpy material or disintegrate readily through chemical action into an efflorescent powder which causes such strata, when protected by a harder layer above, to recede from the general vertical profile of the bluff, thereby forming bluff caverns overhung by ledges.

The outcrops of the more persistent ledges oxidize to darker colors, but often strong yellow, orange, and white prevail. On fresh fracture the stone is light yellowish drab, with many small specks or spots, usually not much larger than coriander seed. Near the surface these inconspicuous specks oxidize into yellowish and strong red colors, which do not permeate the whole mass of the rock but appear as large blotches of red color, as if stone had been partially burned.

Microscopic study has revealed the fact that the seed-like spots are fossil Foraminifera, of which the rock is largely composed, and that their shells are filled and coated with a mineral which in all probability is glauconite, the oxidation of which gives rise to the orange-stained blotches. So far as examined, this rock is more largely composed of Foraminifera than any of the whole Comanche series. In one thin section *Rotalia*, *Textularia*, *Globigerina*, and fragments of three or four other genera of Foraminifera have been recognized.

DETAILS OF OCCURRENCE, PALEONTOLOGY, AND THICKNESS.

The outcrop of this formation is very limited, occurring as a narrow belt between the Del Rio clay and the Eagle Ford formations extending from the Brazos and the Colorado and thence onward to the Rio Grande. From the Brazos southward to the San Gabriel it constitutes merely the narrow outcrop of a thin ledge of rock. It is only from Georgetown southward that it begins to have pronounced surface representation. The formation is first seen near Bosqueville, McLennan County. Thence it outcrops in various places through McLennan, Bell, Williamson, and Travis counties, passing near Moody, west of Pendletonville, and about halfway between Temple and Belton.

A low bench of Buda limestone caps the high bluff 2 to 3 miles below Georgetown, on the south side of San Gabriel River, and forms the crest of the escarpment that extends from the west end of this bluff around the valley 2 to 3 miles east and southeast and 3 miles south of Georgetown. From the road 3 miles south of Georgetown it continues south, capping the low escarpment, to Brushy Creek, opposite Round Rock.

Buda limestone occurs exposed in the bed of San Gabriel River for 1 mile below Town's milldam until concealed by Eagle Ford shale. It also occurs along the banks of Brushy Creek from the Balcones fault at Round Rock to very near the mouth of Channel Creek.

Near Georgetown, Round Rock, and Austin the formation constitutes toppling bluffs in the creeks, as already described, and also underlies small areas of forested plain covered by growths of beautiful live-oak trees which find foothold in the limestone crevices. The agarita (*Berberis fremontii*) and the large nopal (prickly pear) also grow upon the rocks. The somewhat high plateau of west Austin, on which the Pease mansion is situated, is established upon this formation. The residual soil is rich and of a brownish-chocolate color. It is usually shallow and stony, however.

The Buda limestone contains many fossils, mostly casts and molds, which, with the exception of *Gryphæa mucronata* and *Pecten roemeri*,[1] have not as yet been scientifically determined.[2] *Gryphæa mucronata* (see Pl. XXXVII, fig. 1), which also occurs in the top of the underlying Del Rio clay, passes upward into the limestone, and occurs abundantly in the basal band of limestone. Above this, however, it occurs but rarely.

While the formation has increasing thickness and areal development south of the Colorado, having a thickness of nearly 100 feet on the Nueces, it thins out gradually north of the former stream, finally disappearing entirely as a limestone formation north of the Brazos. In the western limits of Austin this bed is nearly 80 feet thick. From this place it decreases in thickness northward at the rate of about 2 feet per mile. At Round Rock it is nearly 20 feet thick, and on the San Gabriel it has diminished to less than 10 feet. At Moody it is from 3 to 5 feet thick; and near Bosqueville, McLennan County, on the Brazos, where it is last recognizable, it is only one-half foot thick.

Its stratigraphic position is gradually occupied to the northward by the marls of the Grayson formation. Unfortunately the writer has had no opportunity to trace this formation in the transitional area between the Brazos and the Trinity, and hence can not describe this feature of its occurrence.

SUMMARY AND CORRELATION OF THE WASHITA DIVISION.

BROAD VARIATION IN LITHOLOGIC CHARACTERS.

From the descriptions and sections given it will be seen that the members of the Washita division, through gradual changes in the nature of the sediments of which they were formed, completely change in lithologic character and grouping as they are traced across the State. These changes, whereby a formation which is a clay on Red River becomes a limestone on the Colorado, and vice versa, are so gradual that one can not state exactly where they take place. That the diverse formations of the two regions are synchronous and con-

[1] This fossil is figured on Pl. LVII of Part II of the Eighteenth Annual Report of the United States Geological Survey.

[2] The carefully collected fauna of the Buda limestone was placed in the hands of Prof. George B. Shattuck, of Johns Hopkins University, for final study in 1894, and his results will appear elsewhere.

tinuous manifestations of the same events of deposition there can be no doubt, for the paleontologic facts are such that identical fossil horizons, by which geologic chronology is fixed, can be established in the two sections and continuously traced through them.

CORRELATION OF FOSSIL HORIZONS OF AUSTIN AND RED RIVER SECTIONS.

To establish clearly the correlation between the Denison and Austin sections it is necessary to bear in mind the position of eight marked paleontologic zones which are continuous across the State—beds b, c, d, e, i, o[1], o[2], and p of the Denison section. (See fig. 29, p. 245, and Pl. XV.) Bed b is the zone of *Exogyra plexa;* c, d, the zone of *Pachydiscus brazoensis;* e the zone of *Schloenbachia leonensis* and *Epiaster elegans;* i, the zone of *G. washitaensis* with *O. carinata;* o[1], a persistent zone of *Kingena wacoensis;* o[2], the zone of *Exogyra arietina;* and p, the zone of *Gryphæa mucronata.*

Beds b, c, d, e, and i in the Denison section occur in the distinct Kiamitia, Duck Creek, Fort Worth, and Denton formations. Beds e and i in the Denison section are separated by about 75 feet of marls carrying many fossils, such as *Gervilliopsis invaginata*, etc., which are not found in the Austin section. At Austin the formations still carrying these fossil zones are so coalesced and are lithologically so inseparable that they collectively make a single indivisible formation.

In the Dension section the Weno and Pawpaw formations of the Denison beds have great thickness. These are of a shallow-water, impure nature, as described, lithologically entirely unlike any beds of the Austin section, and, so far as yet known, paleontologically distinct. They gradually lose their identity to the southward and thin out before reaching the Brazos, neither being represented lithologically or paleontologically south of that stream.

Bed o of the Denison section is a coarse limestone formation less than 20 feet thick, characterized in its lower portion by a marked fossiliferous zone of *Terebratula wacoensis*, o[1], and in its upper portion by a similar zone of *Exogyra arietina*, o[2]. These fossils occur in great quantities, and in the Red River section are found only in this particular formation. In the Austin section the fossiliferous zones o[1] and o[2] are more widely separated, the former occurring chiefly as a limestone which is mappable only as the upper part of the underlying (Georgetown) formation, here representing beds e to o[2] of the Denison section. The latter o[2] (*E. arietina*) occurs throughout the clays of the Austin section, but chiefly near their top, about 50 feet above the zone of *Terebratula.* In view of these facts, there can be no doubt that the Del Rio clays, some 70 feet thick, and the upper bed of the Georgetown formation at Austin (10 feet more or less), may be correlated with the Main Street limestone of the Denison section.

The Del Rio clays, upon paleontologic grounds, undoubtedly represent the southern and deeper-water continuation of the Denison beds, at least occupying, with the overlying Buda, the stratigraphic place in the general section of the beds above bed i (the *O. carinata* zone of the Denton subdivison) of the Red River section. Their lithologic nature is so different that correlation would hardly be possible between them were it not that the transition from one to the other is clearly traced along the line of outcrop, and were it not for the continuity of the two strong, definite, and continuous paleontologic zones of *Kingena wacoensis* and *Exogyra arietina*, which persist regardless of change in the character of lithologic matrix.

Bed p of the Denison section is a calcareous and pyritiferous marl, characterized by great numbers of *G. mucronata*, which occurs only in this position in the Denison section. The stratigraphic place of these marls is occupied at Austin by a limestone (the Buda limestone), while the characteristic fossil of bed p occurs at its base and in the top of the Del Rio clay. Inasmuch as the main body of the Buda limestone above this basal zone contains fossils which have not as yet been correlated with the Grayson marls of the Denison section, there is some reason for a tentative hypothesis that much of this limestone may represent a slightly later horizon of the Lower Cretaceous than is exposed in the Denison section. The writer has endeavored to have this problem solved by careful collections, which are now being studied by Messrs. Stanton and Shattuck.

These formations, which have been so carefully studied throughout a wide extent and which carry in their fossils such undisputed bases for comparison, present interesting illustrations of the lithologic variation of synchronous sediments, showing how the material of formations in their horizontal extension may so change that, were it not for the persistence of paleontologic zones, they might be regarded as of distinct origin and different age.

Upper Cretaceous—Gulf Series.

DIVISIONS.

The Upper Cretaceous or Gulf series is confined to the regions of the Eastern Cross Timbers and the Black Prairie. It rests unconformably upon the Comanche series and may be divided into five conspicuous formations (see Pl. XVI), the beds of which grade into one another by imperceptible transition. The lowest of these north of the Brazos, the Woodbine, consists of ferruginous sands and clays. Above this is a formation characterized by bituminous clays, the Eagle Ford. Then follows a conspicuous formation of chalk, the Austin chalk. Succeeding this is a formation of marly clay, the Taylor marl. The uppermost formation, the Navarro, is composed of unindurated beds of glauconitic sands, clays, and a little chalk, as will be described later. There is no sedimental break between these formations, the whole series being practically continuous. All are characterized, with certain exceptions, by their general lack of consolidation, little or no hard rock being found. Although much study has been put upon these formations as a whole, their paleontologic classification and correlation is still far from satisfactory. The terranes, with the exception of the Austin chalk, are so unconsolidated and so mantled with black soil that it is almost impossible to find good stratigraphic outcrops. Furthermore, the beds grade into one another so gradually that partings are mappable only with the greatest difficulty. Often it is impossible to map them at all.

RELATION TO EXTRATERRITORIAL FORMATIONS.

The series as a whole is known to correspond with the Upper Cretaceous of the Meek and Hayden section of the Northwest. There is but little doubt that the three lower formations—the Woodbine, Eagle Ford, and Austin—are in a general way the equivalents of the Dakota and Colorado divisions, while the Taylor marl and Navarro beds, occupying the stratigraphic place of the Pierre and Fox Hills formations, in a manner correspond to the Montana division of the Northwest. It is impossible, however, in the Black Prairie region to group the beds into the divisions established in the Rocky Mountain region. The Woodbine formation is a part of the great basement littoral of the Upper Cretaceous series of the West, representing, like the Basement sands of the Lower Cretaceous, the marginal formation accompanying a subsidence of the sea as it invaded the land from the coast interiorward. Unfortunately, the record of the migration of this shore line has been destroyed by the stripping of the beds from the Central and Great Plains provinces in Texas, but in southern Kansas and northeastern New Mexico there are sufficient data to show that this formation ultimately joins the diagonally transgressing Basement sands of the Comanche series in those regions.

WOODBINE FORMATION.[1]

NOMENCLATURE.

At the time the existence of the Lower Cretaceous or Comanche series was recognized in central Texas, in 1886, certain arenaceous beds lying above it and at the base of the Upper Cretaceous were first defined by the writer[2] as the Timber Creek group or the Lower Cross Timbers formation, and were referred to the Dakota formation by Dr. C. A. White.[3] Previous to the appearance of these papers the beds had been imperfectly and rather confusedly described, portions

[1] See Pl. XVIII, *B*, and Pl. XIX, *C*.

[2] Am. Jour. Sci., 3d series, Vol. XXXIII, April, 1887, p. 291-303.

[3] See Proc. Phila. Acad. Sci., 1887, Pt. I, pp. 39-47.

of adjacent formations having been included with them. Furthermore, their position in the general section had not been ascertained, and they had usually been referred to the Tertiary system.[1]

The Woodbine group in Grayson County was originally described by Dr. G. G. Shumard as the "Tertiary system"[2] and later as the "Arenaceous and Marly Clay, or Red River group."[3]

Dr. B. F. Shumard, who based his conclusions upon his brother's notes and collections, not only did not recognize the Dakota affinities of the so-called Red River group, but gave it several distinct stratigraphic positions in his well-known general section[4] of the Cretaceous formations of Texas, which was so long the standard one for that region. Later, however, he was the first to announce the occurrence of Dakota plants in Texas; but this announcement, based upon fossils sent by his brother from Denison, was unaccompanied by any stratigraphic information,[5] and there is no doubt that he remained unconscious of their position in his section until the date of his death, shortly after.

Owing to the confusion already created in American geologic literature by the indiscriminate use of the term Dakota, as well as for further reasons to be explained on a later page, the writer prefers to apply a local term to this formation in this portion of Texas, and will call it the Woodbine, after a locality in the northeastern part of Cooke County.

CHARACTER AND COMPOSITION OF THE ROCKS.

The rocks of the Woodbine formation are largely made up of ferruginous, argillaceous sands, characterized by intense brownish discoloration in places, which are accompanied by bituminous laminated clays. These sands, like those of the Trinity division (Western Cross Timbers), are unconsolidated in places, but differ from them by containing a greater proportion of iron and other mineral salts, which materially influence the character of the waters derived from them. The sands, which in the unoxidized substructure are usually white and friable, contain particles of iron occurring as glauconite and pyrite. These minerals oxidize toward the superficies, and their solutions consolidate the more porous beds of sand into dark-brown silicious iron ore, occurring in immense quantities in certain localities. Other beds of sand break down into deep, loose soils. These support a vigorous timber growth and are especially adapted to fruit culture. The clays are usually sandy and sometimes bituminous, although in some places,

[1] See Geological sketch of Texas, by Dr. Francis E. Moore, in Texas Almanac, 1860, p. 97; History of Gulf of Mexico, by Eugene Hilgard, in Am. Jour. Sci., 3d ser., Vol. II, 1871, pp. 401–404; Geology of Western Texas, by G. G. Shumard, Austin, 1886, p. 127, etc.

[2] A Partial Report on the Geology of Western Texas, Austin, 1886, p. 127.

[3] B. F. Shumard, Trans. Acad. Sci. St. Louis, Vol. I, 1860, p. 588.

[4] Trans. Acad. Sci. St. Louis, Vol. 1, 1860, p. 583.

[5] Trans. St. Louis Acad. Sci., Vol. II, 1868, p. 140.

as near Denton, of sufficient purity for making stoneware. They occur either as extensive beds or as laminæ and thin strata interbedded in the sands.

The presence of fossil vegetation, such as leaf impressions and lignite, distinguishes the beds of this division from the other formations of the Upper Cretaceous and attests its shallow-water littoral origin.

IRON-ORE KNOBS AND SILICEOUS IRONSTONE.

The formation superficially weathers into a loose, sandy soil, mostly covered with coarse post-oak and black-jack timber, but broken here and there, where the proportion of clay increases, by small prairies. Furthermore, its upper beds, which outcrop on the coastward side, are usually barren of forest. Its surface configuration is undulating or level, with the exception of certain characteristic low hills, known as iron-ore knobs, which approximately follow the interior border of the western belt and occur exceptionally in isolated outlying areas in southern Indian Territory and central Grayson County.

A plainly marked feature of the interior border is the quantity of ferruginous sandstone and siliceous ironstone débris which remains upon the surface along the basal contact after the more friable sands have been worn away. These often extend over the adjacent prairie as scattered fragments upon the eroded edges of Lower Cretaceous strata. These ferruginous sandstones and nodular ironstones are derived from the lower beds of the Woodbine formation. As the softer rocks are removed, these remain upon the surface as ferruginous, flaggy stones and ironstone bowlders, and in some localities are so abundant and persistent as to form the caps of the low oval hills and isolated knobs along the western border of the Eastern Cross Timbers. When viewed from the Grand Prairie, these hills are conspicuous topographic objects, forming the dissected remnants of an inward-facing scarp which overlooks the Grand Prairie to the west. They occur along the western border of the Eastern Cross Timbers throughout their extent, from Whitney, in Hill County, to Red River. Some of the more prominent of these hills are Brushy Knob and Caddo Peak, in Johnson County; Brushy Knob, in northern Hill County; Pilot Knob, northwest of Argyle, and numerous others almost as prominent, but unnamed. Caddo Peak, northwest of Joshua, is a rather precipitous prominence of this character. Here the surface is strewn with detached fragments and bowlders of ironstone and ferruginous sandstone, the prominences being formed principally of rock of this character. The peak is thickly forest clad. A chain of hills of this character extends northward from the Trinity to Red River through the eastern parts of Tarrant, Denton, and Cooke counties. The Pilot Knobs of Grayson County northwest of Alchire switch and 5 miles west of Denison, the knobs between Denison and Sherman, and the knobs of southern Chickasaw Nation are of similar formation and configuration. Viewed from the east, the Eastern Cross Timbers apparently lie in a valley, occupying, as they do, a valley trough on the dip plains which constitute the summit of the Iron Ore Knobs to the west and are bounded on the east by the White Rock scarp.

RELATIONS AND THICKNESS.

The Woodbine formation apparently rests unconformably upon the Grayson marls and Main Street limestones of the Denison beds of the Washita division, at the top of the Comanche series. The upper beds pass, by inseparable transition, from sands into sandy clays and finally into the bituminous clays of the Eagle Ford formation. This transition is so gradual that no exact line of separation can be drawn between the Woodbine and Eagle Ford formations. The parting is arbitrarily established at the zone of *Exogyra columbella*, which is considered as the top of the Woodbine formation.

The formation has a thickness of at least 600 feet in the northern section, and diminishes southward until it disappears by thinning out and overlap at the Brazos. On Aquilla Creek north of Waco the formation is 45 feet thick. According to Taff, it is 200 feet thick in the Cleburne section. On Cottonwood Creek northwest of Hillsboro it is 95 feet thick. In the Fort Worth section its thickness is about 300 feet and in the Denison section about 500 feet.

CLASSIFICATION INTO SUBGROUPS.

Although the beds of the formation show considerable variation in vertical succession, it is impossible to establish accurate mappable subdivisions owing to its lack of consolidation and the intergradation of its members one into the other. As a whole, it is merely a series of sands and clays in which there may be conspicuous layers or beds of either material. Nevertheless, there are certain strong subdivisions which in places are recognizable although not mappable, and in order to discuss these a nomenclature is necessary, however temporary or unsatisfactory it may be.

There are generally two conspicuous groups of ferruginous sandy beds one near the base and one middle of the section underlain, separated, and succeeded by more or less persistent sandy clays. These two horizons are both water bearing.

Dr. G. G. Shumard, who originally described the Woodbine group in Grayson County as the "Tertiary system,"[1] subdivided it into three members: (1) Upper arenaceous group, (2) Middle or green sandstone group, and (3) Gypseous clay group. Unfortunately his

[1] A Partial Report on the Geology of Western Texas, Austin, 1886, p. 127. This group was later described (B. F. Shumard, Trans. Acad. Sci. St. Louis, Vol. I, 1860, p. 588) as the "Arenaceous and Marly Clay, or Red River group."

lower member belongs on top of the other two, and consists of the upper part of the Woodbine and the base of the Eagle Ford. This mistake was no doubt caused by Dr. Shumard's failure to recognize the intricate faulting of the region.

Mr. J. A. Taff has presented many details concerning the stratigraphy of the Woodbine formation, called by him the Red River series[1] and the Dakota.[2] The writer has drawn freely upon his descriptions for the stratigraphic details presented in this paper.

Taff classified the beds of the Woodbine formation as the "Basal clays," "Dexter sands," and "Timber Creek beds." In general his subdivisions have here been followed, but the writer is forced to reject his nomenclature, with the exception of the Dexter sands. The term Basal clay is objectionable under a general rule of the Survey nomenclature, and "Timber Creek," which had previously been used by the writer,[3] is a duplication of a Cretaceous formation name previously used in New Jersey. Therefore the former will be considered as a portion of the Dexter formation, and will be omitted as a mappable formation, but the name will be used occasionally for descriptive purposes. For Timber Creek the term Lewisville will be herein substituted.

The general sequence of the beds, so far as they can be established from the study of the outcrops between the Trinity and Red River, will now be stated. This sequence may prove variable after further study:

1. The lowest beds are usually of impure clay, which is often sandy and lignitic.

2. An extensive formation of yellow ferruginous sandstone and brown siliceous ironstone, in which impressions of dicotyledonous leaves are sometimes found. These are the Dexter sands of Taff.

3. Lignitic sandy clays and sands, frequently accompanied by sulphate of iron, magnesian salts, etc. The sands also oxidize into heavy, siliceous, dark-brown iron ore in places. The subdivision is characterized by an extensive molluscan fauna, which is elsewhere alluded to and which may be characterized as the *Aguileria cumminsi* zone. These are the Lewisville beds.

4. Less ferruginous sands and clays, and in places more calcareous and fossiliferous, gradually passing into the bituminous shale of the Eagle Ford formation. The upper limit of these beds ends with the zone of *Ostrea columbella* Meek.

It is not possible to estimate the thickness of either the Dexter sandstone or the Lewisville beds of the Woodbine, owing to the great variability in the dip planes of the strata, which variability is doubtless in part due to the false bedding.

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[1] Third Ann. Rept. Geol. Survey of Texas, Austin, 1892, p. 271.

[2] Fourth Ann. Rept. Geol. Survey of Texas, Austin, 1893.

[3] Am. Jour. Sci., April, 3d Series, Vol. XXXIII, 1887, p. 298.

EXTENT AND DETAILS OF OCCURRENCE.

The area, extent, and variation of the Woodbine rock sheets are important factors, since they are the water-bearing strata, forming one of the several artesian systems beneath the surface of the Black Prairie region, as will be more fully described later. The extent of this formation has been shown to be approximately coincident with the north-south belt of the Eastern Cross Timber country of Texas from the southern part of Indian Territory north of Red River[1] near the Cooke and Grayson County line to the Brazos, and along two east-west belts in southern Indian Territory and Grayson County, the former beginning with a timbered ridge 3 miles south of old Fort Washita, Chickasaw Nation, and extending east until it is occupied by Red River in its course through Fannin, Lamar, and Red River counties, finally ending in western Arkansas.

The beds of the main Texas, or north-south, belts are well displayed in Texas along the lines of all the railways traversing or following the Eastern Cross Timbers, such as the Texas Pacific road between Handley and Arlington stations, and on the Missouri, Kansas and Texas road between Denison and Pottsboro, Whitesboro and Dexter, Denton and Lewisville, and Alvarado and Fort Worth. In the east-west belt of the Red River district good exposures are seen in all the localities mentioned, but, as elsewhere, it is difficult to obtain a continuous section of the entire formation from bottom to top, or to connect the separated fragmental sectional exposures.

Red River flows in the Woodbine formation from Carpenters Bluff in the northeast corner of Grayson County to Pine Bluff in the northeast corner of Red River County. There are many bluffs of the river along this portion of its course where the Dakota is partially exposed, such as Arthurs, Sowells, Pine Bluff, and others. The most eastern occurrence is at Morris Ferry on Little River in Little River County, Arkansas.

The formation, as well as the Eastern Cross Timbers growing upon it, abruptly terminates at Brazos River a few miles west of Waco, and thence on to the south and west is entirely missing in all the geologic sections taken. The cause of this disappearance is more fully discussed on a later page.

As a whole, the formation could be better appreciated by studying a number of cross sections made at various intervals across its strike, notably at Aquilla, Cleburne, Fort Worth, Denton, Denison, and Paris.

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[1] To say that the Eastern Cross Timbers are exactly coincident in extent with the outcrop of the Dakota division would be slightly inaccurate. A narrow strip of the western border of the Eastern Cross Timbers from Johnson County north through Tarrant, Denton, Cooke, and Grayson counties is underlain by the sands of the upper part of the Pawpaw formation. This is well shown in the northern part of Denison. This strip seldom exceeds a half mile in width and is usually separated from the main body of timber by a narrow belt of irregular prairie underlain by the yellow Main Street limestone. The Grayson marls also occupy a minute portion of the western part of the area of the Eastern Cross Timbers.

Unfortunately, however, for reasons previously stated, these sections have not been obtained with the detail which is possible in dealing with more consolidated formations. Hence it will be necessary to describe the beds along these sections in a general manner, without the completeness of detail that is desirable, beginning at the south, where the formation is thinnest, and tracing its gradual development northward.

Massive beds of friable yellow and brown ferruginous sand begin immediately above the base of the formation at the eastern border of Cleburne and continue upward in strata as they extend east, surfaced by heavily wooded, sandy soil. Exposures of large extent are very rare. The friable sand, as it disintegrates, forms gently undulating surfaces, except where there are local extensive accumulations of indurated ferruginous sandstone and ironstone, which produce "sand roughs" and occasional knobs.

The general character of the formation through Tarrant and Denton counties is illustrated in the Denton-Lewisville section. At the base of the formation in Denton County, along the Dallas and Wichita Railway southeast of Denton, there are 10 to 15 feet of thin ferruginous sand and arenaceous sandy clay, which is succeeded by about 300 feet of heavy-bedded red ferruginous sand, containing many sandy ironstone concretions and nodules, and brown sandstones with very large indurated calcareous sandstone lenses in the upper strata. These are the Dexter sands. They are succeeded by from 50 to 100 feet of strata comprising the Lewisville beds. These are composed of laminated lignitic sands and sandy clays, interstratified with brown sands, ferruginous reddish-brown sandstone, shell sandstone, and argillaceous shelly sandstone, which contains large lens-like calcareous concretions and laminated argillaceous sandstones at the top. Some of these sandstones are very calcareous and, on account of the great numbers of shells of *Ostrea* and other mollusks, may be considered siliceous or argillaceous limestones.

As a whole, the Woodbine formation is best and most conveniently illustrated in the outcrops adjacent to Denison, Texas, but even here the structure is so faulted that it is difficult to point out the sequence of the beds. The formation occupies all the southern half of the city of Denison and an east-west belt of country about 4 miles wide adjacent thereto, resting upon the top of the Comanche series, as previously described.

The base of the Dexter sands may be seen in the south half of Denison, resting on the beds of the Comanche series.[1] The lower portion of the Lewisville or upper sands makes the summits of the Iron Ore Knobs the highest point between Denison and Sherman. The continuity of the section is broken at Cook Spring by the Cook Spring

[1] This contact is the Grayson marls south of the Pawpaw in southeast Denison; the Main Street limestone in southwest Denison.

fault, the downthrow of which is estimated by Taff at 200 feet near Pottsboro, just west of the section line. The uppermost beds outcrop on the downthrown side of the fault, but may be seen to better advantage near Whitesboro, in the western part of the county.

At Denison the base of the section apparently consists of sands resting upon the Main Street limestone, but at a few favorable localities, where the ferruginous débris obscuring the parting has been removed by erosion, it is revealed that the clay beds of the Grayson marls occur between these formations.

In a run on the south side of Choctaw Creek, 2 miles east of the Denison and Bonham road, the contact of the Woodbine formation and Grayson marl is exposed. At this locality the purplish-blue lignitic contact clays at the base of the Woodbine formation have a thickness of nearly 20 feet. The clay is finely laminated and is impregnated with finely comminuted carbonaceous matter. Toward the upper edge the clay becomes sandy and then verges into extensively false-bedded sandstone, which in part is very ferruginous and contains siliceous iron-ore concretions. The basal greenish-blue lignitic clays are not known to contain any fossils except lignite.

Deep cuts in the southern part of the city of Denison, especially one situated 1½ miles southwest thereof, on the Missouri, Kansas and Texas road, show thick strata of white sand through which iron in solution has permeated, cementing it in many places. In these, or rather near their surfaces, are many bands of loosely segregated brown siliceous iron-ore strata. This formation, which corresponds to the Dexter sands, continues to 3 miles south of Denison. Four miles south of Denison these strata are very thick.

Above the Dexter sands from 3 to 5 miles south of Denison are splendid exposures of the sandy laminated clays which may be considered the base of the Lewisville beds. These clays are marly on weathering and show yellow and purplish colors, with much gypsum in places. Sometimes the clay bands are white. In the upper part of the clays on the summit of a hill one-half of a mile north of Cook Spring, on a crossroad between the new and old highways between Denison and Sherman, there are ferruginous iron-ore bands which make the protecting caps of the hills. These contain *Aguileria cumminsi* White and other fossils of the Lewisville beds as found at Lewisville, Denton County, in the Denton-Lewisville section. Not having had an opportunity to measure the altitude of this hill, which is probably from 200 to 300 feet above Denison, the writer can only estimate these beds as having a thickness of about 100 feet.

South of the knobs capped by the fossiliferous Lewisville beds the normally overlying *Ostrea soleniscus* zone drops down a hundred feet below them, and by a series of step faults the top of the Eagle Ford clays is brought down opposite the latter, as shown in the following section:

SECTION NO. 42.—SECTION SOUTH OF COOK SPRING FAULT, BETWEEN DENISON AND SHERMAN, GRAYSON COUNTY, TEXAS.

	Thickness.	Total depth to bottom of stratum.
Austin chalk:	*Feet.*	*Feet.*
High, black waxy prairie, representing the base of the Austin chalk, only a few feet of the weathered edge of which is seen, the summit of which is faulted down to the level of the *A. cumminsi* zone capping the iron-ore hills	±10	10
Eagle Ford formation:		
Black clays with *Ostrea lugubris* and sharks' teeth	±20	30
Black shales	±30	60
North of this fault and abutting against the foregoing the section shows as follows:		
Woodbine formation—		
Yellow decomposing bands of limestone in beds of 6 inches, alternating with shales containing *Cyprimea*, *Ostrea soleniscus*, *Arca*, and *Exogyra columbella*	30	90
Ferruginous sands.		

In the Red River region east of Grayson County studies thus far made have not resulted in any definite idea of the sequence of the beds, and their thickness here can only be approximated by studying the Paris well section. The Red River flows for miles upon this formation, and an undermining bluff now and then reveals a little of its substructure. Its outcrop is so unconsolidated and is so densely covered with timber and old alluvial deposits that its interpretation would be a labor of years.

In this general region the beds are found adjacent to the Red River Valley, nearly to Red River County, outcropping in various undermining bluffs, such as Sowells Bluff in Fannin County and Arthurs Bluff of Red River, north of Maris. At the latter place the formation consists of laminated clays and sands, the clays predominating. This locality is especially interesting on account of the numerous plant remains, a list of which is elsewhere given (pp. 314–318). In this region the upper sandy beds also pass so imperceptibly into the Eagle Ford clays that the boundary can only be approximated.

A section line drawn north and south through Paris and Arthurs on Red River shows many outcrops of the Woodbine formation. On the north side of the river, at the outer edge of its valley, there is a narrow belt of the forested sands. At Arthurs good exposures of sandy clays are seen in the immediate river bluff. The formation is greatly obscured along this section by old river alluvium, and its differentiation is exceedingly difficult.

At Pine Bluff, on Red River, in the northeast corner of Lamar County, there is an undermining bank on the south side about 50 feet high vertically with a summit slope of 50 feet more. At the base of this bluff is an arenaceous-ferruginous shale containing occasional nodules with fossils and leaf impressions. About 25 feet above the base there is a lignitic layer with fragments of wood. This subdivision is about 38 feet in thickness. Above this, making a summit rock of the bluff, is a 12-foot stratum of greensand, which oxidizes rapidly into siliceous iron ore. In the lower portion of this greensand there are traces of a very fine siliceous pebble and rolled-clay lumps. A fossil ammonite (*Scaphites?*) and a crab were found at the base of this greensand, attached to a log of lignite. The slope at the top of the bluff consists of clays with fossil *Arinea* and *Scaphites*.

Section No. 43.—Exposure of the Woodbine formation at Rock Ford of Red River, Lamar County, Texas.

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
River bluffs: Several layers, in all about 4 feet thick, of white fossiliferous limestone	33	33
Land Slip, river bluff: Two beds, each about 1½ feet thick, of soft, crumbling glauconitic sandstone. Above this is a yellowish glauconitic sand	20	53
At base in bed of river: Dark, fine-grained sand, weathering yellowish and in joints yellow	10	63

The most eastern outcrop of the Woodbine formation is in southwestern Arkansas, at Morris Ferry, on Little River, where a single exposure, as described by the writer,[1] occurs in a forested wilderness of alluvial deposits.

The foregoing outline of the Woodbine formation having been presented, it is necessary, owing to their intimate relation to the artesian-water conditions, to give more explicit details concerning the Dexter and Lewisville subformations.

DEXTER SANDS.[2]

GENERAL CHARACTER AND LITHOLOGIC FEATURES.

The Dexter sands are an extensive deposit of brown and yellow ferruginous sandstone heavily laden with silicious ironstone. These sands are the lower, best, and most important water-bearing horizon

[1] Bull Geol. Soc. Am., Vol. V, 1894, p. 312.

[2] Basal clays and Dexter sands of Taff.

of the Woodbine artesian system, and hence must be described somewhat fully.

The Dexter sands form the most conspicuous portion of the Woodbine formation north of Johnson County, but are subordinate to the Lewisville beds south of that locality. They may be traced across Tarrant, Denton, and Cooke counties to Red River by the line of ferruginous knobs previously mentioned.

In lithologic character they are excessively cross bedded, and vary locally, being in general thicker and more purely arenaceous to the north. They may or may not be accompanied by clays in their lower portion. Massive false beds of sand are observed succeeding much of the lower and occasionally the upper portion of the Dexter sands. Generally the individual strata grow thinner from the base of the Dexter beds upward, and very near the upper limit lens-like, hard segregations occur. Some of these are nearly globular, while others are nearly flat, and they range in size from small lenses to masses 6 to 10 feet in diameter. They occur also in the lower part of the Lewisville beds.

CONFUSION CONCERNING THE BASE OF THE BEDS.

There is still some obscurity concerning the exact nature of the base of the Woodbine formation, due to the unsatisfactory character of the contact exposure. Taff is of the opinion that the basal beds are usually a clay formation, and his contention seems tenable, at least for the region between Trinity and Red rivers. Complete exposures of this basal clay have not been seen. Its thickness is estimated at 10 to 15 feet. It is believed to vary locally in thickness, structure, and lithologic character, however, and in support of this conclusion the following data are presented by Taff: In Denton County, along the Dallas and Wichita Railway, southeast from Denton, 10 to 15 feet of thin ferruginous sand and arenaceous sandy clay occur at the base of the Woodbine, which is succeeded by the heavy sands of the Dexter beds. In the town of Denton blue and dark-brown arenaceous clay, ferruginous sands, and sandy clays form the basal clay bed of the Woodbine formation in contact with the Lower Cretaceous. An earthenware factory is established at the southeast corner of the town, where a dark-blue to gray clay is obtained which is considered to belong to this bed, and from the clay from the pit a fair grade of earthenware is produced. At the east border of Denton Creek Valley, between the Missouri, Kansas and Texas Railway and the mouth of Isle du Bois Creek, purplish-blue sandy clay of the basal clay bed was observed at intervals beneath the heavy ferruginous sands, but the contact rock between the Comanche series and Woodbine parting was not seen.

There are other contacts noted by Taff and observed by the writer which lead to the conclusion that the basal clay is not a persistent feature, but becomes more arenaceous and lignitic in places. For instance, Taff notes that the sand rests upon the Grayson marl at a point 6 miles southeast of Gainesville, at the north line of the William Campbell survey, apparently without an interposed stratum of clay. With this exception the basal stratum of the Woodbine was not seen exposed in Cooke County. In many places the Main Street limestone was observed projecting from the surface with weathering Woodbine sandstone falling over. In a branch of Rock Creek 1 mile south of the Rock Creek road crossing the contact with the Grayson marl and the Woodbine sand is well exposed. Here the lignitic sandy clay of the Woodbine rests upon the blue limestone of the Main Street in apparently parallel strata. The lignitic sandy clay of the Woodbine is 10 to 15 feet thick and is succeeded by massive false stratified beds of brown and yellow sandstone.

In a tributary of Rock Creek near the west line of the John Brown survey, in northwest Grayson County, lignitic sandy clays occur in contact with the Grayson marl. The lignitic clay contains thin seams of lignite and lignitic sand and lignitized wood débris, which gives it the appearance of a lagoon or swamp deposit. The lignitic clay is 10 to 15 feet thick and is succeeded by massive beds of yellow and brown sand, interstratified with occasional lenticular deposits of blue and black clays.

The basal contact beds of the Woodbine formation are well shown in the bluffs of a small creek one-fourth of a mile southwest of Cedar Mills, Grayson County (see section No. 44, p. 307). Here a band of greenish-blue clays 15 inches thick occurs between massive yellow Woodbine sand and Grayson marl of the Comanche series, in apparent conformability. This clay produced no fossils, and, as a similar clay is exposed in a run at the south side of Cedar Mills unconformable with the Main Street limestone beneath similar yellow sand, it was considered to belong to the Woodbine formation.

Ten feet of greenish-yellow to yellow massive friable sand succeed the basal greenish-blue clays in the bluff one-fourth mile northwest of Cedar Mills, which sand is in turn succeeded by 10 feet of purplish-blue lignitic clays interstratified with thin bands of sand. The lignitic clay is overlain by nearly 15 feet of friable yellow sand. In the bluffs of the run at the south side of Cedar Mills the greenish clays and sands cited above are observed to rest in contact with successive strata of Main Street limestone and marl within a range of 50 feet, but at no locality observed had the Main Street limestone been completely removed prior to the deposition of the Dakota sediments. The successive strata of the basal Woodbine beds occur here as in the bluff one-fourth mile northwest of Cedar Mills. No débris of Lower Cretaceous rock or derived fossils were found in the contact strata of the Woodbine.

In the bluff of Big Mineral Creek, at the bridge 1 mile east of Cedar Mills, exposures occur bearing the Main Street limestone with more than 100 feet of basal Woodbine strata. The greenish-blue contact clay is here not more than 4 inches thick, and is overlain by nearly 100 feet of brown and yellow sand interspersed with few layers of blue and whitish sandy clays. Ironstone and thick, dark-brown and red ferruginous sandstone occur in the upper portion of the Dexter sand at this locality.

In the bluffs of a small creek at the north line of the Joseph Strickling survey, SSE. of Bounds Ferry, Grayson County, blue clay rests upon Grayson marl, as at Cedar Mills. Yellow and white sandy clay and sand continue above the clay. Ferruginous sandstone, with much ironstone, occurs higher in the sandstone strata.

EXTENT AND DETAILS OF OCCURRENCE.

East of Fort Worth, between a point about 2 miles west of Handley Station and Arlington Station, the Dexter sand occurs, and the formation does not differ materially from the same beds as they occur in the Cleburne section—thick beds of soft sands, for the most part interstratified with varying and minor beds of clay. Near the base there are considerable quantities of indurated ferruginous sands and nodular ironstone. In the main the sands are porous and are admirably suited for absorbing and transmitting water.

In Denton County, along the line of the Dallas and Wichita Railway, the Dexter sands have an estimated total thickness of 300 feet (see section *C* on Pl. XIX). They consist of heavy-bedded red ferruginous sand, with many sandy ironstone concretions and nodules, and brown sandstones with very large indurated calcareous sandstone lenses in the upper strata. In this section the Dexter sands continue with outcrops at intervals southeastward along the Dallas and Wichita Railway to the north side of Hickory Creek Valley, one-half mile from the creek. They also form rugged bluffs on Hickory Creek southeast of Alton. The rocks as they occur at the surface in railway cuts one-half mile and 1½ miles southeast of Denton are dark-brown, orange-yellow, compact and friable sands. In places they are heavily charged with iron. Gnarled segregations and nodular iron concretions are of common occurrence.

The Dexter sands crop out in the bluffs of Big Elm Creek between Denton and Lloyd, and continue northward from Big Elm Creek, forming at this locality and along the eastern border of the creek valley to the mouth of Isle du Bois Creek a prominent ridge, its western face strewn with dark ferruginous sandstones and iron-ore concretions. Indian Creek, from the Texas and Pacific Railway to its mouth in southwest Cooke County, flows in the center of the outcrop of this sand.

The sand extends northward by way of Woodbine, Callisburg, and Dexter, with its peculiar surface characters—a loose, broken, sandy, forest-clad country with much ferruginous sandstone and siliceous ironstone concretions. Between Callisburg and Dexter the strike of the outcropping sand turns east from a nearly north line.

The Dexter sands are finely exposed in fragmental outcrops of the east-west belt in Grayson County, but their continuity is so broken by faulting that their occurrence is difficult to explain. The main north-south belt terminates at Red River along the line of Cooke and Grayson counties. From this a belt of outcrops projects to the eastward, as previously mentioned, through Grayson County, constituting the belt of iron-ore knobs found between Denison and Sherman.

From Dexter the strike bears due east, and the sand presents many exposures and forms rugged "sand roughs" along the border of Red River Valley north of Cedar Mills to Old Georgetown north of Pottsboro. The rocks crop out in the bluffs of Big Mineral Creek at many places between a point due east of Gordonville and the bridge east of Cedar Mills.

On Hickory and Big Mineral creeks the heavy ferruginous Dexter sandstones also continue below to the base of the Woodbine, with the exception of thin irregular bands of clay interstratified and at the base of the formation. In places the sandstone occurs in false beds, with interstratified lenses and wedges of blue and black clay, which present clear indications of contemporaneous deposition and erosion. The lower 100 feet of the sandstone is ferruginous and contains much dark-brown indurated ferruginous sandstone and iron concretions.

The Dexter beds of Grayson County are a part of the middle or green sandstone group of Dr. G. G. Shumard's Tertiary system of Grayson County, but were so confused in his descriptions that his definitions are obscure. These rocks were supposed by him to be limited to the northwestern portion of the county, where sections of them are exposed nearly 50 feet in thickness. They also occur in the southern part of Denison, as will be shown later. The best sections of these strata described by him are exhibited along Walnut and Cedar creeks, these streams having cut through the formation to the depth of 40 or 50 feet.

The principal rocks consist of sandstone and clay. The sandstone varies somewhat in character, being both soft and hard and massive and thin bedded, or even schistose. Its color is usually white or green, from which it passes into various shades of red, yellow, and brown. It is composed of coarse quartzose grains cemented by siliceous and calcareous matter. In some instances the percentage of lime is very large, in which case the quartzose grains are usually distinct.

The following partial section of the Dexter sands in bluffs of a small creek one-fourth mile south of Cedar Mills, in Grayson County, illustrates the general character of the beds:[1]

SECTION NO. 44.—PARTIAL SECTION OF DEXTER SANDS IN BLUFFS OF SMALL CREEK ONE-FOURTH MILE SOUTH OF CEDAR MILLS, GRAYSON COUNTY, TEXAS.

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
4. Friable yellow sand	15	15
3. Purplish-blue lignitic clay interstratified with bands of sand.	10	25
2. Massive, friable, greenish-yellow to yellow sand	10	35
1. Greenish-blue clays	1.25	36.25

One and one-half miles northeast of Pottsboro the Dexter sand abruptly terminates and the prairie of the Eagle Ford clay joins that of the Fort Worth limestone and Denton marls. This abrupt termination is caused by the southwest downthrow of nearly 200 feet of the rock in the Cook Spring fault, which at this locality bears approximately N. 42° W. Two miles east of Pottsboro the Woodbine sand appears on the northeast side of the fault, and abuts abruptly against the fault line from a point due east of Pottsboro to Cook Spring on Iron Ore Creek, 6 miles north of Sherman. From the fault line here the Woodbine formation continues east, forming the timbered, rolling, sandy lands between Denison and Iron Ore Creek and between Denison and the Cook Spring fault 2 miles east of Pottsboro.

Extensive deposits of ferruginous sandstone and siliceous ironstone of the Dexter formation occur, forming in great measure the Pilot Knobs, northwest of Alchire Switch, 5 miles west of Denison. Iron Ore Creek below Moss Springs and Choctaw Creek from the mouth of Iron Ore Creek to the Denison and Bonham road flow over these sands, presenting them in the bluffs with all their variations in structure and lithologic characters.

The sands are best exposed in the southern portion of Denison and the adjacent country. Here they are probably over 100 feet thick and contain impressions of dicotyledonous plants.

The Dexter sands at Denison consist in their lower part of free white sand containing minute flakes of mica and numerous specks of glauconite. The latter, intensely oxidized at the surface, produces first a red and then a dark-brown color. The hydrated iron cements the more porous sand beds into firm siliceous iron ore. Excellent cuttings into these sands are seen along the grades of the Missouri, Kansas and Texas Railway and the dummy line in southwest Denison. The wells of the city waterworks are also sunk into these sands in

[1] J. A. Taft, Third Ann. Rept. Geol. Survey Texas, p. 295.

the southwestern suburbs. Thin layers of clay appear in the upper part, increasing in proportion relative to the sand in ascending order.

Fossil plants occur in a horizon of the Dexter sands at Denison between 20 and 150 feet above the base of the sands, fragments of these being found in the well at Mr. T. V. Munson's place, 1½ miles southwest of the station, and in a single stratum 12 or 18 inches thick located in a little hill between Texas street on the south and Hull street on the north, just north of Mr. A. H. Rhamey's house. A list of these plants is given on a subsequent page (p. 316). It is fully 2½ to 3 miles across the strike of these sands, which would give them a thickness of nearly 250 feet. Above the sands clay occurs in sufficient quantity to make the roads firm.

East of Grayson County the strike of the Dexter formation crosses Red River into southern Choctaw Nation, where it is well exposed near Yarnaby and Armstrong Academy. To the east its outcrops become lost in the vast veil of alluvial deposits, while no attempt has as yet been made to differentiate the members of the Woodbine formation.

The dips of the Dexter sands are altogether too obscure for the estimation of thickness. The false bedding is deceptive. Local disturbances occur also. For instance, on the Dallas and Wichita Railway 1½ miles southeast of Denton the bedding planes dip from 20° northwest to nearly an equal dip southeast within a stone's throw. The dip of the Lewisville beds along Timber Creek is also variable. However, an approximate estimate may be made by considering the dip of the strata in the formations in contact above and below. Putting the average of the Woodbine at 40 feet per mile (which is approximately the dip of the Comanche series below and of the Eagle Ford above), the thickness of the basal sand of the Woodbine approximates 160 feet. The general dip is ESE.

LEWISVILLE BEDS.[1]

CHARACTER AND COMPOSITION.

The Dexter sands are succeeded by from 50 to 100 feet of strata comprising the Lewisville beds. The latter are composed of laminated lignitic sands and sandy clays, interstratified with brown sands, ferruginous reddish-brown sandstone, shell sandstone, and argillaceous shelly sandstone which contains large lens-like calcareous concretions and laminated argillaceous sandstones at the top. Some of these are very calcareous, and, on account of the great number of shells of *Ostrea* and other mollusks, may be considered siliceous or argillaceous limestones. Silicified and lignitized wood is common in these strata.

The clays in the Lewisville beds are invariably laminated, and in the

[1] The typical Lewisville beds outcrop at the banks of Timber Creek just above a point due south of Lewisville, Denton County.

more arenaceous clays there are numerous very thin bands of sand. As a rule, the clays are blue on fresh exposure, but turn to mottled yellow as weathering proceeds. The structure varies markedly from stratum to stratum. Impure clays, sands, and sandy clays succeed one another with varying percentages, and interspersed are occasionally bands of very thin lignite, lignitic sandy clay, and silicified fragments of trees. A single bed of homogeneous rock rarely exceeds 5 feet.

These beds are characterized by the occurrence of a peculiar molluscan fauna, enumerated on page 314.

The Lewisville beds are not always covered by timber, but often underlie a considerable portion of what would be topographically classified as a part of the western border of the Eagle Ford Prairie. This makes a gently undulating prairie, with fine brown sandy clay soil. Four miles northwest of Gordonville and at Whitesboro, northwest Grayson County, this type of prairie may be seen. In southern Chickasaw Nation, just east of the lower course of the Washita and north of where it empties into Red River, there are extensive stretches of this type of prairie.

DESCRIPTION, BY TAFF, OF TYPICAL SECTION AT TIMBER CREEK.

Following is a description by Mr. Taff of the typical section of the Lewisville beds, called Timber Creek by him, along the line of the Dallas and Wichita Railway in Denton County:

One-half mile north of Hickory Creek, on the Dallas and Wichita Railway, lignitic sandy clays of the Timber Creek beds succeed the brown sandstone of the Dexter sand beds. The clay is black to purplish blue, and contains lenticular bands of argillaceous lignite, which is heavily charged with sulphate of iron, magnesian salt, and probably other soluble mineral salts. Wells located in the vicinity of the outcrop, and penetrating the bed, have their waters so heavily charged with these salts as to be unfit for use. The lignitic band varies from zero to 2 feet in thickness, and its inclosing clays, for several feet above and below, contain thin bands of sand and fragments of lignitized wood. These lignitic clays and sands crop out in Timber Creek southwest of Lewisville, 1 mile above the Lewisville and Shiloh road. Laminated brown and argillaceous sands and reddish sands succeed the lignitic bed with nearly 25 feet of strata, which crop out in the creek bluffs above the Lewisville and Shiloh road.

Near the base of the sandstone there is a thin band of *Ostrea carica*, and in the sand above this are fragments of both silicified and lignitized wood. Near the upper edge of the sandstone occurs a calcareous sand bed, 3 to 4 feet thick, which contains masses of *Ostrea soleniscus* and *Exogyra ferox*, and in the sandstone, 5 feet yet higher, there is a thin band of *Cerithium tramitensis*. The small *Ostrea carica*, which occurs immediately above the lignitic horizon, is present 2 to 3 feet beneath the *O. soleniscus* zone.

Continuing down Timber Creek for nearly a mile below the Lewisville-Shiloh road, calcareous indurated sandstone and brown sandstone, with large lens-like segregations, crop out almost continuously in the bluffs and base of the creek. *Exogyra ferox* and *O. soleniscus* fossils are especially abundant in these rocks.

Succeeding these hard layers there is a zone of moderately hard calcareous sand, 8 to 9 feet thick, with great numbers of *O. soleniscus*. Two or three feet below the upper edge of this zone there is an exceedingly fossiliferous calcareous sand, 6 to 8 inches thick, containing the following fossils: *Arca siouxensis*, *Modiola filisculpta*, *Arca galliennei* var. *tramitensis*, and *Turritella renouxiana*, besides other fossils undetermined. A portion of the strata above the horizon of *O. soleniscus* is concealed.

Succeeding this interval there is partially compact and calcareous and argillaceous sand, which includes a bed containing *Aguileria cumminsi*, with which are associated *Arca galliennei*, *Turritella renouxiana*, and other forms near the base. Immediately below the *Aguileria cumminsi* zone there is a calcareous sand bearing masses of *O. soleniscus* and a ledge containing *Cerithium tramitensis*.

Laminated and stratified calcareous and argillaceous sand and comparatively compact friable sand-bearing fragments of lignitized and silicified wood continue above the *Aguileria cumminsi* zone through a thickness of nearly 20 feet. Laminated blue clays succeed the above lignitic sand and sandy clays to an interval which conceals at this locality the parting between the Dakota and Eagle Ford formations. The final horizon in other sections is marked by the occurrence of *Exogyra columbella* Meek.

These beds, which underlie the coastward border of the Eastern Cross Timbers, are traceable just west of the interior border of the Eagle Ford Prairie from McLennan County northward to Red River, attaining greater and greater development toward the latter stream. The following partial section on Cottonwood Creek northwest of Hillsboro will give the character of the beds near their southern termination. This section is compiled by Taff from a series of connected sections near the top of the Timber Creek beds along Cottonwood Creek from Woodbury road near Osceola to within 1½ miles of the mouth of the creek.

SECTION No. 45.—COTTONWOOD CREEK SECTION, NORTHWEST OF HILLSBORO, SHOWING UPPER PART OF WOODBINE FORMATION.

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
13. Eagle Ford clay from the parting upward, few feet exposed.		
12. Pack sand	10	10
11. Clay and sand, alternating in thin bands	15	25
10. Sand and sandy clay, which bear great numbers of *Ostrea* and bivalves of the Timber Creek beds	6	31
9. Arenaceous clay, varying in thickness of layers and percentages of sand and clay	10	41
8. Slightly arenaceous laminated blue clay	10	51
7. Stratified pack sand	5	56
6. Arenaceous, laminated blue clay	4	60
5. Soft, false-bedded sandstone	8	68
4. Laminated sandstone	6	74
3. Laminated clay and sand, equal proportions	10	84
2. Very arenaceous, finely laminated clay	3	87
1. Soft pack sand.		

DISTRIBUTION AND OCCURRENCE.

From Alvarado southeastward along Chambers Creek the upper strata of the Lewisville beds outcrop, exposing rocks which vary but little from those in the vicinity of Alvarado, with the exception that the proportion of siliceous material is less.

One-half mile west of the Missouri, Kansas and Texas Railway, on the south fork of Chambers Creek, sandstones crop out, which contain Lewisville fossils in the greatest profusion, *Aguileria cumminsi* being especially numerous.

One-half mile below and also above Mansfield, Tarrant County, are exposures of lignitic, sandy, laminated, impure blue clays, interstratified with sands and indurated ferruginous yellow to red clay. Rocks having similar characters occur in Mill Creek south of Arlington, Tarrant County.

Sandstones and sandy clays of the Lewisville beds crop out in the banks and bed of Walnut Creek, 3 to 4 miles below Mansfield. The rock varies throughout from an argillaceous sand to a sandstone, and in the strata occur indurated calcareous shell sandstones, which bear great numbers of the Lewisville bed fossils, also present in the loosely compact argillaceous sandstone.

On Walnut Creek, 5 miles northeast of Mansfield, Tarrant County, near where the parting between the Woodbine and Eagle Ford formations cross Walnut Creek, numerous Lewisville fossils—*Aguileria cumminsi*, etc.—occur near the base in compact calcareous sandstone. The same kind of sandstone continues downward beneath the bed of the creek.

The Lewisville beds crop out in the banks and bluffs of Timber Creek above a point due south of Lewisville, Denton County, with the slaty blue laminated clays of the Eagle Ford above them. This succession, which has been more fully described on page 310, may also be seen on the same creek above the Lewisville and Dallas road crossing.

Lignitic sandy clays and calcareous and shell sandstones of the Lewisville bed crop out between Big Elm and Little Elm creeks 2 miles SSW. and 4 miles SSE. of Lloyd; also along the east side of Little Elm Creek Valley east of Lloyd. The *Ostrea soleniscus* zone is especially prominent at these localities. A part of the bed containing this fossil is composed of masses of *Ostrea* shells. The lignitic sandy clays and sands, with bands of lignite, from very thin sheets to beds 1 foot thick, occur 2 miles SSW. of Lloyd, with the same characters and in the same relations to the beds above and below as on Timber Creek.

From the vicinity of Lloyd, Denton County, the Lewisville beds continue nearly due north through western Grayson County, between Collinsville and Ethel, by way of Whitesboro to the vicinity of Gordonville, Grayson County. Between Lloyd and Whitesboro these rocks are rarely seen at the surface, the country being smooth, gently rolling, and covered by a heavy residual soil. Occasional low bluffs expose the upper strata of sandstone and sandy clays along Hog Creek west of Ethel. The shallow wells in the west side of the valley of Hog Creek deriving their supply from these sands have their waters heavily charged with magnesian salts.

As the Lewisville beds are traced northward they vary in the character of the materials entering into their composition. The amount of sand contained in them grows less, until in the vicinity of Gordonville and in the valley of Big Mineral Creek the clay is more abundant than the sand.

At the 6-mile post north of Whitesboro casts of Lewisville fossils are found. They continue westward to within 15 miles of Gainesville. The beds here form glady prairies in cross timbers. One and one-half miles east of Sandusky (7½ miles north of Whitesboro) iron-ore casts of fossils are found.

In northwestern and north-central Grayson County these beds have extensive development, notably in the sandy prairies around Gordonville and Whitesboro and on the summit of the knobs south of Denison. The Lewisville beds on Hickory and Big Mineral creeks, Grayson County, increase in thickness to extensive deposits of sandy clays with local seams of lignite, the relative amount of sand having decreased, and are surmounted by a greenish-gray sandstone stratum bearing *Exogyra columbella* of Meek.

The lignitic clays of the Lewisville beds underlie a rather extensive area of prairie land north of Gordonville, and crop out in the bluffs of Walnut Creek north, in Brushy Creek southwest, and in Big Mineral Creek east of Gordonville.

The clay is dark blue and the sandy clays are brown, in the central portion of which thin layers of an impure lignite occur. A single bed of this, 3½ feet thick, crops out in a run nearly a mile east of Big Mineral Creek, between Gordonville and Pottsboro, and similar layers occur at the surface in Walnut Creek, north of Gordonville. From the vicinity of Gordonville the strike of the Lewisville beds bears nearly directly east. The upper stratum passes through Martin Springs, but elsewhere in the vicinity of Martin Springs or Pottsboro the beds are concealed by the heavy residual soil.

Where the Lewisville beds crop out at the border of the Red River Basin in Grayson County, on Hickory and Big Mineral creeks, the lignitic sand and sandy clay at the base have increased to extensive deposits of sandy clays with local seams of lignite, some of which approximate a thickness of 2 to 3 feet. Here the relative amount of sand, as a whole, has decreased considerably, while the beds themselves have increased in thickness and terminate with a greenish-gray sandstone stratum bearing *Exogyra columbella* Meek.

The upper ferruginous group in Grayson County, as described by

G. G. Shumard, corresponds to the Lewisville beds. According to him it is composed of strata variable in character, being in some places rather hard and firm and in others rather soft—but little firmer than loosely coherent sand. These strata as exposed in Iron Ore Knob were given a thickness of 150 feet. The summits of these knobs owe their existence to the protective cap of indurated ferruginous sandstones, containing the typical Lewisville fossils. The strata usually occur in massive beds, and the divisional lines between them are indistinct and often not at all visible. Shumard also found this formation upon the summits of the hills in the northwestern portion of the county.

Section No. 46.—Section by Dr. G. G. Shumard, of the bank of Iron Ore Creek, at a point where the creek cut through a portion of Iron Ore Ridge, Texas.

	Thickness.	Total depth to bottom of stratum.
	Feet.	*Feet.*
8. Hard, blue and yellow, fine-grained, glistening, calcareo-siliceous sandstone, when freshly fractured blue, but turning yellow on exposure	30	30
7. Soft, rapidly crumbling, fine-grained, yellow siliceous sandstone	10	40
6. Fossiliferous band composed of *Ostrea* cemented with calcareo-siliceous matter	3	43
5. Soft, fine-grained, yellow, rapidly crumbling sandstone, with fossils near the base	15	58
4. Indurated blue and yellow clay with selenite	5	63
3. Lignite	3	66
2. Indurated blue clay with selenite and lignite in small particles	5	71
1. Soft yellow clay with fossils	5	76

The Cook Spring fault throws the Lewisville beds beneath the surface southeast of Pottsboro. At Moss Springs, on Iron Ore Creek, 6 miles north of Sherman, where the Cook Spring fault crosses the creek, the upper strata of the Lewisville beds, on the south side of the fault, abut against the upper strata of the sands. Three-fourths of a mile below Moss Springs the *Ostrea soleniscus* zone of the Lewisville beds crops out in a high bluff of Iron Ore Creek. The fossils occur here in a massive sandstone 6 to 10 feet thick.

PALEONTOLOGY OF WOODBINE FORMATION.

The Woodbine formation of the East-Central Texas Province is of extraordinary interest geologically, because it contains by far the most complete molluscan fauna ever found in the alleged Dakota formation. This fauna, appropriate to its position, is certainly unique, differing entirely from the forms of the underlying Comanche or overlying

Eagle Ford. The following molluscan fossils have been found by various persons in the Lewisville beds of the Woodbine formation of northern Texas:

Barbatia micronema (Meek).
Arca galliennei var. tramatensis Cragin.
Ostrea soleniscus Meek.
Modiola filisculpta Cragin.
Aguileria cumminsi White.
Cytherea leveretti Cragin.
Trigonarca siouxensis (Hall and Meek).
Turritella renauxiana d'Orbigny?
Cerithium tramatensis Cragin.
C. interlineatum Cragin.
Pteria salinensis White?
Natica humilis Cragin.
Nerita sp. Cragin.

None of these fossils occur in either the overlying Eagle Ford or the underlying Comanche series, and, so far as known, the fauna is the most peculiar yet found in beds occupying the typical Woodbine position.

The Woodbine formation also contains fossil plants of the Dakota type.[1] The writer has collected them from Denison and Arthurs Bluff on Red River, north of Paris. A small collection has been also made at Woodbine, Cooke County, by Mr. G. H. Ragsdale. These collections were all turned over for examination to Prof. F. H. Knowlton, whose reports upon them are given below.

Reports by Prof. F. H. Knowlton.

Fossil Plants from Arthurs Bluff of Red River, Lamar County, Texas, collected in 1894 by T. Wayland Vaughan.

The matrix in which this material is preserved is very sandy clay, passing into a loose, friable sandstone. It is not well fitted to hold organic remains, and as a consequence hardly one of the plants is entirely preserved. This fragmentary condition makes a number of determinations doubtful. My examination shows the following results:

Salix deleta Lx.

Found before only at Pipe Creek, Cloud County, Kansas.

Myrica longa (Heer) Lx. (see Pl. XXXIX, fig. 7).

Found in Greenland and in Ellsworth County, Kansas.

Platanus primæva Lx.

This consists of a number of flower leaves that agree with the figures of this species given by Lesquereux. No leaves or fragments were found that could belong to *Platanus*. The species is common in the Dakota of Kansas.

Ficus glascoeana ? Lx.

There are a number of leaves that I refer with some hesitation to this form. They are somewhat smaller, but appear to agree in variation. Found originally near Glascoe, Kansas.

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[1] Dr. G. G. Shumard first collected the plants from these beds, which he sent to his brother, Dr. B. F. Shumard, who announced their discovery in Trans. St. Louis Acad. Sci., Vol. II, 1868, p. 140. The latter stated that he had sent the plants to Dr. Lesquereux for determination, but Lesquereux says (Rept. U. S. Geol. and Geog. Survey Terr., Vol. VI, Cretaceous Floras) that they were never received. Dr. B. F. Shumard gave these beds no place in his geologic section.

In 1885 the writer revisited Dr. Shumard's locality near Denison, and was so fortunate as to determine their stratigraphic position to be above the Washita, and to collect a good representation of the species, which was deposited in the National Museum. This collection having been lost in storage, the writer has several times endeavored to find more of the plants at Denison, but without success. Recently, however, Mr. T. V. Munson succeeded in securing some specimens, which he kindly sent to the writer.

PLATE XXXIX.

PLATE XXXIX.

Fossil Plants from the Woodbine Formation.

Fig. 1. Diospyros steenstrupi ? Heer.
Fig. 2. Lindera venusta Lesq.
Fig. 3. Diospyros primæva Lesq.
Fig. 4. Andromeda pfaffiana Heer.
Fig. 5. Cinnamomum heerii Lesq.
Fig. 6. Salix hayei Lesq.
Fig. 7. Myrica longa Lesq.

FOSSIL PLANTS FROM THE WOODBINE FORMATION.

1. Diospyros steenstrupi ? Heer.
2. Lindera venusta Lesq
3. Diospyros primæva Heer.
4. Andromeda Pfaffiana Heer.
5. Cinnamomum Heeri Lesq.
6. Salix Hayei Lesq.
7. Myrica longa Heer.

Lindera venusta Lx. (see Pl. XXXIX, fig. 2).

Only a single leaf, yet it must be this species, which was before known only from Ellsworth County, Kansas.

Diospyros primæva Heer (see Pl. XXXIX, fig. 3).

A common Dakota plant. Represented by a single broken and more or less doubtful leaf.

Viburnum robustum Lx.

Represented by a single nearly perfect leaf. The species was known before from Ellsworth County, Kansas.

Aralia wellingtoniana Lx., n. var. vaughanii.

This is the most abundant form in the collection, and the best preserved. It approaches closely to the type, but seems to differ uniformly in being always three lobed, with more slender and entire lobes. There are other minor differences which entitle it certainly to varietal and possibly to specific rank. The type is from Ellsworth County, Kansas.

Sapindus morrisoni ? Lx.

A number of doubtful fragments. The species comes from Morrison, Colorado, and Cloud County, Kansas.

Liriodendron pinnatifidum ? Lx.

A mere fragment, with the venation and, as far as can be determined, the outline of this species. It was known before from Kansas.

Liriodendron snowii Lx.

Only a fragment, but it is very characteristic and is undoubtedly this species. It was before known only from Ellsworth County, Kansas.

Phyllites rhomboideus Lx.

Represented by a single broken example, which seems to be this species. It has also resemblance to *Hedera*, *Paliurus*, etc., and may represent a new species. It was described originally from Decatur, Nebraska.

Besides the above-enumerated species there are a number of more or less fragmentary specimens that I have not been able to determine with satisfaction. They seem to belong to the genera *Ficus*, *Eucalyptus*, *Aralia*, etc., and may represent new species.

The species that I have been able to identify all belong to the Dakota group; that is to say, they have heretofore come only from strata known in the broadest sense as the Dakota group.

DAKOTA PLANTS FROM WOODBINE, COOKE COUNTY, TEXAS, COLLECTED BY THE LATE G. H. RAGSDALE, OF GAINESVILLE.

The material is very scanty, and only fills a small cigar box. It is a typical hard brown sandstone, and, while none of the leaves are absolutely perfect, it shows that good material could be obtained if time were devoted to collecting at that locality.

I have identified the following species:

Andromeda pfaffiana Heer (see Pl. XXXIX, fig. 4).

Eugenia primæva Lx.

Diospyros primæva Heer.

This is a common Dakota group plant, and was also found in the Arthurs Bluff material.

Cinnamomum ellipsoideum Sap. and Mar.

A perfect leaf, except a portion of one side. Its identification is absolute.

Cinnamomum n. sp. ?

Two or three small fragments that do not seem to belong to any described species.

Phyllites aristolochiæformis ? Lx.

These species are all of the Dakota group, and it is of course interesting to find them in new localities.

REPORT ON SMALL COLLECTION OF FOSSIL PLANTS FROM RHAMEYS HILL, DENISON, TEXAS, COLLECTED BY MR. T. V. MUNSON, OF DENISON.

The material, which consists of about twenty pieces of matrix, is preserved in a coarse-grained, brown sandstone. Two localities are represented. They are as follows:

"MUNSON HILL: S. E. of house next Fannin ave."

This material embraces four pieces of matrix. The leaves preserved on them are so fragmentary that is is quite impossible to make out even the genera represented. They are undoubtedly dicotyledonous, but beyond this it is not possible to go.

"RHAMEY HILL."

The remainder of the material belongs to this locality, and shows beautifully preserved and very perfect leaves. I have been able to identify the following species:

Diospyros steenstrupi Heer (see Pl. XXXIX, fig. 1).
Cinnamomum heerii Lx.
Inga cretacea Lx.
Magnolia speciosa Heer.
Magnolia boulayana Lx.
Liquidambar integrifolium Lx.
Laurus proteæfolium Lx.
Sabi sp.?
Populus sp.?

These species all belong to the flora of the Dakota group as that formation is usually understood. Of the seven species identified, three—*Diospyros steenstrupi*, *Inga cretacea*, and *Magnolia boulayana*—have not before been reported outside of the State of Kansas, at least in this country. Two or three of the others have also been found in Kansas, but are not confined to that locality.

RELATION OF WOODBINE FORMATION TO DAKOTA EPOCH.

THE TERM "DAKOTA," ITS ORIGIN, DEFINITION, AND APPLICATION.

Although the term Dakota has been frequently applied to the Cretaceous formations in western United States which are nearly related to the Woodbine formation, the writer has thus far refrained in this paper from associating that term with the latter. His reasons for this have been due to the fact that the limitations of the sediments of the Dakota epoch, as based upon observations of its occurrence elsewhere, have never been definitely known, and it is only in the light of the Texas section herein described that these limitations can be fixed.

The term "Dakota group" was first used by Prof. F. B. Meek in his description of the Meek and Hayden section of the Cretaceous of Nebraska Territory, a section which has become classic in American geologic literature.[1] The name was first applied to a formation which these geologists had previously called "No. 1," in "a section of the members of the Cretaceous formation on the Missouri and thence westward to the Mauvaises Terres, as the result of an expedition by Mr. Meek and Dr. Hayden, sent by Prof. James Hall to the uplands of Nebraska Territory and published in the Memoirs of the American Academy of Arts and Sciences at Boston, Vol. V, in 1856." According

[1] Meek, U.S. Geol. and Geog. Survey Terr., Vol. IX, 1870, p. xxiii.

to Meek[1] "this was the first section showing all the various members in the order of their succession in the undoubted marine Cretaceous series of the Upper Missouri, occupying the space between the well-marked Tertiary above and Carboniferous below." In Vol. IX of the Hayden Survey, two plates of fossils (pls. 1 and 2) were published from the alleged Dakota formation, one of which was from the typical locality above given and the other from Salina, Kansas. These two plates are now known to represent fossils from two entirely distinct formations, the first representing the fauna of the typical Dakota locality in Nebraska, the other the fauna of the Denison beds of the Comanche series in Kansas. Thus it will be seen that the author of the term "Dakota formation" himself included within it the equivalent of at least two distinct, unrelated formations and faunas of the Texas section.

From the original definition of the term Dakota group it is seen that its beds are genetically a part of the general sedimentation of the Upper Cretaceous series, passing by conformable gradation into the beds of the overlying Colorado division. Furthermore, the name as originally defined and as it was afterwards extensively applied was supposed to include in the Dakota formation all the basal Cretaceous formations prior to the Benton subepoch, the existence in America of the Comanche series not then being known.

At most places where it has been found the Dakota rests unconformably on beds of Permian and Carboniferous age. Nowhere outside of the Greater Texas region were its basal relations with previous Cretaceous formations ascertained; hence the question of its further downward limitations or basal relations with the Lower Cretaceous formations has never been considered, although the term has become fixed and widely used in nomenclature. In fact, not until the study of the Texas sections could be presented has it been possible to define the basal limits of the formation and epoch.

Since the original studies of Mr. Meek numerous writers have reported the discovery and occurrence of the Dakota formation in various localities of the far West; White, Stevenson, Stanton, Hicks, Snow, Williston, Weed, Hay, Gilbert, Peale, Powell, Aldrich, Cross, Emmons, and others have alluded to it throughout the Rocky Mountain and Great Plains region.

Where these pioneer writers saw the Dakota in Montana, Colorado, Utah, Wyoming, and the Plains region of New Mexico and southern Kansas its base apparently rested on pre-Cretaceous formations, and they had no data for fixing a definite lower boundary of the formation. Furthermore, the continuity of the formation between these localities has been so greatly interrupted by erosion and so overlapped by later formations that the relation of its parts, such as those of the widely

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[1] Meek, U. S. Geol. and Geog. Survey Terr., Vol. IX, 1870, p. xxiii.

separated Texas Great Plains and Rocky Mountains regions, have not been determined.

The beds of the alleged Dakota age have also unfortunately suffered great denudation in earlier Tertiary, Pleistocene, and recent epochs, so that only fragmentary areas of them are found, insufficient to demonstrate whether they once formed a continuous sheet of sediments or a series of unassociated contemporaneous deposits. It is very probable that the greater portion of them, including those of the Great Plains region, the Atlantic coastal region, and the eastern Rocky Mountain front south of Wyoming, represented a continuous basement littoral of Atlantic sedimentation, although some of them may have been land made synchronously with this littoral as the result of local lacustral conditions, especially in the nucleal Cordilleran region.

In the determination that formations of these widely separated localities were Dakota, great importance was given to the identity of the dicotyledonous plants, which had been studied principally by Professor Lesquereux. Although this eminent savant, in his admirable treatise on the Dakota group, also clearly showed that much yet remained to be ascertained about the horizons of these plants, subsequent events have shown that the exact range and occurrence of the fossil plants called Dakota had not been sufficiently determined to justify minute stratigraphic correlation of widely separated beds, though the writer does believe that when the exact horizons of the many plants of the so-called Dakota flora are ascertained such correlation may become possible. So fixed had become the conception of this flora as indicative of the Dakota formation, although the apparent suddenness of its appearance was inconsistent with the laws of evolution, that to discover any of the well-known species of plants in any bed resulted in its reference to the Dakota formation.

We know that the littoral formation of the great arm of the sea which gradually encroached northward over the Great Plains region during Upper Cretaceous time was bordered on both sides by land upon which plant life flourished both before and after the Dakota period. The growth of plants on these land areas must have been continuous, and hence it is impossible to conceive that the rich dicotyledonous flora could have suddenly sprung into existence during Dakota time or could have been preserved in only this single time division of the Cretaceous. In other words, the entombment of plants must have progressed during all Cretaceous time along the marginal shore lines of the sea. If this be true, then we should have expected that future researches would have shown many lower plant-bearing horizons as the investigation of these marginal deposits progressed.

It has been lately shown by the writer,[1] with the aid of Prof. F. H. Knowlton's determinations, that many of the fossil plants hitherto

[1] Am. Jour. Sci., 3d ser., Vol. L., 1895, pp. 205–234.

relied upon to distinguish the Dakota formation begin in Kansas with the Washita division—far lower in the Cretaceous series than the base of what has hitherto been considered the Dakota formation, and hence they are no longer satisfactory independent criteria for determining exact stratigraphic position.

From the foregoing statements it is evident that deposits of alleged Dakota age have a wide distribution in the United States, but that, in view of the discovery of still lower formations and the downward range of Dakota plants into them, much remains to be done to fix the basal limit of the Dakota, as well as to determine many points concerning its mode of formation and correlation. Inasmuch as the term "Dakota" is applicable as a designation of time as well as of a formation, it is desirable that some criteria be established for its use in this connection.

In summarizing the data the following facts are evident:

1. That the original definition and description of the Dakota group was based upon a type locality, the Big Sioux River, where the earlier Cretaceous beds were not present. It was originally considered the base of the American Cretaceous system, and was supposed to rest exclusively on beds of pre-Cretaceous age.

2. That at the time of its original definition, before minute stratigraphic and paleontologic study had been sufficiently made, the formation as above defined was widely correlated throughout the Great Plains region north of Texas, in Kansas, Nebraska, and the Dakotas, and the Rocky Mountain and Atlantic coastal regions, with other isolated outcrops of arenaceous, ferruginous Cretaceous formations containing dicotyledonous leaves.

3. That in most of these localities the top of the Dakota, so called, has been sufficiently defined to prove that it passes upward conformably into the Colorado division as now accepted.

4. That subsequent discoveries of beds of Lower Cretaceous age in the north Rocky Mountain and Texas regions render it necessary to add to the original definition a boundary between it and the beds of Lower Cretaceous age discovered since its original definition.

5. That paleontologic criteria for recognition of the Dakota horizon by molluscan remains have hitherto been insufficient. Since these earlier studies the writer has shown that in southern Kansas the typical Dakota formation of Meek may be found resting on older marine Cretaceous deposits. He has also shown that by tracing the Dakota of the Rocky Mountain front down the valley of the Canadian it could be found in northeastern New Mexico resting on the undoubted uppermost horizon of the Comanche series. Investigations made in Montana have proved that lower formations were accidentally included with the Dakota group as originally used.

6. Finally, it has been shown that the most complete section of the

Cretaceous in North America, embracing an entire suite of separable beds extending from the Wealden to the Senonian, is to be found in central Texas. In this section the Woodbine formation contains not only the Dakota flora, but a unique molluscan fauna which occupies a position indicating Dakota time, resting on the uppermost beds of the Comanche series and lying beneath the Benton. Thus it stratigraphically satisfies the conditions of the Dakota formation and also occupies in fact the position to which Meek and Lesquereux had theoretically assigned the Dakota group—i. e., as the base of the Meek and Hayden Cretaceous section, probably corresponding, as they said, to the Cenomanian stage.

REASONS WHY THE WOODBINE FORMATION IS CONSIDERED TO OCCUPY THE DAKOTA TIME POSITION.

While preferring the local name, the writer believes the Woodbine formation of Texas is of Dakota age, for the following reasons:

1. It occupies the stratigraphic position of the Dakota. Like the Dakota of all the other regions, it lies beneath the beds of the Colorado division and continues up into them without stratigraphic break, and hence makes the base of the Upper Cretaceous series. It also lies unconformably above the rocks of the Lower Cretaceous with its well-defined characteristic and peculiar fauna, just as the Dakota of the other regions lies unconformably upon the beds of the Paleozoic, Trias, and Jura.

2. It contains the dicotyledonous flora which is elsewhere found in the Dakota formation, and which has been the only paleontologic criteria for its correlation.

3. It is of the same general lithologic aspect and maximum thickness—about 500 feet—as the Dakota, as seen throughout the Rocky Mountain and Great Plains regions.

4. In addition, it possesses a peculiar molluscan marine fauna, different from the faunas in the overlying Benton and underlying Denison beds.

Here, then, we have in continuous section in Texas, as nowhere else, a formation occupying the Dakota time position, clearly defined between the overlying Benton and underlying Washita division, of the typical lithologic character, containing the Dakota dicotyledonous flora and a unique marine molluscan fauna, which should serve as a standard for the study of the Dakota formation in America.

EAGLE FORD FORMATION.[1]

GENERAL CHARACTER AND LITHOLOGIC COMPOSITION.

In the region discussed in this paper this is essentially a bituminous clay formation, accompanied in places by thin laminated clay limestones and nodular septaria of blue limestone. These clays are notable in the Texas section, where the other clay formations are mostly of a marly nature by reason of their bituminous character, resembling the shales of the Cretaceous formations of the Rocky Mountain region and the northern part of the Great Plains. Dark-colored clays of this character, although prevalent in the Cretaceous formations of the Rocky Mountain region, are of exceptional occurrence in the Texas section, lighter colors usually prevailing. Hence the Eagle Ford formation, when compared to others of the region under discussion, is rather exceptional in this particular. Even these dark-blue clays become more calcareous in the upper layers and in the extension of the beds south of the Brazos, but north of that stream they form most of the medial and lower portion of the beds. From Dallas north the nodular septaria, locally called "turtles" or "niggerheads," are of large size and abundant. These have often proved obstacles in well drilling. Portions of these shales are feebly oil bearing, as at Austin, Fiskville, and Waco, where frequently appreciable quantities of rock oil appear upon the surface of the waters. In age these beds are identical with the Benton formation of the Meek and Hayden section.

GENERAL OCCURRENCE.

The Eagle Ford clays occur in a north-south belt which underlies the Eagle Ford Prairie and are coincident in extent with that topographic feature, as shown on the maps and elsewhere described in this paper. They also have considerable extent in the Red River counties, as seen in an east-west belt from Bells, Grayson County, east to the eastern part of Lamar. In the latter region good exposures are so few that it is almost impossible accurately to delineate the details of extent and thickness.

Like the Woodbine formation, the Eagle Ford has its chief and greatest development northward, gradually decreasing in thickness to the south. Unlike the latter, its extent is continuous across the State. In the northern or Red River section, where this formation has its greatest development, it is of the character above described, consisting primarily of blue and black laminated bituminous clays, accompanied in places by large septaria and occasional thin, arenaceous laminæ. Southward they become thinner, more marly, and more arenaceous.

In the northern area, as far south as the Brazos, these clays succeed the Dakota by gradual transition. The upper beds of the Dakota pass

[1] See Pl. XVIII, *C*; Pl. XIX, *D*; and Pl. XX, *G*.

from sands into sandy clays and then into the noncalcareous papyraceous clays of the Eagle Ford formation. To the south, in Williamson County, as well as at all other points south of Bosque River where it has been observed, the Eagle Ford shale rests directly and perhaps unconformably upon the Buda limestone. The Eagle Ford beds are everywhere limited above by the white limestones of the Austin chalk, into which they pass rather abruptly.

In the Red River counties east of Grayson County the Eagle Ford formation underlies much of the black land belt north of the Transcontinental Railroad between Bells, Grayson County, and Paris, Lamar County. Garretts Bluff, in northeastern Fannin County, is composed of blue marly Eagle Ford shale, with hard concretions (septaria). Sowells Bluff, Fannin County, rises 135 feet above the river and consists of a sandy clay shale, with the Eagle Ford septaria occurring just below a sandstone. The characteristic Eagle Ford fossil here is *Buchiceras swallovi* Shumard (see Pl. XL, fig. 2). The beds of this locality represent the gradation of the Woodbine into the Eagle Ford formation.

In western Grayson County these beds also underlie an extensive belt of prairie in the southwestern portion of the county belonging to the main Texas area, as seen between Sherman and Whitesboro. From Whitesboro they extend south in a continuous belt through Grayson, Collin, Dallas, Hill, and McLennan counties to the Brazos and thence on intermittently to the Rio Grande via Moody, Belton, Round Rock, Austin, New Braunfels, San Antonio, and Spofford. The outcrops of this formation make extensive black waxy lands of the fertile Eagle Ford Black Prairie lying between the White Rock scarp and Eastern Cross Timbers as far south as the Brazos.

On Red River, in the Paris section, their thickness is estimated at 600 feet; in the Sherman section, 600 feet; in the Dallas section, about 480 to 500 feet; near Midlothian, 350 feet; in the Waco section, south of South Bosque, 200 feet; in the Austin section, 30 feet; on the Nueces, 200 feet.

In the counties of Dallas, Collin, and Grayson, where the beds have their greatest development, near Sherman, they show the following sequence: The lower portion is made up of very thin laminations of deep-blue or black clays with occasional laminæ of sand, passing upward into purer clays locally containing irregular bands of thin calcareous matter and ferruginous clay nodules. This clay is usually highly indurated and of a laminated character. It is generally largely intermixed with selenite, which is disseminated through it in the form of minute lenticular crystals. Sometimes the gypsum is so abundant as to constitute a fourth or fifth of its bulk, and consequently the water flowing through this formation is generally bitter and disagreeable. In a few instances thin seams of selenite have been detected traversing the clay horizontally, and in others the clay appears reticulated with the selenite. Small septaria composed of hard, compact, blue, argillaceous limestone are also sometimes met with in the lower bed. The only limestone element of the lower part of the formation occurs in the nodules or segregations embedded in the clay. These are generally flattened, from 1 to 2 inches thick, and vary in width from a few inches to 1 or 2 feet. They are usually hard, compact, and of an earthy texture. Externally they are of an iron-rust color, but when broken exhibit various shades of blue and brown. These nodules usually occur in the clay in the form of distinct bands or layers, which are nearly horizontal. Sometimes several of these bands are seen in the same section.

In the central portion of the formation are a few persistent flaggy layers of laminated arenaceous-argillaceous limestone, seldom over an inch in thickness and aggregating 10 feet, which weather into buff colors. Although in themselves not very durable, these are of sufficient relative hardness to produce a distinct escarpment and dip plain, which makes a conspicuous topographic feature, as seen west of Dallas, between that city and Eagle Ford. These layers are also exposed in Grayson County, near the source of Mustang Creek, in northern Denton County, and west of Hillsboro in Hill County, and are apparently the base of the beds which in the southward extension constitute the prevalent material of the Eagle Ford formation.

Succeeding these medial arenaceous layers are considerable thicknesses of the blue-black clays in which are numerous spherical septaria, some of which attain a diameter of 3 feet. These are composed interiorly of a dense blue limestone and are cracked in numerous directions by cross fissures which are filled with crystals of calcite and selenite. This portion of the section contains beautifully preserved fossils with a nacreous coating, including many ammonites, such as *Buchiceras swallovi*, *Placenticeras*, etc.

In the upper portion of these clays and about 50 feet below the summit of the formation in the Dallas and Sherman sections there are other calcareous and flaggy sheets containing numerous remains of fish teeth, *Inoceramus* sp., and *Ostrea lugubris* Conrad (see Pl. XL). These flaggy, arenaceous layers increase in general thickness and in percentage of sand in their northward extension, having a thickness of 10 or 15 feet in Grayson County, as seen in the western portion of the city of Sherman. Above this there are 10 or 20 feet more of the blue laminated shale.

The following section at Sherman, Grayson County, Texas, 2 miles west of Binkley House, shows the character of the upper beds:

SECTION NO. 47.—SECTION AT SHERMAN, GRAYSON COUNTY, 2 MILES WEST OF BINKLEY HOUSE, TEXAS (SEE PL. XVIII, *C*).

	Thickness.	Total depth to bottom of stratum.
7. Austin chalk.		
Eagle Ford shale:	*Feet.*	*Feet.*
6. Sandy clay shales with *O. lugubris*	±10	10
5. Thin slabs of brown sandstone with small rounded conglomerate of jasper pebble. *O. lugubris* and fish teeth	5	15
4. Blue laminated clay, weathering into limonitic colors	10	25
3. Massive agglomerate of *O. lugubris*	2	27
2. Sandy clay shale in thin alternations of clay and sand; clay efflorescent and drab-colored on drying. *O. lugubris*	+40	67
1. Blue clays with gigantic septaria.		

VARIATION OF EAGLE FORD FORMATION SOUTHWARD.

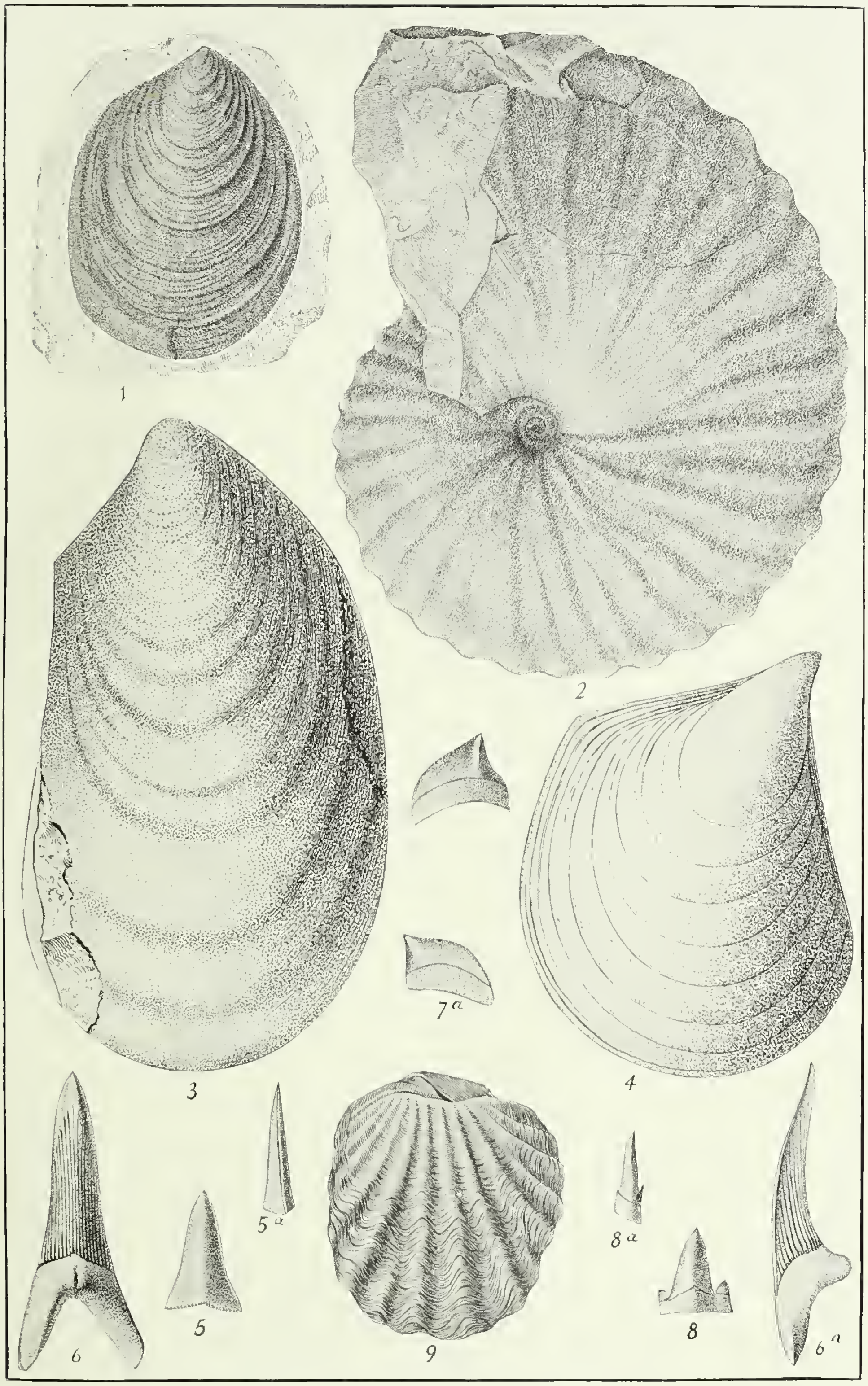
While the Eagle Ford formation decreases in thickness southward, this decrease is apparently accomplished by the gradual disappearance in that direction of the lower beds of the formation, the upper calcareous layers with laminated flagstones alone persisting and increasing in that direction, until at Austin they are almost the sole representative of the beds.

The upper contact of the Eagle Ford clays and Austin chalk crosses the Brazos above the mouth of Bosque River. The lower contact between the Eagle Ford and the Buda formations may be seen in the high bluff of South Bosque River between Hog Creek and the Middle Bosque. The thickness of the formation in this general section has not been satisfactorily obtained. It is probably from 100 to 200 feet.

Southwest of Waco the Eagle Ford formation makes the base of the White Rock scarp along Bosque River. This overlooks a dip plain of the Del Rio formation to the west. Farther south the same scarp also includes the Del Rio clays, the two together overlooking a dip plain of the Washita limestone on the west.

One of the best exposures of the formation is that seen in the bluffs of the Bosque at Prather's tank, a few miles south of Waco. Here the beds consist of bluish and bluish-gray clays and arenaceous shales, in which many fish remains have been found.

Between the Brazos and the Colorado the outcrop of the Eagle Ford



COMMON FOSSILS OF THE EAGLE FORD FORMATION.

1, Inoceramus labiatus Schlotheim; 2, Buchiceras swallovi Shumard; 3, Inoceramus labiatus Schlotheim, 4, Inoceramus fragilis Hall and Meek; 5, 5*a*, 6, 6*a*, 7, 7*a*, 8, 8*a*, fish teeth; 9, Ostrea lugubris Conrad.

formation is a very narrow belt and in places is interrupted by faulting. It can be traced southward through Bell County, and is well shown about 4 miles west of Temple on the Belton road.

In this region, where the Woodbine formation is missing, the Eagle Ford formation differs very slightly in general character from the underlying Del Rio clays. Like them, it forms a dark-brown soil, which makes it impossible to draw a line between the two, so closely do they resemble each other. The only marked stratigraphic difference between them is that the Eagle Ford formation is highly laminated, while the Del Rio formation is not. The laminæ often appear as shaly fragments on the weathered surfaces of the outcrops, and sometimes as good-sized slabs which are weathering into laminæ. In the Del Rio clays there is an almost entire absence of any hard rock.

In Williamson County sections of the Eagle Ford shales are exposed on San Gabriel River below Town's mill and on Brushy Creek 3 miles below Round Rock. Elsewhere, between San Gabriel River and Brushy Creek, the rock is concealed by surface soil and drift, which prevails over a considerable portion of the Upper Cretaceous here. At the locality below Town's mill and 1 mile below the mill on San Gabriel River these beds are well exposed in bluffs 10 to 40 feet high. Here they show large lenticular bands of arenaceous laminated limestone, interstratified at the base with flaggy, arenaceous, and pyritous shale. In their upper portion they consist of stratified and laminated layers of bituminous shale, dark blue on fresh exposure and weathering light yellow, of very calcareous, bright yellow, laminated clay, with calcareous, chalky, soft flagstones at the top. There are many shades of color, from dark blue to bright yellow and white. *Ammonites* sp. ind. occurs in the lenses and lenticular bands of indurated lime at the base of the bed. Fish bones and teeth are scattered in the arenaceous flaggy and pyritous shale. The flaggy layers contain numerous small undetermined *Ostrea*. A band of blue granular shale near the center of the bed contains many small brown fish scales, beautifully marked. Higher strata carry numerous individuals of a large flat *Inoceramus*. Fragments of fish bones and teeth can be detected throughout the whole bed. An occasional thin band is composed almost wholly of fragmentary fish remains. On striking this shale sharply with a hammer, or rubbing two pieces briskly together, a fetid odor, as of bitumen or of crude petroleum, is produced.

In the Austin section (see Pl. XX, *E*) the shales are reduced to a thickness of less than 50 feet, and have the lithologic character of the Williamson County beds, which is that of the indurated calcareous beds of the northern division. Some of these layers make fair flagstones, suitable for structural uses. The formation is exposed in the Sixth ward of the city and along the breaks of Shoal Creek, where its contact with the Buda limestone is well shown. It is also well displayed in the banks of Bouldin Creek, on the south side of the river. The outcrop of the beds in this vicinity weathers into a rich black soil, bearing a growth of mesquite and hackberry. The formation here can always be distinguished by its laminated character, a feature not present in the other limestones of the vicinity. Fish remains, *Ostrea*, and *Inoceramus* also abound in these beds at Austin.

The following fossil vertebrates from the top of the Eagle Ford formation at its contact with the Austin chalk were collected at Bosque farm, southwest of Waco, Texas, by Mr. J. L. Prather, and have been determined by Mr. F. A. Lucas, of the United States National Museum: *Clidastes*, *Icthyodectes*, *Xiphactinus*, *Protosphyræna*, *Oxyrhina extenta*, and fragments of *Plesiosaurus* and possibly *Cimoliasaurus*.

From Austin southwestward the Eagle Ford formation thickens again, until near Brackett it attains a thickness of 250 feet.

PALEONTOLOGY OF EAGLE FORD FORMATION.

The Eagle Ford clays in their entirety are not very fossiliferous, except in the upper portion. In the northern areas the lower blue-clay portion contains several characteristic ammonites, such as *Buchiceras swallovi* (Pl. XL, fig. 2) and a few other forms which are preserved with their nacreous shell coloring. In the medial beds fossils are rarely found, except in the septaria. The arenaceous layers of the upper portion are remarkable for the number of fish remains, chiefly teeth, which abound in them, and contain also the following species:

Ostrea lugubris (Pl. XL, fig. 9) is a characteristically marked fossil of a certain bed near the top of the Eagle Ford shales north of the south line of Dallas County. It appears in the city of Sherman, at a ravine near the northeast corner of the female college, and south of Cook Spring, 5 miles north of the town. One mile west of Sherman it forms a solid mass 4 to 5 feet thick. This bed decreases in size as it continues south, and disappears beyond the Brazos. *Inoceramus fragilis* and *I. labiatus* (see Pl. XL, figs. 1, 3, and 4) and a small form like *O. congesta* are abundant in the upper portion of the beds.

In all, the following invertebrate fossils have been reported from the Eagle Ford beds:

Placenticeras syrtalis Mort. var. cumminsi Crag.
Ammonites woolgari Mort.
Sphenodiscus dumblei Cragin.
Buchiceras inequiplicatus Shum.
Buchiceras swallovi (Shum.).
Tapes hilgardi Shum.
Anchura modesta Cragin.
Fusus graysonensis Cragin.
Natica striatacostata Cragin.
Neritopsis brangulatus Shum.
O. lugubris Conrad=O. belliplicata Shum.
Inoceramus fragilis Hall and Meek.
I. labiatus Schlotheim.

AN OUTCROP OF THE AUSTIN CHALK, ONION CREEK, TRAVIS COUNTY, TEXAS.

AUSTIN CHALK.

GENERAL CHARACTER AND LITHOLOGIC COMPOSITION.

Owing to its whiter color and greater induration, this is the most readily distinguishable of the several formations of the Upper Cretaceous, which are mostly unconsolidated clays (see Pls. XLI, XLII, XLIII). These facts make it a most important datum point in differentiating the strata of the Upper Cretaceous and are of special value in aiding in the determination of the depth of underground waters. Hence the formation will be frequently referred to in the economic discussions of this paper.

The formation consists of beds of impure chalk containing 85 per cent or more of carbonate of lime, interstratified with softer beds of marl. It is usually of an earthy texture, free from grit, and when freshly exposed easily cut with a handsaw. Under the microscope the material shows calcite crystals, particles of amorphous calcite, and the shells of foraminifers, mollusks, echinoids, and other marine organic débris, such as usually constitute chalk formations.

The saturated subterranean portions of the rocks have a bluish color, but the air-dried indurated surfaces are glaring chalky white. The air-dried rock usually weathers in large conchoidal flakes, with an earthy fracture. Occasionally small nests of pyrites of iron occur in the fresh rock. On weathered surfaces these are usually altered into round balls of marcasite an inch or less in diameter. Streams of rust from these locally discolor the face of the rocks in places.

The Austin chalk was called magnesian limestone by some of the earlier writers, and is still so called by some persons. Only a small percentage of magnesia is found in it. The following analysis shows its average chemical composition:

Average composition of Austin chalk.

	Texas.	Rocky Comfort, Arkansas.
Calcium carbonate	82.512	84.48
Silica and insoluable silicates	11.451	9.77
Ferric oxide and alumina	3.618	1.25
Magnesia	1.189	Trace.

The individual beds vary slightly in hardness, although the degree of surface induration is considerable in places. In the vicinity of igneous intrusions, as near Austin, the rock is somewhat altered by contact, having been converted into marble at Pilot Knob, south of

Austin. In general the formation regains its usual aspect a very few feet away from these intruded masses.

On account of the compactness of the formation the streams cutting through it form bluffs on one or both sides, in which the stratification and effects of weathering are most finely displayed. The marly and softer limestone bands are readily removed, leaving the harder layers projecting in rounded or subangular shelves. The result is that the face of the bluffs is carved into alternations of horizontal grooves and ledges of great persistence, which extend along the bluffs until they finally disappear with gentle dip beneath the surface. In localities great masses have fallen from the bluffs.

On complete disintegration the Austin chalk weathers into a black residual soil, very similar in appearance to that of the adjacent formations. Though the regolith is not so deep or productive as that of the Eagle Ford country on the west or the Taylor marls on the east, it forms in the aggregate a vast area of excellent agricultural land. As this soil mantles the uplands and divides, it is only with difficulty that the formation can be determined in such areas. In the slopes and drainageways the formation is very conspicuous by reason of the glaring white color of its outcrops. Such outcrops of the chalk form ribbons of white rock in the normally dry beds of the intermittent creeks and high undermining bluffs along the courses of the larger rivers. Some of these bluffs, like those west of Waco and on the south side of the Colorado at Austin, are picturesque.

RELATIONS TO OVERLYING AND UNDERLYING FORMATIONS.

Throughout the area included in this report the Austin chalk rests upon 5 to 10 feet of finely laminated and usually arenaceous, calcareous, argillaceous yellow to bluish material constituting the top of the Eagle Ford formation, and ordinarily termed the Fish beds. The formation passes upward into the Taylor marls without stratigraphic break. Southeast of Waxahachie, at the upper contact or parting between the Austin chalk and the Taylor marl, the marl rests directly on the massive upper strata of the chalk, the transition being very abrupt; but south of Waxahachie there are several feet of calcareous, arenaceous marl intervening between the two divisions which are included with the chalk.

The thickness of this formation is difficult to determine with accuracy. Southeast of McKinney it is 625 feet; at Waxahachie, 550 feet; and, southeast of Sherman, Dallas, and Waco it is estimated to be very nearly 600 feet thick. At Austin, according to the log of the Manor well, it is about 410 feet thick, but the exact thickness has not been determined.

The most eastern outcrop of this chalk is in Little River County, in the southwest corner of Arkansas, but it is not found in Indian Ter-

A BLUFF OF AUSTIN CHALK, TRAVIS COUNTY, TEXAS.

ritory. Owing to faulting it is largely concealed along the south side of Red River until the Cooks Springs fault is crossed, north of Sherman. From 2 miles north of Sherman southward to the Rio Grande, in the main Texas region, the Austin chalk outcrops as a narrow belt in a general region of Black Prairie.

The interior or western outcrop of the Austin chalk makes the conspicuous topographic feature elsewhere described as the White Rock escarpment, and passes from Sherman to Austin through or near McKinney, Dallas, Hillsboro, Waco, and Temple. From Austin the outcrop continues through New Braunfels, San Antonio, and Fort Clark, crossing the Rio Grande between Del Rio and Eagle Pass. It is an interesting fact that the larger cities and towns of the Black Prairie region, like Sherman, McKinney, Dallas, Waco, Austin, New Braunfels, and San Antonio, are built upon this formation, the sites having been originally chosen, no doubt, on account of the better natural conditions for habitation, such as stable foundation, superior water, building material, shade, and higher altitude relative to the adjacent Black Prairie.

DISTRIBUTION, THICKNESS, AND PALEONTOLOGY.

The local details of the outcrop of the formation, so far as known, are very much the same wherever encountered, although its variations have not been as minutely studied as have those of the underlying formations. Where first seen in the woods of Little River County, Arkansas, it is largely concealed by superficial deposits and vegetation, outcropping as glaring white spots in a region otherwise made up of different-colored soils derived from the higher formation. Here and there in the vast areas of black soil between Paris and Garland there are several outcrops of white rock, some of which are tentatively held to be the Austin chalk.

The main belt of the formation is exposed along the White Rock scarp, as previously described, between Sherman and Austin. Here the chalk outcrops in low but steep cliffs, with crumbling débris, and in places is partially covered by tree growth of live oak, hackberry, and juniper. The chalk is seen to advantage only along this western border of its outcrop. Excellent exposures are shown from Oak Cliffs, the western suburb of Dallas, south through Dallas and Hill counties, nearly to Waco. Eastward, away from the scarps, the outcrop is a dissected treeless dip plain, cut into numerous low mammillary hills, with rounded slopes, making a north-south belt averaging about 5 miles in width. This plain slopes gently eastward, and deeply cut drainageways have made numerous valleys across it.

The chalk is very conspicuous in places on the south side of the Brazos at Waco, making the beautiful white cliffs of the Brazos known as Lovers' Leap, a few miles west of Waco. It is exposed in the cuttings of the Cotton Belt Railway toward Gatesville, ending as the cap of the escarpment one-half mile east of South Bosque River. It is also seen along the Missouri, Kansas and Texas Railway between Waco and Lorena.

From Brazos River south to Belton, the Austin chalk, covered with a thick growth of cedar and some oak, forms the harder cap of the White Rock scarp, the base of which in this region usually consists of the softer Eagle Ford and Del Rio clays. No finer illustration of the relation of relief to formation can be found than along that portion of the White Rock scarp which forms the great bluffs overlooking the Bosque southwest of Waco. As in many other places, the normal course of the Bosque is here sharply deflected by this scarp. On meeting the scarp the river, which has been flowing southeast toward the Gulf with the dip of the lower rock sheets, turns at right angles to its former course and flows northeastward with the strike of the chalk. Farther south, toward Belton, the scarp is not so abrupt. The growth of trees on the chalk also practically ceases here, leaving open prairie. In every other essential detail the same features can be seen here as farther north.

The eastern border of the Austin chalk is difficult to delineate, inasmuch as its gradation into the Taylor marls is largely concealed by the upland black soils. The chalk can be seen along this border only in the drainage and railway cuts or when revealed by well-holes. This eastern border is exposed at Garland, in Dallas County. Four miles beyond the latter place, on the railway to Rockwall, there are big cuts through yellow marl resembling the Taylor, which is also well exposed at Rowlett. One mile east of Garland, Taylor marls can be seen on top of chalk. At Arnold, 6 miles east of Dallas, the chalk is exposed in a well. Exposures can be occasionally seen along the eastern border in Hill, McLennan, and Bell counties.

Still southward, through Williamson County, the eastern parting of the Austin-Taylor chalk is seen in a creek 2 miles southwest of Hutto. It likewise outcrops at Palm Valley, where it is covered with live oak and is very much jointed. Its continuation south through Travis County is shown upon the map.

Taff has presented a study of these rocks along a section line in Williamson County, which shows their typical occurrence in Williamson and Travis counties. Here the rock at the base is a comparatively firm chalky limestone, marly to arenaceous lime in the central portion and lime marl at the top. The whole is stratified in beds from 6 inches to 10 feet thick, light blue to cream colored before oxidation, and cream colored to pure white after long exposure. There are rarely thin bands of argillaceous lime, which crumbles readily on exposure. Along bluffs and banks of creeks these argillaceous bands form recesses by rapid disintegration, leaving the more indurated limestone layers

Volcanic tuff. Austin chalk. Tuff.

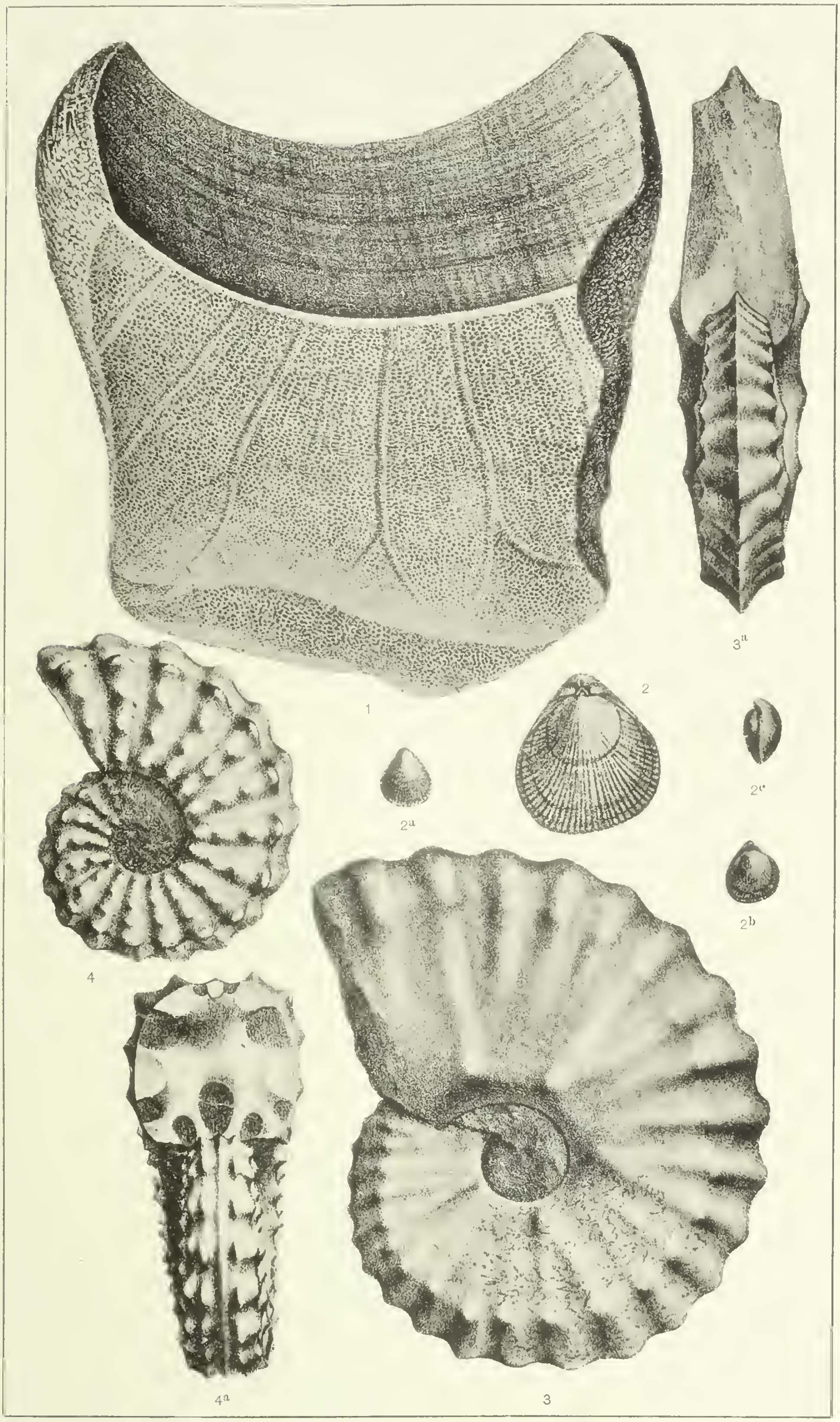
AN OUTCROP OF THE AUSTIN CHALK NEAR KOUNZ, TEXAS.

PLATE XLIV.

PLATE XLIV.

Characteristic Fossils of the Austin Chalk.

Fig. 1. Radiolites austinensis, Roem.
Figs. 2, 2a, 2b, 2c. Terebratulina guadalupæ Roem.
Figs. 3, 3a. Ammonites dentatocarinatus Roem.
Figs. 4, 4a. Mortoniceras texanum Roem.
Fig. 2 is enlarged 5 times; other figures are natural size.



CHARACTERISTIC FOSSILS OF THE AUSTIN CHALK

THE MERIDEN GRAVURE CO.

projected in parallel benches. Even in the thick bed there is much variation in their resistance to weather, which is governed by the varying percentage of siliceous material of which they are composed.

From the base upward for about 200 feet the limestone is in its purest state and occurs in massive beds from 2 or 3 to 10 feet thick, with borders of slightly argillaceous limestone. *Mortoniceras texanum* (see Pl. XLIV, figs. 4, 4a) and a large species of *Inoceramus* are found. Typical exposures of this portion occur along the immediate bank of Brushy Creek from 2½ to 6½ miles below Round Rock.

The succeeding strata become slightly arenaceous, containing about 10 per cent of silica, and occur in slightly thinner beds, which are much more fossiliferous than the more chalky layers below. These slightly arenaceous beds, the exact thickness of which is not known, pass up into a marly chalk about 60 feet in thickness, containing vast numbers of a small gryphæa of the variety called *Gryphæa aucella* (see Pl. XLV, figs. 4, 4a) by Roemer, associated with *Exogyra ponderosa* (see Pl. XLV, fig. 1). Above the foregoing the beds become still more marly in character and contain many specimens of *Exogyra ponderosa* and *Ostrea diluviana* (see Pl. XLV, fig. 2). The latter fossil is peculiar to this zone, which is considered the conventional top of the Austin chalk. Above these there are about 100 feet of chalky marl of a dull yellowish-blue color, containing many fossil *Ammonites*, *Baculites*, *Anomia*, *Inoceramus*, *Pecten*, and especially *Ostrea larva* (see Pl. XLVIII, figs. 5a and 6), which are placed in the base of the Taylor marls.

The exact thickness of the Austin chalk at Austin could not be accurately estimated on account of the disturbances incident to the Balcones fault, which passes west of its border, through Round Rock and Georgetown. Small faults, with throws both east and west, transect the beds at short intervals and cause the dip to vary to such a degree that it is not reliable for estimating the thickness of beds. It varies locally from 5 degrees toward the southeast to zero, and in a few instances it is slightly reversed. By an estimate based upon the Eagle Ford shale beneath the Austin limestone, the dip of which could be determined, the base of the chalk was found to dip about S. 30° E. nearly 100 feet per mile. The average width of the chalk on a level surface in the direction of the dip is nearly 6 miles. The thickness by this estimate would be 600 feet in Williamson County, but this is probably an overestimate.

The Austin chalk continues in a narrow belt through Travis County, where it is typically exposed in the city of Austin on both banks of the Colorado from the mouth of Bouldin and Shoal creeks eastward to Montopolis Bridge, the piers of which rest upon its uppermost stratum. Excellent exposures are seen in all the streets, bluffs, and creeks in Austin, and the State capitol is built upon the formation.

The Austin chalk is characterized by many fossils, especially in the southern portion of its extent. Large specimens of *Inoceramus* are numerous from the base to the top. *Exogyra læviuscula* (see Pl. XLV, fig. 3) and *Exogyra ponderosa* are abundant and especially numerous in the upper bed; *Radiolites austinensis* (see Pl. XLIV, fig. 1) and several other unidentified forms are found in various strata; *Baculites*, *Placenticeras*, *Mortoniceras texanum*, and *Nautilus dekayi* also occur.

TAYLOR FORMATION.[1]

UNCONSOLIDATED CHARACTER OF UPPER CRETACEOUS.

The Cretaceous section above the Austin chalk in the Black Prairie region of Texas is composed almost entirely of unindurated layers, firm rock strata being very few and exceptional. The beds are principally calcareous clays which weather so rapidly into a mantle of thick black soil that continuous sections of them can not be seen or measured with accuracy, and hence their thickness, sequence, and general character must be judged largely from well holes. These unindurated uppermost Cretaceous strata in places, as at Corsicana, are fully 2,000 feet thick. They can be differentiated, after a manner, into two general formations, the lower of which may be termed the Taylor and the upper the Navarro. In some places, notably in the northeastern corner of the State, the upper formation, which will be described later, is separable into several members.

GENERAL FEATURES AND THICKNESS OF TAYLOR FORMATION.

The Taylor formation consists of calcareous clay marls which are locally known as "joint clays." These are blue-black in the substructure, but weather into a deep regolith consisting of a whitish-yellow subsoil and a dense black soil which characterizes the main "black waxy" belt of the Black Prairie. The regolith is jointed, laminated, and friable throughout, having a crackled appearance when dry. Because of their rapid surface disintegration the character of the unaltered beds is seldom seen except when their material is brought up by the well digger or is exposed in freshly cut ravines or creeks. To the eye this clay marl is generally lacking in siliceous material, although a portion may be detected by chemical analysis. The bituminous matter which characterizes the Eagle Ford formation and the grains of glauconite which are found in the rocks of the overlying Navarro beds are also less notable. Their accessory constituent is lime, in a chalky condition. The marls are of fine consistency, compact, and apparently massive until their laminated character is developed by exposure. At the Blue Bluffs of Colorado River (see Pl. XLVI), 6 miles east of Austin, and a few other localities, good natural exposures are afforded, where portions of the clays can be readily studied and diagnosed.

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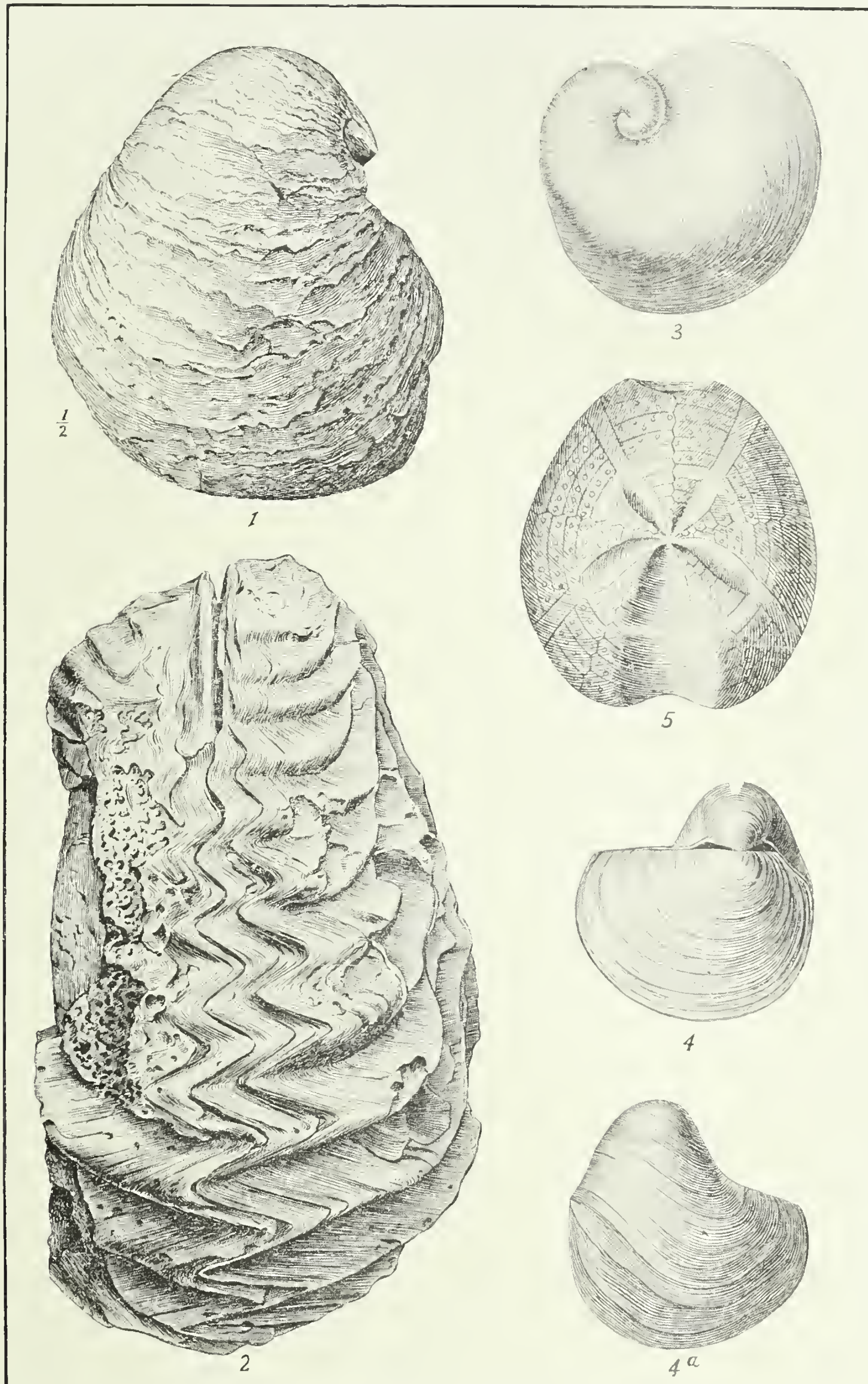
[1] Exogyra ponderosa marls of the author's earlier writings.



CHARACTERISTIC FOSSILS OF THE AUSTIN CHALK.

1, Exogyra ponderosa Roemer (one-half natural size); 2, Ostrea (Alectryonia) diluviana Lamarck 3 Exogyra læviscula Roemer; 4, 4*a*, Gryphæa aucella Roemer; 5, Hemiaster texanus Roemer

These marls may be said to commence quite above the zone of *Ostrea* (*Alectryonia*) *diluviana* (see Pl. XLV, fig 2), which occurs at the top of the Austin chalk. The lower portion of the clays is often calcareous and very fossiliferous, containing many specimens of *Exogyra ponderosa* (see Pl. XLV, fig 1).

The middle portion of the beds is apparently devoid of all well-preserved fossils, yet impressions are abundant in places. At the top, as seen at various places in Travis County east of Austin, the beds grade into the slightly arenaceous and concretionary fossiliferous marls of the Navarro subdivision.

The Taylor and Navarro formations have not been differentiated north of the San Gabriel section, although both are well developed and can be seen in frequent exposures. In the Red River counties, also, they have not been differentiated.

Owing to lack of outcropping sections for measurement it is difficult to ascertain the exact thickness of this formation or to separate it from the overlying Navarro formation. In the latitude of Austin, as determined from the well at Manor, the beds are about 650 feet thick. In north Texas we have no reliable records by which to estimate their thickness. At Corsicana there are at least 1,500 feet of clays above the Austin chalk, a portion of which belong to the Taylor marls. Taff gives the Taylor marls nearly 1,000 feet in Williamson County, but this is probably overestimated. Six hundred feet of the Terrell well section at San Antonio may belong to the Taylor beds.

ANALYSES OF TAYLOR MARLS.

The following typical analyses of the Taylor marls from Williamson County have been published by Mr. J. A. Taff:[1]

Analysis of marl from lower portion of bed.

	Per cent.		Per cent.
Water	4.36	Carbonic acid	10.36
Silica	45.02	Potash	.975
Lime	14.26	Soda	3.22
Magnesia	None.	Phosphoric acid	.113
Sulphuric acid	.97		
Alumina	16.17	Total	100.228
Ferric oxide	4.78		

Analysis of marl from central part of Taylor marl bed.

	Per cent.		Per cent.
Water	3.68	Carbonic acid	8.30
Silica	48.72	Potash	1.14
Lime	11.79	Soda	3.07
Magnesia	Trace.	Phosphoric acid	.109
Sulphuric acid	2.21		
Alumina	16.10	Total	99.989
Ferric oxide	4.87		

[1] Third Ann. Rept. Geol. Survey Texas, Austin, 1892, pp. 356, 357.

Analysis of marl from Taylor marl bed, on Brushy Creek.

	Per cent.		Per cent.
Water	3.77	Carbonic acid	22.80
Silica	28.34	Potash	.29
Lime	29.76	Soda	2.04
Magnesia	None.	Phosphoric acid	.118
Sulphuric acid	1.04		
Alumina	7.50	Total	99.578
Ferric oxide	3.92		

NAVARRO FORMATION.

GENERAL CHARACTER, RELATIONS, AND VARIATIONS.

The Navarro formation includes the highest beds of the Cretaceous which outcrop along the eastern portion of the Black Prairie region and of the northern margin of the Rio Grande Plain. This formation is the upward continuation of the Taylor marls, the one passing into the other by gradual transition. The chief lithologic differences are that the clays, chalks, and sands composing the Navarro formation contain more or less sand and glauconite, while the Taylor marls are apparently free from those substances. Besides these lithologic differences, there are conspicuous changes in the fossils. The latter become more plentiful in the Navarro formation and have the same character as those of the Upper Cretaceous of the New Jersey and Alabama regions, of which they are the equivalent and continuous beds, being especially marked by *Gryphaea vesicularis*, *Exogyra costata*, *Ostrea larva*, *Sphenodiscus lenticularis*, and numerous other forms. (See Pls. XLVII and XLVIII.)

The beds of this uppermost formation throughout its whole extent from New Jersey to the Rio Grande are largely concealed beneath the overlap by the Tertiary and Pleistocene deposits, and in general outcrop only in exceptional localities, where these later formations have been eroded away. Furthermore, in Texas they occupy a region of sublevel soil-covered prairie where it is impossible to map good exposures and connected sections.

North of the Sulphur Fork, owing to the fact that the overlying formations are usually composed of a contrasting material of different texture and composition, the underlying Navarro Cretaceous may be recognized. South of that stream the surficial deposits are derived largely from the Cretaceous material and assume similar surface aspects. Hence in large and frequent areas the formations are almost indistinguishable.

In the southwest corner of Arkansas and in the Red River counties the uppermost Cretaceous beds show considerable stratigraphic differentiation, consisting of beds of glauconitic clay marl, chalks, and glauconitic sands. South of the Sulphur Fork of Red River to the

OUTCROP OF THE TAYLOR MARLS, COLORADO RIVER, EAST OF AUSTIN, TEXAS.

Colorado the beds consist almost exclusively of glauconitic sand and clay marls, there being only a few local occurrences of secondary limestone or arenaceous flags.

From San Antonio westward to El Paso the beds of the uppermost Cretaceous consist of yellow clays, impure ferruginous limestones, and beds of lignite, and exhibit a general increase in thickness, showing a transition to the facies of the synchronous beds of the Rocky Mountain region.

PREVIOUS ATTEMPTS AT CLASSIFICATION.

For convenience the author has in previous papers spoken of the formation as it occurs from San Antonio north, where it presents facies of the Atlantic States, as the Glauconitic division, and of the beds of the Rio Grande and Trans-Pecos region, as the Montana division, the latter name having been previously used for the allied formations in the Rocky Mountain region. The term Glauconitic has always been considered unsatisfactory, inasmuch as it is not a geographic word. The word Montana can not be used with certitude for the beds of the northern area until they are proved by paleontologic evidence to be identical with the Rocky Mountain deposits bearing that name. The beds of the two regions are different in lithologic aspect, and must be distinguished until they are proved to be the same. In the present paper the term Navarro will be given to the formation as it is known east of the Colorado. The term Ripley has been used as a generic one for beds of the Navarro formation in Texas, but without specific definition. Since the word Ripley was originally restricted to some of the many beds in Mississippi composing the equivalent of the Navarro formation as a whole, it is hardly appropriate to apply that name to the formation in Texas.

Notwithstanding various attempts on the part of the writer and others, the parting between the uppermost Cretaceous beds and the Basement beds of the Eocene Tertiary which borders it on the east can not be accurately mapped at present. The substructure is unconsolidated, and is but rarely exposed, and then only at places in the drainageways. The soils are deep and mantle the whole superfices. Furthermore, there are surficial deposits derived from the Cretaceous beds which it is difficult to distinguish from the substructure.

DISTRIBUTION AND OCCURRENCE.

The beds of the Navarro formation occur in southwest Arkansas as a group of inliers within the Eocene and Pleistocene area, and have been described in the writer's Arkansas report.[1] The details of their continuation into Texas have also been extensively studied, but, owing to the difficulties of the problems encountered, these studies have not

[1] Ann. Rept. Geol. Survey Arkansas for 1888, Vol. II, Little Rock, 1888.

been carried to completeness and much remains to be found out.[1] Their occurrence in the Red River counties has also been briefly described by the writer.[2]

The formation is first seen in Texas, in the Red River tier of counties—Red River, Lamar, Fannin, and Delta. Its easternmost occurrence is in two small spots in Bowie County, north of DeKalb station, upon the Friese place, where it consists of calcareous glauconitic sands beneath the overlapping Tertiary and river alluvium. This mode of occurrence is geologically known as an "inlier," and there are several more of these inliers to the south, well within the Tertiary area in Wood, Smith, and Anderson counties. These are in the direct line or strike of the Arkansas beds, which they resemble in detail, and their mode of occurrence indicates the overlap of extensive areas of the eastward extension of the Cretaceous by Eocene deposits. The outcrops of the formation become more extensive in area along the interior margin of the Atlantic Timber Belt in northern Texas, and attain considerable development in the southern half of the Red River tier of counties, as far west as Delta County, whence they deflect south, and thence on make the eastern margin of the Black Prairie as far south as Webberville, on the Colorado.

SUBDIVISIONS OF NAVARRO FORMATION.

In southwest Arkansas and northeast Texas, along the region adjacent to Red River, the Navarro formation presents the following distinct lithologic units, beginning with the lowest:

Brownstown beds.—Yellow clay marls resembling, lithologically, the Taylor marls, already described, but different from them by the presence of a quantity of glauconitic grains, interspersed throughout and characterized by different fossils. These beds have great development in Hempstead and Clark counties, Arkansas.

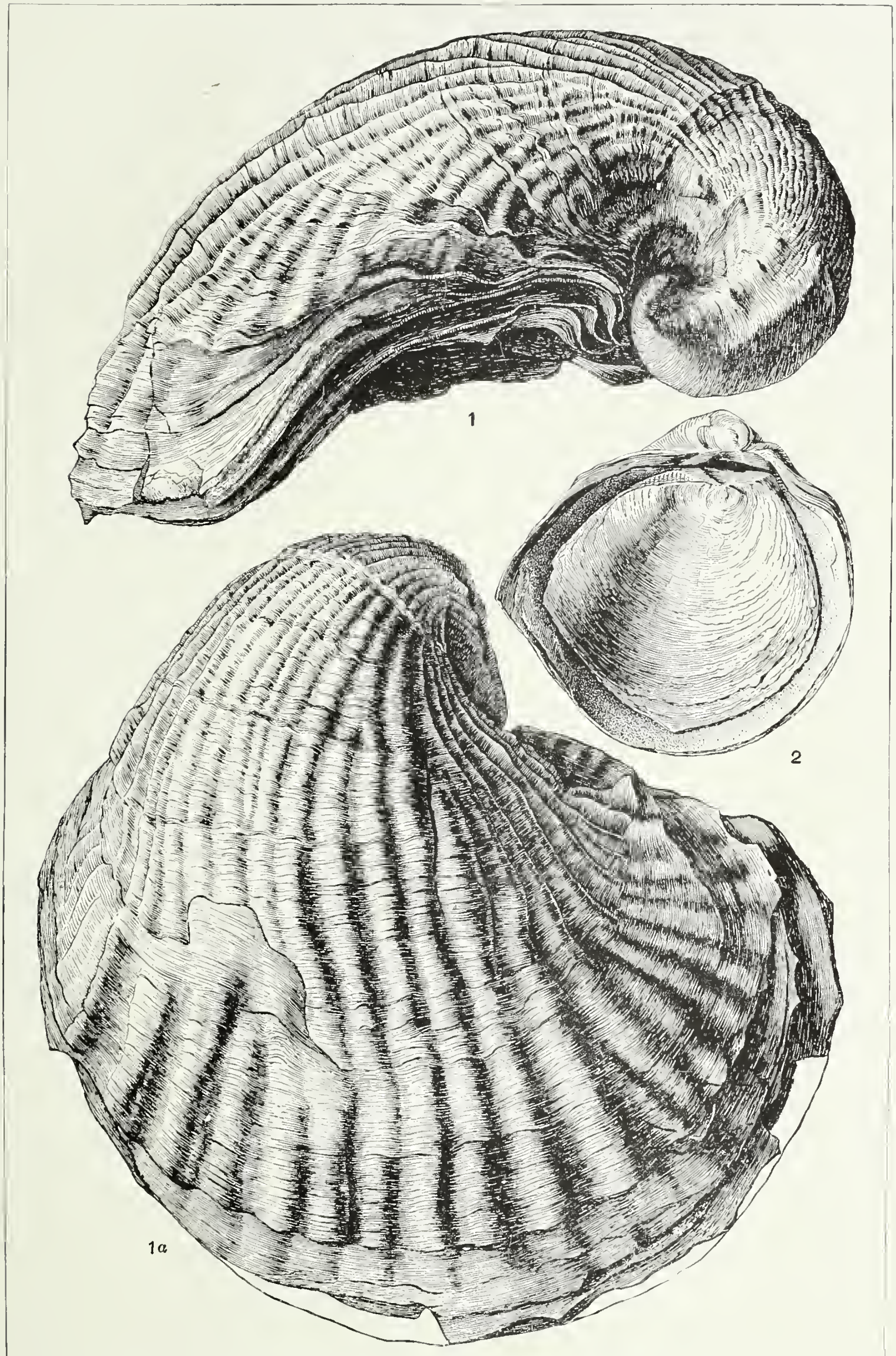
Roxton beds.—A glauconitic calcareous stone outcropping near Roxton and Honey Grove in Texas, and at the base of the White Cliff section on Little River, Arkansas.

Anona chalk.—This bed is composed of the purest white chalk, the White Cliffs chalk of the writer's earlier papers. It occurs in Texas in the vicinity of Clarksville and Anona, Red River County, and is typically exposed in Arkansas along the White Cliffs of Little River in Hempstead and Sevier counties, where it has a thickness of about 100 feet.

Washington beds.—The Washington beds, surmounting the Brownstown marls, are composed of glauconitic sands. The glauconite occurs

[1] Since this paper was written Mr. J. A. Taff, of the U. S. Geological Survey, has made a still later study of the areas of the Navarro formation in southwestern Arkansas in connection with their economic products. His report will appear in the Twenty-second Annual Report of the Survey.

[2] Geology of parts of Texas, Indian Territory, and Arkansas adjacent to Red River: Bull. Geol. Soc. America, March, 1894, pp. 297–238.



CHARACTERISTIC FOSSILS OF THE TAYLOR AND NAVARRO FORMATIONS.

1, 1*a*. Exogyra costata Say

2. Gryphæa vesicularis Lamarck.

in so great abundance as to give the deposits the character of the marl beds which are worked for fertilizers in New Jersey, with which these Arkansas beds seem paleontologically identical. These beds are not positively identifiable in Texas, being mostly overlapped by the Tertiary formations.

Arkadelphia beds.—The arenaceous Washington beds are succeeded in Arkansas by a very black, compact, laminated clay shale, with thin partings of ferruginous sand, as exposed at Arkadelphia, Arkansas. This is a formation concerning the age of which the writer expressed doubt in his report upon Arkansas, and provisionally considered it the base of the Eocene. The subsequent investigations of Harris resulted in paleontologic determinations which must place these beds at the top of the Cretaceous.

DIFFICULTIES OF CORRELATION SOUTH OF RED RIVER.

It will be seen that the succession of glauconitic chalk, glauconitic marls, glauconitic sands, and clay in this upper division of the Cretaceous in northern Texas and southern Arkansas presents as great a variation in sedimentation as is found in all the other divisions collectively. The writer must confess his utter inability, notwithstanding years of study, to correlate the various outcrops of these beds, nor can it be done except by minute paleontologic research, such as he has not had opportunity to undertake.

Beginning in the eastern Red River country, the sandy glauconitic beds of the Roxton character outcrop in places as far west as Ladonia, Fannin County. In the vicinity of the latter point, where the influence of the Cook Spring fault has no doubt affected the strike and outcrop, and where there is so deep a mantle of black soil, even hypothetical correlations can not yet be made of the beds and their extent south.

Marls of the same character as the Brownstown occur as far west as the Kickapoo in Delta County and south of Paxton, Lamar County.

The chalky (Anona) beds (the White Cliffs chalk of the writer's Arkansas section) outcrop at Clarksville and thence via Paxton and Honey Grove nearly to Bonham, but are not known south of these points. The writer has considered this chalk to represent a higher horizon than the Austin chalk, but its exact relationship is subject to future determination.

South of the Sulphur Fork of Red River to the Colorado, beds of the Navarro formation make the eastern margin of the Black Prairie, but their substructure is so poorly exposed in the level Black Prairie country that it has thus far proved absolutely impossible to classify them in a satisfactory manner, or even to draw definite lines of demarcation between them and the underlying Taylor marls. The following outcrops have been noted in this district.

At Payne's store sandstone and greensand are observed in the Navarro formation. At Rockford Bridge over Cow Creek Fork of the Sabine, 13 miles northwest of Lone Oak, greensand and limestone occur. These are probably the uppermost Cretaceous beds exposed north of Colorado River. Fossils were observed in the Navarro formation, 1 mile west of Terrell, in a railway cut.

Near Farmersville the Navarro formation consists of black and yellow clays and (like the Anona) very thick white joint clays with white nodules. A few sandy strata were noticed in the Navarro formation 3 miles northeast of Farmersville, where the black lands end. One mile beyond large white phosphatic-looking nodules were seen in the clay. At Celeste the rich black lands are underlain by joint clay with characteristic glauconitic grains.

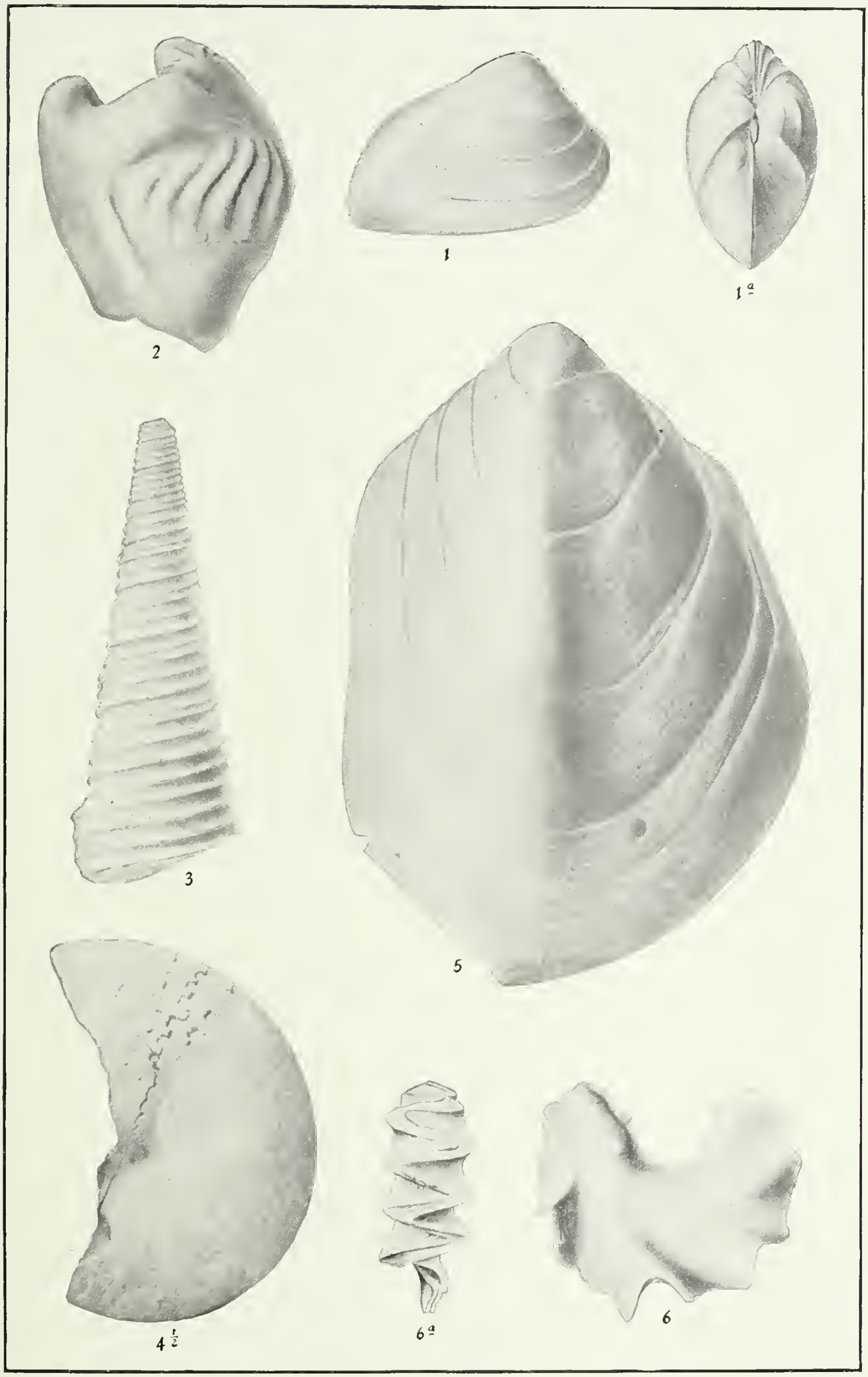
Glauconitic clays also occur 4 miles south of Wolfe City. One mile north of the same place there is a big cut with glauconitic bowlders in clay. A white sandy rock is seen in the Navarro formation 1½ miles south of the station at Ladonia. A highly disturbed outcrop of white rock occurs in the cut north of Pecan Gap station. Ben Franklin is situated on the Navarro Cretaceous. The Navarro formation bears timber all the way from Pecan Gap to Roxton. One mile east of Roxton a section in a creek shows white rock in the bed, with lemon-yellow clays above. Two miles east of Roxton a true white rock (chalk) is exposed in a small creek; the horizon is uncertain.

From Sulphur River, in Delta County, to the Brazos there are two lithologic phases of the upper beds of the Navarro formation, but these can not as yet be satisfactorily correlated with the beds of the Red River and Arkansas sections. They may be called the Corsicana and the Kemp beds.

Corsicana beds.—The Corsicana beds are a brown sandy marl, with an occasional band of hard, calcareous sandstone in its upper portion. The sand is exceedingly fine, and is usually so mixed with clay as to be almost imperceptible. There are a few very fine pebbles of jasper and quartz in the upper part of the formation embedded in the clay. The whole weathers into a sticky black sandy soil. This formation has its greatest development in Navarro County, making a north-south belt through the county. Its eastern edge extends from Richland Creek 1 mile above the mouth of Pine Creek, through the town of Corsicana, to a point 4 miles east of Chatfield, and averages about 5 miles in width.

From Chambers Creek, just northeast of Corsicana, to Chatfield a band of calcareous limestone only a few feet thick, with *Ostrea larvanana*, occurs in the Navarro formation. Near Chatfield, in Navarro County, the limestone concretions of the Corsicana beds contain beautiful fossils preserving their nacreous colors.

Sandy clays similar to the Corsicana beds are traceable south through



CHARACTERISTIC FOSSILS OF THE TAYLOR AND NAVARRO FORMATIONS.

1, 1*a*, Venilla lineata Shumard; 2, Pregnellus densatus Conrad; 3, Turritella trilineata Conrad; 4, Sphenodiscus lenticularis? Meek; 5, Pachycardium spillmani Conrad; 5*a*, 6, Ostrea larva Lamarck.

Navarro, Limestone, and Falls counties to Brazos River, their eastern margin passing just west of Tehuacana.

In this area, as already stated, it is impossible to differentiate the partings between the Navarro beds and Taylor marls, inasmuch as they grade into each other and their parting is mantled by thick soils. The well sections at Corsicana (see Pl. LXIX, p) penetrated 1,200 feet of blue clays representing these two divisions, which show little or no differentiation. A similar thickness is indicated by the Terrell well. In this general region it is also very difficult to distinguish the uppermost Cretaceous from the overlying surficial deposits and the basal clays of the Eocene, which form a narrow strip along the western edge of the Atlantic Timber Belt.

Kemp clay beds.—Above the Corsicana bed east of Chatfield and Corsicana there is a yellow clay bed containing nodules with supposedly Cretaceous fossils. The town of Kemp, Kaufman County, is 1 mile west of the eastern edge of the outcrop of the clay. This clay extends from Trinity River north of Chatfield to west of Stranger, in Falls County. So little is known of this formation that it can not be defined with accuracy, nor can its Cretaceous age be asserted with positiveness.

From southern Navarro County to the Brazos the eastern margin of the outcrops of the Navarro formation is limited by a series of low hills known as the Tehuacana Hills, surmounted by a Tertiary limestone which is adjoined above and below by sands. Throughout this portion of its extent the surface of the Cretaceous area is largely covered with a fine pebble composed of chert, flint, jasper, and silicified wood. This may be either an aggradational deposit of later age or a residuum of the Cretaceous sands themselves. Pebbles similar to these occur in the upper layers of the Corsicana formation, and future research may show that much of the supposed drift of this region has a residual origin.

Blue Ridge, a prominent elevation extending N. 25° E. between Big Creek and Little Brazos River, Horn Hill, Big Hill, and Tehuacana Hill are all a continuation of a ridge of Tertiary rocks which have been upheld by the limestones. This limestone continues as far south as Salt Creek, a tributary of Little Brazos River, about one-half mile above its mouth. The rock is a yellow fossiliferous limestone, estimated not to be more than 15 feet thick. On the Brazos at Blue Shoals there are dark to light blue marls containing *Exogyra costata* and small pieces of oyster. At Black Bluffs, Robertson County, near the line of Falls County, the Cretaceous and Tertiary are seen in contact—the only locality along the eastern border where it is clearly shown.

Dark-blue compact marls, very similar to those at Blue Shoals, but containing a slightly larger percentage of sand, occur at the

Josiah Hogan survey on Brazos River. A white efflorescence appears on the surface of fresh exposures of these clays. At the south line of the same survey this marl becomes more sandy and more clearly stratified; definite Cretaceous fossils disappear and are replaced by a fauna resembling the Lower Eocene. This rock with its abundant molluscan fauna, occurs at intervals between the Milam and Falls county line, and in the so-called high bluffs of the Brazos River.

Continuing south from the Brazos River through Milam, Williamson, and Travis counties, the Cretaceous-Tertiary parting is very indefinite, and uppermost Cretaceous deposits are recognizable only at rare intervals. In the creek beds can be found occasional recognizable outcrops of sandy clay marls containing Cretaceous fossils, notably on Elm Creek near the mouth of Alligator Creek, on Turkey Creek west of the Williamson and Milam county line, and in the banks of San Gabriel River, one-half mile east of the Williamson County line, all in Milam County.

In Williamson County fragments of Upper Cretaceous fossils can be found in Mustang Creek above its mouth, while the Taylor marl is exposed in the bluff at the mouth of Battleground Creek.

Webberville beds.—Along the Colorado section below the mouth of Onion Creek the Taylor marls grade upward into beds which represent the Navarro formation. These are glauconitic marls, in the upper portion of which, on Gillespie Creek, are beds of impure secondary limestone, finally passing into bituminous black arenaceous clays at Webberville.[1] These beds, so slightly exposed in eastern Travis County, represent all that is known of the equivalents of the Navarro formation in the Colorado section of Texas.

Although probably not the highest beds of the Navarro formation, the Webberville beds are the highest Cretaceous strata exposed along the Colorado River section, for below Webberville the next recognizable beds are those of the lignitic or basal division of the Eocene. From Colorado River, southwest, through San Antonio and on to the Nueces, we are permitted only an occasional view of the beds of this uppermost formation along the water courses where erosion has cut through the overlying veil of Pleistocene deposits. Near San Antonio, as shown by the artesian well borings, they are represented in a great thickness of joint clays.

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[1] In the First Annual Report of the Geological Survey of Texas, page 20, the characteristic outcrops of Webberville beds are erroneously referred to the Wills Point beds of the basal Tertiary, and described as follows: "On the Colorado River it is seen cropping out at a point 16 miles by river below Austin, and 1 mile below the mouth of Onion Creek, in a bluff some 40 feet high and a mile long. Also at Webberville, on the line between Travis and Bastrop counties, where it is seen in a low bluff just above the water's edge. This is a much darker and more massive clay than that seen in most other outcrops. In the bluff 16 miles below Austin are found a few fragments of fossils, but they are all so broken as to make their determination very doubtful."

The investigations of the writer have shown them to contain the typical fossils and characteristic strata of the upper division of the Upper Cretaceous. These species are as follows:

Leda protesta.	Drillia? distans.
Corbula crassiplica.	Sphenodiscus lenticularis.

The uppermost Cretaceous formations of the eastern margin of the Black Prairie are succeeded by the old Eocene beds of the basement Tertiary. These in places are a narrow strip of clays or sandy clays which superficially much resemble and sometimes are indistinguishable from the Cretaceous formations, and which are in turn succeeded a few miles to the east by more arenaceous Eocene beds covered by forests of the Atlantic Timber Belt.

SURFICIAL AND ALLUVIAL DEPOSITS OF BLACK AND GRAND PRAIRIE REGIONS.

The Cretaceous formations of the Black and Grand prairies are veneered in places by detrital alluvial deposits, especially along the incised stream valleys, where such formations are known as bottom and second-bottom lands, and even upon the uplands of the eastern marginal region. These surficial formations have agricultural and hydrographic conditions quite different from those of the Cretaceous formations, and hence it is necessary that they be described. (See Pl. LXVI.)

Origin and Distribution of Alluvial Deposits.

UPLAND ALLUVIUM, SECOND BOTTOMS, FLOOD PLAINS, AND WASH.

The entire substructure of the Black and Grand prairies, in common with the whole Regional Coastward Slope, has been gradually rising above sea level, probably since Eocene time, although there have been alternating minor periods of depression. Accompanying this regional elevation has been corresponding degradation of the superfices through processes of erosion, and it has been etched over and over by streams. These have not only cut the present visible stream valleys, but in times past have occupied what are now the upland surfaces between valleys, where they deposited alluvium, which now makes no distinct topographic feature, but is only recognizable here and there as solitary patches or pieces of gravel. These oldest and highest deposits are especially conspicuous toward the eastern margin of the mapped area, occupying isolated summits, like that upon Bald Knob, near Manor, Texas. Formations of ancient origin no longer adjacent to stream courses, usually occupying divides, may be spoken of as upland gravel or alluvium. (See Pl. L.) Descending the slopes of the stream valleys successive terraces appear, which become topographically more distinct as one approaches the streams. Some of these old alluvial beds formed terraces far above the present level of the streams and are still recognizable as distinct benches. These distinct alluvial levels within the slope of the drainage valley and above the present plane of alluvial deposition may be termed second bottoms or old terraces, a fine illustration of which may be seen in Pl. VIII. Then there are often one or more alluvial terraces which, although seldom flooded, are within the limits of overflow. These are simply termed bottom lands. Finally there is the normal flood plain, which includes the stream bed proper. The relative positions of the upland alluvium, second bottoms, and flood plains are shown in figs. 34 and 35.

The flood plains, owing to the great difference in volume of the streams at their periods of maximum and minimum flow, are usually narrow in the Grand Prairie, but wide in proportion to the streams, and normally, in time of low water, have the appearance of ancient alluvial plains. Upon reaching the Black Prairie the flood plains increase in width and become very wide, often 2 miles across.

Another character of surficial deposits is the "wash" of soil and débris which is spread by the sheet floods from local showers over upland slopes, a process which is more fully described in the text of the Nueces folio (No. 42) of the Geologic Atlas of the United States. In the Black Prairie region this wash is very extensive, making a thick mantle of soil which intermittently creeps with each rainfall toward a lower and lower level.

These upland alluvium and alluvial terrace or second bottom formations of the Black and Grand prairies are parts of a series of phenomena which have wide and related development throughout the

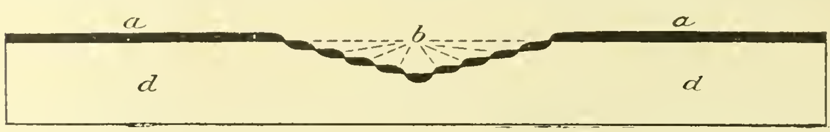

FIG. 34.—Alluvial deposits of the Black Prairie region. *a*, Upland gravel; *b*, valley terraces; *d*, underlying rock.

Regional Coastward Slope from the Cordilleras to the sea. Their final interpretation and the determination of their relation to the marine deposits of the Coastal Plain will require the collection and study of a vast number of data.

UPLAND ALLUVIUM OF UVALDE TYPE.

The upland alluvium (see Pl. L and cap rock, Pl. XLIII), which may in general be referred to the Uvalde formation, like that of the second-bottom formation, is the débris of the upstream regions, but almost entirely of the districts west of the Balcones fault line, and was largely made at a time when the streams of the Edwards Plateau reached base-level near the present borders of the Black Prairie and Grand Prairie subprovinces, probably in Miocene and Pliocene time. They record in a manner the great erosion which the Central and East-Central provinces suffered in those epochs.

West of the Balcones fault line these deposits may be found to occur as high terraces up the streams of the Edwards Plateau and the rivers of the Grand Prairie and the Central Province, where traces of them

OLD ALLUVIAL MATERIAL OF COLORADO RIVER, RESTING UPON THE EDWARDS LIMESTONE, AUSTIN, TEXAS.

are preserved in such streams as Onion and Barton creeks and Llano and Noland rivers, in certain flint bowlders on the higher slopes, far above the well-defined second bottoms. As these stream valleys emerge across the fault line the gravel deposits become more distinct and spread out away from the present streamways, finally coalescing within the Black Prairie Province across the present divides. This union takes place a few miles east of the Balcones scarp, usually over the area occupied by the Taylor marls, as seen in Williamson and Travis counties and the counties to the south.

UVALDE FORMATION.

The old upland deposits are hardly longer recognizable within the Grand Prairie region. Upon the isolated buttes of the Lampasas Cut Plain, like Comanche Peak, an occasional rounded piece of quartz or other gravel foreign to the region, attesting the former occupation of the area by alluvial deposits, can occasionally be picked up. Certain black sandy and gravelly lands on the outer margins of the Brazos in the vicinity of Whitney, Hill County, and around Elm Mott, McLennan County, are specimens of the older alluvium. Similar patches may be found occasionally on the high slopes or uplands in Grayson and other counties.

South of the Brazos the old alluvial formations are conspicuous features of the Black Prairie east of the Balcones fault zone, consisting of deposits of flint and limestone gravel embedded in a matrix of white calcareous marl which weathers into a typical black waxy soil. These deposits have been denominated the Uvalde formation.[1] This material is largely derived from the destruction of the Edwards formation. The Uvalde type of formation is especially well shown in the eastern part of Travis County, where it covers nearly all the higher divides between the streams, underlain by the Taylor marls, and it extends west in places to the Balcones fault line. It caps Bald Knob (altitude 675 feet) just west of Manor and is 25 feet thick at the latter place. Bald Knob is fully 275 feet above Colorado River. This material continues north nearly to the Brazos, its interior border passing diagonally across the strike of the Black Prairie from its western border at Austin to its eastern edge near Corsicana.

Near Holland, Bell County, 4 miles south of Little River and 200 feet above that stream, there are immense upland gravel beds lying beneath a black soil indistinguishable from the residual soils of the Black Prairie. This black soil is the residuum of a white, calcareous matrix in which the gravel is embedded. Gravel can be detected in nearly all the rich black soils from Noland River to Taylor and Hutto, and, while it extends far above the present streamway, it is not as yet positively

[1] See Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 244–247; also Nueces and Uvalde folios (Nos. 42 and 64) of the Geologic Atlas of the United States.

determined whether it caps the divides. This gravel is all of the Uvalde type.

Between Temple and Milano Junction, along the stream divide across the Black Prairie followed by the Gulf, Colorado and Santa Fe Railway, upland flint gravel begins to appear in great abundance, especially on the long upgrade east of Heidenheimer station. About 2 miles southeast of the latter station are high hills capped by the typical Uvalde material. One mile east of Rogers the flat country is covered with flint gravel, which is very abundant in the plowed soil of the fields. This continues 3 miles southeast of Rogers, where sets in a mesquite forest which is growing in a gravelly soil, the material of which covers the slopes and hills. Four miles from Rogers the gravel is a surface formation, 5 or 6 feet of its thickness showing in the railway cuts. This gravel extends to beyond Buckholts, where it is beautifully shown in scrapings and cuts. This country is composed of rolling hills with hog-wallow surfaces, and extends to a mile beyond Buckholts. At the latter point the gravel begins to have a red, sandy matrix. Four miles southeast of Buckholts the summits are of red loam, while the low, wide valleys are thickly covered with residual gravel, which continues 7 miles southeast to where the post-oak belt begins and to within 2 miles of Cameron, where there are large gravel beds. Cameron is near the border of the post-oak gravel soils and the parting of the Cretaceous and the Eocene formations, which are also overlapped by the gravel sheets.

Another section from Milano to Taylor also shows the relations of these upland gravels to the Eocene and Cretaceous. From Cameron to near Thorndale the substructure is Eocene. One-third mile east of Thorndale the Black Prairie begins, which here consists of dense growth of mesquite trees with an underbrush of nopal or opuntia. Two miles west of Thorndale the mesquite thicket ends and the gentle rolling open Black Prairie commences.

Four miles west of Thorndale, along the International and Great Northern Railroad, the gravel attains a depth of 18 to 20 feet. In a well at the section house 4¼ miles west of Thorndale it seemed stratified, as observed from the surface. The material is very coarse, many fragments being the size of a man's fist. Erosion has not exposed fresh surfaces to show the thickness at this point. Many individuals of *Gryphæa* and *Exogyra* are mingled with the gravel. Worn *Exogyra ponderosa* are also common. Elsewhere no flints are visible on the surface, but it is probable that these prairies are largely underlain by the gravel formation, the material of which is concealed by the grass and residual soil, for as the edge of this upland prairie is approached at a little creek east of Taylor the typical upland gravel can be seen making the edge of escarpments.

The Uvalde formation, or its equivalents, have not been studied between the Brazos and the Sulphur, and if it occurs there it may be to the east, well within the general Tertiary area. In southwestern Arkansas and the Choctaw Nation it is represented by an extensive deposit of upland gravel derived from the Ouachita Mountains and now capping the divides of the streams flowing south from them. (See fig. 21.)

There is no doubt that the Uvalde formation is of great age, probably as old as the Miocene Tertiary, and that it represents the deposition of an erosion epoch when the plateaus of the Central Province were being stripped of the Edwards limestone, of which the Callahan Divide is a survival.

SECOND-BOTTOM FORMATIONS.

The second bottoms are distinct terraces of the streamways, and vary in number in proportion to the age of the streams. (See Pl. VIII.) The alluvial deposits of the stream valleys are rather extensive and of several categories, forming in the through-flowing rivers, such as the Red, Brazos, and Colorado, many distinct benches or terraces, a type locality of which at Austin has been described in the Eighteenth Annual Report, Part II. In their seaward extension into the Coastal Plain these terrace deposits spread out and coalesce with those of parallel streams into estuarine and marine littoral deposits. In the Central and East-Central provinces the old second-bottom formations deposited by the streams above their present flood plains in times past are developed in both the through-flowing rivers of the type of the Red, Brazos, and Colorado and in the valleys of the major streams of the prairies, such as the Trinity, Leon, and San Gabriel. In the Colorado at Austin, for instance, six or more of these are well preserved; in Noland River near Temple three or more can be traced; in the Trinity at Fort Worth at least three; in the valley of Red River east of Paris a large number. It is impossible, inasmuch as these terraces have never been made the subject of detailed investigation, minutely to correlate or differentiate them, and the writer can only present such casual observations thereon as he has made from time to time.

The terraces of the major streams of the Brazos, Colorado, and Red rivers are made up largely of red sands and clays derived from the denudation of the Central Province, the color of which is conspicuous in contrast with the whitish tints of the Cretaceous substructure upon which they are deposited. (See Pl. XLIX.)

West of the interior margin of the Black Prairie these second-bottom deposits of the major streams are well developed in places, but are more restricted in width, owing to the harder structure of the canyon-like valley borders. In going east across the Black Prairie into a region of softer rock the streams were allowed greater latitudinal migration and the old levels of deposition correspondingly increased in area. Thus it is that the old terraces become especially abundant as the rivers cross from the hard rock districts into those of softer rocks in the Colorado at Austin, in Noland River at Belton, the Brazos at Waco, the Trinity at Dallas, and the Red River below Denison.

MATERIAL OF THE SECOND-BOTTOM ALLUVIAL FORMATIONS.

The material composing these second-bottom alluvial formations is principally that of the country drained by the upper and middle courses of the streams to the west. Where this material consists of foreign matter derived from the formations of the Central and Plains provinces, as it does in the valleys of the through-flowing rivers, it is easily distinguishable by its red colors and arenaceous character, but when it is composed of the calcareous material of the Cretaceous rocks of the Black and Grand prairies it weathers into black soils very difficult to distinguish from the residual soils of the Black Prairie. Thus it is that in the alluvium of the through-flowing rivers much of the débris of the Paleozoic and Red beds formations of the Central province is found. In the terraces of the Colorado may be recognized the débris of the Plains Tertiary, Cretaceous, Permian Red Beds, Carboniferous, Silurian, Cambrian, and Algonkian. In the Brazos the débris of the Carboniferous, Red Beds, and Cretaceous and Plains Tertiary may be identified. In Red River west of the mouth of the Kiamitia the material of the Plains Tertiary, the Red Beds, and the Cretaceous compose most of the débris. East of the last-mentioned stream, in Red River and Bowie counties of Texas, the southeastern portion of the Choctaw Nation, and southwestern Arkansas, there are immense surficial formations composed of the débris of the Paleozoic Ouachita Mountains.

In the rivers of the prairie proper, the Trinity, Paluxy, Leon, and San Gabriel type, the alluvium is nearly all derived from the Cretaceous, but is of two distinct and contrasting types. One of these, derived from the limestone formations, is of the nature of light-colored calcareous marls with pebbles of rolled fossils and Cretaceous limestone, usually accompanied by vast quantities of flint; the other, found only in the Leon, Bosque, Paluxy, and Trinity drainage, is made up largely of sands derived from the Paluxy and Trinity formations.

The alluvial material of the streams rising within the Black prairie between Trinity River at Dallas and Red River is nearly all redeposited black, waxy soil, derived from the Navarro, Taylor, and Austin formations and so resembling in composition the adjacent residual soils, both of which make a mantle of deep black loam, that the two are almost indistinguishable. The Sulphur River deposits are composed largely of the black, waxy material mixed with the Eocene sands.

UPLAND GRAVEL, UVALDE FORMATION, SOUTH OF AUSTIN, TEXAS.

SECOND-BOTTOM FORMATIONS AN INDEX TO DENUDATION OF CENTRAL PROVINCE.

While terraces of the same relative age and level are not always composed of similar material, the degradation of the Central province from layer to layer has been so uniformly progressive in geologic time that sufficient data are recorded in this material, when properly referred to its appropriate source, to enable us to interpret the history of the denudation of the vast Central Province and the recession of the scarps of the Great Plains and the Black and Grand Prairie regions. Thus it is that the older alluvium of the Colorado and Brazos basins is largely made up of flint débris derived from the Edwards limestone, which once covered the Central Province, while the newer terraces are successively made up of the older and older formations of the Central Province as denudation proceeded downward in the latter region.

TERRACE FORMATIONS ALONG THREE PARALLEL NORTH-SOUTH LINES.

It is impossible in the present paper to give full and accurate details of the occurrence and extent of the old alluvial terrace deposits, but the following data will afford some idea of their nature. The notes to be given may be considered as representing three north-south lines across the State from the Colorado to the Brazos. The most western of these is across the western margin of the Grand Prairie and the eastern border of the Central Province. The middle line crosses the region near the junction of the Black and Grand prairies, while the third line is approximately along the eastern border of the Black Prairie and the Eocene area.

Along the western line it may be said that the Colorado in eastern Burnet County, the Llano in Llano County, the Brazos in Parker and Hood counties, and the Red adjacent to Cooke and Grayson counties show each at least two distinct terraces of old alluvial formation.

The Llano branch of the Colorado shows a lower bluff of light-brown loam fully 20 feet thick and standing 50 feet above the present flood plains. Still above this—75 feet above the river—there are deposits of coarser flint bowlder material, preserved as coarse gravel the size of a child's head, from which the softer and finer material originally accompanying it has been removed. The second-bottom deposits of the Colorado are not well shown in the course of that river through the granite area of the Burnet uplift, but above and below this, in San Saba and eastern Burnet, a lower terrace of fine red loam and an upper one of coarse residual flint bowlders are shown. These phenomena have not been studied, however, to any considerable extent.

The Brazos along the line of Hood and Parker counties shows extensive terraces of lower major second-bottom benches of red loam, above which, as can be seen south of Powells Ferry, there is a coarser deposit of bowlder flint material. The Brazos at Granbury shows two well-defined old terraces composed of rich sandy red loam rising fully 100 feet above the present stream. These second bottoms occupy extensive areas at intervals along this river entirely across the Cretaceous prairies.

The second bottoms of Red River are conspicuous along the course of that stream through the Grand Prairie along the line of Cooke and Grayson counties, being composed of fine red loam and gravel 30 feet or more in thickness and standing fully 100 feet above the present streamways (see Pl. LII, figs. *C*, *D*). No attempt has been made to differentiate the minor terraces of any of these streams, but the phenomena are most extensive and show the vast prehistoric degradation of the Central Province.

The secondary streams along the western border of the Grand Prairie, such as the Llano, Leon, Cowhouse, Indian Creek, and the Washita, all show at least one well-defined second-bottom terrace, usually composed, except those of the Washita, of fine whitish, calcareous loam and pebble and the débris of the Trinity sands.

Along the medial line of north-south sections following the borders of the Black and Grand prairies the terraces become more numerous and spread out over wider areas. Three marked terraces persist and dominate the minor ones.

In a previous publication[1] a minute analysis of the series of alluvial terraces in the vicinity of Austin has been given. Here there are at least seven recognizable terraces distinctly referable to the old alluvium of the Colorado and below the upland deposits of the St. Elmo and Uvalde type (see fig. 35). At Austin these are at altitudes of 215, 205, 195, 130, 105, 80, and 60 feet above the river, and are divisible into three general groups. Those at 215, 205, and 195 feet above the river level are the higher or Asylum group; those at 130 and 105 feet, the Capital terrace, and those at 60 and 80 feet, the depot group, each of which is a very marked and distinct feature. A description of the Asylum terraces will suffice to show the general character of all these phenomena.

ASYLUM TERRACES AT AUSTIN AND SIMILAR TERRACES ELSEWHERE.

The Asylum terraces, which are the oldest and highest of the group at Austin, are the most extensive and conspicuously developed. A typical example of this is seen at the State insane asylum grounds, situated nearly 3 miles north of the Colorado and over 200 feet above its level. This consists of a wide constructional plain of red sands, clays, and gravels, containing much of the Burnet granite, and is covered by a dense forest of post oak.

A similar terrace at the junction of the Black and Grand prairies on

[1] Geology of the Edwards Plateau and Rio Grande Plain: Eighteenth Ann. Rept. U. S. Geol. Survey, Part II, 1898.

the north side of Noland River, between Belton and Temple, occupies a like position. This is often several miles wide and is composed of red sand with numerous pebbles and gravel beds, some of the latter being extensively worked east of the river for ballast for the railway. At this locality a pit, nearly 30 feet deep, reveals a lower portion composed of fine white gravel and sand. Unconformably above this is yellow, coarse-bedded, laminated sand, which is deposited over an unequal erosion surface. At the surface there are 3 feet of red gravel and clay, which is unconformably deposited upon the yellow sand. This ancient terrace much resembles, in position and size of particles, the Asylum terrace at Austin, and is likewise covered by a dense growth of black-jack and post oak. The material is mostly Cretaceous débris.

Another terrace of like character is found on the north side of the Brazos Valley at Waco. This terrace level is also apparently well developed in the northern and eastern portions of Dallas, on the Trinity, where it occurs as high as 100 feet above the streamway. High terraces corresponding to this level also occur in Cooke and Grayson counties adjacent to Red River. The Colorado terrace contains pebbles of Paleozoic limestone, Cambrian quartzite, and Algonkian granites; the Brazos terrace is made up of Carboniferous and Permian débris; the Trinity terrace, of the débris of the Trinity sand with minute pebbles derived from the disintegration of the Trinity conglomerates; and the Red River terrace above the mouth of the Washita, of the débris of the Red Beds and the Llano Estacado.

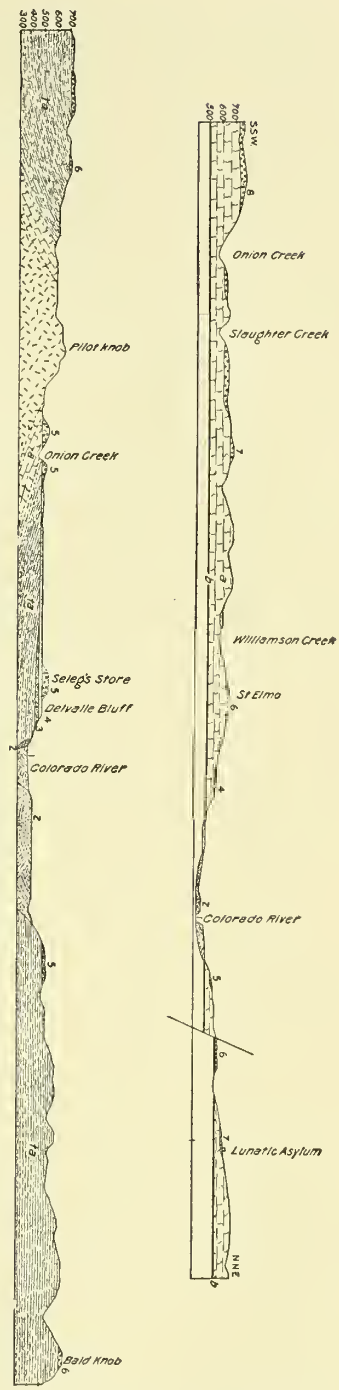

FIG. 35.—Cross sections of the alluvial formations of the Colorado Valley, Travis County, Texas.

The high terraces of this general character extend down the rivers mentioned in widening belts as far as the eastern margins of the Black and Grand prairies, where they fan out on either side and coalesce across the divides, so that an almost continuous belt of alluvial material with small pebbles extends along the parting of the Cretaceous and Tertiary, overlapping the rocks of both periods, from Caldwell County northward to the Trinity, through Travis, Williamson, Bastrop, Milam, Falls, Limestone, Navarro, and Henderson counties. The coastward continuation of this formation and its relations to the marine deposits of the coast prairies have not been determined. In general it represents an epoch when stream erosion to the west had cut through the calcareous strata of the Comanche series into the Basement Trinity sands and Paleozoic rocks of the Central Province, and is the product of the denudation of the sands over vast areas of the Central and East-Central provinces.

Another terrace allied to the Asylum terrace, occurring 130 feet above the river, at the mouth of Onion Creek, in Travis County, is of interest because in it were found fossil remains of vertebrates of supposedly Pliocene age. This formation is a marked feature of the streams of the prairie class, and consists of a calcareous marl accompanied by small pebbles. It is well defined in all the streams of the Black and Grand prairies and the Central Province north to Red River, ordinarily making a well-defined terrace above the present flood plain of the secondary streams.

TERRACES OF LOWER ALLUVIUM.

Below the level of the Asylum terrace there are five or six distinct terraces in the Colorado and Brazos valleys within the Black Prairie region.

Continuing north from the Colorado, along the medial line of sections, it may be said that the alluvial deposits of Noland River between Belton and Temple are exceptionally fine. On the east side of this stream there are three distinct alluvial plains above the present flood plain. The first of these is about 30 feet above the river and makes a well-defined second bottom, often 100 yards or more in width, composed of a light-colored calcareous marl. Still above this is a second bench, 20 feet in height, composed of the same material as the first terrace. Both of these are of the Onion Creek type. Over half a mile back of the river there is an upland plain, 150 feet above the stream, making the highest and oldest alluvial deposit, the Asylum terrace, previously mentioned.

Along the Trinity, from Fort Worth eastward, second-bottom phenomena are very conspicuous. At Fort Worth, on the north side of the river, there is a wide alluvial plain, fully 75 feet above the river and nearly a mile wide. Still above this, on the south side east of the town, there are old gravel beds over 100 feet above the river. At Dallas, the old alluvial deposits are very conspicuous, extending through the southern and eastern portions of the city. Several distinct levels rising as high as 100 feet above the Trinity are recognizable. At Denison, on Red River, there is an alluvial bench on the south side of the stream 5,000 feet wide and 100 feet above the stream. On the north side, in Indian Territory, there are higher and older benches, reaching fully 195 feet above the stream southeast of Marietta. Another terrace, 20 feet thick, rises to 40 feet above the river.

ALLUVIAL DEPOSITS ALONG EASTERN BORDER OF BLACK PRAIRIE.

The alluvial deposits along the eastern border of the Black Prairie region are very wide and extensive. In this general region many of the formations which make restricted stream terraces along the lines previously described spread out and coalesce into an almost continuous sheet of upland gravel, concealing the Cretaceous and Tertiary boundary, while newer and lower terraces continue adjacent to the streams. The Colorado, near the Travis-Bastrop line, shows a terrace 30 feet thick near the river at Webberville. This forms a flat belt 40 feet above low water and over a mile in width. More than a mile back of the river is a bluff surmounted by another terrace of larger and coarser material standing 120 feet above the river, that being very near the level of the Capitol terrace at Austin. Above this all the uplands are covered by a fine silt with small pebbles, which reaches 20 miles south to Lytton Springs and northwest to Mustang Creek, Williamson County.

Some years ago the writer's former assistants, Messrs. J. W. Stone and J. A. Taff, studied the surface phenomena along this line between Travis County and Trinity River, along the eastern border of the Black Prairie. The following notes were furnished by them:

DETAILS OF OCCURRENCE.

Pebbly drift occurs over the surface 2 miles above the junction of Mustang and Brushy creeks. This is of various colors and character. Many slightly waterworn *Exogyra ponderosa* and *Ostrea larva* are scattered among the pebbles in the bed of the creek. They show that they have been transported but a short distance.

From Mustang Creek north to the International and Great Northern Railroad the alluvial drift continues to be sparsely scattered, and yet of a depth in places sufficient completely to cover ground on high land. This is made up of well-worn foreign pebbles of red, gray, and varicolored quartzites, small fragments of flint quartz, and sandy fragments of silicified wood.

Two miles west of the Williamson and Milam county line, in Turkey Creek, pebbly drift of the same character as that above described continues in considerable quantity on the upland surfaces. The topography is undulating. From Turkey Creek near the Williamson and

Milam county line north to San Gabriel River the old alluvium almost completely covers the surface.

Waterworn drift pebbles occupy the upland country outside the river flood plain in the vicinity of San Gabriel post-office to a depth of 10 to 30 feet. These are of the same character as those cited above, viz, various colored quartzite, quartz, unknown metamorphic rocks, conglomerate, and flint. Rarely fragments of silicified wood, and *Gryphæa* and *Exogyra ponderosa* are found. There is much fine sand. The surface is completely covered by alluvium, often to a depth of several feet, between the San Gabriel at the mouth of Alligator Creek and Little River, 2 miles below the mouth of Clays Creek. In places post-oak timber grows on this alluvium-covered surface.

At the edge of the flood plain of Little River are terraces similar to those on Colorado River between Austin and Webberville. Many springs issue from their bases into the river valley. Two distinct terraces were here observed. The upper one is nearly a mile back from the river and about 100 feet above the flood basin, while the lower terrace is about one-half mile distant and nearly 50 feet high.[1]

On the south side of Brazos River terraces are distinctly shown. Near the south line of Falls County the upper terrace is about a mile from the river. At the top fine sand and pebble occur; below it is coarser. This terrace is of the same material as that occupying the upland surfaces farther south, previously described. The lower terrace is not always continuous, for in places the river approached sufficiently near the upper terrace to cut the lower one completely away. On the north side of the Brazos, as at Little River, the upper terrace grades into the lower, so that it is often not possible to tell where the one ends and the other begins.

The materials composing these terraces are practically the same on both sides of the river. The flood plain on the north side grades into the lower terrace opposite Adhall. Between Little River and Adhall, and between Adhall and Cameron, alluvium occupies the upland surface, often to a depth of 30 feet. In the vicinity of Cameron the fine sand becomes abundant and is apparently a later deposit than the coarse upland drift of the higher ground. The tooth of a *Mastodon americanus* was found in this sand, in a railroad cut, 10 feet beneath the surface.

On the west side of Big Creek Basin sand appears and continues 3 miles to the west. This sand was believed to be Brazos River drift deposit. It is fine, yellow to brown sand on the surface, and the surface is so level that no deep exposures are seen. West of the sand belt pebbles become abundant, in places completely covering the surface.

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[1] The whole area between Little River and the Brazos was flooded to a depth of 65 feet during the great flood of July, 1899.

Collections taken from these contain quartz, quartzite, veined blue, red, and gray conglomerates, chert, flint, silicified wood, and a hard, smooth, black metamorphic rock.

The flood plain of Big Creek opposite Stranger, which is typical of all the minor creeks north to Red River, is nearly a mile wide and is covered by a fine black silt, very sticky, derived from the Black Prairie.

From the Brazos River flood plain opposite the south line of Falls County to the east branch by way of Reagan, and from Little Brazos River east of Reagan to Brushy Creek, the surface rock is composed of river sand of geologically recent origin; no rocks beneath it were to be seen. In the vicinity of Reagan and northward there is some coarse material in the alluvial sand. The pebbles are not large and are composed of flint, quartz, quartzite, and silicified wood.

The surface between Pond and Briar creeks, Falls County, is nearly level and but little above the flood plains of the creeks. No fresh exposures could be found. Coarser pebbles of the drift, noted before, are absent here. Only small pebbles of quartz and quartzite remain, with fine sand. This is believed to be the upper edge of a recent flood basin of Brazos River. In the flood basins and banks of the larger creeks and small rivers near the Cretaceous and Tertiary parting, exposures of rocks in situ are rarely found because of the great depth of alluvium. In most cases the streams are sluggish and the banks high where they approach the sandy timbered region, and the beds of these streams are now rapidly shifted, as would not be the case were the currents swifter and the basins more shallow.

These facts and the occurrence of such an abundance of upland alluvium on the high ground make it difficult to locate the Cretaceous-Tertiary boundary. The varied erosion when the alluvium was originally deposited, together with the erosion that has since taken place, considering the low dip of the rocks, has no doubt cut the border into a tortuous line and in many cases left remnants of Tertiary rocks in the Cretaceous area.

West of Hornhill and Brushy creeks upland alluvium drift continues widespread, but is less abundant than farther south. The pebbles are of the same character. Near the high land between Christmas and Cottonwood creeks, and eastward along the divide to Kirk, the pebbly alluvium increases in quantity until at the latter place it almost covers the rocks beneath. Some of the pebbles are as large as hens' eggs.

Between Christmas Creek and Long Branch a mantle of pebbly alluvium and sand almost covers the Cretaceous rocks. This is composed of the same material as that previously collected in the Brazos River Basin.

The alluvium of the Rio Navasota flood plain is very deep. The flood basin averages $1\frac{1}{2}$ miles in width. Its surface is a fine black silt (except near the river's bank, which is a fine sand), very rich, and nearly covered by a dense forest of briars, thorns, elm, ash, and swamp oak. Between Long Branch and Rio Navasota the alluvium completely covers the rocks of the substructure. A large number of the pebbles are quartzite, white, yellow, and other colors. About one-fourth are black and red metamorphic rocks, sandstone, silicified wood, flint, etc., of unknown origin. Few of the pebbles weigh more than a pound.

From the Rio Navasota southwest of Tehuacana to Corsicana the alluvium is thinly scattered on the upland. The pebbles are small and consist of quartz and quartzite. This alluvium continues over the surface from Corsicana to the outer margin of the Trinity River alluvium at Chatfield.

The old alluvial deposition of Trinity River is enormous along this line. To the west this river flows through the greatest thickness of Trinity and Woodbine sands of the Cretaceous, and this material makes the alluvium for the most part, with often a small percentage of red and yellow clay. This river alluvium is evidently a later deposit than coarser material on the uplands between the river and creek basins, for the latter is cut away or covered up by the former and its place occupied by entirely different material.

No rocks of the substructure are exposed beneath the Trinity River alluvium along the Cretaceous border across Henderson County. This whole area is covered by oak, hickory, elm, etc., except an occasional glade having impervious clay subsoil. Possibly these glades are small prairies or islands of Cretaceous or Tertiary surrounded by alluvium. Some of them, especially the one at the south end of Porters Bluff section, have hog-wallow surfaces, and all are so level that no fresh exposures could be found.

From Kaufman County north the alluvium of the valley of the Sabine obscures the underlying rock. The Sabine, which is crossed near its head by this line, shows some terraces, but feebly developed. In the second bottoms of this stream are seen low, circular eminences, seldom exceeding 20 feet in diameter or 3 feet in height, which resemble Indian mounds. These peculiar hummocks are a marked feature of all the bottoms of the forested region as far north, at least, as the Arkansas.

The Sulphur has wide, low bottoms and second bottoms of a different type from those of the rivers of the prairies. These have not been critically studied.

Red River along the borders of Lamar, Red River, and Bowie counties makes a remarkable display of bottom and second-bottom phenomena, often miles in width; but they belong to the Coastal Plain, and need not be discussed at present.

Résumé of Alluvial Phenomena along Tertiary-Cretaceous Parting.

Some features of the occurrence and character of the alluvium along the Tertiary-Cretaceous parting justify close study. North of Trinity River the belt of highland alluvium bears farther east on the Tertiary area, where it is less abundant and of coarser material and character, as seen near Kemp. It continues parallel to the parting and is thickest on high divides between creeks and rivers. The character of alluvium is substantially the same throughout each of the hydrographic basins of the principal rivers, but it is not the same in any two of the three basins of Colorado, Brazos, and Trinity rivers. Occasional pebbles in one basin become abundant in another. For instance, in the Colorado Basin the prevailing material is flint, often in large fragments. Similar but smaller pebbles occur in the alluvium of Brazos and Trinity basins. In the Colorado Basin quartzite is not abundant, but this is the prevailing rock in the Brazos Basin. A very hard subangular quartzite, often in large fragments, is common in the Trinity Basin, especially on the north side; this is rare in the valleys of the other rivers.

Summary and Conclusions.

The writer regrets that too little detailed study has as yet been made to trace out the beginning, development, and ultimate disposition of each level or to correlate all the terraces of the different streams with one another. Nor can this be done until there are better maps of the Texas region and more interest is taken in local geology.

Collectively the terraces represent stages in the history of the restoration of the Regional Coastward Slope, and are intimately connected with similar phenomena extending from the Cordilleran front to the sea.

The cutting through of the older terraces by the streams to lower levels indicates successive renewals of uplift. The terrace deposits themselves indicate pausation periods during the general uplift which has brought the Regional Coastward Slope above the sea since the close of Cretaceous time.

In general the width of all the terraces increases coastward, and theoretically they fan out into marginal sea deposits. Terraces of the Asylum type, for instance, which can be clearly identified with a particular stream in the western part of the Black Prairie region, spread out and encroach upon the divides to the eastward until finally, toward the eastern margin of the Black Prairie, they coalesce by spreading across the dividing area between the streams.

This area of fanning out or coalescence was in most instances at marine base-level at the time of deposition. This area of shore-line deposition has migrated back and forth during the different epochs of Tertiary and Pleistocene time. The line of base-level of each terrace is different in location and should indicate the situation of the coast line for each terrace epoch. During some of these epochs, as that of the Uvalde formation, the shore line was approximately coincident with the present junction of the Black and Grand prairies, a little east of the Balcones escarpment. During the epoch of the Asylum terrace stage it was at the eastern border of the Black Prairie south of the Sabine. The areas of coalescence of the lower terraces lie eastward, within the unstudied region of the Coastal Plain.

The area of what was formerly the level of the oldest, or Uvalde, deposits was a constructional plain which has been later elevated and then dissected by the newer drainage developed upon it, so that the formation now occurs only on isolated hills and divides, like Mustang Ridge, Travis County, and the eastern prairies of Williamson County south of the Brazos. Furthermore, the eastern border of the former coastal plain, composed of the Uvalde formation, approximately corresponding with the present eastern margin of the Black Prairie, was later bordered by a still lower marine base-level, during the epoch of formation of the Asylum terrace, so that the broadened marginal seaward sediments of the latter coalesced along this line. The broad sea-border sheet of Asylum terrace deposition was in turn elevated, dissected, and degraded by later streamways. Thus these processes have continued across Texas from Tertiary time to the present.

It is difficult to more than surmise the age of the different alluvial formations. The oldest upland gravel extends as terraces back into the canyons of the Edwards Plateau, which were eroded at least as far back in time as the pre-Lafayette erosion epoch, which is considered to be of early Pliocene age. If this is true, the Uvalde beds which occur in the bottom of these canyons are as old as late Pliocene age. But the still younger Asylum terraces which were deposited in the old valleys 140 feet lower than the highest of the Uvalde beds at Austin, if the evidence of a fossil *Bos scaphoceras* Cope is to be relied upon, are of late Pliocene age, and hence the Uvalde terraces may be as old as the Miocene.

The lower terraces of the Colorado, of the Capitol and depot type, may safely be considered to represent the Columbian Pleistocene.

Throughout the region, in nearly every county, notably at Indian Creek, Comanche County; near Granbury, Hood County; at Dallas, Gainesville, Oatman Creek near Llano, and other places, remains of *Mastodon* have been found in the surficial deposits, but there are no definite data for determining whether these were found at any particular level.

The correlation of the alluvial formations of the Black and Grand Prairie region with the post-Cretaceous sheets of the Coastal Plain, of which they may have in times past been the upstream continuation, is a problem for future research in Texas. Nothing is now known of the relations of the newer terraces to the Pleistocene deposits of the Coastal Plain east of the Black Prairie.

The coastward continuation of the Uvalde formation is probably the Reynosa formation of Penrose, seen on the Lower Rio Grande. Its gradation into marine deposits of the Coastal Plain has not as yet been traced out.

IGNEOUS ROCKS.

The Black and Grand prairies north of the Colorado are singularly free from igneous rocks. At only one locality is there a known outcrop of volcanic material. This is just east of Austin, where a small neck protrudes, one of the outlying phenomena of the Pilot Knob area (see Pl. XLIII), which has its main development just south of the Colorado, in the Black Prairie of Travis County, and which is more fully described in the Eighteenth Annual Report of the United States Geological Survey, Part II (1898), pp. 256–257.

A single dike is known to occur within the area of the Black Prairie in the vicinity of Rockwall. This is sandstone material occupying fissures in the Taylor marls, and is traceable for a considerable distance through Rockwall County.

GEOLOGIC STRUCTURE.

The arrangement of the rock sheets, including their horizontality, inclination, thickness, outcrop, and relations to other strata, like the assemblage of material into an edifice, is known as the geologic structure. (See Pls. LII and LIX.) The character of the geologic structure—the arrangement of the rock sheets relative to one another—is one of the chief factors controlling the occurrence and distribution of rock waters and their availability to mankind.

The geologic structure of the rocks described in the preceding pages will now be set forth. It will greatly assist the reader if the order of succession of the beds or formations (given on Pl. XVI, p. 110) which make the explored crust of the region be kept in mind. Their order of superposition is illustrated in the sections and profiles.

Three great structural groups of rocks.

By examining the profiles (see Pl. LXVIII, figs. AA–JJ) it will be seen that for the purposes of this paper all the rock sheets may be regarded as falling into three great structural groups which rest unconformably upon one another. The first of these includes all the pre-Cretaceous rocks, which are in places strongly tilted, or even folded, and have an inclination largely away from the present seacoast, or in a direction toward the Cordilleran region. The second group embraces all the Cretaceous and later formations, and these are gently tilted so that they incline (or dip) toward the present sea borders. The third group includes the surficial and local formations. The first-mentioned group may be said to be the system of the Paleozoic floor or basement; the second, the system of the coastward incline. The third system is of secondary importance, and need not be further considered.

PALEOZOIC BASEMENT.

The Paleozoic rock sheets may be seen outcropping from beneath the interior margin of the Western Cross Timbers and thence west across the Central Province. From the fact that the Cretaceous rocks can actually be seen resting upon these Paleozoic rocks of the Central Province and that the deep drill holes of the artesian wells far coastward, after passing through a thick covering of the more horizontal Cretaceous rocks, often penetrate the same Paleozoic rocks as those now outcropping along the western border, it is known that the Paleozoic rocks make a floor or foundation beneath the Grand and Black prairies, upon which the Cretaceous rocks are laid down.

The rocks of the Paleozoic basement can be seen extending from beneath the western edge of the Grand Prairie along its entire course. Well drills at several places, notably at Denison, Fort Worth, and Copperas Cove, after passing through the Cretaceous rocks, have penetrated the underlying Carboniferous floor at depths of 1,200 feet at Fort Worth, 1,900 at Waco, and 2,200 feet at Austin. At Fort Worth the drill went through 1,200 feet of Paleozoic rocks below the Cretaceous. The Paleozoic rocks also outcrop in one or two places as inliers within the Cretaceous area, notably south of Lampasas.

Furthermore, from the fact that remnants of the Cretaceous rock sheets, like those making the Callahan Divide, are still found resting upon the Paleozoic rocks far west of the present interior border of the main Grand Prairie area and well within the Central Province—in fact, extending completely across it—the conclusion is inevitable that most, if not all, of the Paleozoic rocks of the Central Province, with the exception of the Ouachita Mountains, were once buried by the Cretaceous rock sheets which formerly extended west to the Cordilleran region. We also know that the present interior margins of the outcrops of the rocks of the Grand and Black prairies are retreating or receding east, as shown by the erosion of their western escarpments.

It is known that the Cretaceous rocks become nearly horizontal as they cross the Central Province, and that on its opposite or western side there are other cliffs (the Breaks of the Plains) which face east or opposite those of the Black and Grand prairies and which are receding in an opposite or western direction. These facts indicate that the Central Province may have once been the site of a gently arched monocline of Cretaceous rocks, the wide—almost flat—crest of which has been peeled away layer by layer through erosion, reexposing in places the extensive area of the old Paleozoic floor.

WICHITA PALEOPLAIN.

Wherever contacts are seen between the overlying Cretaceous rocks and the underlying Paleozoic rocks they are found to be unconformable, and inasmuch as the same stratum of Cretaceous rocks rests in different places upon the planed-off edges of different layers of the Paleozoic rocks, the conclusion is reached that the Paleozoic rocks endured a long period of erosion prior to the deposition of the Cretaceous rocks, and that this erosion took place during an interval of time before the invasion of the Paleozoic rocks by the Cretaceous sea. This erosion epoch, as we know by the absence of marine Triassic and Jurassic sediments, must have extended through a vast interval of time. It is also logical to surmise that the degraded Paleozoic land was once much higher, and that it once possessed irregularities of surface, which were lowered and smoothed down toward the general level of the sea (base-leveled). An old eroded land surface of this character

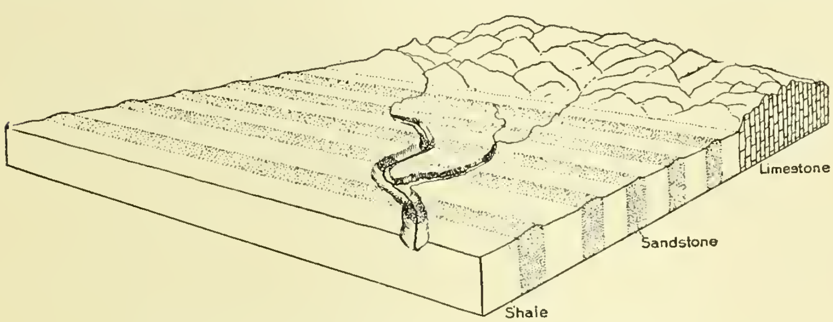

FIG. 36.—Uncovered Wichita paleoplain, Ardmore, Indian Territory.

may be geologically termed a paleoplain, and we may call this particular pre-Cretaceous surface which underlies all the East-Central, Central, and Great Plains provinces the Wichita paleoplain.

RESTORATION OF CONFIGURATION OF PALEOPLAIN.

Too little is as yet accurately known of the Wichita paleoplain to outline correctly its concealed configuration, but sufficient is known to state that it represents what was once an extensive land area in Jurassic time which was base-leveled and invaded by the sea in Cretaceous time. That portion making the Paleozoic floor of the Black and Grand prairies is only a part of the entire vast paleoplain which occupies all of what is the present Greater Plains region lying between the old nuclei of the Cordilleras on the west and an indefinite boundary situated somewhere east of the present Black Prairie, and between it and the present Texas gulf coast.

That irregularities of configuration once existed in this pre-Cretaceous land is also shown by some of their degraded remnants that still persist, like the Ouachita Mountains, which were not completely buried beneath the Cretaceous sediments, and the Burnet uplift, which was finally buried before the close of the Lower Cretaceous. At the beginning of Cretaceous time a plateau stretched west, from the eastern edge of which rose a system of mountain folds, of which the present Ouachita Mountains were a part. This eastern mountainous crest comprised the Massern Ranges of the Ouachita uplifts still surviving in Indian Territory and their former southward continuation from central Indian Territory near Atoka through Texas, which is now buried beneath the Grand Prairie. From the facts at hand the buried portions of this old land seem to have been lowest along Red River and to rise from the Brazos south toward the Colorado, being highest in the Burnet district. The axis of highest elevation of their buried portion seems to extend from Bowie to the western edge of Comanche County and south to Burnet.

The vast country to the west or on the interior side of this mountain belt was a sublevel plateau, lower than the crests of the eastern border mountains, but generally standing far above the level of the sea. This plateau was composed of Red Beds formations—the accumulations of a great interior sea in Permian and Triassic time—the surface of which extended as a gently rolling plateau far west to the nucleal Cordilleran summits existing at that time.

In addition to the main Appalachian-like folds of the eastern Ouachitan uplifts, or Massern Ranges of southern Arkansas and Indian Territory, and their buried continuation south beneath the Grand Prairie of Texas, which attended the eastern border, there were certain other mountain ranges within the main area of the great Wichita paleoplain which crossed it in an east-west direction. The chief of these were the Wichita-Arbuckle uplifts of Oklahoma and the Burnet uplifts of south-central Texas.[1]

The western continuation toward the Cordilleras of the old ridges of Paleozoic limestones and granites making the Wichita-Arbuckle uplifts, which stretch north of west from south-central Indian Territory near Atoka to the one hundredth meridian, is still buried beneath the Tertiary plains formations which conceal the paleoplain in the

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[1] The apparent alignment of the granitic outcrops in Texas, Indian Territory, and Missouri in northeast and southwest directions, together with a supposed similar alignment of outcrops of allied rocks at intervals along the eastern front of the Cordilleran region of Colorado, New Mexico, and Trans-Pecos Texas in a northwest-southeast direction, has suggested the existence of two elongated approximately north-south converging axial lines of fundamental rocks in the widely separated Cordilleran and Central regions, which were apparently the geologic foundations, and upon which all subsequent structure was laid down. These two major lines of ancient rocks, the one accompanying the Cordilleras with a supposed continuation into Mexico, the other on the east extending from the Ozark district of Missouri to the Burnet district of Texas, have been considered a more or less continuous V-shaped Archean foundation which influenced the entire history and structure of succeeding geologic epochs. This view of the arrangement of these older rocks, in the light of more recent knowledge, is not tenable.

As will be seen on closer analysis, the eastern granitic outcrops in Texas and Indian Territory do not occur in linear axial arrangement as described. It is doubtful whether the widely separated outcrops of its members are even genetically related. So far as observed, these outcrops represent ancient local occurrences of different geologic age.

Great Plains region. They divide the Texas subprovince of the Central Province from the northern or Oklahoma-Kansas subprovince, and have no immediate bearing upon the Black and Grand prairies, except that their presence in Cretaceous time so interfered with the northern migration of the Cretaceous seas that the waters were deflected around them, causing a variation in the lithologic details of the synchronous Cretaceous sediments north and south of this barrier in Kansas and Texas.

Along the western half of the northern border region of the Grand Prairie these older rocks occur as the central axis of the folds of the Arbuckle group of the Ouachita system, and if their strike should be continued in a south-of-east direction it would cross Red River in the vicinity of Clarksville, Texas, and directly across the trend of the Massern or eastern ranges of the Ouachita uplifts.

Southward, as exposed in Burnet and Llano counties, there was the great mass of granitic and older Paleozoic rocks of the Burnet uplift, which was a monadnock in the Wichita paleoplain. The portion of this now exposed by erosion indicates that it is the eastern terminus of a long east-west swell which extended from Burnet County west

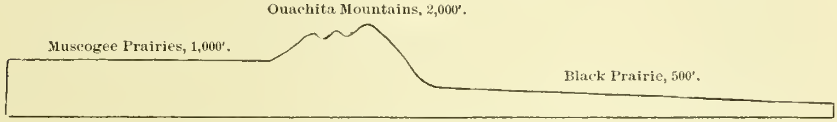


FIG. 37.—Profile north and south across southern Indian Territory, showing coastward scarp of Wichita paleoplain.

toward the Cordilleras, and that the southern and eastern borders of its harder, resistant structure largely determined the feature known as the Balcones fault, to be described later. That this protuberance persisted above the general level of the Wichita paleoplain far into Cretaceous time is attested by the manner in which the successive Cretaceous sediments embedded it until they finally overcame it at the close of the Fredericksburg subepoch.

Still a third feature of the Wichita paleoplain, and one having a most important bearing upon the subsequent Cretaceous geology, as ascertained by a study of the artesian-well drillings, was the scarp-like character which the mountainous east edge of the old plateau presented toward the sea, just as the south front of the Ouachita Mountains presents a similar slope toward the Coastal Plain in southern Arkansas and northern Texas to-day. A profile from the prairie plains of eastern Oklahoma across the Ouachita Mountains to the Grand Prairie of southern Indian Territory would be very similar to that of the ancient topography of the Wichita paleoplain, showing the elevated interior plateau, the mountain folds along its edge, and a steep descent to the Coastal Plain. (See fig. 37.)

STRUCTURE OF PALEOZOIC BASEMENT OF WICHITA PALEOPLAIN.

Let us now briefly examine the geologic structure of the Paleozoic floor forming the great Wichita paleoplain. The granites and older Paleozoic rock strata of Cambrian and Silurian age, exposed only in the Burnet district and the Wichita-Arbuckle folds, are probably part of an older or pre-Carboniferous mountain structure, but this question has not been positively determined. The absence of the Upper Silurian, Devonian, and Lower Carboniferous rocks is circumstantial evidence of the existence of land in these epochs. No knowledge exists of the condition of occurrence of the pre-Carboniferous rocks in the area now concealed by the Cretaceous formations between the Colorado and Red River, or in the Ouachitan uplifts east of the Missouri, Kansas and Texas Railway and south of Arkansas.

The rock sheets of the Carboniferous system occurring in the mountains along the coastward margin of the Central Province and beneath the interior margin of the Black and Grand prairies, as has been described, are a plexus of closely folded strata, which are most intensely folded to the coastward, revealing the lowest strata in the latter direction. The folds become more open and less complex toward the interior, and finally the uppermost strata, which are least folded, dip away to the west and northwest beneath the Central Province with but little deformation.

The Carboniferous rocks of the northern border region, embracing the Massern portion of the Ouachita system lying east of the Tishomingo district, are closely folded and overthrown and represent the interior portion of a vast anticlinorium.

There can be no doubt that the folds of these mountains now exposed are the marginal remnants of the interior side of a long belt of Appalachian-like mountain folds, the former coastward border of which was planed off by base-leveling before and during early Cretaceous time and buried beneath the system of rocks of the coastward incline. The coastward extension of the planed-off folds of this mountain system, base-leveled as above stated, may be seen and traced for many miles south of the Ouachita front in southern Arkansas and the Choctaw Nation, well within the Cretaceous area, where its strata are exposed by the deeper stream cuttings, and there is every reason to believe that it lies buried beneath the Grand Prairie.

The uppermost Carboniferous (or Permo-Carboniferous) and Permian Red Beds series of rock sheets, comprising the chief formations of the Central Province or plateau portion of the old Wichita paleoplain, with the exception of those of the little Smithwick district of the Burnet Country, occur as the eastern limb of a synclinal trough lying between the Grand Prairie and Cordilleran provinces, which dips away from the eastern belt of folded Carboniferous rocks or old mountains.

This westward inclination in a direction opposite to that of the continental slope and the overlying Cretaceous rocks, with a few local exceptions, prevails throughout the Central Province and beneath the western margin of the Grand Prairie. Beneath the Plateau of the Plains, in the trough of this great syncline, the strata become subhorizontal. When these rocks appear again in the Pecos Valley west of the Plateau of the Plains their dip is east from the Cordilleran front. This trough, except where broken by the disturbing element of the Ouachita Mountains, is of great length and width. The eastern limits of this vast syncline, where it flexes upward into the Ouachita folds, is buried in Texas beneath the Cretaceous rocks of the Grand and Black prairies.

STRUCTURE OF CRETACEOUS FORMATIONS.

The numerous Cretaceous strata of the Black and Grand prairies which lie unconformably above the Paleozoic rocks are of great uniformity and persistence in subhorizontal extent, inclination, and thickness. Notwithstanding this apparent persistence and horizontality there are certain variations in the structure which must be explained before the conditions of the distribution of underground water can be fully presented.

GENERAL ARRANGEMENT OF THE ROCKS.

If one begins at the coast and travels west across the Black and Grand prairies until he reaches the lowest Cretaceous beds at the western border of the Grand Prairie, he will find that while he is constantly ascending in altitude above sea level he is descending the geologic series, for he is crossing the outcrops of successively lower and lower strata; that is, each of the successive belts of country which he crosses, accompanied by its peculiar soil, rock, and flora, is due to the outcrop of that particular rock sheet upon which the country is founded, and these are successively lower and lower in geologic

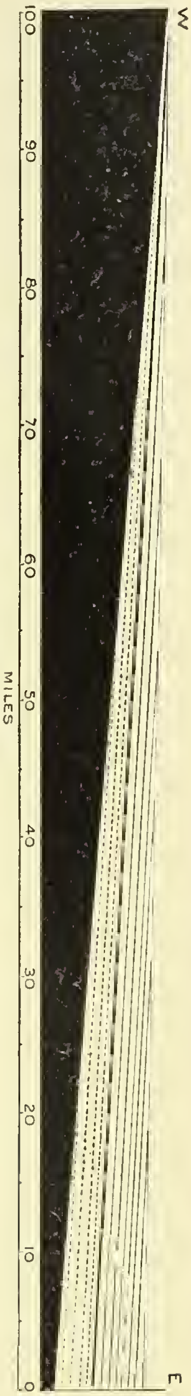


FIG. 38.—Imbrication of strata.

sequence to the west. The newer formations occupy the belts toward the coast; to the west the older formations successively outcrop until we arrive at the Central Province. Each outcropping layer encountered in turn from east to west represents an older rock sheet, the bottom one representing the Basement sands resting on Paleozoic rocks. In other words, all the Cretaceous strata dip beneath others toward the coast and outcrop to the northwest. Proceeding east across the Black and Grand prairies, as one ascends the series the different strata become embedded beneath one another and their depth constantly increases, owing to the fact that the dip, which is usually greater than the regional slope, carries them downward beneath successively higher layers.

This simple monoclinal geologic structure is the key to the succession of the various kinds of rocks in the East-Central Province and Coastal Plain—a country embracing the whole eastern half of Texas and southern Indian Territory, an area which is more than 170,000 square

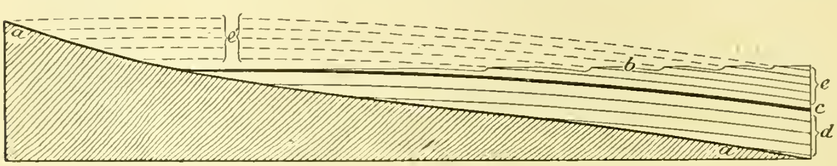


FIG. 39.—Section showing original succession of deposition from the coast interiorward. *a*, The floor upon which the Cretaceous formations were laid down; *b*, exaggerated profile of the surface; *c*, persistent stratum, the extent of which has not been broken by erosion; *d*, persistent embedded strata beneath *c*, showing overlap to the interior; *e*, outcropping strata, appearing as if they succeeded one another coastward, but which once overlapped one another interiorward, as in the case of *c*, *d*; *e'*, former extent of *e*.

miles in extent and which includes all the humid and semihumid regions of the State. There are certain variations in the detail of this general plan, which will be stated later.

In all the cross sections (Pl. LXVII) the outcrops of the strata down to a certain horizon succeed one another in reversed imbricated arrangement from the interior coastward (from west to east in Texas and from north to south in the Red River sections) by outcropping from beneath a higher stratum which overlaps them coastward. In other words, the outcrop of each rock stratum becomes embedded to the east beneath a higher stratum in imbricated arrangement and the strata are continued indefinitely beneath the surface in the same orderly succession, as revealed by their outcrop.

This regular imbrication or underlapping of the outcrops of the strata with eroded interior edges in uniform sequence may suggest that the strata were originally successively deposited upon one another coastward, as shown in fig. 38. This was not the case, however. The present interior borders of the rock sheets as seen in the outcrops of the strata do not represent, except in cases of some of the lowest beds, the original interior margins of the rock layers where they abutted against the land, but in most cases are the eroded edges of strata which once continued far interiorward, their former extent in that direction having been worn away. The order of deposition was, in fact, from the coast interiorward—just the reverse of their present apparent order of succession. In certain places, as revealed by well drillings and as shown in fig. 39, this normal condition of succession of overlapping strata to the interiorward is still preserved.

As indicated by their contact with the underlying Paleozoic floor, the shore line of the oldest layers of the Cretaceous rocks was near the present coast. As the sea progressively invaded the land, the successive beds, representing higher and higher horizons in the series, extended westward, their western margins resting upon the Paleozoic floor. Thus the oldest Cretaceous rocks are found only to the east of the interior margin of the Central Province; the beds of the next horizons overlap these and extend farther west, until finally, in eastern New Mexico and southern Kansas, still later horizons represent the shore line contact between sediments of the advancing Cretaceous sea and the basement rocks upon which they were deposited.

THREE STRUCTURAL CHARACTERISTICS.

There are three structural characteristics of the Cretaceous which must be considered. The first of these consists of variations in the thickness and composition of the strata, due to the original conditions of sedimentation; the second is their tilt or dip, due to the general uplifts of the whole Regional Coastward Slope; the third is displacement and other minor deformation, due to adjustment, through weight and faulting, of the Cretaceous envelope to the basement of harder Paleozoic rocks.

VARIATION IN THICKNESS AND COMPOSITION OF STRATA.

Although the various beds of the Cretaceous formations of the Texas section are very uniform throughout vast distances, yet, in accordance with well-known laws, the strata ultimately change in thickness and composition. These changes may be observed along the lines both of strike and of dip. Instances of great persistence in thickness and composition of the strata are exhibited in the Austin chalk, which along the line of strike from Sherman, near Red River, to the Rio Grande west of Eagle Pass, 500 miles, maintains a uniform thickness and composition, averaging about 500 feet of chalky limestone, and no important differences have been observed in any part of its course.

The composition of beds, although not observably changeable along short lines of outcrop, ultimately changes in character. The most notable instance is that of the Denison beds of the Washita division, as has been presented in the comparisons of the Austin and Denison sections. In the former the whole of the formation is represented by about 70 feet of clay and 40 feet of limestone, all of which are oceanic sediments, comparatively free from land débris, yet not of a deep-sea character, probably representing the lightest and last-deposited débris of the land where it mixed with the purely oceanic sediments. On Red River the beds of this formation have increased in thickness and are entirely different in composition, so that except by paleontologic evidence it is impossible to correlate the different horizons. At Denison the formation is a great thickness of impure, sandy, lignitic, near-shore clays developed between two littoral limestones, and exhibits various other differences which need not here be discussed.

The variations in thickness and composition along the dip of the several beds are much greater than those along the strike. In general it may be said concerning all the formation that the belts of land-derived sediments, sands, and clays, such as the Trinity, Paluxy, and Eagle Ford, are more or less lens-shaped in cross section, first thickening and then thinning seaward.

The formations composed of land débris thicken shoreward and thin seaward; those composed of sea-derived material, such as chalks and chalky limestones, thicken seaward as far as they are traceable, although they would doubtless be found to thin out again in that direction if their continuation could be traced. It may also be said that the materials composing all the beds are coarser shoreward and finer seaward. The original land margins of all the strata are apt to be arenaceous and to pass outward into clays, then into marls, and finally into chalky limestones. Some of the brecciated limestones and shell conglomerates of mixed species are near-shore formations. Certain great thicknesses of strata composed exclusively of one kind of shell, such as the Gryphæa breccias and Requienia limestones, may represent colonies of organisms that thrived in deeper water than the Mollusca, which lived near the shore. Limestones of this purely organic origin should not be confused with true sediments derived from the land, or with rocks of near-shore origin.

The above propositions are illustrated in many of the beds of the Cretaceous section under discussion. The Woodbine (Dakota) formation, which is of a shallow, near-shore nature, decreases in thickness from over 500 feet at Red River to zero at the Brazos, completely dying out seaward. The original land from which these sands were derived was the Ouachita Mountains of southern Indian Territory and perhaps a now degraded land in the northeastern portion of the Central Texas Province. The same may be said of the Eagle Ford clays, which are fully 600 feet thick on Red River, less than 100 at the Brazos, and only 25 at the Colorado.

An instance of a formation which both thickens and changes in composition seaward is found in the beds of the Edwards formation of the Fredericksburg division. In southern Indian Territory adjacent to the old shore line these are represented by the upper part of the Antlers sands, a few feet of clay, and 20 feet of the characteristic chalky limestone. At the Brazos the Basement sands have changed into clays, and the group is represented by about 200 feet of calcareous clays and 100 feet of chalky limestones. On the Colorado the Basement clays change into chalky limestone, and the total group is represented by nearly 400 feet of chalky limestone. At the Pecos all the members of this group are represented by nearly 700 feet of oceanic limestone, which thickens to 1,200 feet on the Rio Grande.

In accounting for the variations of the various Cretaceous formations, it is important to consider the former location of the shore line during the time of their deposition. The Ouachita Mountains, to the north, at least as far west as the ninety-ninth meridian, were a more or less persistent shore line during the Lower and Upper Cretaceous epochs. The sea may have occasionally receded slightly back and forth from this, but it was a permanent shore in comparison to that of the main Texas area, where the shore line was less stable and there were grander sweeps of the ocean unimpeded by mountain barriers.

The steep eastern slope of the Wichita paleoplain, previously described, formed a comparatively permanent shore during the Trinity epoch of Lower Cretaceous time. This barrier was completely overcome in Texas during the Fredericksburg subepoch, and the ocean was then free in Fredericksburg, Washita, Dakota, and Upper Cretaceous time to transgress upon the great unbroken plain which stretched far west toward the Rocky Mountain nuclei. The general progress of this shore line as recorded in the transgressing basement littoral, notwithstanding minor pausations and oscillations, from the beginning of the Fredericksburg to the end of the Washita was west from the ninety-seventh meridian to the one hundred and fourth meridian, or more than 900 miles.

After overcoming the temporary barrier of the eastern scarp of the Wichita paleoplain during the Trinity subepoch the littoral margin of the Cretaceous seas migrated constantly westward. At the close of the Lower Cretaceous there were uplifts, and the shore line returned from the Rocky Mountain region coastward of the present eastern margin of the Black Prairie. During the Upper Cretaceous the sea again migrated westward over the Greater Plains region.

EXTENT AND LIMITATION OF THE EMBED.

While the outcrops of the various strata are the most available guides to the variations in structure, it is equally important to know the variations in conditions of the embed, or those portions of the various rock sheets which are buried beneath the surface. Fortunately the artesian-well records throw much light upon this aspect of the subject. Most of the formations are embedded to the coastward of their outcrop. Certain formations, like the Basement sands, undoubtedly underlie the whole of the Black and Grand prairies region; others, like the Woodbine sands, of which neither the outcrop nor the embed is traceable south of the Brazos, underlie only portions of the area.

The Basement sands of the Comanche series undoubtedly underlie the whole area of the Black and Grand prairies. The Glen Rose formation also underlies most of the Black and Grand prairies, but is apparently unrepresented in the extension of the Cretaceous formations over the Central Province, beyond the west margin of the Grand Prairie, as shown by sections made along the Callahan Divide. (See Pl. LIV.) This fact leads to the presumption that the Wichita paleoplain persisted as land throughout the Central and Great Plains provinces during the time of the Trinity division, and was not completely drowned by the Cretaceous sea until the close of that subepoch, when it was covered by the Edwards limestone. This fact is further attested by the thinning out of the Glen Rose beds toward the Central Province in all east-west sections east of it, as elsewhere stated.

South and east the outcrops of the Paluxy sands thin out—or, rather, pass into lime-clay sediments—and are hardly represented south of the latitude of the valley of the Leon at Gatesville. Neither is their embed detected in the artesian-well sections south of Belton. Hence we may infer that their embed underlies only the northern two-thirds of the area of the Black and Grand prairies.

The occurrence of the Paluxy sands as an eastward-projecting sheet from the Basement beds for a distance of at least 75 miles east of their most western outcrop, interlain with limestones between which there is nowhere evidence of unconformity, is a phenomenon difficult to explain. The hypotheses suggested are (1) that there was a pausation in the general subsidence of Lower Cretaceous time or (2) that there was a recedence within the sea itself of the line delimiting arenaceous deposition, such as might have taken place through changes of current and eddies and conditions of slope.

The shore line of the Paluxy sands in general was far north and west of that of the Travis Peak sands. It can not be exactly located now, for the present outcrops in Texas are eroded edges of the formation which have receded far coastward of any perceptible contact with the preexisting lands and everywhere within our province rest conformably upon the preceding Cretaceous beds.

The Edwards limestone, which is the most extensive of all the formations, stretching west toward the Trans-Pecos Mountains region across the Central Province, outcrops throughout the Lampasas Cut Plain as the surface rock and is embedded beneath the entire Black Prairie and all that portion of the Grand Prairie north of the Brazos.

The outcrops of the Preston beds of the Red River section, including the Kiamitia clays, Duck Creek limestones, and nearly 100 feet of marly clays above the latter in the Denison section, aggregating nearly 150 feet of thickness, gradually thin out to the south and finally disappear at the San Gabriel, where the whole group is represented by a bed less than 2 feet thick. This change is so gradual and imperceptible that it amounts to only six-tenths of a foot to the mile, a measurement imperceptible to the eye and detectible only by comparison of the various cross sections measured along a base of 250 miles.

The Fort Worth–Georgetown formations and the Denison beds are embedded only beneath the Eastern Cross Timbers and the Black Prairie. Their variations have been fully described elsewhere in this paper (pp. 241–244).

The Woodbine formation, which thins rapidly south from Red River to the Brazos, is not recognizable in any of the well sections south and southeast of Waco. Strata of this formation are encountered in the deep wells at Corsicana and at Greenville, on the eastern margins of the Black Prairie, and hence we may conclude that they are embedded beneath that portion of the Black Prairie north of the latitude of Waco and east of the Eastern Cross Timbers. The cause of their disappearance southward can not be stated with positiveness.

COMPOSITION AND THICKNESS OF TRINITY DIVISION.

The individual beds of the Trinity division change in composition relative to their original depositional distance from the Paleozoic floor, and pass eastward into fine sand, clays, calcareous clay, and finally into limestones. Vice versa, the limestone beds of the coastward extension ultimately grade westward into clays and sands along the depositional planes. Hence the limestones penetrated by the drills in the Black Prairie region, where the Trinity sequence is the thickest, are seldom represented in outcrops of the western border region, or, if at all, by only a few feet of calcareous clay and thin, impure limestones, gradually passing into a bed of Basement sands, which is everywhere adjacent to the Paleozoic floor, from which certain sandy beds forming well-defined horizons also branch off and pass east between the limestone beds.

Thus the cross sections vary in composition and thickness in proportion to the horizontal distance of any given point from the western or interior Paleozoic border, and present greater proportions of limestone coastward as the distance increases from this shore line, as shown in sections and figures. In other words, the embedded portion of the Trinity division constantly gains in thickness and calcareous composition away from the outcrop, and its successive beds overlap one another westward and gradually pass into a bed of Basement sand in that direction.

The total eastward increment of the Trinity division from Twin

Mountains to Glen Rose, 36 miles, is 300 feet, or at the rate of 8.3 feet per mile, the beds being 308 feet at the former and 606 feet at the

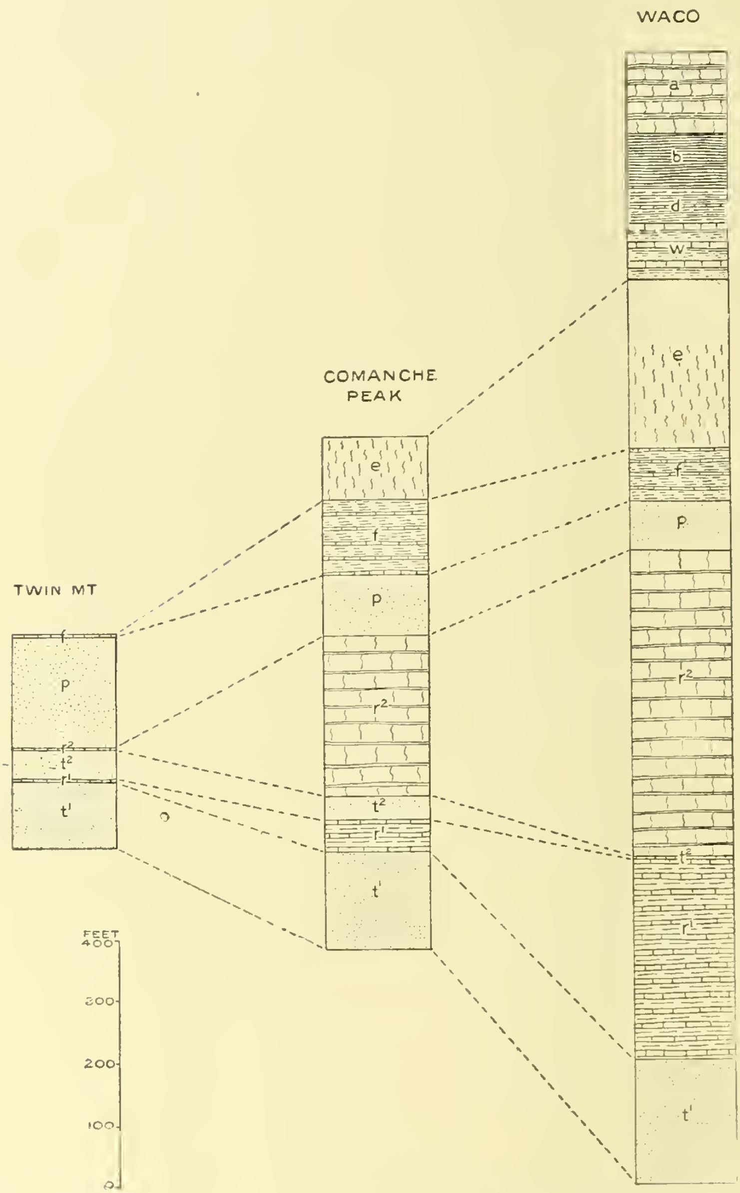


FIG. 40.—Comparison of Twin Mountain, Comanche Peak, and Waco sections, showing increment of Glen Rose beds. (For explanation of symbols, see Pl. XVI, p. 110.)

latter. Between Glen Rose and Waco, 58 miles, the increment is 500 feet, or 8.45 feet per mile; from Dublin to Waco, 80 miles east, it is 9 feet per mile, and from Post Mountain west of Burnet to Austin, 25 feet per mile.

This apparent eastward increase in the thickness of the Trinity division is not to be considered as a wedge-like thickening of individual beds, although some of the beds do thicken or thin in horizontal direction, but rather as a constant increase by the successive accretion of horizontally deposited layers which overlap one another to the west, the interior ends of which merge into the bed of Basement sand at the base of the Cretaceous, next to the Paleozoic floor, as shown in fig. 40. Paleontologic and stratigraphic studies have shown that the horizons a and b maintain their horizontality and merge westward into sands of the basement littoral.

The eastward increment of the embed of the Trinity division is well illustrated in the cross section (E—E, Pl. LXVII) extending southeastward from Twin Mountain, Erath County, via Bluffdale and Glen Rose, to Waco, a distance of 94 miles.

At Twin Mountain, Erath County, on the western border, a careful section of the eastern escarpment of the Grand Prairie was made by Taff. Another section was measured by the writer at Glen Rose, and the artesian-well drill at Waco gives the thickness there. These thicknesses of the beds of the Trinity division at the three localities are as follows:

Approximate thicknesses of the Trinity division.

	Twin Mountain, Erath County.	Glen Rose.	Waco.
	Feet.	*Feet.*	*Feet.*
p. Paluxy	190	100	0
r^2. Glen Rose	5	261	570
t^2. Upper sand	22	40	10
r^1. Limestone	1	55	310
t^1. Basement sand	90	150	200
Total	308	606	1,090

It will be seen in the section that the thickness of the Trinity division has increased from 300 to 1,100 feet, or a total of 800 feet, between Twin Mountain and Waco, a distance of 94 miles, or at the rate of 7.77 feet per mile. Between Twin Mountain and Glen Rose, 36 miles, the increase is 300 feet, or at the rate of 8.3 feet per mile; and between Glen Rose and Waco, 58 miles, it is 500 feet, or at the rate of 8.45 feet per mile.

This increase has been in the calcareous beds r^1 and r^2, while the arenaceous beds t^1, t^2, and p have varied but little or decreased.

Similar studies along a line from Dublin on the western margin, where the entire Trinity division is represented, to Waco, 80 miles, show the increase to be also at the rate of 9 feet per mile. Sections from Twin Mountain, Lampasas County, west of Lampasas to Belton, and from Burnet to Austin, also show this increment of the Trinity beds to the east at the rate of from 8 to 9 feet per mile.

FIG. 41.—Diagram showing slope of surface and dip of strata in 1 mile. *a a*, dip of rocks of Grand Prairie at 27 feet per mile; *b b*, inclination of Grand Prairie at 16 feet per mile; *c c*, sea level.

This increase in thickness of the beds of the Trinity division from the western marginal border of the Grand Prairie coastward is especially well shown in a section from Burnet to Austin. The Trinity division is seen at Post Mountain, 1 mile west of Burnet, in the northern bluffs of the Colorado Valley 9 miles east of Burnet, 19 miles east of Burnet, and 34 miles east of Burnet, beneath Austin. The Glen Rose beds (r^2) are represented by only 25 feet at the first-mentioned locality, 235 feet at the second, 430 at the third, and over 600 feet at Austin.

The beds of the Trinity division below the Glen Rose formation are represented at Post Mountain by 20 feet of basal sand and conglomerate (t^1) and about 25 feet of shell breccia (r^1). In the section 9 miles east they are represented by 263 feet of strata, including a conglomerate and sand bed at the base (t^1) 50 feet thick, thin beds of clays and limestones aggregating about 35 feet (r^1), and an upper sand and conglomerate group (t^2), the Hensel sands, about 120 feet in thickness.

At Austin the lower sand of this group is 200 feet thick; r^2 has increased into a group of limestones and shales 460 feet thick; t^2 has thinned to 25 feet in thickness; r^2 is 600 feet, giving a total of 1,285 feet in thickness at Austin. The total increase in thickness of all the beds of the Trinity division is from 80 feet at Post Mountain to 1,185 feet at Austin—in a distance of 44 miles an increment of 25 feet, of which 90 per cent is in the limestone formations.

STRIKE AND DIP OF CRETACEOUS FORMATIONS.

The strike of the Cretaceous formations is generally in the direction of their lines of outcrop. In the Red River district this strike is due east and west from Murfreesboro, Arkansas, to Marietta, Indian Territory, 300 miles. From the latter point the strike is irregularly southward toward San Antonio, Texas. The strike of the present outcrops is not everywhere parallel to the original shore line of deposition. It is so in the Red River district, but in the Main Texas belt there are some variations, to be noted later.

Since their original deposition as ancient sea bottoms the sediments making the Cretaceous formations of the Black and Grand prairies have been tilted by the uplifting forces which brought up the whole Greater Plains region, so that they now incline seaward with great uniformity, except in minor instances, to be noted later. This inclination, although there are some interesting variations in the amount and direction of dip, averages about 40 feet to the mile, and is everywhere so gentle and so slight as to be hardly perceptible to the eye (see fig. 41). The details of the dips are shown in the numerous cross sections presented herewith.

The general direction of the dip of the various Cretaceous formations is coastward, in directions at right angles to the lines of outcrop.[1] Thus the rocks of the Red River district in general incline south, while those of the main Texas belt dip in easterly directions.[2]

One of the most peculiar facts concerning the structure of the Black and Grand prairies is the sudden and radical change in strike and dip which takes place at the junction of the Red River and Texas belts. In the Red River belt along the southern front of the Ouachita Mountains the strike of the Cretaceous formations is due east and west and the dip is to the south (usually a little east of south). Passing west of the line of the Preston and Cook Spring fault zone, which passes northwest and southeast through a point west of Marietta, Chickasaw Nation, and south of Denison, Texas, the strike and dip suddenly change, the former being north and south through Texas and the latter eastward (usually south of east). The causes of this abrupt change in strike and dip can not be fully explained, but it is possible that adjustment of the Cretaceous strata to the underlying configuration of the old Paleozoic basement is largely responsible for it.

The dip of the Cretaceous rocks, although apparently everywhere uniform in the Main Texas belt, presents minor variations and is changed in places by small faults. The average inclination of the rock sheets above the Trinity division on a line drawn from Decatur at the western margin of the Grand Prairie to Corsicana on the east is about 40 feet[3] to the mile. In the north-south Texas belt the dip east and west from Weatherford to Fort Worth is about 24 feet to the

[1] This statement is not entirely true in all cases. The several outcrops of the Glen Rose beds, especially along the western border region, are not parallel to the strike of the beds, which is an east-of-north direction from Austin toward Dallas, and thence presumably eastward beneath the Black Prairie, parallel to the Ouachita Mountains, and east-west sections are therefore slightly diagonal to the dip. It is most probable that the change in strike of the Glen Rose beds from the east-of-north and west-of-south direction to an east-west direction takes place in the embedded portion of the area beneath the second tier of counties south of Red River, but there are in the well records no positive data showing that they have been penetrated by the drills east of the Texas Central Railway or north of the latitude of Fort Worth, except a record at Denison which indicates the occurrence of thin limestone beds of Glen Rose character in the Antlers sands beneath that city.

[2] The direction of the dip in the Main Texas area varies slightly in different portions of the outcrop, varying from nearly east along the Colorado to N. 60° W. along the Paluxy.

[3] All the estimates of dip in this paper are approximate only, and subject to future correction, when better hypsometric data are procurable than exist at present.

mile; from Arlington to Dallas the dip of the Woodbine formation is estimated at 42.1 feet to the mile; from Britton to Corsicana, 45 miles, 41.3 feet to the mile.

The dip of the Cretaceous rocks in the Red River district, which strike east and west, is much greater than that of the Main Texas belt of the Black and Grand prairies, which strike north and south. The dip of the Washita and succeeding formations in the Paris section, kk, is estimated at 57 feet to the mile; a portion of the section north and south through Denison, across the fault zone, shows a dip of 135 feet to the mile.

While the rocks of the Texas belt apparently have a continuous monoclinal dip toward the coast, there is an important change in the amount of the dip, the strata throughout the Lampasas Cut Plain being flatter and those of the Black Prairie region more steeply inclined. This change in rate of dip takes place at the east end of the fault zone at the junction of the Black and Grand prairies, as elsewhere described.

The inclination of the Cretaceous rocks approximately west of the ninety-sixth meridian is coincident with the continental slope, so that they are parallel to the surface in the Central and Plateau provinces and the Lampasas Cut Plain; but approximately east of that meridian their dip becomes slightly greater than that of the regional slope, so that toward the sea the strata become embedded beneath the interior outcrops of the successively newer and newer formations which overlap them in that direction.

This change in rate of dip, first perceptible in the Fort Worth and Dallas section, is so slight that it can hardly be detected. The divergence increases south, however, the western halves of the strata becoming more horizontal in that direction and the eastern portions more steeply inclined. The dip of the rocks of the Fredericksburg division from west of Weatherford to Fort Worth is approximately 24 feet to the mile; east of Fort Worth the angle increases to 40 feet to the mile.

Throughout the Lampasas Cut Plain between the Brazos and the San Gabriel, where the dip of the Edwards limestone coincides with the summit regional slope, it averages about 17.5 feet to the mile. Below the Edwards limestone the Basement Trinity beds have a greater dip, as will be presently shown. Along the western margin of the Black Prairie region, along the more acutely faulted portion of the Balcones fault zone, the aggregate dip or downthrow of the rocks increases to over 100 feet to the mile, being estimated at 110 feet in the Austin section.

The Basement sands in the same region as the overlying beds have a greater inclination, proportionate to the constant increment of the Glen Rose beds. Furthermore, the dip of the beds of the formations

FAULTS IN THE EDWARDS LIMESTONE, BARTON CREEK, NEAR AUSTIN.

below the Edwards limestone everywhere differs slightly from that of the overlying beds, owing to the wedge-like increase in thickness of the Glen Rose strata.

The following table will show some of the estimated dips of all the strata, including and above the Fredericksburg division, in proceeding southward. The figures given are subject to correction.

Table showing dip along various cross sections.

Lampasas Cut Plain and Grand Prairie.*a*	Dip per mile.	Black Prairie.	Dip per mile.
	Feet.		*Feet.*
Weatherford to Fort Worth	24–27	Arlington to Dallas	42.1
Round Mountain, Comanche Co., to Valley Mills, Bosque Co.	17.1	Keller to Dallas	41
		Mansfield to Palmer	40
West of Waco	17.6	Britton to Corsicana	41.4
Goldthwaite to Townsends Mills	16.7	Waco to Marlin	42
West of Belton	17	East of Belton	*b* 70
West of Georgetown	18	East of Georgetown	*b* 50
West of Austin	13.5	East of Austin	*b* 70

a These dips are calculated from the altitudes and depths of the strata at the points given. They are taken along long lines, from 12 to 70 miles in length, and while it is not claimed that they are accurate to the ultimate degree of refinement, they are much more accurate than average dip calculations based upon clinometer measurements. The dips of the Lampasas Cut Plain are those of the Edwards limestone; the dips of the Black Prairie are those of the Austin chalk and the water-bearing beds of the Woodbine formation.

b These measurements are within the area of the faulted zone and must be regarded as conjectural only.

APPARENT DIVERGENT DIPS OF CONFORMABLE STRATA IN THE SAME CROSS SECTIONS OWING TO INCREMENT.

Owing to the increment to the eastward of the thickness of the beds of the Trinity division between the Paleozoic floor and the Edwards limestone, it will be found that the rock sheets of the Trinity division have a different apparent dip from those of the overlying sheets of the Fredericksburg and succeeding divisions. Thus, for instance, in a cross section 36 miles long drawn through Weatherford and Fort Worth (see fig. 76), the formations of the Fredericksburg division dip at the rate of 27.8 feet to the mile. The Basement sands of the Trinity division in the same section dip at the rate of 40 (39.5) feet to the mile. In other words, there is an eastern divergence between the dip of the bottom of the Basement sands and the Edwards limestone of 11.7 feet to the mile. This apparent divergence of dips, due to the eastern increment in thickness of the rocks of the Trinity division, has a most important bearing upon the estimates of depths of artesian waters.

This divergence is due to the contour of the preexisting floor of the Wichita paleoplain, which, as before stated, presented a steep escarp-

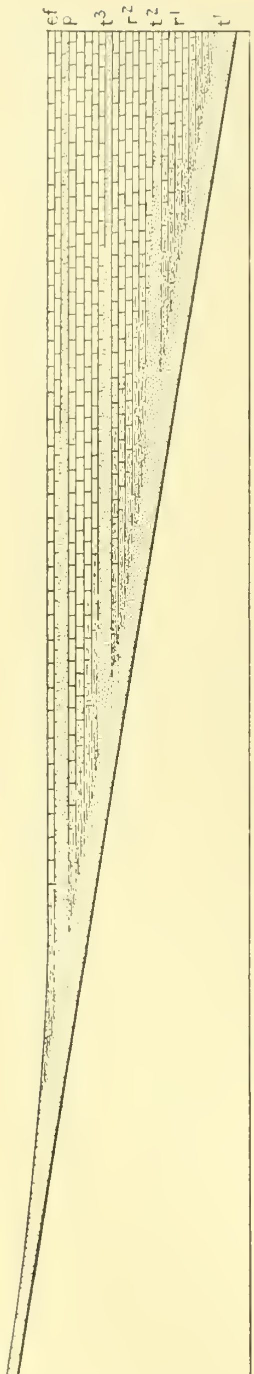
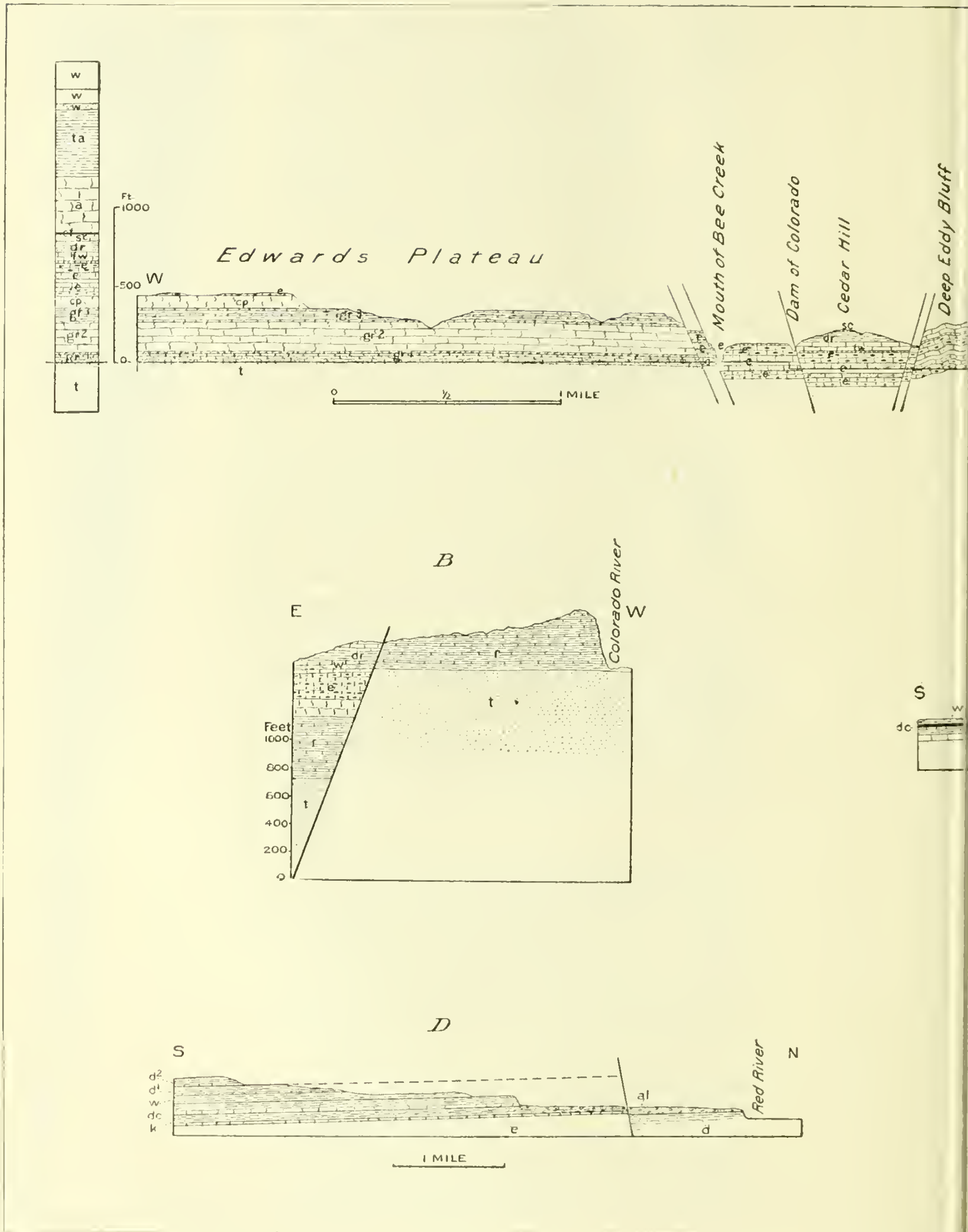


FIG. 42.—Section from Burnet to Manor, showing increment of beds of the Trinity division.

ment to the east, extending beneath the Grand Prairie in a west-of-south direction from the neighborhood of Atoka, Indian Territory, toward the town of Burnet, Texas, and from Burnet west to the Pecos. As the old pre-Cretaceous land—which at the beginning of Cretaceous time extended far shoreward of the present coastward margin of the Black Prairie—was gradually overwhelmed by the sea through subsidence, it was covered with a mass of sediments along this slope, which in the aggregate were thicker toward the east and thinner toward the west. By the close of the Fredericksburg subepoch, when the slope was entirely overwhelmed by the sea, the vast deposit of Trinity division sediments which had accumulated on its eastern side was overlapped by the Edwards limestone, so that the latter rested on a wedge-shaped mass of earlier Cretaceous sediments in the Black and Grand prairies east of the old plateau edge, and almost directly upon the Paleozoic rocks west of it (see fig. 42). Hence the Edwards limestone now has a greater horizontal extent than the underlying formations, and it may be assumed as a standard of horizontality from which the thickness of the underlying strata can be measured in any part of the field.

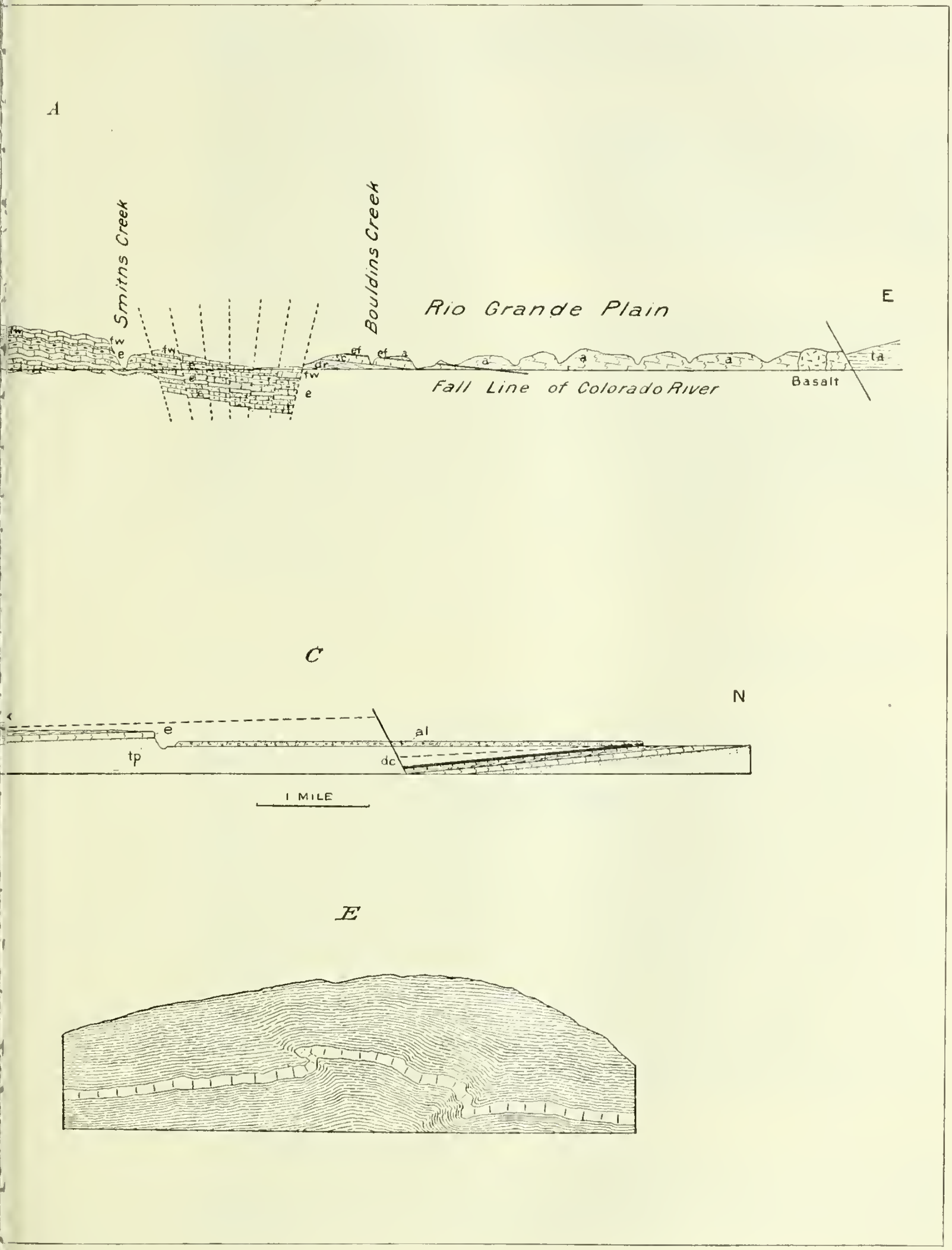
The vertical distance between the Basement sands and the Edwards limestone constantly increases coastward with the thickening Glen Rose sediments from the eastern crest of the old Wichita paleoplain, and the dip of the Basement sands is as much greater than that of the Edwards limestone as the amount of thickening of the Glen Rose beds.

Rate of increase in thickness of Glen Rose beds.—The importance of a thorough understanding of the rate of increase in the aggregate thickness of the beds of the Glen Rose formation becomes apparent when the conditions of artesian water are considered.



FAULTS AND I

A, Section of Balcones fault zone, south bank of Colorado River, Austin; *B*, main Balcones fault at east base of Mount Bonnell; *C*



ACEMENTS.

ver fault at Preston; *D*. Red River fault north of Denison; *E*. local disturbance in Woodbine formation 2 miles west of Bedford.

Although there may be a general thickening of some of the individual strata, the increment is largely by the overlapping upon the sands of successive limestone layers.

The progressive thickening of the Glen Rose beds toward the coast from the Paleozoic shore line is well shown in cross sections of the Black and Grand prairies (see Pl. XLIX). The outcrops of the Glen Rose formation along the western border region are very thin and consist almost entirely of thin, sandy, yellow, calcareous clays, grading above and below into pack sands. The thickness of the beds increases rapidly to the east.

Carefully measured sections along the breaks of the Colorado in Blanco, Burnet, and Travis counties have shown the following coastward increment in the Glen Rose beds (see fig. 43).

West of Round Mountain post-office, Blanco County, the entire Trinity division between the Cambrian limestone below and the Fredericksburg above consists of less than 200 feet of pack sands and sandy clays, of which the upper 50 feet are clays and limestones of the Glen Rose type containing *Nerinea*, resting upon Basement sands. Seven

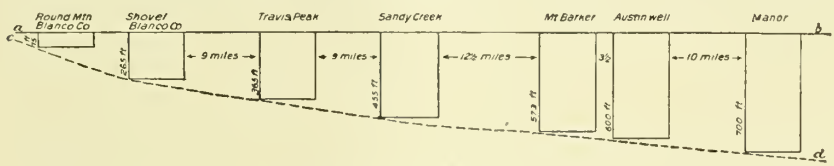


FIG. 43.—Increment of Glen Rose formation along a section from Round Mountain, Blanco County, to Manor, Travis County, Texas.

miles east, at Shovel Mountain, the Glen Rose limestones are 60 feet thick, being increased at the rate of 26.4 feet per mile; 8 miles east of Shovel Mountain, near the Travis-Blanco county line, the Glen Rose beds are 265 feet thick, the increment being 12.5 feet per mile; 9 miles farther east, at Round Mountain, Travis County, the Glen Rose beds are 455 feet thick, having gained 90 feet, or 10 feet per mile. Twelve and a half miles east, in the bluffs of Mount Barker, 3½ miles west of Austin, the beds are estimated to be 575 feet deep, the increment being at the rate of 9.5 feet per mile. At Austin the beds are found to be 600 feet thick in the artesian-well drills. The average increment between Shovel Mountain and Austin is 7.8 feet per mile. This section shows that the gradient of dip of the base of the Glen Rose beds is a curve which flattens coastward, the increment being greatest immediately east of the western border outcrop, where it is at the rate of 26 feet per mile.

In Twin Sisters Peaks, in western Lampasas County, the Glen Rose formation is about 90 feet thick, while at Bachelors Peak, 18 miles southeast, it is over 200 feet thick, showing an increment of 6.5 feet per mile.

At Mount Airy, Erath County, 32 miles northwest of Iredell, the Glen Rose beds are 50 feet thick. At Iredell, Bosque County, these rocks are estimated to be 400 feet thick. This makes an increase of 10.9 feet per mile along the dip.

At Twin Mountain, Erath County, 36 miles due west of Comanche Peak, the Glen Rose formation is very thin. Beneath Comanche Peak, Hood County, between the Peak and Glen Rose, the Glen Rose limestone and marl is 236 feet thick. This gives an increase of 7 feet per mile.

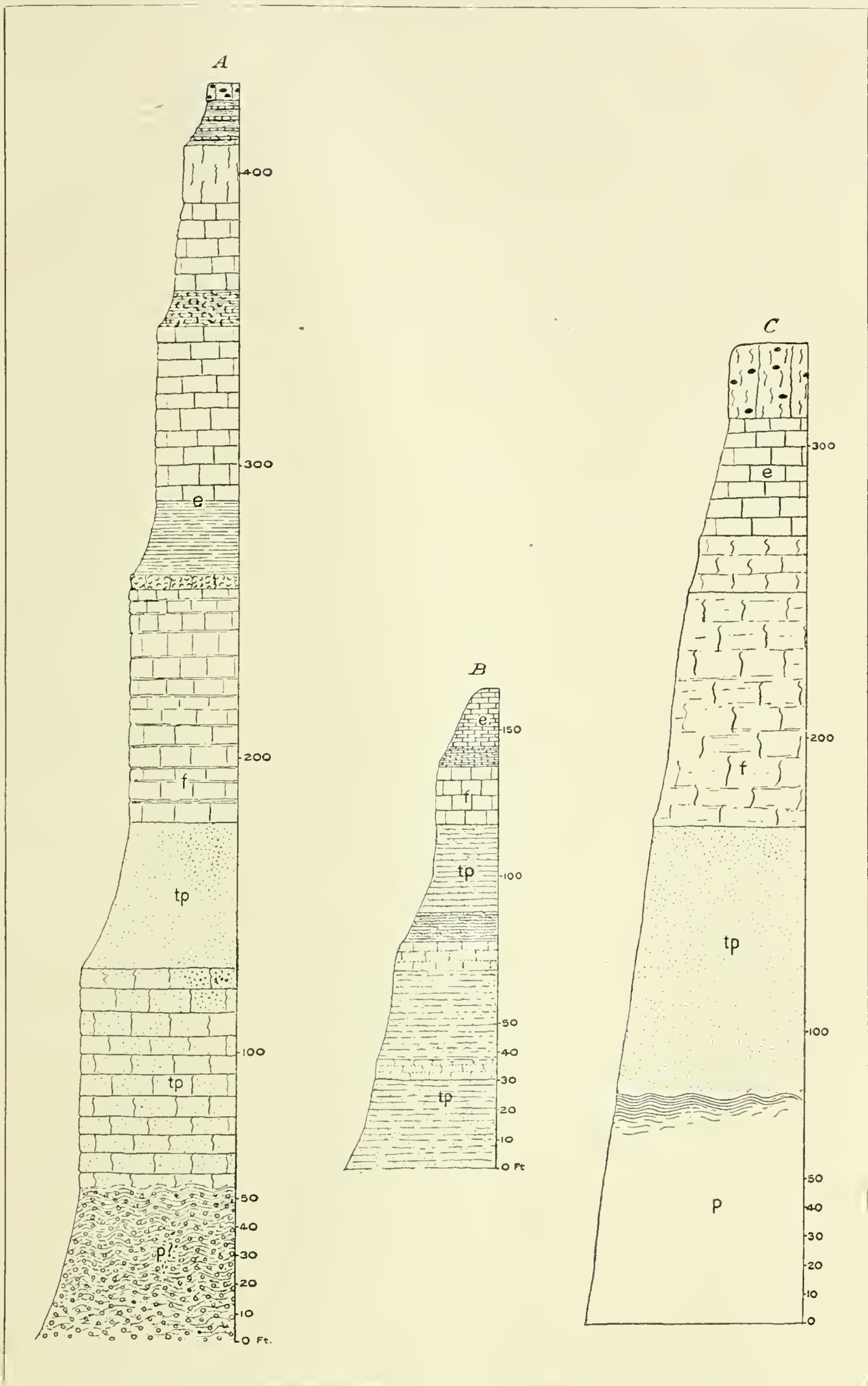
The Glen Rose beds in Wise County are less than 20 feet thick. At Fort Worth, 36 miles south of east, they are estimated from well drills to be 470 feet thick, giving an increase of 13 feet per mile.

DISPLACEMENT.

In addition to the normal inclination of the strata described, the tilt of the rock sheets is varied in places by displacement or faulting and very gentle folding. There are two major fault zones crossing the Black and Grand prairies. One of these runs diagonally subparallel to the strike in a general direction of N. 30° E., through points near Austin, Belton, and Waco, and probably continues northeast by Rockwall and Paris to Red River near Antlers. This may be called the Balcones fault zone. The second zone of faulting runs in a north-of-west and south-of-east direction, at right angles to the Balcones fault, through Chickasaw Nation and Grayson and Fannin counties, Texas, and may be known as the Red River fault zone. (See maps, Pls. LXVI, LXIX, LXX.)

BALCONES FAULT ZONE.

The Balcones fault zone consists of a number of subparallel step faults or numerous small jogs, the aggregate displacement of which attains a maximum of 1,000 feet. This zone is limited nearly everywhere on the west by a larger fault, which may be called the mother fault, and which at Austin has a downthrow of nearly 500 feet. (See Pl. LII, *B*.) It is in reality a number of short faults overlapping en échelon. This mother fault line from the Nueces to the Brazos makes the dividing line between the Black and Grand prairies. North of Waco it passes into the unconsolidated clays of the Black Prairie, between Whitney and Aquilla. It is impossible to trace its continuity east of north from the last-mentioned locality. The details of this faulting have been worked out minutely only at Austin, as shown in Pl. LII, *A*. The fault zone is very conspicuous west of Georgetown, at Belton, and in the vicinity of Waco, where the downthrow has decreased. At Belton the faults are well shown in the valleys of Noland and Lampasas rivers, but the details have not been mapped. In the vicinity of Waco the fault zone is of considerable width and



SECTIONS OF THE CRETACEOUS FORMATIONS IN THE EDWARDS PLATEAU.

A, Section of Castle Mountain near Pecos River, west edge of Llano Estacado; *B*, section of east edge of Edwards Plateau, 15 miles west of San Angelo; *C*, section of Church Mountain, Runnels County.

may be seen in the Austin chalk. West of the city, at the very edge of the chalk outcrop, a fault runs due north and south and is evidently of considerable extent. This is the only fault in the vicinity which has been distinctly noted. The presence of many others is indicated by dislocation and joints filled with calcite veins and by numerous slight crumplings and breaks.

The presence of these small faults is also proved by the borings for artesian waters. The data from this source, owing to the nature of the rocks, is not as yet complete, but sufficient has been obtained to show a considerable downthrow on the east caused by the faults of the Balcones zone running between Waco and the Bosque. There may also be faults farther west in the Del Rio and Eagle Ford beds. Traces of the Balcones fault zone are also visible in Hill County between Aquilla and Whitney, and in Dallas County, but the displacements are unknown. At Arthurs Bluff on Red River the strike of the zone of faulting is clearly indicated in faults there seen in the Woodbine clay. This is also seen one-quarter of a mile south of Rockwall, where there is a so-called dike. This dike is a vertical vein 3 inches thick, composed of a siliceous glauconitic quartzite with clay inclusions. It extends 2½ miles southeast to 2½ miles northwest of Rockwall. The dike follows the edge of a valley striking northeast and southwest.

The Balcones faulting does not affect the rocks of the Lampasas Cut Plain west of the mother fault, with the exception of slight jointing and dragging immediately along the margin. The extent of the zone to the east is also undetermined, for wherever the faulting passes into the unconsolidated beds of the Taylor and Navarro formations it is utterly impossible to determine the displacement. Here and there notes have been made which show that the zone, in places, extends nearly to the eastern margin of the Black Prairie. For instance, a small normal fault belonging to this zone and having a downthrow of about 5 feet southeast crosses Mustang Creek about 1¾ miles above the mouth. At this fault the strata are slightly flexed into a small synclinal fold. At the southeast corner of the Ann Coss survey, in Falls County, a normal fault extends southwest across the creek with downthrow to southeast but a few feet. Near the east line of Ann Coss survey, on Christmas Creek, the Taylor marl is much disturbed; the dip changes from nearly horizontal to 20° within 100 feet. In fact, throughout the Black Prairie, wherever a fresh exposure is found, joints or small faults are seen, mostly having the N. 30° E. trend of the disturbances of the Balcones fault zone, and in north Texas these extend through a wide belt. For instance, the Eagle Ford beds between Rhea Mills, Collin County, and Mountain Peak, Ellis County, and the Austin chalk at Rhea Mills are excessively jointed, with large springs at places issuing from the joints. These joints extend as far east as Garland, Dallas County, and Frankfort, in southern Collin County.

Another fault of this general zone near the eastern limit of the Black Prairie extends W. 30° E. across the Tehuacana Hills immediately west of Tehuacana College, with a downthrow of about 40 feet to the northwest. This fault is normal, with a hade to the east.

RED RIVER FAULT ZONE.

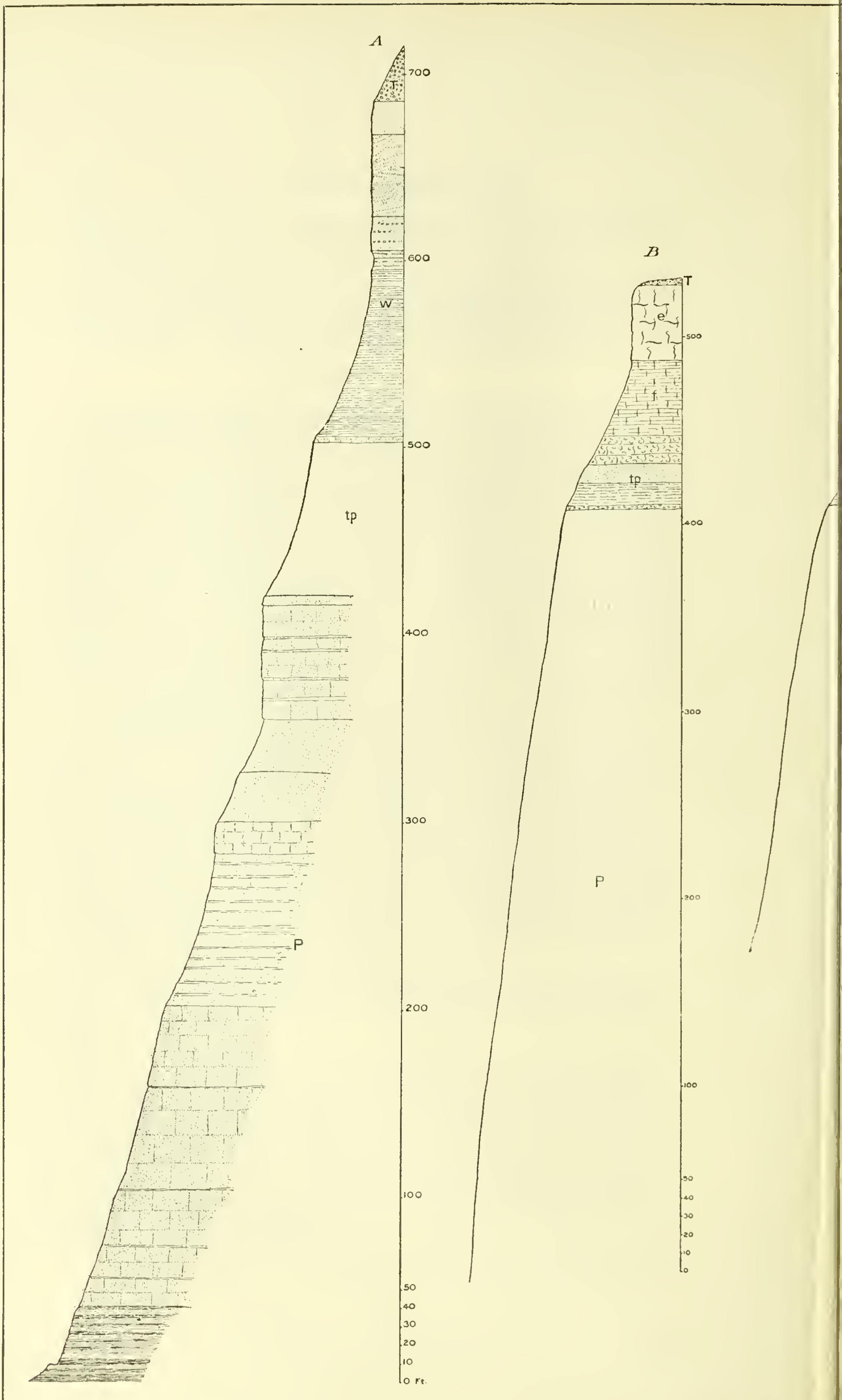
The Red River fault zone (see map, Pl. LXVI, and Pl. LII, figs. *C* and *D*) consists primarily of two subparallel major fault lines extending E. 30° S., or in a direction complemental to that of the Balcones fault zone. Their downthrows are in opposite directions, and between is a strip or block of uplifted strata, as seen between Red River north of Denison and Cook Spring to the south. The most northern of these faults, which may be termed the Preston, follows Red River from Marshalls Bluff, near old Preston, to the northeast corner of Grayson County. Its downthrow is north, and it is occupied by Red River from the former locality due north of Denison. Owing to its occurrence all the beds on the north side of Red River from the Woodbine formation downward are lowered until they oppose the Antlers sand and Goodland limestone on the south. The total downthrow at Preston is about 626 feet, and 617 feet north of Denison.

Subparallel to this fault and from 5 to 7 miles south of it is the Cook Spring fault. This fault line passes from the northwest corner of Grayson County south of east near Pottsboro and through Cook Spring. Its downthrow consists of several steps to the south and amounts to about 200 feet near Pottsboro. One and one-half miles northeast of Pottsboro the Dexter sands abruptly terminate and the Eagle Ford clays are faulted down opposite the Fort Worth limestone and the basal Denison beds. This abrupt termination is caused by the southwest downthrow of the rock of the Dakota. The fault at this locality, according to Taff, bears approximately N. 42° W.

Two miles east of Pottsboro the Dakota sand appears on the northeast side of the fault, and abuts abruptly against the fault line from a point due east of Pottsboro to Cook Spring, 6 miles north of Sherman.

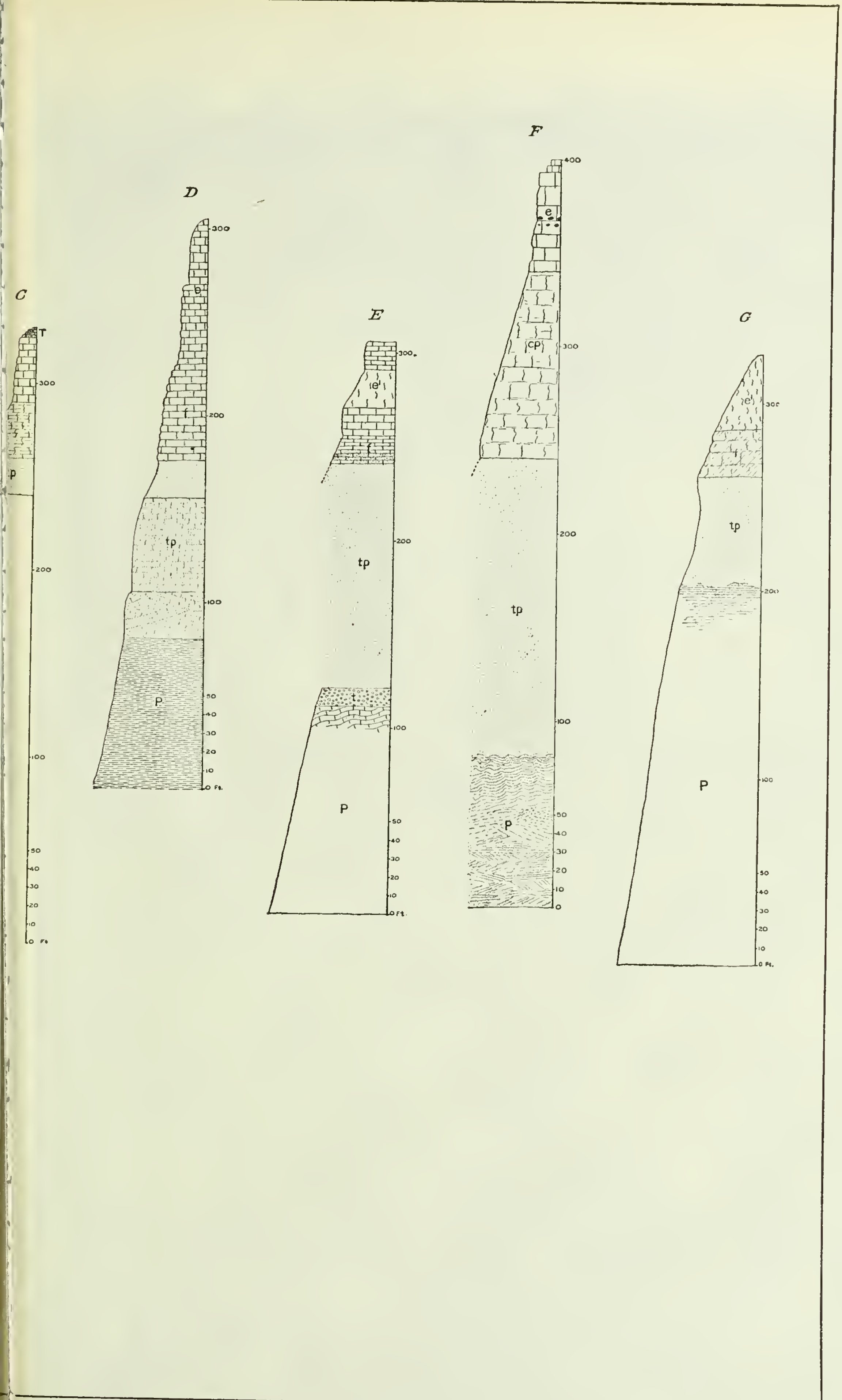
Near Cook Spring the base of the Austin chalk is brought down so that it opposes the upper beds of the Woodbine formation, while to the northwest the base of the Eagle Ford formation is brought down so as to oppose the Fort Worth limestone. East of the outcrop of the Austin chalk in Grayson County the faults of this zone are not directly traceable in the unconsolidated rocks of the Black Prairie, although their presence there is revealed by their effect upon the areal distribution of the formations.

At Moss Springs, on Iron Ore Creek, 6 miles north of Sherman, the



SECTIONS OF CRETACEOUS FORMATIONS AT TUCUM

A, Tucumcari Mesa; *B*, Double Mountain, Stonewall County; *C*, Muchakuya; *D*, Signal Mo



NEW MEXICO, AND ALONG THE CALLAHAN DIVIDE.

...oward County ; *E*, Bitter Creek, Noland County ; *F*, Horse Mountain ; *G*, Castle Mountain.

fault crosses the creek. The upper strata of the Lewisville beds on the downthrown side of the fault abut against the upper strata of the Dexter sands on the upthrown side.

The Balcones fault zone is probably due to the adjustment by weight of the Cretaceous rocks to the slope of the buried eastern margin of the Wichita paleoplain. The Red River fault zone can not at present be explained, but it coincides in direction with the older folds of the Wichita and Arbuckle mountains.

In addition to the displacement by faulting as above described, there are a few low undulations of the strata. These are incipient folds of such wide area and gentle uplift that they are hardly perceptible to the eye and cannot be shown to scale in diagrams and cross sections (see Pl. LII, *E*). The most notable of these low folds extends N. 30° E. from the Bosque to the Brazos, and is especially well shown along the Paluxy between Glen Rose and where the Paluxy empties into the Brazos.

Conclusions.

In conclusion, the writer regrets that lack of space prevents the extension of these remarks upon the Cretaceous formations to the entire area of their occurrence in the Texas-Mexico region. He can only append a few typical figures showing comparative sections of the rock sheets of the Black and Grand prairies to the southwest, west, and northwest. (See Pls. XV, LIII, and LIV.) By comparing these with the sections the following facts concerning the stratigraphy set forth in the foregoing pages will be apparent:

The paleontologic zones persist in horizontal extent regardless of change in lithologic nature of the matrix.

The beds vary in lithologic composition along horizontal lines toward or away from original shore lines of deposition.

Similar lithologic character diagonally transgresses time horizons.

The invasion of the western continent by the Cretaceous seas, as shown in the details of the Central and East Central provinces, commenced far coastward of the present eastern border of the Black Prairie, and, as the bottom gradually subsided, the transgression of the Basement littoral sands westward can be traced far into the Rocky Mountain region. This continuous arenaceous terrane, which along the eastern border of the Black Prairie is of the very oldest Cretaceous age, and along the western border of the Grand Prairie is largely of the age of the Paluxy sands, is equivalent to the Denison beds in northern New Mexico. Thus it is that everywhere at the base of the Cretaceous system there is a continuous bed of sand which, when considered as a formation, transgresses much of the range of Cretaceous time.

Although the lithologic characters of the various beds are remarkably uniform and traceable through great distances and over vast areas, each formation eventually changes in thickness or composition according to the conditions of deposition, or grades up or down into the lithologic character of the adjacent beds, so that in exceptional instances a particular paleontologic horizon may be a sandstone on Red River and a limestone on the Rio Grande, or a limestone on the Brazos and a bituminous clay in southern Kansas and New Mexico.

The law of the diagonal transgression of the Basement sands of the Trinity division applies in a degree to all the other Cretaceous beds in their ultimate extension, but not so markedly. Limestone beds likewise diagonally cross the geologic column, for it can be shown that the base of the thick limestone of the Edwards formation, which occupies the position of the Walnut clays in the Rio Grande, passes upward until it is above the Walnut horizon on the Brazos and at the very top of the Fredericksburg on Red River.

PART IV.

ARTESIAN WATERS OF BLACK AND GRAND PRAIRIES.

PRINCIPLES GOVERNING UNDERGROUND WATER.

It is well to understand the elementary laws of the occurrence, distribution, and availability of underground waters, which are as simple as those controlling the surface supply, for large sums have been wasted in boring in unfavorable localities, and impractical notions have obtained current belief. Intelligent and economic work requires a knowledge of—

1. The geography of the region.
2. The local geology, including the composition, variation, and arrangement of the rocks underlying the region and affecting the distribution of water.
3. The simple laws of the occurrence and distribution of underground water.

In the preceding parts of this report every known detail concerning the geography and geology of the Black and Grand prairies (the East-Central Province) has been given, and the remainder of this report will be devoted to the practical application of these in their relations to the occurrence of artesian waters.

The laws governing the occurrence of earth water may be briefly epitomized as follows:

The rocks of the earth form a system of natural works by which water is collected, stored, and distributed. They constitute the basins, reservoirs, conduits, and other portions of the plant for retaining and distributing underground water.

The details of natural waterworks differ in different places, in the same way that the details of artificial systems differ in different plants, but the distribution in both is governed by the common principles of hydrostatics. The efficiency of a natural system is determined by the texture of the rocks and the geologic structure of the region, so that an understanding of the availability of underground water in any region necessitates a knowledge of the elementary geology of that region.

(1) The primary source of all underground water is the rainfall.

(2) Rocks imbibe water. Imbibition takes place by absorption and percolation.

(3) Water flows in rocks, and the rapidity of this flow is an index of the capacity for transmission.

(4) Different kinds of rock have different capacities for imbibing and transmitting water. The capacity for imbibing and that for transmitting have not a fixed ratio, their relation to each other varying according to the kind of rock.

(5) All water entering the earth tends to gravitate downward along lines of least resistance—the lines of easiest transmission.

(6) The only ordinary agency by which rock sheets may be naturally drained of their water is gravity.

Rainfall the Source of Artesian Water.

The rainfall is the source of all underground water, and, with the exception of certain deep-seated artesian wells, the source is usually the rain which falls in the immediate vicinity, as the physician knows when called to treat disease caused by seepage from the adjacent soil into the family well.

Water which falls upon the surface of the earth as rain is disposed of by evaporation, by surface run-off, and by percolation and absorption into the underlying rocks. The water which is evaporated passes again into the atmosphere; that forming the run-off passes over the surface to form streams and lakes; the remainder sinks below the line of evaporation into the rock mass beneath, supplying wells and springs. The proportional disposition of the rainfall in the above manner varies with the climate and geologic conditions, but so far as underground waters are concerned it is necessary to consider only the water which sinks into the ground.

Nature of Rock Saturation.[1]

That portion of the earth visible to human inspection, known as the crust, is more or less saturated with water. In times of drought and in arid regions this is not always evident at the immediate surface, where evaporation is taking place, but a post hole, a plow furrow, a blast in a quarry, or a newly dug well reveals the dampness of the rock material. This moisture is sometimes invisible to the eye, but in general its quantity varies in proportion to the compactness or porosity of the rocks, the number of joints, fissures, or other crevices, and such features of relief as control the drainage.

If rainfall be long continued the portion of the crust upon which the water falls becomes completely saturated. Upon cessation of the rain,

[1] The reader who wishes to continue this subject further is referred to two papers in the Nineteenth Annual Report of the United States Geological Survey, Part II. One of these, by F. H. King, is entitled "Principles and conditions of the movements of ground water" (pp. 50–294); the other, by C. S. Slichter, "Theoretical investigation of the motion of ground water" (pp. 295–387). Mr. Slichter gives a bibliography of technical papers on the subject. See also "The requisite and qualifying conditions of artesian wells," by T. C. Chamberlin: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125–173.

evaporation or drying begins at the surface, causing the line of saturation to sink deeper and deeper. Thus it is that in the Eastern States, where rainfall is excessive and evaporation slow, the line of saturation usually coincides with the surface, while in the extremely arid regions it is often several hundred feet below the surface. In the latter region holes 300 feet deep are often drilled through soil and rock as dry as powder without reaching the lines of saturation, while at places in the East, for example in New Orleans, water is so near the surface that dry graves can not be dug.

If the earth were of uniform composition, porosity, and temperature the water it contains would be more uniformly distributed through it, as is the water in a well-soaked sponge. But this is not the case in nature, for the outer portion of the globe consists of rocks of much less density than those of the interior, while the downward percolation of water in some instances encounters the superheated mass of the earth's interior and is forced back to the surface as steam, as in geysers and volcanoes, or enters into mineral combinations. Hence, the available water is confined to that portion of the earth's crust between the lines of heated interior and surface evaporation. Even in this narrow belt the distribution of water is very irregular.

Geologic Factors Bearing upon Distribution of Earth Water.

The factors which prevent the uniform saturation of the earth's crust and which control the distribution and occurrence of earth water are (1) the composition of the rocks and (2) their arrangement in sheets and masses, or, in other words, the geologic structure. Inasmuch as there is great diversity of geologic structure, the possibility of securing water at any given point must be largely determined by the local formation.

A stratum or rock sheet usually consists of two related parts—the outcrop and the embed. That portion exposed at the surface of the earth is the outcrop and that portion which is concealed under ground, beneath and between the other rocks, may be termed the embed. The outcrop of a water-bearing stratum constitutes its main catchment or receiving area, and the embed constitutes the storage reservoir.

CAPACITY OF ROCKS FOR ABSORBING WATER.

Rocks imbibe moisture in proportions varying with their physical structure, a fact which can be demonstrated experimentally by saturating specimens of rocks of familiar types.

The manner in which rocks imbibe water is simple. In most rocks, however compact to the eye, there exist interstices, cavities, and other spaces in which water may enter and be stored. This is especially true of all sedimentary rocks, which comprise a large percentage of the earth's crust. A fine sandstone, whose grains and intervening spaces are indistinguishable to the eye, when placed under the microscope resembles a mass of cobblestones in which the spaces may occupy as much of the aggregate area as the solid particles. Into a gallon measure of dry pebbles varying in size half a gallon of water may sometimes be poured.

Rocks of open texture, such as loose sands and sandstones, gravels, and chalk, have a sponge-like capacity for imbibing water. Water poured upon sand will quickly disappear by imbibition. If we wish to filter water we run it through beds of sand or gravel. Bricks are sprinkled before they are put into buildings, and they absorb from 20 to 60 per cent of their weight of water. On the other hand, wishing to shed water or otherwise prevent its percolation, one constructs roofs of tile, makes tables of marble, and builds tanks and cisterns of cement or clay. Few stop to consider when thus using rocks that they are making practical application of the broad principles which control the occurrence of underground water. By careful and accurate experiments the capacities of rocks for the imbibition and transmission of water have been determined, and it is shown that sandstone or chalk will absorb many times as much water as slate, marble, or granite. These facts can be observed after every rain. If the rain falls upon loose, sandy soils, like those of the two cross-timber regions of Texas, it quickly disappears by absorption; if, on the other hand, it falls on the clay soils of the prairies, it stands for some time in pools, such as those called "hog wallows" in Texas. Glass is similar in water capacity to some large areas of volcanic rocks and will absorb no perceptible amount of moisture; marble will drink in only a slight quantity, while chalk, sand, and brick will absorb nearly their own weight of water.

While water-bearing rocks are always porous and usually are but slightly if at all consolidated, the degree of consolidation has but little bearing upon the retaining function of impervious strata. Soft clay shale is practically as impervious as hard slate. People often discredit the possibility of obtaining artesian water in many favorable localities because of the absence of visible indurated strata, which they suppose are necessary to constitute the impervious stratum above the one containing the water. In fact, the presence of hard rocks is not a necessary condition for the obtainment of artesian water; for the older formations of the earth, which are usually more consolidated, as well as more metamorphosed, and more disturbed by tilting, faults, and folds, are least favorable for the occurrence of artesian water. On the other hand, the later formations present the opposite and more favorable conditions, and with few exceptions the great artesian wells of the world are found in them.

FLOW OF WATER THROUGH ROCKS.

The capacity of rocks for the transmission of water is entirely different from their capacity for imbibition. Each kind of rock has an individual capacity for the transmission of water. If one should construct of sand, clay, slate, granite, and chalky and close-textured limestone filtering vessels of equal capacity and fill them with water, one would see diverse results, illustrating the capacity of these rocks for transmission of water. Water would pass so slowly through the close-textured limestone, slate, and granite, that the quantity filtered would be practically imperceptible. At first the sand and chalk would drink in the water equally fast, but after complete saturation it would require much longer for the water to percolate through the chalk than through the sand.

If the component particles of a rock present an impervious surface, water will adhere to the surfaces of the individual particles until the entire specimen is enveloped in a coat of water, which gradually penetrates the interior of the rock through the interstices between the particles. If the interstices are smaller than the average drop of water, the resistance of cohesion to the transmission of water will be proportionately greater; hence, while fine-grained rocks, such as a chalk or a brick, may drink in much water, they will transmit it slowly, while water will pass rapidly through coarse gravel. Thus, some sandstones of exactly the same capacity for imbibition as chalk transmit water many times faster. The capacity for transmission in rocks of different grain and the accompanying adhesion are similar to those which may be seen in passing water through sieves of different mesh.

INFLUENCE OF STRATIFICATION ON DISTRIBUTION OF UNDERGROUND WATER.

The distribution of underground water is dependent upon the arrangement of rocks in sheets or strata. The rock materials of the earth have been sorted by the waters which originally deposited them into definite sheets or strata of different capacities for imbibition and transmission. Thus another important fact in the question of underground water is introduced—the stratification or arrangement of the rocks relative to one another.

Direct and Artesian Drainage of Strata.

By the arrangement of porous strata between impervious strata nature has constructed reservoirs and conduits for the storage and transmission of water. The horizontality or inclination of the rock sheets determines the manner of distribution of underground water, constituting negative or positive conditions for the procurement of springs and wells.

If strata are horizontal the water tends to remain stored in them unless they are cut across by valleys, in which case the water will flow laterally and escape from the edges of the strata as seepage springs. If the water-bearing strata are inclined and are included between overlying and underlying impervious strata the water will sink until this pervious sheet is entirely saturated, the overlying impervious sheet opposing the tendency of the water to rise through hydrostatic pressure, and the impervious stratum beneath preventing escape downward. Both of these types of stratum drainage, that of the horizontal and that of the inclined strata, are due to gravity.

Gravity drainage is of two kinds, direct and artesian. Direct drainage is that by which water escapes at the bottom of a hydrostatic column. If sheets, beds, or masses of rock containing water be cut into by a wellhole, a ditch, erosion, or other means, to a lower level than that at which the water entered, the water above the level of the incision will be drained from the rocks by the simple process of seepage, just as water escapes from the bottom of a wet sponge or from the faucet at the bottom of a barrel. This is the method by which water is obtained from ordinary nonartesian or dug wells and from seepage springs so frequently found along the low banks of rivers, valleys, or other natural incisions into the strata. Modern agricultural field subdrainage depends upon the same principle. Artesian drainage is that in which the water rises above or escapes from a level higher than the bottom of the hydrostatic column. The simplest illustration of this principle is the equilibrium maintained by water in the two limbs of a U-shaped tube. Water from high reservoirs carried by pipes to the upper stories of buildings also illustrates this principle. Artesian water will not rise higher than its head or source, and its pressure varies with the difference between the altitude of the head and that of the outlet.

When the embedded water-bearing strata are inclosed between impervious beds and incline beneath the surface and the water is conducted to a lower level than the outcrop, it will remain stored in the earth under hydrostatic pressure until an outlet is provided for it. Water conducted downward to a lower level by an embedded stratum possesses a tendency, due to hydrostatic pressure, to rise higher than the overlying retaining bed when an outlet is afforded. If the retaining beds overlying such a water-bearing stratum are penetrated by an opening, artificial or natural, the contained water will rise higher than the overlying bed.

Artesian Wells Defined.

Earth waters which, under the influence of hydrostatic pressure, rise through an opening to a higher level are known as artesian waters. Hence an artesian well may be defined as one in which the water rises by means of hydrostatic pressure above the reservoir or embedded stratum in which it is contained. If the water rises to the surface, the well is known as a flowing artesian well; if the water fails to rise to the surface, the well is known as a nonflowing artesian well.

The height to which the water will rise depends upon several conditions. If the embedded water-bearing stratum is incised at only one place down the dip from its surface outcrop, the water at the place of incision will rise to the same level as the line of complete saturation of the bed. This level is somewhat lower than that of the lowest point of the surface outcrop. If there are several incisions the question is not entirely one of static equilibrium. For instance, if water is naturally received by the stratum in one part of its outcrop and discharged from another lower part, the conditions in the intervening area are those of dynamic rather than static equilibrium, and the water will rise in a well to a level intermediate between the receiving and discharging levels.

The water-bearing stratum may be termed an artesian reservoir. This and the impervious strata beneath and above constitute an artesian system.

Influence of Relief on Artesian Supply.

The relief of a country has important bearing upon the conditions of occurrence of underground water. If the earth's surface were level and the strata horizontal, earth water would be at a uniform depth throughout, as in an undrained field. But the surface is broken into mountains and plains and scored by valleys, while strata in nature are rarely absolutely horizontal. In general, mountains owe their existence to the relative hardness and imperviousness of their strata, and are less favorable for the storage of underground water than plains areas, and owing to the action of gravity underground water is constantly being drained away at the levels of the valleys.

Valleys, according to their kind, serve either to store or to drain the underground water. In the Greater Texas region there are two kinds of valleys: (1) Active valleys, which are in process of being cut out at the present time by streams seeking base-level; and (2) ancient valleys, which originated in past geologic time and have been partially refilled with the débris of the adjacent region. All the valleys in the mountains proper and the plains of the Regional Coastward Slope (and of eastern United States) belong to the first class, which may be called stream valleys. Valleys of this class usually so cut the strata that they break the continuity of the rock sheets and tend to underdrain the divides. The altitude of the line of saturation near a stream is reduced by springs occurring near the water level. The valleys of the second class, or basin valleys, are characteristic of the great arid Cordilleran region, and with one or two exceptions are void of running surface water. They are filled with porous débris above an impervious plain of buried mountain rock, and are favorable reservoirs of underground water. When surrounded by vast areas of mountain surface they are more apt to contain underground water in quantity than when the area of mountain slopes is smaller, for impervious mountains serve to shed and deliver the rain water, which runs down their slopes to the pervious valleys, thereby increasing the available water supply beneath the latter.

In general it may be said that the most favorable topographic conditions for the occurrence of artesian water, but the least favorable for seepage springs, are found in gently sloping plains underlain by unconsolidated rock sheets where the strata incline in the same direction as but at a slightly greater angle than the surface slope, and where the relief is but slightly broken by valley incisions. Where the strata are thus arranged and are composed of extensive alternating pervious and impervious sheets, so that in traveling up their slope, although constantly ascending in altitude, one encounters the outcropping edges of rock sheets of lower and lower stratigraphic position, the artesian conditions are favorable. The rainfall upon the outcropping edges of the pervious layers is conducted downward by gravity along the inclined plane of their embedded continuation. Each particular water-bearing stratum becomes embedded deeper and deeper toward the less elevated side of the plain. In such cases the area of availability and catchment is inversely proportional to the degree of inclination of the strata, increasing as the inclination decreases.

ARTESIAN-WELL SYSTEMS OF TEXAS.

There are several distinct artesian systems in Texas, some of which are capable of supplying large areas. There are also extensive areas where, although the conditions for obtaining artesian wells are unfavorable, both the geologic structure and expensive experiments showing the impossibility of securing flowing water, an occasional small well may be obtained.

The geologic structure of the Greater Texas region is broadly divisible into a few simple types, corresponding to the geographic provinces, each of which exemplifies the principles controlling underground water, as set forth on preceding pages. In a general manner it may be stated that the eastern portion of the State embraced within the Southern, East-Central, and Eastern provinces, including the region east of the Balcones scarp line from the Rio Grande to the Pecos, and east of the Western Cross Timbers from the Colorado to the Ouachita Mountains, presents favorable conditions, although there are districts within this area in which they are unfavorable. Likewise it may be stated that the structure of most of the region west of

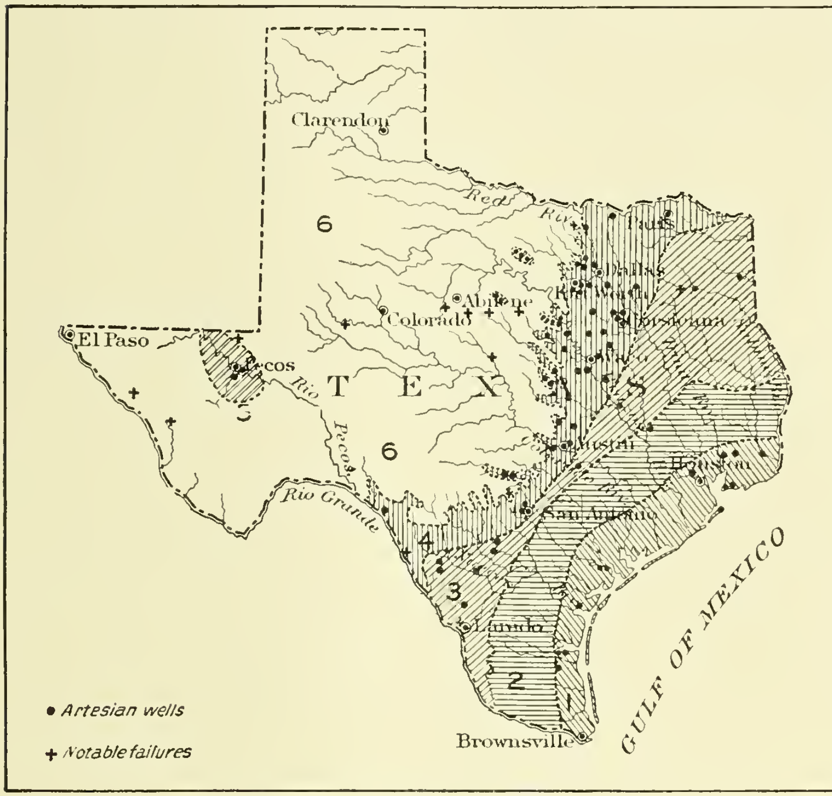


FIG. 44.—Map showing artesian districts of Texas.

1, Coast Prairie system; 2, Hallettsville system; 3, Carrizo system; 4, Black and Grand prairies system; 5, Trans-Pecos Basin system; 6, Stevens County and Jack County systems.

the above line, including the Central and Great Plains provinces and much of the Trans-Pecos province, is unfavorable to the procurement of artesian water.

Regions in which Artesian Conditions are Unfavorable.

As shown in the accompanying diagram (fig. 44), the general negative regions are: (1) The Central Province, including the vast country underlain by the Paleozoic formations and the Red Beds; (2) the Plains Province, including the Llano Estacado and Edwards Plateau; (3) the mountainous areas of the Trans-Pecos Province. In general, the geologic structure in the regions mentioned is unfavorable for the procurement of flowing wells, and it is proper to caution the citizens and communities thereof against making expensive experiments without competent expert advice.

Water is transmitted by gravity in the direction of the dip (inclination) of the strata, and if the topographic conditions are favorable flowing wells are obtainable at points lower in altitude than the outcrop and more or less distant therefrom. If the strata of a plain incline in a direction opposite to the general slope of the country, no matter how favorable the other conditions, they will furnish no flowing artesian wells, for the catchment area is lower than the surface above the embed, and water can not rise above the height of the receiving area. Such strata may, however, furnish water for pumping wells.

Because of this principle there is a vast area of Texas and western Oklahoma, including most of the great Central Province, where artesian wells are unobtainable. In the Central Province wells 2,000 feet or more have been bored at several places, notably at Thurber (3,000 feet), Cisco (1,800 feet), Abilene (2,000 feet), Merkel (about 2,000 feet), and Colorado City (1,200 feet), and in no case were there any results which disprove the previous negative opinions based upon the geologic formation.

Other great areas of plains present unfavorable artesian conditions, because the water-bearing strata are intercepted and drained by bordering valleys. The water of saturation in buttes, mesas, and tablelands in general, which usually consist of horizontal strata, is reduced by seepage toward the level of the surrounding valleys, or, when alternations of pervious and impervious strata occur, the water is conducted horizontally until it seeps out as springs at their contact. The Llano Estacado, or great Staked Plain of Texas and New Mexico, is the largest of all the American mesas in area, and is surrounded by deep valleys. Its geologic structure consists essentially of a pervious surface formation 300 feet, more or less, in thickness, resting upon a foundation of impervious clays and other rock. The upper formation readily imbibes all the surface rainfall, which ultimately escapes near the bases of the surrounding valley escarpments. Throughout this large area, once considered hopelessly void of water, good nonflowing wells are now everywhere obtained by boring to the lower depths of the saturated summit formations, while springs occasionally break out at the margin of the plains where the two formations are in contact. We have no record of any wells upon the Llano Estacado or Edwards Plateau which have penetrated to depths beyond 1,000 feet, or in which the water rises under hydrostatic pressure. The structure of this plateau of circumdenudation and its higher topographic situation relative to the surrounding regions are unfavorable to securing flowing wells.

In Texas the mountain regions present less favorable conditions for procuring artesian water than the plains. The rocks which compose most of the mountain masses of the Greater Texas region are quartzites, clays, massive limestones, and igneous rocks, which are usually more consolidated, compact, and impervious, and hence less adapted for the storage and passage of water than those underlying the plains.

Furthermore, as in most mountain regions, the strata are excessively inclined, and artesian wells are improbable if not impossible over any wide area, for the embedded strata dip within short distances to depths below all available borings. A common idea that artesian wells are peculiar to regions of great stratigraphic dip is fallacious. A dip of 2° is scarcely visible to the eye, but it will carry a stratum downward 184 feet in a mile; a dip of 10° is hardly noticeable, but it will make the stratum 918 feet deep in a mile; a dip of 45° will make a stratum 4,329 feet deep in 1 mile, a greater depth than any drill can profitably penetrate. Of the many artesian wells in the Texas region, all occur within areas where the dip of the rock is less than 1°. In the Trans-Pecos region there are certain basin deserts, or bolsons, in the lower portions of which favorable artesian conditions occur, but the mountainous portions present a field which is hopeless in this respect.

A section from the Gulf of Mexico to the Rocky Mountains—from Galveston to Las Vegas, New Mexico—illustrates some of the facts herein set forth. From the interior edge of the Grand Prairie to the coast there is a large series of alternations of porous and impervious strata of the later geologic ages, dipping at an almost imperceptible angle toward the sea and outcropping to the west, the outcrops of which are favorable receiving areas for artesian systems. The above group of rocks rests upon another series of older rocks outcropping in the Central Province which incline in a direction opposite to that of the topographic slant, and hence present negative conditions for artesian water. No artesian wells of large flow have been or are apt to be obtained in the latter region. Above the western part of this series is the mesa of the Llano Estacado, the nonartesian conditions of which have been explained. A second negative area is shown in northeastern New Mexico, where the inclination of the strata is again opposite to that of the topographic slant. Where the front of the Rocky Mountains appears the conditions are unfavorable for artesian wells owing to the faulting and excessive dip of the strata.

Artesian-Well Systems of the Texas Coastal Plain.

For the purposes of the discussion of the artesian-water problems, all of that portion of the eastern half of Texas lying east of the Central Province and Edwards Plateau may be discussed under the generic name of the Coastal Plain.

Inasmuch as the artesian-well systems of the Black and Grand prairies are related to the broader group of artesian-well systems in general underlying the whole Coastal Plain of Texas, it is appropriate to introduce here a few remarks upon the latter as a whole.

The subdivisions of this plain include the familiar belts of country which have been described under the following names:

1. Coast Prairie.
2. Fayette Prairie.
3. East-Texas Timber Belt.
4. Black Prairie, including the Eastern Cross Timbers.
5. Grand Prairie, including the Western Cross Timbers.
6. Rio Grande embayment, which embraces the modified continuation south of the Colorado of 2, 3, 4, and 5.

The artesian wells and well systems[1] of this portion of Texas are numerous and extend over considerable areas. This portion of the State constitutes one of the most productive artesian regions in America, if not in the world, extending from near Red River, Denton County, to the Rio Grande at Del Rio, a length of 448 miles, and averaging 300 miles in width. In this general region there has been a great development of artesian wells within the last fifteen years. At numerous places in districts which a few years ago possessed only inadequate supplies of water, flows have been secured and artesian wells now supply water in great quantities to cities, ranches, and farms, and improve the sanitary and domestic conditions.

Flowing wells have been successfully obtained at Fort Worth, Waco, Dallas, San Antonio, Houston, and Galveston, the principal commercial cities of the State, having populations of from 25,000 to 50,000. Denton, Taylor, McGregor, Corsicana, Temple, Marlin, Hillsboro, Morgan, Belton, Hallettsville, and other prosperous towns have also been supplied. The number of these wells and the wide areas over which they are found suggest that there must be some general laws by the application of which the possibility and value of such wells in this region can be predicted with considerable certainty, and these laws are worthy of investigation.

The whole Coastal Plain is underlain by little-consolidated strata of Cretaceous, Tertiary, and Pleistocene ages. These strata consist of sediments deposited in and around the Gulf of Mexico during its various epochs of expansion and contraction coincident with continental subsidence and elevation. They all incline coastward at a very slight angle, a little greater than the surface gradient, producing long and gentle inclinations very favorable to artesian conditions. The rock sheets, a table of which is given in fig. 1 (p. 32), are composed of alternations of pervious and impervious layers presenting favorable conditions for the transmission of artesian water.

[1] The term "system" includes all wells belonging to a group having their source in the same set of rock sheets or strata

The water-bearing beds occur in four conspicuous groups of formations of different ages. These, in descending series, are: 1, The coastal clays of Pleistocene age; 2, the *x* beds of probable Tertiary age, underlying the coastal clays; 3, the generally sandy beds of the Fayette division of the Eocene; 4, the sandy beds of the Camden or Lignitic series of the Eocene; 5, the Woodbine sands at the base of the Upper Cretaceous; 6, certain arenaceous and cavernous beds of the Fredericksburg in the middle of the Lower Cretaceous; 7, the Paluxy sands; 8, the Trinity sands.

Each of these groups of water-bearing strata supplies a corresponding geographic province, constituting an artesian system, and each system may be named either from some typical place of its occurrence or from the geologic strata which supply the artesian waters, as follows:

Coastal system.
Carrizo system.
Hallettsville system.
Woodbine system.
Fredericksburg system.
Paluxy system.
Trinity system.

Each of these systems is of great importance to the economic welfare of the region which it supplies, and is worthy of a minute description. In the succeeding pages such a description of the four last mentioned will be attempted, but owing to the lack of sufficient reconnaissance and exploration and geographic mapping of the coast region underlain by the artesian reservoirs above the Woodbine system, they can be described only briefly and in an imperfect and preliminary way; therefore the body of the present report will be devoted to the artesian systems supplied by the Cretaceous formations.

As a whole the rock sheets of the Coastal Plain may be collectively discussed as the systems of the coastward incline. If one begin at the coast and travel westward across this region he will find that, while constantly ascending above sea level at a slight gradient, he will be descending the geologic sequence; that is, he will cross successive belts of country, each with its peculiar soil, rock, and flora, and can scarcely fail to observe that each of these different aspects is due to differences in the rock sheets of which the surface is formed. The outcrops of the various strata, owing to their physical and chemical composition, have weathered into diverse characters of country—forest and prairie, broken or level—exactly as the substructure permits. If the underlying rock is sandstone, the soil and other surface débris resulting from the weathering of the underlying rock sheets are usually covered with timber, and surface wells are abundant; but if it is marly (chalky) clay, the soil will be black, sticky, and treeless, and the water poor and scarce.

It will greatly assist the reader to grasp the arrangement of these rock sheets if the order of succession of the main beds or formations which constitute the explored crust of the earth in this region be kept in mind. The various strata which form the coastward incline are superposed upon one another in definite order. The arrangement of the formations may be illustrated by a package of cardboard, representing the strata or rock sheets (see fig. 45). When properly placed on the table the topmost sheet represents the newest geologic formation, or coastal prairies. A few sheets immediately beneath represent the strata of the underlying Washington-Fayette prairies. Each cardboard in turn represents an older rock sheet, the bottom card representing the Trinity sands resting on Paleozoic rocks. Place the pile in a northwest-southeast direction, so as to uncover the upper surface of a large number of sheets, and a very correct idea of the manner in which the various geologic formations occupy the surface of the eastern half of Texas may be obtained. *A* is the top sheet of the pile and *Z* is the bottom one, yet both are visible. If the hand be passed from *A* to *Z* along the extended pack, it must traverse in turn the exposed surface of each sheet until it arrives at the bottom one. Further, if, instead of looking from above down upon the pack, one

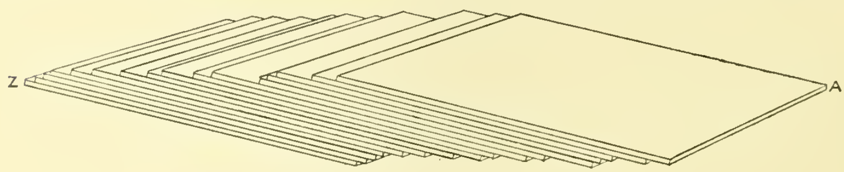


FIG. 45.—Diagram illustrating sequence of strata.

looks at the side elevation, it will be seen that the cards are not horizontal, but tilt slightly from northwest to southeast; in other words, they dip southeast. Anyone who travels across this region in a northwesterly direction will pass over the various strata forming the surface as the hand passes over the sheets of cardboard. All the strata dip toward the southeast and crop out toward the northwest. The succession and outcrops of the various strata are shown in the section of the country from the coast to the Central Denuded region. The newer formations are on the southeast and the older formations successively occupy the country until we arrive at the Paleozoic sandstones and shales of the Central region. This is the key to the succession of the various kinds of rocks in the coastward incline.

Beginning with the bottom sheet, it will be seen that the face of each sheet forms an inclined plain of stratification, the exposed portion of which is terminated to the eastward or lower edge by an ascending escarpment formed by the edge of the next higher sheet, and to the westward or higher edge by a step-off or descending escarpment formed by its own edge. This inclined plain is known geologically as a dip plain, as distinguished from a mesa or plateau, in which all the edges are free escarpments. All the parallel belts of country of the coastward incline are dip plains. The valley where the escarpment meets the dip plain may be called a valley of stratification; and there are many of these in the region under discussion, the most conspicuous of which is that of the Western Cross Timbers.

Furthermore, to one traveling across these escarpments and dip plains, it will be evident that while the sudden descents of the escarpment faces are great, the gradual ascents of the dip plains are greater in aggregate height, so that while the last valley of stratification is several hundred or thousand feet lower in the geologic series, it is several hundred feet higher in altitude, thus illustrating the apparent paradox that the receiving areas of artesian-well systems are often valleys.

Finally, if the whole pack of cards should be completely fractured or cut through by a knife, and one side dropped down or raised up, this would constitute what is geologically known as a fault. If the dislocation or throw of the fault is great, the continuity of the transmitting strata is broken and the artesian conditions are seriously affected. If the downthrow is interiorward, the receiving area may be reduced too low to afford pressure for a supply of water at the point where a well may be desired.

Now, it happens that throughout the vast region of the Coastal Plain there are two of these great fault zones—one of each kind—the first of which, the Balcones zone, extends from near Dallas to Del Rio, via Waco, Austin, Heliotes, and Uvalde, and is a strike fault which downthrows to the coastward; while the other, the Red River fault zone, which extends from near Marietta, Indian Territory, southeastward through Preston, Denison, and south of Paris, Texas, is a dip fault, with its downthrow interiorward. These are both described in detail in the geologic chapters.

COAST PRAIRIE SYSTEM.[1]

Beneath the extensive Coast Prairie region which borders the Gulf of Mexico there are many sheets of artesian water-bearing strata, as may be seen in the accompanying descriptive section of the deep well at Galveston, Texas, which will serve to illustrate the general geologic structure of the Coast Prairie region.

[1] The writer can not here give minute details concerning the volume, chemical composition, and uses of the artesian waters of the Coastal Plain in general, but wishes merely to present a conspectus of their geographic and geologic occurrence and availability. Valuable details of the character above mentioned may be found in a paper entitled Preliminary Report on the Artesian Wells of the Gulf Coastal Slope, by J. A. Singley, Austin, June, 1893.

SECTION NO. 48.—DEEP WELL AT GALVESTON, TEXAS.

	Thickness.	Depth to bottom of strata.
Pleistocene:	*Feet.*	*Feet.*
1. Buff gray sand	46	46
2. Reddish-brown clay, inclosing calcareous concretions, ferruginous sandstone, and quartz pebbles, nodules of dark-gray clay, and shell fragments	17	63
3. Mottled red and blue clay, full of shell fragments. The last 16 feet of this clay is full of lignitic matter and has fewer shells	37	100
4. Gray sandy clay	10	110
5. Fine gray sand, containing some fragments of lignite	57	167
6. Buff-colored sandy clay	112	279
7. Fine gray sand, containing a few fragments of lignite	26	305
8. Grayish-brown clay, inclosing fragments of lignite	10	315
9. Fine sand, varying in color from gray to ash gray and buff gray. Fragments of lignite were met with throughout this bed and the last 35 feet were slightly micaceous	125	440
10. Grayish-brown clay, containing fragments of lignite, shells, coral, and a fragment of the claw of a crustacean	18	458
Age doubtful:		
11. Gray sandy clay, slightly micaceous	10	468
12. Brownish-gray sandy clay	29	497
13. Fine light-gray clayey sand, micaceous	78	575
14. Brownish-gray sandy clay	17	592
15. Gray sand, micaceous	20	612
16. Brownish sandy clay, containing a few shell fragments	35	647
17. Light-gray sandy clay	27	674
18. Reddish-brown sandy clay, containing finely comminuted shell fragments	32	706
19. Buff-colored sand, slightly micaceous	14	720
20. Brownish-gray clayey sand	17	737
21. Light-gray clayey sand, the last 11 feet containing a few shell fragments and large pieces of lignite	90	827
22. Coarse silver-gray sand, composed of angular fragments of translucent and smoky quartz not much waterworn. This is the water-bearing sand from which most of the city's water supply is derived	55	882
23. Buffy sandy clay	11	893
24. Gray sand, full of fragments of lignite and a few shells	10	903
25. Brownish-clayey sand	8	911
26. Indurated coarse gray quartz sand, inclosing fragments of lignite and shells (too finely comminuted for determination), calcareous concretions, and small ferruginous sandstone pebbles	3	914

SECTION No. 48.—DEEP WELL AT GALVESTON, TEXAS—Continued.

	Thickness.	Depth to bottom of strata.
Age doubtful—Continued.	*Feet.*	*Feet.*
27. Fine ash-gray micaceous sand	16	930
28. Fine clayey sand, changing from brownish gray above through olive-buff to ash-gray below, micaceous throughout	102	1,032
29. Sandy clay, varying buff, brownish, and greenish tints	228	1,260
30. Coarse gray quartz sand (water-bearing sand)	28	1,288
31. Greenish-gray sandy clay	31	1,319
32. Buff-colored clay	11	1,330
33. Coarse gray sand, composed of rounded, waterworn fragments of quartz (water-bearing sand)	10	1,340
34. Greenish-gray sandy clay	17	1,357
35. Brownish clay	10	1,367
36. Ash-gray clay	17	1,384
37. Reddish-tinted coarse gray sand	9	1,393
38. Greenish sandy clay	17	1,410
39. Buff, sandy clay	20	1,430
40. Greenish-gray sandy clay, the last 6 feet changing to buff color	18	1,448
41. Medium coarse sand of rounded fragments of translucent and smoky quartz; a ferruginous stain gives this sand a reddish tint	6	1,454
42. Greenish-gray sandy clay, the lower 9 feet shading into buff color	28	1,482
43. Brownish clay	11	1,493
Upper Tertiary:		
44. Greenish gray sand, micaceous (water-bearing sand)	18	1,511
45. Laminated greenish clay, containing small rounded pebbles of ferruginous quartz and sandstone, jasper, flint, calcareous concretions, and a few fragments of opalized wood; shells, lignitized wood and fruits, and fragments of claws of a crustacean	95	1,606
46. Brownish gray sandy clay	22	1,628
47. Brownish gray clayey sand	126	1,754
48. Cream-colored, gritty, calcareous conglomerate	4	1,758
49. Fine gray sand, micaceous	22	1,780
50. Olive-buff sandy clay	20	1,800
51. Fine greenish gray sand, micaceous	32	1,832
52. Olive-buff sandy clay	13	1,845
53. Fine dark gray sand	31	1,876
54. Brownish clay, containing fragments of lignite, calcareous concretions, and finely comminuted shell fragments	19	1,895
55. Dark gray sand, micaceous	28	1,923

SECTION NO. 48.—DEEP WELL AT GALVESTON, TEXAS—Continued.

	Thickness.	Depth to bottom of strata.
Upper Tertiary—Continued.	*Feet.*	*Feet.*
56. Greenish sandy clay, containing calcareous concretions and lignitized wood and fruits. A few broken shells were taken from between 1,879 and 1,990 feet	113	2,036
57. Fine gray clayey sand	24	2,060
58. Buff sandy clay	8	2,068
59. Greenish-gray clayey sand	29	2,097
60. Laminated greenish clay, containing calcareous concretions, fragments of lignite, and shells too poorly preserved for identification	41	2,138
Upper Miocene:		
61. Fine dark gray sand, micaceous	15	2,153
62. Greenish clay (the first 10 feet laminated) containing lignitized wood and well preserved fruits and corals. The color markings are preserved on some of the shells from this stratum	43	2,196
63. Indurated fine gray sand	24	2,220
64. Dark colored clay, full of lignitized wood and fruits, corals, fish vertebræ, and shells	29	2,249
65. Light buff-gray clayey sand	39	2,288
66. Siliceous calcareous shell conglomerate, of a bluish-gray color and very hard, forty hours having been taken to penetrate the $3\frac{1}{2}$ feet	3.5	2,291.5
67. Buff-gray clayey sand	18.5	2,310
68. Light gray sand, micaceous	13	2,323
69. Brownish sandy clay	7	2,330
70. Greenish-gray clayey sand	15	2,345
71. Medium coarse gray sand, composed of well rounded translucent and smoky quartz fragments, micaceous (water-bearing sand)	32	2,377
72. Greenish clay, inclosing a few comminuted shell fragments and particles of lignite	10	2,387
73. Mottled blue and brownish clay, containing calcareous concretions, rounded pebbles of ferruginous quartz, nodules of iron pyrites, fragments of lignitized wood, and shark teeth	23	2,410
74. Laminated blue clay, containing calcareous concretions, iron pyrites, rounded calcareous and ferruginous sandstone pebbles, lignite, coral, shark teeth, and shells	15	2,425
75. Red and greenish mottled clay, containing a few rounded pebbles of flint, iron pyrites in nodules, lignite, coral, and shells	7	2,432
76. Buff-colored sand of rounded quartz fragments (water-bearing sand)	11	2,443
77. Mottled brown and greenish clay with calcareous concretions, lignite, and fish vertebræ	8	2,451
78. Lignite	2	2,453

SECTION NO. 48.—DEEP WELL AT GALVESTON, TEXAS—Continued.

	Thickness.	Depth to bottom of strata.
Upper Miocene—Continued.	*Feet.*	*Feet.*
79. Mottled brown and greenish clay, with calcareous concretions, rounded pebbles of bluish siliceous limestone, lignite, coral, fish spines and vertebræ, otoliths, and water-worn shells	23	2,476
80. Light-gray sand (water-bearing sand)	9	2,485
81. Dark-gray sand, somewhat coarser than last	19	2,504
82. Light buff-gray sand, micaceous	17	2,521
83. Dark-gray sand, micaceous	31	2,552
The last three beds are a continuation of No. 80, water-bearing sand.		
84. Laminated greenish clay, with calcareous concretions, lignite, coral, fish vertebræ, otoliths, shark teeth, and shells	15	2,567
85. Greenish gray micaceous sand. A large number of shells were secured from this sample, but there is no doubt but that many of them are from the clay immediately overlying the sand, as the clay was caving in while the pipe was penetrating the sand	31	2,598
86. Mottled brown and greenish clay, containing a large number of shells, mostly fragmentary	33	2,631
87. Fine ash-gray sand	6	2,637
88. Brownish sandy clay, hard, containing fish vertebræ and teeth, otoliths, corals, and shells	61	2,698
89. Buff clayey sand	19	2,717
90. Greenish clay, laminated after the first 16 feet, with calcareous concretions, cylindrical gray sandstone casts or concretions, waterworn limestone pebbles, lignite, coral, fish vertebræ, spines, and teeth, otoliths, claws of a crustacean, and many well-preserved shells. Fragments of lignite with teredo borings and a well-preserved lignitized cone of one of the conifers were found in this bed. The last 60 feet changed to a bluish color	166	2,883
91. Gray sand, the grains of very uniform size of rounded translucent quartz. A few grains of smoky quartz were also found in this sand	37	2,920
A strong flow of water was encountered in this bed, forcing the sand for 200 feet up the pipe. The water was brackish.		
92. Gray clayey sand	65	2,985
93. Brownish sandy clay	40	3,025
94. Dark gray sandy clay, micaceous, and containing a few fragments of lignite	22	3,047
95. Coarse gray sand of rounded translucent quartz fragments, slightly micaceous (water-bearing sand)	23	3,070
The water is brackish, but apparently less so than that from any other well on the island.		

Résumé of the formations of the deep artesian well at Galveston, Texas.[1]

Depth, in feet.	
46–458 (412)	Pleistocene.
458–1,510 (1,052)	Doubtful.
1510–2,158 (648)	Upper Tertiary.
2158–2,920 (762)	Upper Miocene.

The economic importance of this system can hardly be overestimated. The commercial cities of Galveston and Houston are largely supplied by these waters. Galveston's city water supply is from 33 artesian wells located on the mainland, the water being piped under the bay to the city. The source of supply being wells from 700 to 850 feet deep, no organic impurities or sewage contaminations are to be found in the water. The chemical impurities are principally bicarbonate of soda and common salt, not necessarily injurious to health or rendering the water unfit in any way for household or industrial uses. There are also over 25 of these wells in the city. They supply not only the city (previously dependent upon cistern storage) with water for domestic purposes and fire protection, but afford a pure supply for the shipping which leaves that port.

Houston is even more abundantly supplied with this water, having nearly 100 wells, which obtain water at depths varying from 140 to 500 feet. In the writer's opinion nothing has so much contributed to the rapid rise of Houston to the first rank in commercial importance as this supply of pure water for domestic and manufacturing purposes. These wells are obtained with certainty nearly everywhere within a radius of 50 miles from Galveston, and are used upon the sugar plantations. They have been secured in Orange, Liberty, Chambers, Galveston, Harris, Brazoria, Fort Bend, Refugio, and San Patricio counties. West of the Guadalupe the Coast Prairie is still largely given up to extensive cattle ranches, and in at least one instance the waters are of great value to stock raisers.

Much of the Coast Prairie of Texas, like its continuation in Louisiana, is well adapted to rice culture, and in one or two instances certain wells are used for flooding the fields.

In that portion of the Coast Prairie north and east of Houston and Galveston wells have been reported from Devers, Liberty County, and on the east side of Galveston Bay in Chambers County, showing the extent of this system in that direction.

Westward, along the coast, another group of wells is found around the mouth of the Brazos in the vicinity of Velasco, where water is obtained at depths varying from 650 feet at Quintana, directly at the mouth of the river, to 1,025 feet at Velasco. There is no reason to believe that these wells are not exactly identical in source with those at Galveston and Houston.

[1] Harris, Fourth Ann. Rept. Geol. Survey Texas, Austin, 1892 (published 1893), p. 118.

This office has no record of artesian experiments from the mouth of the Brazos to the Guadalupe, over 100 miles. In Refugio County, Texas, Mr. Dennis O'Connor has three artesian wells in which water was reached at 825, 919, and 946 feet. The water they afford has not been exactly measured, but one of them is said to flow 150,000 gallons each twenty-four hours from a 5-inch pipe, while another having an 8-inch pipe is said to flow 300,000 gallons. These wells are said to come from two water beds, one occurring at a depth of from 765 to 820 feet and one from 916 to 940 feet. The last furnishes most of the water and is cooler. The quality of both these is said to be very similar, the water being as soft as rain water and free from saline material. The wells are at present used exclusively for stock purposes.

From San Antonio Bay to the Rio Grande little artesian exploration has been attempted in the coast counties. At Corpus Christi water is obtained at 1,765 feet. The greater depth of this well indicates a variation from the uniformity of conditions which has prevailed along the coast from Galveston to the mouth of the Guadalupe. From Corpus Christi southward there is a stretch of 150 miles of the Coast Prairie from which we have no reports of artesian investigation.[1]

It will be observed that there are at least two chief water-bearing strata in these walls of the Coast Prairie region at Galveston, and that this sequence is shown as far west as Refugio County. The uppermost of these, which is struck at a depth of about 825 feet at Galveston, seems to be the chief source of supply. The other available stratum lies at 1,260 feet.

While lack of knowledge of the exact geology of the strata renders it impossible to say that the waters all come from identically the same geologic horizons, it is probable that all the wells from the Louisiana line to O'Connor's wells in Refugio County come from closely allied beds, and the wells of this particular coastal tier of counties will be referred, at least tentatively, to one general system.

There are no data for defining precisely the geographic limits of possible success. There is little reason to doubt that in the whole Coast Prairie belt from the Sabine to the Rio Grande wells of this character may be obtained, yet, owing to the insufficiency of exact geologic data, it is impossible to give more particulars concerning the system.

Certain wells at Rancho, about 7 miles northwest of Goliad, concerning which there are no geologic data, in which flowing water is obtained at a depth of 60 feet, may possibly represent the western limit of the coastal artesian system.

Keno, in northern Liberty County, is probably west of the limit of possible flow. All that can be said at present is that the belt of

[1] Newspaper reports since this paper was written announce the successful drilling of several flowing wells on the King ranch, in Nueces and Hidalgo counties, thus extending the known field much farther southward.

success is confined approximately to the coastal tier of counties west of the Brazos and to the coastal and adjacent counties north of that river.

These waters occur in a series of beds underlying the coastal clays, the geologic age of which is probably late Tertiary and Pleistocene. Furthermore, these water-bearing beds, which have been called the *x* beds in the geologic description, have not been traced to the surface and may possibly receive their waters by underground connection with other sheets. All that can be said at present is that these great sheets of water-bearing strata, as shown by actual exploration, do underlie the Coast Prairie of Texas and adjacent islands and are available for the use of man.

HALLETTSVILLE SYSTEM.

We place in a second artesian-well system of Texas a belt of wells extending partially across the Southern Province, lying along the border of the Coast Prairie and Fayette Prairie regions. This includes a narrow strip of country extending from Brenham southward to the Rio Grande at Hidalgo, including portions of the counties of Colorado, Lavaca, Dewitt, Victoria, Goliad, Bee, Live Oak, western Nueces, eastern Uvalde, Starr, and Hidalgo. Owing to lack of exploration, exploitation, and sufficient geologic data, together with the irregularity of the geologic formations and the difficulties surrounding their interpretation, it is not possible to speak of this group as coming from one definite geologic terrane, but it includes wells procured from several different beds in a series of Tertiary strata lying above the Carrizo system and beneath those supplying the Coastal system. It is very probable that some of the wells, if not most of them, are derived from the highly favorable sandy terranes of the Fayette series of the Eocene Tertiary.

It is probable that the conditions throughout this belt so vary locally that much time and study will be required to define the limits and possibilities of the water flow or flows, if possible at all. Artesian experiments have been made in this belt at Hallettsville, Shiner, Yoakum, Victoria, Yorktown, and Hidalgo. The writer can only present the records of success and failure within this region.

The wells at Hallettsville may be taken as a type of successful flow. Several artesian wells occur in this prosperous town. Two flows have been secured at the depths of 300 and 560 feet. At the well of the Oil Mills these furnish 20,000 and 40,000 gallons a day, respectively. The city is supplied with drinking water from artesian wells. The writer has been unable to procure a geologic section of these wells, but there is reason to believe that their water comes from the Fayette series, or upper division of the Eocene, a source lying lower in the geologic column than that of the Coast Prairie wells and higher than that of the wells in the belt lying to the west, next to be described.

With the data at hand no positive statements can be made concerning the extent and possibilities of the belt. Its eastward extent has not been explored. A line drawn through Shiner to Yoakum and Yorktown will possibly indicate the western limit of the field.

At Shiner, 15 miles west of Hallettsville, a flow of water was struck at 90 feet from the surface, supplying 35,000 gallons a day. This water is apparently derived from the same beds as the Hallettsville wells, and if so the inclination of the beds is from 20 to 40 feet to the mile in an easterly direction. The Shiner well was commenced at a low altitude relative to the surrounding country, and its slight depth indicates that it is very near the western limit of the Hallettsville flow.

Yoakum apparently lies at the western edge of the Hallettsville belt. Many experiments have been made at this place to secure a good flow of water for city supply, but with no success. At a depth of 100 feet, after a stratum of harder rock had been passed, 88 feet of water-bearing sand were encountered, from which the water rose to within 19 feet of the surface. In another well in the town a feeble flow was struck at 252 feet, which was of no value.

The following notes from Mr. J. W. Greer, secretary of the Yoakum Improvement Company, Yoakum, Texas, and the section in fig. 46, give instructive data concerning the experiments at this place:

FIG. 46.—Well at Yoakum, Texas.

NOVEMBER 8, 1895.

At the request of Mr. J. L. Slayden, one of the owners of the plant with which I am connected, I will endeavor to give a brief history of our efforts to get artesian water in Yoakum.

At Hallettsville, 16 miles north of us, there is artesian water of the softest and purest kind, flowing from seven wells within a radius of 3 miles. Flowing water was struck at depths ranging from 375 to 525 feet, the strongest well flowing through a 4-inch pipe, 40,000 gallons per day.

At Shiner, 12 miles northwest of us, flowing water was struck at 90 feet, the output being 35,000 gallons per day. The water rose to a height of 6 feet above the surface. This well was bored in a low place. A second attempt, on the side of an elevation 24 feet higher, resulted in failure to get a flow at the same depth, although at a corresponding depth the same water stratum was penetrated and water rose within 19 feet of the surface. This second well was continued to a depth of 250 feet, at which depth a feeble flow of muddy water was had. The flow was so small and the water so impregnated with sand and mud as to be valueless, so the flow was cased off and the well was continued through very hard rock to a depth of 450 feet, then passed successively through clay, lava, and slate, and stopped at 700 feet in a stratum of dead, dry-looking clay. This well was without result, although but for lack of funds it could have been bored much deeper.

With the above data before us, and knowing that two attempts had been made in Yoakum to get artesian water (with drop drills), both of which failed at about 600 feet because the casing had been reduced to so small a size as to preclude reaching a greater depth with drop drills, we determined to make another effort for artesian water. We employed Charles Karsch, who bored the wells at Hallettsville and Shiner and who works with the appliances of the American Well Works, a rotary hydraulic system.

The two previous attempts to bore artesian wells in Yoakum were made on an elevation 20 feet higher than our plant. In one of the wells, it was claimed, water rose within 19 feet of the surface. Our present attempt is being made between two surface wells which now supply through the medium of steam force pumps all the water used through the waterworks system here, about 100,000 gallons per day. At 100 feet we passed through a rock and struck 8 feet of water sand, the water rising up to a level with the water vein in the surface wells, but flowing seemingly only into one of them. This materially increased our water supply and has improved the taste and quality of the water very much. The surface water seems to be a combination of lime, magnesia, and saltpeter. It is anything but pleasant to the taste and has a bad effect until one has become accustomed to it. At a depth of 245 feet we passed through 15 feet of water sand, and the water rose within 40 feet of the surface. This water was pure and sweet to the taste. At 324 feet we again struck water, but it rose no higher than the previous vein, so we could not tell anything about the quantity or quality, as it might be that the higher stratum was following the case downward and rising within it. About this time we struck 3½ feet of quartz, almost as clear as diamond and exceedingly hard, requiring nine days of constant work to penetrate it, and leaving the hole slightly out of round, so that it was necessary to reduce the case from 8 inches to 6 inches, which we have continued to the present depth—940 feet—from 346 feet.

I have sent by express thirteen samples of the different strata passed through, beginning at a depth of 520 feet and continuing at intervals to the bottom of the well. In specimen No. 5, marked "Lava and cinders," a small piece of wood (lignite) came up on the drill at 760 feet below the surface. The drill seemed to work through wood about 18 inches.

We have not been able to detect water since leaving the stratum at 332 feet. Below 800 feet the nature of the different strata, as shown in the last three samples, Nos. 11, 12, and 13, indicates strongly, so Mr. Karsch claims, that we are in close proximity to water.

A trace of semiliquid asphaltum or substance of that nature was passed through at the same depth, nearly, as the wood and cinders.

Very respectfully, yours, J. W. Greer, *Secretary.*

At Yorktown, Dewitt County, shallow wells were procured at 60 feet, from which flows of water were obtained possessing the same character as that from the Hallettsville and Shiner wells. The shallowness of these wells is a sure indication that they are situated very near the western limit of the area of successful experimentation. Karnes City probably lies entirely west of this belt, for at this point an experiment of 1,800 feet failed to develop flowing water. Data are absolutely wanting concerning the longitudinal extent of this belt. The experiments near Hidalgo lead us to believe that it may reach as far south as the Rio Grande.

In Hidalgo County, near the town of Hidalgo, on the Rio Grande, two wells have been sunk, to 700 and 1,000 feet, and the water rises in each of these to less than 100 feet of the surface. These wells may possibly procure their waters from lower beds than the Fayette series, the easternmost outcrop of which is near this point. This experiment shows that the artesian conditions are at least partially favorable in this region.

CARRIZO SYSTEM.

The 2,000 feet of strata composing the Lower Eocene is made up largely of pervious sandy beds alternating with layers of clay, presenting perfect conditions for the storage and transmission of water. In fact, of all the great series of rock strata entering into the structure of the State of Texas, no others present so large a proportion of arenaceous beds having the proper texture for the storage and transmission of water.

Many artesian wells in Texas derive their waters from the beds of this series. These are found at various intervals along a belt extending completely across the State from Carrizo Springs, Dimmit County, near the Rio Grande, northeastward, to Jefferson, 500 miles. Wells of this system occur in Dimmit, Webb, Lasalle, Frio, Gonzales, Bastrop, Burleson, Grimes, Robertson, Wood, and Marion counties.

On the Rio Grande, commencing at Laredo, and occurring at intervals northward nearly to Red River, are several local groups of artesian wells derived from various horizons of this formation, some of which are probably, but not positively, from higher beds than those of the Carrizo belt.

Except for the purposes of city supply, artesian wells are not especially desired in that portion of the timber belt lying north of the Brazos, inasmuch as good surface wells are nearly everywhere obtained, and the country has abundant rainfall for agriculture. Wells are especially desirable, however, in that portion lying west of the Brazos, and they increase in importance and necessity as the conditions become more arid.

While all of these wells are obtained from the Camden series, it is not probable that they all come from the same strata in the series, and hence they can best be discussed by classifying them into local groups, as follows:

Carrizo group.
Frio group.
Smithville group.
Robertson County group.
Marshall group.

Carrizo group.—There are about twenty-five flowing wells at Carrizo Springs, Dimmit County, the depth of which is from 60 to 250 feet. In boring these, alternations of clay and sandstone were passed through, the water being obtained from the sandstone. The flows were not measured, but apparently are not very strong. The quality of the water is good, but it is allowed to waste, practically no irrigating being done.

At Almus Ranch, owned by Joe Dickens, 4½ miles east from Carrizo

Springs, on the road to Encinal, there is a flowing well 200 feet deep. The water is found in coarse sandstone below a stratum of clay. The flow is good, clear, and free; it has not been measured, but is small—sufficient to irrigate a very small garden patch.

At Cotulla, 30 miles east of Carrizo, according to Mr. J. A. Taff, a well has been drilled to a depth of 825 feet by the International and Great Northern Railway Company. This well gives a flow of water sufficient for the needs of the railway company and the town. The water is impregnated by salts of magnesia and other material.

The waters of the wells at Carrizo Springs and Cotulla are derived from beds known as the Carrizo sandstones of Owen, which, according to the observations of Mr. T. Wayland Vaughan, of this Survey, occur low in the Eocene series, just above the equivalent of the Wills Point (Midway) horizon.

The catchment area is coextensive with the outcrop of the Carrizo sandstone, which forms a marginal strip of mesquite and cactus covered land along the eastern border of the Cretaceous, just south of and parallel to the Southern Pacific Railway west of San Antonio to Uvalde County, and thence south to the Rio Grande, as shown on the map.

Carrizo Springs seems to lie very near the western limit of the field, as the water-bearing beds terminate by outcrop north and northwest of that locality.

Experiments in Zavalla County, around Batesville, which is situated in or near the outcrop of the water-bearing beds, show that this place lies inside of the area of possible flow from this system. Similar experiments in southern Uvalde County, 3 miles east of the Nueces, show that the strata are entirely missing there.

We can not say that the series of wells above described, situated along a line 42 miles long, extending from Carrizo Springs to Cotulla, have their source in identically the same stratum, but it is very probable that they all come from closely allied beds which have an inclination to the south or east of south. Neither can the dip be correctly determined from this line of wells, for the true direction of dip is more southerly than this line, which crosses it diagonally. The strata deepen along this line, however, from 60 feet at Carrizo Springs to 825 feet at Cotulla, or an average of about 18 feet to the mile. If this dip is persistent the limit of possible success at 2,000 feet would be 40 miles or more southeast of Cotulla, which would reach as far east as Tilden, McMullen County, and thence on at a constantly increasing depth.

Two small flowing wells are reported near Laredo, 100 miles south of Cotulla, at a depth of 170 feet, and have weak flows. These wells are found in strata lying above the probable position of the Carrizo sandstone, which is probably at a depth of nearly 1,000 feet at Laredo and barren of water. North of Laredo, at Cactus station, there is a shallow flowing well 170 feet deep.

A deep artesian well at Laredo was begun in the same belt of sandstone that outcrops at the surface at Cotulla—not much over 100 feet thick—but according to Mr. Taff it had been put down to a depth of 1,200 feet (June, 1891) without obtaining a flow of water. This shows that the water-bearing rock reached at Cotulla is not of continuous extent toward the Rio Grande, and experiments in areas lying in that direction should be made with caution.

So far as exploited, the area of possible flow of these wells may be summarized as a limited region embracing the southeastern portion of Dimmit, Lasalle, and the western half of McMullen counties. To the northeast the system may merge into the one next to be described.

To the south and southeast of Carrizo Springs, at elevations not higher than Carrizo Springs, artesian water should be obtained. The extent of the sands from which the water is derived is not known. They may change their character as the distance from the old shore line to seaward increases.

Frio group.—In eastern Frio and western Atascosa counties, 20 miles southwest from Pleasanton, several wells have been drilled to depths less than 350 feet which afford abundant flows of water, but it is said to be so sulphurous in some instances that stock will not drink it. These wells have their source in beds of the division of the Lower Eocene, and the sulphur they contain is no doubt derived from the abundance of pyrites which accompanies the lignite deposits in these beds.

Smithville group.—At Smithville, Bastrop County, there is an artesian well about 480 feet deep with a weak flow, which obtains its water from the Lower Eocene sands. This passed through the following strata: First, 35 feet of light sand; then 10 or 15 feet of red clay; next, 100 to 150 feet of soapstone mixed with shells; balance of depth, white clay and soapstone. The water is said to be excellent. There is no other well in the vicinity.

Robertson County group.—In Milam, Robertson, Burleson, and Brazos counties, along the valley of Brazos River, there is a remarkably productive artesian area which probably derives water from the sandy Lower Eocene beds.

The wells in this region are found along the east side of the Brazos Valley in Robertson, Brazos, and Anderson counties, at depths varying from 230 to 587 feet. This depth varies with the difference in the altitude of the points at which they are sunk relative to the stream way of the Brazos. This group is very extensive and is worthy of a special study and description.

Experiments at Bremond (altitude 467 feet), 1,500 feet, and Franklin, 1,200 feet, indicate that the water from the beds which supply the valley wells will not rise on the high divide to the east of the Brazos Valley.

At Bremond a drill hole was likewise begun in strata geologically lower than the water-bearing beds of the Camden series, and penetrated only 1,500 feet of the barren Upper Cretaceous beds which lay above the next or Woodbine water-bearing horizon. The eastern portion of the timber-belt region is greatly eroded into hills of considerable height, and although future experiments and mapping (which is the foundation of all accurate artesian prognostication) may disprove this assertion, it is probable that flowing wells will be obtained only in the stream valleys of this region. This is shown in the Robertson County area, where the water is easily obtained in the river bottoms and for a certain distance up the slopes, but will not rise to the towns on the high divides inclosing the Brazos, as has been demonstrated by failures at Franklin and other places.

This office possesses no data concerning artesian-well experiments in the extensive strip of Tertiary country lying between the Brazos and the Texas Pacific Railway.

Marshall group.—Artesian wells have been procured from the Eocene sands at several localities in the northeastern portion of the State.

At Marshall, Texas, the water supply for the town is obtained from twenty-eight flowing wells about 3 miles north of the city. The depths of the wells vary from 30 to 70 feet and the water rises 13 feet above the surface of the ground. The supply is 500,000 gallons daily. The water, which is chalybeate in quality, is pumped into town from the wells. The wells are situated in a creek valley and the water was found in a bed of gravel and sand.

According to Mr. T. Wayland Vaughan, who obtained the foregoing data from Mr. William Waskom, the strata consist of alternations of sands and clays, or interlocking lenses of sand and clay. It is probable that the wells are derived from sand beds which outcrop to the northwest.

Some time since an experiment was made for a deep well at Marshall by Mr. E. Sutphin, who bored to a depth of over 1,100 feet without obtaining flowing water.

At Hawkins, in Wood County, which is situated in the valley of the Sabine, a flowing well is reported at a depth of 200 feet. At Jefferson, in Marion County, a well 802 feet deep has a feeble sulphur flow. At Minneola, also in Wood County, according to Mr. Marshall, the well driller, a well was bored to a depth of 1,600 feet. The water rose to within a few feet of the surface.

Owing to the great erosion, by which the surface of the country underlain by these beds is cut into numerous hills north of the Brazos, it is not possible to say that artesian waters can be procured generally throughout the area of their extent and embed. Without accurate topographic maps it would be difficult to prognosticate the possible areas of flow from this system, even if we possessed accurate geographic knowledge. There are a few facts which can be given concerning unfavorable areas.

There is little doubt that in the eastern half of the country underlain by the Lower Eocene, local artesian flows can be secured if the wells are properly located.

Wells will hardly be obtained along the western border of the timber region, as the basement beds of the Camden series are the impervious Wills Point clays, having a thickness of 200 feet or more, and below these are nearly 1,000 feet of Upper Cretaceous strata, mostly barren clays. The catchment area must lie east of this belt, and due allowance must be made for its width. Hence a general statement can be made that the western margin of the areal exposure of the Camden series along a belt 10 or 15 miles wide is unfavorable. Certain conspicuous failures testify to the truth of this statement, such as the experiments at Bastrop, where the drill probably began in strata of the Camden series lower than the water-bearing beds, and hence could have found water not less than 3,000 feet lower, from the same beds as those which supply Austin and Manor.

ARTESIAN WELLS OF BLACK AND GRAND PRAIRIES.

We have now arrived at the discussion of the system of wells found beneath the Black and Grand prairies and deriving their waters from the Cretaceous strata. The artesian-well systems of the interior margin of the Rio Grande Plain and the Edwards Plateau have been recently made the subject of a special paper by Mr. T. Wayland Vaughan and the writer.[1] The present paper will discuss only the region underlain by the Cretaceous formations north of the Colorado.

NOTES ON HISTORY AND OCCURRENCE OF ARTESIAN WELLS.

Artesian development in the Black and Grand prairie regions of Texas is comparatively recent and its history can not be fully written. There has been great progress in the last few years. At numerous places copious flows of water have been obtained from wells drilled by the enterprise of citizens or communities. (See Pl. LXVIII.) Five or six deep wells have been drilled for State institutions. Twenty years ago these were poorly watered districts, while now they abound in fine artesian wells which supply water in large quantities to cities and farms.

Not many years ago a citizen of Fort Worth sunk a shallow artesian well for the purpose of obtaining water for stock. This was secured at a depth of about 300 feet. In a short time more wells were sunk to the same water level. As is generally the rule, the well drills stopped

[1] Geology of portions of the Edwards Plateau and Rio Grande Plain, etc.: Eighteenth Ann. Rept. U. S. Geol. Survey, Part II, 1898, pp. 193–322.

at the first water reservoir penetrated, and several years passed before Fort Worth discovered that her water supply came from the uppermost of a series of artesian reservoirs.

The purity of this artesian supply for domestic purposes, and its healthfulness, gave Fort Worth an enviable superiority. Rival cities were not slow to imitate her, and as a result of her success nearly every city and village in the Black and Grand prairie regions, and in fact throughout the State, made artesian experiments. Some of these were made in unfavorable localities and were failures; hundreds of others were successful, and to-day most of the important cities of the State, which before this artesian epoch were without sufficient water, have, if not an abundance for all purposes, at least a healthful supply for drinking.

The area in Texas in which wells of this system are obtainable is larger than that of the average State and about equal to that of Kansas. To deal with such a vast field would be difficult were it not for the great uniformity of the geologic structure, upon which the whole artesian water supply is dependent.

The flowing wells, which are more specifically described in later pages, vary in depth from 100 to 3,330 feet and are found at every interval between these extremes. They also vary in flow and in pressure, ranging from feeble streams of a gallon a minute to spouting wells of high pressure furnishing 1,000,000 gallons a day.

From answers to inquiries sent out by this office in 1897, there were then 964 artesian wells in the Black and Grand prairie regions, of which 458 were flowing and 506 nonflowing. There are probably 100 or more wells than are shown by these figures, from which no reports were received. The number and character of these wells, by counties, are as follows:

List of flowing and nonflowing artesian wells reported from the various counties of the Black and Grand prairie regions of Texas in 1897.

County.	Flowing.	Nonflowing.	County.	Flowing.	Nonflowing.
Bell	41	5	Jack	4	12
Bosque	44	32	Johnson	10	29
Brown	....	12	Kaufman	0	8
Burnet	3	12	Lamar	0	2
Collin	1	9	Lampasas	0	7
Comanche	1	16	McLennan	27	8
Cooke	10	32	Milam	2	2
Coryell	24	27	Mills	0	10
Dallas	60	17	Navarro	3	....
Denton	43	*a* 30	Parker	12	16
Ellis	22	14	Red River	0	2
Erath	2	25	Somervell	80	0
Falls	1	....	Tarrant	*b* 25	*a* 75
Fannin	....	*b* 6	Travis	9	11
Grayson	10	16	Williamson	7	13
Hamilton	2	20	Wise	1	12
Hill	5	14	Total	458	506
Hood	8	12			
Hunt	1	....			

a Or more. *b* About.

ARTESIAN SYSTEMS.[1]

Before giving the details of occurrence concerning the wells themselves it will be appropriate to discuss a little more fully the systems of strata which supply them.

The procurement of artesian wells in the Black and Grand prairie regions is dependent upon the geologic structure. The artesian wells of the Black and Grand prairies are all derived from the strata of the Cretaceous formations, which are fully described in Part III. The reader who has followed the descriptions of the stratigraphy of the Cretaceous formations given in Part III will have acquired a knowledge of all the geologic conditions influencing the artesian-water supply.

In discussing the artesian reservoirs the lithologic character, porosity, water capacity, thickness, and extent of each rock sheet, together with details of its outcrop, embed, and the nature of the retaining or overlying and underlying strata must be considered. The inclination of the stratum and its depth beneath all known points must also be considered. In the geologic portion of this report the lithologic

[1] See Pls. LXVIII, LXIX, LXX, LXXI.

character, details of outcrop, extent of embed, and inclination of the rock sheets have been discussed in detail. Further remarks concerning the rock sheets will relate solely to their capacity as retainers and distributers of underground waters, and their availability for artesian wells.

In order fully to determine the availability of these artesian reservoirs it is necessary to understand the simple stratigraphic arrangement and areal and underground distribution of the rock sheets composing the reservoirs, as set forth in the maps, text, and cross section profiles accompanying this paper. (See Pls. LXVI–LXXI.) These maps and cross sections are made with such detail that they will serve every purpose of the intelligent engineer or geologist in solving all practical questions, and the following pages are written for the benefit of those who are not familiar with practical geologic questions.

CAPACITY OF THE VARIOUS CRETACEOUS ROCK SHEETS FOR WATER.

The composition, texture, sequence, and arrangement of the rock sheets constituting the systems of underground waterworks in the region discussed having been described, the part that each particular stratum plays in the distribution of water may now be considered.

Of the numerous beds mentioned, all those composed of impervious material, such as clays and close-textured limestones, may be considered as nonwater bearing, and their function in the artesian systems is that of control, not of supply, since they merely serve to retain the water in the water-bearing beds. In this list may be included most of the Glen Rose formation and the formations of the Edwards division (although there are exceptions to this rule, as will be shown), all the formations of the Washita division (with the possible exception of the Pawpaw), the Eagle Ford, Austin, and Taylor formations of the Upper Cretaceous, and most of the Navarro formation.

Rocks of open texture, such as sands, conglomerates, porous chalky limestones, and massive rocks shattered by joints, fissures, honeycombs, or other openings, are usually water bearing. In this class of porous water-bearing rocks may be placed one or more beds of the Basement (Trinity) sands, certain beds of the Glen Rose formation, the Paluxy sand, a portion of the Fredericksburg division south of the Leon, the Pawpaw formation, the Woodbine formation, and the Corsicana beds of the Navarro formation.

The Cretaceous strata may in a general way be classified by their permeability and conductivity into two groups, as follows:

Permeability and conductivity of the Cretaceous strata.

Formation.	Permeability and conductivity.
Navarro in general	Poor.
Corsicana bed	Fair.
Taylor	Poor.
Eagle Ford	Poor.
Woodbine in general	Good.
Lewisville beds	Good.
Dexter sands	Good.
Denison beds in general	Poor.
Pawpaw beds	(?)
Fort Worth	Poor.
Preston beds	Poor.
Edwards	Poor.
Walnut	Poor.
Paluxy	Good.
Upper Glen Rose	Fair.
Lower Glen Rose	Poor.
Basement (Trinity)	Good.

The strata above mentioned may be classified by their capacity for water into two groups, one of which may be termed "water bearing" and the other "nonwater bearing," as shown below:

Water-bearing and nonwater-bearing Cretaceous strata.

Water-bearing strata.	Retaining or nonwater-bearing strata.
8. Corsicana sands of the Navarro beds.	
	7. Taylor marls. Austin chalk. Eagle Ford clays.
6. Woodbine and Denison beds, in part.	
	5. Washita division, including the Denison beds, Fort Worth limestone, Duck Creek chalk, Kiamitia clays.
4. Beds in the Edwards formation.	4. Fredericksburg division, including the Edwards limestone and the Walnut formation.
3. Paluxy.	
2. Portions of the Glen Rose beds.	2. Portions of the Glen Rose beds.
1. Trinity.	

THE CRETACEOUS ARTESIAN RESERVOIRS.

Of the water-bearing strata or artesian reservoirs above mentioned, the Corsicana sands, which occur along the eastern border of the Black Prairie, can not be seriously considered in the discussion of the prairie region, for little is known as to their water-bearing capacity, and the wells penetrating them within the Black Prairie region are nonartesian. Omitting these sands from consideration, there are four water-bearing formations in the section, separated by impervious layers, each of which constitutes an artesian system. Each of these formations may contain several distinct beds of water-bearing sand, or artesian reservoirs, which are numbered from below upward. Thus the various reservoirs of the Trinity system are numbered t^1, t^2, t^3, etc., in ascending series. The artesian reservoirs are as follows (see fig. 47):

Artesian reservoirs, or water-bearing formations, of the Black and Grand prairies.

Reservoir.	Formation.	Symbol.
Woodbine	Woodbine and Pawpaw	x^1, x^2, x^3, etc.
Fredericksburg	Horizons in the Fredericksburg division south of the Brazos.	f.
Glen Rose	Horizons of the Glen Rose beds	t^4 or r.
Trinity	Several sand strata in the Basement beds of the Trinity division.	t^1, t^2, ^{3}t.

These reservoirs and groups of reservoirs are separated from one another by impervious clays and limestones. The several beds of the Trinity sands are separated from one another by limestones and marls, which increase in thickness to the coastward (see discussion of the increment of the Glen Rose beds, pp. 381–382). The Paluxy system is likewise separated from the Trinity system by an increasing thickness of the Glen Rose formation. Between the Paluxy and the Woodbine systems is the great thickness of limestones and marls described in the geologic portion of this report under the heads of the Fredericksburg and Washita divisions. The various water-bearing horizons of the Woodbine system are separated from one another principally by bituminous clays, although a thin limestone formation lies between x^1 and x^2. Above the Woodbine system there are over 2,500 feet of barren strata, including about 500 feet of bituminous clays (the Eagle Ford formation), 1,400 feet of marly clays called "joint clays," and 500 feet of chalk (the Austin chalk).

Each of these water-bearing strata outcrops to the westward in a characteristic area, and its embed is concealed to the eastward beneath overlying beds, so that the contained water is transmitted under hydrostatic pressure to lower depths in the latter direction.

Each water-bearing stratum differs from the others in thickness, extent, and capacity for imbibing and transmitting waters; also in chemical composition of the water which it supplies.

Each water-bearing stratum ultimately increases or decreases in thickness in some given direction, resulting in variation in the water-supplying capacity. These variations are indicated in the general sections, profiles, maps, and geologic descriptions.

AVAILABILITY OF UNDERGROUND WATER RESERVOIRS OF BLACK AND GRAND PRAIRIES.

In seeking information concerning the possibility of procuring artesian water beneath any locality within the area under discussion three essential points must be determined: (1) Whether one or more artesian reservoirs are embedded beneath the locality; (2) the depth of the embedded reservoir; (3) the altitude to which the water under hydrostatic pressure will rise when these reservoirs are penetrated. These inquiries will be answered separately.

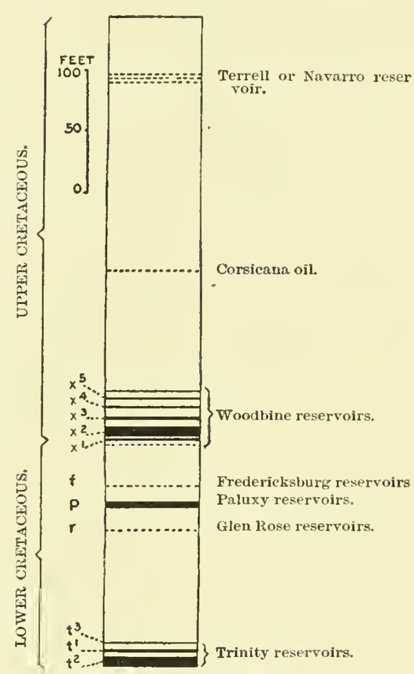


FIG. 47.—Artesian reservoirs of Cretaceous formations; ideal presentation.

The determination of the existence of an available reservoir must be made from geologic data. The position of the formation at the surface in the geologic series can be ascertained in a general way from the map.

The depth of a water reservoir at any locality is that of the depth of the embed of the water-bearing stratum, and hence a determination of the latter will give the depth of the former. From typical cross sections and profiles of the Black and Grand prairie regions as given, which extend from the interior coastward, it will be seen that the strata incline coastward with remarkable uniformity, although there are certain minor variations which are elsewhere noted. Furthermore, it is to be observed that the topographic profiles also slope coastward in the direction of the inclination of the strata, but at a slighter angle to the horizon. Since the strata incline eastward more rapidly than the surface slopes, they get correspondingly deeper and deeper into the earth in that direction. Not only do these rock sheets become deeper and deeper eastward, but they are successively covered in that direction by higher rock sheets, which must be drilled through to reach any given bed. Conversely, the depth of any rock sheet in the series decreases westward until it outcrops at the surface.

This structure, whereby the water-bearing strata incline coastward at an angle only slightly greater than that of the topographic slope, furnishes, as already explained (p. 376), ideal conditions for transmission and storage of artesian water beneath large areas.

There are two methods by which the depth of an artesian reservoir beneath any locality can be ascertained. The first is based upon the dip of the strata; the second consists in computing the thickness of the overlying formations by adding together the known thicknesses of their outcrop.

In order to approximate the depth of any artesian reservoir by the first method it is desirable to know (1) the rate of dip of the stratum in feet per mile, (2) the distance of the locality from the catchment area along the line of dip, and (3) the difference in altitude between the locality and the catchment area. The altitude of much of the area may be ascertained from the topographic sheets of the United States Geological Survey. A list of altitudes in the various counties is appended to this report.

Formula for ascertaining depth (x) of a reservoir beneath any locality.

D = distance from outcrop in miles.
d = dip of reservoir stratum in feet per mile.
A = altitude of nearest portion of catchment area.
a = altitude of surface at locality where well is desired.
X = depth of embedded reservoir beneath a.
$x = Dd - (A-a)$.

Multiply D, the distance (in miles) of the locality from the outcrop of the reservoir stratum by d, the rate of dip (in feet per mile) of the latter, and from the result subtract the difference in altitude (in feet).

If A is higher in altitude than a, the water will usually flow at the surface. If a is higher in altitude than A, the water will rise only to approximately the altitude of A, and the well will not flow.

In using this formula it must be remembered that the dips vary slightly in the different profiles and sections and in different portions of each profile section. Hence the table of dips given on page 379 of the geologic portion of this report should be consulted. Furthermore, in profiles A, G, H, and I, Pl. LXVII, the continuity of the dips is broken by faults, and the downthrow of these must be considered.

The second method of ascertaining the depth of the artesian reservoirs, by a knowledge of the geologic horizon of the formation at the outcrop, may be explained as follows: The observer, having determined the geologic horizon of the locality by means of the fossils or the character of the formation, as explained in the geologic portion of this report, or by aid of the geologic maps and profile sections, will be able to ascertain, by reading the descriptions of the formations, the approximate thickness of the various rock sheets which lie between the surface and the artesian reservoir. These thicknesses vary in accordance with laws elsewhere explained, and it would be well for the observer to utilize in these computations the cross section nearest to his locality, as given on Pl. LXIX.

The following tables show the approximate depths of the various reservoirs:

Approximate depth in the Main Texas area of the available reservoirs beneath each belt of outcrop as shown on the geologic map, reckoning from the top of the formation.

Outcropping formation.	Reservoir.			
	Navarro.	Woodbine.	Paluxy.	Basal Trinity.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Navarro	200	2,600	3,000	4,000
Taylor	....	2,000	2,000	3,000
Austin	....	1,000	1,500	2,300
Eagle Ford	....	500	1,000	1,900
Woodbine	....	100	500	1,600
Denison	....	....	500	....
Fort Worth	....	....	300	1,400
Edwards	....	....	200	1,200
Walnut	....	....	100	500
Paluxy	....	....	....	400
Glen Rose	....	....	....	300
Trinity	....	....	....	0

By examining the profiles and maps it will be seen that drill holes sunk along the line of any section in the various belts of outcrop of the formation of the Western Cross Timbers, the Grand Prairie, the Eastern Cross Timbers, the Eagle Ford Prairie, the White Rock or Austin chalk belt, and the Grand and Black prairies, must penetrate greater and greater thicknesses of rock strata eastward in order to reach any particular underlying artesian reservoir.

Beginning at the western margin of the Western Cross Timbers, it will be observed that here the strata of the lowest reservoir—the Trinity—outcrop and that ordinary surface wells derive their waters therefrom; therefore a well drilled west of this locality could not possibly obtain water from any of the reservoirs of the coastward incline, for they are not embedded in that direction.

By proceeding eastward along any of the profiles it will be seen that a well sunk in the Glen Rose Prairie must go through a thickness of

Glen Rose formation before reaching the Basement reservoir. A drill hole farther east, on the outcrop of the Edwards limestone, must go a depth equivalent to the additional thickness of the formations of the Fredericksburg division. Wells sunk in the belts of country where the formations of the Washita division outcrop will have to go a depth equivalent to the thickness of the rocks of that division and those previously mentioned in order to reach the Basement sands. This constant addition of geologic formations to be encountered eastward continues until at the extreme eastern margin of the main Black Prairie a drill hole at such points as Greenville, Terrell, Kaufman, Corsicana, Thorndale, Marlin, and Manor would be obliged to penetrate the entire sequence of Cretaceous formations in order to reach the bottom or basement reservoir (t^1).

This idea may be further illustrated along the line of profiles EE, Pl. LXVII, as follows: At Glen Rose, situated near the base of the Glen Rose formation, the well drills penetrated only a few feet of the later formation in order to reach the basement reservoir. At Hillsboro, on the Austin chalk belt, 38 miles to the east, the drills had to penetrate the entire thickness of the Eagle Ford, Woodbine, Denison, Fort Worth, Edwards, Walnut, and Paluxy formations and nearly 400 feet of the Glen Rose formation, a distance of over 1,500 feet, before reaching the strata outcropping at the surface at Glen Rose. At Hubbard, 25 miles east of Hillsboro, situated on the Taylor belt, the drill had to penetrate a great thickness of the Taylor marls and Austin chalk before reaching the strata which outcrop at Hillsboro, all the strata passed through at Hillsboro before reaching the horizon outcropping at Glen Rose, and all the strata below Glen Rose before reaching the Basement reservoir (t^1).

Thus it will be seen that while a drill on the western edge would begin in the Basement sands, which are there at the surface, on the eastern margin of the Black Prairie the drill must penetrate the entire thickness of the two Cretaceous formations to reach the same sands, or between 3,500 and 4,000 feet, as at Terrell, Greenville, Corsicana, Marlin, and Thorndale.

The manner in which the depth of an artesian reservoir can be approximately prognosticated by a knowledge of the horizon of the geologic formation outcropping at the surface at the locality where the well is desired may be illustrated as follows:

In the region where the Glen Rose beds compose the surface the upper Trinity reservoir is not over 500 feet deep, the maximum thickness of the Glen Rose formation; where the rocks of the Fredericksburg division occupy the surface the Paluxy reservoir is from 0 to 300 feet deep, and the basal Trinity reservoirs are from 500 to 1,000 feet deep; where the Fort Worth beds occupy the surface the depth of the Basement flow is from 1,000 to 1,500 feet; on the outcrop of the

Woodbine formation this depth is in the neighborhood of 1,500 feet; on that of the Eagle Ford, from 1,500 to 1,800 feet; and along the line of outcrop of the Dallas chalk, from 1,600 to 2,000 feet.

By a study of the maps and profiles it will be seen that all of that portion of the Black Prairie country east of the Eastern Cross Timbers and between Brazos and Red rivers is underlain by the entire set of strata constituting the artesian reservoirs, although some of them may be practically unavailable through great depth. South of the Brazos (as seen in the profiles) the Woodbine reservoir ceases by thinning out, and the Paluxy reservoir practically ceases. In the northern or Red River districts all the Trinity and Paluxy reservoirs are united and shown as one in the sections.

Beneath the Gainesville and Fort Worth belts of the Grand Prairie the Paluxy and Trinity reservoirs only are available, for the Woodbine reservoir does not occur in this region, having been stripped away in past time by erosion.

The summit region of the Lampasas Cut Plain is completely underlain by the reservoirs of the Trinity system and partially by the Paluxy reservoir, which extends as far south as the Leon.

TRINITY RESERVOIRS.

The Trinity reservoirs (see Pl. LXIX) include all the beds of sand of the Trinity division below the Paluxy formation. In places this is a single stratum of sand, while elsewhere, as shown in the geologic description, it is a group of sand strata separated by impervious beds. For the present we shall discuss this group of reservoirs as a unit.

The Trinity sands are the most extensive and porous water-bearing of the Central Province, and are everywhere available as the supply for either surface or artesian wells. In the main these are clean, white, fine-grained quartz sands, pressed compactly together, and popularly known as pack sand. This is a sandstone in which the individual grains are so slightly cemented that the material is but poorly consolidated—not sufficiently so to be used for building stone, and yet it requires a slight blow from a pick or shovel to cut it. This lack of consolidation testifies to the purity of these sands and to their freedom from accessory mineral materials, such as lime and iron, which occur in comparatively small proportions. As a result of this loose texture these sands are remarkably well adapted to the imbibition and transmission of water.

When dry these sands absorb water freely. By experimenting with sand collected from this bed at a number of localities, it has been shown that a cubic yard will absorb 80 gallons of water. It has been roughly estimated that the Trinity artesian reservoir contains approximately 531,300 tons of water. Of course these estimates can not be more than crude approximations, but they will give some idea of the vast amount of water in this one underground reservoir.

The Trinity sands supply the purest, softest, and most abundant waters of the artesian system. Water falling upon their outcrop and brought to them by running rivers and creeks enters them readily and becomes available as a source of artesian supply.

The outcrop (or catchment area) occurs along the narrow belts of the Western Cross Timbers, as shown on Pls. LXVI, LXIX, and LXX. It so borders the entire province as to afford catchment for all the embed. In addition to the above general catchment area, there are a few outcrops within the incised valleys of the main area of the Grand Prairie, as described on page 198. This catchment area of the water-bearing Trinity division (Trinity sands and alternating beds) makes the surface of vast areas in southern Indian Territory, and in Montague, Wise, Parker, Hood, Erath, Somervell, Comanche, Brown, Mills, Lampasas, and Burnet counties north of the Colorado in Texas. From the line of exposure or outcrop this water-bearing bed of sand becomes embedded by dip beneath the whole area of the Black and Grand prairies and the Eastern Cross Timbers.

The embedded Trinity reservoirs underlie the entire area of the Central Province coastward of the western escarpment, with the exception of the few exposed areas in the incised valleys of the Leon, Paluxy, and other streams, as above noted, and at Lampasas, forming one or more sheets of water-saturated sands, which are available for artesian supply at depths varying from less than 100 feet near the interior border to 4,000 feet, more or less, at the eastern edge of the Black Prairie, as is more minutely discussed in the chapter on availability (pp. 421 et seq.).

The embed of the Trinity sands presents two peculiar features which are of importance in the consideration of the artesian-water problem. The first of these is that the Basement Trinity sands have a greater inclination than the other rocks of the Cretaceous system, and practically its general dip is diagonal to them, as fully set forth on pages 379–382 of this report. The second peculiarity is that these sands differentiate to the coastward in their embedded area into two or more well-defined sheets of arenaceous water-bearing strata, separated by impervious limestones and clays. These various water-bearing reservoirs have been designated in this report by the symbols t^1, t^2, t^3, etc., t^1 representing the lowest or basement beds and the others the higher formations in sequence. Inasmuch as these secondary strata do not outcrop at the surface and are ascertainable only through study of the artesian-well records, in instances where the latter are deficient their differentiation is not always clear or possible.

In the section illustrating the Weatherford well (see Pl. XIX, A) it will be seen that there are at least three or more of these lower-lying water-bearing sand strata in the Trinity division. In the Comanche Peak section (fig. 12) there are two conspicuous water-bearing sand strata. In the Waco well sections three or four of these sandy strata have been struck, having a thickness of 15, 20, and 28 feet, respectively. In the Colorado section there are at least two conspicuous Trinity reservoirs, besides numerous smaller beds. In the San Marcos section there are two conspicuous sandy beds and perhaps more, for the drill hole ceased before reaching the bottom of the series.

The thickness of the outcrop of the Trinity sand varies from nearly 125 feet at its southern end to about 200 feet or more on Red River. A low estimate of the average thickness of the sand at its outcrop is 150 feet. The thickness of the beds which become differentiated in the region of the embed is difficult to ascertain, but it may be estimated that the main basement sand, t^1, maintains a thickness of 100 feet or more, while from well records t^2 and t^3 are much thinner, varying from 15 to 40 feet.

Retaining beds.—The Basement sands (t^1) rest upon an impervious floor of Paleozoic rocks, as described in the geologic portion of this report. They are overlain by calcareous clays and limestones. In many of the deep wells a red clay, called kiel by the drillers and similar to that found in the outcrop of the Travis Peak formation as described on page 140, is found above the Basement sands (t^1). The beds t^2 and t^3 are included between limestones and blue clays denoted in the various sections by r^1.

To appreciate and understand the artesian possibilities of the Trinity reservoir it is fundamentally essential to study and understand the geologic sections of the Trinity division already given, as a whole, and the data concerning artesian wells to be presented later.

Areas of obtainable flow from the Trinity reservoirs.—While the Trinity reservoirs underlie all of the East-Central Province, flowing artesian wells can be obtained from them only within certain well-defined areas, principally in the Main Texas area. These, with few exceptions, are below 750 feet in altitude, and it is safe to say that no flowing wells are apt to be secured at any point having a greater altitude.

The area of available flow from the waters of the Trinity sands (t^1, t^2, and t^3) is shown on the map (Pl. LVII). It embraces all those counties or portions of counties south of the Preston fault of the Red River fault zone and east of an irregular line drawn through Gainesville, Stringtown, Bluffdale, Iredell, Busyton, Pidcoke, and Kempner, and east of the Balcones fault from Georgetown to Austin.

The area of availability begins on the west in the beds of the deeply incised streams of the Grand Prairie and Lampasas Cut Plain and gradually widens as those streams are descended until it finally extends across the divides between the streams, east of which places flowing wells are available in both uplands and valleys.

The line which separates the area where flowing wells can be obtained only in the valleys from the area where they can be obtained both upon the uplands and in the valleys is an important one, as it divides the whole region of available flow into two broad districts. The first of these, on the west, may be termed the district of shallow valley wells; the other, the eastern district of deep wells. The line of separation, which is practically the 750-foot contour line on the maps, runs irregularly southward from Gainesville through the central portion of the counties of Cooke, Tarrant, Johnson, Hill, McLennan, Bell, Williamson, and Travis.

In both districts, in accordance with the laws of the dip of the strata, previously explained, the Trinity artesian reservoirs become more deeply imbedded from west to east. The flowing wells of the western district, being nearer the catchment area, are shallower than those of the eastern district, the former ranging from 100 to 1,000 feet deep and the latter from 1,000 to 3,000. Hence the western district may be considered one of relatively shallow flowing wells, and the eastern district one of deep flowing wells.

A composite section of a line of wells from Bluffdale, Erath County, through Glen Rose, Kimball, and Waco to Marlin, will illustrate the stratigraphic character and constantly increasing depth of these wells to the eastward. The geologic structure is also illustrated in the profile sections E E and F F of Pl. LXVII.

Areas of shallow flowing wells in incised valleys of Lampasas Cut Plain.—Artesian flows can not be obtained within the area of the outcrop of the Trinity sands along the western border belt. Abundant nonflowing wells, however, are usually obtainable everywhere throughout the catchment area of the western border region at shallow depths, and if these are large and deep enough they can probably be used for garden irrigation. The southeastern part of the town of Comanche is situated in these sands and the abundant well water of that place is derived from them. Flowing wells are obtainable, however, very near the western border in the valleys of the incised streams of the Grand Prairie and Lampasas Cut Plain.

As outlined on the map, long, finger-like strips of available areas of flowing wells extend westward from the main area of the Black Prairie region up the incised creek and river valleys of the Lampasas Cut Plain and Grand Prairie, in general, until the creek or river bed approximates an elevation equal to that of the lowest altitude of the western outcrop of the Basement sands. These incised creek and river valleys of the Lampasas Cut Plain and Grand Prairie constitute small individual areas where shallow-flowing wells may be obtained from the Trinity reservior.

In all of these valleys the nearer the well is located to the source of the streams inside the flowing area the shallower will the wells be required to be drilled. Furthermore, the areas of available flow widen downstream, gradually passing up the valley slopes until they coalesce with one another near the western margin of the Black Prairie.

The principal of these areas south of Brazos River are in the valleys of Paluxy Creek in Somervell and Hood counties; Neils, Meridian, and Spring creeks and East Bosque River in Bosque County; Salado, Lampasas, and Leon rivers in Coryell and Hamilton counties, and the Brushy and San Gabriel in Williamson County.

Passing northward to the numerous drainage heads of the Trinity River system which ramify throughout that portion of the Grand Prairie between the Brazos and the Trinity, shallow wells are found in the valley of Walnut Creek in northeastern Parker County; along Denton Creek in western Denton County; and in the valleys of Clear Fork and Big Elm Fork in southern Cooke County.

In that portion of the Brazos Valley lying in the western district, artesian flows have been obtained from a point about 10 miles due southeast of Granbury, where three Trinity flows (t^3, t^2, and t^1) were struck at 190, 210, and 235 feet, respectively, at the border of the eastern district near Fort Graham.

The Paluxy Valley in Somervell, Hood, and Erath counties, below the junction of North and South Paluxy creeks, is an area of numerous shallow artesian wells. From Morgan's mill, Erath County, to 4 miles west of Glen Rose, Paluxy Creek has cut through the Glen Rose limestone and flows over the Trinity sands. Flowing wells are obtained everywhere along the Paluxy from Bluffdale, Erath County, to its mouth. Many of the flowing wells in this valley begin in the second reservoir of the Trinity sands (t^2) and obtain their flow from the Basement sands (t^1). Such are the wells at Bluffdale and Paluxy and along the creek valley above and below Paluxy which obtain their waters from the Basement sands (t^1). There are thin beds of clay and limestone (r^1), which are of considerable extent and separate the reservoirs t^1 and t^2. Wells begun in the Trinity sand (t^2) here penetrate these clay beds into t^1 at depths near 100 feet, receiving a small flow of water. Lower down the river, 4 miles west of Glen Rose, supplies are obtained in the Paluxy Valley from both of these reservoirs. At and near Glen Rose there are at least three reservoirs in the Trinity system, at depths of 40 feet (t^3), 70 feet (t^2), and 170 feet (t^1). Wells are very numerous in this locality, as more fully described under the head of Somervell County.

Artesian wells below the outcrop of the lower Glen Rose limestone

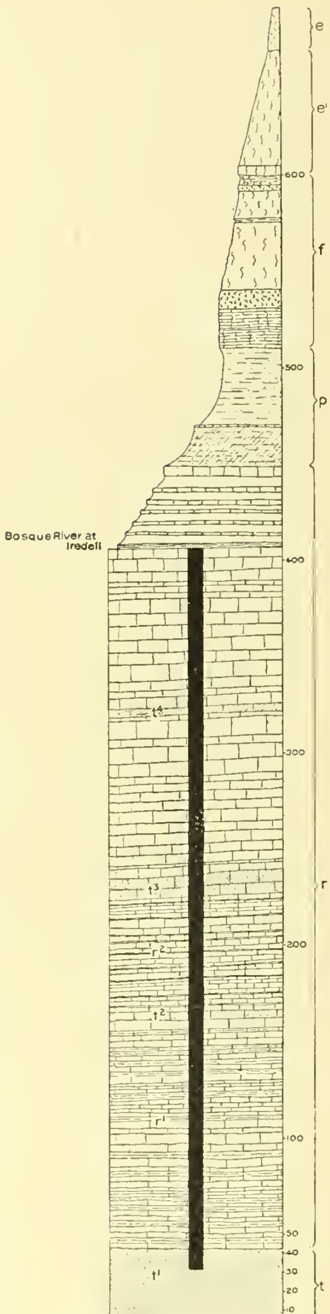


FIG. 48.—Section of Johnsons Peak and artesian well, Iredell, Bosque County, Texas. (For symbols see Pl. XVI.)

(r^2) in the bed of Paluxy Creek, 4 miles west of Glen Rose, receive flowing water from the t^2 sand that crops out at the surface about Paluxy post-office. These wells receive greater volumes of water than those at Paluxy and Glen Rose drilled down to t^1.

Beginning near the mouth of Walnut Creek, southeast of Granbury, shallow flowing wells may be had along the immediate valley of Brazos River to the northwest corner of Hill County at depths varying from 100 feet at the former locality to nearly 300 feet at the latter.

Flowing wells in valleys of Bosque River between Duffau and Valley Mills.—In the tributaries mentioned flows will hardly be obtained less than 600 feet deep. In the immediate valleys of these creeks 6 to 10 miles above their mouths the Paluxy artesian reservoir will also be found, the first at a depth of 100 to 300 feet.

Flowing wells with water from the Basement sands (t^1) can be had in the valley of East Bosque River and of Duffau Creek below the north line of Bosque County at depths ranging from 300 to 450 feet. The top of the Glen Rose limestone at the border of the valley opposite the mouth of Duffau Creek is 400 feet above the Trinity artesian reservoir.

A powerful flow is obtained in Iredell (see fig. 48) from the Basement sands (t^1) at a depth of 375 feet; t^3 and t^2 are struck at 180 and 280 feet, respectively. Flowing wells are possible along the river valley from the mouth of Greens Creek to Iredell at depths varying from 150 feet at the former to 375 feet at the latter locality. From Iredell eastward to the Bosque Valley the wells increase in depth at an average rate of an additional 10 feet for every mile of distance. At Meridian, 13 miles below Iredell, the Paluxy reservoir is encountered at 195 feet, t^3 at 200 feet, and t^1 at 500 feet; at Clifton, 10 miles below Meridian, the Paluxy reservoir is encountered at 140 feet, t^2 at 650, and t^1 at 675 feet; about 10 miles southeast of Clifton, 5 miles north of Valley Mills, the Paluxy water was estimated at 400 feet and t^3 at 840 feet.

The area of artesian flow of Leon River extends down the valley from a point east of the town of Hamilton to Pecan Grove. At the first-mentioned point on Leon River the Basement sands will be penetrated at a depth of a few hundred feet. The depth at which the flow can be obtained will increase along the immediate streamway as the valley is descended and with the ascent of the valley slopes toward the divides of the artesian area.

At a point about 3 miles north of Hamilton, in the immediate valley of the Leon, flowing water was procured at a depth of 100 feet; at Busyton, about 5 miles southeast, this water was obtained at 156 feet; at Gatesville, 20 miles below Busyton, the three reservoirs of the Trinity sands were tapped at the depths of 150 (t^4), 400 (t^3), and 700 (t^1) feet, respectively. At Pecan Grove, 11 miles below Gatesville, flows were reached at 275 (t^4), 300 (t^3), 416 (t^2), and 590 (t^1) feet. The reservoir t^4 in the foregoing wells may be the Paluxy.

Excellent flowing wells are obtained in the valley of Steels Creek near Morgan from the Trinity reservoirs, at depths of 425, 550, and 600 feet, and are possible from Morgan to where the creek flows into the Brazos.

Flowing wells are obtainable along the valley of the Lampasas from the town of Kempner, near the southwest corner of Lampasas County, to the borders of the eastern district near Belton. These wells mostly begin in the Glen Rose formation and penetrate two or three reservoirs of Trinity water, t^1, t^2, and t^3. At Kempner t^1 and t^2 reservoirs are 50 and 150 feet in depth, respectively, or 100 feet apart; 5 miles southeast of Kempner t^2 and t^3 are struck at 73 and 111 feet, 38 feet apart; at Maxdale three flows are struck, at 90 (t^3), 140 (t^2), and 160 (t^1) feet; a few miles east of Maxdale three flows are struck, at about 230, 360, and 410 feet.

Flowing artesian wells are obtainable from the Trinity reservoirs in the valleys of the Cowhouse from 3 or 4 miles west of Pidcoke to where this stream joins the Leon in Bell County. These wells vary in depth from 100 to 250 feet at Pidcoke. Flows are reported in the latter vicinity at depths of 100 (t^3), 124 (t^2), and 250 (t^1) feet.

Wells are obtainable for short distances up the valleys of San Gabriel and Brushy creeks west of a line drawn between Round Rock and Georgetown, Williamson County.

North of Brazos River wells are obtained in the valleys of the Clear and West forks of Trinity River, and of their principal tributaries, Bear Creek, South Fork of Trinity River, and Marys, Silver, and Walnut creeks. These are areas of shallow artesian wells, the value of which has not been appreciated.

Walnut Creek Valley, in northeastern Parker County, presents artesian conditions similar to those of Paluxy Creek Valley. The wells of Walnut Creek Valley occur between Springtown and Azle post-offices at depths of 45 to 279 feet. Three reservoirs are struck near Azle at 40 (t^3), 180 (t^2), and 279 (t^1) feet. Springtown, situated on the Trinity sand in Walnut Creek Valley, receives flowing water from beneath thin impervious strata near the middle of the Trinity group of reservoirs at depths of 90 to more than 100 feet. From Springtown to Reno Mills, according to Taff, wells from 100 to 200 feet deep will receive flowing water. From Reno Mills to the mouth of Walnut Creek wells 150 to 400 feet deep will secure good flows.

The flowing wells along the West Fork, Denton Fork, Clear Fork, and Elm Fork of Trinity River are all derived from the combined Paluxy-Trinity catchment area, which has been described under the name of the Antlers formation. Although the outcrop of this formation is incapable of being subdivided into distinct beds, its embed in the area of flowing wells shows considerable increment by thickening to the eastward, and is differentiable into several water-bearing reservoirs, four of which were encountered at Gainesville, at 320 (t^4), 340 (t^3), 460 (t^2), and 670 (t^1) feet (see fig. 75). These reservoirs exhibit an analogy in position and sequence to the four water reservoirs of the Paluxy and Trinity system found in the region of the Lampasas Cut Plain.

In the valley of the Clear Fork of Trinity River south of Benbrook, according to Taff, a flow from the Trinity artesian reservoir may be had at a depth of 450 feet. Above Benbrook, in the valleys of Bear Creek, South Fork, and Clear Fork of Trinity River, less and less depths will be required. From a point in Clear Fork Valley opposite Benbrook, down the valley, a second source of shallow artesian wells becomes available in the Paluxy reservoir. Between Benbrook and Fort Worth, along the Trinity River Valley, flowing wells may be had at depths of from 100 to 200 feet. To tap the Trinity reservoir opposite Benbrook, 500 to 550 feet will be required, while at Fort Worth the Trinity reservoir is nearly 700 feet below the surface, as shown by wells already drilled in the river valley there. From Fort Werth up the West Fork Valley to the north line of Tarrant County the artesian conditions are the same as those outlined for the Clear Fork Valley.

The area of flow in the Denton, Clear, and Elm forks begins from 10 to 15 miles east of the western escarpment of the Grand Prairie.

In the West Fork the first wells encountered are in the vicinity of Newark, Wise County, where the reservoirs are struck at depths of 60, 150, and 385 feet.

In the Denton Fork the most western flowing wells are in Denton County, just east of the Wise County line, where three reservoirs are struck, at 100, 135, and 180 feet. There is probably a lower reservoir here which has not been penetrated.

The western limit of flowing wells yet discovered on the Clear Fork is about 3 miles west of Bolivar, in northwest Denton County. Two reservoirs have been penetrated, at 130 and 135 feet.

Gainesville seems to be at the interior limit of flowing wells on the Elm Fork of the Trinity. Excellent wells have been obtained at this point at a depth of 570 feet, passing through other reservoirs at 220, 340, and 450 feet.

Area of possible artesian flow on Red River.—Shallow wells receiving a flow from the Trinity-Paluxy source are possible along the portion of Red River Valley on the Indian Territory side, and perhaps in Grayson County below the mouth of Duck Creek, north of Denison (see fig. 79). At Carpenters Ferry, east of Denison, wells 350 to 400 feet deep should receive a flow from the top of the Antlers sand. Depths to the artesian source will increase at localities down the river and decrease at those up the river to a point where water will approach within about 100 feet of the surface. No experiments have yet been made in this district.

Eastern district of deep flowing wells from reservoir of Trinity division.—Toward the eastern margin of the Grand Prairie and beneath all the Black Prairie region the slope of the land has so lowered the surface that nearly all the uplands, with certain exceptions to be noted, as well as the valleys, are of lower altitude than the catchment area of the Trinity reservoirs, and hence good flows of water are usually obtainable from the Trinity reservoirs. The latter, however, are very deeply embedded in this general region and can seldom be struck at a less depth than 1,000 feet, and hence this district, so far as the Trinity reservoirs are concerned, is essentially one of deep and expensive exploitation, in which artesian experiments can be profitably conducted only for municipal and industrial water supply.

The western edge of this district practically follows the Balcones fault line from Austin, via Round Rock, Georgetown, and Belton, to the northeast corner of Coryell County. From the latter point it continues irregularly, via Crawford and China Springs, McLennan County, and Whitney, Hill County, to Fort Worth. From Fort Worth the line of upland availability extends north via Roanoke, Argyle, Denton, Sanger, and Valley View. The wells are shallower to the northward, being probably derived in the latter direction from a reservoir of the Antlers sand corresponding to the Paluxy reservoir. The area is limited on the north by an irregular line, as shown on the map (Pl. LXIX), extending south from Valley View around the White Rock escarpment to the Trinity valley at Dallas, and thence irregularly and indefinitely north and east toward Clarksville, on Red River.

The reservoirs deepen to the eastward, as shown on map, from 1,000 feet to 4,000 feet, until they get below practicable depths. Deep wells have been drilled at Manor, Marlin, and Hillsboro, which show the great depth of the embed. At Manor, 20 miles east of Austin, the depth of an upper reservoir of Trinity water was about 2,300 feet. At Marlin, 22 miles southeast of Waco, an upper Trinity reservoir was struck at the depth of 3,300 feet. At Hubbard, 23 miles east of Hillsboro, a wellhole 3,050 feet deep had not reached the bottom of the Glen Rose formation. At Corsicana wells 2,700 feet deep do not reach the top of the Lower Cretaceous, while at Terrell a well 2,600 feet deep had not more than reached the Woodbine sands. From the foregoing data and the law of increment of the Trinity division it may be roughly estimated that the lowest of the Trinity reservoirs (t^1) lies fully 4,000 feet below the surface along the extreme eastern margin of the Black Prairie.

GLEN ROSE RESERVOIR.

From Waco southward water is usually encountered in the upper portion of the Glen Rose formation. This occurs in arenaceous marls and minute shell breccia which are highly mineralized with epsomite and other salts. The waters from this reservoir are always charged with mineral impurities, which destroy their potability. For medicinal purposes these waters are valuable and present on analysis the qualities of many of the famous waters of Germany and other places of continental Europe. Such waters, however, are deleterious for general uses and should be cased off if pure water is desired. Many fine wells have been spoiled by permitting these waters to contaminate them. The mineral contents of the medicinal waters of Marlin, Georgetown, and other places are largely derived from this horizon.

Wells from the Trinity reservoirs in this area have been drilled at Austin, Round Rock, Belton, Temple, Troy, Moody, Eddy, Waco, Hillsboro, Fort Worth, and numerous other places, and these afford copious supplies of water, as more fully described in the chapters treating of the counties.

PALUXY RESERVOIR.

The Paluxy sand (p) constitutes an important artesian reservoir (see Pl. LXX). These sands are practically the culmination of the Trinity group and coalesce interiorward with the Basement sands (t^1), uniting with the latter in the latitude of Decatur, so that thence northward they constitute a continuous formation, the Antlers sands. Hence the equivalents of the Paluxy in that region are treated under the head of the Trinity system.

The Paluxy is separable from the other sands of the Trinity division only in the general region lying between Parker and Burnet counties, and makes the first timbered sandy belt along the immediate western margin of the limestone prairie.

Little more can be said concerning the composition, texture, and structure of the Paluxy water-bearing beds than has been presented in the general discussion of the sands of the Trinity division. Like the other beds of the Trinity division, they are exceedingly friable and porous, adapted to drinking in most of the rainfall and transmitting it freely down the embed.

The waters from this system are in general less copious in flow than those of the Basement sands (t^1) of the Trinity system, and differ slightly from the latter in chemical qualities. This is especially true where the Paluxy sands are thin, in which case the water becomes charged with salts of iron, strontium, magnesium, and other soluble mineral salts, making it often unfit for common use.

The catchment area (see Pl. LXX), which follows an irregular line within the main area of the Edwards Cut Plain from the Leon River northward to Decatur, Texas, is fully shown on the geologic map and described on pages 193–195. The areas of catchment and embed are less extensive than those of the Basement sands, although the outcrop and thickness of the Paluxy sands are rather large in Hood, Bosque, and Hamilton counties, where the formation can be recognized as the upland post-oak sandy region; southward its thickness decreases and it becomes less valuable for water-bearing purposes.

The data in hand indicate that the embed of this formation is beneath the whole region east of the outcrop, as described, and north of Leon River. This embed of the Paluxy sand has been positively shown to continue eastward as far as Hearst Lake, nearly 50 miles east of Weatherford, and there is no reason to doubt that it continues eastward beneath all the counties of the Black Prairie region north of the thirty-first parallel.

The underlying beds beneath the Paluxy sands are the thinly bedded limestones and the whitish or greenish-white marly clays of the upper Glen Rose beds. The limestone layers are usually thin and very crystalline (see Weatherford section). The overlying strata of the Paluxy sands are the basal beds of the Fredericksburg division, consisting usually, if not always, of alternations of bluish calcareous marl and thin dark-blue limestone and shell agglomerate of the Walnut formation. These rocks are accompanied by innumerable individuals of two characteristic species of fossil oyster, *Gryphæa corrugata* Say, and *Exogyra texana* of Roemer. Specimens of the *Gryphæa corrugata* overlying the Paluxy sands were brought up in the Hubbard City well from a depth of 2,600 feet, showing the persistence of this characteristic fossil in the embedded retaining layers nearly 100 miles away from any known outcrop. Upon striking these fossils in a well the driller can be readily assured that he is within 100 feet of the Paluxy sand.

The upper layers of the Paluxy sands near the border of the overlying Walnut formation are charged with varying quantities of iron, lime, and other mineral matter, which affect both the quantity and the quality of the water contained in them. The purest water is to be found in the central portion of both the Trinity and the Paluxy reservoirs.

Between the West Fork of Trinity River and Red River the exposed edges of the Trinity and Paluxy sands form a single connected catchment area—the Antlers sands—but, as shown by the records at Gainesville and elsewhere, these become well differentiated within the area of the embed. Water received on the catchment area is distributed to these several reservoirs in the region of the embed. Between Trinity River in Wise and Leon River in Coryell County catchment areas of the Trinity and Paluxy reservoirs are separated by limestone of the Glen Rose formation. This limestone continues to separate the Trinity and Paluxy reservoirs beneath the surface south of Wise, Denton, and Collin counties, so that there are at least two distinct artesian reservoirs in the embedded part of the Comanche series lying beneath the eastern portion of the Grand Prairie in Tarrant, Dallas, Ellis, Johnson, Hill, Bosque, and McLennan counties and all that portion of the Black Prairie north of the Brazos.

The reservoir formed by the Paluxy sands is everywhere overlain by the lime marls and limestones of the Fredericksburg division, which constitute a mass of impervious strata above it, averaging from 450 to 600 feet thick south of Red River.

The outcrop of these sands forms an extensive independent catchment area along the eastern border of the Western Cross Timbers between the West Fork of the Trinity and Leon River, and they are embedded to the southeast beneath the Grand Prairie, Eastern Cross Timbers, and a part of the Black Prairie. North of the West Fork of the Trinity the catchment area is consolidated with that of the Trinity reservoirs. This reservoir as a whole has the general form of a wedge, having its thick edge exposed in the catchment area and thinning out with the dip. It remains, now, to give as nearly as possible the limit of this artesian reservoir and its character and value.

In tracing the outcrop of the Paluxy sand bed down the Brazos and Trinity River valleys, where it has been eroded and exposed for 50 to 60 miles, a gradual and constant decrease in thickness in the direction of the dip may be noticed. By estimating this average decrease in thickness it is possible to estimate the distance to a point beneath the artesian area where the Paluxy reservoir ultimately thins out. Artesian wells at Waco have shown that the Paluxy reservoir ceases to the southeast, and wells at Hubbard, Cleburne, Fort Worth, and other localities on the Grand Prairie show that it thins to the eastward.

The average increase in depth to the Paluxy water reservoir on a level line bearing S. 60° E. is 35 to 40 feet for each mile, and in the opposite direction, N. 60° W., there will be a corresponding decrease. The dip of this reservoir is practically that of all the Cretaceous rocks above it, and inasmuch as it is above the top of the Glen Rose formation the difficult problem of estimating the eastward increment in thickness of the latter does not have to be considered, as it does in the case of the Trinity reservoirs.

Wells of the Paluxy system.—The first successful wells in the Black and Grand prairie region were drilled in the river valley (altitude 490 feet) on the western edge of the city at Fort Worth, and struck moderate flows of water at 263 feet in depth, or 484 feet below the highest part of the city (altitude 662 feet). Many of these shallow wells were bored, and they constituted the chief artesian supply of Fort Worth for many years before the deeper and more abundant supply of the Trinity system was developed.

South of the West Fork of Trinity River the catchment area of the Paluxy is lower in altitude than that of the Trinity, on account of its separation and more easterly exposure, but north of the West Fork the Paluxy area is above that of the Trinity, and therefore has advantages over the Trinity reservoirs. From these facts it is plainly evident that artesian wells in Denton, Cooke, and Collin counties may sometimes derive good supplies of water from the Paluxy reservoir without going into the lower and deeper Trinity reservoirs.

In Bosque County, in the valleys of Brazos and Bosque rivers and on Meridian and Neils creeks, good flowing water may be had from the Paluxy reservoir at depths ranging from 100 to 300 feet. The valley of the Clear Fork of Trinity River between a point south of Benbrook and Fort Worth is a field for shallow artesian wells, which vary from less than 100 feet south of Benbrook to 200 feet at Fort Worth. Between Fort Worth and Randol, along the West Fork, abundant flows may be had from wells ranging from 200 feet at the former to 600 or 650 feet at the latter locality.

The valley of the West Fork of Trinity River from Fort Worth to near the mouth of Silver Creek, in Tarrant County, may be compared to the Clear Fork Valley above Fort Worth, and flowing water may be had at the same depth in both.

Wells have been procured from this reservoir as far north as Sanger, Denton County (altitude 628 feet), and as far east as Hearst's fishing lake, 10 miles east of Fort Worth. They are also obtained in southern Tarrant County.

There is but little doubt that this water can be obtained over all the Grand Prairie in Tarrant County wherever the altitude is less than 750 feet; this includes all the creek and river bottoms in the county and all the upland prairie and Eastern Cross Timbers in the eastern half of the county. The depth will not exceed 600 feet at the eastern edge of the area, and decreases 28 feet per mile to the west.

The Paluxy reservoir sands, which outcrop around the base of Comanche Peak and just west of Weatherford, are between 1,050 and 1,150 feet above the sea; at Fort Worth they are 200 feet above the sea, or 300 feet below the bed of Trinity River and 590 feet below Tuckers Hill; at Dallas they should be 1,300 feet below the surface, and at Terrell 3,200 feet more or less below the surface. The sands also underlie the area of the Woodbine reservoir at a depth of about 500 feet below the bottom of the Woodbine water, which thickness equals that of the average of the Washita and Fredericksburg divisions.

It will not be advisable to reckon upon large supplies of water from the Paluxy reservoir in Ellis County, nor in McLennan and Hill counties. Weak flows may be secured, but they should not be considered when additional drilling of 500 to 1,000 feet will produce powerful flows from the basement Trinity reservoirs. Since the Paluxy sand stratum attenuates to the southward, it would be hardly practicable to anticipate waters from it south of the latitude of Coryell County.

The possibility of flowing wells from this source does not extend in Texas north of the southern border of the tier of Red River counties, as has been proved by extensive experiments at Gainesville, Denison, Honey Grove, and Paris, but the water will rise in these regions to the altitude of the outcrop of the catchment area, which in most places will bring it within a practicable pumping distance of the surface.

There is no doubt that the embed of the Paluxy sands may be reached over a much wider area than has been exploited. It could be reached anywhere in the area described in the discussion of the Woodbine system between the depths of 500 and 600 feet beneath the latter. It has been a surprising fact that Dallas has never drilled to this water. Other cities along the White Rock belt situated similarly to Dallas have struck the Paluxy water as follows; Ferris, 1,300 feet; Hillsboro, 1,200 feet. At Corsicana the Paluxy bed ought to be from 500 to 700 feet below the present flow, and could be reached in the neighborhood of 3,200 feet. The water should be available at Terrell and Kaufman at about the same depth.

It is apparent that flowing wells may be had at any point east of and lower in altitude than the eastern arm of the Western Cross Timbers south of the West Fork of Trinity River. The approximate western border of the area of flowing wells from this source is designated on the map. Along this line water will approach the surface of the ground in wells which penetrate the Paluxy sand at depths varying from less than 100 to 1,000 feet, the depth depending upon the distance of the well from the eastern edge of the Western Cross Timbers receiving area.

At all localities where flowing waters can be had from the Paluxy reservoir more powerful and abundant flows may be obtained from the Trinity reservoirs by continuing the drilling through the Paluxy sand and Glen Rose formations and the upper Trinity reservoir to the Basement sands (t^1). As with wells receiving water supply from the Trinity reservoir, those drilled into the Paluxy basin should not be abandoned by the drill as soon as the first flow is obtained; instead, the drilling should be continued until the base of the sand is passed.

FREDERICKSBURG RESERVOIR.

Certain beds (one or more) of the Fredricksburg division in the area of its embed south of the Brazos are water bearing, as is attested by many well records in Coryell, Bell, and Travis counties. In Travis County these waters apparently come from certain arenaceous and cavernous layers in the Edwards limestone; in Coryell County the Walnut formation seems to be the source of the waters. The water is usually highly impregnated with sulphur, and is small in quantity and can not be relied upon as a source of artesian supply.

WOODBINE RESERVOIRS.

Beds and catchment areas.—The Woodbine reservoirs include the sandy strata of the Pawpaw formation (x^1), which are of insignificant value and need hardly be considered further, and the Dexter sands (x^2) and Lewisville beds (x^3) of the Woodbine formation. (See Pl. LXXI.) They underlie that portion of the Black Prairie region which is east of the Eastern Cross Timbers as far south as the Brazos.

The beds forming the Woodbine reservoirs are composed of quartzitic sands accompanied by accessory clay layers, lignites, some glauconite, and pyrites of iron. The character of the waters also indicates that some beds of the system contain iron and salt. The structure of the water-bearing sheets shows varying size of interstitial spaces between the grains of sand. It has been impossible to make a thorough series of laboratory tests of the exact porosity of these rocks, and until this is done their relative capacity for the imbibition and transmission of water can not be stated. It is only known by well experiments that it is sufficient to produce free-flowing wells.

The Dexter sand bed (x^2), constituting, on an average, the lower 100 feet of the Woodbine formation, is the only reliable portion for the production of large artesian flows, although many wells secure water from reservoir x^2. The Dexter sand crops out and forms the hilly, sandy country in the western half of the Eastern Cross Timbers. Many layers of considerable thickness are free from soluble mineral matter and are rather porous, while others contain such quantities of iron ore as to become solid or compact ferruginous sandstone.

The Lewisville beds (x^3), which occur in the upper half of the Woodbine formation and occupy the eastern portion of the Eastern Cross Timbers, are not reliably water bearing on account of the large quantities of subimpervious, ferruginous, argillaceous, and calcareous materials in them. They also contain quantities of vegetable and animal remains in the form of impure lignites and shell beds, together with soluble salts of iron and magnesium, which so impregnate the water as to render it deleterious to both animal and vegetable life. An occasional layer of sand in the Lewisville beds contains wholesome water which will supply shallow-flowing and nonflowing wells in and near the eastern border of the Eastern Cross Timbers in the principal creek and river valleys through Dallas and Johnson counties. For a detailed account of the Lewisville beds see pages 309–311.

The catchment area of the Woodbine system is coincident with the extent of the main belt of the Eastern Cross Timbers in Texas and along Red River. The total catchment area of the Main Texas belt from Red River to Waco, as carefully mapped out under the writer's direction, is 794 square miles. The average rainfall is 36 inches per annum over this area. Of this amount at least 50 per cent is imbibed and becomes the source of artesian water.

The water beds of the Woodbine formation are embedded beneath all the Black Prairie region north of the Brazos and south of Red River, and are available at depths of from 100 to 3,000 feet. The embed also underlies a few local areas in the southern part of the Chickasaw Nation north of Grayson County, Texas. The embed inclines, in harmony with the general structure of the Black Prairie region, at a gentle angle of about 40 feet to the mile.

The Woodbine embed is known to extend coastward of the region of its outcrop, i. e., from Little River, Arkansas, to a point near Fort Washita, Indian Territory, east and west, and thence due south to the Brazos. The area of the embedded portion of these strata can be predicated only from artesian-well experiments. We know from their thinning out at the Brazos that they hardly occur south of that stream. Furthermore, although we do not possess accurate data on the point, it has been reported that this stratum was not struck in the well at Marlin. The embed certainly extends as far east and south as Corsicana, where it is reached at a depth of 2,500 feet. From geologic considerations we can have no doubt that it continues under the whole of the northeast Texas region north of Corsicana in the direction indicated by the outcrop; but, as will be shown, the occurrence of this sheet throughout so extensive an area does not necessarily mean that it is coincidentally available, for north of Red River the outcrop is in a region of lower altitude than the surface of the country to the south.

The impervious beds underlying the Dexter sands (x^2) are the limestones and marls of the Washita and Fredericksburg divisions down to the Paluxy sands, aggregating a thickness of over 500 feet. Inasmuch as the greatest pressure of the water in the sands is apt to be in that portion of them lying nearest to the impervious underlying strata, it would be advisable in all artesian experiments to carry the well drillings down until these underlying rocks are reached. The driller can readily recognize them by the sudden transition from the noncalcareous or very slightly calcareous sandy nature of the water-bearing strata to the excessively calcareous marls or limestones which characterize the whole series to which these underlying beds belong. Furthermore, on reaching these underlying beds, if, perchance, the driller has not succeeded in obtaining satisfactory results from the overlying rocks, he can be positively assured that at least from 500 to 700 feet (the thickness of the Washita and Fredericksburg divisions) of impervious nonwater-bearing rocks lie below him before there is a possibility of striking the Paluxy reservoir.

The overlying impervious strata of the Woodbine system are the clay shales of the Eagle Ford formation, which, with the succeeding impervious formations of the Austin, Taylor, and Navarro formations, constitute an impervious system above these reservoirs which attains a maximum thickness of over 2,500 feet.

Many well records in Johnson, Hill, Tarrant, and other counties show the occurrence of a hard layer of rock from 1 to 3 feet thick immediately above the first water reservoir. This is an irregular bed of quartzitic calcareous sandstone.

The Eagle Ford clays, which form the impervious roof of the water-bearing beds of the Woodbine system, may be recognized in the drillings by the blue-black or black character of the clays, in contradistinction to the light-blue or grayish tints of the other sediments usually encountered in the well drillings in any other portion of the Cretaceous section, and by the numerous nodules or septaria which are encountered by the drill. In the lower portion, as the water-bearing beds are approached, these clays show frequent thin sandy layers, and the proximity of the water-bearing strata can usually be detected in the area underlain by the embed of the artesian sheets of the Woodbine system by the appearance of these thin sandy seams in the clays. These retaining layers, as we have shown in the descriptions of the general geologic section, increase in thickness southward from over 500 feet in Grayson County to less than 200 feet at the Brazos.

Flowing wells of the Woodbine reservoirs.—The flowing artesian wells of Pottsboro, Dallas, Ferris, Waxahachie, Corsicana, and Ennis, and the nonflowing artesian wells of Sherman, Paris, and Midlothian—a north-south belt of country extending from the Red River fault zone to near the Brazos—all have their origin in or pass through the reservoirs of the Woodbine system.

Many of the artesian wells which have been drilled into the Woodbine system are incomplete, inasmuch as they have only penetrated the uppermost of the Lewisville reservoir (x^3). These may have their flows increased many fold by continuing to the Dexter reservoir (x^2), or, if necessary, to the deeper Paluxy and Trinity reservoirs, still below the Woodbine system. In all cases where good and abundant water is desired the first flow (x^3) should not be considered, but drilling should be continued 200 to 300 feet farther, into the Dexter reservoir (x^2).

Wells within the area of availability of the Woodbine system by much deeper drilling may receive abundant water from the Paluxy and Trinity reservoirs, which underlie also the Black Prairie. The quantity and pressure of the water from the Trinity will in most cases greatly exceed those of the water from the Paluxy.

The limit of possible flowing water from the Woodbine reservoir is very different from the limit of profitable flowing water. The upper portion of the artesian reservoir contains much soluble mineral matter, and by the time water passes through this for a distance of 60 miles and to a great depth, where its temperature is raised, it is highly impregnated.

Areas of flowing and nonflowing wells.—The line between the areas of flowing and nonflowing wells from the Woodbine reservoir may be seen on the map (Pl. LXXI).

The area of availability of flowing wells, like that of the Trinity reservoirs, may be divided into two general districts—a western one of shallow wells, obtainable only in the lower creek valleys, and an eastern district of deeper wells, from which a flow is obtainable on the uplands as well as in the valleys. As in the case of the Trinity areas of availability, the eastern district is separated from the catchment area by a belt of higher upland which lies between them and to the surface of which the waters will not rise. In this particular instance this subordinate belt is the White Rock escarpment, and its surmounting dip plain is marked by the outcrop of the Austin chalk.

The average altitude of the eastern edge of the catchment area of the Woodbine system is 600 feet, and of the western edge 736 feet. Since the White Rock cliffs of the Austin-Dallas chalk to the east average 750 feet, except where cut through by drainage valleys, as at Dallas, it is evident that the areas where a flow well is possible will be (1) the valleys of the Eagle Ford Prairie, in Grayson, Collin, Denton, Dallas, Tarrant, Hill, and Johnson counties, which lie between the White Rock escarpment and the cross timbers; (2) the valleys within the eastern edge of the cross timbers themselves; (3) the valleys of rivers transecting the outcrop of the Austin chalk; (4) that portion of the main Black Prairie east of the outcrop of the Austin chalk which has altitudes of less than 500 feet.

On account of the greater altitude of the Eagle Ford and Austin chalk prairies in the Main Texas belt immediately east of the Eastern Cross Timbers, there is a considerable area embraced by these belts of country where flowing water can not be obtained, except in the transecting creek valleys, which are cut below the general levels of the Eagle Ford prairie and Austin chalk belt.

Beneath the northern tier of counties in Texas, south of a line drawn from Bells to Bowie County, the water-bearing strata of the Woodbine system are embedded, but the water will rise in the drill hole only to the height of the outcrop, which east of Grayson County, except in the immediate valley of Red River, is generally lower than the catchment area. Costly experiments at Clarksville, Paris, Honey Grove, and Bonham have demonstrated this proposition.

A small local area of exceptional flowing wells from the Woodbine formation in this district is reported in the northeastern corner of Fannin County, between Ivanhoe and Red River, where wells are said to be obtained from the Woodbine reservoir at depths of from 45 to 75 feet.

Artesian wells may possibly be had in the valley of Iron Ore Creek, between Denison and Sherman, by drilling 100 to 300 feet. The Cook Spring fault follows the valley of Iron Ore Creek for several miles, passing very near Moss and Cook springs. This fault marks the border here between sandy and clay lands. On the north side of this fault line it will require nearly 200 feet less drilling to secure flowing wells. Moss and Cook springs are natural artesian wells.

Favorable conditions for the procurement of artesian flows from the Woodbine reservoir exist in southern Chickasaw Nation, between the cross-timber hills south of Fort Washita and the fault line at Red River. The structural conditions of this region are favorable for flowing artesian wells from both the Woodbine and the Trinity reservoirs.

In the northern part of central Grayson County there is a small local area of flowing wells from the Woodbine reservoir (see fig. 77). This lies between the towns of Gordonville and Saddler on the west, Pottsboro on the east, and Southmayd on the south. Flowing wells are obtained within this area at depths varying from 90 to 500 feet. This area is limited on the northward by the Cook Spring fault, extending from the vicinity of Cedar Mills through Pottsboro to Cook Spring, and wells can not be obtained between this line and Red River from the Woodbine reservoirs. The flowing area is limited on the east by the greater altitude in that direction. Water is obtained in this area from several of the Woodbine reservoirs, which were encountered in one of the deepest wells at depths of 154 to 500 feet.

These wells were drilled through a part of the Lewisville reservoir into the Dexter reservoir of the Woodbine formation, from which they receive their abundant water supplies. Eastward or westward from the wells the sand which supplies their water is found at much higher elevations than those of the wells.

From southern Denton County to Dallas favorable artesian conditions prevail in the valley of Elm Fork of Trinity River, as also in the West Fork Valley, below the Tarrant-Dallas county line. Flowing wells from 60 to 150 feet deep are secured in this valley in northwest Dallas County. The great number of artesian wells at Dallas attests the value of the Woodbine reservoir as a source of artesian water in the valley of the Trinity River.

From a point in the valley of the West Fork of Trinity River near the west line of Dallas County to Dallas artesian water may be had at a depth of 100 to 800 feet. The first and smaller flow will come from the Lewisville reservoir (x^3), in the upper portion of the Woodbine group.

The large flows of artesian water at Dallas are from the Dexter reservoir (x^2), but in boring wells in the valleys of the Trinity River and Mountain and Chambers creeks it will be most profitable to extend the boring completely through the Dexter sand bed to the Lower Cretaceous limestone or marl in order to secure the largest and strongest flows.

Shallow flowing artesian wells, from 60 to 90 feet deep, are obtained in Mountain Creek Valley, in southwest Tarrant and southeast Dallas counties. Lower down, the creek flows east of north, nearly parallel with the strike of the rocks, and therefore parallel with the catchment area of the Woodbine formation. Hence wells at the same elevation in Mountain Creek Valley must be drilled to approximately the same depth to receive flowing water from the Woodbine reservoir. Along this portion the valley wells drilled 400 to 500 feet, to the Dexter sand (x^2) of the Woodbine group, will receive larger flows of good water. Most of the wells thus far drilled have stopped at the upper or Lewisville flow.

Chambers Creek Valley.—The area of possible flowing wells from the Woodbine reservoir in Chambers Creek Valley has been exploited from Auburn to Italy, in Ellis County. There are a few flowing wells in the upper portion of the valley which receive their water from the Lewisville reservoir (x^3), in the upper portion of the Woodbine group of reservoirs, at a depth of from 135 to 196 feet. The same water is struck at 260 to 280 feet halfway between Auburn and Italy, and at 400 feet at Italy. The shallower wells may be found in the creek valley in southeastern Johnson County. By continuing the boring to the base of the Dexter reservoir, about 100 feet below the first-mentioned reservoir, a larger and stronger flow will be obtained in all cases, and the quality of the water will be better than that of the first.

As the valley of Chambers Creek is descended, an additional depth of about 50 feet per mile will be required to drill from the surface to the artesian source, but a greater and stronger flow will be obtained. The quality of the water is not likely to be as good as that from the wells near the catchment area, higher up the creek, on account of the increase in the quantity of mineral matter in solution.

It is possible to obtain small nonflowing artesian water from the Woodbine reservoir in central Hill County, along Hackberry Creek above and below Hillsboro, by drilling 160 to 400 feet. Artesian water from the Woodbine basin is impossible in the Brazos Valley elsewhere than in central Hill County.

Deeper flowing wells of eastern district of Woodbine area of availability.—In that portion of the main Black Prairie south of the Trinity and east of the belt of outcrop of the Austin chalk flowing artesian wells have been obtained from the Woodbine reservoirs. These wells have been bored at Lancaster, Palmer, Milburn, Ferris, Waxahachie, and Corsicana, at depths of 1,100 to 2,500 feet. Little exploitation has been made of this district north of the Trinity until the Red River counties are reached. In the latter, deep wells into the Woodbine reservoir fail to secure flowing water. At Terrell a hole 2,200 feet deep failed to reach the Woodbine flow, although it would have been encountered had the well been continued a few hundred feet.

From the record of the deep-well sections at Dallas and Corsicana it is evident that the Woodbine reservoirs decrease in thickness and deteriorate in character as they pass downward toward the southeast as well as toward the south, parallel to their outcrop in the Eastern Cross Timbers.

The sandy character of the Woodbine formation and the thickness of its reservoirs increase northward, and in the same ratio its power for receiving and transmitting water increases. The Hillsboro and Dallas artesian well sections indicate a decrease in the thickness of the reservoirs and an increase in the proportion of clay in an easterly or southeasterly direction. Twelve or 15 miles west of Hillsboro the sand beds at the base are rather extensive, yet they produce only a small flow of water in the Hillsboro well. The Dallas wells receive their large flows from the Dexter sands (x^2), 50 feet thick, near the base of the Woodbine system, yet the same bed at its outcrop in the western portion of the Eastern Cross Timbers, in northeastern Tarrant County, is more than 100 feet thick. The fact is that much of the impervious clay occurring above the heavy water-bearing stratum in the Dallas well section is not found at the outcrop farther west. The Waco deep wells and the Marlin deep well, as illustrated by their sections, do not encounter the Woodbine reservoir at all. The deep well at Corsicana, as reported by Mr. Johnson, drilling superintendent, penetrated 15 feet of sand in the Woodbine reservoir at a depth of 2,400 feet, which gave a large flow of water so heavily charged with mineral matter that it was almost valueless. Before reaching the sand the drill penetrated 100 feet of clay interstratified with layers of sand, which doubtless belong to the Woodbine system.

Negative, nonflowing wells in which the water rises near the surface, like the well at Sherman, can be obtained along the divide of Red River and the Sulphur Fork, and in the White Rock belt over most of the Main Texas area.

The effect of the White Rock scarp upon the areas of possible flow illustrates the bearing of the topography upon the availability of an artesian reservoir. North of Dallas, upon the summit of the White Rock escarpment, water from the Woodbine basin will not rise to the surface. There is a large area of nonflowing wells of the Woodbine system extending from Oak Cliff southwestward with the ridge of Austin limestone, by way of Cedar Hill, Midlothian, and Mountain Peak, to Chambers Creek Valley opposite the junction of North and South Chambers creeks. From Chambers Creek Valley opposite the mouth of South Chambers Creek the ridge of Austin limestone continues southward, east of Files Valley and Hillsboro.

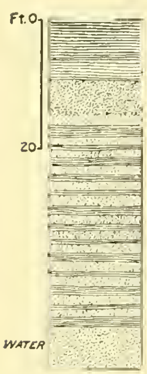


FIG. 49.—Shallow well of the Texas Midland Railway at Terrell, Texas, showing details of Terrell reservoirs.

It is hardly necessary to state that no artesian waters of the Woodbine system can be obtained outside the area of availability we have above defined, but it may be well to epitomize the reasons:

According to the law that water will not rise above its level, it is evident that artesian wells can not be expected from the Woodbine reservoir except at points to the eastward of their outcrop and at a lower altitude. West of the Eastern Cross Timbers these waters can not be found, inasmuch as the water-bearing strata do not exist in that direction. Wells can not be found in that portion of the East-Central Province west of the medial portion of the Eastern Cross Timber belt, because in that region the water-bearing beds form the surface outcrop, and hence are nonartesian. For the same reason wells can not be obtained from these reservoirs in northeastern Grayson County north of the Missouri, Kansas and Texas Railway and east of the Cook Spring fault, or in Indian Territory north of Iron Ore Ridge, which passes east and west through a point south of Fort Washita. Owing to the absence of the Woodbine sands from the geologic structure of the country south of the Brazos (see sections, Pl. LXVII), no water can be obtained from this system south of the Brazos. It is not possible to mark definitely the southern border of the Woodbine, but it does not extend to or south of the latitude of Waco. From the southern limit of the outcrop of the Woodbine formation on Brazos River west of Aquilla Creek this border bears eastward beneath the Black Prairie.

TERRELL RESERVOIR.

The name "Terrell system" is proposed for certain water-bearing sands in the Navarro formation outcropping along the northern portion of the eastern border of the Black Prairie. Little is known concerning the availability and capacity of this system, which has not been thoroughly studied (see fig. 49). It supplies many nonflowing wells along the eastern border of the Black Prairie, but its embed is chiefly beneath the western margin of the Tertiary area, and hence it will not be further considered in this report.

CHEMICAL QUALITIES OF THE ARTESIAN WATERS.

Unfortunately, no complete systematic study of the chemical qualities of the Cretaceous rocks of Texas and their resultant products, such as soils, waters, etc., has been made. The writer initiated an investigation of this character many years ago, but was not able to carry it to completion. It would be an interesting experiment to collect and analyze these various waters and to compare their analyses with one another and with those of the rocks from which they flow, and the writer hopes that this will yet be done.

Many individual analyses have been made of wells by various chemists, but no attempt has hitherto been made to assemble or classify these analyses, many of which are not even obtainable at present. From time to time some of these analyses have fallen into the writer's hands. From the chemist's standpoint many of them are inadequate and incomplete. Nevertheless, so far as they show the chief mineral ingredients of the waters, from a practical standpoint they are of great value and convey some important lessons.

The table herewith presents a few analyses of the waters from the various beds, gathered from miscellaneous sources. These analyses indicate four or five broad classes of water, varying in chemical impurities according to the reservoirs from which they come. The analyses, notwithstanding their imperfection, show also that while the waters of approximately the same horizon present certain marked generic resemblances, they are chemically dissimilar in some specific respects. The waters analyzed from the deeper reservoirs are all probably more or less contaminated by mixture with flows from the higher reservoirs. This is specially true of the Marlin, Hubbard, and Milford wells. The waters of the Hillsboro well, which are placed in the Woodbine and Paluxy group, may be from the Paluxy horizon. This well obtains its supply from the combined Woodbine, Paluxy, and Trinity reservoirs, and hence its analysis is not of much value. The Denton well penetrates the Paluxy reservoir only and is a type of the Paluxy water.

In order to ascertain the exact proportion of the various elements, the analyses should be recalculated and the mode of statement changed. The hydrogen is derived from the bicarbonates; SO_4 is the acid radical of the sulphates; CO_3, of the carbonates; PO_4, of the phosphates.

The Woodbine reservoirs are very low in lime (calcium carbonate), only one well showing an appreciable amount thereof. This is the only common feature of the two reservoirs of this system, for they otherwise show a most striking contrast between bad and good qualities.

The upper Woodbine water, as reported from many wells, of which complete analyses are not given, is so heavily charged with deleterious chemicals as to be practically unfit for human use. In general the analyses show an excess of solids, averaging 340 grains per gallon, including salt, gypsum, and magnesium. Magnesium sulphate is common, one well showing 23.6 grains, and another 5.28 grains. Chloride of magnesium in one of the wells occurs to the extent of 37.56 grains per gallon. Calcium sulphate is also very high, one well showing 127.8 grains per gallon.

The main Woodbine reservoir averages only 62.5 grains of solids per gallon, as opposed to 340 grains per gallon in the upper Woodbine reservoir. It shows a slightly greater proportion of salt than good water should have, but it is probable that in most cases this salt is derived from the seepage of the upper Woodbine waters. Magnesium sulphate is rare—almost absent. There is less than 1 grain per gallon of calcium sulphate.

It is unfortunate that we have no good analysis of the water from the Fredericksburg reservoirs. These are usually highly charged with mineral matter and the supply is small. In fact, this reservoir should never be used on account of the proximity of better supplies of water below it.

The well at Denton is from the Paluxy reservoirs and is the nearest analysis we have to an undoubted Paluxy horizon; it may be accepted as a type of the waters from that reservoir. It will be seen that this water differs from the Trinity by the greater amount of salt, the smaller proportion of carbonates, and the presence of magnesium.

The waters of the Glen Rose reservoir are thoroughly bad when considered in any other than a medicinal sense. They contain more kinds of deleterious minerals than any other reservoir, and a far greater quantity of them. From a medicinal standpoint, however, they are of value, and are acquiring a high local reputation. The waters more nearly resemble those of Carlsbad and other German spas than any other American waters. The Georgetown, Marlin, and Round Rock wells supply extensive commercial demands.

From the analysis of the Sixth street well at Austin, Professor Harper concludes that this well yields a sulphur water resembling the waters of the Blue Lick Springs, Nicholas County, Kentucky; of Hanna Springs, Lampasas, Texas, and of the springs at Harrogate.

Loca	mi- m.	Oxide iron.	Silica.	Alumina.	Total grains solids to 1 gallon.	Chemist.	Reporter.
Tioga, Grayson	9911		4.6651	1.1780	340.2036		
Elm View, Gra			9.62		399.83	Texas Agricultural and Mechanical College.	H. C. Sperry.
Corsicana					360.60	Prof. H. H. Harrington	
Big Mineral Cr County.		0.25	*a* 0.53	0.07	14.32		W. C. Eubank.
Court-House Sq		Tr.	.3503		85.61	L. Myer Connor	
Waxahachie			.94		87.5	Texas Agricultural and Mechanical College.	E. A. Du Bose, mayor, Waxahachie.
Hillsboro *b*						Texas Geological Survey	
Denton					33.5144	Texas State Geological Survey.	
Milford		*c* 0.437	1.195	*c* 0.437	329.659		
Milford			1.24		493.74		
Taylor		0.1100	0.2900	0.2600	96.9000	Dr. E. Everhart	
Near San Jacin streets.					598.6513	Dr. H. W. Harper	
Round Rock					359.82	Prof. R. S. Hyer	J. D. Robertson.
Mineral well at	3900		0.99		378.99	Dr. E. Everhart	
Marlin	2000				508.47	Dr. W. H. Allen	
Hubbard City							
Newark			1.00		*f* 107.07	Prof. H. H. Harrington	
Gainesville			.6003				President of company.
Gainesville			2.10				Officers of company.
Valley View			1.51		59.67	Prof. H. H. Harrington	R. P. Head.
Fort Worth			0.66		56.56		The company.
Waco			.7464	*g* 0.1457	56.8653	State Geological Survey	
Bosque Farm, r			.42	*g* .16	31.60		John K. Prather.
Waco		0.1493	1.0356	Tr.	53.8201		
Troy *h*					90.00		Prof. C. L. Myers.
McGregor			.300	*g* .100	45.021		President of company.
Palo Pinto			1.195	*g* 0.874			
Lampasas *i*			.496	.059	106.701	Prof. F. Waller	

a Insoluble
b This wate
c Alumina a
d This is the ... sibly from the Glen Rose reservoir.
analysis, Eight ... not included in total.

Analyses of artesian waters.

[Showing amount of solids, in grains per gallon.]

Location.	Owner.	Chlorides. Total	Chlorides. Sodium	Chlorides. Calcium.	Chlorides. Magnesium.	Chlorides. Potassium.	Carbonates. Total.	Carbonates. Calcium.	Carbonates. Ferrous.	Carbonates. Sodium.	Carbonates. Magnesium.	Sulphates. Total.	Sulphates. Sodium.	Sulphates. Magnesium.	Sulphates. Potassium.	Sulphates. Iron.	Sulphates. Calcium.	Sulphates. Aluminum.	Oxide iron	Silica	Alumina	Total grains solids to 1 gallon	Chemist	Reporter.
WELLS FROM THE UPPER WOODBINE RESERVOIR.																								
Tioga, Grayson County	George W. Rains	126.8824	89.5140		37.[illegible]							207.4778		76.601			127.8865	80.9911		1.0654	1.1380	540.[illegible]		
Elm View, Grayson County		68.90	68.90				[illegible]			33.500		287.8100	273.8[illegible]	5.2800			8.7000			9.62		399.83	Texas Agricultural and Mechanical College	H. C. Sperry
Corsicana		272.06	272.06				7.1800	5.1800				82.4000	83.400									360.60	Prof. H. H. Harrington	
WELLS FROM THE MAIN WOODBINE RESERVOIR.																								
Big Mineral Creek, Grayson County.	W. C. Eubank		1.73				8.220	0.350		7.8700		3.4000	3.100	0.230	0.17				0.2[illegible]	a0.83	0.0[illegible]	14.32		W. C. Eubank
Court-House Square	Dallas		17.5230				52.0[illegible]	2.3364		47.4302	2.9197	15.1866	15.1866		Tr.				Tr.	.583		80.61	J. Myer Connor	
Waxahachie	City	14.0800	12.940		0.440	0.700	45.9300			45.9300		25.270	24.580				0.880			.94		87.[illegible]	Texas Agricultural and Mechanical College	J. A. Du Bose, mayor Waxahachie
Hillsboro*b*	City	14.5658	11.0900	0.4758			1.0[illegible]2		1.0382			8.5665	8.4198	.1467									Texas Geological Survey	
WELLS FROM THE WOODBINE AND PALUXY (?) RESERVOIRS.																								
Denton		19.8823	10.4065	9.4758			9.4800		1.0382	8.4438		0.1167		0.1167								29.5111	Texas State Geological Survey	
Millord		20.081	20.081				50.9070	15.6570		29.0640	6.1860	256.5990	256.5990						c[illegible]	1.195	c[illegible]	[illegible]		
Millord		51.20	51.20				1.2600		1.2600			110.010	399.0000				11.010			1.21		463.71		
WELLS PROBABLY FROM THE FREDERICKSBURG RESERVOIR.																								
Taylor	Artesian Well Co. of Taylor	28.5620	22.3000	6.2620			19.1900			19.1900		18.1920	16.5720	0.3200	1.8000				0.1100	0.2900	0.2600	96.2000	Dr. F. Everhart	
WELLS FROM THE GLEN ROSE RESERVOIR.																								
Near San Jacinto and Fifth streets.	Austin	378.8171	351.9084		26.9087		67.4174		0.5086	66.9088		152.1168	d55.3939		11.3824		56.6405					598.6513	Dr. H. W. Harper	
Round Rock			50.02				37.6300	19.3300		18.3000		272.1700	206.0700	44.1900			21.9100					[illegible]	Prof. R. S. Hyer	J. D. Robertson
Mineral well at Georgetown.	Mr. Page		58.72				25.4100	23.1100	.81	1.2200		293.8400	198.5700	62.9300	5.6300		18.020	e8.3900		0.99		378.99	Dr. F. Everhart	
Marlin			112.39				15.2600	34.10		14.1600		347.1400	312.3200	16.1500	8000	3.020	3.940	11.2000				408.47	Dr. W. H. Allen	
Hubbard City			292.00				110.4000			110.4000		281.200	195.0000	6.4000	10.4100	20.200	19.300							
WELLS FROM THE LOWER TRINITY RESERVOIR, NORTH OF THE TRINITY.																								
Newark	C., R. I. and P. Railway	70.02	67.76			2.26	24.7800	1.40		23.3800		11.2700	10.1400	1.1300						1.00		f107.07	Prof. H. H. Harrington	
Gainesville	Gainesville Ice Co.		1.1006				20.6123			20.6123		1.7510	1.7510							.6063				President of company
Gainesville	Gainesville Oil Mill and Gin Co.		1.70			Tr.	27.9900	1.0000	1.7300	21.8300	0.4300	2.8800	2.8800							2.40				Officers of company
Valley View	E. M. Overshiner		7.32				35.5300			35.5300		13.9600	12.7200	.2500			0.9900			1.51		59.67	Prof. H. H. Harrington	R. P. Head.
WELLS FROM THE TRINITY RESERVOIRS, FORT WORTH SOUTHWARD.																								
Fort Worth	Chicago and Fort Worth Packing Co.		9.82				36.8800	0.3900		36.1800	0.3100	9.2000	9.2000							0.66		56.86		The company.
Waco	Wells of the Bell Waterworks		5.3418				26.7211	1.4579		25.2632		23.9103	23.9103							.7164	g0.1157	56.8653	State Geological Survey	
Bosque Farm, near Waco	Mr. W. L. Prather		4.33				11.6500	5.1000		4.8600	1.6900	15.0400			0.4700		11.5700			12	g.16	31.60		John K. Prather.
Waco	Mr. Moore		6.0267				22.6598	1.1579		20.6587	.8452	23.9183	23.9183						0.1493	1.0856	Tr.	53.8201		
Troy *h*	Prof. C. L. Myers		46.00				3.0000	3.0000				40.3600	40.3600									90.00		Prof. C. L. Myers.
McGregor	McGregor Water Co.		1.706				23.5910	.7500		22.1410	.4000	16.3240	16.3240							.500	g.100	44.021		President of company.
WELLS FROM THE UNDERLYING PALEOZOIC ROCKS.																								
Palo Pinto			20.081				50.9070	15.6570		29.0640	6.1860	256.599	256.599							1.195	g0.871			
Lampasas *i*	Hancock Sulphur Springs	77.141	19.836	9.040	18.265		24.3340	24.282	0.0520			1.4860			2.0240		2.1620			.496	.059	106.701	Prof. F. Waller	

a Insoluble matter.
b This water from well at Hillsboro may come from lower reservoirs.
c Alumina and iron 0.871 in original analysis.
d This is the sum of sodium sulphide, 1.2332; sodium hyposulphite, 6.6186; sodium silicate, 9.2469; sodium sulphate, 38.2652, as determined by Dr. Harper. See complete analysis, Eighteenth Ann. Rept. U. S. Geological Survey, Pt. II, p. 304.
e Alumina and potassium sulphate.
f Including insoluble matter, not given in table, 1.88.
g Alumina and iron.
h These waters are from an upper Trinity reservoir, or possibly from the Glen Rose reservoir.
i This water also contains 0.186 grains lithium bicarbonate not included in total.

Yorkshire, England. It can be profitably used medicinally in such cases as would be benefited by waters from the sources named.

The Glen Rose waters show a larger proportion of solid matter to the gallon, and of salt, magnesia, and lime, than those of any other reservoir, and for this reason they are unfit for ordinary uses. The solid matter, averaging 462 grains per gallon, is seven times as great as in the lower Trinity waters. Sodium sulphate is the chief constituent, averaging 252.74 grains per gallon. Calcium sulphate (gypsum) is also excessive. Chloride of magnesium occurs in one of the wells to the extent of 26.9 grains per gallon. Lime is also abundant, averaging 26.4 grains per gallon. Magnesium sulphate (epsom and Glauber's salts) is very abundant, averaging 32.46 grains per gallon.

Of the wells given as coming from the Trinity reservoirs, those of the Chicago and Fort Worth Packing Company, the Bell Waterworks at Waco, and Mr. Moore's well at Waco are known to be from the lower Trinity reservoir, and there is a remarkable similarity in their composition. These waters are soft and potable and show that this is by far the best of all the reservoirs.

The water of the wells of Mr. Prather and the McGregor Waterworks probably come from the upper Trinity reservoir. The same is probably the case with the well at Troy. The analysis of the water from the latter is very incomplete. The wells classified under the head of the Antlers reservoirs represent the northern continuation of the Trinity reservoirs. The two waters from the deep wells at Gainesville show a strong resemblance to those of the Trinity reservoirs. Such is the case with the water from the well at Valley View. The waters from these reservoirs are soft and are used for drinking, cooking, bathing, and washing—in a word, for all domestic purposes. They are also used for sprinkling flowers and lawns. They have not been used extensively for irrigation, but so far have proved very satisfactory for this purpose.

Too little is known of the upper Trinity water to permit a determination of its chemical qualities, as no reports have been received. The Prather well near Waco and the Troy well show a higher mineralization than the wells from the lower Trinity reservoirs. They have an average of about 4 grains per gallon of lime, which is not observable in the analyses of the wells from the lower reservoirs. The lower Trinity reservoir shows a small proportion of total grains of solids per gallon, a small proportion of salt, an almost entire absence of gypsum and lime, and the sodium occurs as sulphates and carbonates. None of the analyses show any trace of magnesium sulphate. The waters are also very free from lime, which may account for their soft quality. Calcium sulphate is absent from all the lower Trinity wells, and is present in only one upper Trinity well.

In examining the table of averages it will be seen that two of the reservoirs are especially bad when considered from any other than a medicinal standpoint. These are the upper Woodbine and the Glen Rose reservoirs. In each of these the total sulphates, as expressed by the number of grains per gallon, is very high, while the sulphates and chlorides far exceed the carbonates. Both reservoirs have a high percentage of magnesium and sodium chlorides, and are not well adapted for other than medicinal purposes.

On the other hand, the waters from two of the reservoirs are strikingly superior in their chemical composition. These are the lower Woodbine (x^2) and lower Trinity (t^1 and t^3) reservoirs. In each of these the proportion of solids is relatively small, being less than one-fifth of what it is in the upper Woodbine and Glen Rose reservoirs. The chlorides, carbonates, and sulphates are relatively in more equal proportions, while gypsum and magnesium sulphates are conspicuously absent. Of these two good reservoirs, the main Woodbine is inferior to that of the lower Trinity, having a greater proportion of salt and lime.

Although few in number, these analyses exhibit the qualities of the water reservoirs, as is evident to anyone who sees them, and correspond in a general manner with the composition of the geologic strata from which they are derived. Each of the waters enumerated in the foregoing pages has a close chemical resemblance to the rocks from which it is derived. It is impossible to state the proportion of ingredients of each particular stratum, because we have not a series of rock analyses, but certain chemical qualities are very marked in each. From our knowledge of the rocks through which these wells are drilled we know that the different strata vary greatly in chemical character, some being comparatively free from all soluble mineral ingredients except lime carbonate, which is nearly always present, while others carry various accessory impurities.

The Navarro and Taylor marls contain but little water or chemical impurities other than oil. The Austin chalk, miscalled magnesian limestone, contains no magnesia, and hence the magnesian constituent of the water it carries must originate below that formation. It does contain considerable lime and pyrites, the latter sufficient to supply iron and sulphureted hydrogen. The upper part of the Eagle Ford shales is somewhat similar to the Austin chalk, but the lower portion contains much gypsum, alum, iron, and bituminous matter, all of which contribute to the bad quality of the upper Woodbine reservoirs.

The writer has never been able to obtain a complete analysis of the Buda limestone, but there is reason to believe that water penetrating it would take up sulphur, iron, and saline impurities, such as can be seen incrusting it at Austin, where efflorescences of salt and magnesium sulphate have been observed. There is little doubt that water transmitted through these beds, at least in Travis County, will be strongly "mineralized."

The Del Rio clays are very impervious and not apt to affect underground water seriously, unless it percolates through the pyritiferous fossiliferous beds, in which case much sulphureted hydrogen will be taken up.

The waters passing through the Fort Worth limestone and the upper part of the Edwards limestone are impregnated with mineral matters somewhat analogous to those of the higher Buda limestone and lower Glen Rose beds. Such minerals form an efflorescence on the surfaces of the protected rock ledges or in the bluff caverns, as can be seen in many places where they outcrop.

The rocks of the middle and lower parts of the Edwards formation are principally lime, and contain accessories of magnesium and sodium.

The Paluxy sand, as noted by Taff, near the upper border is charged with deleterious mineral matter, and is purer in its central portion.

In the upper Glen Rose beds, as can be seen in the bluffs of Mount Bonnel, west of Austin, there are certain strata that contain strontium, magnesium, and sodium, which undoubtedly affect the water, as shown by the analyses.

Another magnesium horizon occurs near the top of the Travis Peak beds, but below that these beds are very free from any unpleasant ingredients, as is attested by the analyses of the waters and of the rocks of certain of the beds.

From these studies of the chemical nature of the waters some useful deductions can be made. Bad waters should be cased off wherever encountered and the well continued until a purer flow is struck in a lower reservoir. This is done in many instances. In the writer's opinion, no matter how firm the drill hole, it would pay in all instances to drill to the lower waters and case up the well above them, in order to insure against the seepage of these mineral waters. In the light of the facts set forth in this report, it will hardly be excusable hereafter to allow such waters to flow, when intelligent continuation of the well may obtain superior supplies.

PART V.

ARTESIAN CONDITIONS OF THE BLACK AND GRAND PRAIRIES, BY COUNTIES.

In the following pages there will be given a brief description of the artesian conditions of each of the counties in this region, together with typical well sections and other data that will afford practical aid to those who wish to undertake artesian exploitation. The general geologic conditions controlling the occurrence of artesian water in these counties have been discussed in the preceding part of this report; hence in the individual descriptions the geologic references will be brief and supplementary to the broader treatment.

CLASSIFICATION OF COUNTIES ACCORDING TO ARTESIAN CONDITIONS.

The counties lying within the Black and Grand Prairie region may be divided according to their artesian conditions into four general groups:

1. Counties of the western border region, in which the water reservoirs outcrop at the surface or are so slightly embedded that they are available within a few hundred feet of the surface. Although there are a few exceptional artesian wells in some of these counties, the conditions are in general unfavorable for obtaining flowing waters. In this list we may include the following counties:

Wise.	Eastland.	Hamilton.
Parker.	Comanche.	Lampasas.
Hood.	Brown.	Burnet.
Erath.	Mills.	

2. Counties in which artesian conditions are largely favorable, and which may be said to constitute the main artesian belt. In this list may be placed the following:

Somervell.	Bell.	Ellis.
Bosque.	McLennan.	Hill.
Coryell.	Cooke.	Johnson.
Travis.	Dallas.	Tarrant.
Williamson.	Denton.	

3. Counties of the Red River district and eastern portion of the Black Prairie in which the altitude of the surface is generally higher

than the catchment area. These counties hence are unfavorable for flowing wells. This district includes the following counties:

Collin.	Lamar.
Fannin.	Red River.
Grayson County (in part).	

4. Counties of the eastern border, in which the reservoirs are so deeply embedded as to render them available only at great expense. This group includes the following:

Falls.	Milam.
Hunt.	Navarro.
Kaufman.	Rockwall.
Limestone.	

WESTERN COUNTIES LYING WITHIN THE GRAND PRAIRIE AND THE LAMPASAS CUT PLAIN

The counties of Cooke, Montague, Wise, Parker, Eastland, Erath, Comanche, Brown, Mills, San Saba, and Burnet lie along the interior border of the Cretaceous Western Cross Timbers, where the edges of the formations constituting the artesian reservoirs discussed in this paper overlap the Paleozoic formations of the Central Province.

In general they present from west to east five relief features having an important bearing upon the occurrence of underground water within the Cretaceous area.

1. A western belt of broken land established upon the Paleozoic formations.

2. A belt of sandy forested land occupied by the Western Cross Timbers, which surmounts the Paleozoic belt.

3. The slope of the western scarp of the Grand Prairie, which rises above the Cross Timbers.

4. The summit of the Grand Prairie, which inclines gradually seaward from the edge of the scarp.

5. Streams flowing down the slope of the Grand Prairie or completely across it, and occupying valleys that have been deeply incised below its summit level.

The portions of these counties lying within the Central Province are usually unpropitious for artesian waters and do not come legitimately within our field of discussion. The portion of these counties within the Cretaceous area (see geologic map, Pl. LXIV) is underlain by the Trinity division, and the Grand Prairie and Lampasas Cut Plain are also underlain in part by the Paluxy division.

The Trinity divisions outcrop at the surface within the Western Cross Timbers, and there constitute the catchment area for the embedded Trinity reservoirs to the east. The shallow surface wells of this area derive their water from the same strata that lie 1,800 feet below the surface at Waco. The main belt of the Western Cross Timbers, with certain exceptions, is therefore unproductive of artesian wells, although in a few of the valleys, such as those of the Trinity, Bosque, Paluxy, and Leon, shallow flowing wells are obtained within the area of the eastern arms of the Western Cross Timbers.

Upon the escarpment slope and summit plains of the Grand Prairie and Lampasas Cut Plain within these counties flowing artesian wells are impossible, as the surface is higher than the outcrop of the water-bearing formations to the west, and the water will rise in these localities only to the altitude of the lower-lying catchment area of the Western Cross Timbers.

The valleys of streams like the Paluxy, Bosque, Leon, Lampasas, San Gabriel, and the forks of the Trinity, which are incised to a lower altitude than the outcrops of the water-bearing formations to the west, present in some cases favorable conditions for securing shallow artesian wells like those at Stringtown, Parker County, and Oakalla, Burnet County.

WISE COUNTY.

This county has an area of 893 square miles. The eastern half lies within the general area of the Grand Prairie, the highest portion of which is about 1,100 feet above the sea. The western portion, occupied by the belt of the Western Cross Timbers and threaded by the Trinity River, is much lower, the altitude of the valley of that stream varying from 956 feet at the northwest corner to 500 feet at the southeast corner.

The formations exposed embrace the Washita division on the highlands, the Fredericksburg division in the escarpment, and the Trinity division along the valley of the Trinity River. These in turn rest upon the Carboniferous in the northwestern portion of the county.

The combined Trinity-Paluxy (Antlers) water-bearing strata have a wide area of outcrop throughout the west-central portion and are embedded beneath the eastern half. The surface of the prairie region, except in the deeply incised valley of the Trinity River in the southeast corner, is generally higher than the outcrop, and hence flowing wells are improbable.

Only one flowing artesian well has been reported from Wise County. This is at Newark (altitude 692 feet), in the Trinity Valley, in the extreme southeast corner. This well, drilled for the Chicago, Rock Island and Texas Railway, is 385 feet deep and penetrated three artesian reservoirs at depths of 60, 150, and 385 feet. The quantity of flow is not given.

At Rhome (altitude 923 feet), on the crest of the Grand Prairie, Mr. J. T. Hoggsett drilled a well 200 feet deep into the upper reservoirs of the Antlers (Paluxy) formation. The water rose to within 50 feet of the surface, or to an altitude of 873 feet. Shallow nonflowing wells of this character could undoubtedly be procured throughout the eastern portion of the county lying within the Grand Prairie belt.

Schedule of wells in Wise County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.*a*	Quality.*b*	Used for irrigation.*b*
		Feet.	*Feet.*	*Feet.*	*Feet.*			
T. J. Hopper	Hauna, 1 mile west of	112	90	......	......	No.	1	×
Colbert	Bridgeport post-office	119	100	......	......	No.	1	....
R. Bonnifield	Bridgeport, 3 miles southeast of	244	......	......	204	No.	3	....
T. Mahaffy	Jim Ned, 2 miles east of	236	......	......	190	....	3	....
T. Sargent	Chico, 3 miles south of	158	150	......	67	No.	7	....
R. P. Cochran	Cottondale, near post-office	110	±80	......	60	No.	1	....
W. M. Horn	Cottondale, 200 yards east of	105	65	100	+50	No.	1	....
C. A. Whitehead	Decatur (2 wells)	{ 178 155	} 130	......	......	No.	....	....
W. H. Cundiff	Decatur, 4 miles west of	175	100	......	......	No.	2	....
J. Spencer	Decatur, 1½ miles northwest of	200	56	120	144	No.	....	×
C. W. Martin	Decatur, in limits of	125	117	......	15	No.	{ 1 7	} ×
J. T. Hoggsett	Rhome	198	......	......	......	No.	....	....
The Chicago, Rock Island and Texas Rwy.	Newark	385	60	150	......	×	....	....

a × = yes.
b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

PARKER COUNTY.

Parker County (area, 866 square miles) lies mostly within the area of the Grand Prairie, the region of the Cross Timbers being limited to the western third of the county. The summit of the Grand Prairie is dissected by many parallel valleys, the deepest of which is that of Trinity River.

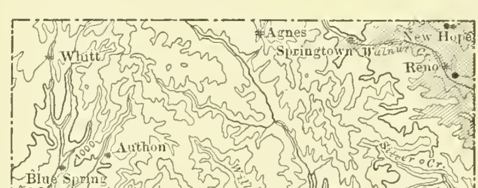


FIG. 50.—Artesian map of Parker County, Texas. Shaded portion shows areas of possible flowing wells; ●, flowing wells from Trinity reservoir.

The geological formations consist of the Cretaceous strata of the Washita, Fredericksburg, and Trinity divisions, the Washita capping the highest divides and the Fredericksburg and Trinity resting upon the Carboniferous in the western portion of the county.

The whole of the Grand Prairie portion is underlain by the reservoirs of the Paluxy-Trinity formation at moderate depths, but the altitude seems unpropitious for flowing wells except immediately along the valley of Walnut Creek in the eastern part.

Several artesian wells have been drilled which completely penetrate the artesian reservoirs, but with one or two exceptions the water failed to rise to the surface. The deepest of these wells, at Weatherford, is about 500 feet.

The only flowing wells reported are from the vicinity of Springtown, on Walnut Creek, in the northeastern portion of the county. These are all less than 100 feet deep and begin and end in the lower part of the Trinity division.

Several wells have been drilled at Weatherford (altitude, 870 feet), but the city is too high to procure flowing water. A good supply of pumping water is obtained. The section of the well of the Weatherford Water, Light, and Ice Company is given below. (See Pl. XIX, *A*, and fig. 19.)

SECTION NO. 49.—SECTION OF WELL OF WEATHERFORD WATER, LIGHT, AND ICE COMPANY, AT WEATHERFORD, PARKER COUNTY, TEXAS.

(See Pl. XIX, *A*.)

Formation.	Material.	Thickness.	Depth.
		Feet.	*Feet.*
	Soil	10	10
	Clay	18	28
Paluxy	Pack sand	20	48
Glen Rose	Shales and limestones	400	448
Trinity	Gravel and sand	6	454
	Red clay	34	488

Water was struck at 402 feet. The well does not flow.

The postmaster at Carter says: "The water, both surface and underground, is failing gradually in this part of Texas. There is no question or doubt of this fact, as I have carefully noted the decrease for a period of forty-five years."

Schedule of wells in Parker County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Water formation.	Rise of water. *a*	Flowing well.	Decrease of flow. *a*	Quality. *b*	Used for irrigation. *a*
		Feet.	*Feet.*	*Feet.*						
City water supply	Weatherford	402	.....	.....	t^1, t^2	×	No.	....	....	....
Schoolhouse well	.....do	500	.....	.....	t^1, t^2	50	No.	....	....	....
S. A. Davis	Springtown, 1 block west of square in.	80	25	50±	t^1, t^2	×	No.	×	1	No.
J. R. Cole	Springtown post-office, 400 yards from.	70	18	.....	t^1, t^2	×	×	×	{1, 2}	No.
Six or seven wells	Springtown	{75–100}	.....	.....	t^1, t^2	....	×	....	....	....
J. W. Lyle	.....do	100	36	85	t^1, t^2	×	No.	....	1	No.
J. A. McCrary	Reno, ¼ mile southwest of	100	30	97	t^1, t^2	....	×	....	1	No.
J. A. M. Crary	Reno, ¼ mile southwest of, on high ground 300 yards from.	200	.....	.....	t^1, t^2	×	No.	....	1	.....
P. W. Austin	In Walnut Creek Valley, 1 mile west of Reno.	85	40	45	......	....	×	....	1	No.
	Reno post-office, 100 yards west of.	130	60	70	......	×	No.	....	1	No.
W. B. Austin	Reno Park post-office, 100 yards north of.	147	60	125	......	×	No.	....	1	No.
R. A. Parker	Reno post-office, 300 yards east of.	157	65	150	......	×	No.	....	1	No.
R. E. Miller	Reno post-office, 200 yards east of.	126	47	120	......	×	No.	....	1	×
Chas. McFarland	Aledo, 4 miles south of	240	120	210	......	×	.....	....	1	×
J. Jones	Aledo, 4 miles southeast of	140	100	136	......	×	No.	....	1	No.
E. D. Farmer	Aledo, 4 miles north of	315	280	......	......	×	No.	....	2	×
Mrs. Higbee	Aledo, 3 miles northeast of	189	145	171±	......	×	No.	....	1	No.
Do	Aledo, 3 miles northwest of	234	216	......	......	×	No.	....	2	No.
S. W. Middleton	Bear Creek, Tarrant County, 1¼ miles southwest of.	220	.....	......	......	....	No.	....	1	No.
J. B. Carnahan	Bear Creek, Tarrant County, 2 miles west of.	139	139	......	......	×	No.	....	2	No.

a × = Yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contaius iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

HOOD COUNTY.

Hood County has an area of 424 square miles. This small county is a typical example of the dissected Lampasas Cut Plain. Its relief consists of various benches incised below the high topographic level of the old cut plain which is preserved in the plateau of Comanche Peak, at an altitude of 1,250 feet. These benches lead down to the trough of the Brazos River on the east, which has an altitude of from 550 to 750 feet as it crosses the county and the Paluxy Valley on the south.

The geological formations consist of all the Lower Cretaceous beds from the Edwards limestone, capping Comanche Peak, to the basement sands of the Trinity division, seen in the valley of the Brazos north of Granbury and at Paluxy village on the Paluxy. (See Pl. LXVI.) The Paluxy formation constitutes the surface formation of a large portion of the summit areas, such as the platform around Comanche

Peak and the high divide of the Brazos and the Paluxy in the western portion. It also outcrops along the western escarpment of the Grand Prairie in the eastern part of the county. The valley slopes and prairies are mostly underlain by the Glen Rose formation. The sequence and occurrence of the formations is shown in the Comanche Peak section. (See fig. 12.)

The excessive dissection of the Paluxy formation renders it unavailable as a source of artesian supply in this county, except for a few nonflowing wells in the extreme northeastern portion. The Trinity reservoir is more completely embedded beneath the county except immediately along the valley of the Brazos north of Granbury, and constitutes an available supply for nonflowing wells. Except in the extreme southeast corner, the topographic conditions are unpropitious for flowing wells.

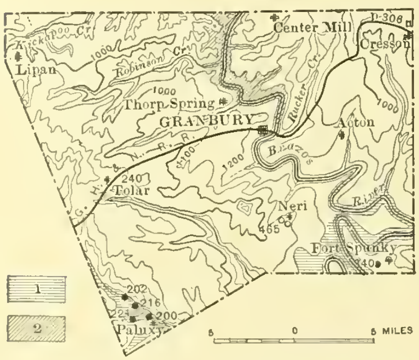


FIG. 51.—Artesian map of Hood County, Texas. 1, area of possible flowing wells; 2, area not underlain by Cretaceous reservoirs; ●, flowing wells from Trinity reservoir; ○, nonflowing wells from Trinity reservoir; figures indicate depth of wells in feet.

The only flowing wells so far reported are in the vicinity of Fort Spunky, in the Brazos Valley, and near Paluxy post-office, in Paluxy Valley, in the southern part of the county.

The artesian wells of Paluxy village belong with the group of Glen Rose wells and are of interest, inasmuch as they illustrate the character of the strata of the basement water-bearing formations of the Trinity division. The surface formation at this locality is the outcrop of the t^2 reservoir, from which most of the deep wells farther east procure water, and the impervious retaining layers are mostly the red and blue clays separating the t^1 and t^2 reservoirs.

The well of John Randall is 2½ miles west from Paluxy and is 216 feet deep; depth to first water, 30 feet; to other waters, 120 feet. A section of this well entirely in the Basement beds of the Trinity division is as follows:

SECTION NO. 50.—SECTION OF WELL OF JOHN RANDALL, NEAR PALUXY, HOOD COUNTY, TEXAS.

	Feet.
Sand and lime rock (t^2)	58
Blue keel and yellow clay	95
Red keel rock	2½
Water sand (t^1)	75 or 100
Red keel.	

Mr. Randall writes: "Some of my neighbors, after passing through the water sand, have drilled 2 or 3 feet and found nothing but red clay."

The well of J. V. Brooks, 3 miles west of Paluxy, is 202 feet deep. Depth of first water is 45 feet. Mr. Brooks writes:

I think at or about 175 or 180 feet we struck a stratum of flowing water, for the water rose to within 3 or 4 feet of the surface and stood there until the drill went down to about 195 feet; then the water began to rise again and continued until 202 feet. We went 212 feet, but the water failed to flow any stronger and we quit. Three other wells sunk on lower ground caused my well to quit flowing.

In the well of Mr. Jack Underwood, 2½ miles southwest of Paluxy, the total depth of water is 221 feet; depth to first water (t^2), 65 feet; to other waters (t^1), 210 feet. The well is nonflowing, the water rising about 200 feet. The well furnishes 4,500 gallons an hour. After the first water sands had been passed 65 to 80 feet, soapstone, or a clay formation, of a gray or blue color was struck; this finally changed color to alternate streaks of blue and red; the artesian water sands were encountered at about 210 feet.

The well of Isaac Moore, 1 mile from Paluxy, is 200 feet in depth; first water (t^2), 30 feet. It has a 3-inch flow, and furnishes 3,600 gallons an hour.

The wells in the Brazos Valley near Fort Spunky mostly commence well up in the Glen Rose beds.

The well of Mr. H. Pinson, 1½ miles from Fort Spunky, is 356 feet deep; depth of first water (t^2), 340 feet. The first flow was struck at 356 feet. The well is used for irrigating a garden and a cotton field.

In the high portions of the Brazos Valley there are no flowing wells, but good nonflowing wells are obtained at various places at depths varying with the altitude.

Mr. A. J. Peare's well, 1½ miles southwest from Neri, is 300 feet deep; depth to first water (t^2), 80 feet; to other waters (t^1), 275 feet. The well furnishes 500 gallons a day. The section of the well is as follows:

SECTION NO. 51.—SECTION OF WELL OF A. J. PEARE, 1½ MILES SOUTHWEST OF NERI, HOOD COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay	10	10
Pack sand	30	40
Lime rock	230	270
Sand clay and yellow keel	30	300

W. J. Johnston, of Neri, states that the wells range from 150 to 300 feet deep, and says, "We have one well in our neighborhood that is 465 feet deep; it does not flow, but is the deepest well in the county. The water rises 300 feet."

The well of B. W. Camp, 2 miles south of Neri, is 415 feet deep; depth of first water, 35 feet; to other waters, 293 feet. The well is nonflowing; water soft, with trace of sulphur. A partial section is as follows:

SECTION No. 52.—PARTIAL SECTION OF WELL OF B. W. CAMP, 2 MILES SOUTH OF NERI, HOOD COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	8	8
White pack sand (t^3)	10	18
Lime rock	17	35
Sand, first water (t^2)	2	37
Rock	33	70
Soapstone	20	90
Rock, with a thin stratum of blue mud	160	250
Blue sand rock	40	290
Second water (t^2) at		293

Cresson, in the extreme northeastern corner of the county, lies upon the slope of the Grand Prairie toward Fort Worth. Good nonflowing wells are obtained at this place from the Paluxy sand. The postmaster gives the following section of the well of the Cresson Water Supply Company, which supplies 22 families with water:

SECTION No. 53.—SECTION OF WELL OF CRESSON WATER SUPPLY COMPANY.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay (Washita division)	100	100
Solid rock	20	120
Rocky clay (Walnut formation)	100	220
Sand and hardpan	50	270
Stratum of white sand		
Blue hardpan	8	
Water-bearing white fine sand		
Blue hardpan		306

Schedule of wells in Hood County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water formation.	Rise of water. *a*	Flowing wells. *a*	Decrease. *a*	Quality. *b*	Irrigation. *a*
		Feet.	*Feet.*	*Feet.*							
J. Underwood	Paluxy, 3 miles southwest of.	172	30	.....	t^2	t^2t^1	×	No	×	1	×
J. Randall	Paluxy, 2½ miles west of	216	30	120	r	$t^3t^2t^1$	.....	×	×	1	×
J. Underwood	Paluxy, 2½ miles southwest of.	221	65	210	r	t^2t^1	×	No	×	7	No
D. E. Walton	Paluxy, 2 miles northwest of.	240	40	235	r	t^2t^1	.....	×	×	9	No
I. Moore	Paluxy, 1 mile southwest of.	200	30	.....	....	......	×	×	×	1	×
J. M. Stewart	Paluxy	237	.....	.....	....	......	.....	×	....	2	No
W. F. Larned	Paluxy, within 100 feet of post-office (2 wells).	190 190	160	180	t^3	t^1	.....	×	×	1	×
W. S. Ethridge	Paluxy	236	150	.....	t^3	t^2t^1	.....	×	....	1	×
M. A. Meeker	Tolar, 3 miles northwest of.	277	60	.....	....	pt^3	×	No	....	1 7	×
W. J. Bowers	Tolar, 2 miles northwest of.	260	80	250	....	pt^3	×	No	....	1	No
J. V. Powell	Tolar, 2 miles east of	250	204	.....	....	pt^3	×	No	....	1	No
J. R. Cherry	Tolar post-office, northeast from.	240	225	.....	....	pt^3	No	No	....	1	No
W. L. McGaughey	Tolar, 10 miles west of Granbury.	230	180	.....	....	pt^3	×	No	....	2	No
B. W. Camp	Neri, 2 miles south of	415	35	293	....	pt^2	×	No	....	1	No
A. J. Peare	Neri, 1½ miles southwest of	300	80	275	....	......	×	No	....	1	No
S. Eden	Fort Spunky, 3 miles west of.	290	190	.....	....	......	.....	×	....	1	×
H. Pinson	Fort Spunky, 1½ miles from.	356	340	.....	....	......	.....	×	×	1	×
Cresson Water Co	Cresson, 300 yards south of.	308	60	.....	....	......	×	No	....	1	No
J. Brooks	Cowan, ½ mile east of	202	45	.....	....	......	×	No	....	1	No
J. Kirkland	Thorp Springs, 3 miles west of.	108	35	.....	....	......	×	No	....	2	No

a ×=yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11 contains alum; 12, contains magnesia.

ERATH COUNTY.

Erath County has an area of 1,091 square miles, and is of varied relief. It consists of a high crown or table-land, a remnant of the Lampasas Cut Plain, which extends irregularly northeast and southwest through the county, sending tongues of upland southeastward between the streams, and terminating abruptly on the northwest with an escarpment overlooking a low area in the northwest corner of the county. The highest altitude is on the plateau to the northwest of Stephenville, 1,600 feet, while the streams flowing in all directions from this summit area cut down to a level of 1,000 feet at the margins of the county.

The outcropping rocks consist of formations from the Walnut to the basal Trinity (Pl. LXVI), inclusive, the former capping the high divides along the summit of the plateau from Dublin northward and the latter being exposed at the base of the western escarpment and in the stream cuttings of the Paluxy in the extreme eastern portion. This group of rocks rests unconformably upon the Carboniferous formations which outcrop in the northwestern portion in the vicinity of Wylieville and Thurber.

The Cretaceous formations above mentioned have a very slight dip to the southeast, and are incised in all directions by the stream valleys, so that they are cut and torn on every hand and their capacity for perfect artesian conditions in this county is destroyed.

The group of Cretaceous strata outcropping in this county includes at least four distinct water-bearing formations, three of them belonging to the Trinity division (t^1, t^2, t^3), and the fourth being the Paluxy. Owing to the dissection of the strata by numerous canyons their waters are not artesian except in the extreme eastern portion, near Bluffdale, on the Paluxy, and possibly just below Hico, on the Bosque. Nevertheless, the strata are so easily within reach that they constitute the source of numerous drilled wells in all parts of the county except in the Carboniferous area.

Flowing artesian wells have been obtained on the extreme eastern edge of this county, at Bluffdale, in the valley of the Paluxy. This locality probably represents the western limit of possible flow in the Paluxy Valley, the wells of which are more fully described under the head of Somervell County.

The Carboniferous area in this county, as elsewhere, presents unfavorable conditions for procuring artesian waters. One of the costliest and most barren artesian experiments was made at Thurber, in the extreme northwestern portion, by the Texas and Pacific Coal Company, which sank a well 3,050 feet through the Carboniferous strata. According to Mr. W. K. Gordon, superintendent of the company, this well penetrated through shale and slate for the entire distance.

Another notable artesian failure was the experiment at Dublin. This village is situated upon the top of a high divide, from which the outcrop of the Trinity formation may be seen in the valleys on either side, some 400 feet below. Notwithstanding endeavors to discourage the attempt to secure an artesian well at this place, persons who did not believe that geological principles govern artesian conditions insisted upon drilling this well and suffered great financial loss.

The following letter from Mr. F. W. Morrison, a well driller of eighteen years' experience, ably describes the underground water conditions of this county. The symbols of the reservoirs have been inserted in brackets.

This is one of the best-watered counties in the State. Every farm man in the county can get plenty of water either from a spring or a well not over 250 feet deep. I have drilled over 100 wells, probably one-fourth of all in the county. The water occurs in strata reaching through the county. They mostly dip southeast; the highest one [the Paluxy reservoir] is beneath the prairie, 3 miles north. I have bored about 40 wells in that stratum, which runs deeper to the east. Twenty miles east of Stephenville this water is 175 feet below the surface. This stratum can be traced by springs and running branches through the county on the east of Stephenville and for 9 miles on the west. This is a very strong stream; a good windmill can run all the time. There are 40 or 50 windmills on this prairie, 6 running branches on the east and 2 on the south, which do not seem to exhaust the supply any. The water is a little hard; 50 feet under this first reservoir is the second [t^3], not so strong; about 100 feet below this second is a third [t^2], about the same; under this 200 feet is the fourth [t^1], very strong.

Northeast of Stephenville 15 miles, at Bluffdale, on the Fort Worth and Rio Grande Railway, are several flowing wells from the fourth [or t^1] stratum. At Bluffdale the reservoir is about 100 feet below the creek and the water will rise above the creek 75 feet; but the railroad has put in a pump that stops the flow in all the other wells in 20 minutes after it commences pumping. These flowing wells are on the Paluxy, and can be obtained east through Erath and Somervell counties along this creek.

I will give you the description of one well, which will hold good for many others in this and adjoining counties as to quality and quantity. This well is in Stephenville, and runs a large gin, corn mill, and electric plant, and will afford 7 gallons per minute all the time. The beginning is mostly soil, and then a yellow clay, or rather lime rock; at the bottom of that is a seep and then the blue lime rock, mostly composed of shell, which is known as the concrete shell. Some of this is very hard, with layers of black soapstone or slate to the depth of 165 feet from the surface of the ground. Then comes whitish clay, which changes color to blue-green, light-red, and dark-red sand [p]; then coarse sand, which is the water sand, and water 185 feet. Under this sand was a vein of very hard lignite 5 feet thick; it has been struck at three or four other places, but never tested. This is in the fourth stratum, and is 200 feet deep. There are 13 such wells in less than one-half mile.

The surface stratum here is No. 3 [t^2], which is about 40 feet. There are hundreds of wells in it, some strong enough to run a windmill. No irrigation in this county. The above distances and directions are mostly guessed at, but about correct.

The following data from various correspondents will convey an idea of the character of the strata penetrated and depth to water in various portions of the county:

Postmaster at Dublin states that wells in that section vary in depth from 16 to 200 feet. One well in Dublin is 400 feet deep, the water rising to within 8 feet of the surface.

Joseph Perry, who lives 2 miles east of Pizarro, says that his well is 218 feet deep and does not flow; the first water was 204 feet from the surface. There are six drilled wells in an area 3 miles square, varying from 250 to 300 feet in depth.

George Jackson owns a well 4½ miles southeast of Bluffdale. It is 190 feet deep, and the drill penetrated common clay and gravel until first water was reached at a depth of 48 feet; then came a blue soapstone, next red clay or keel, and finally white sand, at a depth of 190 feet. Water rose to the surface of the ground when the white sand was reached.

W. O. Herring, who drilled a well 1 mile east of Skippers Gap, says that the first 28 feet was gravel and the balance was lime rock until water was obtained in pack sand 138 feet from the surface. The well does not flow.

J. H. Herring, who has a well located 1 mile east of Skippers Gap, writes that he struck first water, which was weak, at a depth of 173 feet and second water at 190 feet. The depth of water in this well is 9 feet, and the windmill will not lower it. The nearest flowing well is 10 miles to the east.

T. L. Stigler, who has a well 137 feet deep, 1 mile south of post-office at Chalk Mountain, gives the following record of strata: A white lime rock for 75 feet (e), then 30 feet of blue clay (f), and the remainder interspersed with sand and gravel (p). There are many similar wells in this locality, ranging in depth from 140 to 200 feet, though generally the supply is much better, being more than can be pumped out by a windmill.

W. H. Chaney has a well 2 miles south of Clairette, which is 215 feet deep. He states that his place is located about 1½ miles from the Bosque River, near the edge of the timber. The well passed through rock and clay for about 160 feet, and then struck sand (p), which continued until finished. The sand seemed to get softer with increased depth, and after water was struck it seemed to be quicksand. The water is generally struck at from 200 to 275 feet in this region and is good for drinking.

J. L. Blackstock, well driller, of Highland, gives the following information:

I have gone down as far as 306 feet for water, but sometimes got it at 20 feet. In deep wells we first go through the soil, which is of dark sandy loam; then clay of different color and rock for 40 to 60 feet; then into a blue rock which varies from 2 to 8 feet, which is very hard to drill in; then into a kind of blue clay which varies from 20 to 75 feet; through this into white sand until we come to a bed of gravel of all shapes and colors, in which is plenty of water which can not be exhausted.

Schedule of wells in Erath County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water. *a*	Flow. *a*	Quality. *b*	Irrigation. *a*
		Feet.	*Feet.*	*Feet.*				
W. A. Bissel	Stephenville	190	....	......	×	No..	1	....
W. F. Chambers	Stephenville, 200 yards southwest of.	190	Surface, 40.	......	×	No..	7	×
T. J. Frey	Bluffdale, northwest of	126	14	112	....	×	1	....
J. F. Robinson	Bluffdale, 8 miles southeast, at Cowen post-office.	208	42	165	....	No..	{ 1, 5 }	...
G. Jackson	Bluffdale, 4½ miles southeast of	190	48	118	....	No..	{ 4, 5 }	...

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda, 9, alkali; 10, contains potash; 11, contains alum; 12, contains magnesia

Schedule of wells in Erath County, Texas—Continued.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Quality.	Irrigation.
		Feet.	*Feet.*	*Feet.*				
W. K. Gibbs	Bunyan, 1 mile north of	100	17	......	×	No..	2	....
W. P. Bowen	Topaz, 600 yards from (3 wells)	216	90 140 190	......	×	No..	7	....
J. G. O'Brien	Dublin, 5 miles east of	340	......	......	×	No..	2	×
J. S. Blackstock, reports	Highland, post-office yard	229	224	......	....	No..	2	....
F. Kring	Huckabay, 5 miles east of	220	......	......	....	No..	7	....
V. A. Roberts	Clairette, 1 mile south of	210	200	......	×	No..	1	....
W. H. Chaney	Clairette, 2 miles south of	215	140	185	....	No..	7	....
J. F. Bennett	Clairette	208	190	......	....	No..	1	....
C. Duncan	Clairette, 1½ miles north of	133	90	100	×	No..	2 7	×
J. H. Herring	Skippers Gap, 1 mile east of	199	173	190	....	No..	2	....
J. H. F. Skipper	Skippers Gap	190	141	183	....	No..	1	....
J. L. Kamage	Skippers Gap, 2 miles southeast of	128	80	......	....	.	1	....
W. O. Herring	Skippers Gap, 1 mile east of	138	28	110	....	No..	1	....
J. W. Taylor	Skippers Gap, ¾ mile southwest of	110	60	90	×	No..	2	....
Jos. Perry	Pizarro, 2 miles east of	218	......	......	×	No..	7	....
Henry Roberson	Pizarro, 1½ miles from	230	200	......	....	No..	2	....
T. J. Hannie	Chalk Mountain	160	50	......	....	No..	1	×
T. L. Stigler	Chalk Mountain, 1 mile south of.	137	127	......	×	No..	1	....
J. Dotson	Chalk Mountain, 3 miles northwest of post-office.	196	130	......	×	No..	1	....
Guyton Bros	Chalk Mountain, 4 miles west of.	318	150	200	×	No..	2	....
W. P. McCarty	Chalk Mountain, 3½ miles southeast of.	150	120	......	....	No..	2	....
L. B. Howard	Chalk Mountain, 100 yards from.	177	170	......	....	No..	1	....

EASTLAND COUNTY.

Only the southern half of Eastland County lies within the Cretaceous area, and in this the conditions for securing artesian water are not favorable.

Costly artesian experiments have been made in the Carboniferous rocks of this county at Eastland and Cisco. At Cisco a well was bored 1,680 feet. (See fig. 52.) Salt water rose within 25 feet of the top, and the work was discontinued; it cost between $3,500 and $4,000. Altitude at Cisco is 1,600 feet. The strata were all of the Carboniferous.

At Eastland, according to Roessler, a well was bored 500 feet and discontinued. A second well with 6-inch bore secured salt water at 1,300 feet, but there was no flow. The two wells were bored in 1882 and cost the owner $3,500.

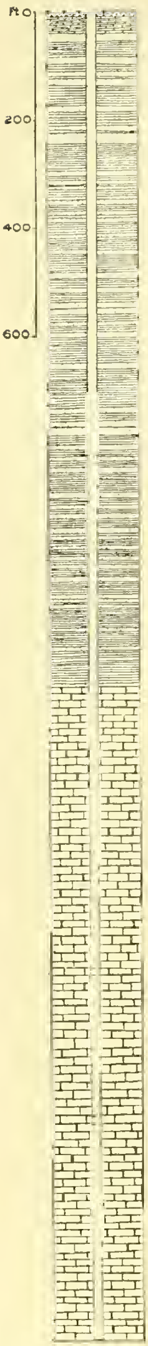


FIG. 52.—Well hole at Cisco, Texas. (See Section No. 51.)

SECTION No. 54.—SECTION OF ARTESIAN WELL LOCATED ON HILL 125 FEET ABOVE TOWN OF CISCO, EASTLAND COUNTY, TEXAS.

(See fig. 52.)

Stratum.	Thickness.	Depth.
	Feet.	*Feet.*
4. Conglomerate in situ; thin eroded stratum	10	10
3. Blue limestone in beds with crinoids; thin stratum	30	40
2. Blue and red argillaceous clays, here called soapstone; slightly arenaceous	1,160	1,200
1. Hard blue limestone in which artesian well drill was working	200	1,400

With the possible exception of the first 10 feet all of this section consists of Carboniferous strata.

COMANCHE COUNTY.

Comanche County has an area of 954 square miles and consists of a greatly dissected remnant of the Lampasas Cut Plain, as found in a range of buttes and mesas extending through the county, out of which have been eroded the wide and deeply incised valleys of the Leon drainage. The area of the county is about one-half divided between upland calcareous prairie and the sandy soils of the Western Cross Timbers and Carboniferous formations, which are found in the lower slopes and valleys. The youngest rock is the Edwards limestone, which caps the Cut Plain buttes, and the oldest rocks are the Carboniferous formations, which are found in the valleys of the Leon and its tributaries, in the northern half of the county. (See fig. 23.)

The conditions for procuring artesian waters in this county are almost entirely unfavorable, owing to the fact that the water-bearing formations either outcrop at the surface or, where embedded, are without sufficient head to raise the water to the surface. Hundreds of ordinary wells are found in the county, however, which are mostly supplied from the lowest strata of the Trinity division. Such is the case with all the wells in the county seat.

BROWN COUNTY.

Brown County presents no favorable conditions for procuring artesian waters from the Cretaceous strata. As shown upon the geological map, the Trinity formation outcrops across the eastern part of the county, but all the county overlying it in the eastern half is at a much higher altitude than this outcrop.

Numerous drill holes (in some instances 1,100 feet or more in depth) have been sunk in the Carboniferous rocks near Brownwood in search of oil. The water from these wells does not flow, and is usually salty and unfit for domestic use.

MILLS COUNTY.

Mills County, with an area of 696 square miles, lies about half within the western border of the Lampasas Cut Plain and half within the Paleozoic basin of the Colorado River. The parting between these different types of topography runs in a northwest-southeast direction. The eastern half of the county, within the Lampasas Cut Plain, is high, varying in altitude from 1,400 to 1,700 feet. This portion is underlain by the Trinity reservoir, which outcrops along the parting line between the types of country mentioned. The country beneath which it is embedded is higher in altitude than the outcrop, however, and hence flowing wells would be impossible. The western half of the county is underlain by the Paleozoic formations and is unpropitious for artesian wells.

Good nonflowing artesian wells are obtained in places, however. H. Avery states that his well is located 1½ miles east of Antelope Gap, and is 236 feet deep. A windmill is used to raise the water. In drilling the well lime rock, blue clay, hard red rock, gray rock, white sand and gravel, and plenty of water were encountered.

George W. Jackson states that his well is located 3 miles east of Goldthwaite and is 104 feet deep. It is nonflowing. The section of the well is as follows:

Section No. 55.—Section of well of G. W. Jackson, 3 miles east of Goldthwaite, Mills County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
Black soil	8 or 10	10
Chalky clay	10	20
Blue marl	80	100
Pack sand with water	4	104

J. R. Graves reports that his well is located 1 mile from Center City, and is 245 feet deep; depth of first water, 85 feet. It is nonflowing, the water rising 10 feet above the level at which it was reached. The well furnishes 2,000 gallons of soft water daily. He states that some of the wells in this section are inexhaustible.

HAMILTON COUNTY.

Hamilton County (area 849 square miles) is situated near the western border of the Lampasas Cut Plain. It consists of high prairie land, mostly above 1,000 feet, except in the extreme northeastern corner, where the Bosque River has cut a valley down to 900 feet. The highest point, according to the topographic map of the United States Geological Survey, has an elevation of about 1,600 feet. Therefore all of the county except in the incised valley of the Bosque near Hico lies above the height to which artesian waters will rise.

The county is underlain by all the water-bearing formations from the basal Trinity to the Paluxy, inclusive. They are available for deep nonflowing wells at depths varying with the altitude of the surface and the dip of the formation, as shown upon the geological map and cross sections.

Although flowing wells are probably not obtainable in this county, the Paluxy and Trinity reservoirs at shallow depths furnish good supplies of water.

The postmaster at Fairy states that drilled wells run from 80 to 400 feet in depth. The postmaster at Hico reports that bored wells are 100 to 250 feet in depth, with fine cold water in the deeper wells. The postmaster at Indian Gap says that in that locality the wells are nearly all drilled, and are from 75 to 250 feet deep; nearly everyone has a windmill. The postmaster at Pottsville says that the average depth is 150 to 300 feet. He had one drilled 305 feet but did not get any water.

R. M. Brandon, postmaster at Lancing, says: "There are no flowing artesian wells in this neighborhood. We all have drilled wells; on the high prairie they run from 70 to 100 feet deep; in the valleys from 150 to 200 feet, with fine water."

T. C. Pierson, who has a well 166 feet deep $2\frac{1}{2}$ miles from Lancing, reports that within 3 miles of his place there are three wells ranging in depth from 156 to 165 feet.

Patrick Kavanaugh, of Fairy, reports a well drilled by him 2 miles east of Fairy, and says it is located on a range of hills about 100 feet above the surrounding country. The water is obtained from a rock full of small holes, which allow the water to run through it. This rock is generally called honeycomb rock in this section.

At Lanham there are two wells, one bored 470 feet and another 500 feet; in both a layer of material was encountered that made it impossible to proceed with the work, and it was abandoned.

S. W. Kilpatrick has a well 234 feet deep $1\frac{1}{2}$ miles southwest from Hico, in which the following material was penetrated.

SECTION NO. 56.—SECTION OF WELL OF S. W. KILPATRICK, 1½ MILES SOUTHWEST FROM HICO, HAMILTON COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
Black soil	2	2
Yellow clay and gravel	16	18
Alternate layers of soft and hard blue rock	182	200
Pack sand	18	218
Sand and lignite	6	224
Soapstone	4	228
Pack sand	6	234

C. R. Warren, well driller, reports a well drilled by him 3½ miles northeast of Hamilton, in which he penetrated very hard lime rock 180 feet and sand rock 50 feet.

J. N. Stuart owns a well one-half mile west of Ondee. He says: "The strata consist almost entirely of blue rock to the pack sand, in which water was found. The well is 140 feet deep and does not flow."

A. F. Rainwater, who has a well 124 feet deep one-half mile east of Ondee, states that the rock passed through was blue limestone and marl until a depth of 80 feet was reached; the remainder was pack sand; the first supply of water (at 98 feet) is not very copious; the second is decidedly so. He also says that this part of the country is being well supplied with drilled wells.

G. W. Lloyd, who has a well 105 feet deep about 1½ miles southeast of Ondee, says:

The description of my well will apply to two wells on my place about a mile apart, and, in fact, to all wells in the neighborhood [Leon Valley], the only difference being in altitude of the place where the well is bored. We first pass through a stratum of earth, then clay, then, at an average depth of about 40 feet, a layer of gravel 5 or 6 feet; then blue lime rock, sand rock, and, finally, pack sand, in which we find an abundance of water. The water usually does not rise much above where we first strike it, so in order to get plenty we drill down far enough below to give us a sufficient space for plenty of water. My impression is that we live 12 or 15 miles above the flowing district on the Leon; at any rate at about that distance down the country I know of several flowing wells.

Schedule of wells in Hamilton County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water. *a*	Flow. *a*	Quality. *b*
		Feet.	*Feet.*	*Feet.*			
S. W. Kilpatrick	Hico, 1½ miles southwest of	234	218	228	80	No.	1
J. H. Penny	Fairy, 6 miles southeast of	155	136	......	......	No.	1
Do	Fairy, 2 miles west of	129	34	......	10±	No.	1, 8
M. M. McGirk	Shive, 5 miles southwest of	133	120	......	×	No.	2
J. H. Penny	Shive, 4 miles east of	264	100	155	90	No.	1
A. H. Williams	Hamilton, 7½ miles northeast of	138	100	......	......	×	1
C. R. Warren	Hamilton, 3½ miles northeast of	230	......	......	40	No.	2, 7
G. Shear	Ondee, 1 mile south of	98	70	......	......	No.	1
J. A. Shaffer	Ondee, ¼ mile northwest of	205	175	......	×	No.	1
J. N. Stuart	Ondee, ½ mile west of	140	100	......	......	No.	1
J. D. Couch	Ondee post-office, 100 feet east of	132	98	......	×	No.	2
G. W. Lloyd	Ondee, 1 mile west of	105	65	......	......	No.	1
Do	Ondee, 1½ miles southeast of	105	65	......	......	No.	1
A. F. Rainwater	Ondee, ½ mile east of	124	98	......	25	No.	1
A. L. Shipman	Ondee, 1 mile east of	146	120	......	×	No.	1
W. C. Burks	Pottsville	240	......	......	40	No.	7
W. McPherson	Pottsville, ¼ mile north of	202	195	......	25	No.	2
T. C. Pierson	Lanham, 2½ miles north of	166	163	......	152 ×	No.	1
Do	Lanham, 2 wells	470 500	....	....	....	No. No.	....
J. P. Major	Lanham	118	90	......	......	No.	......
W. B. Cornelius	Lanham, ¾ mile southeast of	164	......	......	......	No.	7
H. J. Burleson	Lanham, 5 miles south of	165	156	......	......	×	1

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

LAMPASAS COUNTY.

Lampasas County has an area of 723 square miles and is topographically dominated by the high remnantal summits of the Lampasas Cut Plain. These summits form two irregular chains of flat-topped mesas extending northwest and southeast through the county. One of these follows the eastern boundary. The other, constituting the western escarpment of the Cretaceous area, passes through the western third of the county and overlooks a wide belt of lowland leading down to the valley of the Colorado on the west. (See topographic map of Lampasas quadrangle published by United States Geological Survey.)

This plateau is extensively dissected (see Pl. XIII) by streams flowing eastward into the Lampasas River, or westward down the escarpment to the Colorado.

The northern and eastern portions of the county are underlain by the basement sands of the Lower Cretaceous, but these are somewhat attenuated, and they are so much dissected by erosion that they have not yet, so far as reported, yielded any flowing artesian wells, although the valley of the Lampasas, in the northeastern portion of the county, seems propitious for them.

The geological features consist of the subhorizontal Lower Cretaceous formations (Fredericksburg and Trinity divisions) resting unconformably upon Carboniferous limestones and sandstones, which are exposed along the western third of the county and in a peculiar inlier within the Cretaceous area just south of Lampasas.

An exceptional and unique hydrographic feature found in this county is a group of copious springs which break out from the Paleozoic rocks at Lampasas. They discharge a great volume of water, and have long been noted in Texas for their hygienic properties. Hot-water springs are also reported to occur in the bends of the Colorado below Lampasas, at the southwest corner of the county and at the southeast corner of San Saba County.

BURNET COUNTY.

Burnet County has an area of 992 square miles. The high crest of the western border scarp of the Lampasas Cut Plain runs from northwest to southeast across this county. To the west of this line is the low valley of the Colorado River imposed upon the older Paleozoic rocks. The eastern half of the county consists of high divides of the Lampasas Cut Plain rising to altitudes of 1,600 feet, sloping to the eastward and incised by the headwater drainage of the Lampasas and San Gabriel rivers, the former cutting down to 1,300 feet in the extreme northeast corner.

The Cretaceous formations are of the Fredericksburg and Trinity divisions, with the accompanying artesian reservoirs. All of the surface is too high above the catchment area to permit of flowing artesian wells except at Oakalla, in the extreme northeastern corner, where a flowing well has been obtained. This well is only 96 feet deep. We have two reports from this locality, but it is uncertain whether they represent one or two wells. Mr. J. M. Kincaid reports a well 96 feet deep ending in blue limestone, while Mr. C. R. Warren, well driller, reports a flowing well 1½ miles north of Oakalla 82 feet deep, terminating in granite. It is evident that less than 100 feet of the basal portion of the Lower Cretaceous strata are penetrated at this locality and that the water here rises to a higher altitude than at any other place within the Cretaceous area.

COUNTIES OF THE MAIN ARTESIAN BELT.

For convenience of discussion we have grouped together certain counties constituting a belt of country extending north and south through the center of the Black and Grand Prairie regions under the head of the main artesian belt. This group includes the counties of Cooke, Denton, Tarrant, Dallas, Johnson, Somervell, Coryell, Ellis, Hill, Bosque, McLennan, Bell, and Williamson.

In these counties the most favorable conditions for artesian waters exist, and the most extensive development has taken place.

The artesian conditions prevailing in these counties, while possessing some features in common, are not entirely identical. In fact, they may be arranged in two major geographical subgroups presenting analogous conditions, each of which may again be subdivided. These groups may be enumerated as follows: (a) Counties situated south of the Brazos River: Somervell, Coryell, Bosque, McLennan, Bell, Williamson, and Travis; (b) counties north of the Brazos: Cooke, Denton, Tarrant, Dallas, Ellis, and Hill. The first group mentioned is principally distinguished by the absence of the Woodbine formation and the deterioration southward of the Paluxy formation and the gradual appearance and replacement of the latter by the strata of the Fredericksburg division and Glen Rose formation.

The second group of counties lying north of the Brazos is distinguished by the occurrence of the Woodbine, Paluxy, and the Antlers (united Trinity-Paluxy) formations as sources of artesian supply.

Counties South of the Brazos.

Of this group of counties Somervell, Coryell, and Bosque form a subclass by themselves, lying entirely within the area of the Lampasas Cut Plain. The remaining counties mentioned, Travis, Williamson, Bell, and McLennan, lie along a north-south belt, through the center of which extends the Balcones fault zone. This fault zone makes a serious break in the position of the strata, and on each side of it the artesian depths and conditions are quite different.

The western portion of the Lampasas Cut Plain, as has been explained, is deeply incised at various intervals into deep valleys, often 500 feet below the remnantal flat-topped divides and mesas of the plateau so often seen standing in Hood, Erath, Comanche, Bosque, Hamilton, Coryell, and Lampasas counties. These thinly settled divides are usually capped by the hard, sterile Edwards limestone, while the wide valleys between them are occupied by the fertile soils of the Lower Cretaceous formations or rich stream alluvium, upon which is settled most of the agricultural population of the region. In some of these valleys, such as those of the Paluxy in Somervell County, the Trinity in Parker, and the Cowhouse in Lampasas, are numerous shallow flowing artesian wells which have been inexpensively drilled by the farmers. (See figs. 12 and 48.)

Shallow wells of this character have been most extensively developed in the valley of Paluxy River from above Bluffdale, Erath County, to where the Paluxy empties into the Brazos. The total area of the

Paluxy Valley from Bluffdale to its mouth and of the Squaw Creek Valley, where this series of wells is obtainable, is over 200 square miles.

SOMERVELL COUNTY.

Somervell County is the smallest county in Texas, its area being about 200 square miles, or less than one-fourth that of the average county in the State. Notwithstanding this it is perhaps better supplied with underground water than any other county.[1]

This county is situated within the heart of the Lampasas Cut Plain, the mesa-capped summit of which rises to 1,300 feet in the southern corner of the county. Below the level of this plain are the deeply cut valleys of the Paluxy River, running from west to east, and of the Brazos River, in the eastern portion of the county. (See fig. 12.) The former stream has an altitude ranging from 775 feet upon the extreme west to about 575 feet at its mouth. The altitude of the Brazos is about 650 feet at the northern edge of the county and 560 feet at the southeastern corner. These stream valleys are incised from 600 to 700 feet below the summit of the cut plain and are bordered by wide and fertile alluvial terraces upon which is settled the principal agricultural population. The uplands are not adequately shown upon the topographic map.

Fig. 53.—Artesian map of Somervell County, Texas. Shaded portion indicates area where flowing wells should be obtained from the Basement Trinity reservoir; ●, flowing wells from Trinity reservoir; figures indicate depth of wells in feet.

The county is underlain by the Paluxy and Trinity formations. The Paluxy formation is situated near the top of the "mountains," as the remnantal mesa summits of the cut plain are called by the people, forming a crown of elevated sandy forested land just below the chalk capped summits. This formation is cut by erosion upon every side and hence has no artesian value in this county.

The Trinity reservoirs extend beneath the whole area of the county and are available 750 feet beneath the high summits of the plateau and 30 feet below the bottom of the incised valleys, as at Glen Rose. These waters will not rise, however, above an altitude of 750 feet, and therefore the area of flowing wells is limited to the slopes and alluvial terraces of the Brazos and Paluxy and a few of the tributary creeks. (See fig. 53.)

The water from the shallower wells is usually charged with mineral matter. As a rule this mineral water can be cased off and a better flow obtained by going to the deeper and purer sands.

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[1]A topographic map of Somervell County will be found on the Granbury atlas sheet of the United States Geological Survey.

GEOLOGY.

The geology of the county is very simple. The rocks consist of a series of formations ranging from the Edwards limestone, which caps the summit of the plateau, to the upper or Bluffdale sands of the Trinity division, which are exposed along the Paluxy River, in the western portion of the county. The details of these formations are fully described under the head of the Comanche Peak section. (See fig. 12.)

DEVELOPMENT.

Somervell County has so many flowing artesian wells that it has been impossible to obtain a correct enumeration of them. There are nearly 200 flowing wells, varying in depth from 30 to 300 feet, all of which begin in the various horizons of the Glen Rose formation below the Paluxy sands and reach into the Trinity reservoirs. They occur upon nearly every farm along the valleys of the Paluxy and Brazos, and each household in Glen Rose, the county seat, has one or more of them. The number of wells in Glen Rose alone has been reported as high as 200, but according to Dr. Frank Burns, of the Geological Survey, who attempted to obtain exact information on this subject, there are about 70 flowing wells in this place. They are used for domestic purposes, for watering stock, and in many cases for irrigation. They vary in flow from 10 to 300 gallons per minute, the smaller flows usually being from small bores and wells which do not reach the main supply.

Following is a list of the artesian wells reported:

Schedule of wells in Somervell County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Flow.*b*	Decrease.*b*	Quality.*a*	Irrigation.*b*
		Feet.	*Feet.*	*Feet.*				
A. M. Wilbanks (reports).	Glen Rose, 5 miles north of	340	300	320	×	×	1	....
John W. Campbell	Glen Rose	173	56	163	×	......	4	....
W. M. Rivers	Glen Rose, 1 mile east of	162½	.....	.....	×	......	1	×
P. L. Embree	Glen Rose, 2 miles east of	337	150	160 190 250	×	......	......	×
A. M. Wilbanks (reports).	Glen Rose, 6 miles east of	330	305	......	×	×	Coal 1	....
Geo. Booker	Glen Rose, 1¼ miles south of	216	40	70 170	×	......	1	×
A. E. Arbuckle	Glen Rose	333	50	......	×	×	1	×
Geo. Abel	....do	260	200	......	×	......	......	....
Wm. Lanham	Glen Rose, 6 miles west of	......	......	......	×	......	......	....
O. M. Addison	Eulogy, 3 miles north of	297	40	152	×	......	1	×
W. Walker	Eulogy, 2 miles north of	272	105	265	×	......	1	×
C. F. Bradshaw	Nemo, 3½ miles west of	190	60	120	×	......	1	×
John McVicker	Nemo, 3 miles south of	336	150	180	×	......	1	....

a 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

b × = yes.

In the valleys of the Brazos and Paluxy the artesian wells begin at the surface very near the base of the Glen Rose formation. In the village of Glen Rose it is only 30 feet to the uppermost of the Trinity reservoir (t^3). The Paluxy River flows over this formation in the western portion of the county.

The following notes upon the artesian wells of the county will show their general character. At Paluxy, in Erath County, just west of the Somervell line, and down that stream for a few miles, artesian wells are obtained from the lower or t^1 reservoir at depths of only a little over 100 feet. These wells begin in the t^3 sand, below which they penetrate about 67 feet of thin limestone. Between the county line and Glen Rose are many excellent wells upon the various farms. Mr. William Lanham, who lives 6 miles west of Glen Rose, has an 8-inch well which discharges about 400,000 gallons of freestone water a day.

The following log of the well of Mr. John W. Campbell, at the hotel in the village of Glen Rose, as reported by Dr. Frank Burns, is typical:

Section No. 57.—Section of well of John W. Campbell at hotel in village of Glen Rose, Somervell County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
4. White and blue limestone	56	56
3. Pack sand (t^3)	40	96
2. Blue marls in thin layers	67	163
1. Pack sand (t^2)	10	173

It is remarkable that no accurate log of any of the wells drilled in this vicinity has been kept, and it is therefore impossible to state the exact nature of the water-bearing formations which are here so near the surface. It is not positively known how many reservoirs have been penetrated beneath the village, how deep was the lowest one reached, or whether the Basement sands have been completely pierced to the Paleozoic floor. Here, within convenient reach, at depths of less than 300 feet, could be ascertained the stratigraphy of the reservoirs which in the region lying to the east have such great importance and concerning which accurate knowledge is so desirable.

Glen Rose is uniquely situated in regard to artesian water, being in such a position that it is practically impossible to have a well there without its being an artesian one. Paluxy Creek is cutting down into the Caprotina limestone bed of the Glen Rose formation. Only a part of it, less than 50 feet thick, has to be cut through and a flowing well is obtained from the first reservoir below. The result is that Glen Rose has many flowing wells.

Dr. Frank Burns gives the following report concerning the wells at Glen Rose:

There are in the village of Glen Rose, within a radius of half a mile of the court-house, 70 artificial artesian wells, as well as several natural artesian springs of both mineral and other water that is forced up through crevices of the limestone from the water-bearing "Trinity sands" below. The wells are ever flowing, and have free-stone, chalybeate, and white and black sulphur water, which is pleasant and cool, owing to the shallow depth of the wells, making the town of Glen Rose a great watering place. Besides the wells in the town there are numbers of others in the Squaw Creek and Brazos valleys and up the Paluxy Valley 11 miles to Paluxy post-office. One remarkable fact is that after you get away from Glen Rose a short distance the wells are all of good, sweet, cool freestone water.

One of the first wells drilled at Glen Rose was put down by Mr. John W. Campbell on a bench just 20 feet above the bed of the Paluxy River. At the depth of 56 feet he struck flowing water (a stream of white sulphur). As this well was in his yard at the hotel, it created a great deal of excitement, and everybody "put down wells," as they call it out there. His well soon failed and he had to go deeper, as the first thin bed of sand was exhausted by the constant flow. After two or three more stoppages and deeper borings each time, he struck a permanent flow in a bed of sand at a depth of 163 feet. He then bored 10 feet farther and stopped with a permanent flow of white sulphur water.

This well is given as a typical one, but there are others in the valley only a short distance away that flow permanently at 125 feet, while the wells up the valley are from 70 to 130 feet.

There are deeper wells than the one above described. Mr. George Abel's well at Glen Rose is reported[1] to be 260 feet deep and flows 40 gallons a minute. The water is soft and clear, with a slightly chalky taste. Unfortunately the exact location of this well relative to Mr. Campbell's can not be given or its water reservoirs correlated. If it is in the valley, as may be presumed, the water comes from a lower reservoir than Mr. Campbell's well.

The following is a section of Mr. Abel's well as given by Mr. Roesler:

SECTION No. 58.—SECTION OF WELL OF MR. GEORGE ABEL IN THE VILLAGE OF GLEN ROSE, SOMERVELL COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Sand soil	2	2
3. Impervious yellow clay	8	10
2. Rock and marl	240	250
1. Coarse sand	10	260

[1] See report of F. E. Roesler in a publication of the U. S. Department of Agriculture entitled A Report on the Preliminary Investigation to Determine the Proper Location of Artesian Wells within the Area of the Ninety-seventh Meridian and East of the Foothills of the Rocky Mountains; Ex. Doc. No. 222, Fifty-first Congress, first session, Washington, 1890.

Eastward, down the valley of the Paluxy, the wells gradually eepen and the thick stratum of Glen Rose limestone which forms the bluff of the Paluxy in the town of Glen Rose and overcaps the t^3 reservoir becomes embedded as the creek is descended. Mr. Winfield M. Rivers states that his well is nearly 1 mile east of Glen Rose. It is a flowing well 162½ feet deep, furnishing about 300 gallons an hour from the upper or t^2 reservoir. Mr. Rivers says: "I am unable to give all the strata passed through about ten years ago, but remember that the usual top strata were gone through until the hard stratum of limestone above mentioned was reached. As soon as this was drilled through, the depth being 162½ feet, a column of water jetted from the orifice to a height of 10 feet above the surface, and I was the proud owner of a flowing sulphur-water artesian well, many thinking the water superior to the White Sulphur Springs of Virginia."

Mr. A. M. Wilbanks, well driller, reports that about 6 miles east of Glen Rose the depth of the first water (t^2) is from 305 to 330 feet. In drilling this well he passed through about 10 feet of lignite in the sands.

Still eastward the strata continue to deepen. The t^2 reservoir is nearly 300 feet deep at the Addison well, on the west side of the Brazos River, near the Bosque County line. The following section of this well was reported by F. E. Roesler:[1]

SECTION NO. 59.—SECTION OF ADDISON WELL, WEST SIDE OF BRAZOS RIVER, NEAR BOSQUE COUNTY LINE.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Sandy loam	1	1
3. Coarse gravel	20	21
2. Blue limestone	266	287
1. Sand	10	297

The slope of the valley rises very rapidly in bluffs and terraces as one leaves the alluvial bottom of the Paluxy. Sufficient experiments have not been made to ascertain how high the waters will flow. In ascending the valley of Squaw Creek there is a flowing well of sulphur water at an altitude of about 720 feet, or over 120 feet above Glen Rose. In this county 750 feet may be safely stated as the altitude to which water will rise from the basement Trinity reservoir. Five miles north of Glen Rose a well was drilled many years ago at an altitude of about 940 feet. The water rose to within 200 feet of the surface, or

[1] Report of Department of Agriculture, Ex. Doc. No. 222, Fifty-first Congress, first session, page 267, Washington, 1890.

to an altitude of 740 feet. The geologic horizon of the surface where this well was drilled is that of the middle portion or Glen Rose beds about 100 feet below the Paluxy sands.

USES OF WATER.

The artesian waters of Somervell County are used for domestic and agricultural purposes, and the sulphur waters are considered of great medicinal value and attract many visitors to the picturesque village of Glen Rose. Most of the waters are allowed to go to waste, as no check is placed upon the overflow, and the waste runs off into the river.

In the Brazos Valley, east of where the Paluxy enters it, the wells of Messrs. Addison, Walker, Bradshaw, and McVicker, in the southeastern corner of the county, as shown in the table on page 475, reached three reservoirs of Trinity water. These wells reached the lower reservoir at a maximum depth of about 350 feet in the stream valley. Continuing down the Brazos similar shallow wells, with gradually increasing depth, are found in northeastern Bosque, southeastern Johnson, and western Hill counties, as elsewhere described.

Irrigation with these shallow wells has been demonstrated by farmers of the Paluxy Valley to be both practicable, inexpensive, and profitable.

In a former report the writer has shown that the region is subject to serious droughts. The average yield of cotton is small, running from one-quarter to one-half a bale per acre. Artesian water is not utilized for irrigation to a large degree, because the methods and benefits of irrigation are not understood. Farmers, however, have obtained good results from irrigation. Mr. William Lanham, who lives 6 miles west of Glen Rose, has an 8-inch well which discharges about 400,000 gallons of freestone water a day. With this he abundantly irrigates 30 acres of land, utilizing the water only a few days in the year. Although he came to Texas from more humid regions and had never before seen irrigation his success has been great. He has confined his efforts to the least profitable irrigable crops—corn, cotton, and Louisiana sugar cane—and has never manured or otherwise fertilized his land. The following table shows his experience:

Products.	Average yield without irrigation.	Yield of same land irrigated.		
		1888.	1889.	1890.
Corn .... bushels..	25	75	66	40
Seed cotton .... pounds..	200 to 500	2,200	3,000	4,000
Molasses of Louisiana or Ribbon cane, gallons	....	....	350	350

Several other experiments in irrigation in the same neighborhood have met with equally successful results. No one has irrigated alfalfa, clover, small grains, or small fruits, which are most susceptible to profitable irrigation. At Paluxy, 10 miles west of Glen Rose, were two irrigated farms upon which cotton was growing in a crop promising to yield two bales to the acre.

Should the people of Somervell County desire to utilize their lands for a more intensive agriculture than that now carried on, the artesian waters would be of inestimable value in growing vegetables and fruits, which are now shipped into Texas in immense quantities from Maryland and California.

FIG. 54.—Artesian map of Bosque County, Texas. Shaded portion indicates area where flowing wells can be obtained from the Basement Trinity reservoir. ●, flowing wells from Trinity reservoir; ○, nonflowing wells from Trinity reservoir; figures indicate depths of wells in feet.

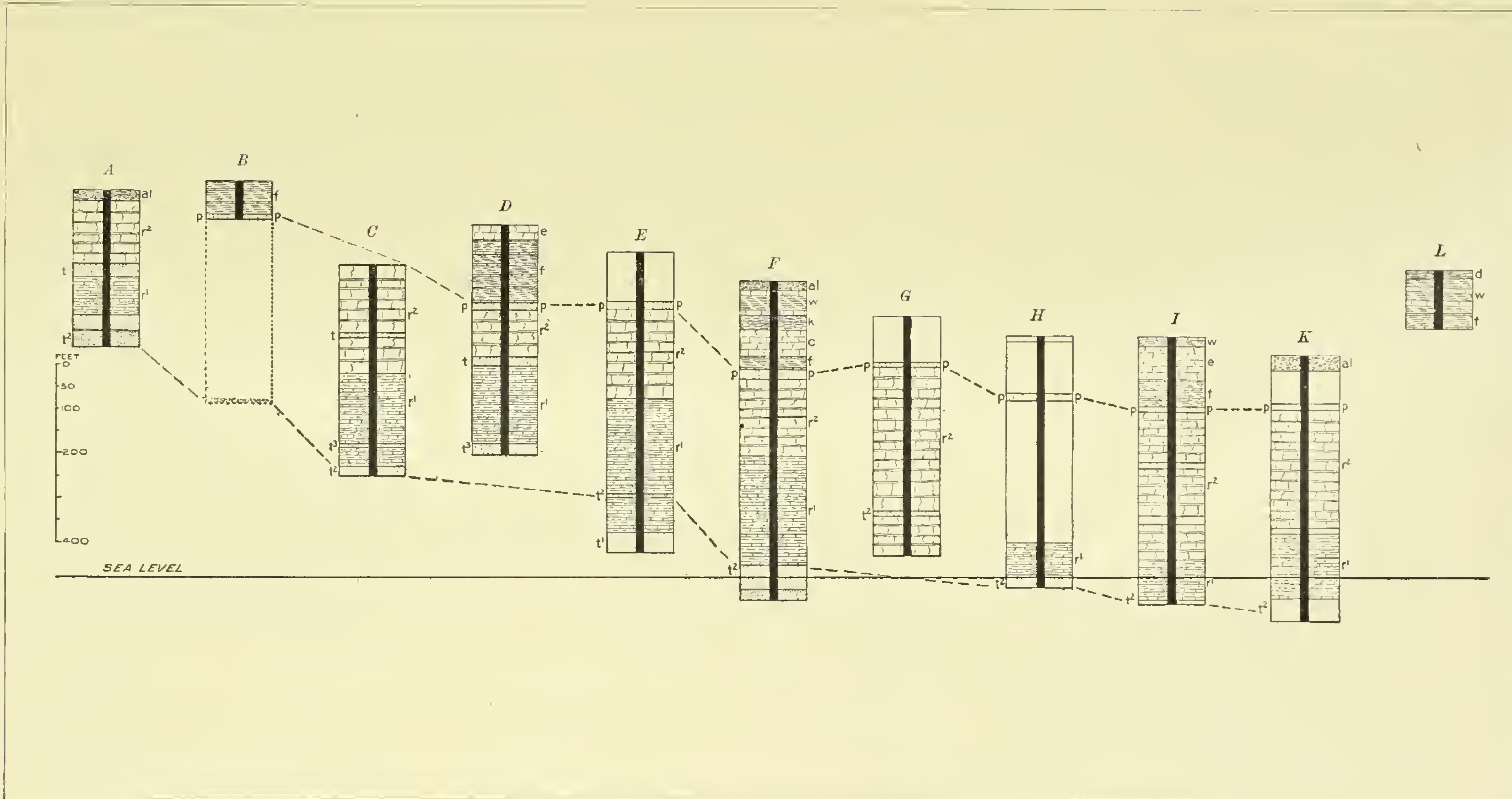
BOSQUE COUNTY.

Bosque County has an approximate area of 980 square miles, and lies entirely within the Grand Prairie region. The relief of the upland is a dissected plain, gently sloping from north of west to south of east, the highest altitude of which is about 1,250 feet in the western portion of the county. This plain slopes eastward at an inclination of from 15 to 20 feet per mile, so far as its surface can be measured on the remnantal divides. It is deeply dissected by the drainage valleys of the Brazos and Bosque rivers and their tributaries. The valley of the Brazos River, which is the eastern boundary of the county, is cut down to depths varying from 575 feet at the northeast corner of the county to about 400 feet at the southeast corner, or to an average depth of 450 feet beneath the upland plain as preserved in the divide of the Brazos and Bosque rivers. The slopes of this valley extend back from the river about 10 miles, and are drained by many small streams, such as Rock, Grass, Plowman, Mesquite, Cedron, Rocky, Little Rocky, Coon, and Childress creeks. The remaining and greater portion of the county is drained by the Bosque and its tributaries. Bosque River flows from northwest to southeast, parallel to the Brazos; its tributaries, such as Duffau, Spring, Meridian, and Neil creeks, flow from west to east. The Bosque River falls from 1,000 feet on the northwest border of the county to about 525 feet where it reaches the southeastern boundary, and is incised to an average depth of 300 feet below the summit plain. The principal east-west tributaries of the Bosque, such as Meridian and Neil creeks, are also incised to a similar depth.

Inasmuch as the principal agricultural interests are situated in these valleys, the different districts of the county are designated by their names, such as the Brazos, Bosque, and Neil Creek valleys, etc. In general, however, the county may be divided into three broad topographic districts. The first of these is the deep indentation of the Brazos Valley on the east. Between this valley and a point near where Bosque River enters the county, near Valley Mills, the upland prairie, extending close to the river, is of the Fort Worth type, consisting of gently rolling black lands. West of the Bosque the upland prairie is of the Lampasas Cut Plain type, consisting of flat-topped mesa divides composed of the hard Edwards limestone with rocky slopes leading down to the streamways, along which may be found a variety of soils upon the diverse belts of successively outcropping geological formations.

GEOLOGY.

The Cretaceous formations constitute all the surface rocks of the county with the exception of the alluvial deposits which veneer the broad, flat terraces in the streamways. The formations exposed in the county in descending series from east to west are those of the Washita and Fredericksburg divisions, and the Glen Rose formation of the Trinity division. West of the Santa Fe Railway and north of Meridian Creek, in the district of the Lampasas Cut Plain, the high divides are all composed of the Edwards limestone, beneath which the Walnut, Paluxy, and Glen Rose formations constitute slopes leading down to the Brazos on the north and the Bosque River in the central portion. The Brazos Valley, in the extreme northern portion of



ARTESIAN WELLS OF BOSQUE COUNTY, TEXAS.

A, Iredell; *B*, Walnut Springs; *C*, 1 mile north of Eulogy; *D*, Meridian; *E*, Morgan; *F*, Clifton; *G*, Valley Mills; *H*, Fowler; *I*, Kopperl; *K*, 1 mile east of Cyrus; *L*, 1 mile north of Cyrus.

the county, and the Bosque River and Duffau Creek in the portion west of Iredell, are underlain by the Glen Rose formation. The valley of Steele Creek, below Walnut, and the valleys of the Bosque and the East Bosque from the junction of the East and West forks almost to the southern border of the county, are underlain by the Walnut formation. The high divide of the Brazos, the Bosque, and the portion of the county south of Meridian Creek show the Fort Worth limestone and other formations of the Washita division and the Edwards limestone at the surface. The Paluxy sands outcrop in an upland forest area below the summits of the slopes of the Chalk Mountain divide, in the northern portion of the county, and on the Johnson Peak divide south of Iredell. These sands become embedded near the junction of the Bosque and East Bosque rivers, and near Kimball, on the Brazos. (See fig. 48.)

WATER CONDITIONS.

The chief and most available artesian reservoirs are those of the Trinity division. These are embedded beneath the whole county, and are the source of many artesian wells. Near Iredell (see fig. 48), in the western portion of the county, the t^2 reservoir is 550 feet above sea level and deepens gently to the southeastward across the county at an average rate of 17.7 feet per mile. Near Cyrus and Greenock this reservoir is practically at or less than 50 feet below sea level. At Meridian this reservoir is 260 feet below sea level, and has an average inclination of 21.5 feet per mile between Iredell and that point. Measured from the surface along the stream valleys tributary to the Bosque, this formation increases from 350 feet in depth at Iredell in the western portion to 850 feet at Valley Mills in the southeastern portion of the county, and to about 1,000 feet in the valley of the Brazos at the extreme eastern edge of the county. On the uplands these waters are correspondingly deeper. Flowing artesian wells are obtained in all the principal valleys of the county from the t^1 and t^2 reservoirs, principally the latter. These waters are used for supplying the farms, ranches, and small towns.

The Paluxy formation is embedded in continuous area in that portion of the county lying east of the Gulf, Colorado and Santa Fe Railway, which practically follows the Bosque River as far north as Morgan. This formation is exposed in the cutting of the Brazos Valley, in the northeastern portion of the county northwest of Fowler. The stratum is so thin and so charged with mineral water in this portion of the county that it is hardly worthy of further consideration.

The Paluxy formation also occurs beneath the remnantal summits of the Lampasas Cut Plain in the western portion of the county, outcropping on all sides along the slopes of these hills. Hence it does not present artesian conditions. In the southeast corner of the county, upon the headwaters of Willow and Childress creeks, certain shallow wells are reported which obtain their waters from what is termed a "rotten honeycombed limestone" in the Fredericksburg or Washita division. This occurrence, although of no artesian value in this county, is of interest, inasmuch as it indicates the first appearance, in going southward across the county, of water-bearing strata in the Fredericksburg division, which becomes of such importance in the more southern counties of Williamson and Travis, and in the Rio Grande Plain.

The Glen Rose formation, which constitutes the principal matrix between the Paluxy and t^2 reservoirs to be drilled through by the artesian wells in the county, consists largely of limestone and marly clays. While this formation no doubt increases in thickness from west to east, the writer has been unable to procure sufficient data to ascertain the amount of increase with exactness. (See fig. 55.) At Clifton the total thickness of the calcareous Glen Rose formation beneath the Paluxy sands and above the t^2 reservoir of the Trinity sands is about 420 feet. Except in the vicinity of Iredell this approximate thickness must be penetrated everywhere after passing the easily recognizable Paluxy sands before the best waters of the t^2 and t^1 reservoirs can be obtained.

AVAILABILITY.

Flowing wells from the t^2 reservoir can be obtained beneath about one-half the area of the county. Iredell, on the west, seems to be near the limit of altitude (881 feet) to which waters will rise. The water flows to the surface at Meridian (altitude 793 feet), Morgan (734 feet), Clifton (671 feet), and near Valley Mills (600 feet). In McLennan County, to the east, water rises at Crawford to an altitude of 700 feet. While it is a well-known fact that the altitude to which the waters will rise from a formation gradually decreases to the eastward, we may safely assume that flowing artesian wells may be obtained from the basement reservoir of the Trinity division anywhere in Bosque County at altitudes of less than 750 feet. The water actually rises to nearly 900 feet in the valleys of the Bosque River and Neil Creek, in the western portion of the county.

Upon the accompanying map, fig. 54, that portion of the county which lies below 800 feet in altitude, together with a small extension of country above this altitude up the Bosque River and Neil Creek to the 900-foot contour, is shaded to represent the area where artesian flows may probably be secured. The area where flowing wells may be obtained constitutes about one-half the total area of the county and lies principally within the stream valley slopes of the Brazos and Bosque drainage. The only uplands coming within this area of flowing wells are a small portion of the prairies in the southeastern corner of the county east of longitude 97° 30′. All the uplands to the west of that line, including most of the divides of the Brazos and Bosque, and comprising nearly one-half the county, lie above the altitude to which water will rise.

DEVELOPMENT.

Reports have been received from nearly seventy artesian wells in Bosque County, all of which, with a single exception, obtain their waters from the Trinity reservoirs, principally the t^2 reservoir, as enumerated in the following table:

Schedule of wells in Bosque County, Texas.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flowing well.*a*	Increase.*a*	Decrease.*a*	Quality.*b*	Used for irrigation.*a*
			Feet.	*Feet.*	*Feet.*	*Feet.*					
Pat Cavanaugh	Iredell, 5 miles north of		229	220		120	No.			1	
Do	do		96	35			No.				
J. C. Lane	Iredell		390	265	300 360	370	No.				×
J. C. Phillips	do		350	180	280		×			1	
J. L. Myers	Iredell post-office, 400 yards from.		390	220	340	200	No.			1	
Pat Cavanaugh	Iredell, 1 mile west of		280	135	250 275	125	No.			4 5 8	
Hutson & Bullard	Iredell, 2 miles northeast of		336	225	328		No.				
Pat Cavanaugh	Iredell, 5 miles south of		103	91			No.				
R. Phillips	Iredell, 6 miles south of		207	140		30±	No.			1	
L. H. Hebflin	Meridian, 7½ miles west of.		236	203			No.			1	
J. J. Walling	Meridian, 8 miles west of	800	258	220		16	No.				
T. J. Overton	Help, ½ mile northeast of		350			×	No.			7	
A. N. Moore	Help, 3 miles east of		228	202			No.			1	
G. W. May	Womack, ½ mile northeast of.		116	21			No.			2	
Dr. J. T. Glass	Womack, 1 mile north of		192	125		× 45	No.			2 7	
T. H. Wilson	Cranfills Gap, ¼ mile northwest of.		166	126		40 ×	No.			1	
S. B. Cranfill	Cranfills Gap, 2 miles north of.		220	110		×	No.			1	
H. J. Hansen (farm)	Cranfills Gap, 3 miles south of.		153	120		×	No.			1	×
C. R. Ellington	Cranfills Gap, 6 miles south of.		106	100		60	No.			1	
Jo. Walker	Eulogy, 2 miles west of		121½	70		×	No.			2	
J. R. Hall	Eulogy, ¼ mile west of		430	60	200		×			1	×
A. M. Wilbanks	Eulogy, 1 mile north of		475	425	450		×			1	×
A. L. Cotton	Eulogy, ¾ mile north of		460	45	400		×		×	4	×
Mrs. A. Womble	Eulogy, 3½ miles east of		385	100	200		×			1	×
Richard Archer	Kimball, 6 miles west of, and 6 miles east of Eulogy.		564	65	450		×			1	×
Tuttle & Smith	Morgan post-office, 10 feet north of.	722	675	100	550	×	No.			1	
Do	Morgan post-office, 10 feet south of.		603	50	425		×			1	×
A. M. Wilbanks	Morgan post-office, 15 feet south of.		619	550	600		×			1	×
J. L. White	Morgan, ¼ mile southeast of.		600	90	flow 520		×			1	×

a × = yes.

b 1, soft and portable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

Schedule of wells in Bosque County, Texas—Continued.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flowing well.	Increase.	Decrease.	Quality.	Used for irrigation.
			Feet.	*Feet.*	*Feet.*	*Feet.*					
A. M. Wilbanks	Morgan, 1 mile southeast of.	....	575	500	550	....	×	×	...	1	....
N. & F. Logan	Morgan, 5 miles east of	....	780	200	300	....	×	...		1	....
E. B. Cass	Valley Mills, 5 miles north of.	700	877	80	400, 860	....	×	...	...	1	....
Do	Valley Mills	592	805	200	600, 706	....	×	...	...	9	×
A. J. Blackwell	Valley Mills, 5 miles north of.	....	870	100	400	....	×	...	...	1	×
G. Smith	Cyrus post-office, 1 mile east of.	....	1,000	400	600	....	×	...	...	4, 8	...
W. C. Talbert	Greenock, 3 miles south of.	600	330	330	....	....	×	...	...	3, 4	...
C. O. Holen	Norse, 4 miles southwest of.	850	622	190	580, 605	....	No.	...	...	1	....
C. O. Bronstad	Norse, 4 miles north of	....	125	100	....	40, ×	No.	...	...	1	....
J. Olson	Norse, ½ mile east of	....	200	140 or 150	....		No.	...	...	1	....
J. J. Lumpkin	Meridian *a*	793	575	185	....	....	×	...	...	1	×
S. H. Lumpkin	Meridian	....	525	300	....	....	×	...	×	1	×
Tom Gandy	Meridian, 2 miles south of.	....	167	137	....	×	No.	...	...	1	....
Tom Frazier	Kopperl, 3¼ miles west of	....	609	450	515	....	×	...	...	1	×
M. S. Greer	Kopperl, 900 yards northeast of post-office.	....	625	540	620	....	×	...	...	1	×
G. T. Russell	Kopperl	....	400	87	100	....	×	...	...	1, 4	...
G. D. Greer	Kopperl, ¾ of mile east of	....	600	68	....	....	×	...	...	1	....
H. A. Fitzhugh	Meridian, 10 miles east of.	....	850	400	775	....	×	...	...	1	....
Do	Meridian, 12½ miles east of.	....	875	400	775	....	No.	...	...	1	....
Neal Nelson	Clifton, 3 miles west of	....	612	130	550	....	×	...	...	1	×
O. H. Dahl	Clifton, 1 mile west of	....	687	200	625	....	×	...	...	1	....
....	....do	....	715	220	625	....	×	×	...	1	....
N. J. Nelson	Clifton, ¾ mile west-southwest of.	....	700	220	650, 675	....	×	...	...	1	×
Kell & Gibbs	Clifton, 3 miles north of	....	662	182	610	....	×	...	...	1	×
E. Johnson (reports)	Clifton (2 wells)	....	650	....	....	....	×	...	...	1	....
Do	Clifton, about ½ mile west of. (3 wells).	....	700	....	....	....	×	...	...	....	....
Mrs. L. Ross	Clifton	....	700	....	....	....	×	...	...	....	×
Kell & Gibbs	....do	....	640	114	....	....	×	...	...	1, 8	×
Do	Clifton, 3½ miles north of	....	670	....	....	....	×	...	...	1, 8	×
Do	Clifton, 8 miles southeast of	....	840	....	....	....	×	...	...	1, 8	×
C. D. Johns	Fowler, 1½ miles north of	....	735	60±	....	....	×	...	...	1	×
E. J. W. Ogden	Fowler, 3½ miles south of	....	203	200	....	155	No.	...	...	1	....
F. M. Lochert	Cayote, 2½ miles from	....	150	....	....	×	No.	...	...	2, 7	...
W. H. Martin	Cayote, 4 miles north of	....	145	140	....	56	No.	...	...	1	....
J. C. Gray	....do	....	150	145	....	×	No.	...	...	2	....
J. B. Richards	Cayote, 3 miles northeast of	....	439	145	274	×	No.	...	...	9	....
J. S. Butler	Cayote, 4 miles northeast of	....	172	158	....	×	No.	...	...	1	....

a Six additional wells of this character are reported in Meridian by M. L. Clark.

WELLS FROM THE PALUXY RESERVOIR.

The Paluxy reservoir is passed through at depths of from 75 to 100 feet by nearly all the deeper drill holes of the Bosque Valley, as is shown in the various sections to be presented and the figures of well sections on Pl. LV. The only flowing well thus far recorded from the Paluxy reservoir in Bosque County is reported by Dr. Scott Milam, of Glen Rose. The depth of this well is stated to be 79 feet and it is said to flow about 10 gallons a minute; the water is used for domestic purposes and for garden irrigation. A section of this well is as follows:

SECTION NO. 60.—SECTION OF WELL NEAR WALNUT SPRINGS, BOSQUE COUNTY, TEXAS CENTRAL RAILROAD.

(See Pl. LV, *B*.)

	Thickness.	Depth.
	Feet.	*Feet.*
3. Earth, sand, and clay	12	12
2. Hard limestone and marl (Walnut)	62	74
1. White sand (p)	7	81

The Paluxy formation is the source of many dug wells throughout the western portion of the county. Near Cranfills Gap an abundance of water is obtained in this manner at depths ranging from 120 to 200 feet.

Mr. E. E. Erickson, well driller, gives the following section of a well 153 feet in depth, drilled by him 3 miles south of Cranfills Gap for H. J. Hanson. This section shows the character of strata in the wells upon the Walnut prairies which secure their water from the Paluxy formation.

SECTION NO. 61.—SECTION OF WELL OF H. J. HANSON, 3 MILES SOUTH OF CRANFILLS GAP.

	Thickness.	Depth.
	Feet.	*Feet.*
11. Yellow clay (Walnut)	4	4
10. Marly clay (Walnut)	18	22
9. Shell agglomerate (Walnut)	2	24
8. Marly clay (Walnut)	40	64
7. Honeycombed limestone (Walnut)	35	99
6. Blue marl (Walnut)	19	118
5. Hard rock (Walnut)	2	120
4. Green marl and sandstone (Paluxy)	4	124
3. Loose sand with water (Paluxy)	19	143
2. Black joint clay (Glen Rose)	2	145
1. Lime rock (Glen Rose)	8	153

An artesian well situated upon the highlands 8 miles west of Meridian was drilled 258 feet. After passing through the Edwards limestone and Walnut formation it reached the Paluxy reservoir at a depth of 220 feet and penetrated its sands for a distance of 30 feet. A section of this well is as follows:

SECTION NO. 62.—SECTION OF WELL OF J. J. WALLING, 8 MILES WEST OF MERIDIAN, BOSQUE COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
5. Soil	16	16
4. White lime rock, (Edwards and Walnut)	184±	200
3. Sand (p^2)	8	208
2. Soapstone (p)	20	228
1. Sand (p^1)	30±	258

In a similar well 236 feet in depth, belonging to L. H. Hefflin, 7½ miles west of Meridian, the following material was penetrated: Surface dirt, 8 or 9 feet; lime rock, 200 feet; sand, about 30 feet.

There are many artesian springs in the county deriving their waters from the Paluxy reservoir. These have been described in a letter from the writer's former assistant, Mr. J. S. Stone,[1] as follows:

The abundant springs along many of the streams are properly artesian springs. Thus, along Steele Creek, along the Bosque, in plains along the Brazos, and in many other less important places, springs are very common. At first sight they appear to be springs which have their origin in the rainfall which has soaked through the alluvial lands of the streams, has met the hard rock below them, and has been thus forced to come out as springs in the banks of the streams. This supposition, however, is soon seen to be insufficient to account for the immense flow of water in all of these many springs, even after long drought. In the second place, the rocks directly above which the springs rise are usually, in fact almost invariably, the loose *Gryphæa pitcheri* beds. When this latter fact is considered and it is remembered that the Paluxy sands directly underlie the Gryphæa beds of the Walnut clays, the reason for the many springs is at once seen. The water is artesian; it permeates the sands and, where it gets a chance, forces its way upward through the overlying beds and flows out as springs. The artesian origin of these springs is confirmed by their occurrence usually low down on the streams, where they can get a "head," rather than higher up, where the Paluxy sands are only at about the same elevation. Thus, on the Bosque the great number of springs at Clifton is noteworthy as compared with their rarity higher up the river.

[1] The writer regrets that he has been unable to obtain a full report of Mr. Stone's valuable studies of the geology of this county. While employed as the writer's assistant upon the Texas State Geological Survey and under his personal direction he carefully studied and mapped the geology of Bosque County. The notes and results of this work, however, were turned over to the late State Geological Survey of Texas and the writer has not had the benefit of them in preparing the present report.

WELLS FROM THE TRINITY RESERVOIR.

A number of excellent wells are found along the Brazos Valley in the vicinity of Eulogy, Kimball, Kopperl, Fowler, and Cyrus, and along the entire western border of the county. These represent a continuation of the artesian belt developed to the northwest in the Paluxy and Brazos valleys of Somervell County.

These wells increase in depth from northeast to southwest, varying from the t^2 reservoir at a depth 475 feet north of Eulogy to a depth of nearly 1,000 feet near Cyrus at the southeastern corner of the county.

The following facts concerning a well of this description may be of interest:

Mr. A. M. Wilbanks reports that a well drilled by him 1 mile north of Eulogy (see Pl. LV, *C*) flows from the Trinity (t^1) reservoir at depths of 425, 450, and 475 feet. He notes the occurrence of lignite and pyrites in the lower formations passed through. The upper Trinity (t^3) reservoir near Eulogy was struck at a depth of 70 feet in the well of Mr. Jo Walker, 2½ miles west of that place.

The well of Mr. J. R. Hall, about one-fourth of a mile west of Eulogy, obtained the first or t^3 water at a depth of 60 feet, and a t^2 reservoir at 200 feet. At Eulogy post-office the t^3 water was struck at 30 feet and the t^1 water at 450 feet. The flow increased when this was penetrated 480 feet. The water is soft and clear and almost free from mineral impurities. Other wells in the same neighborhood show some sulphur water and a little oil, which undoubtedly comes from the upper reservoir and could be cased off. Farther down the river, in the vicinity of Kopperl, the wells increase in depth. At Kopperl there are three wells, 525, 600, and 800 feet in depth. (See Pl. LV, *I*.) The shallowest of these is the public well, the depth of which is given at 400 feet by the mayor of the city. It flows 30 gallons an hour. The 625-foot well belongs to Mr. M. S. Greer, who states that a little flowing water was struck at 300 feet from the surface.

Mr. C. D. Johns, who has a flowing well 735 feet deep, 1½ miles north of Fowler (see Pl. LV, *H*), 45 miles northwest of Waco, states that the well is located about 1 mile from the Brazos River, and that the drill passed through "soapstone" in many places, and lime rock, and struck water in sandstone. The sand is the t^2 reservoir of the Trinity sands.

Still farther down the Brazos, 1 mile east of Cyrus, there is a flowing well owned by Mr. Gip Smith, alleged to be 1,000 feet deep, and to have a pressure of 90 pounds to the square inch. This well obtains its water from the t^2 reservoir, and is the deepest one in Bosque County.

In the Bosque Valley artesian wells are everywhere obtained along the immediate stream valley from Iredell southeastward to Valley Mills, the basement Trinity reservoirs being reached at depths of from 350 feet at the former place to 840 feet at the latter.

Mr. John L. Myers, mayor of Iredell, says:

There were six flowing wells with a depth of 390 feet in this town, but all six have stopped flowing. The seventh is still flowing, rising about 1 foot above the gravel. A steady north wind affected all of them. While flowing a good stream, let the wind blow from the north two days and they would stop, so that it was necessary to put pump and windmill in four of them.

These wells begin in the upper portion of the Glen Rose formation (see Pl. LV, *A*, and fig. 48). A log of the public well at Iredell (altitude 880 feet), which furnished 28 gallons a minute when first drilled, is as follows:

SECTION NO. 63.—SECTION OF PUBLIC WELL AT IREDELL, BOSQUE COUNTY, TEXAS (ALTITUDE 881 FEET), SEE PL. LV, *A*, AND FIG. 48.

	Thickness.	Depth.
	Feet.	*Feet.*
10. Soil	20	20
9. Limestone	10	30
8. Soft blue marl	80	110
7. Blue marl	6	116
6. Soft white stone	50	166
5. Sandstone (t^3 at 180 feet), limestone, marl	100	266
4. Soft sand rock } 3. Hard sand rock } t^2	45	311
2. Fine-grained sandstone	6	317
1. Pack sand (flow of water, t^1)	18	335

Iredell is situated very near the limit to which the waters will rise to the surface. In fact, it is slightly higher than the water will theoretically rise a short distance to the east.

Down the valley of the Bosque, toward Iredell, the next wells reported are at Meridian, about 13½ miles from the former place in a direct line. At Meridian the Walnut formation is near the surface.

There are 6 artesian wells reported in this city. Mr. S. H. Lumpkin, who owns a flowing well at Meridian 525 feet in depth, gives the following section (see Pl. LV, *D*):

SECTION NO. 64.—SECTION OF WELL OF S. H. LUMPKIN AT MERIDIAN, BOSQUE COUNTY, TEXAS.

(See Pl. LV, *D*.)

	Thickness.	Depth.
	Feet.	*Feet.*
6. Soil	18	18
5. Mostly limestone rock, beginning on top very hard and of dark color and getting softer and lighter below (Edwards and Walnut, and upper part of Glen Rose)	282	300
4. Sand, t^3 } 3. Limestone rock (Trinity division) }	206	506
2. Green marl or shale (Trinity division)	2	508
1. Sand, t^2	17	525

The above section makes no mention of the Paluxy sands, which should be passed in this well at a depth of 185 feet. This well either does not go to the lower Trinity reservoirs encountered in the Morgan, Clifton, and other wells of the county, or the record is deficient.

At Morgan post-office and in the valley of Steel Creek, about 10 miles northeast of Meridian, flowing wells are received from the t^2 and t^1 reservoirs at a depth of 550 and 675 feet, respectively. The wells at this place flow about 20 gallons a minute. In drilling the well from the t^2 to the t^1 reservoir Messrs. Tuttle and Smith state that they passed through hard sandstone and red clay and also a small vein of coal. These facts have been also noted in the case of the wells in the Brazos Valley near Eulogy.

At Clifton, about 12 miles east of south of Meridian, in the valley of Bosque River, there are several flowing wells, some of which have probably penetrated to the t^1 reservoir.

Mr. E. E. Erickson gives the following section of a flowing well drilled by him for Messrs. Kell and Gibbs of Clifton. The total depth of the well was 662 feet; depth of first water from the Paluxy reservoir was 182 feet; other waters were struck at 610 and 662 feet. (See fig. 55 and Pl. LV, F.)

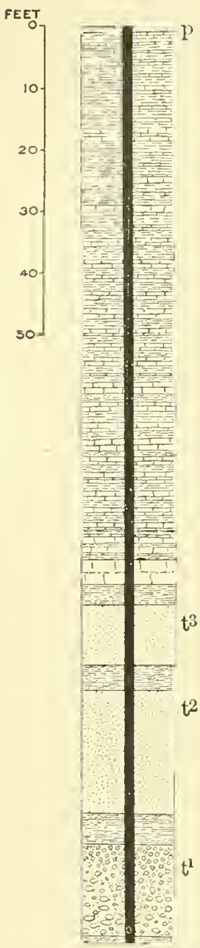


FIG. 55.—Partial section of artesian well of Kell & Gibbs at Clifton, Texas (Nos. 1–11, inclusive, of section No. 64), showing details of Trinity reservoir. (For explanation of symbols see Pl. XVI, p. 110.)

SECTION NO. 65.—SECTION OF WELL OF MESSRS. KELL AND GIBBS, OF CLIFTON, BOSQUE COUNTY.

	Thickness.	Depth.
	Feet.	*Feet.*
19. Yellow clay and gravel	12	12
18. Marl ("soapstone") and shell agglomerate in small layers	68	80
17. Honeycombed white limestone		
16. Joint clay	72	152
15. Hard limestone		
14. Hard limestone	2	154
13. Green-colored marl	8	162
12. Hard sand rock (p)	6	168
11. Soft coarse-grained sandstone (p)	22	190
10. Limestone	325	515
9. Blue marls and layers of white limestone	85	600
8. Hard rock stratum	4	604
7. Greenish sandy marl	3	607
6. Quicksand (t^3)	10	617
5. Blue marl	4	621
4. Cavernous sandstone (t^2)	20	641
3. Coarse black joint clay	5	646
2. Coarse gravel (t^1)	15	661
1. Clay and red marl	1	662

This well probably begins at the surface in the Fort Worth limestone and passes through about 100 feet of the Washita division before reaching the Edwards limestone, striking the Paluxy reservoir at a depth of 182 feet.

The first flowing water was obtained from the t^3 reservoir in No. 6. A second flow was procured in No. 4. The third and lower flow was obtained in No. 2, and this is generally the strongest.

Mr. E. E. Erickson gives the following information concerning another flowing well drilled by him 1 mile west of Clifton. The total depth of this well is 715 feet; depth of first reservoir, 220 feet; other reservoirs, 640 feet. This well is drilled on a hill, and hence the flow is weak—60 gallons a minute.

SECTION NO. 66.—SECTION OF WELL DRILLED BY E. E. ERICKSON, 1 MILE WEST OF CLIFTON, BOSQUE COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
19. Alluvial conglomerate	24	24
18. Yellow clay	10	34
17. Clay ("soapstone")	50	84
16. White limestone rock	2	86
15. Blue marl	40	126
14. Honeycombed limestone	50	176
13. White rock	35	211
12. Blue marl and layers of shell rock	2	213
11. Water sand (p, flow rises about 100 feet)	10	223
10. Joint clay	13	236
9. Limestone	327	563
8. Blue marl	80	643
7. Hardpan	4	647
6. Quicksand (first flow) t^3	20	667
5. Joint clay	8	675
4. Honeycombed sandstone (second flow) t^2	28	703
3. Joint clay	3	706
2. Coarse sand rock mixed with gravel (t^1)	10	716
1. Sticky black joint clay	2	718

At Valley Mills, about 11 miles southeast of Clifton, the t^2 reservoir is struck at depths of about 706 feet (see Plate LV, *G*). Mr. E. B. Cass, well driller, reports that the material of these wells above the Paluxy reservoir, which is struck at 200 feet from the surface, is mostly the blue and white limestones and marls. He remarks that after going through the underlying Glen Rose he usually strikes three distinct water-bearing strata before reaching the red clay formation at the bottom of the wells. He states that he has never gone through this, but has bored into it 60 feet at one place. It would be interesting to see a specimen of this red clay, usually called "keel" by correspondents, in order to ascertain whether any of these wells have penetrated through the Cretaceous rocks. There is a red clay of this description in the lower beds of the Trinity division quite different from another red clay which is sometimes encountered in the Paleozoic rocks. We are unable to judge by the logs of the Bosque County wells whether the Cretaceous has been completely perforated or not.

J. F. Robinson has a well at Cowan post-office, 8 miles southeast of Bluffdale, on Sycamore Creek, a tributary of Paluxy River. This well is 208 feet deep; depth of first water, 42 feet. He states that in drilling the well water was struck at 136 feet after going through a stratum of probably 20 or 30 feet of what drillers call red keel. The water from this stratum rose to within 16 feet of the surface. After passing another stratum of red keel to a depth of 165 feet, the water rose to within about 6 feet of the surface. After passing through still another stratum of this red keel water was again struck in sand at about 196 feet, and this water rose to the surface and began to flow when a depth of 200 feet was reached. Between these water strata there is rock of various kinds, with red clay, mud, or keel just above the various strata of water sand.

WELLS FROM THE FREDERICKSBURG RESERVOIR.

Dr. J. T. Glass, who has a well 192 feet deep located 1 mile north of Womack, in the eastern portion of the county, gives the following section of the well:

SECTION NO. 67.—SECTION OF WELL OF DR. J. T. GLASS, 1 MILE NORTH OF WOMACK, BOSQUE COUNTY.

	Thickness.	Depth.
	Feet.	*Feet.*
5. Black soil	1	1
4. Yellow clay and gravel	5	6
3. White limestone (Fort Worth limestone?), thin layers of few inches with clay between	14	20
2. Slate-colored stone, called rotten limestone, (Kiamitia and Edwards)	107±	127
1. A porous white limestone (Edwards), which is the water-bearing stratum	65	192

This section is of interest because it shows the existence of a water reservoir in a porous white limestone in the lower portion of the Fredericksburg division which, while of no economic importance in Bosque County, becomes an important factor in the artesian systems in the country southward.

CORYELL COUNTY.

Coryell County has an area of 1,065 square miles, and lies entirely within the Lampasas Cut Plain. The summit remnants of this plain consist of a series of long scarped table-land divides between the wide and deeply incised valleys of the Leon River, Coryell Creek, and Cowhouse Creek, and extend in a southeasterly direction. The highest summits are about 1,200 feet, in the western corner. The Leon Valley, in the eastern corner, is only 600 feet above the sea.

The geologic formations comprise the usual sequence of the Lampasas Cut Plain, the Edwards limestone capping the high divides and the

Walnut, Paluxy, and Glen Rose formations outcropping in the slopes and bottoms of the incised valleys. The lower strata of the Washita division are also preserved in the eastern and northeastern portions.

The Trinity sands are completely embedded in this county. The Paluxy sands outcrop in the lower part of the valley of the Leon, and are embedded in the eastern portion.

The entire county is underlain by the Trinity reservoirs, of which three (t^1, t^2, and t^3) may be recognized in the various artesian-well drillings. The Paluxy reservoir is a recognizable water horizon in

FIG. 56.—Artesian map of Coryell County, Texas. Shaded portion indicates area where flowing wells are likely to be obtained; ●, flowing wells from Trinity reservoir; ○, non-flowing wells from Trinity reservoir; □, non-flowing wells from Paluxy reservoir; figures indicate depth of wells in feet.

the northern portion of the county. The Fredericksburg division is also apparently water bearing in the eastern portion, and several shallow artesian wells in the valley of the Leon adjacent to Whitson, Oglesby, and Pecan Grove probably get water from this source.

The lowest Trinity reservoir lies within 300 feet of the surface at Copperas Cove and Pidcoke, in the western part of the county. The eastward inclination carries it to a depth of 700 feet at Gatesville, near the center, and to 1,100 feet at The Grove, near the eastern border. So far as we can ascertain, this reservoir has been penetrated at

Copperas Cove and Gatesville only. The wells near Pidcoke may also probably reach it.

The second Trinity reservoir (t^2), of fine white pack sand, seems to satisfy the well driller in most localities, as in the case of the Pruden well at The Grove, a section of which is given.

The t^3, or Glen Rose reservoir, is frequently reported as yielding water in this county from cavernous or honeycombed limestones. The supply from this source is feeble and usually highly mineralized.

S. A. Wylie has a well in the southeast corner of the county, 4 miles from Leon Junction. It is 217 feet deep and apparently derives its waters from the Fredericksburg reservoir. He says: "In many places here water is found in this hard blue rock, and when these rock fragments are closely examined they are found to be fragments of sea fossils." The above strata are probably the equivalents of the Walnut formation, and a large number of observations contribute similar testimony as to the geologic horizon.

DEVELOPMENT.

The topographic and structural conditions in Coryell County are unusually favorable for procuring artesian wells, at least in the wide valleys, where the population is located. Artesian wells have been procured in the valleys of the Leon and Cowhouse nearly the entire distance across the county. A number of flowing wells have been reported, while good nonflowing artesian wells are obtainable at depths varying from 150 feet in the western portion of the county to 900 feet in the east.

W. H. Morgan, well driller, Leon Junction, gives the following information concerning wells drilled by him:

Near the county seat (Gatesville) nonartesian water is found at 75 and 100 feet [p]; generally good for all purposes, and all of the northwest of the county at about the same depth. At about 200 to 300 feet in the same section of the country we strike the next water reservoir [t^3], which is mineral; at 500 feet we strike a third flow [t^2], still mineral; at from 700 to 800 feet a large flow of soft water is reached [t^1]; in the west part of the county, and more particularly on the Cowhouse River, we can get a good flow from 200 to 300 feet; in the eastern part of the county we have to go from 100 to 500 feet to strike the first water and it is mineral, salt, soda, or some other mineral.

We have two records of wells, at Gatesville and Copperas Cove, which have completely exploited the Cretaceous artesian reservoirs. Most of the other wells are incomplete, the drilling having been conducted entirely regardless of geologic guidance and having ceased at the reservoir nearest the surface, or, if continued, little care has been taken to case off deleterious waters when struck.

SECTION NO. 68.—SECTION OF WELL OF R. T. ELLIOTT, AT COPPERAS COVE, CORYELL COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
8. Limestone (Fredericksburg and Glen Rose)	450	450
7. Red sand (Trinity)	50	500
6. Red clay (Paleozoic)	50	550
5. White limestone or marble (Paleozoic)	50	600
4. Black shale (Paleozoic)	400	1,000
3. Sandstone (Paleozoic)	30	1,030
2. Black shale and coal (Paleozoic)	70	1,100
1. Shale and sand (Paleozoic)	775	1,875

Near Copperas Cove (altitude 1,092 feet) the base of the Cretaceous formations is reached within 500 feet. Below this are Carboniferous rocks. Mr. S. H. Walton, of Belton, Texas, drilled a well near this place on the divide between the Lampasas and Cowhouse for Mr. R. T. Elliott. The depth was 1,865 feet, 1,365 feet of which was into the Paleozoic floor beneath the Cretaceous system.

Water was reached in the Paluxy reservoir at approximately 128 feet, and in the upper Trinity reservoir at 246 feet, and the lower Trinity reservoir at about 500 feet. The water rose to within 100 feet of the surface, or to an altitude of 900 feet. Other nonflowing waters were reached in the Paleozoic rocks, but, as usual, they were excessively salty and destroyed the potable qualities of the waters from the Cretaceous formations.

There are ten or fifteen flowing wells within a radius of 5 miles of Pidcoke in the valley of Cowhouse Creek. These all commence in the Walnut or Glen Rose formation, and, owing to their situation near the western border of the Cretaceous area, where the Glen Rose beds are thinnest, have to penetrate only to shallow depths to secure water.

W. H. Belcher owns a flowing well 290 feet deep, located 1 mile from Pidcoke (altitude about 500 feet), in which water was reached at 140 and 190 feet. He kindly furnishes the following section, which is typical of the region:

SECTION NO. 69.—SECTION OF WELL OF W. H. BELCHER, 1 MILE FROM PIDCOKE, CORYELL COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
5. Sand and gravel (alluvium)	25	25
4. Limestone (Glen Rose)	150	175
3. Porous sandstone (t^2)	2	177
2. Limestone (water seeping)	100	277
1. Sandstone (t^1?)	13	290

There are a number of flowing wells at Gatesville, from 500 to 700 feet deep. The first flowing water is reached at about 500 feet, and is found in a very white pack sand, which is probably the t^2 reservoir. Some wells discharge a good stream at that depth and others very little. Several wells there have been drilled some 200 feet farther and find another flow, which furnishes more water, but the pressure is about the same. This is probably the basal or t^1 reservoir. Mr. S. H. Walton says that Gatesville is the only place he knows of in this county where a flow of good water has been secured below the t^2 reservoir. The formation between t^1 and t^2 flows is a red clay and the lower water-bearing formation is a red gravel. Mr. Walton correctly thinks this reservoir is below the reservoir at Belton and had wells at the latter place gone 50 feet farther they would probably have reached this basal reservoir.

The State of Texas drilled a well at the Reformatory, 3 miles north of Gatesville, but as in the case of all other State wells drilled at various localities and institutions, no record has been procurable.

The well of Dr. W. B. Newland, 6 miles southeast of Gatesville, presents the following section:

Section No. 70.—Section of well of Dr. W. B. Newland, 6 miles southeast of Gatesville, Coryell County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
7. Limestone (Fredericksburg division), (water at 120 feet)	120	120
6. Marly clay	3	123
5. Marl and limestone (Glen Rose, water at 300 feet)	350	473
4. Stratum of hard siliceous limestone (t^3)	12	485
3. White pack sand (t^2, water)	20	505
2. Hard stratum similar to No. 4	1	506
1. Sand and vari-colored gravel (t^1, water)	....	....

The well of T. Brock (387 feet deep, first water at 30 feet, second water at 350 feet, t^2 reservoir), 4 miles southeast from Leon Junction, illustrates a large number of wells which stop in the t^2 reservoir. He gives the following section:

Section No. 71.—Section of well of T. Brock, 4 miles southeast from Leon Junction, Coryell County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
White lime rock (Fredericksburg)	50	50
Blue lime rock	100	150
Soapstone and more blue rock (Glen Rose)	200	350
Sand rock where water was obtained (t^2 reservoir)	37	387

Mr. J. F. Pruden, of The Grove, has kindly furnished a section of his well, from which the artesian conditions of the eastern half of the county may be inferred. In this area the surface formation is usually the Edwards and Georgetown formations. His well is 900 feet deep and presents the following section (see fig. 57):

Section No. 72.—Section of well of J. F. Pruden, The Grove, Coryell County, Texas.

(See fig. 57.)

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone (Edwards)	300	300
Marly clay (Walnut, in part, water at 388 feet) (f)	100	400
Soft limestones (r^1)	500	900
White pack sand (t^2)	± 10	....

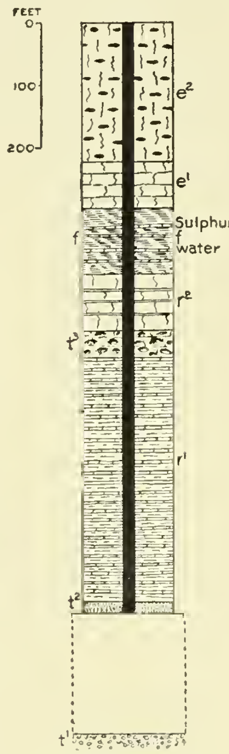


Fig. 57.—Section of J. F. Pruden's well in the village of The Grove, Coryell County, Texas. (For explanation of symbols, see Pl. XVI, p. 110.)

In this well, water was procured from three reservoirs, the Fredericksburg, the Glen Rose (t^3) and the t^2. The Fredericksburg water was procured from the horizon, approximately, of the Walnut clays of the Fredericksburg division, but which may be the attenuated Paluxy sands, and which was impregnated with "salts and other things." At 500 feet water was reached in the upper part of the Glen Rose beds and at 900 feet the upper or t^2 reservoir of the Trinity sands was encountered. The well stops about 200 feet above the lower reservoir as developed at Gatesville. The water rises in this well to within 20 feet of the surface.

In the eastern portion there are many wells which penetrate only to the Fredericksburg and Glen Rose (t^3) reservoirs.

G. Y. Coap, of Straws Mill, says: "Have 9 wells in this portion of the county ranging from 125 to 175 feet; hard water." These wells are all probably from the Fredericksburg division.

J. Lynn, of Whitson, says: "We get water all around this post-office by boring from 150 to 500 feet." These waters are derived from the Fredericksburg and t^3 reservoirs.

In this county, as elsewhere, the artesian flows diminish with the increase of number of wells. G. T. Willis, who has a well 475 feet deep 150 yards northeast of the public square in Gatesville, states that his well "flowed 1½ gallons a minute at the start, but on account of other wells being drilled on lower ground it stopped flowing and stands a few feet below the surface. The water can be lowered to a depth of 20 feet, which I suppose is on a level with the flowing wells."

B. H. Baird, who has a flowing well 250 feet deep 2 miles south of Pidcoke, says: "There are 10 or 15 wells within a radius of 5 miles; some outflow 2 to 3 gallons per minute. Very little irrigation here, nor do I think it will answer for permanent irrigation; after two, three, or seven years the surface becomes hard and impenetrable; some people say it is the iron in the water and experiments and trials indicate the effects of iron held in solution. To a great majority this water is wholesome, and to many beneficial."

Schedule of wells in Coryell County, Texas.

Owner.	Location.	Total depth.	Depth of first water.	Other waters.	Rise of water.a	Flow.a	Quality.b	Irrigation.a
		Feet.	*Feet.*	*Feet.*	*Feet.*			
C. R. Warren	Izoro	150	110	150	40	No.	2, 7	No.
M. W. Risinger	Gatesville, 14 miles south of; Purmela, 14 miles south of.	200	70	......	150	No.	7	No.
L. P. Taffinder	Gatesville, 14 miles west of; Purmela, ½ mile to.	112, 97	66	86, 88	No.	No.	2, 7	No.
Dr. J. M. Brown	King, 1 mile west of	275	200	......	....	×	1	×
Wiley Basham	King	220	20	325	....	×	1	×
M. M. Young	Levita, 2¼ miles southwest of.	340	150		×	No.	1	No.
M. Simpson	Levita, ½ mile northeast of.	361	12	60, 361	....	No.	2	No.
B. H. Baird	Pidcoke, 2 miles south of.c	250	......	......	×	......	....	
W. H. Belcher	Pidcoke, 1 mile from	290	140	......	....	×	1	×
C. T. McClure	Pidcoke post-office, 2 miles from, in a valley.	124	124	......	×	......	3, 8	No.
....	Pidcoke post-office, on Cowhouse Creek.	250	±100	250	....	×	1	
G. L. Dickson	Pidcoke, 2 miles south of.	250	......	45	....	×	1, 3, 5, 8	No.
....	Copperas Cove post-office, near.	250	135	240	No.	No.	....	
....	Copperas Cove post-office, 4 miles north of.	500	90	......	×	No.	2, 3	No.
R. T. Elliott	Copperas Cove	1,875	128	600, 1,600	1,400	No.	3	No.
Mr. Walton (reports)	Well at Copperas Cove	1,865	......	......	1,765	......	....	
J. N. Hill	Hurst, ½ mile west from	316	310	......	×	No.	1	No.
H. H. Bailey	Hurst, 1½ miles northwest of.	342	50	324	×	No.	1	No.
E. B. Cass	Gatesville, 8 miles west of.	612	150	402	462	No.	....	No
R. J. Brown	Gatesville, in city limits	700	150	460	....	×	1	×

a ×=yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

c A correspondent says there are 10 or 15 flowing wells at or near Pidcoke.

Schedule of wells in Coryell County, Texas—Continued.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Quality.	Irrigation.
		Feet.	*Feet.*	*Feet.*	*Feet.*			
W. B. Newland	Gatesville, 6 miles southeast of.	558	120	500	....	×	1 9	×
J. A. Morgan	Gatesville, 2½ miles west of.	500	65	300 475	....	×	1	×
G. T. Willis	Gatesville, 150 yards northeast of public square.	475	......	......	×	No.	1 3 4	×
G. Y. Coop	Straws Mill, 2 miles from; 5 wells.	125 to 175	75 to 150	.....	×	No.	2	No.
J. M. Brown	Straws Mill, ½ mile southeast of.	100	40	100	×	No.	2	No.
W. J. Toliver	Coryell post-office, 400 yards southeast of.	102	102	......	×	No.	2 3	No.
E. B. Cass	Coryell, 3 miles east of...	940	60	360 860	890	No.	1	No.
T. Brock	Leon Junction, 4 miles southeast of.	387	30	350	200	No.	9	No.
L. Lane	Mound, 2 miles northeast of.	697	225	300 425 690	692	No.	1	No.
S. A. Wylie	Leon Junction, 4 miles from southeast part of county.	217	134	......	No.	No.	2 9	No.
G. W. Dalton	Waldo, 2 miles south of ..	423	125	420	338	No.	3	No.
J. F. Pruden	The Grove, in village of .	±900	388	±600	886 887	No.	....	
A. Moore	Pecan Grove, 3 miles east of.	275	210	......	....	×	1	No.
J. H. Morris	Oglesby, 2½ miles west by north of.	500	125	360	×	No.	3 8	No.
W. McKelvey	Oglesby, 4 miles due west of; 2 wells.	35 105	.....	......	×	No.	4	No.
H. Cousins	Whitson, ¾ mile northeast of.	140	112	......	88	No.	1 9	
J. T. Reed	Whitson post-office, 1 mile north of.	147	114	......	×	No.	1	No.
J. Anderson	Whitson, ½ mile southeast of.	136	25	136	×	No.	9	No.
E. G. Toliver	Whitson, ¼ mile south of.	100	80	90	± 30	No.	2 3	No.

TRAVIS COUNTY.[1]

Travis County has an area of 1,040 square miles. It is sharply divided into two distinct major geographical districts—the Lampasas Cut Plain (or Edwards Plateau, as it is called, on the south side of the Colorado River) and the Black Prairie region. These are separated from each other in the northern portion of the county by the sharply marked line of the Balcones escarpment, which runs northwest and southeast across the county from the vicinity of Cedar Valley toward Round Rock, in Williamson County. The country west of this line is that of

[1] Detailed topographic and geologic maps of this county are published or in course of publication by this Survey.

the highly dissected Lampasas (Edwards) Cut Plain, capped on the highest points by the firm resistant strata of the Edwards limestone. In this district the high summits have an altitude of 1,350 feet in the extreme northwestern corner of the county, standing nearly 600 feet above the catchment area of the Trinity reservoir, which follows the foot of the western escarpment of the cut plain in Burnet County. From this altitude the summit of the plain slopes southeastward to just west of Austin, where it attains an altitude of 925 feet, the highest point on the eastern margin of the plateau, being just northwest of

FIG. 58.—Artesian map of Travis County, Texas. 1, Area where wells less than 1,000 feet deep are likely to be obtained from the Basement Trinity reservoir; 2, area where conditions are affected by igneous rocks; 3, area where wells from 1,800 to 4,000 feet deep are obtainable from the Basement Trinity reservoir; ●, flowing wells from Trinity reservoir; ○, nonflowing wells from the Trinity reservoir.

Spicewood Springs. East of the Balcones fault, northeast of McNeil, the Black Prairie country is a low-lying plain, the higher profiles of which, as seen along the divide of the Brazos-Colorado drainage in the northern border of the county and Mustang Ridge in the southern part of the county, decrease in altitude from 900 feet at the western to 600 feet at the eastern boundary. Between these two plains, south of Amboy station, 6 miles north of Austin, there is a triangular area which broadens to the south and which is known west of Manchaca as the "Hardscrabble" country. This is a portion of the downthrown coastal plain like the Black Prairie, but is underlain by different geologic formations—those of the Washita division and the Edwards limestone.

Running diagonally southeast and northwest through the county across the strike of these plains and fault lines, the Colorado River has incised a deep valley, which is sharply canyoned in the region of the cut plain. The bottom of this canyon is 750 feet below the high summit of the cut plain at the western end of the county, that being the distance between the river level (altitude 650 feet) west of Travis Peak post-office and the top of Postoak Ridge (altitude 1,350 feet). In the eastern part of the county, near Webberville, the valley is about 200 feet below the summit level of the Black Prairie. The total fall of the river valley across the county is 300 feet, or from 650 feet on the west to 350 feet on the east. Thus it will be seen that the extremes of altitude of this county are greater than throughout the Black and Grand Prairies.

GEOLOGY.

The geologic features of the county are as follows:

In the district of the Lampasas Cut Plain west of Roger's ranch, Oak Hill (Oatmanville), the State Encampment northwest of Austin, Amboy, and Duval, and east of McNeil, the strata are even bedded and uniform. The summit formation is the base of the Edwards limestone, which here dips parallel to the surface slope, or about 14 feet to the mile. Beneath this the Glen Rose formation, which constantly increases in thickness from west to east, usually constitutes the canyon slopes down to the river's level. Along the river west of Anderson Mills the Travis Peak formation is exposed almost to its bottom. Immediately east of the main Balcones fault line (see Pl. LII, A) the strata have fallen down some 500 feet or more through faulting, so that the edges of the Edwards limestone of the lower Coastal Plain are opposed to the Travis Peak formation of the higher cut plain. Between this main fault and the top of the Austin chalk and Taylor marls, east of Austin, there is a zone of minor faulting which adds great complexity to the stratigraphic continuity. (See Pl. LII.) The parting between the Upper and Lower Cretaceous follows an irregular line west of Mountain City, Carpenters Hill, Manchaca, Davis Hill, Austin, Spicewood Springs, and between Spicewood Springs, Watters, and Merrilltown. From Spicewood Springs southward between the western border of the Black Prairie and the main Balcones Fault line in the Hardscrabble belt of country the Edwards limestone is the chief surface formation. The Georgetown limestone, Del Rio clay, and Buda limestone are exposed in faulted blocks at the western border of the Black Prairie. The Eagle Ford formation outcrops in a narrow belt immediately beneath the western border of the Austin chalk. The latter formation constitutes a conspicuous belt of white-rock country through the center of the county, passing east of Merrilltown through

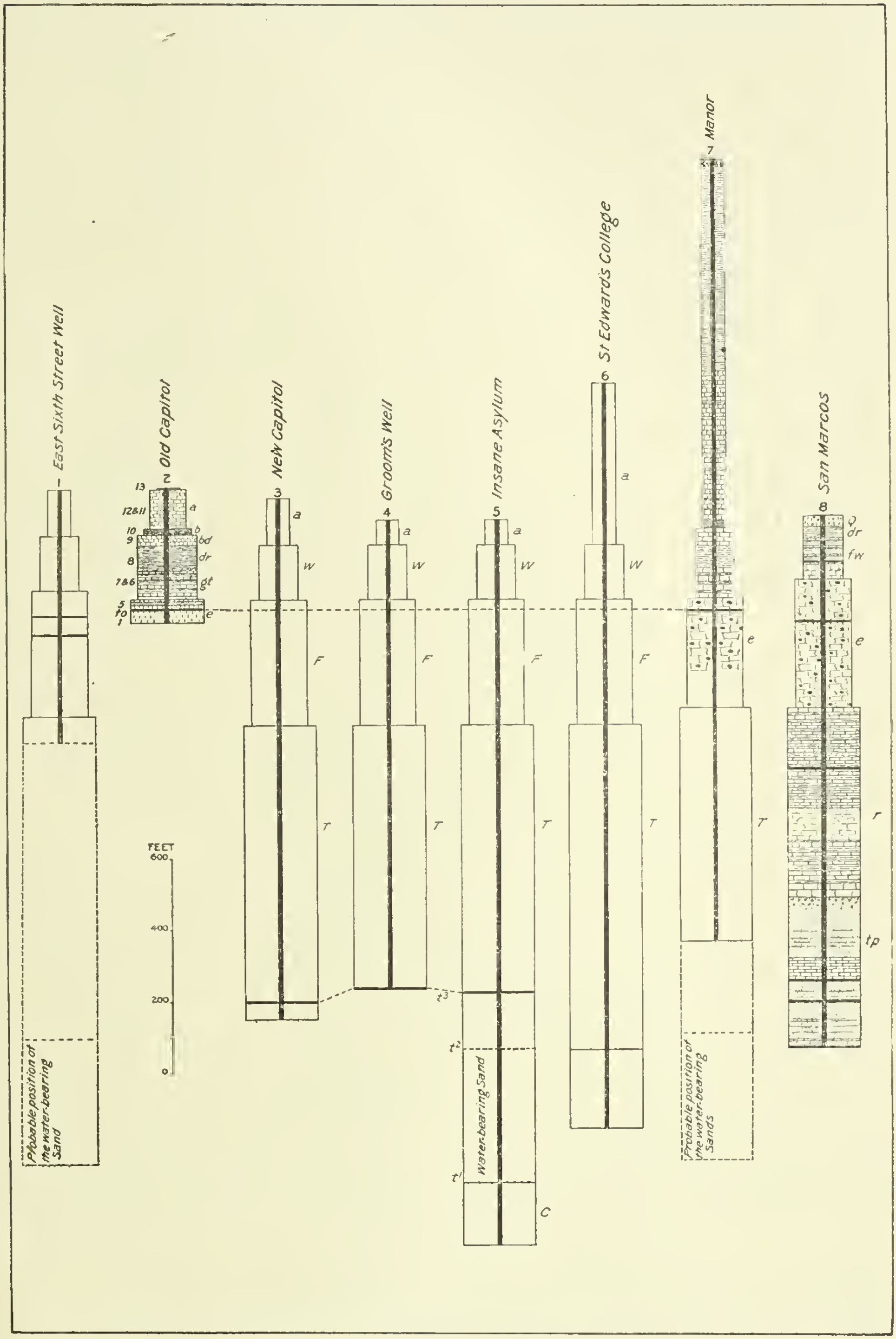
Fiskville, Austin, St. Elmo, Manchaca Springs, and southward toward Buda, Hays County. Eastward of the white-rock belt the Taylor marls form extensive prairie lands. The latter are bordered on the east by the Webberville formation of the Cretaceous, and these in turn are succeeded east of Manor by the lower formations of the Eocene. At one point north of the river, or about 2 miles east of the station at Austin, there is a small outcrop of volcanic rock, while south of the river Pilot Knob is a conspicuous volcanic neck. Furthermore, on this side of the river there are many volcanic dikes which cut the sedimentary strata, notably at Kounz station and elsewhere.

The surficial formations are also very extensively developed in this county, the Uvalde gravel capping all the high divides of the Black Prairie region, while there are remarkable terraces of the river alluvium in the Colorado Valley, especially in the Black Prairie district.

An excellent detailed geologic map of the larger portion of this county has been made by this survey and will soon be published as a separate folio.

WATER CONDITIONS.

All of Travis County is underlain by the Trinity reservoirs, which outcrop as the Travis Peak beds at the extreme western edge of the county and which are struck in the wells at Austin at depths of from 1,500 to 2,000 feet, or from 1,000 to 1,500 feet below sea level. East of the Balcones Fault line the Fredericksburg reservoir is also embedded, and its waters are reached at Austin at a depth of 419 feet. The artesian reservoirs and conditions of availability are entirely different in the Edwards Cut Plain, Hardscrabble, and Black Prairie districts. In the former the Trinity reservoirs alone are available, but it is hardly probable that flowing water can be obtained at all in this district except in the immediate valley of the Colorado Canyon below altitudes of 650 feet. In the Hardscrabble district the Fredericksburg reservoirs are embedded and available as well as the Trinity reservoirs. This district is excessively faulted and jointed, and many artesian springs reach the surface. In the Black Prairie district the Fredericksburg and Trinity reservoirs are deeply embedded, and the area in which deep-flowing wells can be obtained is extensive, practically including all points below 630 feet, except in the vicinity of the Pilot Knob, where volcanic rocks introduce an uncertain and unknown condition in the regularity of the strata.



ARTESIAN WELLS OF TRAVIS COUNTY, TEXAS.

The following is a list of wells reported from Travis County:

Schedule of wells in Travis County, Texas.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.*a*	Increase.	Quality.*b*	Temperature.	Irrigation.
			Feet.	*Feet.*	*Feet.*	*Feet.*					
WELLS PENETRATING THE TRINITY RESERVOIRS.											
Town of Watters	Watters		700								
State Colored Institute		650									
H. McGillvray	Austin, corner of Fifth and San Jacinto streets.		2,020	350	450, 1,800		×		1	21.2°C. at 600 ft.	
State Capitol	Austin	520	419				×				
State Lunatic Asylum	do	635	1,975				×				
St. Edward's College	do	660	2,053				×				
Groom well	do	615	1,300				×				
Natatorium well	do	500	2,025				×				
New Capitol well	Austin		1,450				×				
	Manor		2,560 or 2,400				×				
WELLS IN THE GLEN ROSE FORMATION.											
B. Hayden	Volente, 3 miles south of.		139	104	135	×			2		
J. Williams	Volente, 1 mile south of.		100	90		10			2		
J. W. Townsend	Cedar Valley, 1 mile east of.		116	78		×					
R. A. Moore	Cedar Valley, ½ mile from.		160	140		30±			2		
G. Cezcaux	Cedar Valley, 1 mile east of, 2 wells.		132, 128	130, 103		70, 100			2		
J. J. Davis	Manchaca, 4 miles north of.		350	200	320	×			2		
	Bee Cave, 4 miles north of.		163	35	128	50					
WELLS PENETRATING THE FREDERICKSBURG RESERVOIR.											
Von Rosenburg	Manchaca post-office, 400 feet of.		244	100		×			1		
L. A. Adams	Williamson County, 1½ miles south of Round Rock.		400	35	100, 350	×		×	2		×

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

WELLS FROM THE FREDERICKSBURG RESERVOIR.

There are several wells in Travis County, principally along the western edge of the Black Prairie and between the latter and the Balcones Scarp line, which obtain considerable supplies of water from reservoirs in the Edwards limestone of the Fredericksburg division. Some of these wells flow, but most of them must be pumped. The water is usually highly charged with sulphur and mineral impurities. The most conspicuous example of a well of this character is the one bored by the State authorities on the capitol grounds in the year 1858. This was carried to a depth of from 419 to 471 feet. This well obtained its water from the Edwards limestone in the Fredericksburg division. The log of this well, as published by Dr. B. F. Shumard, the first State geologist of Texas, is much more detailed than any other in the neighborhood, and is here given.[1] The character and thickness of the different strata passed through, as shown from an examination of the borings preserved by Mr. Peterson, are given in the section, Pl. LVI, *B*.

SECTION NO. 73.—LOG OF OLD STATE CAPITOL WELL, AUSTIN.

	Thickness.	Depth.
	Feet.	*Feet.*
13. Soil and subsoil	5	5
12. Soft, white chalky limestone, disintegrating more or less rapidly on exposure to the air	18	23
11. Moderately hard, bluish-gray and cream-colored argillaceous limestone, containing teeth and scales of fishes, *Inoceramus* (*Trichites*) *lerouxii*, ammonites, and other fossil remains	94	117
10. Dark, bluish-gray, indurated marl	14	131
9. Compact, bluish-gray limestone	31	162
8. Blue, marly clay with fossil shells coated with iron pyrites, chiefly *Exogyra arietina*, *Janira*, and *Dentalina*	70	232
7. Hard, dark bluish-gray, earthy pyritiferous limestone and shale, containing *Exogyra arietina*, *Gryphæa pitcheri*, *Janira*, and *Toxaster*. Many of the fossils of these strata are wholly or in part composed of iron pyrites	47	279
6. Soft, sandy, argillaceous limestone, with fossils like those of 7	25	304
5. Soft, earthy, sandy, fine-grained limestone of a dull-gray hue	6	310
4. Indurated, bluish-gray silico-magnesian limestone, containing a good deal of sulphuret of iron	6	316
3. Grayish-white, earthy, fine-textured sandy limestone (magnesian?), with *Toxaster* and *Exogyra*. Water at 323 feet; rose 283 feet to within 40 feet of surface	13	329
2. Bluish-gray, sandy, magnesian limestone with thin marly partings and abounding in organic remains—*Exogyra arietina*, *Gryphæa pitcheri*, *Janira*, *Dentalina*, and fish teeth. Many of these fossils are coated with sulphuret of iron, which gives to them an elegantly bronzed appearance	48	377
1. Gray, earthy limestone, of a fine sandy texture, with gypsum, nodules of flint, and masses of iron pyrites, and also a few organic remains, chiefly *Exogyra* and *Toxaster*.	94	471

[1] Texas Almanac, Richardson & Co., Vol. III, pp. 161–162, Galveston, 1859.

The foregoing section of Dr. Shumard's may be interpreted as follows:

No. 13 is the ancient terrace gravel.

Nos. 12, 11, and 10 collectively represent the Austin chalk and the fish beds ("*a*" strata of McGillvray's logs).

No. 9 is the Buda limestone ("*b*" strata of McGillvray's logs).

No. 8 is the Del Rio clay ("*c*" strata).

No. 7, at 232 feet, seems to represent the upper part of stratum "*d*" of McGillvray's logs and the top of the combined Fort Worth and Edwards limestones. If this is so and the assumed thickness of the Fort Worth limestones, 70 feet, is correct, the top of the Edwards limestone lies 302 feet beneath the surface of the capitol grounds where this well was dug, and the flow of water struck at 323 feet in No. 11 comes from a horizon not over 21 feet beneath its summit.

No. 6 may be the bottom of the Fort Worth beds, in which case the sulphur water struck would be only 27 feet below the summit of the Edwards limestone, or in the chalky beds immediately below those known as the "lithographic flags."

The beds from 5 to 1, including 192 feet of strata, all undoubtedly belong to the Edwards limestone, extending downward into the magnesian beds exposed about 35 feet above the water in the Bee Caves bluffs. The interesting fact in relation to this Shumard well section is that every foot of the strata penetrated by the well can be seen outcropping within 4 miles of its location, in the western suburbs of Austin, to the mouth of Bee Creek.

The writer has long doubted the accuracy of the paleontologic determinations of bed No. 2. Among the fossils enumerated are *Exogyra arietina* and fish teeth, and the writer knows that these do not occur at this horizon. The specimens may have been mixed by the well drill. They certainly do not belong here.

Dr. Francis Moore, in The Texas Almanac for 1860, page 96, has also given a section of this well, which disagrees with the one given by Dr. Shumard both in minor details and in total depth. Dr. Moore's section is as follows:

SECTION NO. 74.—OLD STATE CAPITOL WELL, AS GIVEN BY DR. FRANCIS MOORE.

	Feet.
1. Limestone containing *Ammonites, Inoceramus*, etc	18
2. Blue argillaceous limestone	58
3. Dark carbonaceous marl	24
4. Slaty marl	9
5. Hard, compact, yellowish limestone with *Hippurites*	35
6. Blue marl with pyrites	62
7. Limestone with masses of chert and flint	61
8. Siliceous limestone	2
9. Blue limestone with pyrites, minute *Exogyra*, etc	150
Total	419

The writer's interpretation of these beds is as follows: Nos. 1 and 2, Austin chalk; 3 and 4, fish beds; 5, Buda limestone; 6, Del Rio clays; 7, 8, and 9, Edwards limestone.

Notes on three other wells, which are apparently of the same character, are appended.

Von Rosenberg & Summerson, of Manchaca, furnish the following facts concerning a well belonging to them located 400 feet from Manchaca post-office. The first stratum was of soft limestone (Austin chalk), commencing within 3 feet of the surface and of a depth of about 20 or 30 feet, where it changes to blue clay stone (Eagle Ford). This continued until a depth of 120 feet was reached, when a hard, light-colored stone (Georgetown formation) was struck, which changed but little until water was reached at a depth of 243 feet. The stone in which water was obtained was a porous limestone kind known as "honeycombed" rock (Edwards limestone). The well was drilled in 1891, and since then has never shown the least shortage in water supply. It is 244 feet in depth.

L. A. Adams, well driller, says that in a well 400 feet in depth, drilled by him between Round Rock and Austin, 1½ miles south of Round Rock, he passed through the following material:

SECTION NO. 75.—SECTION OF WELL 1½ MILES SOUTH OF ROUND ROCK, TRAVIS COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
12. Yellow limestone (Austin)	35	35
11. Light-blue limestone (Austin)	55	90
10. Blue marl (Eagle Ford)	50	140
9. Hard gray limestone (Buda)	45	185
8. Blue marl (Del Rio)	45	230
7. Light-blue limestone (Georgetown)	100	330
6. Gray limestone (Edwards)	30±	360
5. Yellow limestone (Edwards)	10±	370
4. Porous limestone, light brown (Edwards)	15±	385
3. Sandstone (Edwards)	20±	405
2. Black flint (Edwards)	2±	407
1. Sandstone and water rock combined (Edwards)	40±	447

Mr. J. J. Davis reports that his well is 350 feet deep and is located 4 miles north of Manchaca. He gives the following section of the well:

SECTION NO. 76.—SECTION OF WELL OF J. J. DAVIS, 4 MILES NORTH OF MANCHACA, TRAVIS COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Joint clay and gravel	13	13
5. Joint clay (Eagle Ford)	67	80
4. White lime rock (Buda and Del Rio)	50	130
3. Blue clay (Buda and Del Rio)	10	140
2. Rock mixed with clay and yellow sand (Georgetown and Edwards) 1. White sand rock with water (Georgetown and Edwards)	210	350

WELLS FROM THE TRINITY RESERVOIRS.

Throughout the portion of the county situated in the Lampasas (Edwards) Cut Plain shallow, nonflowing artesian wells are obtained from the upper Trinity reservoirs.

According to the postmaster at Volente, near the mouth of Cypress Creek, where the base of the Glen Rose formation outcrops, several wells in that immediate vicinity obtain water at a depth of about 150 feet from the Trinity reservoirs. One of these gives strong sulphur water; the others are slightly sulphur.

J. Williams, 1 mile south of Volente, states that the following material was passed through in drilling his well: Clay, 4 feet; limestone, 76 feet; sandstone, 20 feet. The well is 100 feet deep.

R. A. Moore reports that his well, one-half mile from Cedar Valley, is 160 feet deep; was drilled all the way through solid blue limestone. The water in this well rises about 30 feet from the bottom of the well.

Successful flowing artesian wells have been obtained at only two localities in Travis County—at Austin and Manor—both in the Black Prairie district.

At least six flowing artesian wells have been sunk in the vicinity of Austin—one at the State Institution for Colored Dependents, altitude 650 feet; the Groom well (Pl. LVI, *D*), altitude about 615 feet, and one at the insane asylum (Pl. LVI, *E*), altitude 635 feet, both in the northern suburbs of the city beyond the university; two on the capitol grounds (Pl. LVI, *B* and *C*), altitude 520 feet; one on Fifth street east, altitude 500 feet, and one at St. Edwards College, altitude 660 feet, 2 miles south of the river. They all pass through similar formations as far as they go, but the Asylum and St. Edwards wells are the only ones which have been drilled to the basal Trinity beds. The flowing well at Manor (Pl. LVI, *H*) was drilled to a total depth of 2,560 feet, as elsewhere described.

Attempts to obtain water have been made at the Institution for Colored Dependents, northwest of Austin at Watters, and on a farm near Creedmoor. The first two wells were not drilled to a sufficient depth to reach the basement Trinity reservoirs which furnish a flow. The writer has been unable to secure returns concerning the latter.

The Groom and Capitol wells at the present time have only a small discharge, 5,000 or 6,000 gallons a day. The Asylum well (altitude 635 feet) had a discharge of 150,000 gallons a day and threw the water to a height of 40 feet. In St. Edwards well, which is 25 feet higher in elevation than the latter and obtains its supply from the same source, the water comes within about 5 feet of the surface and has to be pumped.

The Natatorium well (altitude 490 feet) discharges 250,000 gallons per day. The fact that the water does not flow out at the surface at St. Edward's College (altitude 660 feet) would indicate that the 650-foot contour on the Austin sheet marks the possible limit of flowing wells in the vicinity.

The Asylum well is 1,975 feet deep, and the material passed through in order downward from the surface, as reported by Mr. McGillvray, the driller, is as follows:

SECTION NO. 77.—LOG OF WELL AT INSANE ASYLUM (ALTITUDE 635 FEET), AUSTIN.[a]

(See Pl. LVI, *E*.)

	Thickness.	Depth.
	Feet.	*Feet.*
10. Dark shale	80	80
9. Very hard limestone (Buda)	25	105
8. Blue marl (Del Rio)	90	195
7. Limestone and alternations of limestone, marl, and sand	1,105	1,300
6. Water-bearing sand[b] (t^3)	15	1,315
5. Limestone	60	1,375
4. Rotten shale	50	1,425
3. Limestone	60±	1,485
2. Sand, water-bearing (t^1 and t^2)	315	1,800
1. Blue shale or marl; no limestone	175	1,975

[a] Statistics collected by Mr. Cyrus C. Babb, U. S. Geol. Survey.
[b] 2 to 6 inclusive = 490 feet.

Mr. McGillvray states that stratum 9 is very hard limestone and is easily recognized whenever encountered; stratum 7 contains occasional streaks of shaly water-bearing sand. In the Capitol well, at 400 feet, a small flow having a disagreeable odor was encountered. The beds marked 2, or the 315 feet of Trinity (Travis Peak) sands, consist of alternate bands of from 25 to 35 feet of thin sand and from 5 to 6 feet of brown and reddish shale, and are the equivalent of the t^1 and t^2 artesian reservoirs of the Waco wells.

These strata represented the following formations:

10. The lower part of the 80 feet of dark shale is the Eagle Ford shale, locally known as the "Fish beds." The surface portion is composed of Pleistocene terrace material.

9. The 25 feet of very hard limestone represent the upper portion of the Buda beds.

8. The 90 feet of blue marls are the Del Rio beds.

7. The 1,105 feet of limestone include 70 feet of the Fort Worth limestone, about 250 feet of the Edwards limestone, about 60 feet of the Comanche Peak and Walnut beds, 450 to 500 feet of the Glen Rose formation, and 275 to 225 feet of the Travis Peak.

6–2. These beds (490 feet) are probably the basement beds of the Travis Peak formation of the Trinity division.

1. This stratum may or may not belong to formations older than the Cretaceous.

It should be borne in mind that the thickness of strata as reported from churn well drillings is never accurate within 10 feet or more.

The Groom well, altitude 615 feet, is 1,300 feet deep, and is said to receive its supply of water from stratum 6. The total depth of the new Capitol well is about 1,450 feet. Its water is supposed to have its source in a stratum similar to that of the Groom well, but 100 feet deeper. The surface of the Capitol well is 65 feet lower than the Groom well. This would give a difference of 165 feet in the depth of stratum 6 in the two wells. This difference may result from downthrow by faulting between the two localities.

The St. Edward's well, sunk in the winter of 1892–93, is 2,053 feet deep and obtains its supply from the basement reservoirs (t^1 and t^2). At this point the surface is near the top of the Austin chalk and is 500 feet above the bottom of the blue marl.

The following record of the Natatorium well, on East Fifth street, will also afford an idea of the nature of the rocks encountered.

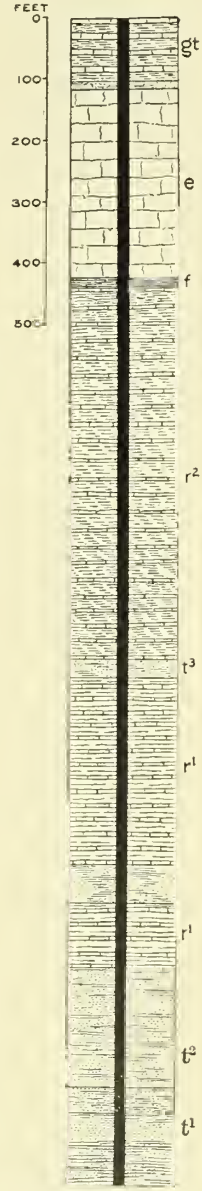


FIG. 59.—Details of the Natatorium well at Austin, Texas, from the Georgetown formation to bottom. (For explanation of symbols see Pl. XVI, p. 110.)

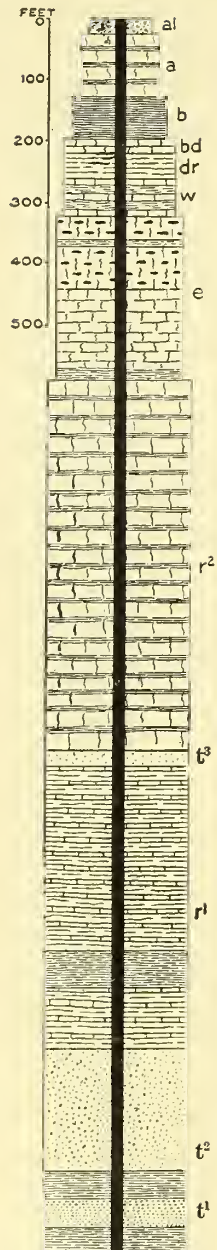


Fig. 60.—Artesian well at Natatorium, Austin, Texas. (For explanation of symbols see Pl. XVI, p. 110.)

Section No. 78.—Section of well corner of Fifth and San Jacinto streets, Austin, Travis County, Texas.

(See fig. 60.)

	Thickness.	Depth.
	Feet.	*Feet.*
19. Surface dirt	20	20
18. Gravel bed (water)	5	25
17. Limestone	100	125
16. Shale	70	195
15. Limestone	25	220
14. Blue marl	40	260
13. Limestone	100	360
12. Sand rock	10	370
11. Limestone	70	440
10. Sand rock and limestone (f) (sulphur water *a*)	150	590
9. Limestone (r^2)	600	1,190
8. Sand rock (water) (r or t^3)	25	1,215
7. Limestone (r^1)	300	1,515
6. Blue shale	60	1,575
5. Limestone (r^1)	100	1,675
4. Sand rock, main flow (t^2)	200	1,875
3. Blue shale	40	1,915
2. Sand rock (t^1)	50	1,965
1. Blue shale	60	2,025
Shale	....	....

a See analysis, table opposite p. 448.

The well at the Colored Asylum, 2 or 3 miles northwest of the State capitol, commences in the Buda limestone and passes through the Del Rio and Fort Worth beds and the Edwards limestone, penetrating the Glen Rose formation. The water probably comes from the t^3 reservoir. It does not rise to the surface.

It has not been possible to obtain a complete log of the second well bored by the State upon the capitol grounds about ten years ago. It is reported that it was drilled to about 1,450 feet and stopped just as it reached and before completely penetrating the greater Basement group of water-bearing strata. Hence its flow, which probably comes from the t^3 reservoir, is feeble.

A valuable contribution to the knowledge of the extent of the artesian field in Travis County was made by the drilling of the well at Manor in 1895. This well is situated about 20 miles east of Austin, near the extreme eastern margin of the Black Prairie and on the outcrop of the base of the lower portion of the equivalent of the Eagle Pass beds. Through the kindness of Mr. G. J. Eppright the writer has obtained the following log of this well, which enables him to locate the water vein with some definiteness and also to ascertain the thickness of the Taylor and Austin beds of the Upper Cretaceous, which had not before been accurately measured. (See fig. 61.)

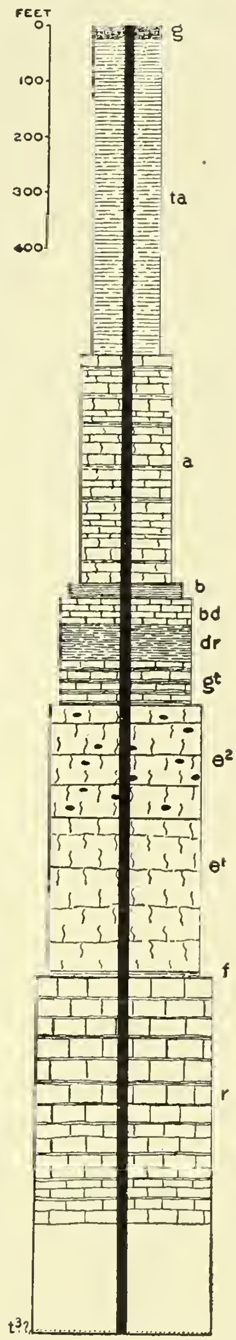


FIG. 61.—Partial section of well at Manor, Texas. (For explanation of symbols see Pl. XVI, p. 110.)

SECTION NO. 79.—LOG OF ARTESIAN WELL AT MANOR, TEXAS, BY G. J. EPPRIGHT, CONTRACTOR.

(See fig. 61.)

	Thickness.	Depth.
	Feet.	*Feet.*
16. Black soil (g)	6	6
15. Yellow clay (g)	11	17
14. Flint rock and gravel (g)	3	20
13. Yellow and joint clay (g)	30	50
12. Blue clay. At 400 feet blue clay gets lighter color; from 435 to 480 very dark and caves some (ta)	540	590
11. Rock. At about 800 feet deep soft strata in rock (a)	410	1,000
10. Shale. Caves badly (b)	25	1,025
9. Hard rock (bd)	50	1,075
8. Blue clay (dr)	60	1,135
7. Lime rock. Water at 1,250 feet—no good (gt)	115	1,250
6. Rock. At 1,300 feet pyrites bowlder (e)	50	1,300
5. Rock. Hard and soft in places (e)	70	1,370
4. Sandy and soft rock (e)	8	1,378
3. Limestone (e)	42	1,420
Stopped drilling at 1,420 feet, in hard gray rock. (r?)		

Mr. Eppright's contract ceased at 1,420 feet. The well was continued below that point by

Mr. W. H. McGillvray to a depth of 2,000 feet. The following record below 1,420 feet is from Mr. McGillvray:

Section No. 79, continued.—Log of artesian well at Manor, Texas.

	Thickness.	Total depth.
	Feet.	*Feet.*
3. Solid limestone	480	1,900
2. Blue marl	10	1,910
1. Solid limestone	440	2,350

At a depth of 2,350 feet Mr. Wilbahn succeeded Mr. McGillvray as contractor. He carried the well down to 2,560 feet. The writer has been unable to secure a log of the 210 feet drilled by Mr. Wilbahn. At 2,560 feet flowing water was obtained in a fine-grained calcareous sand.

Having very recently studied the section of the rocks through which the Manor well passes, the writer can approximately identify the different strata as follows:

16, 15, and 14 are the post-Cretaceous Uvalde formation, here having a total thickness of 20 feet.

13 to 12 are the Webberville and Taylor marls or "joint clays."

11, 10, and 9 are the Austin chalk, having an aggregate thickness of 410 feet.

8 is the Eagle Ford shale, and is stratum 10 of the Asylum well section at Austin.

7 is the Buda limestone.

6 is the Del Rio clay.

5, 4, and 3 are the upper part of the limestone group, 7 on the Austin section.

2. Salt clay occurs at 1,920 feet.

1. Bottom of well at last information, April 19, 1897, was 2,220 feet. This lies close to the base of the Cretaceous system at a depth of from 1,400 to 1,750 feet below the top of the Buda limestone.

Quantity of water discharged per hour when well was at a depth of 1,420 feet, 4,166$\frac{2}{3}$ gallons. Size of discharge pipe, 6 inches. Temperature of water, 93°.

Water from the f reservoir will rise in pipe about 30 feet above the surface. The first effort to drill this well failed, as it caved in at the depth of about 1,100 feet. The present well, bored by Mr. G. J. Eppright, was finished about February 13, 1896, and cost $4,060.

A specimen of the sand from the bottom of the well was kindly furnished by Mr. Eppright. It is a very fine-grained calcareous pack sand, such as is always found at a considerable distance above the Paleozoic floor of the Cretaceous rocks and indicates that the basement or t^1 reservoir has not yet been reached at Manor. The present water at 2,560 feet in all probability represents the t^2 reservoir.

The base of the Austin chalk in the Manor well is 1,000 feet below the surface. At Austin 1,900 feet of strata intervene between this horizon and the bottom of the t^1 reservoir. The Manor well has penetrated only 1,560 feet of the strata below the Austin chalk, and still lacks 340 feet of attaining the depth which has been reached at Austin. To this must probably be added 140 feet or more, representing the average eastward thickening of the strata, making a total of 480 feet which must be drilled to reach the bottom of the Cretaceous at a depth of 3,040 feet.

All the information the writer has been able to obtain concerning the deep flowing wells of Austin and Manor is plotted upon figs. 59 and 61, and Pl. LVI. He has endeavored to show the geologic position of the surface at the location of the well, and has referred all the wells to a common geologic datum—the top of the Buda limestone, which seems to be recognizable in most of the well records.

From the records thus plotted valuable generalizations can be made, as follows: There are at least three important water-bearing horizons in the Lower Cretaceous series beneath Austin. The first of these, the Fredericksburg reservoir, which is conspicuously illustrated by the Manor flow of 1896, is recognizable in the old and new Capitol wells and in the Sixth street well. This water was also probably struck in the other three wells, but we have no detailed record thereof. It is highly charged with sulphur and injurious mineral ingredients, as will be described later, and in all instances where encountered should be cased off. This water is most probably obtained in the Edwards beds from strata which, according to the best computations we can make at present, lie from 21 to 50 feet below their summit, or 90 to 140 feet below the summit of the combined Georgetown-Edwards limestone group, commencing below the Del Rio clays.[1]

The next flowing reservoir (t^3) occurs about 1,000 feet lower in the series, in strata which may be considered as practically the transition ground between the Glen Rose and Travis Peak beds. This water is from the uppermost of the water-bearing strata characterizing the base of the Cretaceous.

In the Asylum well the above-mentioned flow is separated by about 160 feet of limestone and shale from the third and lowest of the water reservoirs (t^1 and t^2) the basement, Travis Peak, or "Trinity" sands. This is ordinarily the most productive of all the reservoirs of the series. According to Mr. McGillvray's record these water-bearing beds are 315 feet in thickness and are marked by thin bands of reddish clay.

So far as the data at hand can be interpreted it will be seen that

[1] According to the best computations we can make at present sulphur water was struck in the Edwards formation at a depth of 120 feet below the bottom of the Del Rio clays in the Sixth street well, 78 feet in the old Capitol well, 50 feet in the new Capitol well, and 35 feet in the Manor well.

only one of the wells has positively penetrated to the bottom of the entire series of beds composing the Cretaceous system, thereby exploiting its fullest capacity and reaching into the underlying impervious Paleozoic formations. This is the well at the insane asylum. It is very probable that the well at St. Edward's College has also penetrated the entire thickness of water-bearing strata, but we have been unable to obtain an exact log of it. All the other wells are incomplete, inasmuch as they have not reached the best water of the district—the t^1 reservoir.

WILLIAMSON COUNTY.

This county, with an area of about 1,148 square miles, has one of the most irregular outlines of any in Texas. Its width from north to south is 30 miles and from east to west nearly 55 miles. It comprises nearly all the belts of Black and Grand Prairie country, as shown upon the geologic map (Pl. LXVI), and is situated directly in the main artesian belt of counties.

The relief of the county, which is mapped upon the Taylor, Georgetown, Bastrop, and Austin atlas sheets of the United States Geological Survey, is diversified. In that portion of the county lying west of the Balcones fault, which approximately runs north and south through Round Rock, Georgetown, and Belton, it consists of the intensely dissected uplands of the Lampasas Cut Plain. East of this line the surface is composed of the rolling black land prairies. A narrow belt along the western prairie of the latter east of Round Rock, Georgetown, and Corn Hill represents the southern continuation of the Grand Prairie of the Fort Worth type. The altitude varies from 1,400 feet on the west to 500 feet on the extreme east.

GEOLOGY.

The surface rocks of the county consist of the Glen Rose, Walnut, Comanche Peak, and Edwards formations in the Lampasas Cut Plain, or that portion of the county west of the Balcones fault line. In this district the Edwards limestone is approximately a cap rock which surmounts the highest divides and dips coincidently with the regional slope. The other formations are exposed in the valley ways incised below the level of this plateau. In the Black Prairie region east of the Balcones fault line the formations in ascending series and succeeding each other eastward consist of the Edwards, the Georgetown, the Del Rio, and Buda formations of the Lower Cretaceous, which occur only in a narrow belt just along the western border of the Black Prairie, and the Austin and Taylor formations, which constitute the greater area of the Black Land country, and the Navarro and Eocene formation in the extreme eastern portion of the county.

The entire county is underlain by the Trinity and Fredericksburg reservoirs. The Paluxy and Woodbine reservoirs do not extend into this county. In the western part or district of the Lampasas Cut Plain the Fredericksburg reservoir is not embedded, and hence need not be considered. The Trinity reservoirs are available in the valleys of the many deeply-incised streams, such as the North and South Forks of the Salado, Barry Creek, the North and South Forks of the San Gabriel, and the headwaters of Brushy Creek, at depths of from 200 feet on the western edge to 500 feet at the Balcones fault zone.

The conditions in these valleys are very similar to those in the Lampasas Valley in Bell County, already described, only the valleys are not cut quite so deep beneath the regional surface as is the valley of that river, and hence the conditions for obtaining flowing wells are

FIG. 62.—Artesian map of Williamson County, Texas. Shaded portion indicates area where flowing wells may be obtained; ●, flowing wells from Trinity reservoir; ○, nonflowing wells from Trinity reservoir; figures indicate depths of wells in feet.

inferior. In the district east of the Balcones fault line the Fredericksburg and Trinity reservoirs are both embedded, owing to the sudden downthrow of the geologic series of approximately 500 feet along the fault line. At Round Rock, near the western border of this district, the lower Trinity reservoir is some 1,400 feet from the surface and more deeply embedded eastward, as shown in the discussions of Bell County to the north and Travis County to the south.

The conditions at the extreme eastern corner of the county are very similar to those at Marlin and Hubbard City, except that the Paluxy and Woodbine reservoirs encountered in those wells would not be reached here, and it is doubtful if a well under 3,500 feet in depth would reach below the Fredericksburg division. Fortunately there are no cities or towns in this portion of the county requiring water supplies.

The value of the Fredericksburg (or San Antonio) reservoir in this county has not been fully determined. It is the writer's opinion, however, that the 1,500-foot well at Taylor obtains its water from this reservoir. This opinion is based upon studies of the geologic formations and the similarities in the occurrence of this water at Manor and Austin. According to his studies the Basement sands at Taylor should be fully 2,500 feet beneath the surface. In that portion of the county lying east of Taylor the reservoirs become practically embedded beyond the belt of availability, and the agricultural community must depend upon surface wells or cisterns.

The western half of Williamson County is mostly too high to permit the rise of artesian waters to the surface, except in the low stream valleys. Only the eastern third of the county is below 700 feet, and flowing water can not be expected to reach the surface in the remaining portions of the county, except possibly in the deep valleys west of a line drawn from Leander to Corn Hill.

In general, it may be concluded that in this county flowing wells from the Trinity reservoirs are not likely to be obtained on the uplands, except in those portions of the eastern half of the county below an altitude of 700 feet, and that such wells must be drilled to approximate depths of 2,000 feet or more, the depth increasing to the eastward. In the portion of the county west of the Balcones fault line nonflowing wells from these reservoirs should be obtained at depths of less than 900 feet, the depth decreasing to the westward. It is also probable that shallow flowing wells similar to those of southwestern Bell County and Coryell County may be obtained up the stream valleys of the forks of the San Gabriel anywhere west of the Balcones fault line.

DEVELOPMENT.

In Williamson County artesian experiments have been relatively few and incomplete, but some important deductions can be made from such wells as have been drilled. Several deep-flowing wells have been drilled at Taylor in the Black Prairie belt; one flowing well 96 feet deep is reported by Mrs. Mary S. Keen, 11 miles west of Georgetown, on the North Fork of the San Gabriel; one flowing well 279 feet deep, by T. Cooper, about 6 miles east of Georgetown, and a few shallow wells at the junction of Dry and Running Brushy creeks west of Round Rock.

The only complete artesian experiment thus far made in the county is the nonflowing well at Round Rock (altitude 720 feet). This well is 1,400 feet deep, and the water rises to within 4 feet of the surface. This well commences near the contact between the Washita and Fredericksburg divisions, and probably derives its water from the t^1 reservoir. The well penetrates nearly all the geologic series from the top of the Edwards to the base of the Trinity division, as shown in the

Austin section, deriving waters at 100 feet, 500 feet, and 1,400 feet from the Fredericksburg, t^3, and t^2 reservoirs, respectively. The 100-foot water is strongly mineral, and is derived from the Fredericksburg reservoir. The 500-foot water is also strongly impregnated with mineral matter. This is undoubtedly from the celestite and epsomite beds of the Glen Rose formation (t^3), while the 1,800-foot water is from one of the lower Trinity reservoirs (t^1 or t^2), as at Waco and Austin.

At Taylor (altitude 560 feet) several deep-flowing wells, the exact records of which are unobtainable, have been drilled to depths approximating 1,500 feet. The earliest of these wells flowed abundantly, throwing the water from a 4-inch pipe to a height of 40 feet, but the wells have ceased to flow at the surface. Another well drilled at this place failed to secure any flow at all. It is unfortunate that records and specimens from these wells were not preserved.

Mr. H. C. Mantor kindly furnishes the following data concerning the wells at Taylor:

There have been four deep wells bored in this city, as follows: First, a well in the north-central part of the city on the block south of the public school. This well was bored in the spring of 1890. It is 1,450 feet deep. At the time of its completion the flow was estimated at about 140,000 gallons in twenty-four hours; the flow has diminished somewhat, but is still more than 100,000 in twenty-four hours; the temperature of the water is something over 90°.

The second well was bored a few years later, and is situated about 350 feet west of the first well, and is 1,600 feet deep. The flow is small, but still continues. I can secure no estimate of the flow.

The third well is situated about 500 feet east of the first well. It is 2,400 feet deep, with a small and unsatisfactory flow. The second and third wells were sunk by the Taylor Water Company and they have them turned into their reservoir.

The fourth and last well is in the southern part of the city in the Washington Heights addition; it is nearly south of the first well, is 1,425 feet deep, and has a much better flow than any of the wells except the first; is a qualified success.

The water in all these wells does not appear to be suited to use in boilers and for mechanical purposes; is considered medicinal and splendid for bathing. I regret that I am able to give you only an incomplete report on these wells and that I can secure none of the rock gotten out of any of them; none has been preserved and so long a time has elapsed since they were bored that I can get none from the surface around them. All these wells are still flowing, but I think that the first one is the only really successful one; it was bored by a stock company, and the Washington Heights one by the parties owning that addition to the city.

The town of Taylor is situated upon a horizon of the Taylor marls from 600 to 800 feet above the base of the Austin chalk, below which, between Waco and Austin, the Trinity reservoirs lie at an average depth of 1,800 feet. It follows from this that Taylor is situated about 2,600 feet above the big flows of the Trinity, and the flow struck in the first well there, if its depth is 1,500 feet, as reported, must have been from a horizon much higher than the Trinity reservoirs—either at the top of the Glen Rose beds or in the Edwards limestone, more probably the latter. Hence the hypothetical conclusion is reached that the wells at Taylor have not been drilled to sufficient depths to fully exploit the artesian resources beneath that city and beneath the Black Prairie belt in Williamson County.

The following important deductions may be made from the Round Rock experiment (see fig. 63):

1. That the potable Trinity reservoir is reached in central Williamson County at a depth of 1,400 feet below the top of the Georgetown formation and should be reached at a similar depth at Georgetown and other points along the strike of that formation.

2. That the Trinity water will rise to about 715 feet above sea level in this vicinity.

3. That at Taylor, which is situated about 1,000 feet higher in the geologic series, the wells drilled have only penetrated approximately to the f reservoir, and are incomplete relative to the Trinity reservoirs by 900 feet of penetration.

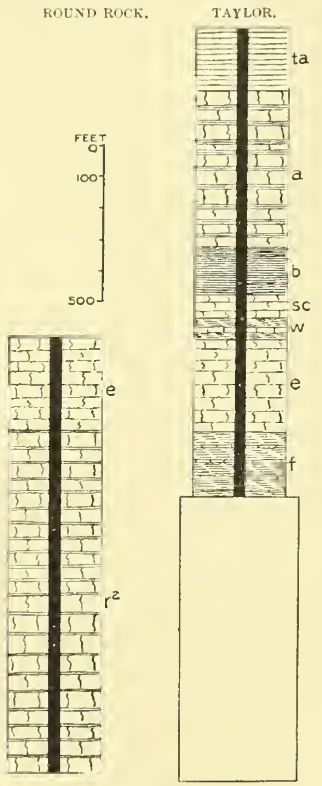


FIG. 63.—Comparison of wells at Round Rock and Taylor, Texas, showing incompleteness of latter. (For explanation of symbols see Pl. XVI, p. 110.)

A few miles above Round Rock, in the forks of Brushy Creek, there are some shallow flowing wells about 100 feet deep, which derive their water from the Glen Rose or t^3 reservoir.

Mrs. Keen's shallow flowing well upon the North Fork of the San Gabriel and those at the junction of the branches of Brushy Creek are shallow wells of the Glen Rose formation similar to those of the Lampasas Valley as described in Lampasas County.

Mr. T. Cooper reports a flowing well about 6 miles east of Georgetown and about one-third the distance between the latter town and Taylor, which is said to be only 279 feet deep. There is not sufficient data at hand to permit any conclusions concerning this well. The following material was penetrated:

SECTION NO. 80.—SECTION OF WELL OF T. COOPER, ABOUT 6 MILES EAST OF GEORGETOWN, WILLIAMSON COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
Gravel	15	15
Soapstone	255	270
Sandstone	9	279

At Georgetown, the county seat, no attempt has been made to secure a deep artesian well. Several wells have been drilled from 200 to 285 feet. The city well is 193 feet deep, and supplies fresh water, which is pumped to a stand pipe 114 feet above the San Gabriel River. The writer has an unverified report of an artesian well 2 miles east of the town which is 320 feet to first water and 520 feet to sulphur water. Another well, owned by Mr. Schell, between the North and South San Gabriel, is 310 feet deep. A well drilled at this place would probably pass through the same section as at Round Rock, and would have to go to the same depth, approximately 1,400 feet, to reach the Trinity reservoir. This water would not rise to the surface at the town (altitude at station 753 feet), but would probably flow in the valley of the San Gabriel in the northern suburbs, where the altitude is less than 650 feet.

Mr. R. R. Allen, well driller, states that his nonflowing well, 153 feet in depth, located 3 miles northeast of Cedar Park, was drilled six years ago, and contains about 100 feet of water. Drought has no effect on it. The material was white and blue limestone to within a few feet of water, when water was struck in sand rock. In his well, and in nearly all wells drilled by him, something like tar is found, having the smell of coal tar. Never, except in a few instances, has he found any amount of water in limestone. The depth of water varies from 100 to 300 feet.

Mr. H. C. Smith states that his nonflowing well is 169 feet deep and is located 2 miles southeast of Cedar Park. He gives the following data concerning it. The first 9 feet (Walnut formation) consists of petrified shells, yellow clay, and flint gravel, oyster shells predominating. The other 160 feet (Glen Rose formation) is solid limestone to red sand to an abundance of water, which rose rapidly to within 6 or 7 feet of the top of the well. A dry warm wind from north to southwest will lower the volume of water.

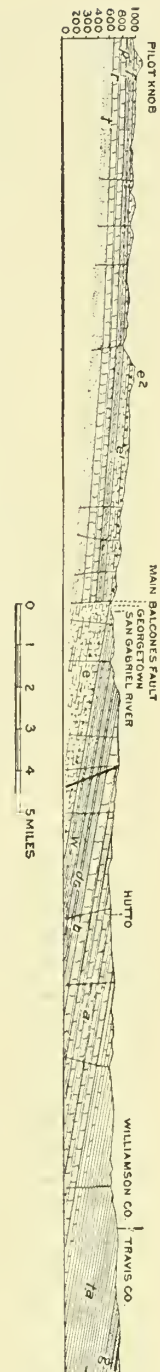


Fig. 61.—Section across a portion of Williamson County, after Taff. (For explanation of symbols see Pl. XVI, p. 110.)

The Postmaster at Walburg says: "In our immediate region are no artesian wells. There are a good many wells from 200 to 450 feet; most of them have good water, some sulphur. The limerock is from 250 to 300 feet deep. The water comes out of sand."

Mr. S. M. Morris, of Kelichor, says: "There are a few artesian wells in this locality, ranging from 260 to 2,000 feet. None of the water is fresh, most of it being sulphur. The deep wells flow hot or warm water."

Schedule of wells in Williamson County, Texas.

Owner.	Exact location.	Total depth.	Depth to first water.	Other waters.	Rise of water. *a*	Flowing wells. *a*	Quality. *b*	Irrigation. *a*
		Feet.	*Feet.*	*Feet.*				
A. P. Wagner	Bertram, 9 miles south of	390	390	.....	×	No.	1	×
M. S. Keen	Georgetown, 11 miles west of, on North Fork San Gabriel.	96	......	.....	......	×	......	No.
C. Smith	Leander, 5 miles southeast of.	132	......	.....	×	No.	{2, 7, 4}	No.
R. R. Allen	Cedar Park, 3 miles northeast.	153	123	.....	×	No.	{2, 4}	No.
H. C. Smith	Cedar Park, 2 miles southeast.	169	9	.....	×	No.	2	No.
J. Decker	Rutledge, ½ mile northeast	210	25±	.....	×	No.	2	No.
A. J. Robertson	Corn Hill, in	404	370	.....	122	No.	......	.
City well	Georgetown	193	......	.....	......	No.	......	.....
T. B. Champion	Round Rock, near depot in	1,400	100	.....	1,396	No.	......	No.
J. D. Robertson	Round Rock	1,400	{Lime 100}	{350, 550}	1,396	No.	......	No.
......	Georgetown, 2 miles east of	520	320	.....	......	×	......	.....
T. Cooper	Georgetown, about 6 miles east of.	279±	265±	.....	......	×	{1, 4}	No.
T. Bruce	Jonah, on hill, 1½ miles west of.	300	......	.....	250	No.	3	.....
C. N. Leatherwood	Gravis, ¾ miles east of	164	121	.....	......	No.	1	No.
A. Hancock	Gravis, 1 mile east of	170	140	.....	No.	No.	2	No.
P. L. Koontz	Gravis, 1½ miles north of	412	200	.....	322	No.	{red, 4}	No.
City well	Taylor	1,500	......	.....	......	×	......	.....
Taylor Water Co	do	1,600	......	.....	......	×	......	.....
Do	do	2,400	......	.....	......	×	......	.....
......	do	1,425	......	.....	......	×	......	.....

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

BELL COUNTY.

Bell County is so situated that its eastern half lies within the Black Prairie region and its western half within the Grand Prairie, the line of separation of these two districts passing approximately north and south through the center of Belton, the county seat, and west of Pendletonville. East of this line the country is the open rolling Black Prairie, no point of which attains an altitude greater than 750 feet. Even this altitude is attained in only one small area just north of Pendletonville.

The western half of the county represents the eastern border of the Lampasas Cut Plain, with deeply incised valleys of the Leon River and its principal tributaries from the west: Cowhouse Creek, South Noland River, Lampasas River, and Salado Creek. These creeks, with the exception of the Salado, have all cut deep valleys below the high flat-topped divides of the Lampasas Cut Plain. The summits of the latter attain an altitude of over 1,200 feet in the extreme western portion of the county. The valley of the Leon River extends north and south through the county until it reaches the Black Prairie east of Belton, when it turns southeast. This valley constitutes a wide

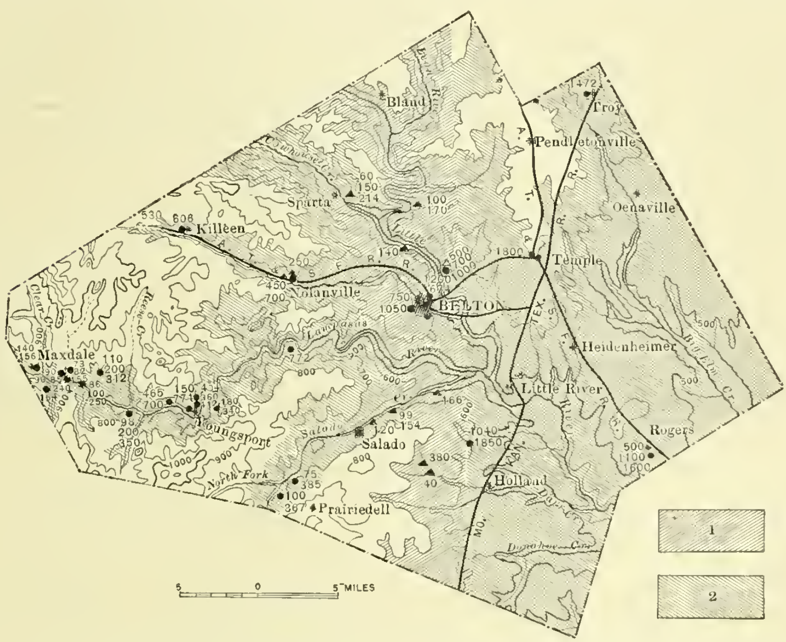


FIG. 65.—Artesian map of Bell County, Texas. 1, areas in which flowing wells can be obtained from the Fredericksburg reservoir; 2, areas where flowing wells are likely to be obtained; ●, wells from the Trinity reservoir; ▲, flowing wells from the Fredericksburg reservoir; figures indicate depths of wells in feet.

area below the general level of the country. All of the regions included in the valleys of the streams are so situated that flowing wells are obtainable in them at points below 750 and 800 feet in altitude.

The county is divisible into two artesian districts east and west of the Balcones fault zone, which extends in a northeast-southwest direction from the vicinity of Troy, between Belton and Temple, and west of Salado.

Bell County is underlain by the three artesian reservoirs of the Fredericksburg, Glen Rose, and Trinity systems, the last of which alone underlies the whole county and is the most reliable source of artesian water. There are no data for ascertaining the dip of these reservoirs east of the Balcones fault line except immediately along it, as at Temple and Waco. The same structural conditions probably continue in Bell County as in McLennan County, and if so the reservoirs rapidly deepen in eastern Bell County at the rate of 150 feet or more per mile.

The Paluxy and Fredericksburg artesian reservoirs are available in the western district at depths of from 300 to 750 feet above sea level, while the deeper Trinity reservoir is accessible at depths of from 300 feet above sea level at the western edge of the county to sea level at Belton.

The exceptional and but imperfectly understood reservoirs intercalated in the limestone strata of the Fredericksburg and Washita divisions, which we have classified under the head of the Fredericksburg system, are apparently the source of many shallow wells situated in a belt extending through the center of the county from Salado northward toward Pecan Grove, Coryell County.

The Glen Rose formation in Bell County is hardly worthy of consideration for economic purposes, the flow of water from it being inappreciable. It is chiefly valuable as a landmark to the driller. No wells are positively known to utilize the waters, although further study may show that some of the wells accredited to the San Antonio system originate in this reservoir.

The principal and best source of supply in both districts is the waters of the Trinity reservoirs, which are found at depths of from 400 to 500 feet above sea level at the extreme western edge of the western district to 983 feet below sea level at Troy, having an average inclination of about 40 feet per mile.[1] In the eastern district the depths of the wells are greatly increased by the downthrow of the Balcones fault, which amounts to about 260 feet between Belton and Temple.

The several reservoirs of the Trinity system are not as yet well classified in this county. It has been assumed that the reservoir 400 feet below sea level at Belton is not the Basement reservoir of the Trinity division, but the t² reservoir, which lies 100 feet or more above it. Unfortunately no specimen well cores have ever been procured from this county whereby this point could be determined positively. Mr. S. H. Walton, whose wide practical experience entitles his opinion to great consideration, writes: "The formation between the two Trinity flows at Gatesville [Coryell County,] just north of Bell County, is a red clay or something of that nature, and the lower flow of water is found in a red gravel. It has been the opinion that there is no water below the first Trinity sand [t²] struck at Belton, but from the work done at Gatesville it would indicate that there is another flow of water below the sand in which we find the water at Belton, or

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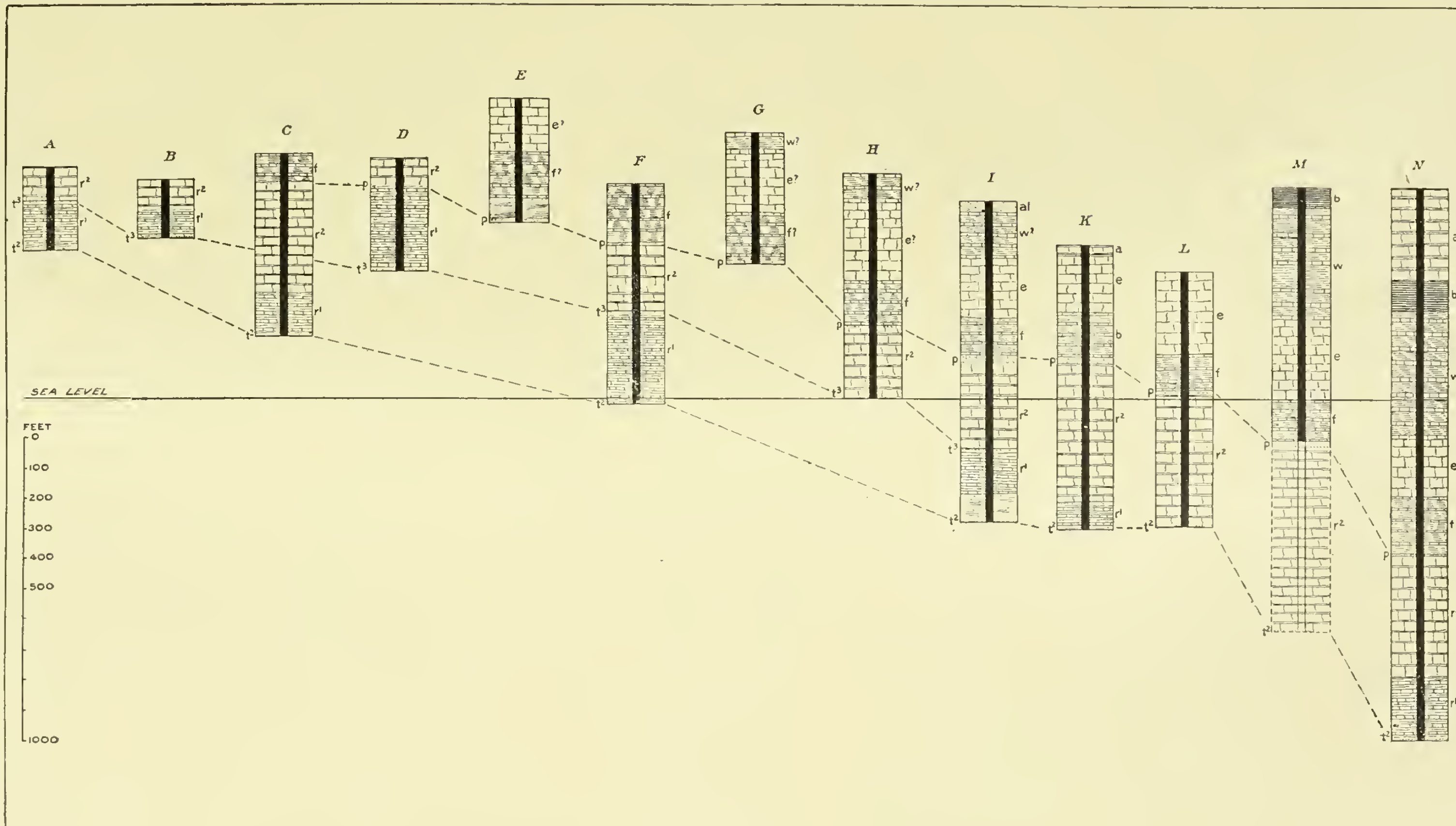
[1] The dip of the t² reservoir in a distance of 16½ miles from Killeen to Belton is about 640 feet, or at the rate of 39 feet per mile.



WELLS OF BELL COUNTY, TEXAS.

A, 1½ miles southwest of Maxdale; *B*, Maxdale; *C*, Killeen; *D*, 4 miles west of Youngsport; *E*, 1½ miles north of Youngsport; *F*, Youngsport; *G*, 1¼ miles east of Youngsport; *H*, 4 miles west of Belton; *I*, J. L. Miller's well, 1 mile southwest of Belton; *K*, A. J. Harris's well at Belton; *L*, Belton jail; *M*, Troy; *N*, Temple.

else the two strata come together somewhere between Belton and Gatesville."

On the other hand, two reports from Belton testify to a black clay at the bottom of the wells which has every aspect of the Paleozoic rocks at the bottom of the Cretaceous system. This clay at the bottom of J. Miller's well is so tough the drill would not cut it so it could be pumped out, neither would water soften or dissolve it so it could be removed. A small specimen from one of the wells at Belton would undoubtedly settle this question.

Between Belton and Lampasas there are important structural and stratigraphic differences bearing upon the Trinity reservoirs. The rocks of the old Paleozoic floor, which outcrop at Lampasas, rise more rapidly here than they do to the northward, and the strata of the Trinity division grow correspondingly thin quite rapidly along this line and become more arenaceous, resulting in several minor water reservoirs encountered in wells in southwestern Bell and northwestern Burnet counties at Oakalla, Maxdale, and Burnet, which are not met with in wells to the east. These variations prevent a classification of these various Trinity reservoirs.

DEVELOPMENT.

Bell County possesses many excellent artesian wells, varying in depth from 100 to 1,800 feet. These are nearly all situated approximately west of the Missouri, Kansas and Texas Railway in the Black Prairie region and in the valleys of the Leon, Salado, Lampasas, and Noland rivers. Returns have been received showing in all the following wells:

Schedule of wells in Bell County, Texas.

WELLS DERIVING THEIR WATERS FROM THE FREDERICKSBURG OR PALUXY RESERVOIRS.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water. *a*	Flowing well. *a*	Increase. *a*	Decrease noted. *a*	Quality. *b*	Irrigation. *a*
			Feet.	*Feet.*	*Feet.*								
Love & Kohn....	Salado, northeast of.	.....	120	120	.....	W.	f?	.....	×	...	...	1	×
W. P. Wells......	Salado, 2½ miles east of.	....	159	94	.....	W.	f?	.....	×	...	×	1, 4	..
J. C. Moore.......	Salado, 5 miles southeast of.	.....	412	60	.....	W.	f?	15	No.	...	...	2	...
J. V. Jones.......	Salado, 3 miles east of.	....	150	80	.....	W.	f?	.....	×	...	...	1, 4	..
Jim Ferguson ...	Salado, 4 miles east of, near Salado Creek.	.....	166	50	.....	W?	f?	.....	×	...	...	4	×
T. Jones.........	Belton............	.....	100	100	.....	......	......	.....	×	...	...	1	...

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

Schedule of wells in Bell County, Texas—Continued.

WELLS DERIVING THEIR WATERS FROM THE FREDERICKSBURG OR PALUXY RESERVOIRS—Continued.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water.	Flowing well.	Increase.	Decrease noted.	Quality.	Irrigation.
			Feet.	*Feet.*	*Feet.*								
S. H. Walton (reports).	Belton, 4 miles northwest of.	....	140	....	....	W.	f?	....	×	....	....	....	....
J. M. Dodson.....	Bland post-office, 2½ miles northwest of.	....	165	165	....	....	....	....	×	....	....	1	....
J. A. Morgan.....	Belton, 6 miles north of, on Leon River.	....	170	100	124	F.	....	....	×	....	....	4	....
M. N. Walton	Sparta, ¼ mile east of.	....	214	p ^{t3}, 60 ^{t2}	150, 214	F.	p?, t^3, t^2	....	×	....	×	3	....

VALLEY WELLS OF THE WESTERN DISTRICT DERIVING WATERS FROM THE TRINITY RESERVOIRS.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water.	Flowing well.	Increase.	Decrease noted.	Quality.	Irrigation.
T. A. Speer.......	Maxdale, 2 miles west of.	....	156	140	....	gr?	t^3	....	No.	....	....	1	....
E. H. Hammack .	Maxdale, 2 miles southwest of, on slope near Goodland.	....	164	90	....	gr?	t^3, t^2	....	No.	....	....	1	....
M. Carpenter	Maxdale, 1 mile south of.	....	116	116	....	gr?	t^3	....	×	....	....	4	....
F. N. McBride ...	Maxdale, ½ mile south of.	....	240	90±	185	gr?	t^2, t^3	....	×	....	....	....	....
W. L. Story	Maxdale	....	155	73	82	gr	t^4	....	No.	....	×	4	....
J. T. Hunt	Maxdale, ½ mile south of, on Lampasas River.	....	285	125	255	gr	t^3, t^2	....	No.	....	....	1	....
W. M. Hoover....	Maxdale, 1½ miles southeast of.	....	150	36	100, 114	r?	t^3, t^2		....	....	....	2	....
J. P. Hoover	Maxdale, 2 miles east of, on Lampasas River.	....	312	60	120, 200	....	t^2, t^3, t^1	....	×	....	....	1	....
Bill Haynes	Youngsport, 4 miles west of.	....	380	98	200	r?	t^3, t^2, t^1	....	×	....	....	1	....
J. O. Stark	Youngsport, 100 yards northwest of post-office.	....	417	18	360, 412	r?	t^2, t^3	....	×	×	....	1	×
J. E. Place	Youngsport	....	404	160	325	r?	t^3, t^2, t^1	....	×	....	....	1	....
W. P. Wells	Youngsport, ½ mile north of.	....	444	150	412	r?	t^3, t^1	....	×	....	....	1	×
Baker & Vickory.	Belton, 10 miles west of.	....	+300	300	....	r?	t	....	×	....	....	....	....
Joel Ray	Youngsport, 1 mile east of.	....	340	180	....	r?	t	....	×	....	....	1, 3	....
P. C. Mitchell....	Youngsport, 1¼ miles east of.	....	433	170	....	r?	t	....	×	....	....	1	....
F. M. Robinson ..	Salado, 5 miles southwest of.	....	385	75	....	r?	t	....	×	....	....	3, 4, 8, 9	....
W. P. Wells	Salado, 4 miles southwest of.	....	385	....	....	r?	t	....	×	....	....	....	....
S. H. Walton (reports).	Youngsport road, 9 miles southwest of Belton.	....	772	....	....	r?	t	....	×	....	....	....	....
C. O. Ferguson...	Prairiedell, 2 miles west of.	....	367	100	....	r?	t	....	×	....	....	1, 4	....

Schedule of wells in Bell County, Texas—Continued.

VALLEY WELLS OF THE WESTERN DISTRICT DERIVING WATERS FROM THE TRINITY RESERVOIRS—Continued.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water.	Flowing well.	Increase.	Decrease noted.	Quality.	Irrigation.
			Feet.	*Feet.*	*Feet.*								
S. H. Walton (reports).	Belton, 19 miles west of.	.....	530	465	.....	r?	t	.....		...	...	...	...
Do...........	Killeen...........	.....	606	.....	.....	f	t	546	.....	...	...	...	...
F. Austin........	Belton, 9 miles southwest of.	.....	700	250	450	.....	t	.....	×	...	...	...	...
J. Miller..........	Belton, 1 mile southwest of Bell County court-house.	.....	1,060	750	1,000	W?	t^2	×	×	...	...	1, 3, 8	..
Ludlow..........	Belton, 1 mile south of.	.....	+1,000	300	700	W?	rt^2	.....	×	...	...	...	...
A. J. Harris......	In Belton..........	520	975	434	950	W?	rt^2	.....	×	...	...	1, 8, 10	×
H. A. Wear......	In Belton, 3 wells..	.....	900 to 1,200	450	.....	W?	rt^2, t^1	.....	×	...	×	1, 3, 4, 8	..
S. H. Walton (reports).	3 in Belton, averaging.	.....	1,000	.....	.....	W?	t	.....	×	...	...	...	...
W. Venable......	Belton, 2 miles northeast of.	.....	1,000	+300	+700	W?	rt	.....	×	...	...	...	×
J. L. Wallace.....	Holland, 6 miles north of; Belton, 10 miles southeast of.	.....	1,800	+300	1,040, 1,600	ta?	t	.....	×	...	...	1, 4, 11	..
C. L. Myers......	Troy..............	.....	1,473	.....	.....	a?	t	.....	×	...	...	1	×
S. H. Bowers.....	.....do...........	.....	1,474	.....	.....	a?	t	.....	×	...	...	1	...
J. W. Watson	Troy post-office, 150 yards from.	.....	1,464	.....	.....	a?	t	.....	×	...	...	1	...
J. E. Moore	Temple post-office, 1 mile west of.	.....	1,850	±100	.....	ta	t	.....	×	...	...	1	...
S. H. Walton (reports).	Well at Temple....	.....	1,800	.....	.....	ta	t	.....	×	...	...	...	...
Town well.......	In Rogers, near post-office.	.....	1,600	1,100	500	.....	.....	.....	.....	...	...	4	...

SHALLOW WELLS OF THE SAN ANTONIO AND GLEN ROSE SYSTEMS.

There is a belt of country 6 or 8 miles in width running north and south through central Bell County in which shallow flows of water sufficient for domestic purposes can be had. This belt extends from Salado Creek as far north at least as Gatesville.

There are about six or eight artesian wells of this character on Salado Creek that flow all the way from a few hundred gallons to 100,000 gallons in twenty-four hours, and range in depth from 125 feet to 350 feet. This water is used for domestic purposes, but is of a mineral character, with more sulphur in it than anything else.

According to Mr. Walton, the water is found in a drab-looking limestone which varies in thickness from a few feet to 75 feet. In some places this rock is very porous, and in others very close and hard, which causes some wells to flow more water than others. This limestone is undoubtedly one of the beds of the Fredericksburg division. Flowing water from this stratum can be had only in the valley of the Salado or in the valleys of some of the tributaries of that stream. It has very little pressure.

James E. Ferguson, who owns a flowing well 4 miles east of Salado, near Salado Creek, the total depth of which is 166 feet, first water about 50 feet, says: "There are seven wells within a radius of 6 miles of this well, and the flow in each was obtained at an average depth of 150 feet, and all are strong sulphur wells."

J. C. Moore, who owns a well 412 feet deep, located 5 miles southeast of Salado post-office, in the southern part of the county, says: "This well is on the top of a high hill. The formation (Washita and Fredericksburg) is lime rock, with soft streaks and hard ones all the way down; the hard part is white, the soft ones a little yellow, till near the bottom they get to a bed of bluish color; we did not have to case it; was hard enough to stand without."

According to the postmaster the ordinary wells of Prairiedell average about 150 feet; at that depth they are supposed to strike a nonfailing supply of water in the Fredericksburg division.

There are many artesian wells in the valley of the Leon, north of Belton, which apparently derive their waters from the same source as those at Salado; or, if not, from a reservoir which lies but a few feet below. Mr. Walton drilled one well of this character to 140 feet, 4 miles west of Belton on the Leon, and got about 10,000 gallons in twenty-four hours. Many others have been drilled which flow from 10,000 to 100,000 gallons.

J. A. Morgan, well driller, gives the following section of a flowing well drilled by him on the Leon River, 6 miles north of Belton. The total depth of this well is 170 feet; first water, 100 feet; other water, 124 feet.

Section No. 81.—Section of artesian well on Leon River, 6 miles north of Belton.

	Thickness.	Depth.
	Feet.	*Feet.*
5. Sand and clay	25	25
4. Blue limestone	70	95
3. White limestone	5	100
2. Sand or water rock	10	110
1. White limestone	24	134

Then change in every few feet from white lime to white sand. "The water began flowing at 100 feet and gradually grew stronger as far as

I drilled (170 feet)." These limestones are probably all of the Edwards formation.

Water from this system has also been found near Bland. The postmaster says: "Drilled wells in this section are from 160 to 250 feet, and almost all would flow if properly cased, for the water rises near the surface, and when cased flows out."

WELLS FROM THE TRINITY RESERVOIRS.

The Trinity reservoirs underlie all portions of Bell County and are available at depths ranging from 500 feet above sea level at the extreme western end of the county to 1,000 feet below sea level along the line of the Missouri, Kansas and Texas Railway. East of the main Balcones fault line these beds dip downward very rapidly until they are embedded over 2,000 feet below sea level at the eastern edge of the county. (See Pl. LXIX.) In the district west of the Balcones fault line water is obtained from depths ranging from 285 feet below the surface west of Maxdale, or about 700 feet above sea level, to a depth of about 700 feet below sea level at Troy. (See Pl. LVII, *B*.)

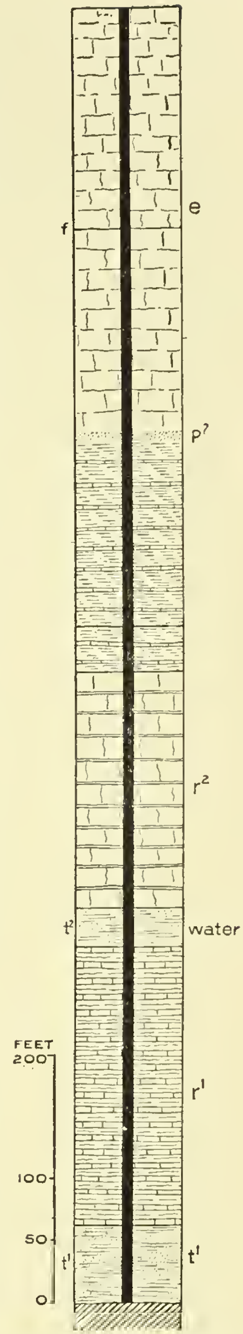


Fig. 66.—Log of well at Belton, Texas.

The development thus far has taken place principally along the incised valleys of the Lampasas, Noland, Cowhouse, and Leon rivers and in the upland eastern district, where deep wells have been drilled at Temple and near Little River. The chief development has been along the deep-cut valley of the Lampasas between Maxdale, at the extreme western edge of the county, and Youngsport. This region seems exceedingly prolific of artesian wells at depths of from 400 to 750 feet. The surface rocks along this valley are mostly of the Glen Rose formation, and hence no great amount of strata need be penetrated to reach water. There are many wells in the vicinity of Maxdale from 240 to 400 feet in depth (see Pl. LVII, *A* and *B*), which yield small flows—a few gallons a minute. Farther eastward, down the valley, there are three wells, at Youngsport, drilled to the Trinity reservoir, but owing to the elevation the flow is small. (See Pl. LVII, *E* and *F*.) There are also a number of similar small-flowing wells between Youngsport and the junction of the Lampasas and Leon.

Mr. J. O. Stark, who owns a flowing well 100 yards west of Youngsport, says: "The drills usually pass first through limestone rock; then a blue gravel; then a dark-colored sandstone; then blue calcareous rock again, finally reaching the water in a white pack sand."

There seem to be two or three water-bearing horizons or reservoirs in the Trinity system along this belt, and many of the wells stop before penetrating the lowest of these. Development does not seem to have been so extensive along the valley of Noland River, although experiments at Killeen, Nolandsville, and Belton show the availability and depth of the waters. At Killeen (see Pl. LVII, *C*), near the western edge of the county, altitude 835 feet, a well 606 feet deep found plenty of water, which rose to within 60 feet of the surface, or to an altitude of 775 feet. At Nolandsville the Trinity reservoirs were struck at 250, 450, and 700 feet. At Belton, still to the eastward, the lower two Trinity reservoirs were struck at 750 and 1,050 feet below the surface.

At Belton (see fig. 66) there are eight or ten deep artesian wells, which obtain waters at a depth of about 1,000 feet, or 240 feet below sea level. According to Mr. Walton, of Belton, these wells strike two of the Trinity reservoirs, from which flows are obtainable. They strike the first, which is only a small flow, at about 500 feet, and the lower, which is near the Basement reservoir, at 1,000 feet. These wells flow from 75,000 to 1,000,000 gallons of water in twenty-four hours, and the temperature is about 83°. The water, like that of all the wells from the Trinity reservoirs, is of good quality and contains a small percentage of salt, soda, and sulphur.

The geologic position of Belton is near the base of the Washita division. The top of the Edwards limestone is exposed in the banks of Noland River, which flows along the south side of the city. The following section, by Dr. Wilson Davidson, of the well at the county jail in the city of Belton shows the general character of the strata:

Section No. 82.—Section of well at county jail, Belton, Bell County, Texas (altitude 519 feet).

(Pl. LVII, *L*.)

	Thickness.	Depth.
	Feet.	*Feet.*
11. Soft limestone	25	25
10. Blue marl or slate (gt, e)	300	325
9. Blue limestone (gt, e)	50	375
8. White putty or mud (gt, e)	15	390
7. White limestone (soft) (gt, e)	50	440
6. Sand rock with iron pyrites (hard) (p?)	10	450
5. Limestone (Glen Rose)	100	550
4. White mud (Glen Rose)	25	575
3. White limestone (Glen Rose)	250	825
2. White mud	25	850
1. Sandstone (t^1?)	40	890

Mr. S. H. Walton says that the pressure of the wells at Belton ranges all the way from 25 to 75 pounds, depending on the elevation of the well.

The valley of the Cowhouse is a favorable location for artesian wells similar to those found along the Noland and Lampasas rivers, but the writer has received no reports of wells drilled along this stream, although they are found higher up its valley to the westward, in Coryell County.

The divides between the stream valleys are in general too high for procuring flowing wells from the Trinity, the limit of which seems to be the 800-foot contour in this portion of the State. The highest well in the eastern district of which a report has been received is located about 4 miles southwest of Salado. Mr. W. P. Wells, the driller, has kindly furnished the following log of this well:

Section No. 83.—Section of well 4 miles southwest of Salado, Bell County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Yellow limestone (Edwards), with some flint	80	80
3. Blue limestone (Walnut) in alternating layers of different degress of hardness	65	145
2. Alternating yellow, white, and blue limestone and marl (Glen Rose)	240	385
1. Pack sand (Trinity)	±10	395

The deepest well west of the main Balcones fault line so far reported is at Troy. (See Pl. LVII, *M*.) Two wells have been reported from this town which have very large flows of water having a temperature of 91° F. The water in the well of Mr. S. H. Bowers contains salt, soda, magnesium, and iron, but is well adapted for domestic and steam-making purposes. (See analysis facing p. 448.)

In that portion of Bell County lying eastward of the Balcones fault line and constituting the eastern artesian district there are only a few successful artesian wells. All of these are approximately 1,800 feet deep and commence in the Austin chalk or higher beds, and are located close to the western margin of the eastern district.

There are two of these wells at Temple. (See Pl. LVII, *N*.) One is in the center of the city, where the surface has an altitude of about 725 feet above sea level. It is estimated to flow about 100,000 gallons a day, which an air-tight pump will double. The waters are used to supply a natatorium. It is excellent for domestic use.

J. E. Moore owns a well about 1 mile west of the post-office in Temple and some 66 feet higher than the well in the center of the city, his well having an altitude of about 791 feet. This well does not flow, but is capable of supplying 50,000 gallons a day. These two wells are situated very near the limit to which water from the artesian reservoirs will rise to the surface. The writer has been unable to obtain an exact section of these wells, but from observations in adjacent regions would say that the strata passed through would be about as follows:

Section No. 84.—Theoretical section of well at Temple, Texas.

[Pl. LVII, N.]

	Thickness.	Depth.
	Feet.	*Feet.*
Austin chalk	500	500
Black bituminous clays of the Eagle Ford formation	125	625
Blue calcareous clays and thin limestone of the Washita division	300	925
Hard white limestone (Edwards)	300	1,225
Softer blue limestone and clay in alternating degrees of hardness (Walnut)	115	1,340
Thin sand	10	1,350
Alternating white, yellow, and blue limestones and marls (Glen Rose)	400	1,750
Trinity sands	50	1,800

The Temple wells penetrate nearly 1,000 feet more strata than the Belton wells, including all of the formations of the Washita division and the Eagle Ford and Austin chalk of the Upper Cretaceous.

The only other well reported east of the fault line is the well of Mr. J. J. Wallace, located 6 miles north of Holland, about 10 miles southeast of Belton. This is geologically situated similarly to the Temple wells, penetrates the same strata, and obtains water at the same depth.

East of these two wells the water reservoirs deepen very rapidly. It is doubtful if the Marlin well has as yet reached the t^1 and t^2 reservoirs, from which Temple derives its water. Assuming that it has, the inclination of the reservoirs would be at the rate of at least 40 feet per mile. Therefore the Trinity reservoir, which is 1,000 feet below sea level at Temple, is over 2,500 feet below sea level at Marlin, about 25 miles to the east. In the eastern portion of Bell County the conditions for obtaining underground waters at shallow depths are exceedingly unfavorable. Several experiments have been made at Rogers, where unsuccessful wells have been drilled to a depth of 1,600 feet. These will probably have to be carried at least 400 feet deeper to reach the upper horizon of the Belton well and probably to a depth of 2,500 feet before reaching the main Trinity reservoir.

M'LENNAN COUNTY.

[See Pls. LXVIII, LXIX, LXX, and fig. 67.]

McLennan County has an area of 1,055 square miles, and is one of the most fertile and prosperous in Texas. Its surface consists of rich black prairie underlain by the Cretaceous formations from the Fredericksburg division upward, which outcrop in successive subparallel belts to the eastward, extending in a north-south direction across the county. The whole eastern half lies within the area of the Black

FIG. 67.—Artesian map of McLennan County, Texas. Shaded portion indicates area of possible flow from the Burnet-Trinity reservoirs; ●, flowing wells from Trinity reservoir; ○, nonflowing wells from Trinity reservoir; ■, flowing wells from Paluxy reservoir; □, nonflowing wells from Paluxy reservoir; △, nonflowing wells from Fredericksburg reservoir; figures indicate depths of wells in feet.

Prairie, while the western portion is upon the eastern border of the Grand Prairie. The broad and fertile alluvial valley of the Brazos River cuts directly across the trend of these upland prairie belts, and thus the county is richly endowed with the two most fertile types of soil in Texas.

There are only two conspicuous relief features in this county. These are the Brazos Valley, the bluffs of which are seldom over 100 feet high, and the White Rock escarpment, which extends east of north and west of south through the center of the county, especially south of the Brazos River along the east side of the South Bosque River.

The highest altitude is at the extreme western corner, where a small area attains 950 feet. No other point east of the Gulf, Colorado and Santa Fe Railway, except a small area just east of Moody, attains an altitude of over 800 feet. The summit of the White Rock scarp varies from 650 feet near West to 783 feet just east of Moody. Toward the eastern edge of the county the altitude of the divides does not exceed 534 feet, which is reached at Axtel. The uplands of McLennan County may be said to lie between the extreme altitudes of 950 feet on the west and 534 feet on the east, giving a total regional slope of 416 feet in a distance of about 36 miles, or about 14⅓ feet per mile. The Brazos Valley, which cuts diagonally across this plain, decreases in altitude from 425 feet upon the west to 350 feet upon the east. In general it may be said that the greater part of McLennan County, with the exception of a small area in the extreme western corner and the heights east of Moody, lies below an altitude of 750 feet, and hence is hypsometrically so situated as to be within the available field of flowing wells from the Trinity reservoirs.[1]

McLennan County is partially underlain by the Woodbine and Paluxy formations, and entirely by the Trinity formation. Of these the first is known to exist only beneath the northeastern portion, in the vicinity of Gerald, and is of no water value. The Paluxy waters are feeble and, with certain exceptions, unreliable, and hence the Trinity reservoirs constitute the only valuable and reliable source of supply.

There are at least 3 available reservoirs in the Trinity system (t^1, t^2, t^3) beneath this county. (See Pl. LVIII.) The lowest of these systems (t^1) has probably been reached only in the deep wells in the city of Waco and at Farwell Heights, 3 miles to the northwest of Waco.

The chief supply of the wells of the county may probably be derived from the water-bearing strata of the t^2 reservoir. Mr. Padgett's well on the South Bosque, 5 miles west of Waco; Prather's well, 6 miles southwest of Waco, and the wells at Eddy, Bruceville, Lorena, China Springs, and Crawford, in the writer's opinion have not penetrated to the lowest water, as can be seen from the figures given on Pl. LVIII. The upper or t^3 reservoir is of little value and need hardly be considered.

As a whole, these reservoirs become more deeply embedded from east to west. There are some differences about the inclination, availability, and value of the Trinity reservoirs in McLennan County which

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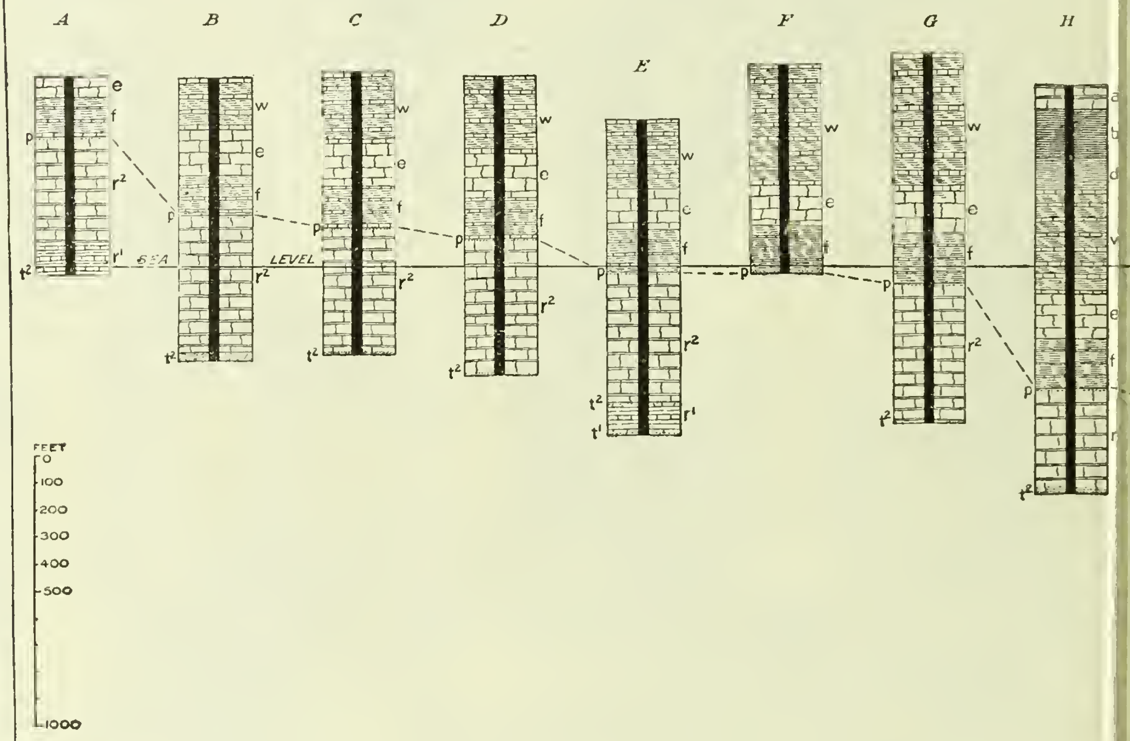
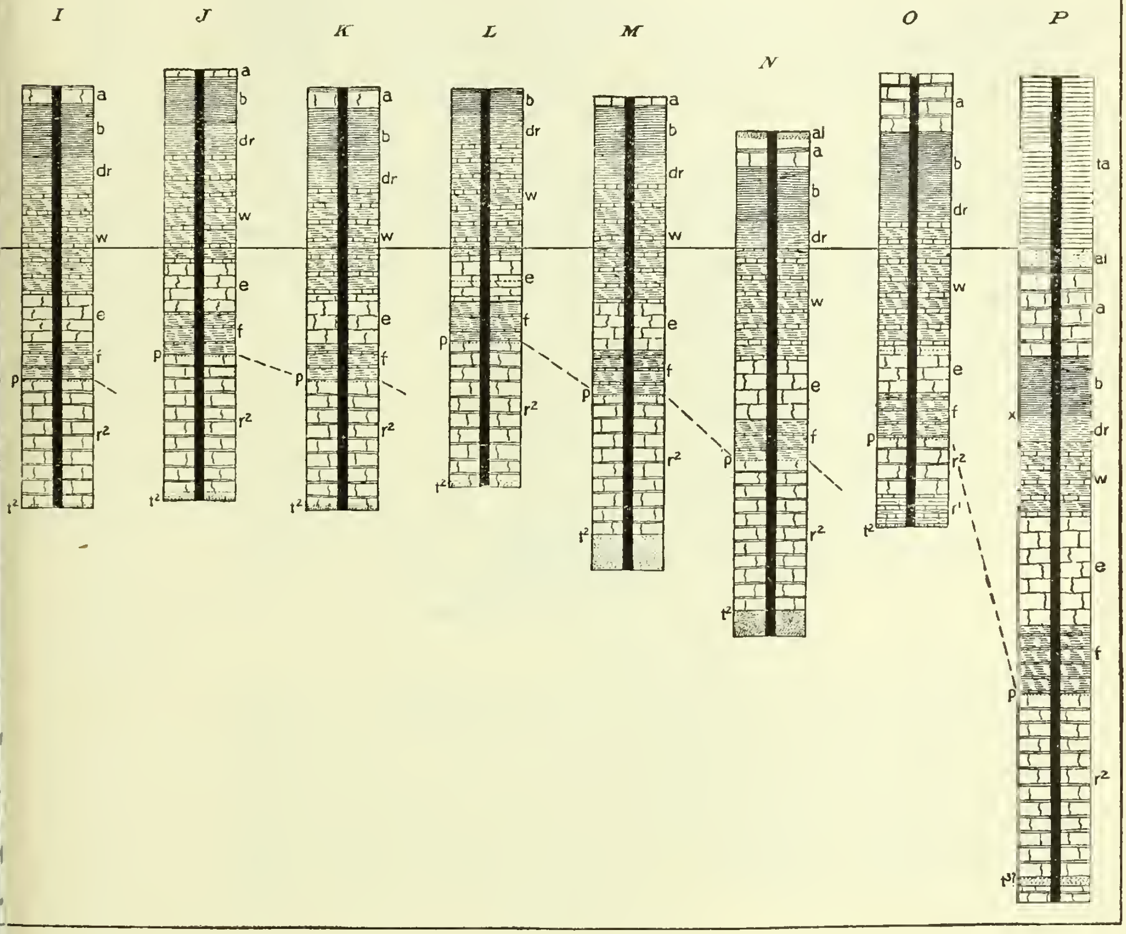
[1] Topographic maps of the western four-fifths of McLennan County will be found on the Waco, Temple, Gatesville, and Meridian atlas sheets of the United States Geological Survey.



WELLS OF McLENNAN A

A, Clifton, Bosque County. *B*, Crawford; *C*, McGregor; *D*, Ocee; *E*, China Springs; *F*, R. F. Barnes's well, 5 miles west of Lorena *G*
N, Padgett well, in Waco;



)SQUE COUNTIES, TEXAS.

y; *H*, Eddy; *I*, Padgett well, 5 miles west of Waco; *J*, Prather well, southwest of Waco; *K*, Bruce; *L*, Lorena well; *M*, Farwell Heights;
t; *P*, Marlin, Falls County

must be explained. In the first place, the reservoirs have different degrees of inclination east and west of the Balcones fault line, which runs diagonally north and south through the county and divides it into two distinct artesian districts. This fault line zone extends from the vicinity of Temple northward, just west of Waco, through the extreme northeastern corner of the county, and results in a break in the regularity of inclination whereby all the strata east of that line are dropped 200 to 300 feet or more. Hence the reservoirs east of this fault zone are somewhat deeper than they would be were the continuity of the dip unbroken.

The exact course of the Balcones fault line has not been mapped. It probably cuts the water-bearing strata just west of Waco, between the wells of that city which lie on its downthrown side and those of Prather and Padgett's places and Hermosa, which are upon the upthrown side.

The reservoirs of the Trinity and the Paluxy systems dip from west to east at divergent angles, and hence the distance between them constantly increases to the eastward. A calculation based upon a line between Clifton and Hermosa, 24 miles apart, shows that the Paluxy sands are 480 feet above sea level at the former place and 120 feet below, or 600 feet lower, at the latter, and dip at the rate of about 25 feet per mile. The Trinity reservoir (t^2) is at sea level at Clifton and is 800 feet below sea level at Hermosa; hence it dips at the rate of $33\frac{1}{3}$ feet to the mile. Therefore these strata become separated by an additional $8\frac{1}{2}$ feet in each mile to the eastward. The average dip of the t^2 reservoir west of the Balcones fault, as estimated from all possible data in McLennan County, is about 60 feet per mile.

Upon Pl. LVIII is a series of sections showing the depth and character of the wells of the county.

DEVELOPMENT.

Notwithstanding the remarkable fertility of the rich uplands of this county, the conditions that favor fertility of soil were inimical to the existence of surface and shallow underground waters, and hence artesian waters have been much desired and enterprisingly sought. Numerous artesian wells have been drilled in the county for the purpose of supplying water to the cities, villages, and farms. These wells are noted for their volume of flow and for the excellent character of their waters for domestic purposes.

The total number of wells from which we have been able to receive reports, and their general characters, are shown in the following table:

Schedule of wells in McLennan County, Texas.

WELL OBTAINING WATER PROBABLY FROM WOODBINE RESERVOIR.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water. *a*	Flowing wells.	Increase. *a*	Decrease. *a*	Quality. *b*	Temperature.	Irrigation.
			Feet.	*Feet.*	*Feet.*								°	
J. R. Varner	Gerald, 2 miles northwest of.	600+	296	240	....	a	x	×	+	.....	...	3	...	..

WELLS OBTAINING WATER FROM THE EQUIVALENT OF THE PALUXY-SAN ANTONIO RESERVOIR.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water.	Flowing wells.	Increase.	Decrease.	Quality.	Temperature.	Irrigation.
C. R. Walsh	1 mile north of Patton; 2 miles south of Valley Mills.	750	100	80 / 90	......	W	p	×	...	......	...	2	....	..
J. Arthur	McGregor, 1½ miles west of.	720	130	25	112	W	p	15 / 25	..	......	...	...	...	..
J. S. Elmore	McGregor, east of.	700	167	130	....	W	p	130	...	......	...	2	....	..
W. W. Dyerlie	South Bosque, 3 miles west of.	650	450	120 or 150	......	b?	p	×	×	......	...	1	....	..
L. Hanmah	South Bosque, 1 mile southeast of.	600	320	260	....	b?	p	×	...	......	...	3	....	..

WELLS OBTAINING WATER FROM THE UPPER TRINITY RESERVOIR (t^3) ONLY.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water.	Flowing wells.	Increase.	Decrease.	Quality.	Temperature.	Irrigation.
E. B. Cass reports.	McGregor, 5 miles west of.	825	490	80	410	p 80 / t^3 t^2	......	479	...	......	...	1	....	..
R. S. Barnes	Loreno, 5 miles west of.	650	760	600±	None.	t^3 t^2	......	......	×	......	...	6 / 3	....	..

WELLS OBTAINING FLOWING WATER FROM THE TRINITY RESERVOIRS (t^1) AND (t^3).

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water.	Flowing wells.	Increase.	Decrease.	Quality.	Temperature.	Irrigation.
W. M. Simpson	7 miles south of Valley Mills; 4 miles west of Crawford.	800	1,060	80	....	W.?	p t^1	.....	×	×	...	1 / 4 / 7	....	×
J. B. Nichols	Crawford	675	945	20	400 / oil / 350	W.	t^1	.....	×	......	...	1 / 5 / 8	....	..
Citizens' Water Co.	Crawford, 2 wells.	675	1,000 / 1,040	400	....	W.?	......	.....	×	×	×	1	....	×
M. M. Foster	2 miles south of Farr; 20 miles west of Waco.	.....	1,065	585	....	W.?	t^2 t^3	.....	×	......	...	1	....	..

a × = yes.

b 1, Soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

Schedule of wells in McLennan County, Texas—Continued.

WELLS OBTAINING FLOWING WATER FROM THE TRINITY RESERVOIRS (t^1) AND (t^3)—Continued.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water.	Flowing wells.	Increase.	Decrease.	Quality.	Temperature.	Irrigation.
			Feet.	*Feet.*	*Feet.*								°	
Capt. Higginson	13 miles west of Waco; 1 mile east of Ocee post-office.	600	1,098	550		W.?	t^2 t^3		×			1		×
McGregor Water Co.	McGregor	700	1,030	120	502	W.	pt^2 t^3	×				1	82	
China Springs Water Co.	China Springs in center of village of.	600	1,100	500	2 800	W.	pt^2 t^3		×			9		
W. C. Talbot	China Springs, 150 yards south of.	600	1,110	510	1,050	W.	pt^2 t^3		×			1		
	Moody	775	1,450			W.	t							
L. M. Carmony	do		1,508	400		W.	pt				×	1		×
J. M. Bedichek	Eddy	680	1,565	650	1,350 1,500	a	p_1t^2		×			1		×
Lorena Water Co.	Lorena	600	1,490	517		a, b	pt^2		×			1		×
G. B. Harris	Bruceville post-office, 100 feet northwest of.	600	1,560	600		a, b	pt^2		×			1		×
S. P. Field	Bruceville	600	1,565	500		a, b	pt^2		×			1		×
Bruceville Water Co.	Bruceville	600	1,560						×			6		
Mayor of West	West	660	1,690	1,040					×	×				
T. Padgett	Waco, 5 miles west of.	535?	1,470	1,000			t^2		×			1	90	×
J. Sleeper	In Farwell Heights, addition to Waco.	600?	1,730	670	1,400		t^2 t^1		×			1	103	×
W. L. Prather	Waco, 5 miles southwest of.	665	1,600			a	t^2		×				97	
Bell Water Co	Waco and vicinity, 11 wells.	420 500	1,828 to 1,860	1,100	1,812 and 1,850		pt^1 t^2 t^3		×		×	1	102 103	
Waco Artesian Water Co.	Waco, 5 wells	420 553	1,805 to 1,825	700 to 800	1,800 and 1,815		pt^1 t^2		×		×	1		×
M. V. Fort	Waco		1,825	725	1,300 1,825			×	×			1		×
Kellum	do													
Padgett well	do	420	1,866						×				103½	
H. C. Williams (report).	Lorena		1,800	800					×			1		

PROBABLE WELLS OF THE WOODBINE RESERVOIRS.

In the northeast corner of the county, in the vicinity of Gerald, water will probably rise from the Woodbine formation, which has its southern limitations in this vicinity. This water is salty, however, and does not flow to the surface. This is shown by the well of Mr. J. R. Varner, situated 2 miles west of Gerald. His well was drilled to a depth of

296 feet, passing through 80 feet of Austin chalk and about 160 feet of the Eagle Ford formation into the Woodbine formation. The two supposedly Woodbine reservoirs were struck at 240 and 296 feet. The water rose to within 40 feet of the surface but was so salty as to be unfit for use. Mr. W. J. Curtis, postmaster at Gerald, says there is very little underground water in this community and that several wells have been drilled from 50 to 700 feet without finding water. Gerald is near or at the southern limit of the Woodbine formation and this reservoir is of no value in McLennan County.

WELLS FROM THE FREDERICKSBURG, PALUXY, AND GLEN ROSE RESERVOIRS.

In the western portion of the county there are a number of wells upon the outcrop of the rocks of the Washita division of the same character as the wells of the Fredericksburg system. These obtain their supply from local reservoirs in the limestone of the Fredericksburg division and from the Paluxy reservoir (p).

According to Mr. C. L. Walsh, of Patton, who has been drilling wells in this portion of the county, the white limestones of the Fredericksburg and Washita divisions are usually at the surface and the first water which does not flow is struck in the lower portion of these in a calcareous material, which in some places is white and soft and in others dark and hard. From 100 to 200 feet below these the sulphur flow of the Paluxy reservoir is reached. This usually rises, but is so impregnated with sulphur and iron that only animals can drink it. From 500 to 600 feet below the surface a soft water (t^3), although slightly sulphurous, is struck in the upper portion of the Glen Rose beds.

There are a number of shallow wells in the vicinity of McGregor and South Bosque. The well of Mr. J. S. Elmore, situated east of McGregor, is of this character. Commencing in the rocks of the Washita division, at the surface, it penetrates about 100 feet of shelly white limestone and 25 feet of soft limestone until the water reservoir is reached in a porous calcareous stratum 30 feet below the latter. The water rises 130 feet within the well and furnishes about 60 barrels a day. It is hard and slightly salty. Still farther eastward the well of Mr. W. W. Dyerlie, 3 miles west of South Bosque, is also probably of this character, although it may possibly obtain its waters from the Paluxy horizon. His well discharges about 1,000 gallons per day. There are many other wells in the same neighborhood.

According to Mr. Walton, of Belton, the well of Mr. L. Hannah, one mile east of South Bosque, obtains its water from a limestone at the base of the Walnut formation. The water is salty and contains magnesium.

The waters from the Fredericksburg division are probably from the northern limits of a reservoir which attains more and more importance southward, especially in Bell and Travis counties. (See descriptions of these counties.)

McLennan County, as we have previously explained, is near the southern limit of availability of the Paluxy formation. Nevertheless, the flow from this source is recognizable in all the wells drilled, even in cases, as at Waco, where the sand formation is so attenuated that it is hardly recognizable. This water horizon is an important guide to the well-drillers, however, and in some cases wells have stopped in this reservoir without seeking a deeper supply. The well of Mr. R. S. Barnes, 5 miles west of Lorena, is apparently of this character. It is 760 feet deep. The well commenced at a horizon near the base of the Austin chalk and presents the following section:

SECTION No. 85.—LOG OF WELL OF MR. R. S. BARNES, 5 MILES WEST OF LORENA, TEXAS.

(See Pl. LVIII, *F*.)

	Thickness.	Depth.
	Feet.	*Feet.*
4. Top soil	10	10
3. Blue clay, soft above, hard below (Eagle Ford)	133	143
2. Hard white limestone with many fossil shells (Fredericksburg and Washita)	612	755
1. Fine white sand (Paluxy)	5	760

All of the wells which supposedly stop in the p and f reservoirs are incomplete in that they have not been continued to the best waters of the underlying systems. By going from 500 to 700 feet deeper, they would encounter the purer supply and more copious waters of the Trinity reservoirs.

WELLS FROM THE TRINITY RESERVOIRS.

As shown by the record elsewhere given, numerous wells have been drilled to the Trinity reservoirs in McLennan County. These have been found nearly everywhere west of the Missouri, Kansas and Texas Railroad. They are principally used as sources of village and city supply, although several enterprising farmers have drilled them. The chief source of supply in all these wells is the lower Trinity reservoirs (t^1 and t^2), principally the latter, which is situated only from 150 to 200 feet above the Basement sands or t^1. It has generally been the case that upon striking the t^2 reservoir the water has flowed so copiously that it was impossible to push the drill farther. The wells deriving their water from the t^2 and t^1 are among the most notable in the United States for their excellent flow and the superior quality of the waters for domestic and general uses. The principal wells drilled to these reservoirs are those at Crawford, Farr, McGregor, Ocee, Moody, China Springs, Eddy, the Prather farm west of Waco, Fishing Lake west of Waco, Bruceville, Lorena, Hermosa, Waco, and West. These are all in a belt of country about 24 miles wide, extending from the longitude of Clifton, Bosque County, which is just north of the western corner of McLennan County, where the t^2 reservoir is struck about sea level, to west of Waco, where the t^2 reservoir is struck at 850 feet below sea level, and to Waco, where the reservoir drops down nearly 300 feet lower. (See Pl. LVIII.)

The wells of this system in this county may be divided into two well-marked artesian districts east and west of the Balcones fault line. In the former district the reservoirs incline with the slight and uniform dip characteristic of the Grand Prairie country. East of the fault line the rate of dip rapidly increases, so that the reservoirs are soon carried to depths beyond reasonable availability.

WELLS OF THE WESTERN DISTRICT.

[See Pl. LVIII, *B*.]

In the vicinity of Crawford wells have been struck at a depth of 1,000 feet from the surface. Captain Higginson has a superb well of this character 1,100 feet deep upon his place, 1 mile east of Ocee post-office. The town of McGregor (see Pl. LVII, *C*) has two wells 1,030 feet deep, which furnish 200,000 gallons of soft freestone water a day. It is interesting to note that the water in these wells, which formerly flowed, now stands within 10 feet of the top. There are two of these wells in the village of China Springs (see Pl. LVIII, *E*), one of which, according to Mr. Talbott, the proprietor, discharges 56,000 gallons of potable water a day. There are two deep wells in the town of Moody (see Pl. LVIII, *G*), which is situated at an altitude of 775 feet, near the extreme altitude at which wells will flow. The well of M. L. Carmody is 1,508 feet deep and furnishes 100,000 gallons of pure soft water a day. One of the two wells in this village flowed until the other was drilled, and now the water stands in both of them within 15 feet of the surface. These wells begin at the top of the Lower Cretaceous. Their bottom is situated in a red clay, which, supposedly, overlies the t^1 reservoir.

A group of these wells at Eddy, Lorena, Bruceville, Prather's farm, and Fishing Lake west of Waco, present very similar characters and obtain water at depths varying from 1,450 to 1,600 feet and give copious flows. The well of Mr. John Sleeper, at Hermosa, on Farwell Heights (see Pl. LVIII, *M*), an addition to Waco, about 4 miles west of the city, is 1,730 feet deep and furnishes nearly 200,000 gallons of water, supplying 100 houses for all domestic purposes. The Balcones fault line is supposed to pass just east of this line of wells and the depth of water-bearing reservoirs increases some 200 feet. This is suggested by the fact that the Prather well, situated 5 miles west of Waco at an altitude of 665 feet, has to go only 1,600 feet for water to the t^2 reservoir, while in the city of Waco wells some 240 feet lower at the surface are obliged to go 1,782 feet.

WELLS OF THE EASTERN DISTRICT.

Successful wells have been drilled at Waco immediately east of the fault line, but they are obliged to go some 300 feet lower than the wells to the west. Many wells have been struck in the city of Waco east of this fault line. We have a record of some 21 wells in Waco which will be discussed later.

In the portion of the county east of a line drawn through West and Waco, no deep experiments have been made and no good flowing water is available at a less depth than 1,800 feet. At Marlin, Falls County, 23 miles east of this line, it was necessary to drill over 3,300 feet to obtain flowing water.

The only data for estimating the dip of the strata in that portion of McLennan County lying east of the fault line are the deep wells of Hubbard City, Hill County (see Pl. LIX, *O*), and Marlin, Falls County (see Pl. LVIII, *P*). The Paluxy water was struck in the former at a depth of 1,687 feet below sea level, and in the latter at a depth of 2,000 feet below sea level. By computation the inclination of these strata eastward estimated from Waco and Hillsboro is 95 feet per mile. This dip is so excessive that the Trinity waters, which are 1,400 feet below sea level at Waco, will be over 3,000 feet below sea level at any point 15 miles east of that city and hence practically beyond availability.

THE WACO WELLS.

Notwithstanding the rapid dip of the artesian reservoirs east of the fault line, there is a narrow zone of availability just to the east of it, at Waco, Austin, and elsewhere, which seems to be especially prolific of excellent artesian supply. Owing to the large number of these wells in Waco, and the excellence, copiousness, and temperature of the waters, Waco has been known in Texas as the "Geyser City." The average depth of the wells within the city limits is 1,842 feet. The following notes, kindly furnished by the secretary of the board of trade in 1891, will show the general character of these wells:

As regards the artesian wells in and around Waco, I will say that there are now eleven overflowing and two approaching completion.

Seven of the flowing wells and one nearing completion, now about 1,700 feet deep, are owned by the Bell Water Company. One of the flowing wells and one nearing completion, now about 1,000 feet deep, are owned by the Waco Light and Power

Company. The three remaining flowing wells belong one each, respectively, to the estate of W. R. Kellum, deceased, William L. Prather, and Tom Padgett.

The altitude of the public square of Waco is 421 feet above sea level. The altitude, diameter, depth, estimated flow, temperature, and initial pressure per square foot of the several wells were as follows:

Name of well.	Altitude.	Diameter.	Depth.	Flow per diem.	Temperature.	Initial pressure
	Feet.	*Inches.*	*Feet.*	*Gallons.*	° *F.*	*Pounds.*
The Moore well	493	6	1,840	600,000	103	*a* 60
The Bell well *b*	500	6	1,820	500,000	102½	*a* 60
Jumbo well No. 1 *b*	500	8	1,848	1,200,000	103	*c* 60
Jumbo well No. 2 *b*	500	8	1,860	1,000,000	103	60
The Glenwood	495	8	1,860	1,000,000	103	*a* 65
The Dickey well	532	8	1,840	1,000,000	103	*a* 60
The Bagby well	475	8	1,845	1,000,000	103	*a* 60
The Waco Light and Water Power Co. well	532	6	1,812	300,000	100	40
The Prather well	655	6	1,607	500,000	97	*c* 40
The Kellum well	420	6	1,776	1,000,000	103	*c* 76
The Padgett well (Fishing Club)	485	6	1,866	1,000,000	90	*c* 72
The W. V. Fort well	425	....	1,825	1,300,000	....	....

a Estimated. *b* These three, the Bell, Jumbo No. 1 and No. 2, are 50 feet equidistant. *c* Tested.

The foregoing statements of flow per diem (twenty-four hours) are estimates. An attempt was made to measure the flow of Jumbo No. 1, but it was unsuccessful. An expert, a member of the United States Artesian Survey Corps, who made the attempt and failed, estimated the flow at 1,000 gallons per minute. If this statement is correct the output per diem would be 1,440,000 gallons.

I have assumed the output of this well to be 1,200,000; with this as a basis the output of the other wells has been estimated. The pressure of the Jumbo, Prather, and Padgett wells has been tested. The temperature of all has been ascertained by the thermometer.

A correspondent from Waco writes: "So far as the history of our wells is concerned, except in the case of the well bored by Mr. Fishback and one recently drilled for Mr. Fort, of which no record was kept, all the wells around Waco have been bored by a man who has kept no record of his borings, supposedly for the reason that such records would be of value to his professional rivals."

The log of the Padgett well in the city of Waco was furnished the writer through the kindness of Messrs. Fishback and Pope.[1] (See

[1] The original log of this well, as published in the report entitled "Artesian Waters of Texas" by the Department of Agriculture, Washington, D. C., page 109, was badly mutilated and the original manuscript was lost. For this the writer was not responsible. The log as given on p. 541 was based upon the corrections of the log as originally published. Recently, through the kindness of Mr. John K. Prather, of Waco, Texas, another copy of Mr. Fishback's original log was furnished and the log as here published has been verified by it.

fig. 68.) It should be stated that the character of the strata passed through is not always attested by the churned-up material brought up from the well, and as the writer has not seen the specimens and has no accurate knowledge of the thickness of the formations, the geologic horizons are uncertain.[1]

The total depth of this well is given at 1,866 feet. The log furnished gives a record of only 1,828 feet. The original volume of flow was estimated at 1,000,000 gallons per day, the pressure 72 pounds, and the temperature 103½°.

SECTION NO. 86.—LOG OF PADGETT WELL, WACO, MCLENNAN COUNTY, TEXAS.

(See fig. 68.)

	Thickness.	Depth.
	Feet.	*Feet.*
21. Dark soil, changing to light calcareous loam	18	18
20. Soft white limestone (Austin)	110	128
19. Blue "joint clays" (Eagle Ford)	162	290
18. Light-brown carbonaceous shales (Eagle Ford)	40	330
17. Brown calcareous marl (Edwards and Washita)	15	345
16. Blue "joint clays" (Edwards and Washita)	121	466
15. Brown carbonaceous shales, lignitic in character (Edwards and Washita)	60	526
14. Brown calcareous marl (Edwards and Washita)	38	564
13. Blue "joint clays" (Edwards and Washita)	411	975
12. Brown carbonaceous shales, lignitic in character (Edwards and Washita)	45	1,020
11. Cream-colored calcareous marl (Walnut)	156	1,176
10. White limestones, occasionally interstratified with thin seams of blue shale or beds of light-colored calcareous marl (Glen Rose)	554	1,730

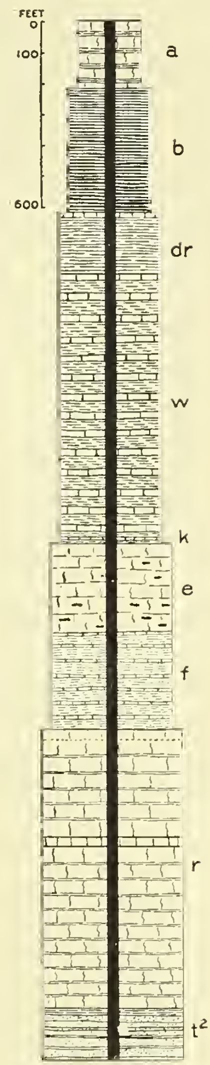


FIG. 68.—Log of wells at Waco, Texas, showing approximate thickness of formations. (For explanation of symbols see Pl. XVI, p. 110.)

[1] It is to be regretted that no minute geologic survey of McLennan County has been made, as it is one of the most important areas in the State. The writer has had opportunity to make a few brief reconnaissances, sufficient to determine the sequence of the formations, but more accurate details are needed concerning the exact thickness of these formations and their areal distribution, and the course of the Balcones fault line across the county.

SECTION NO. 86.—LOG OF PADGETT WELL, WACO, MCLENNAN COUNTY, TEXAS—Cont'd.

	Thickness.	Depth.
	Feet.	*Feet.*
9. Blue calcareous, arenaceous shales. These shales were of somewhat plastic nature, contained some lime, with also considerable proportion of very fine, light-blue sand. This stratum would seem to mark the bottom of the calcareous Glen Rose strata	30	1,760
8. Soft, very fine-grained, gray sandstone (Trinity)	15	1,775
7. Red plastic shale (Trinity)	7	1,782
6. Soft, very fine-grained, light-gray sandstone (Trinity)	17±	1,799
5. Blue shale (Trinity)	5	1,804
4. Soft, very fine-grained, light-colored sandstone (Trinity)	19±	1,823
3. Blue plastic shale (Trinity)	10	1,833
2. Soft, very fine-grained, white sandstone (Trinity)	28	1,861
1. Blue plastic shale (Trinity). The thickness of this stratum unknown, probably	5	1,866

It is impossible to give an exact interpretation of the formations passed through from Mr. Fishback's excellent record. Much of what he terms shale and marl is the pulverized mud of limestones. From all our knowledge of the formations in the vicinity of Waco, based upon the studies of Messrs. J. A. Taff, J. S. Stone, and the writer, it is known that a section can be constructed which will give an approximate idea of the formation beneath that city. While this section is not final and will undoubtedly be corrected in detail when the interesting local geology of Waco receives the attention it deserves, the writer feels confident that the limit of error will be found to be very small.

The section as illustrated in fig. 68, is as follows:

SECTION NO. 87.—SECTION OF THE FORMATIONS PENETRATED BY THE DEEP WELLS AT WACO, MCLENNAN COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	20±	20
Austin chalk	110	130
Eagle Ford shales, accompanied by thin, siliceous, laminated flags	200	330
Buda limestone	5±	335
Del Rio clays, greenish in color	100	435
Georgetown formation, limestones and blue marls in alternations	422	857
Kiamitia formation, blue shale	10	867
Edwards limestone	150	1,017
The Walnut formation, marly shales	150	1,167
The Glen Rose formation, limestones of various degrees of hardness, with occasional marls	554	1,721
The Basement beds of the Trinity division, as detailed in Nos. 1 to 8 of Mr. Fishback's section	145	1,866

The shale at the bottom of the Padgett well was drilled into to a depth of 5 feet, but the flow and pressure of water was so great that the sand pump would not descend through the lower flow of water, and, consequently, the sediment could not be removed from the bottom of the well below the horizon where the heavy flow of water came in, and drilling had to be suspended. Further drilling could be prosecuted only by shutting out the flow of water, extending a string of casing to the bottom of the well, and reducing the size of the well below that point.

The blue shale, in which the drilling was suspended, contains fragments of serpula, oysters, and echinoid spines, showing that the well had not reached the bottom of the Trinity division, but was probably still in the beds of the Glen Rose formation, which outcrop west of Glen Rose.

The various water reservoirs encountered in this well were as follows:

11. Immediately under the last carbonaceous shale stratum, at a depth of about 1,180 feet, and in the upper portion of this marl stratum considerable water came in. The water was highly charged with impurities of lime, sulphur, iron, and probably Epsom salts. This water was not analyzed. The exact horizon of this water is uncertain. It may represent either the northern limit of the Fredericksburg or the Paluxy reservoirs.

10. From about 1,250 feet to 1,500 feet water came at different

horizons of the Glen Rose limestone, making an artesian flow of considerable volume. These flows constitute the t[3] reservoirs. Below 1,500 feet apparently no more water came in until the first sand (No. 6) was reached, at 1,782 feet.

8. This sand, at 1,775 feet, was seemingly dry, producing no apparent increase in the volume of upper water.

6. This sand, at 1,782 feet, responded with water as soon as reached, and gave the first strong artesian flow proper from the well.

4. This sand, at 1,787 feet, largely increased the flow of water.

2. In this sand, at 1,795 feet, the largest volume of water was obtained, slightly increasing the pressure and temperature and nearly doubling the flow from the well.

The sand beds Nos. 6, 4, 2, extending through 60 feet, apparently constitute the Trinity reservoirs.

Mr. Fishback sends the following data:

Pressure of well	pounds..	72
Temperature	°F..	103½
Volume per diem (approximately)	gallons..	1,000,000
Total depth of well	feet..	1,470

Remarks.—While no opinions on matters of this nature can ever be accepted as absolutely correct until verified by the drill, yet from the grain texture, quality, and appearance of the sands I am decidedly of the opinion that the bottom of the sandstone column has not yet been reached in the Waco wells, and that there is strong probability that other and coarser sands may be found still deeper. If found, they would give yet an increased volume of water, with also slight additional pressure and temperature.

H. C. Williams, of Lorena, says: "At Lorena we have a fine artesian well [see Pl. LVIII, *L*], that flows freely and has same pressure as those at Waco. At about 800 feet we found a good artesian flow of sulphur water, with a considerable quantity of oil. Other deep wells in this part of the county have developed considerable quantities of oil. The Lorena well is about 1,800 feet deep, and the water is like that at Waco."

There is but one well east of the line of strike of Waco. This is at West (see Pl. LVIII, *O*). The mayor of West states that the town well was drilled through a loose, caving shell rock, with plenty of water, to a depth of 1,040 feet, when a 2-inch flow was obtained; the next 600 feet was through a very hard gray limestone; the next 50 feet was through honeycombed sand rock, in which the large flow was struck. At the bottom of this limestone a very stiff, sticky blue mud was encountered. The natural pressure was 32 pounds when first tested, and registers 66 pounds to the square inch. The water is excellent for domestic use, and its use has greatly improved the health of the town. The total depth of the well is 1,690 feet, and it furnishes 300,000 gallons day and night.

In the writer's opinion this well does not extend far below the t^3 reservoir, not being so deep as the Waco wells.

Small quantities of oil are struck in the bituminous shales and limestones of many of the wells in McLennan County. At depths of from 500 to 1,000 feet in the Waco wells a small flow of oil is encountered in the Eagle Ford formation and in the beds of the Washita and Fredericksburg divisions. This is cased off and not allowed to flow, as it is not found in paying quantities. This oil was especially noticeable in Nos. 12, 15, and 18 of the Waco well section. The same oil was struck at Bruceville at depths of from 600 to 700 feet, in the rocks of the Fredericksburg and Washita divisions; also at Crawford at 400 feet, in the Walnut clays. These oils occur in all the deeply embedded marls and clays of the Texas Cretaceous, but have thus far been encountered in paying quantities only in the Taylor marls of Navarro County.

No systematic study of the pressure of the wells of McLennan County has been made. The mayor of West states that the pressure of the wells at that place is 66 pounds to the square inch. The original pressures at Waco, so far as measured, are given elsewhere.

It is interesting to note that the flow and pressure of wells in this county, as elsewhere, are always decreased by the drilling of other wells near by. At Moody, for instance, where the surface is very near the limit of possible flow, the first well drilled overflowed, but a second well immediately stopped the flow of the first, in which the water now stands within 15 feet of the surface. At McGregor the wells gradually cease to flow as they increase in number. At Waco, where the pressure is greatest, owing to the low altitude of that city, over twenty wells were drilled without affecting the flow of the others, but the enormous drain upon the reservoir is beginning to be felt, and the writer has heard that the great flow of these wells has been greatly diminished or decreased.

Counties North of the Brazos.

The chief artesian counties north of the Brazos may be divided into two subgroups, the group on the west being composed of Cooke, Tarrant, Denton, and Johnson counties, and that on the east of Dallas, Ellis, and Hill counties.

The first group of counties, Cooke, Denton, Tarrant, and Johnson, lies along a geographic belt characterized by the occurrence of the Eastern Cross Timbers in its eastern portion and the Grand Prairie on the west. In these counties the geologic section is distinguished by a decreasing thickness of the Edwards limestone and a proportional increase in the development of the formations of the Washita division. Furthermore, the Paluxy reservoirs are an analogous formation at the top of the Antlers group, constituting the first available source of artesian supply and, as is too often the case, the only one penetrated.

The second group of counties mentioned lies entirely within the Black Prairie region, and the most available reservoir, and that which is nearest the surface, occurs in the Woodbine formations.

HILL COUNTY.

Hill County, with an area of 986 square miles, is one of the most fertile in Texas, and is well underlain by artesian reservoirs.

The county may be divided into north and south strips, including a portion of the main Black Prairie, the Austin chalk, the Eagle Ford

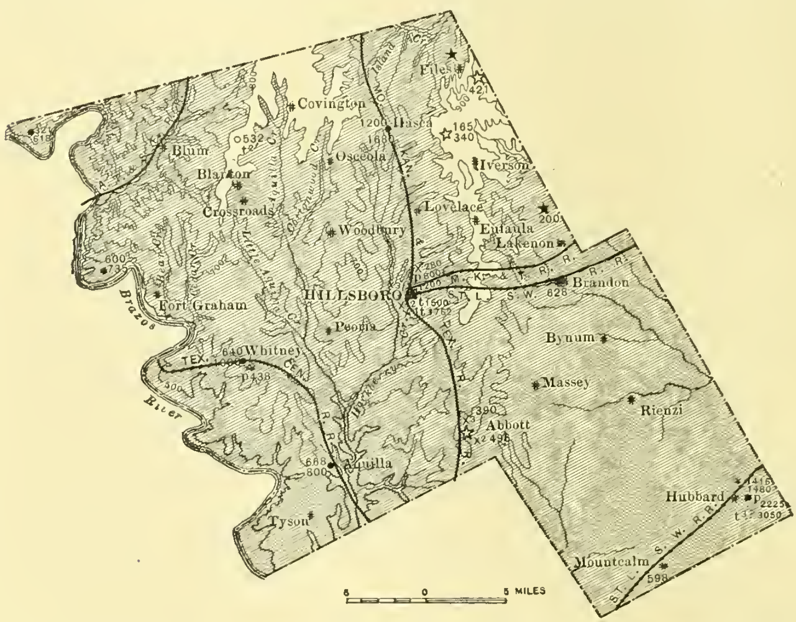


FIG. 69.—Artesian map of Hill County, Texas. Shaded portion indicates area where flowing wells from the Basement sands are theoretically possible; ●, flowing wells from Trinity reservoir; ○, nonflowing wells from Trinity reservoir; ■, flowing wells from Paluxy reservoir; ★, flowing wells from Woodbine reservoir; ☆, nonflowing wells from Woodbine reservoir; figures indicate depths of wells in feet.

Prairie, Eastern Cross Timbers, and the Grand Prairie belts of country. The belt of the Eastern Cross Timbers runs nearly due north and south through the geographic center of the county.

The relief of the county includes a maximum range of altitude of 500 feet; the highest altitude is 900 feet and the lowest 400 feet. The only portions of the county that are at a height of more than 800 feet, above which flowing wells are impossible, are three north-south tongue-like strips in the northern part. The most western of these is the divide between Aquilla Creek and Brazos River, running from Crossroads northward to the northern county line. The middle belt of high altitude is the divide between the heads of Hackberry and Aquilla creeks, in the vicinity of Covington. The third and longest belt, constituting the summit of the White Rock escarpment, extends from east of Hillsboro northward east of Itasca and Files Valley. From these high summits east of the latter ridge the country slopes gradually eastward, but a greater portion of the county, including all of the southwestern half, is within the drainage slope of the Brazos River. The latter stream flows in a deep groove from northwest to southeast and forms the western border of the county This valley of the Brazos has an altitude of 525 feet at the northwest corner and about 400 feet at the southeast corner.

From these altitudes, which can be more readily understood by consulting the Waco and Cleburne atlas sheets of this Survey, which embrace all of Hill County except the southeastern corner, it will be seen that by far the greater area of the county is favorably situated topographically for obtaining flows of water.

In its entirety, Hill County is underlain by the Paluxy and Trinity reservoirs (see Pl. LIX), and in its eastern half by the Woodbine reservoir, all of which are utilized as sources of artesian water. The flowing artesian wells vary from 500 feet in depth at the extreme western edge of the county to over 3,000 feet at the extreme east.

The Trinity reservoir underlies the entire county. The Basement reservoir may be found at depths varying from sea level at the extreme western edge to 3,500 feet below sea level at the extreme eastern edge.[1]

There are at least three available reservoirs in the Trinity system in this county, the lowest of which, as usual, constitutes the source of the purest and best waters, and has the highest pressure. In all of the wells a higher Trinity reservoir, t^2, is encountered. In the extreme western corner of Hill County, just south of Greenway, Johnson County, these reservoirs are about 100 feet apart. In the Brazos bottom just north of Fowler they are 135 feet apart; at Hillsboro they are 262 feet apart, showing a gradual divergence eastward.

The Paluxy reservoir is also available throughout all that portion of the county east of the Gulf, Colorado and Santa Fe Railway, but will not furnish flowing water of a satisfactory character.

The Woodbine formation, which outcrops in this county in the area of the Eastern Cross Timbers, furnishes good pumping wells throughout most of the county east of the Missouri, Kansas and Texas Railway, but does not furnish flowing wells except in the deep valleys of Island Creek and the area east of the White Rock Plateau.

DEVELOPMENT.

A number of artesian wells have been drilled in this county, which are so distributed as to enable a fair interpretation of the artesian

[1] See discussion of the deep well at Hubbard on pp. 556–558.

conditions to be given. The flowing wells vary in depth from 618 feet at the extreme western edge of the county to over 3,050 at the extreme east. The following list of wells has been received:

Schedule of wells in Hill County, Texas.

WELLS FROM THE WOODBINE RESERVOIR.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water. a	Flow. a	Quality. b	Irrigation. a
			Feet.	Feet.	Feet.						
J. H. Farrow (reports)	Itasca, 8 miles northwest from.	.....	110	±15	....	....	x	±15	....	2	...
M. H. Mathews	Itasca, ¼ mile south of post-office at.	.....	160	75	....	....	x	-	....	1	...
J. H. Farrow (reports)	Itasca, 3 miles east of	.....	389	165	185	....	x	-	....	1	...
J. M. Lovelace	Lovelace, ¼ mile north of	.....	150	130	....	....	x	90	....	1	...
J. M. Kennedy	Menlow, 1 mile from	.....	172	86	....	....	x	×	....	1	...
C. A. Stamphill	Menlow, 1 mile east of	.....	235	120	....	....	x	60	....	3	...
R. H. Dearing (reports)	Hillsboro, 1 mile east of	.....	329	250	....	....	x	85	....	1	×
Sides & Hartson (reports).	On mountain in Hill County, east of Files.	.....	443	421	....	a	x	×	....	1	×
J. D. Tinsley	Abbott, 1½ miles north of	710	446	395	....	....	x	160	....	{1 3}	×
....	Abbott	710	486	390	....	a	x	±300	....	3	...
J. H. Farrow (reports)	Files Valley post-office, 10 miles south of.	.....	200	150	....	....	x	13	×	1	...
Sides & Hartson (reports).	Itasca, 8 miles northeast of; Files, 2 miles northwest of.	.....	226	80	....	....	x	.....	×	1	..

WELLS FROM THE PALUXY RESERVOIR.

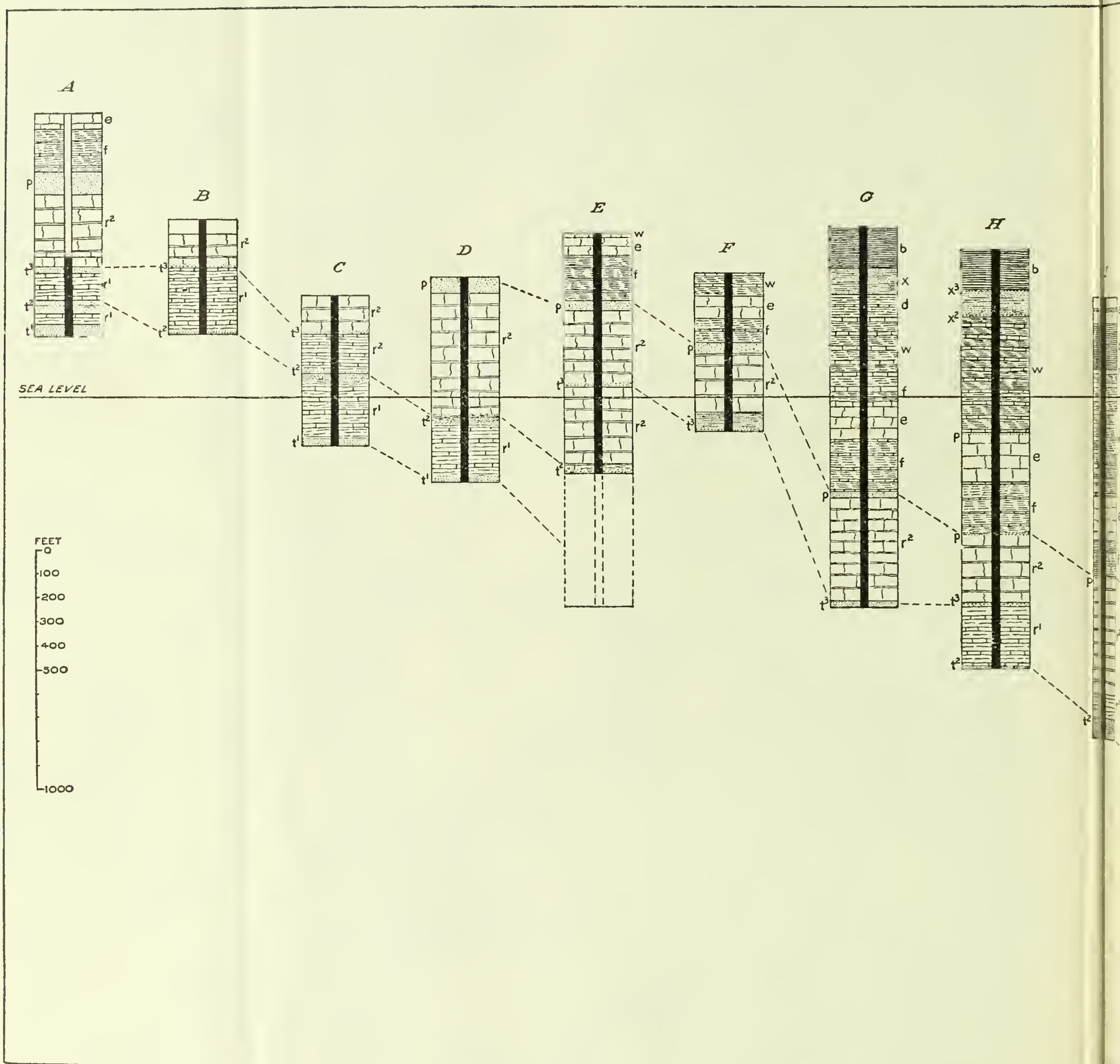
Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water. a	Flow. a	Quality. b	Irrigation. a
Guy Simpson	Whitney, 1½ miles south of	.....	438	.....	....	....	....	×	....	....	×
C. L. Knapp	Blum, 4½ miles east of	.....	532	.....	....	x	p	×	....	1	...
Dr. Ware	Aquilla	500	1,000	658	....	....	....	....	....	....	...

WELLS FROM THE TRINITY RESERVOIR.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Surface formation.	Water reservoir.	Rise of water. a	Flow. a	Quality. b	Irrigation. a
D. S. Mayes	Whitney	586	1,000	±640	....	W	t?	....	×	{1 8}	..
City well	Itasca	711	1,680	1,200	....	....	p	35	×	1	...
G. W. Brown	Hillsboro, 600 feet from post-office.	627	1,762	800	{1,200 1,500}	...	....	....	×	....	...
....	Hubbard City	638	3,166	1,350	{1,400 1,465 2,325}	...	{× t?}	....	....	....	...

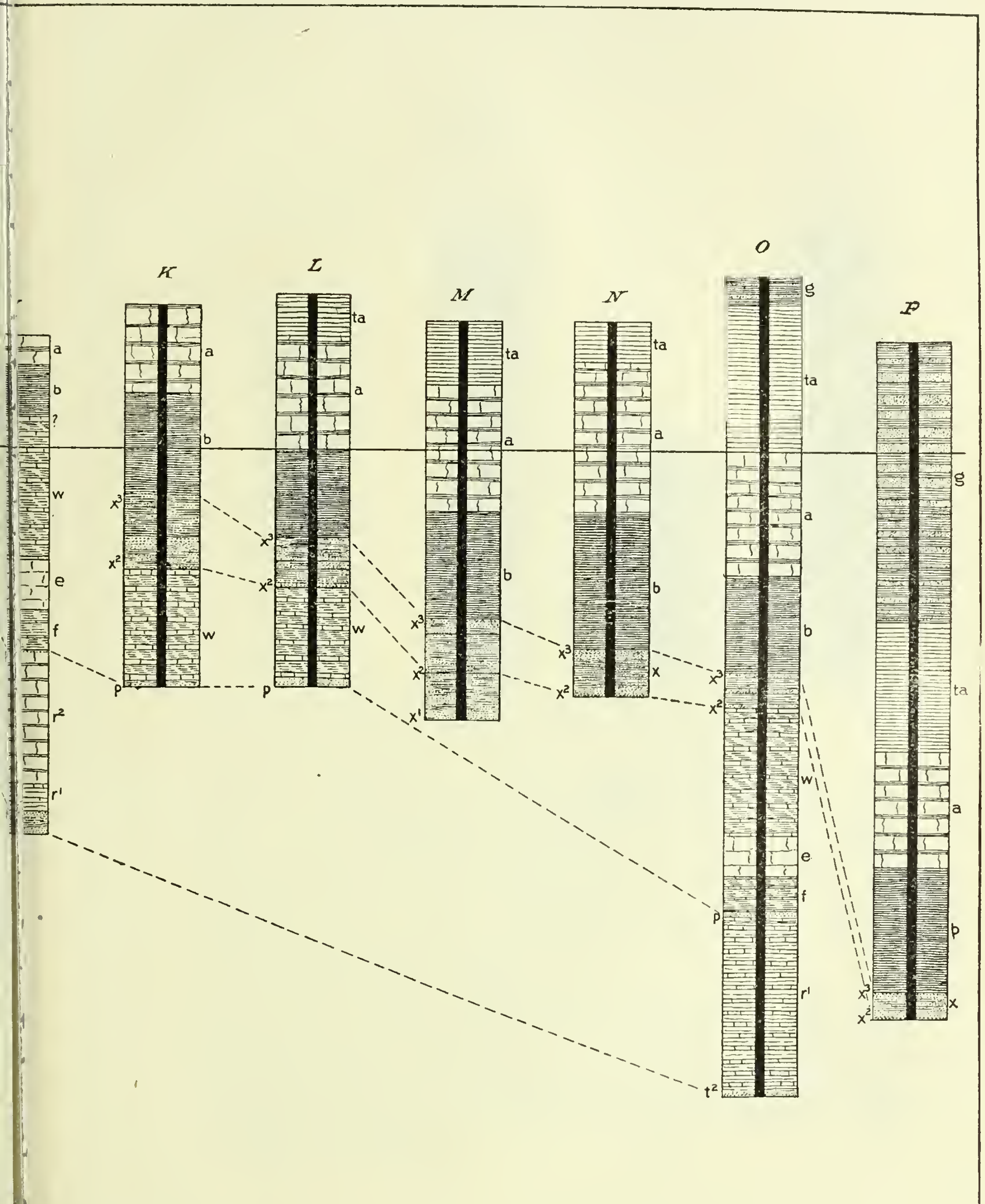
a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.



WELLS IN HOOD, HILL, ELLIS, AND NAVARRO COUNTIES, TEXAS

A, Glen Rose; *B*, Eulogy; *C*, 4½ miles south of Freeland; *D*, north of Fowler; *E*, Whitney; *F*, Aquilla; *G*, Itasca; *H*, Hillsboro



...ING FROM WEST TO EAST.

...co; *K*, Waxahachie; *L*, Italy; *M*, Palmer; *N*, Ferris; *O*, Hubbard; *P*, Corsicana.

WELLS FROM THE WOODBINE RESERVOIRS.

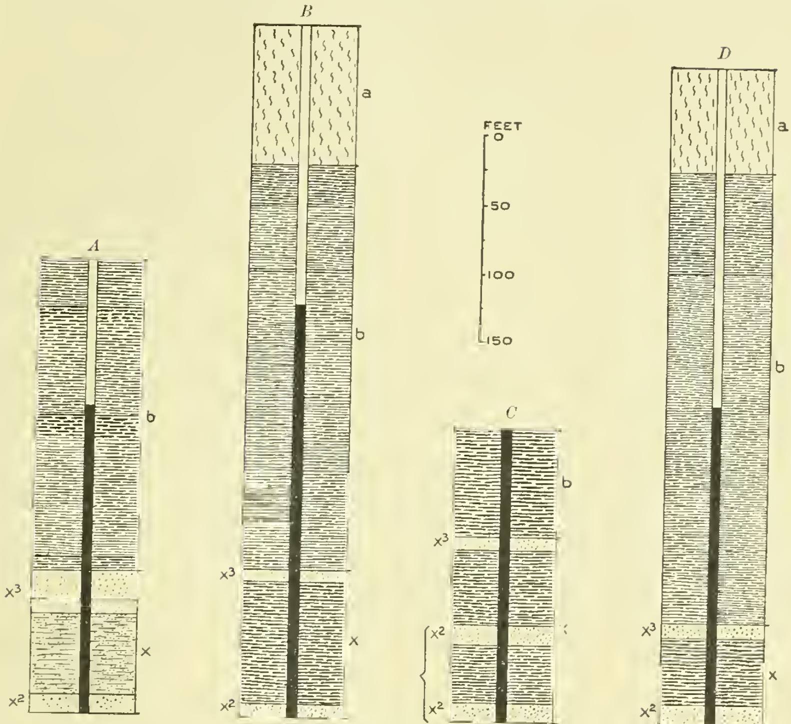


FIG. 70.—Group of artesian wells penetrating the Woodbine reservoirs in Hill County. (For explanation of symbols see Pl. XVI, p. 110.) *A*, well at Hillsboro; *B*, well at Abbott; *C*, well 2 miles northwest of Files; *D*, well on White Rock scarp, east of Files.

In that portion of Hill County east of the Eastern Cross Timbers there are many good wells obtaining waters from the Dexter sands or x^2 reservoir, although they flow in only one or two instances. These wells, owing to the slight depths to which they have to be drilled and the scarcity of surface waters and shallow wells in this region, are of great value. In all of the wells, as shown in fig. 70, there are two or more reservoirs in the sands, and the best and strongest flow comes from the lowest of these.

In the well of R. H. Dearing, Hillsboro (see fig. 70, *A*), the depth to first reservoir (x^3) was 250 feet; to other reservoir (x^2) 80, and the total depth of the well 329 feet. The well does not flow, the water standing within 85 feet of the surface. The well furnishes 15,000 gallons daily and can be lowered only about 100 feet. The water is very soft and pleasant to the taste and is used for irrigating gardens and fruit and shade trees.

A section of this well is as follows:

SECTION NO. 88.—SECTION OF WELL OF R. H. DEARING, HILLSBORO, TEXAS.

(See fig. 70, *A*.)

	Thickness.	Depth.
	Feet.	*Feet.*
8. Soil and joint clay (Eagle Ford)	35	35
7. Shale (Eagle Ford)	80	115
6. Slate (Eagle Ford	100	215
5. Clay (Woodbine)	10	225
4. Sand and shale (Woodbine)	20	245
3. Sand (first water)	10	255
2. Dark-blue or black marl, mixed with fine gravel	59	314
1. Water sand	15	329

In a well reported by Mr. A. F. Wilson, well driller, in the town of Abbott (see fig. 70, *B*), the depth of the first reservoir was 390 feet; second reservoir, 486 feet; total depth, 486 feet. The well does not flow, but the water rises about 300 feet, the quantity obtained being about 30 or 40 barrels per day. The water can be easily lowered. The section as given by the well driller is as follows:

SECTION NO. 89.—SECTION OF WELL IN ABBOTT, HILL COUNTY, FURNISHED BY A. F. WILSON, WELL DRILLER.

(Pl. LIX, *B*.)

	Thickness.	Depth.
	Feet.	*Feet.*
7. White lime (Austin)	90	90
6. Shale (Eagle Ford)	175	265
5. Slate (Eagle Ford)	100	365
4. Soapstone (Eagle Ford)	15	380
3. Water sand mixed with shale (Woodbine)	10	390
2. Blue marl (Woodbine)	88	478
1. Water sand, but very fine and close (Woodbine)	8	486

In the well of J. D. Tinsley, 1½ miles north of Abbot post-office, the first reservoir was 395 feet; other reservoirs and total depth, 446 feet. The well does not flow, the water rising to within 160 feet of the surface. The quantity of water obtained is about 1,000 barrels per day. The water can not be easily lowered, and is a little salty. It is used for irrigation.

The flowing well 2 miles northwest of Files post-office and 8 miles northeast of Itasca, reported by Messrs. Sides and Hartson, well drillers, was drilled on very low ground, as wells on the upland will not flow under 1,800 feet. This is a flowing well, furnishing 324 gallons an hour, but the quantity has decreased because the well was not properly cased. The water is fine and soft, and is used for family and stock. The depth of first reservoir was 80 feet; second reservoir, 140 feet; third reservoir, 206 feet; total depth, 226 feet. The cap rock is on top of water-bearing sand, which was 12 feet thick; from first to second reservoirs was through slate to a depth of 56 feet to second bed of sand, which was 15 feet thick; from second to third reservoirs was also through slate to third bed of sand, where a 1-inch flow was obtained; the third bed of sand was about 20 feet thick. The water from the first reservoir came within 12 feet of the top, that from the second reservoir within 2 feet of the top, and that from the third reservoir flowed 8 feet above the top of the well. A section of this well (see fig. 70, *C*) is as follows:

SECTION NO. 90.—SECTION OF WELL 2 MILES NORTHWEST FROM FILES AND 8 MILES NORTHEAST FROM ITASCA, HILL COUNTY. REPORTED BY SIDES AND HARTSON, WELL DRILLERS.

(Fig. 69, *C*.)

	Thickness.	Depth.
	Feet.	*Feet.*
9. Black dirt	8	8
8. Joint clay	37	45
7. Slate	35	80
6. Cap rock	2	82
5. Sand (water)	12	94
4. Shaly clay	56	150
3. Dexter sand	15	165
2. Clay	40	205
1. Sand	20	225

Another well, reported by J. H. Farrow, well driller, 10 miles south of Files Valley post-office, is 200 feet deep; depth to first reservoir, 150 feet; to other reservoirs, 200 feet. It is a flowing well, furnishing about 5,000 or 6,000 gallons a day. The water is soft and is used for domestic purposes. The first reservoir was struck under a hard rock, and the water rose within 6 feet of the top; the water from the next reservoir rose 3 feet above the surface. Water was struck in white sand.

In a well reported by Sides and Hartson, on the "mountain" in Hill County (Austin chalk scarp east of Files), the depth of first reservoir was 421 feet, total depth 442 feet. (See fig. 70, *D*.) The well does not flow, but the inexhaustible water rises above the level at which it was reached. The water is soft and is used for irrigation.

A section of this well as given by the drillers is as follows:

SECTION NO. 91.—SECTION OF WELL ON MOUNTAIN (AUSTIN CHALK SCARP) EAST OF FILES, HILL COUNTY, REPORTED BY SIDES AND HARTSON, WELL DRILLERS.

(Fig. 69, *D*.)

	Thickness.	Depth.
	Feet.	*Feet.*
6. Soil	3	3
5. White rock (Austin)	74	77
4. Blue Rock (Austin)	48	125
3. Slate (Eagle Ford)	296	421
2. Cap rock	3	424
1. Water-bearing sand (Woodbine)	18	442

Another well 3 miles west of Itasca, reported by J. H. Farrow, well driller, is 389 feet deep. Depth to first reservoir (x^3), 165 feet; to x^2 reservoir, 389 feet. The well is nonflowing, furnishing 480 gallons an hour for boiler and stock.

The driller states that this is the first well in all his experience in which just before striking the sand he found shells which seemed to be petrified oyster shells. A thin stratum of lignite was struck just on top of the sand. The shells are no doubt the fossiliferous horizon of the Lewisville beds. (See pp. 308–318.)

WELLS FROM THE PALUXY RESERVOIR.

There are several wells in Hill County which apparently obtain water from the Paluxy formation, but so far as reported none of them flow to the surface.

In the well of C. L. Knapp, 4½ miles east of Blum, Hill County, the depth of the first reservoir was 532 feet; total depth the same. The water does not flow, but rises 192 feet above the level at which it was reached. It can be easily lowered. It is soft, and is used for running gin and mill machinery.

A section of this well given by Mr. Knapp is as follows:

SECTION NO. 92.—SECTION OF WELL OF C. L. KNAPP, 4½ MILES EAST OF BLUM, HILL COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Pack sand (Woodbine)	20	20
5. Blue marl (Denison)	100	120
4. Lime rock (Georgetown, and Edward)	180	300
3. Blue marl (Walnut)	80	380
2. Hardpan (Walnut)	52	432
1. Water sand (Paluxy)	100	532

Mr. Guy R. Simpson's well, 438 feet deep, is located 1½ miles south of Whitney. The well does not flow, but the water rises to within 6 or 8 feet of the surface. It is used for irrigation. The well averages about 10 barrels an hour.

SECTION NO. 93.—SECTION OF MR. GUY R. SIMPSON'S WELL, 1½ MILES SOUTH OF WHITNEY, HILL COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Lumpy limestone and marl	238	238
5. Sand and fine conglomerate	14	252
4. Limestone	93	345
3. Marl and limestone	60	405
2. *Gryphæa corrugata* agglomerate	30	435
1. Green-colored sand and sandstone	3	438

WELLS FROM THE TRINITY RESERVOIRS.

Deep wells have been driven into the Trinity reservoir at Whitney in the western, Hillsboro in the central, Itasca in the northern, and possibly Hubbard, in the extreme eastern portion of the county. These wells, together with those of adjacent counties, demonstrate the existence of the Trinity reservoir beneath the whole county.

These wells are found in the Brazos Valley at the extreme western corner of the county at depths of about 600 feet, and the depth increases to the eastward until at Hubbard, at the extreme eastern corner and some 60 miles distant, the depth is over 3,000, probably 3,500, feet. This gives an approximate and uniform inclination of the reservoir of 40 feet per mile to the eastward.

There are two or three flowing wells at Whitney and vicinity, concerning which, however, it has been very difficult to procure accurate data. Judging from several reports, it is probable that the Paluxy reservoir is struck at 640 feet beneath the surface and a Trinity reservoir at 1,000 feet. (See Pl. LIX, *E*.)

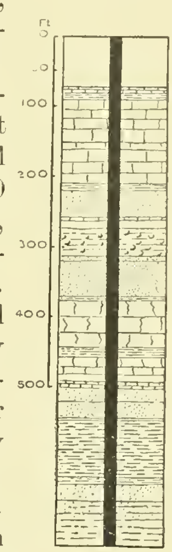


FIG. 71.—Well at Aquilla, Hill County, Texas.

The town well in Whitney, as reported by Mr. D. S. Mayes, secretary, is 1,000 feet deep. The elevation above sea level is approximately 686 feet. It is estimated that the water will rise 40 feet above the surface. The depth to the first reservoir is about 640 feet. The well flows, supplying 200,000 gallons a day for the use of the town. The water is soft, with some evidence of soda. The water from the 1,000-foot reservoir is theoretically from the t^2 reservoir, and that at 640 feet from the t^3 reservoir. Whether the Whitney wells have penetrated to the t^1 reservoir or not we can not say. Another correspondent says the well at Whitney was reported by Mr. Blackstock, the well driller, to be 1,575 feet deep. If this is true, the lowest reservoir has been reached.

Another well near Whitney, owned by Mr. C. M. Carver, is reported to be 1,600 feet deep. No particulars could be ascertained.

In section No. 93 will be found the details of a well near Whitney as far down as the Paluxy reservoir.

At Aquilla, about 10 miles southeast of Whitney, an excellent flowing well is obtained at a depth of 667 feet from an upper reservoir—t^3—of the Trinity system.

The following excellent section of the artesian well at Aquilla, Hill County, was kindly furnished by Mr. N. W. Curry, of Jonesboro, Coryell County, Texas. (See fig. 71).

SECTION NO. 94.—SECTION OF ARTESIAN WELL AT AQUILLA, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
41. Black soil	4	4
40. Yellow clay	6	10
39. Yellow sand and clay	3	13
38. Grayish clay	10	23
37. Gravel mixed with clay	5	28
36. Blue clay	1	29
35. White clay	3	32
34. Black silty clay	40	72
33. Shelly limestone	6	78
32. Shaly black clay	4	82
31. Hard white limestone	10	92
30. Dark-colored clay	3	95
29. White limestone	100	195
28. White chalk or clay	10	205
27. Pale-blue clay	3	208
26. Hard sand or grit	35	243
25. Hard white limestone	5	248
24. Hard dark sandstone	5	253
23. Shelly clay and sandstone	40	293
22. White gritty pack sand	4	297
21. Fine pebbly conglomerate	50	347
20. Light-colored clay	5	352
19. Soft white limestone	70	422
18. Sandy clay	15	437
17. Hard white gritty stone	20	457

SECTION NO. 94.—SECTION OF ARTESIAN WELL AT AQUILLA, TEXAS—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
16. Dark shelly agglomerate	3	460
15. Hard white limestone and clay	10	470
14. Hard black sand rock	15	485
13. Dark conglomerate	6	491
12. Hard pack sand	20	511
11. Sandstone	5	516
10. Dirty shale	10	526
9. Clay	10	536
8. Clay	40	576
7. Dirty shale	11	587
6. Sandy clay with shells	10	597
5. Sand	20	617
4. Sand in layers	30	647
3. Ash-colored sands and clays	5	652
2. Blue sand and marl	5	657
1. Green sand and clay	10	667

The above section is one of the most complete received from the Texas region. Of the section numbers, 30 to 41, inclusive, represent the Kiamitia, Goodland, Duck Creek, Fort Worth, and Denison formations of the Washita division. Nos. 29 and 28 are undoubtedly the Edwards limestone; Nos. 15 to 27, inclusive, the Walnut formation; Nos. 11 to 14, the Paluxy sand, concerning the water-bearing capacities of which the correspondent makes no remarks. Nos. 1 to 10 represent 141 feet of the upper and thinner beds of the Glen Rose formation.

The town well at Itasca, reported by C. C. Weaver, mayor, is 1,680 feet deep, depth of first reservoir being 1,200 feet. The pressure is 14 pounds. It flows 35 feet above ground level, furnishing 9,600 gallons per hour. The water is soft and is thought to contain a small percentage of sulphur. The well cost $5,000.

The Paluxy reservoir was reached in this well at about 700 feet, the t^3 reservoir at 1,200 feet, and the t^2 reservoir at 1,680 feet. The well begins in the middle of the Eagle Ford clays, penetrating about 170 feet of that formation. Below this it passes through about 120 feet of the sands and clays of the Woodbine formation; then through 400 feet of the limestone and blue calcareous marls of the Washita and Fredericksburg divisions to the Paluxy sand. Below this about 400 feet are penetrated to the t^3 reservoir and 450 feet to the t^2 reservoir, or a total of 850 feet of the Glen Rose calcareous formations. Unfortunately no report has been procured concerning the waters encountered in the x, p, and t^3 reservoirs.

The well at the natatorium in Hillsboro (see Pl. LIX, *H*), reported by Mr. G. W. Brown, manager, is 1,762 feet.[1] Depth to first reservoir is 800 feet; to other reservoirs, 1,200 and 1,500 feet. It flows, furnishing 50,000 gallons daily, the amount remaining stationary. The water is used only for the natatorium.

It has been impossible to obtain an accurate log of this well or reports showing the character and productivity of the different water reservoirs passed through. The formations penetrated may be estimated as follows:

	Feet.
Eagle Ford clays	225
Woodbine formation	105
Denison beds of the Washita division	100
Edwards, Fort Worth, and Comanche Peak limestone	240
Walnut beds, blue clays and limestones	120
Paluxy sands	
Upper Glen Rose limestone	300
Upper Trinity reservoir (t^3)	
Lower Glen Rose formation and Basement Trinity sands	460

The Trinity reservoirs have not been exploited in that portion of Hill County lying between Hillsboro and Hubbard, 30 miles southeastward. At the latter city is to be found one of the deepest artesian wells in Texas and one which throws great light upon the availability of the reservoirs of the Comanche series eastward of Hillsboro.

The following log of this well has been furnished by Mr. H. G. Johnston, the well driller. The cores of this well, representing the strata between the depths of 2,260 and 3,166 feet, were purchased by the United States Geological Survey, but it has been impossible to make a minute study of them. The lowest specimens, however, contain characteristic fossil *Rudistes* of the Edwards limestone, which would indicate that the well has not yet penetrated the Trinity reservoirs. The strata at 2,230 feet undoubtedly contain characteristic fossils of the Walnut clays, such as *Gryphæa corrugata*. Below this to a depth of 3,166 feet there is a thickness of 930 feet of limestone having the characteristic appearance of the Edwards and Glen Rose limestone. This thickness is so much greater than any encountered in the wells to the westward or in the surface outcrops of these formations that one can only conclude that these formations have rapidly thickened eastward.

[1] Mr. H. G. Johnston, the well driller, reports the depth of this well as 1,650 feet.

SECTION NO. 95.—LOG OF ARTESIAN WELL AT HUBBARD, HILL COUNTY, TEXAS. FURNISHED BY MR. H. G. JOHNSTON, WELL DRILLER.

(See fig. 72.)

	Thickness.	Depth.
	Feet.	*Feet.*
21. Yellow clay	25	25
20. Marl (ta)	675	700
19. Chalk (a)	330	1,030
18. Shale (b)	320	1,350
17. Sand water (x^3)	15	1,365
16. Blue marl	65	1,400
15. Sand water (x^2)	15	1,415
14. Blue marl	50	1,465
13. Sand water (x^1)	15	1,480
12. Basal clay of the Woodbine and upper part of the Denison beds (d)	168	1,648
11. White limestone	427	2,075
10. Alternating strata of lime and marl which caved badly; 4½-inch pipe extends to 2,230 feet	155	2,230
9. White limestone	30	2,260
(Diamond drill used from this depth to finish.)		
8. Limestone	588	2,848
7. Gypsum	30	2,878
6. Limestone	125	3,005
5. Sand	12	3,017
4. Limestone	24	3,041
3. Sand	22	3,063
2. Sand	19	3,082
1. Limestone	84	3,166

There is a sand at 2,325 feet which corresponds very closely in position with the Paluxy formation, but the Edwards fossils are undoubtedly found in the underlying limestone at the very bottom of the well. The water-bearing sand 60 feet above the bottom of the well corresponds in position to the t^3 reservoir of the Hillsboro and Waco wells, and if this is so, the citizens of Hubbard must go 500 or 600 feet farther before reaching the basement reservoir.

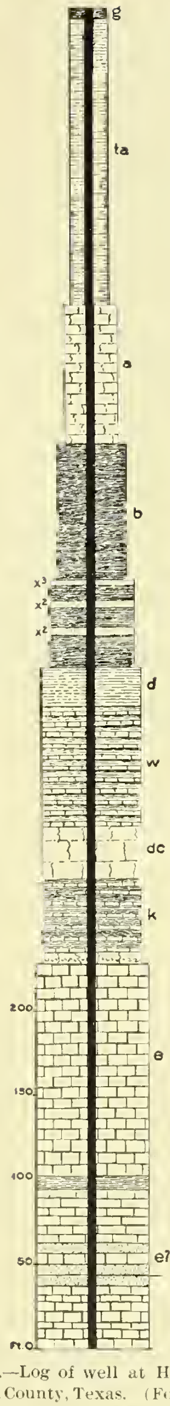


FIG. 72.—Log of well at Hubbard, Hill County, Texas. (For explanation of symbols see Pl. XVI, p. 110.)

This well has cost the people of Hubbard $22,700. The water now flowing from the well is highly charged with mineral matters, as shown by the analysis in table opposite p. 448. It is used only for bathing.

JOHNSON COUNTY.

Johnson County has an area of 725 square miles, and is situated within the heart of the main artesian belt. About one-half of its area, as shown upon the accompanying map, is so situated as to be within the field of availability of flowing wells, while good nonflowing artesian waters can be obtained in all parts of the county at depths of less than 900 feet.

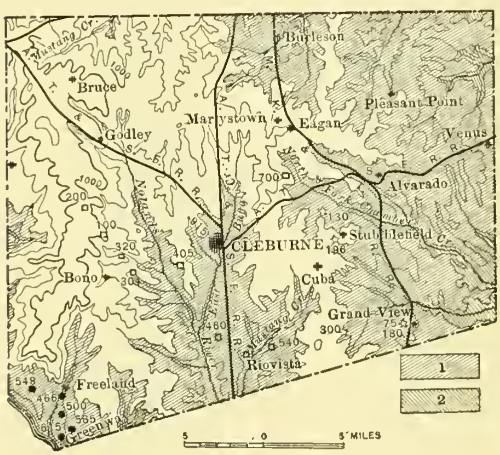


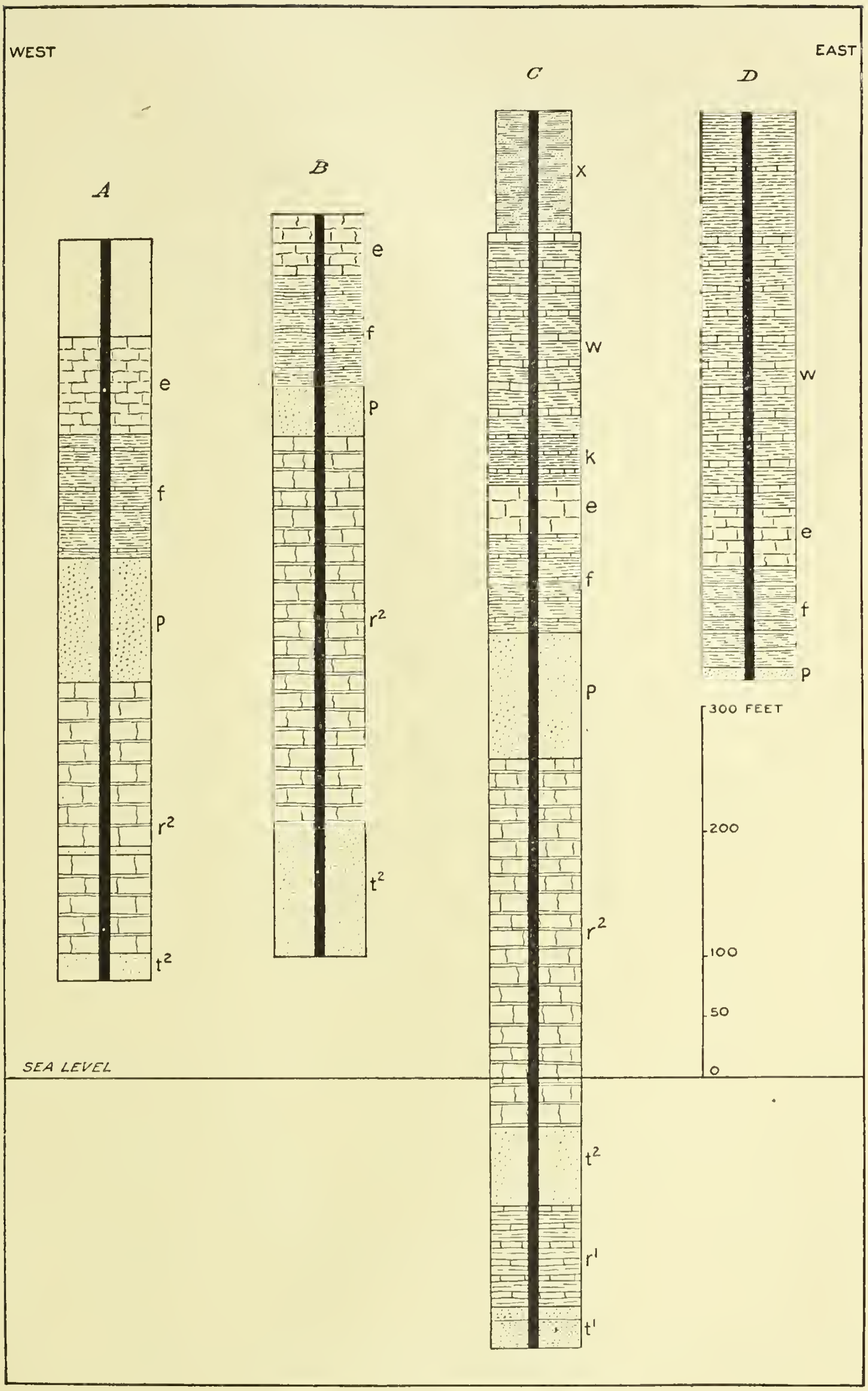
FIG. 73.—Artesian map of Johnson County, Texas. 1, area in which flowing wells from the Trinity reservoir may be obtained; 2, area in which flowing wells from the Paluxy and Woodbine reservoirs may be obtained; ●, flowing wells from Trinity reservoir; □, nonflowing wells from Paluxy reservoir; ☆, nonflowing wells from Woodbine reservoir; figures indicate depth of wells in feet.

The eastern third of the county lies within the fertile black land of the Eagle Ford Prairie. The Eastern Cross Timber belt constitutes a wide ribbon of sandy timbered land extending north and south through the central and northwestern portions of the county, while the Grand Prairie occupies the southwestern portion. A small area of the wide Brazos Valley is in the extreme southwestern corner.

The greatest altitude in the county, along the divide between Brazos and Noland rivers, is 1,000 feet. All the eastern third of the county and the valleys of the Noland and the Brazos are below 800 feet, the maximum altitude to which flowing waters will rise, while the Brazos Valley on the southwest and the valleys of Chambers, Island, and Mountain creeks on the east are as low as 600 feet.

The entire county is underlain by the Paluxy and Trinity formations, and the eastern third also by the Woodbine formation. (See fig. 73.) The Basement Trinity reservoir is 900 feet below the surface at the western border and about 2,000 feet at the eastern edge of the county (from 300 feet below sea level to 1,400 feet above sea level).

The Paluxy formation outcrops at an altitude of about 750 feet on the western edge of the county. It is about 350 feet above sea level in the center of the county and about 150 feet below sea level at its eastern edge.



WELLS IN JOHNSON COUNTY, TEXAS.

A, Isaac Russell's well, 3 miles north of Freeland; *B*, 3 miles northwest of Greenway; *C*, Cleburne; *D*, G. W. Bronson's well, 2¼ miles west of Burleson.

The Woodbine formation (x^2, x^3) outcrops at between 800 and 900 feet above sea level east of Cleburne, and is about 400 feet above sea level at the eastern edge of the county.

The dip of the Woodbine formation is about 40 feet to the mile, unbroken, so far as we know, by faulting. The Basement sands probably dip about 60 feet to the mile, as in the adjacent counties, but this has not been demonstrated by well drills.

The Woodbine, Paluxy, and t^3 reservoirs, of little value in the counties to the southward, become of considerable value in this county.

The county is practically divisible into three artesian districts, as follows: (1) That portion east of the Eastern Cross Timbers where the Paluxy reservoirs are available at depths of less than 400 feet; (2) the Brazos Valley below the 750-foot contour, where the upper Trinity waters (t^3) are obtainable at depths of from 500 to 1,000 feet, and (3) all the county west of the Cross Timbers except the Brazos Valley, where the Paluxy waters are obtainable at depths of less than 600 feet.

DEVELOPMENT.

Notwithstanding the excellent conditions of supply, Johnson County possesses fewer artesian wells in proportion than other counties along the main artesian belt. Many of the wells are incomplete, as they have not been drilled to the best of the available waters. So, judging from the data obtained, no wells have as yet penetrated to the Basement sands or t^1 reservoir, and many of the Woodbine and Paluxy wells stop in the upper reservoirs of these systems instead of penetrating them and securing the purer and more abundant waters in their lower beds. In all we have the following records of artesian wells in Johnson County:

Schedule of wells in Johnson County, Texas.

WELLS FROM THE WOODBINE RESERVOIR.

Owner.	Exact location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water. *a*	Flowing wells. *a*	Quality. *b*	Irrigation. *a*
			Feet.	*Feet.*	*Feet.*				
J. B. Leals	Alvarado, 5 miles southwest of.	750	130	90	......	×	No.	{1, 2}	....
Stubblefield Gin Co	Stubblefield	......	196	15	150	×	No.	2	....
Sides & Hartson	Grand View, 4 miles west of	......	300	86	150	200	No.	1	....
Oil Mill Co	Grand View	702	196	76	180	×	No.	{1, 2}	×
J. C. Smyth	Venus	......	183	50	120	×	No.	1	×

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

Schedule of wells in Johnson County, Texas—Continued.

WELLS FROM THE WOODBINE RESERVOIR—Continued.

Owner.	Exact location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flowing wells.	Quality.	Irrigation.
			Feet.	*Feet.*	*Feet.*				
B. S. Shook	Mansfield, Tarrant County, 2 miles south of. Pleasant Point, ½ mile south of.	.....	225	75	160 200	125	No.	1	....
W. A. Huchabee	Pleasant Point, 3 miles north of.	......	191 116	55 72	170 97	110 55	No.	1 2	....

WELLS FROM THE PALUXY RESERVOIR.

Owner.	Exact location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flowing wells.	Quality.	Irrigation.
Dr. C. M. Yates	Godley, 5 miles south of	......	420	200	300	×	No.	1	....
John Baugh	Bono, 2 miles north of	950	397	370	......	90	No.	1	×
H. L. Russell	Bono, ¼ mile east of	800	311	300	......	×	No.	1	....
T. H. Denton	Joshua, 6 miles northwest of	900	424	410	......	235	No.	1	×
G. W. Johnson	Joshua, 3 miles southwest of	900	525	480	35	×	No.	1	....
G. W. Orr	Rio Vista, 1 mile northeast of.	725	460	440	......	×	No.	1	....
W. J. Ince	Sullivan	750	540	450	......	364	No.	1	....
R. Bartley	Cleburne, 3 miles northwest of.	900	424	350	......	150	No.	1	×
S. N. Clark	Cleburne, 3 miles southwest of.	800	420	300	405	260	No.	1	×
Jas. Drennan	Reports 4 wells in Cleburne	......	360	......	......	200	No.	....	....
M. S. McDowell	Cleburne, 6 miles south of	800	520	400	......	×	No.	1 8	.
V. M. Hightower	Cleburne, 5 miles southeast of.	800	568	540	......	400	No.	1	....
Academy at Keene	Cleburne, 6 miles northeast of.	900	p. 750	100	150 700	450	No.	1	....
G. W. Branson	Burleson, 2½ miles west of	750	465	450	460	×	No.	1	....
R. L. Norwood	Rendon, 2 miles north of (Tarrant County).	......	535	525	......	×	No.	1	....
D. I. Murphy	Burleson, 1 mile west of	775	500	460	......	×	No.	1	....

WELLS FROM THE TRINITY RESERVOIR.

Owner.	Exact location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flowing wells.	Quality.	Irrigation.
....	Virgil *a*	......	800	......	......	......	×	....	....
J. Runnels	Greenway, ¾ mile northwest of.	600	602	490	585	......	×	1	×
R. H. Simpson	Greenway, ½ mile west of	600	590	150	......	×	×	1 8	×
W. A. Killough	Freeland, 1½ miles west of	700	548	+80	......	......	×	1	×
J. Force	Freeland, 1½ miles south of	650	585	+110	485	......	×	1	×
S. Force	Freeland, 2 miles south of, in Brazos Valley.	......	500	100	......	......	×	1	×
A. J. Edwards	Freeland, 4½ miles south of, in Brazos Valley.	......	618	150	322	......	×	1	×
L. W. Chase	Cleburne, 6 wells	750	970 to 1003	425 to 525	825 to 915	×	......	1	....

a Reported by T. E. Roessler.

WELLS OF THE WOODBINE SYSTEM.

There are a few wells in the eastern part of Johnson County which have penetrated the Woodbine reservoirs, notably at Grand View, Stubblefield, Venus, and in the northeast corner of the county, south of Mansfield. These waters will not flow above the 550- or 600-foot contour, and hence flowing wells could be expected only in a small area near Island, Middle Chambers, Chambers, and Cottonwood creeks, but good nonflowing wells can be obtained at comparatively shallow depths everywhere east of the Eastern Cross Timbers in this county.

The well of the Oil Mill Company, in the town of Grand View, is an excellent type of the Woodbine nonflowing wells. It is 196 feet deep; depth to first reservoir (x^3), 76 feet; to second reservoir (x^2), 180 feet. The water reservoirs are soft sand, between 12 and 15 feet deep. The well is nonflowing and furnishes 30,000 or 40,000 gallons daily. Mr. J. H. Farrow, the well driller, says: "I believe this to be one of the strongest reservoirs of shallow water I ever saw." Water is pumped out to run a large oil mill and to water from 1,500 to 2,000 head of cattle.

Messrs. Sides & Hartson, well drillers, give the following facts concerning a Woodbine well drilled by them in the Cross Timbers of Johnson County, 4 miles west from Grand View and 10 miles southeast from Cleburne: The well is 300 feet deep; depth to first reservoir, 86 feet; to second reservoir, 150 feet. It is nonflowing and rises 200 feet from bottom, furnishing 200 gallons of soft water per hour. The first and second waters were not of good quality, but were cased off with iron casing and the drill hole was continued to the lower and softer water. All of the deep water is in beds of white sand ranging from 3½ to 20 feet each in thickness.

The Stubblefield Gin Company reports that their well at Stubblefield is 196 feet deep; depth of first reservoir, 15 feet; of second reservoir, 150 feet. It is nonflowing, and used for running gin. Strata passed through were red sand rock, then blue clay, and then a white sand to water, then back to a blue clay—all beds of the Woodbine formation.

The well of Mr. W. A. Huckabee is located 3 miles north of Pleasant Point, in the Cross Timbers. Total depth, 116 feet; depth of first reservoir, 72 feet; of second reservoir, 97 feet. It is nonflowing, the water rising 55 feet. The first water was of the mineral character called "copperas" in this section. This is generally found in the upper or x^3 reservoir, and can be cased off. The water of the lower or x^2 reservoir is usually very pure and is potable.

Mr. B. S. Shook, driller, reports the following well drilled by himself, one-half mile south of Pleasant Point: The total depth is 191 feet; depth of first reservoir, 55 feet; of second reservoir, 170 feet. The well is nonflowing, but the water rises 110 feet. The well is in the Eagle Ford Prairie. It passed through soil and about 12 or 15 feet of red clay, and then blue dirt to first reservoir, 55 feet; then it passed through water in sand rock and blue dirt to second reservoir. Mr. Shook writes: "On the east side of the Cross Timbers soft water can be obtained from 175 to 225 feet [from the Woodbine reservoir]; on the west side from 475 to 550 feet [from the Paluxy reservoirs]."

WELLS OF THE PALUXY SYSTEM.

In Johnson County, as in Tarrant, Denton, and Cooke counties, to the northward, the Paluxy formation assumes great importance as a source of artesian water. The sands become thicker and the water, especially in their lower part, less impregnated with mineral matter. In the counties named these wells are more numerous than those from any other reservoir, and from an economic standpoint are the most available, inasmuch as they can be obtained nearly anywhere west of the Eastern Cross Timbers at depths of less than 550 feet, and hence are within the reach of the means of the farmers and stockmen.

In Johnson and Tarrant counties these wells are obtainable at depths of from 450 to 550 feet along the western border of the Cross Timbers, and the depth decreases along lines of strike to the westward. The following wells in Johnson County, near Burleson, Cleburne, and Rio Vista, are all near or on the edge of the Eastern Cross Timbers. The 500-foot wells usually pass through about 320 feet of alternate strata of calcareous marl and limestones of the Washita division, about 80 feet of the hard Edwards limestone, and about 100 feet of the shell limestones and marls of the Walnut formation before reaching the Paluxy sands.

The nonflowing well of D. I. Murphy, located 1 mile west of Burleson, is 500 feet deep; depth of the first Paluxy water, 460 feet. The drill passed through the limestones and marls of the Washita and Fredericksburg divisions, penetrating, approximately, their entire thickness. Just above the first water the *Gryphæa corrugata* shell agglomerate was passed, and the first water was obtained in a porous sand rock below it. This was found insufficient in quantity. The drill then went through a hard quartzite stratum, called "flint rock" by the people, and struck the second reservoir of water in the lower portion of the Paluxy sands, which rose about 300 feet and has never been lowered.

Mr. G. W. Bronson has a similar nonflowing well, located 2½ miles west of Burleson (see Pl. LX, *D*). Its total depth is 465 feet; depth of first or upper Paluxy reservoir, 450 feet; of the lower reservoir, 460 feet. The well furnishes 6,000 gallons of soft water a day. The drill passed through strata similar to those above mentioned.

The shell agglomerate just above the first water was probably 8 or 10 feet thick.

The well of G. W. Johnson, 3 miles southwest of Joshua, is also of this type. The total depth is 525 feet; depth of first reservoir, 480 feet; of lower reservoir, 525 feet. It is nonflowing, but furnishes an abundance of fine soft water.

Mr. S. N. Clark's well is 3 miles southwest from Cleburne. It is nonflowing and is almost identical in character and stratigraphy with those at Burleson. Total depth of this well is 420 feet. There are four other wells within a radius of 1½ miles of this one which are 418 to 425 feet deep and afford plenty of water for home use.

Still another well of this type is that of W. J. Ince, postmaster at Sullivan, located 3 miles east from Rio Vista. Its total depth is 540 feet; depth of first reservoir, 450 feet; of second reservoir, 90 feet. It is nonflowing, the water rising 364 feet. The water is soft and is used for drinking and washing. The water was obtained in white sandstone, which was penetrated about 40 feet.

The postmaster at Rio Vista says: "We get similar artesian wells at 450 and 500 feet, but no flow."

Wells from the Paluxy reservoir deepen as one goes eastward into the Cross Timbers, such as that of V. M. Hightower, 5 miles southeast of Cleburne, which is 568 feet deep, and of the Academy at Keene, 6 miles northeast of Cleburne, which is 750 feet deep. The latter is the deepest Paluxy well in the county.

We have reports of only a few of the shallow Paluxy wells in the western part of the county, such as the nonflowing well of Mr. J. S. Baugh, 2 miles north from Bono, which is 398 feet in depth. The water of this well is soft, with a little sulphur.

The nonflowing well of H. L. Russell, one-quarter of a mile east of Bono, 311 feet in depth, is also of this type. Depth of first reservoir, 300 feet. The water from this well is soft.

WELLS OF THE TRINITY SYSTEM.

Excepting the wells at Cleburne and in the Brazos Valley, in the southwest corner of the county, the Trinity reservoirs have not been tapped in Johnson County. This is due to the fact that the farmers and stockmen are usually content with the first good water, and find their wants in this county supplied in the Woodbine and Paluxy reservoirs. Alvarado and Cleburne are the only large towns in the county which could afford to go to the lower Trinity reservoirs as the cities of Hillsboro, Waco, and Temple have done. The writer has been unable to obtain any report from Alvarado, and hence that place stands upon the map as the only town of its size within the artesian belt which has not drilled a deep flowing well. The writer may be mistaken, however, in this conclusion. At Cleburne wells have been drilled to the depth of

1,025 feet into the Trinity reservoirs, which are there about 525 feet below the Paluxy reservoir. (See Pl. LX, *C*.) The writer is unable to say whether or not the Basement reservoir has been penetrated. The geological situation of the city is very similar to that of Fort Worth (probably 100 or 200 feet higher stratigraphically), and wells have probably nearly if not quite reached the Basement sands. In drilling the Cleburne well the Paluxy reservoir was encountered between 425 and 525 feet, an upper Trinity reservoir (t^3) between 825 and 925 feet, and a lower Trinity reservoir (t^2 ?) at 970 feet. Alvarado would be obliged to go from 300 to 500 feet deeper to reach the same strata.

In the extreme southwest corner of the county the wide Brazos Valley is cut down some 400 feet below the level of the adjacent uplands of the Grand Prairie 2 miles north of Freeland. In this valley, between Freeland and Greenway, according to Mr. Blackstock, the driller (see Pl. LX, *A* and *B*), there are a half dozen excellent flowing artesian wells from the Trinity reservoirs at depths varying from 550 to 618 feet. These wells are a continuation of a series which is found along the Brazos and Paluxy valleys in Johnson, Hill, Bosque, Erath, and Somervell counties, from Waco west to Bluffdade.

The wells of the Freeland-Greenway district all commence in a horizon near the base of the Washita and the top of the Fredericksburg division, and are drilled through the river alluvium (in some instances), the Edwards limestone, the Walnut, Paluxy, and Glen Rose formations into the Trinity reservoirs (t^3 ?).

Mr. Isaac Runnel's well, three-fourths of a mile northwest of Greenway, which was drilled on an elevated spot, is a fair type of these wells. Its total depth is 602 feet; depth of first Trinity reservoir, 490 feet; of other reservoirs, 585 feet. It is a flowing well, furnishing 1,320 gallons of pure soft water per hour.

The well of Mr. R. H. Simpson, located one-half mile west of Greenway, is much lower than the above well. It is 590 feet deep, the depth of the first reservoir (Paluxy) being 150 feet. It flows, furnishing 2,700 gallons per hour. The water is soft and contains sulphur and iron.

Mr. A. J. Edwards reports that his well is located 2½ miles south of Freeland. It is 618 feet deep; depth of first reservoir, 150 feet; first flowing water, 372 feet. It is a flowing well, furnishing about 1,080 gallons per hour. Mr. Edwards says: "The flow and pressure depend on the location. In the lower valleys of the Brazos River it is much greater than it is on the second or third terraces and the depth shallower. There is a well about 1 mile across the Brazos River, in the second valley from my well, that flows about 200 gallons a minute. First flowing reservoir, 372 feet; second reservoir, 480 feet."

TARRANT COUNTY.

Tarrant County has an area of 897 square miles. It is one of the most favorably situated counties in Texas for procuring artesian waters, and is a region of great artesian development.

The western half of the county lies entirely within the Grand Prairie, the gently sloping uplands of which are mostly based upon the outcrops of the Fort Worth limestone. The eastern half of the county lies within the belt of the Eastern Cross Timbers. The gently eastward slope of the whole county is broken by the valley of the Trinity River, which is incised about 200 feet below the uplands. The general upland altitude decreases from 1,000 feet at a point northwest of Benbrook to 500 feet at the extreme eastern edge of the county. Fully one-half the area of the county lies below 650 feet, the altitude to which the waters of the Basement Trinity reservoir will rise.

In every portion of this county water can be obtained from one of the many reservoirs at depths of less than 550 feet; hence the county is unusually well supplied with artesian wells.

The entire county is underlain by the Basement Trinity reservoir (see Pl. LXIX), which is about 500 feet above sea level near Azle, at the northwest corner of the county, and about 1,000 feet below sea level at the extreme eastern edge of the county. From this reservoir the so-called "jumbo" flows formerly could be obtained anywhere in the county at points below 650 feet, at depths of from 280 feet on the western edge of the county to 1,500 feet at the eastern line. This reservoir, except in the valley of the West Fork of the Trinity, in the limited area in the northwest corner of the county, where it is available at depths of less than 500 feet, is not often drawn upon by the farmer, for elsewhere in the county he can obtain sufficient water from the Paluxy or Woodbine reservoirs. As will be shown later, however, it is used to an enormous extent by the people and by the breweries, packing houses, and railroads and other industrial concerns requiring large quantities of water.

The Paluxy reservoir (see Pl. LXX) underlies all of the county except about 20 square miles in the northwest corner between Silver Creek and the West Fork of the Trinity. It is the reservoir which is most used by the people, there being some 250 wells from this source alone in Fort Worth.

This reservoir consists in general of two sandy strata separated by a thin layer of quartzite or clay, the upper of which furnishes water highly charged with mineral impurities, while the lower supplies water of purer quality, which is excellent for drinking and domestic purposes. This reservoir is available at a depth of 200 feet along the western margin of the county in the vicinity of Bear Creek, Benbrook, and Avondale; at about 425 feet along the western margin of the

Eastern Cross Timbers; and at about 1,000 feet at the eastern margin of the county. The Paluxy waters will not flow at points having an altitude of over 600 feet.

The Woodbine reservoirs (see Pl. LXXI) underlie all that portion of the county east of the central part of the Eastern Cross Timbers, and approximately corresponding to a line drawn west of Mansfield, Arlington, Euless, and Grapevine.

The Woodbine reservoirs are embedded only to shallow depths in this county, outcropping at the surface in the Eastern Cross Timber belt; the lowest of them is about 125 feet deep at Arlington and about 300 feet deep along the eastern border of the county. There may be two reservoirs in the Woodbine system (x^2 and x^3), situated in this county only a few feet apart, the upper of which furnishes impure water of the quality called "copperas," while the lower is very potable and of excellent quality for domestic and agricultural purposes.

DEVELOPMENT.

Tarrant County will be notable in the history of Texas as the pioneer county in artesian-well development, the first artesian wells having been drilled here. There are numerous artesian wells in the county. The writer has been unable to secure a complete list of wells, especially of those within the city of Fort Worth, but the following record will show most of the wells throughout the county:

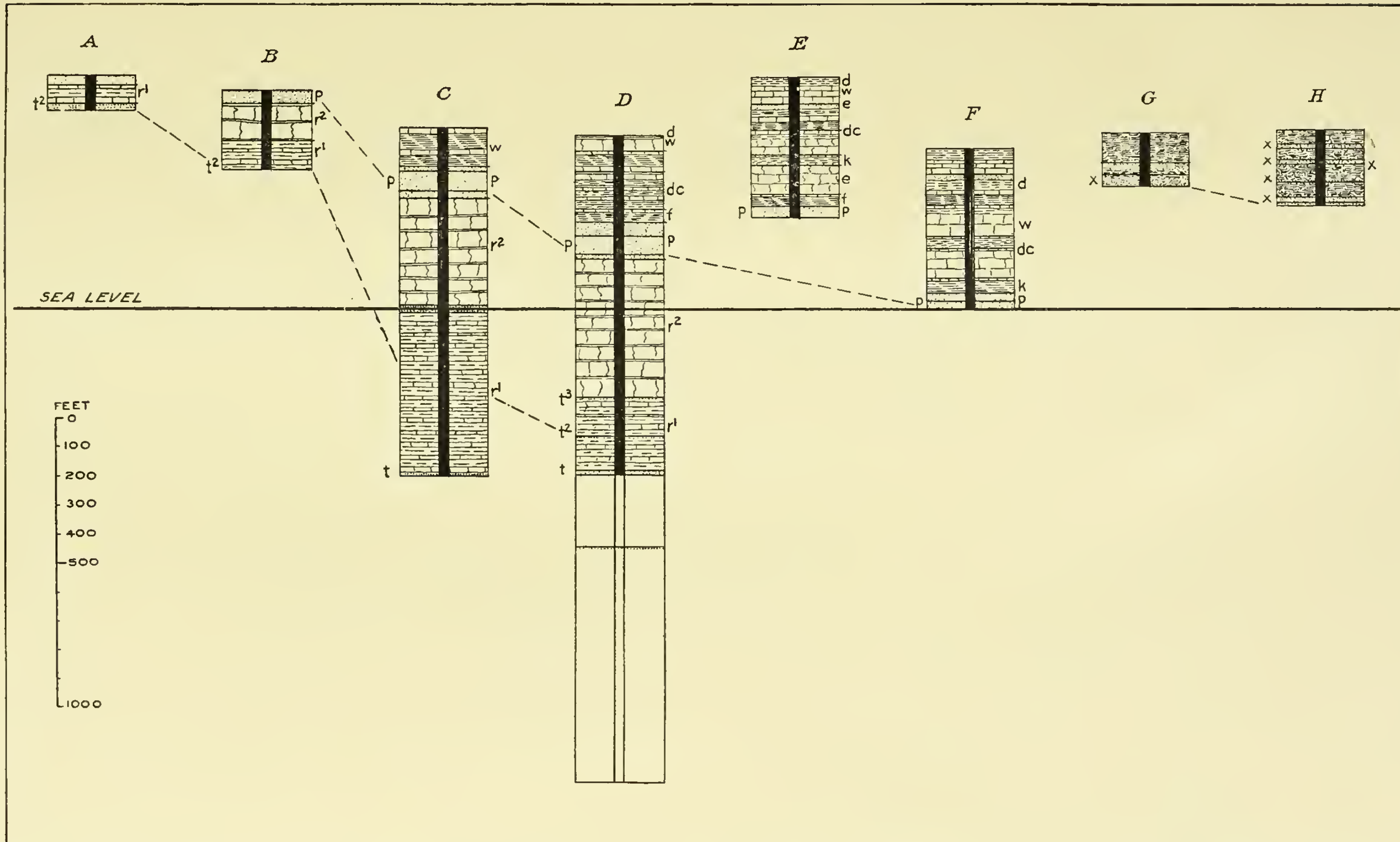
Schedule of wells in Tarrant County, Texas.

WELLS FROM THE WOODBINE RESERVOIR.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water. *a*	Flow. *a*	Increase. *a*	Decrease. *a*	Quality. *b*	Irrigation. *a*
			Feet.	*Feet.*	*Feet.*						
J. A. Morgan, reports..	Mansfield, 4 miles northwest of.	.....	100	90	.....	×	......	...	...	1	...
J. Bryant	Grapevine	600	423	200	400	×	......	...	...	1	...
Dr. Hutchinson	Arlington, 200 yards south of.	.....	235	60	80 200	×	......	...	...	1	...
O. Hiett	Sublett, 1½ miles southwest of.	.....	99	78	.....	45	......	...	...	2	...
....	Sublett, 1 mile south of...	.....	165	73	.....	115	......	...	...	1	...
J. T. Toney	Arlington, 3 miles southeast of.	.....	165	40	75	85	......	×	...	1	...
....	Johnson Station, southeast of.	.....	71	65	.....	×	......	...	...	2	...
W. T. Walton	Johnson Station, 3 miles south of.	.....	210	24	140 185	×	......	...	...	1	...
Mayor of Mansfield	Mansfield, 100 yards from post-office at, about 50 wells.	.....	200	50	150	×	Some do.	...	...	1	...
J. Pinson, reports	Mansfield, ¼ mile from post-office at.	.....	156	24	66	×	......	...	...	1	...

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.



TYPICAL WELLS OF TARRANT AND PARKER COUNTIES, TEXAS.

A, Springtown, Parker County; *B*, Azle; *C*, Packing House well, one-half mile from Marine; *D*, Tuckers Hill well; *E*, Wim's well, south of Fort Worth; *F*, one-half mile southwest of Randol; *G*, 3 miles south of Arlington; *H*, Dr. Hutchinson's well, Arlington.

Schedule of wells in Tarrant County, Texas—Continued.

WELLS FROM THE WOODBINE RESERVOIR—Continued.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Increase.	Decrease.	Quality.	Irrigation.
			Feet.	*Feet.*	*Feet.*						
J. Pinson, reports	Mansfield, ½ mile east of		190	30	150					1	
R. B. Jennings, reports.	Grand Prairie, 4 miles west of.		170	90							
J. Miller	Webb, 1 mile north of		236	190	215					1	
J. Ragland	Webb, ½ mile south of		169	20	69		×			1	
J. D. Cooper	Arlington, 5 miles southeast of.		125	25		×				1	
J. H. Pinson (reports).	Gertie, a little south of, 2 miles east of.		150	105			×			1	
Do	Britton (Ellis County), 2 miles northwest of.		203	20	60 84 140	×				1	
Do	Britton (Ellis County), ¾ mile northeast of.		95	85		×	×			1	
Do	Britton (Ellis County), 2 miles northeast of.		68	60			×			1	
Do	do		107	100			×			1	
	Fort Worth, 19 miles northeast of.		300	260	280	×				1	
G. W. Hewitt	Marine post-office, 1 block west of.		248	230		×				1	
J. S. Loving	Marine, ½ mile north of		240	225		×			×	1	×

ARTESIAN WELLS FROM THE PALUXY RESERVOIR.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Increase.	Decrease.	Quality.	Irrigation.
Mrs. Higbee	Aledo, 4½ miles east of, on divide between two creeks.		290	217	272	×				1	
J. L. Goforth	Bear Creek post-office, 1½ miles southwest of.		200			×				1	×
W. Day	Bear Creek, 1½ miles south of, on divide between Bear Creek and Clear Fork.		170	50	80	×				1	
J. W. Conn	Bear Creek, 2 miles southeast of.		118	102		×				1 8	
Frank Baskin	Avondale, 1½ miles southwest from.		299	288		×				1	
J. C. Shirley	Avondale, 400 yards from.		285		100	×				1	
Geo. Burgis	Avondale		285			×				1	
C. Maloney	Haslet, ¼ mile north of		270	245						1	
E. H. Gibbon	Haslet, 1 mile south of		430	320	335	×				1	
W. V. S. Allen, reports.	Haslet, 3 miles southeast of.	800	480	430	440	×				1	×
	Keller		457								
	do		430								
S. Hays	Crowley, 7 miles southwest of.		430	370	420	×				1	
F. Feltz	Crowley, 5 miles west of		355	340		×				1	×
W. N. Riddle	do		301	282		×				1	
L. Burson	Crowley, 3 miles northwest of.		446	426		×				1	
Hays Bros	Crowley		486	455		×				1	
W. S. Neely	Crowley, 2 miles from, 12½ south of Fort Worth.		484			350				1	×
C. H. Silimore	Fort Worth, ½ mile west of		300	50		100				1	

Schedule of wells in Tarrant County, Texas—Continued.

ARTESIAN WELLS FROM THE PALUXY RESERVOIR—Continued.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Increase.	Decrease.	Quality.	Irrigation.
			Feet.	*Feet.*	*Feet.*						
W. A. McLean	Fort Worth, 6 miles north of, 1½ miles from Saginaw, 6 wells or more.	.....	350	325	.....	×	.....	...	...	1	×
W. J. Gilvin	Fort Worth	.....	353	215	320	×	.....	...	...	1	...
.....	do	.....	263	.....	.....	.....	.....	...	...	...	...
J. A. Wims	Fort Worth	.....	404	.....	.....	.....	.....	...	...	...	...
J. L. Hutchins	Fort Worth, east of	.....	270	28	.....	×	.....	...	...	4 8	...
J. W. Alderman	Fort Worth, ½ mile south of	.....	362	250	346	×	.....	...	...	1	×
E. S. Hall	Fort Worth, 3 miles southeast of.	520 to 599	364	.....	.....	×	.....	...	...	1	...
H. S. Davis	Fort Worth, 4½ miles northeast of.	.....	338	.....	.....	.....	×	...	...	1	×
W. C. Henderson	Fort Worth, 6 miles northeast of.	.....	406	376	.....	×	.....	...	×	1	...
J. M. Popplewell	Birdville, 300 yards west of.	.....	398	15	350	×	.....	...	×	1	...
L. M. Barkley	Birdville, ½ mile from	.....	420	337½	.....	×	.....	...	...	1	...
J. Henderson	Birdville, 1 mile north of.	.....	486	60	.....	×	.....	...	...	1	...
M. F. Akins	Birdville, 1 mile south of.	.....	379	344	.....	.....	×	×	...	1	...
L. P. Powell	Enon, 1 mile west of	.....	430	420	.....	370 ×	.....	...	...	1	...
F. Vaughan	Enon, 1 mile from	.....	485	474	.....	130 ×	.....	...	...	1	...
J. East	Enon, 3 miles northeast of.	.....	460	445	12	×	.....	...	...	1	...
J. M. Handley	Handley	592	510	490	.....	×	.....	...	...	1	...
W. P. Craig	do	.....	510	480	.....	×	.....	...	...	1	...
J. J. Scott	Oak Grove, 3 miles north of.	.....	442	420	.....	×	.....	...	...	4	×
G. W. Tye	Oak Grove, 1 mile south of.	.....	500	460	485	×	.....	...	...	1	...
B. S. Shook	Fort Worth, 12 miles southeast of, east side Village Creek.	.....	535	510	522	×	.....	...	...	1	...
T. S. Clark	Randol, 3 miles southwest of.	.....	420	400	.....	.....	×	...	.	1	...
H. Hubert	Randol, ½ mile southwest of.	500	525	505	515 520	.....	×	...	...	...	...
J. Henderson	Randol, ½ mile north of.	.....	505	30	.....	.....	×	...	...	1	...
John Morrow	Randol, 1 mile northeast of.	.....	546	55	526	.....	.....	...	...	4	...
G. A. Trippet	Bedford, 2 miles south of.	550	603	560	.....	.....	×	...	...	1	...
J. D. Jones	Dove, 1½ miles north of	.....	576	60	.....	.....	×	...	...	1	...

WELLS FROM THE TRINITY RESERVOIR.

Owner.	Location.	Altitude.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Increase.	Decrease.	Quality.	Irrigation.
H. N. Grigsby	Azle post-office	750	279	40	180	.....	×	...	...	1	...
Packing Co	Marine, 3 miles north of	.....	1,200	147	226 600	.....	×	...	...	...	...
Brewery well	.....	.....	800	.....	.....	.....	.....	...	...	...	...
Natatorium	.....	.....	.....	.....	.....	.....	.....	...	...	...	...
Tucker Hill well	.....	.....	1,000	.....	.....	.....	.....	...	...	...	...
Other wells, 13 in number.	.....	.....	950 1,400	.....	.....	.....	.....	...	...	...	...
Arlington Inn	Fort Worth, 3 miles west of.	.....	1,400	.....	.....	.....	.....	...	...	...	...

ARTESIAN WELLS OF THE WOODBINE SYSTEM.

A few shallow flowing wells and many nonflowing wells are found in the eastern part of Tarrant County. They derive their supplies from two or more reservoirs of the Woodbine formation.

The Woodbine formation has an extensive catchment area in the eastern part of Parker County, as shown upon the map (Pl. LXXI). These wells are found within the eastern margin of the Eastern Cross Timbers and the western part of the Eagle Ford Prairie, which extends into eastern Tarrant County from Dallas County. They are all of the same general geologic character, the material penetrated consisting solely of the black shale clays and sands of the basement portion of the Eagle Ford and Woodbine formations and the intercalated water-bearing sand strata of the latter. There are usually several conspicuous water reservoirs separated by only a few feet of black clay. (See Pl. LXI, *G* and *H*, and Pl. LXII, *F–I*.) Some of these wells will now be described, beginning near Mansfield, in the southeast corner of the county.

Mr. B. T. Ramsey, mayor of Mansfield, states that they have about fifty artesian wells in that town, ranging from 130 to 210 feet in depth. These wells strike two principal reservoirs (x^2 and x^3) which are about 100 feet apart, the water from the latter being considered the best, as it is less charged with mineral impurities and is soft and cool. The following section of a well drilled by Mr. B. S. Shook, well driller, 1 mile west of Mansfield, shows the character of the strata passed through (see Pl. LXII, *I*):

SECTION NO. 96.—SECTION OF WELL 1 MILE WEST OF MANSFIELD, FURNISHED BY B. S. SHOOK, WELL DRILLER.

	Thickness.	Depth.
	Feet.	*Feet.*
5. Blue clay	78	78
4. White sand (water)	10	88
3. Blue clay with hard layers	77	165
2. White sand (water)	35	200
1. Blue clay	5	205

Another correspondent, Mr. J. H. Pinson, well driller, reports upon these wells as follows: "There are about 60 drilled wells in the town of Mansfield. Three of these flow from 3 to 6 gallons per minute. Others are near the creek. The depth of the wells in the town ranges from 120 to 190 feet. One of the wells furnishes 4,000 gallons per hour, with the pump pipe only 30 feet deep. The water stands within

3 feet of the surface when not in use. This will give some idea as to the amount of water the wells here will furnish."

There are many wells of this character throughout the region bounded on the north by the Trinity River and on the west by a line drawn through Arlington and Mansfield, though flowing wells are found only in the creek valleys below an altitude of 550 feet. Flowing wells of this character are found northeast of Britton, along Low Branch, Fish Creek, Johnson Creek, and other valleys in the extreme eastern portion of the county. In the town of Arlington (see Pl. LXI, *II*) there are many nonflowing wells from the Woodbine reservoirs to a depth of 200 feet. Flowing wells should be found north of the Trinity, near Enless, and in the valley of Bear Creek, but we have few reports from this portion of the county. At Grapevine the Woodbine reservoirs lie from 200 to 400 feet below the surface, and do not furnish flowing water.

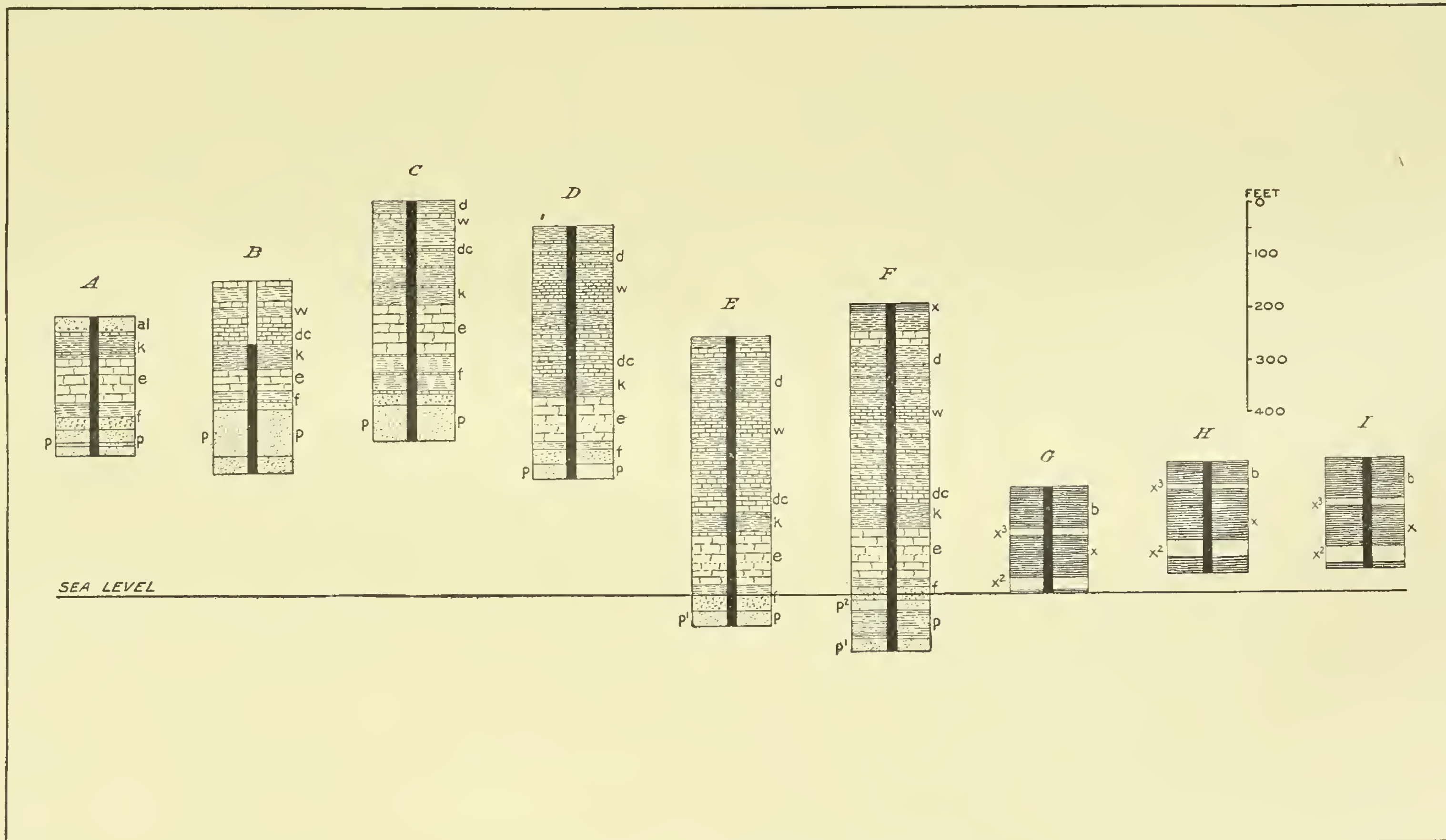
These Woodbine wells in eastern Tarrant and Johnson counties mark the beginning of an extensive artesian district, which has its greatest development in Dallas, Ellis, and Navarro counties, situated to the east, and to be described later.

WELLS FROM THE PALUXY RESERVOIR.

There are numerous artesian wells in Tarrant County deriving their waters from the Paluxy reservoir. Some of these are flowing, but most of them have to be pumped. The Paluxy water is obtained at depths of less than 100 feet along the valley of the Clear Fork of Trinity River, approximately east and west across the county, and near Bear Creek post-office; at 242 feet about 2 miles west of Fort Worth; at 250 feet in the city of Fort Worth; at 546 feet at Hearst Lake, 1 mile east of Randolph post-office and about 9¼ miles east of Fort Worth; and at about 850 feet in the same valley along the eastern line of the county.

On the uplands or surface of the dip plains which form the extensive flat divides of the county the artesian waters do not flow at altitudes higher than 600 feet, and their depth increases from 285 feet at Avondale on the west to about 525 feet along the western border of the Eastern Cross Timbers, and 1,000 feet at the eastern margin of the county. The series of typical wells given on Pls. LXI and LXII will illustrate the character of the strata and the artesian reservoirs. The depth of these wells decreases to the westward with great regularity and uniformity relative to the surface formation. With one exception they all commence in horizons lower than the Woodbine formation.

The deepest of the Paluxy wells reported is that of Mr. G. A. Trippett, 2 miles south of Bedford, which is 603 feet deep, reaching the upper Paluxy reservoir at 560 feet. This well, which begins in or at



SPECIAL WELLS IN TARRANT COUNTY, TEXAS

A, R. H. King's well in river valley, Fort Worth; *B*, Gilvin's well, Fourth and Rusk streets Fort Worth; *C*, Keller; *D*, J. A. Wim's well, 5 miles southeast of Fort Worth; *E*, Hurst Lake, near Randol *F*, G. A. Triplett's well, 2 miles south of Bedford; *G*, A. Woodbine's well, 1 mile west of Mansfield; *H*, Mansfield; *I*, 1 mile east of Mansfield.

the base of the Woodbine formation (see Pl. LXII, *F*) penetrates the whole of the Washita and Fredericksburg divisions before reaching the upper Paluxy reservoir.

Another well, at Dove post-office, in the northeast corner of the county, shows a similar geologic section, and is 576 feet deep. The wells at Rendon, 535 feet deep, and Randol (see Pl. LXII, *E*), 546 feet deep, also begin at the surface very near the boundary between the Upper and Lower Cretaceous formations. The well at Handley (510 feet deep) begins near the Main Street limestone, and penetrates all the underlying strata of the Washita and Fredericksburg divisions.

The correspondents who report these wells all describe in their own peculiar style the various shell rocks, which are easily recognized by the geologist, and which are fully set forth in the portion of this paper devoted to geology. The wells near Crowley, Oak Grove, Enon, Birdville, and Keller all begin in the upper portion of the Lower Cretaceous and reach the artesian waters at depths of from 457 to 500 feet.

The following sections are typical of the wells in these portions of the county:

SECTION NO. 97.—SECTION OF WELL AT KELLER, TARRANT COUNTY, TEXAS (ALTITUDE 740 FEET).

(See Pl. LXII, *C*.)

	Thickness.	Depth.
	Feet.	*Feet.*
10. Yellow clay (Fort Worth and Denison)	20	20
9. Yellow limestone (Fort Worth and Denison)	30	50
8. Brown soapstone (Fort Worth and Denison)	135	185
7. White limestone (Goodland)	100	285
6. Blue soapstone (Walnut)	30	315
5. White limestone (Walnut)	30	345
4. Blue soapstone (Walnut)	25	370
3. Shell rock (Walnut)	22	392
2. Brown sandstone (caving in) (Paluxy)	27	419
1. White sandstone (Paluxy)	28	447

SECTION No. 98.—SECTION OF JOHN A. WIM'S WELL, 5 MILES SOUTHEAST OF FORT WORTH, TARRANT COUNTY, TEXAS (ALTITUDE 629 FEET). REPORTED BY F. A. ROESSLER.

(See Pl. LXII, *D*.)

	Thickness.	Depth.
	Feet.	*Feet.*
19. Yellow clay	30	30
18. Blue soapstone	2	32
17. White lime rock	49	81
16. Blue soapstone	24	105
15. White lime rock	40	145
14. Brown soapstone	20	165
13. Very hard shell rock	2	167
12. Brown soapstone, with hard streaks	28	195
11. White limestone	95	290
10. Blue soapstone	42	332
9. White limestone	52	384
8. Blue soapstone	5	389
7. White limestone	34	423
6. Blue soapstone	5	428
5. White limestone	5	433
4. Blue soapstone	7	440
3. Shell rock	22	462
2. Brown sand rock (p^2)	13	475
1. White sand rock (p^1)•	14	489

No casing. Water rises to 50 feet from surface, and will stand pumping 50 gallons per minute.

The above is one of the very few accurate and intelligible logs of the wells which the writer has been able to obtain and which is readily comparable with the measured sections.

	Feet.
Nos. 12–19 are the Denison formation:	
Nos. 12 and 13 are the Denton beds	30
Nos. 14, 15, and 16 are the equivalents of the Weno beds	84
No. 17 is the Main Street beds	49
Nos. 18 and 19 equal the Grayson beds	32
	195
No. 11 is the Fort Worth and Duck Creek formations	95
No. 10 is the Kiamitia formation	42
Nos. 7, 8, and 9 are the Edwards formation, showing two subdivisions	91
Nos. 3, 4, 5, and 6 are the Walnut formation, No. 3 (22 feet) bearing the typical Gryphæa breccia	39
Nos. 1 and 2 are the Paluxy sand in part	27

As far back as 1890 over 242 artesian wells were reported by Roessler in the city of Fort Worth. A later estimate, made in 1897, places the total number of wells of all kinds at from 150 to 160. A majority of these wells did flow originally and water rose in all of them. Only a few are now said to be flowing, as the artesian supply has been too much drawn upon. A great number of steam pumps are used, drawing from 50 to 100 gallons per minute. Some of the low-lying wells rise a number of feet during each night, but lower during the day. All of the wells, with the exception of about 15, obtain their water from the Paluxy reservoir, which is penetrated about 353 feet below the prairie level of the main portion of the city (the top of the Fort Worth limestone) and about 283 feet below the level of the Trinity River at Fort Worth, which is situated in the Duck Creek formation. Two miles west of Fort Worth one of the earliest wells was reached at 242 feet.

The well of Mr. W. J. Gilvin, corner of Fourth and Rusk streets (see Pl. LXII, *B*), is typical of the Paluxy wells in the main part of Fort Worth (altitude 600 feet) as distinguished from the shallower wells in the valley of the Trinity, where the altitude is less than 550 feet. This well is 353 feet deep. The water rises to within 125 feet of the surface, or to an altitude of 425 feet above sea level. The well yields about 25,000 gallons of water in ten hours. The water is very clear and palatable.

The section of Mr. Gilvin's well also illustrates the strata passed through by these wells, which begin at the top of the Fort Worth limestone in the center of the city of Fort Worth. (See Pl. LXII, *B*.) The section of the well of R. H. King (Pl. LXII, *A*) illustrates one of the river valley wells in the same locality. The latter well passed through the following strata:

SECTION NO. 99.—SECTION OF WELL OF R. H. KING, FORT WORTH, TARRANT COUNTY, TEXAS.

(See Pl. LXII, *A*.)

	Thickness.	Depth.
	Feet.	*Feet.*
8. Clay and sand (alluvium)	31	31
7. Yellow limestone (Duck Creek)	2	33
6. Blue "soapstone" (clay, Kiamitia)	45	78
5. White limestone (Edwards)	83	161
4. Blue "soapstone" (clay, Walnut)	25	186
3. Shell rock (*Gryphæa corrugata*, Walnut)	25	211
2. Brown sand (p^2)	27	238
1. Good white sand (p^1)	25	263

Proceeding westward from Fort Worth, the Paluxy wells continue to shallow rapidly in the valleys but maintain their depths on the upland dip plains to the western escarpment of the Grand Prairie, which follows close to the West Fork of the Trinity River, Mustang Creek, and the Clear Fork of the Trinity. The well of W. V. S. Allen, 3 miles southeast of Haslet, which is on the high prairie at an altitude of over 800 feet, strikes the Paluxy water at a depth of 480 feet. This water rises in his well to within 280 feet of the surface, or to an altitude of 520 feet above sea level. The highest eminence of the Grand Prairie in this portion of the county is 850 feet, or 300 feet above the valley of the Trinity along the same line of strike; this difference must be considered in drilling wells.

On the high prairie at Avondale, in the extreme northwestern corner of the county, where the altitude is nearly 900 feet, the Paluxy reservoirs are situated nearly 300 feet below the surface. All the strata penetrated by the wells can be seen on the surface by descending Indian Creek to the West Fork of Trinity River, which here flows through the outcropping Paluxy sands. In the southwestern portion of the county along Morris Creek, Silver Creek, Woods Branch, Dutch Branch, Bear Creek, and the Clear Fork of Trinity River, which are established upon levels much lower than the higher divides of the Grand Prairies, the Paluxy sands are reached at very slight depths. The well of Mr. Day, located on the divide between Bear Creek and Clear Fork, near Bear Creek post-office, secures the Paluxy water at 170 feet. R. E. Russell, of Bear Creek, says that there are 200 wells in his vicinity, the water of which is found in a white sand stratum from 10 to 40 feet in thickness. None of these wells flow, but they are of greatest value to the agricultural community.

J. W. Conn, whose well is 2 miles southeast of Bear Creek post-office, obtains an excellent supply of water in the Paluxy reservoir at depths of from 102 to 118 feet. The water in this well rises 80 feet. He states that he has five or six wells of this kind on his ranch, varying from 118 to 220 feet, according to the altitude of the surface. The supply seems to be inexhaustible by any ordinary means of pumping, such as windmills or other machinery which farmers and ranchmen use.

The Paluxy sands in the reservoirs embedded beneath Tarrant County, as can be seen at their outcrop at Weatherford and from thence southeast to northwest of Cresson in Parker County, are always found beneath a breccia of *Gryphæa corrugata*, which is popularly called "shell rock." The upper portion of these sands, both at the surface outcrops and in the embed, is usually green or brown, containing much more glauconite and pyrites than their lower portion, which is whiter. The upper portion, the p^2 reservoir, should always be cased off, for the waters are impure and highly impregnated with mineral matter. The water from the whiter sands of the p^1 reservoir is, in nearly every instance, of excellent quality for domestic uses.

ARTESIAN WELLS OF THE TRINITY RESERVOIRS.

For many years Fort Worth was content with the artesian waters derived from the Paluxy sand, which, as we have stated, lay below the city at an average depth of from 250 to 350 feet above sea level. The possession of this water was a source of pride to the city, and the envy of the many towns competing with it in growth of population. It was not then known that below the Paluxy reservoir there lay still untapped at least two Trinity reservoirs from which stronger flowing wells might be obtained. These lower lying artesian reservoirs of the Fort Worth wells are the Trinity sands of the Trinity division, and are separated from the overlying Paluxy formation by the intervening limestones of the Glen Rose beds. Their depths, relation, and stratigraphy will be seen in the maps, sections, and profiles to be given.

In addition to greater volume and pressure, the waters from the lower or Trinity reservoirs possess the merit of being chemically purer and softer than that of the Paluxy. In the language of an enthusiastic resident, this water is "as clear as a diamond and as pure as the melted snow." (See analysis in table opposite p. 448.)

Accounts of the experiments on Tuckers Hill and of the well of the Packing Company north of Fort Worth will illustrate the nature and depths of the Trinity reservoir. It was not until after the city of Waco had secured wonderful flowing wells from the lower-lying Trinity reservoirs that Fort Worth wisely concluded to go deeper in order to ascertain if a stronger flow, greater pressure, and purer water could be obtained below the Paluxy reservoir.

In February, 1890, the city council contracted for the sinking of an experimental well, to fully test the possibilities of the artesian-water supply for city use. (See Pl. LXI, *D*.) The experimental well was located at about the highest point in the city—the top of Tuckers Hill (altitude about 650 feet), about 52 feet above the Main street crossing of the Texas and Pacific tracks, about 42 feet above the court-house square, and about 125 feet above the Trinity River. This well was drilled, according to one correspondent, to a depth of 4,000 feet, but how far this statement can be relied upon the writer can not say. A letter from the contractor, while the well was in progress, mentions the fact that it was "down to a depth of 3,250 feet."

Notwithstanding the great value of a record of a deep well of this character, no specimens or accurate logs have ever been obtainable, and the following remarks are made upon reports or observations which may not be minutely correct:

The surface formation was the brown clay marls of the lower portion of the Denison beds, about 50 feet above the top of the Fort Worth limestone. The Paluxy reservoirs—the same from which the shallower artesian wells of the city are obtained—were reached at 300 feet (p^2) and 425 feet (p^1).[1] At 895 feet a Trinity reservoir was reached, which may be called t^3; below this, between 895 and 1,150 (about 1,035 feet), another Trinity reservoir (t^2) was encountered, and at 1,320 feet a third reservoir (t^1) was penetrated.[2]

According to Mr. Marshall, the last flow was at 1,320 [or 1,120] feet, and measured 295,000 gallons in twenty-four hours; this was from water-bearing sand 39 feet in thickness. Then followed 100 feet of red shale or joint clay. At 1,420 feet slate was struck. From that point the formation ran very regularly in 24- to 30-foot bands of slate, then 1 or 2 feet of hard sandy or grit belt, then shale, and so on to the bottom, 3,555 feet. There was no water, not even a seep.

The water from the p^2 reservoir rose to within 90 feet of the surface, or to an altitude of 560 feet; that from p^1 reservoir to within 70 feet of the surface, or to an altitude of 570 feet; that from t^3 flowed out at the surface at the rate of 170 gallons a minute. This flow was cased off and the boring continued to a depth of 1,035 feet, when a flow of 200 gallons a minute (t^2) was struck, which flowed with a pressure of 21 pounds to the square inch. This stream (t^2) was in turn cased off and the work proceeded 92 feet farther, to a depth of 1,127 feet, when still another fine artesian reservoir (t^1) was pierced. This discharged at the surface 245 gallons a minute, with a pressure of 29 pounds to the square inch. According to Mr. Marshall, all these flows could have been put together, when they would have discharged fully 500 gallons a minute, or 720,000 gallons a day, at a point 142 feet above the Trinity River. This last flow from the t^1 reservoir was cased off and the boring was continued, for experimentation, 1,765 feet farther into the impervious underlying Carboniferous formations, or to a total depth of from 3,200 to 4,000 feet.

This well passed from the Cretaceous into the Paleozoic at a depth of 1,420 [1,120?] feet, and no water was found below 1,300 feet. When the well was at a depth of 3,250 feet Mr. Marshall wrote: "We are now in (and have been for 1,800 feet) a blue slate (clay shale), varied occasionally by hard white flinty seams and an occasional layer of sand rock from 1 to 4 feet thick. The temperature of the bottom of the well (as evidenced by the slush pumpings) was 126°." Some months later another correspondent wrote that the well had been abandoned at 3,350 feet and that the temperature was then 140°. In the strata below the Cretaceous no water nor coal were encountered. All known information concerning this well is shown on Pl. LXI, *D*.

Although the utility of this well was impaired by casing of the waters, as a result of this experimental work the three Trinity reservoirs

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[1] The depths and pressure of the waters as here given are from a letter from Mr. W. S. Marshall, the well contractor.

[2] There is some doubt whether this last figure should not be 1,120 feet.

were located below Fort Worth. The weakest flow from these raised water to a height of 40 feet and the strongest to a height of 61 feet above the highest point in the city. This discovery was quickly followed by further drilling of wells to these lower reservoirs, and there are some fifteen wells of this character in the vicinity of Fort Worth.

The Texas Brewery, located 50 feet lower than Tuckers Hill, sank a well to the upper Trinity reservoir (t^3?) and obtained a flow of upward of 240 gallons a minute, with a pressure which carries the water to the top of an immense building, 90 feet above the ground.

The Chicago and Fort Worth Packing Company began a well at the packing house on the north side of Trinity River, one-half mile north of Marine post-office, 4 miles north of the Tuckers Hill well, which began in the same geologic horizon and went to a depth of 1,200 feet. When drilled through the Paluxy and t^3 artesian reservoirs it was said by a former correspondent "to be flowing at a rate of over 800,000 gallons in twenty-four hours." The lower or t^1 flow was reported as 1,500,000 gallons in twenty-four hours. Concerning this well it was further added that "the Packing House well was undoubtedly flowing, after completion, more water in twenty-four hours than any other artesian well in the State of Texas by at least one-third."

The following report on this well, by Mr. Louis H. Blanke, chief engineer of the Chicago and Fort Worth Packing Company, shows that the above statements are exaggerated:

> This is an 8-inch well; was drilled about 1890; flowed 485 gallons per minute (698,400 gallons per day) when first drilled. It now flows 147 gallons per minute (211,680 per day). We work an air lift in it and get 545 gallons per minute (784,800 gallons per day). The size of the pipe being increased, we could get more. The first water reservoir [p^2] was 6½ feet thick and 147 feet deep. The second reservoir [p^1] is 22 feet thick and its water came within 20 feet of the surface, and the supply through a 5⅝-inch casing is 326 gallons with air lift. This reservoir is struck at 226 feet. The reservoir at 600 feet [t^3?] is about 30 feet thick and its water comes within a few feet of the surface. It has never been exhausted with a deep well pump. The water from the 1,200-foot stratum [t^1] flows out at the surface. It has greatly decreased in pressure in late years. The decrease in the flow of the 1,200-foot reservoir was caused by the drilling of fourteen wells in the same reservoir within 3 miles of here. This strata was struck at about 960 or 1,000 feet. The temperature of the [t^1] water is 78° F.

An analysis of the waters of this well is given opposite p. 448.

The Trinity reservoirs have hardly been touched in Tarrant County outside of Fort Worth except at Azle, in the northwest corner of the county, and at Arlington, some 14 miles east of Fort Worth. This reservoir, which is chiefly valuable to cities and industrial enterprises, has not been penetrated in the main artesian belt north of Cleburne except at Fort Worth, Cleburne, and Handley, although it is, no doubt, available at all the other numerous towns and cities in the intervening country, such as Dallas and Denton. The surface formation at Azle is very near the top of the Glen Rose or base of the Fredericksburg division, and the well at that point is a shallow one, probably penetrating to the upper Trinity waters at a depth of 280 feet.

The well at Arlington, on the eastern edge of the Cross Timbers, about 1 mile from the Eagle Ford Prairie, is interesting chiefly because it gives a knowledge of the eastern extension of the Trinity reservoirs toward the city of Dallas. According to the postmaster at that village the artesian well penetrating the Trinity reservoir is 1,480 feet deep and discharges 30,000 gallons a day. The water is strongly impregnated with sulphur, magnesia, and other salts, which may come from any of the overlying reservoirs which the well penetrated. These in descending order are the two Woodbine reservoirs, 70 and 235 feet in depth, respectively, and the two Paluxy reservoirs, the depth of which is not stated, but which the writer estimates to be about 750 feet below the surface. The country around Arlington is abundantly supplied with artesian waters from the Woodbine reservoirs, as is further discussed.

It is to be regretted that but one analysis of the various waters of the Trinity reservoirs has been obtained (see p. 448). The lower waters, however, are clear, palatable, and sweet, and suitable for nearly every industrial and domestic use.

The flow of the artesian wells of Tarrant County has greatly decreased in many localities. The flow of the packing company's well at Fort Worth, the Natatorium well, and other deep Trinity wells ceased after the drilling of 15 or 16 wells within a small area. In fact, most of the wells which several years ago yielded large volumes of water at the surface now have to be pumped. This decrease in flow of the deep Trinity wells is primarily due to the fact that too many outlets have been made to the reservoirs, although prolonged droughts have also played a part.

The wells from the Paluxy reservoirs have also shown a similar decrease in pressure, probably due to the same causes. At Birdville a well ceased to flow at the surface immediately upon the drilling of a second well on lower ground within half a mile distant. A perceptible lowering has been observable in all the wells of the Paluxy system in Fort Worth. One correspondent states that nearly all the wells have decreased from one-fourth to one-half in volume in the last five years in Tarrant, Dallas, and Ellis counties. Mr. S. A. Hamlin, an intelligent well driller, observes that he has lived in Tarrant and Dallas counties for the last six years, and while he thinks that the decrease in rainfall is one of the causes of the diminution in flow, another cause is that the water is tapped in so many places and so often on lower ground that the higher wells within half a mile distant are always affected. The decrease in flow may also be partially due to climatic causes. In the years preceding 1897 there was a period of slight rainfall throughout Texas, which undoubtedly affected the quantity of water stored in the artesian reservoirs, especially those of Tarrant County, which are situated so near to the catchment areas. It has been observed that the wells of the Paluxy system especially show a perceptible increase in pressure within seventy-two hours after a fall of rain upon the catchment area. At San Antonio there was an increase of pressure in the artesian wells and springs following a period of great rainfall in 1900.

DENTON COUNTY.

Denton County has an area of 972 square miles. The eastern half lies largely within the belt of the Eastern Cross Timbers and the Eagle Ford Prairie, while the western half lies within the summit region of the Grand Prairie. No topographic surveys have been made of any portion of this county except a narrow strip about 2 miles wide along its southern border, which is mapped upon the Fort Worth atlas sheet of the United States Geological Survey.

The relief is very simple, however, and similar to that of the Fort Worth quadrangle north of the Trinity River and of the northwest quarter of the Dallas quadrangle. In general, this relief consists in the western half of the county of a gently sloping dip plain of the Grand Prairie, being a continuation of the slope which extends from the western summit of the latter in Wise County eastward across Denton to the western edge of the Eastern Cross Timbers. Within the Cross Timber area there are a few low iron-ore knobs, while in the eastern portion the highest relief feature is the White Rock scarp, which extends along the eastern border of the county.

The drainage consists of the Elm Fork of Trinity River, which flows north and south through the eastern half of the county, and several tributaries which flow into it from the northwest with the slope of the Grand Prairie dip plain. These stream valleys are not deeply incised.

GEOLOGY.

The geologic features of the county are simple and coincide with the belts of country described. On the extreme east the White Rock scarp is composed of Austin chalk. Beneath this and underlying the Eagle Ford Prairie are the blue-black clays of the Eagle Ford formation, approximately 500 feet thick in this county. Succeeding this to the west and underlying the Eastern Cross Timber belt are the Woodbine sands, constituting the catchment area of the Woodbine artesian system, the details of which are fully explained in the portion of this report devoted to geology. This formation has a thickness of from 300 to 450 feet in this county, increasing from south to north. Underlying the Grand Prairie to the westward are the formations of the Washita and Fredericksburg divisions of the Comanche series, consisting at the surface almost entirely of the formations of the Washita division, and having an aggregate thickness in this county of about

400 to 500 feet. The rocks of the Fredericksburg division, which are encountered in all the artesian wells and which lie within 100 feet of the surface in the extreme western portion of the county, consist of the Goodland limestone and Walnut clays, described elsewhere.

The entire county is underlain by the Paluxy and Trinity reservoirs and the eastern half by the Woodbine reservoir. The conditions for obtaining shallow artesian wells are favorable throughout the whole county, the depth increasing from west to east. It is impossible to give stratigraphic details of the Trinity and Paluxy reservoirs in Denton and Cooke counties. In the catchment areas to the west the Glen Rose limestone, which separates these reservoirs, does not occur, and the Paluxy and Trinity sands are amalgamated into one arenaceous formation. It has been especially desirable to have good logs of the deep wells of these two counties in order to ascertain the nature of the strata of the Trinity division as embedded beneath them, but the writer has been unable to obtain the details of a single well of this character. That the Paluxy and Trinity reservoirs are differentiated beneath them, however, is well shown by the records of many of the wells, but it is impossible to give the details of these reservoirs.

DEVELOPMENT.

There are over 200 artesian wells in Denton County, derived mostly from the waters of the sands at the top of the Antlers formation, which correspond to the Paluxy reservoirs. These are so easily obtained throughout the Grand Prairie region, at depths varying from 150 to 500 feet, that nearly every farmer possesses one or more. In the eastern half the wells obtained are from the Woodbine system, and are similar to those described in eastern Tarrant and Johnson counties. The writer has been unable to obtain a complete list of the wells, but has secured a sufficient number to illustrate their general distribution and character.

Schedule of wells in Denton County, Texas.

WELLS FROM THE WOODBINE RESERVOIR.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.*a*	Flow.	Quality.*b*	Irrigation.*a*
		Feet.	*Feet.*	*Feet.*				
C. J. Thomas	Lewisville	154	....	......	×	......	1, 9	...
Lewisville Water Co	Lewisville, within 100 yards of post-office.	192	120	......	152	......	9	....
J. M. Stover	Little Elm, 300 yards northeast of.	126	40	108	×	......	1	....
J. W. Lane (reports)	Mustang, 4 miles south of	103	103	......	×	......	1, 8	...
A. Coffey	Aubrey, 5 miles southeast of.	156	65	150	104	......	1	×
N. H. Rector	Rector, 1 mile east of	251	....	......	180	......	1	....
Furneaux Bros	Trinity Mills (Dallas County) 4 miles east of (2 wells).	415, 468	390	......	25	......	1, 3, 4, 5	...

WELLS FROM THE PALUXY RESERVOIR.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.*a*	Flow.	Quality.*b*	Irrigation.*a*
J. W. Lane (reports)	Pilot Point, 4 miles west of	250	175	......	200	......	8	....
M. C. Coston	Stony	95	33	70	......	×	1	....
S. F. Vaughan	Drop, 2¾ miles west of *c*	170	....	......	×	×	1	....
W. Pafford	Drop, 2½ miles northwest of	221	196	210	×	......	1	....
John Sprouse	Drop, 2 miles southwest of	196	108	......	......	×	1	....
Do	.....do	228	208	......	×	......	1	....
Do	.....do	196	185	......	×	......	1	....
M. Judge	Drop, ½ mile southwest of	140	120	130	......	×	1	....
M. Burch	Drop, 1 mile southwest of	115	78	108	......	×	1	....
M. Judge	Drop, ½ mile southwest of (north of other well).	140	....	......	×	......	1, 8	...
S. H. Lobdell	Drop	194	180	......	155	......	1	....
J. I. Wilson	Drop, 1¾ miles southeast of	180	....	......	×	......	1, 8	×
J. Burnett	Drop, 2 miles northeast of (3 wells).	(2) 135, (1) 100	100	100 to 150	.....	×	1, 8	×
J. I. Wilson	Drop, 2¼ miles southeast of	220	....	......	......	......	1, 8	×
W. C. Wright	Bolivar, 1 mile west and south of (2 wells).	186, 135	100	135	......	×	1	×

WELLS FROM THE TRINITY RESERVOIR.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.*a*	Flow.	Quality.*b*	Irrigation.*a*
....	Bolivar	1,176, 370, 470	......	......	......	×	.....	....
M. L. Howard	Stony, 2½ miles south from	447½	95	440	......	.	1	....

WELLS FROM PALUXY RESERVOIR.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.*a*	Flow.	Quality.*b*	Irrigation.*a*
W. F. Granbill	Bolivar, 200 yards west of	106	....	......	......	×	1, 8	...
H. B. Helm	Justin, 4 miles southwest of	330	310	......	250	......	1, 8	...

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

c S. F. Vaughan reports 16 additional flowing wells in vicinity of Drop.

Schedule of wells in Denton County, Texas—Continued.

WELLS FROM PALUXY RESERVOIR—Continued.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Quality.	Irrigation.
		Feet.	*Feet.*	*Feet.*				
J. E. Fitch	Justin, ½ mile west of	262	250	......	......	......	1	....
Justin Well Co.	Justin	253	230	250	×	×	1	....
G. W. Brock	Justin, ½ mile east of	240	220	......	......	×	....	....
W. T. Dodson	Justin, 1½ miles northeast of.	300	275	......	......	×	1, 8	....
W. J. Rogers	Justin, 3 miles east of south of	280	......	......	......	×	1	....
D. S. Donald	Krum, 6 miles northwest of.	276	240	260	×	......	1	....
C. Scripture	Krum post-office, 300-400 yards north of.	370	300	......	×	......	....	....
G. B. Egan	Krum, south from	373	330	363	......	×	1	....
C. M. Bates	Krum, ¾ mile east of	317	300	......	......	......	1	....
C. D. Wilson	Krum, 2½ miles south of	450	285	375	×	......	1	....
O. W. Myers	Ponder	292	280	......	245	......	1	×
E. M. Lively	Ponder, 2 miles southeast of.	355	345	......	......	......	1, 8	....
J. Sullivan	Sanger	309	265	300	......	×	1	....
J. R. Phelps	do	+300	270	300, 315	......	×	1	....
......	do	300	......	......	......	......	....	....
Sanger Mill and Elevator Co.	do	313	270	300	......	×	1, 9	....
W. P. Green	West Roanoke	476	440	......	×	......	1	....
R. Eidson	A number of wells in vicinity of Roanoke.	400 to 600	400	......	......	×	1, 8	....
S. L. Smith	Roanoke, ½ mile south of	505	427	......	×	......	1	....
......	Roanoke, 1½ miles from	460	440	......	......	×	1, 8	....
J. H. Johnson	Denton, 7 miles southwest of.	500	460	485	×	×	1	....
......	Bartonville (4 wells)	394, 351, 486, 417	......	......	......	×	....	....
Alliance Mills	Denton, ½ mile south of court-house square,	620	495	600	......	×	....	....
Oil Mills, R. J. Wilson, manager.	Denton post-office, 600 yards southeast of.	606	540	590	......	×	1	....
......	Denton	620	500	580	......	×	....	....
H. Sells	Pilot Point, north end of town of.	937	750	850	×	......	1	....

WELLS FROM THE WOODBINE RESERVOIR.

Like Johnson and Tarrant counties, much of Denton County lies within the catchment area of the Woodbine system and possesses a small strip of Eagle Ford Prairie to the east, beneath which its reservoirs are embedded. No flowing wells have been reported, but the wells are valuable and beneficial to the farmers. Two distinct Woodbine reservoirs are recognizable in most of the wells reported, and as usual the upper one (x^3) is charged with mineral impurities, while the lower contains soft, palatable water.

J. W. Lane, well driller, Pilot Point, says: "You strike the first reservoir in sandy formation from 6 to 8 feet deep, then from 20 to 30 feet you strike the second reservoir, which will supply 15 to 20 times the amount of first. As a rule the soft water all rises."

Mr. E. F. Bates, postmaster at Lloyd, writes as follows:

There are no artesian wells or springs in this immediate vicinity, the nearest being at Denton, 10 miles west. There are three there that flow. Mr. J. A. Taff informed me that artesian water could be had here at a depth of 1,000 to 1,100 feet. Lloyd is in the east side of Denton County, halfway from north to south, and 8 miles from Eline, and in what we call the Lower [Eastern] Cross Timbers, and we have sand strata here that dip southeast. Parties 6 or 8 miles southeast of us have dug down from 300 to 400 feet and struck water, but the water will not rise to the top and flow. We believe if they will go down to the Upper [Western] Cross Timber sand stratum they can get a flow.

Mr. J. M. Stover, who owns a well 300 yards northeast of Little Elm, says: "We went about 6 feet in black soil, about 38 in clay, 64 feet through slate to the main stratum of water; we struck a small quantity of water at about 40 feet, cut that off with casing; at 108 feet found water that rose 65 feet. After we struck water we drilled 18 feet in sandstone; the supply of water is so great that windmill has never lowered it."

Mr. C. J. Thomas of Lewisville, says: "I am interested in a company well in our business center, the total depth of which is 198 feet; does not flow, water rising above point reached, 168 feet. Depth of first water, 120 feet. No exact record of borings, but 30 feet soil and clay; about this depth surface water in drift, pebble, and shells; at 85 feet, hard surface water, clay, and what the laborers called 'putty' (probably brick clay), shale, a little coal, and some sandstone."

Mr. J. N. Kealey, president of the Lewisville Water Company, gives the following information concerning the stratigraphy of its well, located within 100 yards of the post-office in Lewisville. The total depth is 192 feet; depth to first reservoir, 120 feet. At the immediate locality of this well the first 20 feet is through clay resting on a thin sheet of drift pebble and sea shells, in which is tolerably abundant surface water. Thence down to 120 feet was through variations of clay "soapstone," slate rock, and occasionally some hard rock; at this point under some hard rock and in white sand was found the first soft rising water. Thence to 198 feet was through alternations similar to above and occasionally a substance the drillers called "putty," to white sand underlying some hard rock, probably sandstone. The water is in this white sand. Considerable lignite was in the borings.

Furneaux Brothers, who own two wells 4 miles east of Trinity Mills, state: "One well is 468 feet in depth; depth to first reservoir, 415 to 468 feet. The other well is 415 feet in depth; depth of first reservoir, 390 feet. In drilling these wells we passed through slate all the way until we struck water, which was found in very fine white sand."

Spencer Graham, of Roanoke, after giving an account of springs of the Cross Timbers, says: "Below this horizon and not very deep (40 to 50 feet) is a very different water from the former. It is hard and often very good for drinking, but is sometimes charged with minerals. There is still another water horizon beneath these timbers. It is the great artesian stratum that underlies the Grand Prairie [Trinity sands]. It can be reached here at about 600 to 900 feet, or 7 miles east of here, at Grapevine, at 1,000 feet."

WELLS FROM THE PALUXY RESERVOIR.

Wells from the Paluxy reservoir are so common in Denton County west of the Cross Timbers that there is hardly a farm which does not possess one. These wells flow in the valleys, but are nonflowing on the divides in the western portion of the county. The formation reservoir dips to the east at about 40 feet per mile from the horizontal or 25 feet from the surface slope. Beginning on the west, where the wells are shallowest, the following notes may prove of interest:

John Sprause, who owns three flowing wells 2 miles southwest from Drop, says that "flowing artesian wells are very common in the western part of this county, ranging from 90 to 300 feet."

The postmaster at Drop says: "Nearly or quite all the farmers of any consequence now have artesian wells with windmills attached. Some get flowing wells in the low valleys. The depth varies from 150 to 300 feet. East of us they have to go deeper; just west of us a few miles, shallower."

S. F. Vaughan, of Drop, says: "There are 48 wells of the same kind in this locality, ranging in depth from 100 to 300 feet. Of these 16 flow, all soft pure artesian water."

J. Burnett, who owns three flowing wells 2 miles northeast of Drop, says: "The depth of our wells varies according to the distance and height above the level of the bed of Denton Creek, also the amount of water. I know of one well drilled exactly on the level of the top of the bank of Denton Creek that runs 30 gallons per minute."

Mr. S. A. Lobdell, of Drop, gives the following section of his well:

SECTION NO. 100.—SECTION OF WELL OF S. A. LOBDELL, DROP, DENTON COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Loam soils	3	3
5. Clay	15	18
4. Blue calcareous rock	147	165
3. Pack sand	15	180
2. Pure white sand	12	192
1. Blue rock	2	194

The postmaster at Krum says: "Artesian water can be secured here at a depth of 300 to 350 feet anywhere within 5 miles of this place; quite a number of wells north and south of this place flow, but there are none west that flow."

Mr. G. B. Egan, who owns a flowing well 373 feet deep south from Krum, alleges that the drill on his place stopped in a bed of asphaltum.

O. W. Myers, who has a well located in Ponder, says: "The Paluxy reservoir was struck at 280 feet and continued 12 feet, it being fine and white in color. The wells within 5 miles of this place range from 110 to 400 feet in depth, but farther west the water is struck nearer the top, and deeper in the eastern part of this county."

At Justin Mr. S. L. Smith, well driller of Roanoke, drilled a well 237 feet that flowed 41¼ gallons per minute. Other nonflowing wells are reported at depths of 320, 300, 280, 180, and 195 feet. A well 260 feet in depth rises to within 10 feet of the surface.

J. E. Fitch, who owns a well one-half mile west of Justin, says: "My well did stand within 6 feet of top, and it could not be lowered with pump which would throw 15 gallons to the minute, until another well was drilled half mile east of my well and on lower ground, which flows 45 gallons per minute, and lowered mine 16 feet."

W. T. Dodson, who owns a flowing well 300 feet deep 1½ miles northeast from Justin, gives the following record of strata passed through:

Section No. 101.—Section of well of W. T. Dodson, 1½ miles northeast of Justin, Denton County.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Soil	8±	8
5. Blue rock (Kiamitia, Goodland, and Washita) about	150	158
4. Shell rock (Walnut) about	75	233
3. Calcareous clay, "like hard putty"	50	283
2. White sand (first water)	2	285
1. Fine sand (second water)	15	300

J. R. Sullivan, who owns a flowing well 309 feet in depth in the town of Sanger, says: "There are not less than 20 to 30 flowing wells in 6 miles of Sanger. First reservoir reached in my well at 265 feet and flowed out, which is not common. I stopped at second reservoir, thinking I had all the water I needed."

J. R. Phelps, of Sanger, says: "We have here in Sanger some flowing artesian wells. They are all drilled about 300 feet. One is used for running mill and gin machinery and private use. The water is obtained in quicksand. By going about 100 feet deeper than the above wells a much stronger flow of water is obtained. Wells are being put down all over this county."

The postmaster at Sanger says: "Wells average 350 feet at this place. This part of country seems to be over a region of artesian waters that are easily reached. West of this place from 3 to 5 miles there are 8 or 10 good artesian wells scattered over the county, not all the same kind of water."

A correspondent writes: "1½ miles from Roanoke I have 4 artesian wells 460 feet in depth. The first water is 440 feet. The farther I went the more water I got. The well flows about 6 or 8 gallons a minute. West of my farm 2 miles wells will flow only on low places, but they will flow anywhere east of my place."

S. L. Smith, well driller, of Roanoke, says: "If a well is over 140 feet deep we strike clay and shell rock to within 140 feet of water, and then we strike 40 or 45 feet of black shale or slate [Kiamitia]. Passing through this, we strike (always) a hard lime rock [Goodland and Walnut], which runs in this locality about 100 feet. We pass out of rock into pack sand, sometimes only 2 feet and again I have struck as much as 35 feet, and into the water sand. Between the beds of water sand we pass through a hard, tough substance which looks like fire clay."

Section No. 102.—Section at Roanoke, Denton County.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Clay	20	20
5. Shell rock (G. washitaensis?)	1	21
4. Shell rock	300	321
3. White lime rock (Goodland-Walnut)	100	421
2. Sand 1. Sand (Antlers)	70	491

Mr. R. J. Wilson, manager of the Denton Cotton and Oil Mill Company, 600 yards southeast of Denton post-office, says his well is 606 feet deep and flows 40,000 gallons daily.

Myers & Sons, well drillers, report a well drilled by them in Denton, for the Alliance Roller Mill Company. It is 620 feet in depth and flows 50,000 gallons in twenty-four hours. The first 520 feet penetrated in the sinking of this well was "soapstone" (clay) and lime rock; the balance was sand.

At Bartonville the flowing wells are 394, 351, 486, and 417 feet in depth.

Similar wells from the Paluxy flow (upper part of Antlers sand) could be obtained east of Denton at increasing depths, were it desirable. The farmers in that region find an abundance of water in the

Woodbine reservoirs, and there are no large towns or industrial institutions which can afford the expense of deep wells.

WELLS FROM THE TRINITY RESERVOIRS.

It is regrettable that no logs of the deeper wells in Denton County have been kept in order to ascertain the exact nature of the Trinity embed. That there are several reservoirs in the Antlers sand lower than that corresponding to the Paluxy reservoir is attested by many of our reports.

A well 1,176 feet deep has been reported from Bolivar, but no record is obtainable. J. R. Eidson, driller, Roanoke, says:

> If we do not obtain a flow in some places we go deeper, through pervious and impervious sand, for 60 feet. We have gone to a depth of 900 or 1,000 feet; anyway, we have to go some 400 or 500 feet below the first artesian stratum [x^2?] to obtain any more water [p]. I have invariably found when you start west from here the water is shallower. I have drilled wells on a line west of here decreasing in depth all the way from 600 to 100 feet deep; 20 miles west the same water [p] is about 100 feet deep; still farther west you will find this water from 20 to 40 feet deep, but it will not rise much. Ten miles east of here I sunk a well 850 feet before reaching the same water, but the same strata of rock are in all the wells.

Mr. M. L. Howard has a flowing well 1½ miles south from Stony. The Paluxy water is obtained at a depth of 95 feet and a lower Trinity water at 440 feet. Some wells in Denton, for instance, are nearly 800 feet deep, and there we find at that depth as many as three distinct water reservoirs and they are stronger, that is, they flow more, the deeper they go. The water is very soft and cold enough for drinking without ice.

These few facts are sufficient to confirm the geologic evidence that Denton County is underlain by the deeper and perhaps better reservoirs of the Trinity system, should their waters ever be needed.

COOKE COUNTY.

Cooke County has an area of about 928 square miles. This county is the most northern of the group comprising the main artesian belt and deriving their waters from the Paluxy and Trinity reservoirs. The upland topographic features of the county are very similar to those of Denton and Tarrant counties, consisting in the eastern third of the north and south belts of the Eastern Cross Timbers and in the western part of the gently sloping dip plains of the Grand Prairie, which have an altitude of about 1,100 feet in the northwestern portion of the county, decreasing to about 700 feet at Gainesville. No topographic survey has been made of this county.

The Red River Valley makes a deep incision into the general level of the Grand Prairie and Eastern Cross Timbers along the northern border of the county, cutting down about 250 feet below their level and exposing the outcrop of the Paluxy formation along its valley west of a point north of Gainesville and far below the outcrop of the Woodbine reservoir, in the northeastern portion of the county.

GEOLOGY.

The geologic features of Cooke County are very simple. Along the eastern portion of the county the Woodbine formation constitutes the highest and latest of the Cretaceous strata. This is succeeded westward by the successive outcrops of the Washita and Fredericksburg divisions. The Denison beds of the Washita division form a north-south belt of prairie running east of Gainesville. These have a thickness of about 300 feet. From Gainesville westward the Fort Worth, Duck Creek, and Kiamitia formations are the upland surface of the Grand Prairie. The streams in their headwater portions in the western and southwestern part of the county cut down through the foregoing formations successively into the Kiamitia clays, the Goodland limestone, and the Paluxy formation, as seen in the head of Blocker Creek. (See fig. 27.) The total thickness of the rocks of the Washita and Fredericksburg divisions in this county averages about 500 feet.

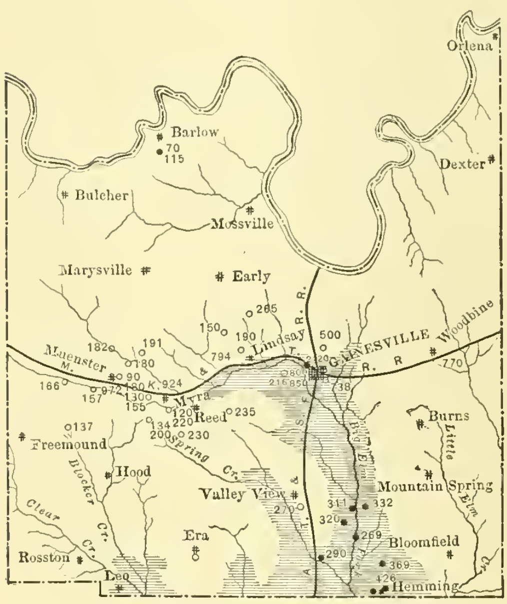


Fig. 74.—Artesian map of Cooke County, Texas. Shaded portion indicates area where flowing wells may be obtained; ●, flowing wells from Trinity reservoir; ○, nonflowing wells from Trinity reservoir; figures indicate depth of wells in feet.

Cooke County, relative to its artesian conditions, may be divided into three districts: First, a belt along the Red River Valley in the northern portion of the county, established upon the upper part (Paluxy horizon) of the Antlers sands, in which, in order to procure flowing wells, the drills must penetrate to the lower or Trinity reservoir, commencing at the surface in the outcrop of the Goodland limestone or Paluxy sands; second, the area of the Grand Prairie south of a line drawn east and west through Early and north and south through Hemming, in which numerous shallow wells, varying from 150 feet at the northwest to 500 feet at the southeast, may be obtained from the Paluxy reservoirs; third, the Eastern Cross

Timber district, along the eastern border of the county. This district lies within the catchment area of the Woodbine reservoir, and flowing wells from this source are hardly probable. To procure artesian wells in this district, one must penetrate to depths of 500 feet or more to reach the Paluxy reservoir, and even then flowing wells are hardly probable. Fortunately they are not necessary, inasmuch as surface wells are everywhere easily obtained in this sandy district.

All of the county, except, perhaps, a small portion northwest of Belcher (see Pls. LXVI and LXIX), is underlain by the Antlers sands, which include at least two well-defined reservoirs corresponding to the Paluxy and Trinity systems southward. In the southwest quarter of the county wells are everywhere obtained from the upper or Paluxy reservoir at shallow depths, varying from 150 feet on the west to 350 feet along the north and south course of the Elm Fork of Trinity River south of Gainesville. These wells will probably not flow at altitudes above 600 feet, and hence flowing wells are obtainable from this reservoir only in the valley of the Elm Fork of the Trinity and its tributaries in the vicinity of Hemming and Valley View, the limit of flow ceasing at some undetermined point about half way between Gainesville and the southern border of the county.

Mr. R. N. Johnson, well driller, has given the following description of the artesian conditions of the upper portion of the Antlers sands, corresponding to the Paluxy reservoir in Cooke County:

In Indian Territory just north of Marysville is a tract of country about 20 miles square in which the water is from 30 to 150 feet in depth, according to the lay of the country. The water seems to be all from the same water reservoir. The wells that I have drilled in this district were only to get a supply of water for ordinary farm use. I have never drilled to the lower water reservoir and never have had a well to flow. There is but little solid rock in this district. The formation is soil, clay, and sand [pack sand] which is almost as hard as rock. The water never rises above where you strike it. This country is different on the prairie. Between Red River and Fish Creek the wells of this district range from 120 to 225 feet, and the formation is soil, clay, and rock [of the Fort Worth and Duck Creek formations], from 30 to 140 feet thick, then black slate, or soapstone, some call it [the Kiamitia formation], but it is very hard; more rock [the Goodland limestone], then 40 to 60 feet of [Paluxy] sand, then water, which never rises above its level. Near Fish Creek, on the north side, the water is shallow, and there are some good springs.

North and south, and 2 or 3 miles west of Gainesville, there is a tract of prairie country where the water is from 225 to 300 feet deep and when drilled rises to within 25 or 50 feet of the top of the ground. The formations are soil and yellow clay 20 to 30 feet, then a pebbly stratum of rock [of Pleistocene age above the Cretaceous strata]; slate or hard black soapstone [Kiamitia formation] comes next, then lime rock, and just underneath the last rock [the Goodland limestone] is the water. I have been told by drillers in that country that there is a second water reservoir not more than 50 feet below the first, but the first reservoir supplies enough water for any ordinary use.

Commencing 2 miles west of Gainesville and going 10 miles west, which is as far west as I have worked, the water is from 150 to 200 feet in depth, but it does not rise above where you strike it. The formation is pretty much the same as nearer

Gainesville. Ten miles south of Gainesville they get flowing wells at 300 to 350 feet, but I never have worked in that part of the country.

I have put down a number of wells in the east and southeast part of this county in the Eastern Cross Timbers, which is a sandy country. The water is from 40 to 100 feet in depth.

The whole county is also underlain by at least two lower reservoirs of the Antlers sands corresponding to the t^1 and t^2 reservoirs of the southern counties, which at Gainesville are about 200 and 600 feet below the Paluxy reservoir. Wells from the lower of these reservoirs will flow at all points below 700 feet in altitude. (See fig. 75.)

The wells of only one locality in the county, at Gainesville, have penetrated to the lower-lying Trinity reservoir, which lies some 500 to 600 feet lower than the Paluxy reservoir. Water from this source rises to an altitude of 700 feet, and flowing wells of this character could no doubt be obtained throughout a narrow belt of country adjacent to the Big Elm Fork south of Gainesville, east of the Gulf, Colo-

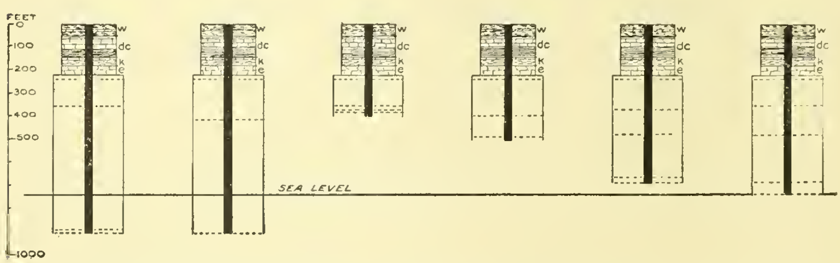


Fig. 75.—Wells at Gainesville, Texas. (For explanation of symbols see Pl. XVI, p. 110.) *A*, Gainesville Water Company; *B*, public well; *C* and *D*, Whaley Mill and Elevator Company; *E*, Gainesville Ice Company; *F*, Gainesville Oil Mill and Gin Company.

rado and Santa Fe Railway, and west of the western border of the Eastern Cross Timbers. It is also probable that flowing wells may be obtained from this lower reservoir along the bottoms of Red River from north of Belcher to the eastern portion of the county.

DEVELOPMENT.

There are over a hundred shallow flowing and nonflowing artesian wells in the western and southern portion of the county west of the Eastern Cross Timbers which derive their waters from the upper or Paluxy reservoir of the Antlers sands. At one point only in the county have artesian wells been drilled into the lower-lying Trinity reservoir at the base of the Antlers sands. This was done at Gainesville, and the experiment there demonstrates beyond doubt that throughout the vast region of the Grand Prairie from Gainesville to Fort Worth the lower artesian flows are obtainable in case the necessities should demand them. The Paluxy reservoir is so prolific throughout this county, however, that only cities and towns wishing a greater volume of flow for municipal or industrial purposes need seek the Trinity reservoirs. The following is a list of artesian wells in Cooke County:

Schedule of wells in Cooke County, Texas.

SHALLOW WELLS FROM THE PALUXY RESERVOIR.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.a	Flow.a	Quality.b	Irrigation.a
		Feet.	*Feet.*	*Feet.*				
W. W. Locker	Barlow, ½ mile south of post-office	115	70	......	......		2, 9	...
H. Wolf	Muenster, 3 miles west of	166	130	......	×	......	1	....
M. Mueller	Muenster, 1 mile southwest of	157	127	......	......	......	1	....
J. H. Theilin	Muenster, 2 blocks east of post-office	105	50	......	......	......	......	....
H. Schoech	Muenster	180	136	165	......	......	1	....
Catholic Church	do	140	100	......	40	......	1	....
H. Vondenbosch	Muenster, 2 blocks east of post-office	108	90	......	90	......	2	×
	Muenster, ½ mile north of post-office	125	110	......	×	......	1	....
N. Kaiser	Muenster, 300 feet south of post-office.	101	60	......	......	......	9	....
F. Herr	Muenster, 2 miles north of	182	176	......	25	......	1	....
H. Henscheil	Muenster, 1 mile northeast of	180	140	......	......	......	1	....
F. Trachta	Muenster, 1½ miles northeast of	191	......	162	......	......	1	....
On farm	Muenster, 1½ miles northeast of	215	170	200	×	......	1	....
M. Hellmann	Muenster, 3 miles southeast of	194	134	......	......	......	1	....
H. Voth	Muenster, 3 miles east of	185	130	......	15 to 20	......	1	....
J. Davis	Hood, 4 miles northwest of	137	......	......	36	......	1	....
A. J. Harris	Myra, ½ mile south of	220	120	200	×	......	1, 8	...
W. W. Hudson	Reed, 2 miles southwest of	218	......	......	×	......	1	....
C. Enderby	Reed, 2 miles east of	235	......	......	80	......	1	×
J. J. Trew	Reed	244	146	200	40	......	1	....
L. Cartwright	Reed, 1 mile southeast of	253	......	+240	±100	......	1	....
G. Ball	Lindsay, 2½ miles northwest of	150	......	115	......	......	1	....
Wm. Flusche	Lindsay, 1 mile northwest of	190	110	185	90	......	1	....
F. Mossman	Lindsay, 2½ miles from	164	......	......	......	......	1	....
F. Loerwald	Lindsay, 3 miles north of	265	235	......	×	......	1, 3	...
H. Sandmann	Lindsay, 1 mile from post-office, on hill.	155	55	......	35	......	1, 8	...
	Gainesville, 2 miles west of	216	25	205	×	......	1	....
R. P. Head	Valley View, 100 feet southwest of post-office.	270	255	......	×	......	1	....
O. A. Hearn	Valley View, 3½ miles southeast of.	269	250	......	......	×	1	....
W. R. Fryer	Valley View, 3 miles southeast of	320	292	......	......	×	1	×
A. Ledford	Valley View, 3 miles east of	311	302	......	......	×	1, 8	×
Mr. Peabody	Valley View, 3½ miles east of	332	......	......	......	×	1	×
E. Wilson	Valley View, 3½ miles from	292	......	......	......	×	1	....
C. H. Gaines	Hemming, 2 miles north of	369	260	......	......	×	1, 3	×

a × = yes.

b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

Schedule of wells in Cooke County, Texas—Continued.

SHALLOW WELLS FROM THE PALUXY RESERVOIR—Continued.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Quality.	Irrigation.
		Feet.	*Feet.*	*Feet.*				
H. Selz	Hemming	426	414				1	
J. W. Lane	do	426					1, 8	
M. A. Stamper	Era	300	200	240, 275, 300				

WELLS FROM THE TRINITY RESERVOIR.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow.	Quality.	Irrigation.
Gainesville Water Co.	Gainesville	850	220	360, 800			1	
Public well, Gainesville	do	850	250	450	×	?	1	×
Whaley Mill and Elevator Co.	do	405	240	375	×		1, 9	
		480	240	400	40		1, 9	
Gainesville Ice Co.	do	632	215	350, 440, 620	7			
Gainesville Oil Mill and Gin Co.	do	700	220	340, 460, 670	30			

Nearly all the artesian wells reported from Cooke County are within 4 or 5 miles of the Big Elm Fork of Trinity River along an east-west belt in the center of the county from west of Muenster to Gainesville and from Gainesville southward toward Valley View and Hemming.

WELLS OF THE PALUXY SYSTEM.

All the wells of the county except the deep wells at Gainesville and possibly one well just south of Barlow are from the top of the Antlers sands, corresponding practically to the Paluxy reservoir, and all of the wells begin in the strata of the Washita division.

The deepest well obtaining water from this reservoir (426 feet) is at Hemming, at the base of the Denison beds; the shallowest (90 feet) is near Muenster, near the base of the Kiamitia clays. At Gainesville the Paluxy reservoir lies about 350 feet below the top of the Fort Worth limestone.

The following reports will show the general character of the wells.

Mr. A. Ledford, who owns a flowing well 311 feet in depth 3 miles east of Valley View, gives the following record of strata passed through:

Section No. 103.—Section of well of A. Ledford, 3 miles east of Valley View, Cooke County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Clay (Duck Creek and Fort Worth)	22	22
5. Blue lime rock (Duck Creek and Fort Worth)	178	200
4. Slate (Kiamitia)	35	235
3. White lime rock (Goodland)	35	270
2. Gray sand rock (upper part of Antlers or Paluxy reservoir)	32	302
1. Water sand (Antlers)	9	311

R. P. Head, who owns a well 270 feet in depth, located 100 feet southwest of the post-office at Valley View, says his well passed through principally soapstone and clay and a little shale just before striking water, which was found in white sand.

J. J. Trew, of Reed, gives the following record of strata passed through in his well, which is 244 feet in depth.

Section No. 104.—Section of well of J. J. Trew, at Reed, Cooke County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Yellow clay (Duck Creek and Kiamitia)	32	32
5. Blue shale (Duck Creek and Kiamitia)	58	90
4. Solid lime rock (Goodland)	30	120
3. Layers of rock from 6 to 12 inches thick and layers of blue shale the same thickness	26	146
2. Coarse white sand and water (Antlers) (p reservoir)	2	148
1. Tough mucky clay shale and sand (Antlers) (p reservoir)	96	244

F. Herr, who owns a well 182 feet deep 2 miles north from Muenster, gives the following section:

SECTION NO. 105.—SECTION OF WELL OF F. HERR, 2 MILES NORTH OF MUENSTER, COOKE COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
11. Black soil (Kiamitia)	6	6
10. Yellow clay (Kiamitia)	3	9
9. Lime rock (Kiamitia)	.5	9.5
8. Clay rock (Kiamitia)	2	11.5
7. Slate (Kiamitia)	15	26.5
6. Solid lime rock (Edwards)	30	56.5
5. Slate (Walnut)	10	66.5
4. Blue rock (Walnut)	15	81.5
3. Soapstone (Walnut)	92	173.5
2. Blue rock (Walnut)	2	175.5
1. Coarse water sand (Antlers) (p reservoir)	6.5	182

Mr. M. A. Stamper, who owns a well 500 feet in depth in the town of Era, Cooke County, gives the following information:

Until recently our water came from surface wells about 20 feet deep, nearly all going dry during summer and fall unless very seasonable. Occasionally near the head of some of the shallows or ravines we found fine water 12 to 18 feet that was almost inexhaustible. For the last few years many wells have been drilled and an abundance of water secured by lifting it to the surface by means of windmills.

After passing through the soil we strike a kind of joint clay and then a blue kind of rock or slaty substance that increases in hardness until it is a solid blue rock. Then we strike what we call a gray shale; then a kind of mixture of various qualities; then a black shale [Kiamitia formation]; then solid rock [Goodland limestone] about 40 to 50 feet; then black sand 5 to 20 feet, and then white sand, pack, or quicksand [p], with water at 200, 240, 275, and 300 feet in depth.

WELLS FROM THE TRINITY RESERVOIR.

Only in the city of Gainesville have wells been drilled to the more copious and stronger waters of the Trinity reservoirs. Five or six deep wells are reported from this city, one of which, as reported by the mayor, furnishes 350,000 gallons of soft potable water a day. In drilling these wells (even although, as usual, no exact log of the strata was kept) this enterprising city has demonstrated the existence of the lower artesian reservoirs beneath all that portion of the Grand Prairie region north of Fort Worth, some 90 miles distant, and an area of over 1,000 square miles.

As shown in fig. 75 (p. 590), it will be seen that the deepest of these wells penetrated 630 feet below the Paluxy reservoir into the Antlers sands, and that no less than four distinct water reservoirs were opened, only the lowest of which had sufficient pressure to force the water to the surface.

These reservoirs were found at approximately the following depths below the Paluxy reservoir: t^4, 140 feet; t^3, 220 feet; t^2, 420 to 432 feet; and t^1, 630 feet.

Of these wells only two, that of the public well and the Gainesville Water Company, are complete in that they penetrate the deepest and best water reservoir at 850 feet from the surface.

J. F. Myers & Son, well drillers, who drilled the well for the Gainesville Water Company (well No. 6, see fig. 75, *A*) could supply the writer with no other information than to state that "the first 240 feet was 'soapstone' and shelly rocks of a limy nature [the Fort Worth, Duck Creek, Kiamitia, and Goodland formations] the balance was principally sand." A log of this "balance," which represents, with the exception of the log of the Denison well (see section No. 17, p. 197), all that is known of the nature of the embedded rocks of the Trinity division in north Texas, would be of greatest value to geologic knowledge.

The mayor of Gainesville reports that the public well is located in the center of the city, is 850 feet deep, first water 250 feet, other waters 450 feet, and furnishes 350,000 gallons per day.

DALLAS COUNTY.

Dallas County has an area of 859 square miles, and is one of the most important agricultural counties in Texas. It also contains one of the four chief cities of the State, with a population of approximately 50,000 inhabitants, and also several important smaller towns.

The relief of the county consists of gently sloping or rolling dip plains constituting the fertile Black Prairies. The western portion consists of the Eagle Ford Prairies; the eastern half of the main Black Prairie country. The monotony of these plains is broken by the White Rock scarp, extending north and south through the county just west of the longitude of Dallas, and the valley of Trinity River, which flows northeast and southwest across the prairie plains. The White Rock scarp, which is called "the mountains" in this portion of Texas, attains a maximum altitude of about 800 feet at Cedar Hill in the southwest portion, and its face or western slope has a maximum relief of about 300 feet, overlooking the lower-lying Eagle Ford Prairie to the west. From the summit of the scarp the country gradually slopes south of east. The valley of the Trinity and its two principal forks, the Elm Fork from the north and the West Fork from the west, cuts through this escarpment at Dallas, where the river has an altitude of about 375 feet above sea level, or 425 feet lower than the highest point above-mentioned at Cedar Hill. This sluggish stream is bordered on either side by wide overflow lands and alluvial terraces.

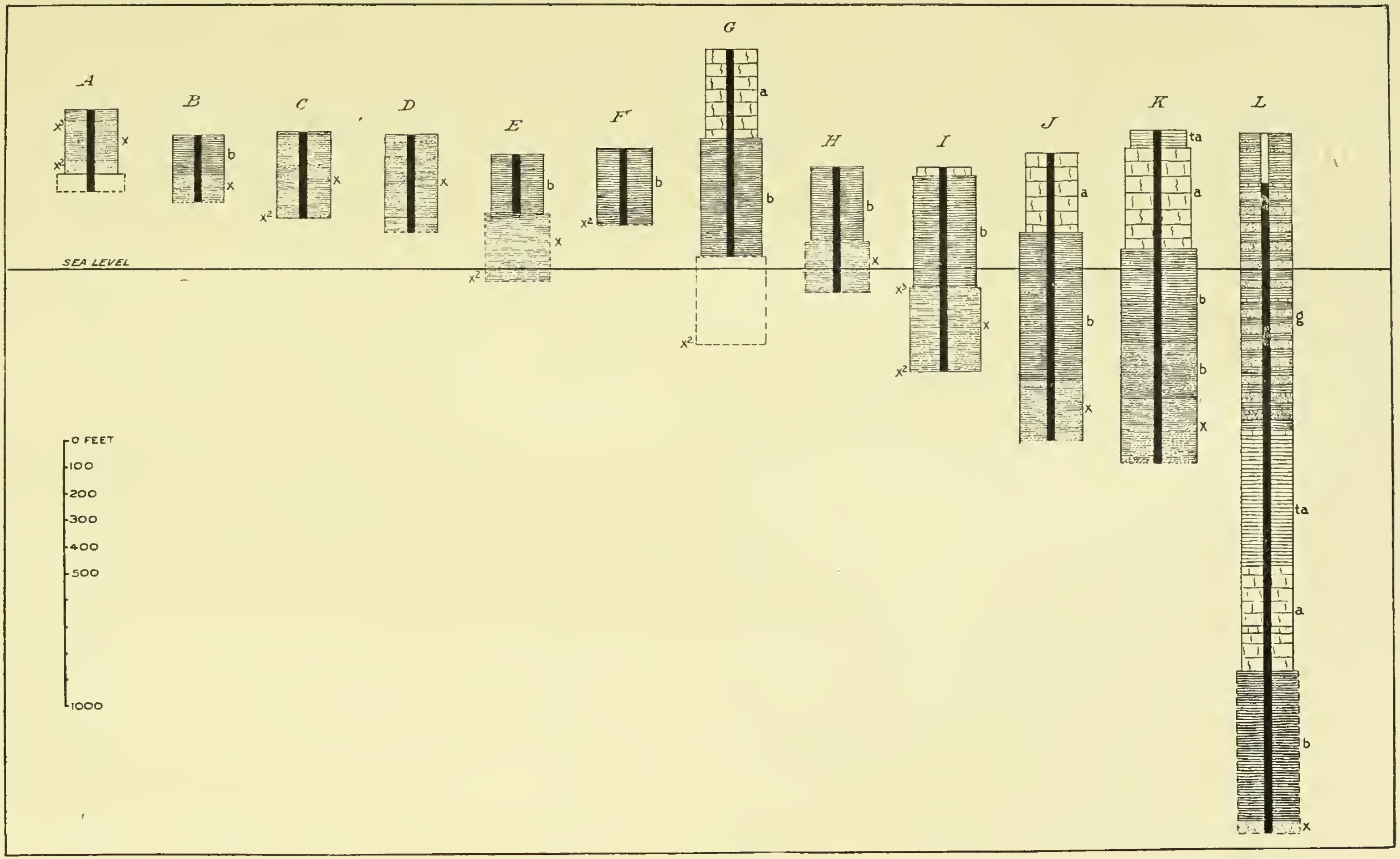
The geology of Dallas County is very simple (see Pl. LXVI), consisting of the following Upper Cretaceous formations:

Taylor and Navarro formations, mostly marls; Austin chalk (the "white" and "blue" rock), 400 to 500 feet; the Eagle Ford shales, about 500 feet; the Woodbine formation, sands and shale, about 300 feet.

The outcrops of the last-named formation barely reach into the county, if at all, extending down the stream valleys from Tarrant County on the west. The formation is embedded beneath the whole county, however, its bottom being about 350 feet deep on the divides at the western edge of the county and probably 1,200 feet on the east, the dip being about 40 feet per mile. The Eagle Ford formation forms a wide belt embracing practically the western third of the county; the Austin chalk or white rock occupies most of the central portion, while the marls are found on the east.

The county is underlain by reservoirs of the Woodbine, Paluxy, and Trinity artesian systems, the first of which alone has been exploited and this principally in the city of Dallas and west of the White Rock scarp. The Woodbine reservoirs consist of several strata of water-bearing sands, which for convenience are classified into two principal reservoirs, x^2 and x^3. The uppermost of these (x^3), which derives its waters from the sands allied to the Lewisville beds of the Woodbine formation, consists of several thin beds of sand, the water being usually impregnated with sulphur and salt. This reservoir is encountered within 100 feet of the surface in the extreme western portion, at or about 466 feet below the surface at Dallas, 800 feet at Arnold, and probably from 1,200 to 1,400 feet below the surface at the western edge of the county. This reservoir should always be carefully cased off in drilling wells, for the waters will contaminate the purer and more potable supply which can be obtained a short distance below, in the x^2 reservoir, derived from the Paluxy sands. The latter (x^3) consists of a purer and thicker sand bed, which lies about 125 feet below the x^3 reservoir at Arlington, Tarrant County, just west of the Dallas County line; about 200 feet beneath the x^3 reservoir at Grand Prairie; about 330 feet beneath the x^3 waters at Dallas; about 400 feet at Orphans' Home, so far as we are able to estimate from the data supplied us. This formation has an inclination of about 40 feet to the mile to the southeast across the county and furnishes a potable water of great value to the farming and industrial communities, although more highly charged with mineral matter than the waters of the Paluxy and Trinity systems.

The Paluxy and Trinity reservoirs, which form the chief source of



TYPICAL WELLS OF DALLAS AND KAUFMAN COUNTIES, TEXAS.

A, Arlington; *B*, near Cedar Hill; *C*, Grand Prairie; *D*, 4 miles northwest of Cedar Hill; *E*, Eagle Ford; *F*, Farmers Branch; *G*, Cedar Hill; *H*, Forks of Trinity; *I*, Dallas; *J*, Lancaster, *K*, Orphans' Home; *L*, Terrell, Kaufman County.

artesian supply of Tarrant County to the west, have not as yet been exploited or utilized in Dallas County owing to their great depth, although they would be of inestimable value to the city of Dallas.

The waters from the Woodbine reservoirs will rise to an altitude of 500 feet in the western part of the county. At Arnold, 8 miles east of Dallas, they fail to quite reach the surface at 525 feet; at Ferris, Ellis County, just south of the Dallas County line, they flow to the surface at about 475 feet. The Paluxy reservoir would probably flow at points 100 feet higher than the Woodbine reservoir, or to an altitude of 600 feet, while the basement Trinity reservoir has sufficient pressure, it is estimated, to force the water to an altitude of 650 feet.

West of the White Rock escarpment, in the valleys of the forks of the Trinity and the lateral creeks, such as Mountain Creek, in the southwestern portion of the county, Hackberry, Grapevine, and Denton creeks in the northwestern portion, and in the lower valley of the Trinity in which Dallas is situated, numerous artesian wells have been developed from the Woodbine reservoir.

Few artesian experiments have been reported in the eastern part of Dallas County. We have reports of only two wells in this portion, at Buckner, Orphans Home, about 8 miles east of Dallas on the Texas and Pacific Railway, and at Lancaster, a little east of south of Dallas, on the Missouri, Kansas and Texas Railway. In all the following well statistics have been procured:

Schedule of wells in Dallas County, Texas.

WELLS FROM THE WOODBINE RESERVOIRS.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.*a*	Flowing wells.*a*	Quality.*b*
		Feet.	*Feet.*	*Feet.*			
J. Alspaugh	Dallas, 18 miles west of; ½ mile east of Cain.	118	68	118	......	×	1, 4
Do	Dallas, 18 miles northwest of	70	......	......	......	×	......
B. Harrington	Estelle, ¾ mile from, on hill	180	20	160	90	......	1
S. M. Williams	Estelle (5 wells), 4½ miles north of east of.	(4) 120+ (1) 183	......	......	......	×(2)	1, 8
A. J. Williams	Estelle, ¼ mile east of, 6 miles north of line from F. D. Worth to Dallas.	106	26	106	40	......	1
S. G. Lackey	Estelle, 1 mile south-southeast of	181	176	......	82	......	1, 9
J. B. Harrison	Coppell, ½ mile southeast of	65	60	......	......	×	......
G. T. Bullock	Coppell, 2 miles east and ½ mile south of.	96	8	96	......	×	1, 8
Barney Gibbs	Farmers' Branch, 2½ miles west of; Coppell, 1½ miles south of (6 wells).	95 to 130	......	......	......	× all.	1, 8, 12
P. D. Geeo	Grand Prairie, 1½ miles west of	102	38	102	60	......	1
J. R. Smith	Grand Prairie, 3 miles south of	(2) 99, 165	......	......	......	×	1
C. A. Varney	Grand Prairie, 4½ miles south of	108	6	......	......	×	1

a × = yes.

b 1, Soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

Schedule of wells in Dallas County, Texas—Continued.

WELLS FROM THE WOODBINE RESERVOIRS—Continued.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flowing wells.	Quality.
		Feet.	*Feet.*	*Feet.*			
R. B. Jennings	Grand Prairie, 4 miles southeast of	196	160	196	......	......	1, 4
Do	Grand Prairie, 3 miles east of	198	......	......	......	×	1, 4
A. J. Colwell	Farmers Branch, 4 miles southwest of	180	30	150	......	×	1
B. F. Millican	Sowers, 2 miles northwest of	200	165	......	35	......	1
......	Eagle Ford	262	......	......	......	......	......
G. T. Myers	Carrollton post-office	245	20	245	......	×	1
John Lucas	Kit, ½ mile east of	275	272	......	270	......	1
S. A. Storey	Kit, 1 mile west of	236	......	......	25 of top.	......	8
J. P. Stockton	Kit, 1 mile northeast of	311	311	......	8—10	......	1
W. H. Butler	Farmer's Branch, 200 yards north of	325	300	......	10	......	1
J. P. Jackson	Trinity Mills, 2 miles east of	375	......	......	315	......	1, 8
T. Flynn	Letot, 1 mile northwest of	304	20	280	......	×	9
S. A. Hamlin (reports)	Cedar Hill, 3 miles west of; Dallas, 19 miles southwest of.	246	170	210, 218	......	×	1
......	Cedar Hill	165, 208	......	......	......	......	......
Mrs. Emma Wilson	Cedar Hill, 4 miles northwest of	372	310	340	......	×	4
Wm. Bryant	Dallas, 19 miles southwest of Cedar Hill.	750	......	......	450	......	1
C. F. Barker	Duncanville, 4 miles west of	197	197	......	......	×	1
Wm. Bryant	Duncanville, 4½ miles northwest of, in Mountain Creek Valley.	237	......	......	......	×	1
S. Q. Richardson	Dallas, 6 miles west-northwest of, on forks of Elm and West Fork.	400+	300	......	......	×	1
Harry Bros	Dallas, 3½ miles west of	417	......	......	......	×	1
J. G. Fleming	Dallas, ½ mile south of	718	600	......	......	×	8
Oak Cliff Water Company.	Dallas, 1 mile east of station	850	200	......	......	×	1
Lancaster Water Co	Lancaster	1,057	850	1,000	......	×	1
S. B. Marshall	Orphan's Home Sta., 2 miles southeast from.	685	525	......	×	......	3
R. C. Buckner	Orphan's Home	1,230	800	......	40	......	1, 3, 4, 5, 8
A. F. Hardie (reports)	Dallas Cotton Mill, at Dallas	850	......	......	......	×	1, 8

WELLS POSSIBLY FROM PALUXY RESERVOIR.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flowing wells.	Quality.
W. J. Borah	Dallas, 16 miles northwest of	970	......	......	......	×	......

The shallowest well reported by Mr. A. F. Hardie, well driller, located 18 miles northwest of Dallas, is only 70 feet deep. It was drilled by Mr. Hardie in 1879, and is said to be still flowing. The deepest well, from the Woodbine reservoir, is that at the Orphans' Home, 8 miles east of Dallas, where the lowest (x^2) reservoir of the Woodbine system was apparantly struck at 1,200 feet.

The stratigraphy of all the wells is very simple. West of the White Rock cliff the only material drilled through is the shale and clay of the Eagle Ford formation. This passes insensibly into the Woodbine formation, which is composed below of alternations of shale and thin beds of sand, the sand becoming thicker in descending series. East of the White Rock cliff and at Dallas the Austin chalk is found above this shale. At Dallas it is coated by the alluvium of the old Trinity River terraces. In the eastern part of the county the Taylor marl, commonly called "soapstone" and "joint clay" by the well drillers, occurs above the Austin chalk. This stratigraphy is well shown on Pl. LXVI.

In the extreme western edge of the county wells are found at very shallow depths similar to those described as occurring in the eastern part of Tarrant County.

R. B. Jennings, of Grand Prairie, says: "The water in the western part of Dallas County is obtained from about 50 to 300 feet, and all about the same water. Some veins are much stronger than others. Some wells flow about 1½-inch stream, while others barely flow; others do not flow at all. The good wells are all in low places."

Concerning the stratigraphy, Mr. E. M. Atchley, of Grand Prairie, says: "We first strike shale, then sand rock, then coarse sand. Then we get all of the water we ever get, and no one has gone through it."

S. M. Williams owns five artesian wells located about 4½ miles north of east from Estelle. Four are about 120 feet deep. One on high ground is 183 feet deep. Four of these wells formerly flowed, but only two flow at present. He states that they passed through soil from 10 to 16 feet, and blue calcareous shale or rock balance of distance to gravel and water. The air dissolves the shale soon after exposure.

P. D. Geeo, who owns a well 102 feet deep, 1½ miles west of Grand Prairie post-office, says: "The first 38 feet was black dirt and yellow clay, then black slate and a little rock and gumbo, then the water."

J. H. Pinson, well driller, reports a well drilled by him in Dallas County, 2 miles east of Gertie, in Tarrant County, and says: "This well is a little extraordinary, as, after passing through the shale, I drilled 45 feet of white soft sand rock and did not go through it. The farther I drilled in it the stronger the water flow became. The well is 150 feet in depth and flows."

G. T. Bullock, who owns a flowing well 96 feet in depth, situated about 2 miles east and one-half mile south of Coppell, says that in drilling his well the following material was passed through: Soil and dirt 8 feet, then shale about 80 feet, then hard sand rock to water.

There are a great many artesian wells in the valley of the Elm Fork and its tributary creeks in the northwestern portion of the county. All of these wells begin in the Eagle Ford shales. The following examples will illustrate their general character.

Thomas Flynn owns a flowing well 304 feet in depth 1 mile northwest of Letot, in which the first (x^3) reservoir was struck at 20 feet and the (x^2) reservoir at 280 feet. Concerning this well he says: "After the first 20 feet the drill struck the shaly clay, which was 280 feet thick. The water leaves a sediment in the pan as black as coal tar."

S. A. Storey, who owns a well 236 feet in depth, 1 mile west of Kit, on level upland, black, sandy, or post-oak land, gives the following section:

Section No. 106.—Section of well of S. A. Storey, 1 mile west of Kit, Dallas County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Soil	38	38
3. Black shale	62	100
2. Gray clay rock	133	233
1. Sand rock	3	236
Under this rock struck water in a bluish-looking sharp sand.		

J. P. Stockton, 1 mile northeast from Kit, says: "The depth of well is 311 feet. In drilling this well went 30 feet through clay and sand; balance of the way through shale. We never struck water until 311 feet had been reached. The water rose within 4 or 5 feet of top in ten hours. The well has been drilled two years; water now stands within 8 or 10 feet of top.

John Jackson, who owns a well 375 feet in depth, 2 miles east of Trinity Mills, says: "The soil here is black waxy to the depth of 4 or 5 feet, gradually turning to clay or yellow soapstone to depth of 20 feet, when blue shale is reached which overlies hard shale. This shale is dark blue and very hard to depth of 300 feet, getting lighter, with some oil, before reaching water; water reached at depth of 373 feet in pure sand."

G. F. Myers, postmaster at Carrollton, owns a flowing well 245 feet deep, and says the drill passed through black soil 8 feet, clay subsoil 20 feet, soft shale 117 feet, and then pack sand with water.

S. Q. Richardson owns a flowing well 500 feet deep on the fork of Elm Creek, 6 miles west-northwest of Dallas, which produces about

100,000 gallons of water daily. From his notes we make the following section of this well:

SECTION NO. 107.—SECTION OF WELL OF S. Q. RICHARDSON ON FORK OF ELM CREEK, 6 MILES WEST-NORTHWEST OF DALLAS, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Soil	25	25
5. Shale	275	300
4. Water sand (x^3) 3. Sandy shale	165	465
2. Hard rock	8±	473
1. Dexter sand (x^2)	30	503

G. Gibbs says: "I have six flowing wells on 4,000 acres 1½ miles south of Coppell. The wells are from 95 to 130 feet in depth." It is probable that these wells all originate in reservoir x^3.

South of the Trinity the flowing wells are mostly obtained in the valley of Mountain Creek at altitudes below 500 feet, all beginning in the Eagle Ford formation. The following are typical wells of this section:

S. A. Hamlin, well driller, reports a well drilled by him 3 miles west of Cedar Hill (see Pl. LXIII, *B*) for W. L. Stephenson, and says: "I find three distinct water reservoirs here, the upper of which will supply any kind of windmill pump. The strata are a soft, porous sand rock, and the water percolates through it; it is not a quicksand. The cuttings from the drill yield a beautiful white sand, sometimes of a yellow cast."

Mr. Hamlin also reports another well, 362 feet deep, drilled by him for A. J. Penn, 3 miles west of Cedar Hill, in what is known as Mountain Creek Valley. The depth of first reservoir was 170 feet; other reservoirs 210 and 218 feet. It is a flowing well; the water contains sulphur, soda, and magnesia.

Mr. Hamlin reports still a third well drilled by him for Mrs. E. Wilson, 4 miles northwest of Cedar Hill, and says:

> This well was drilled at the foot of the "Mountain" [White Rock scarp]. It penetrates five reservoirs. I struck a lime rock in bottom of well [the Comanche series]. This lime rock continues downward some 400 to 500 feet to near the lower reservoirs [the Paluxy] or the Upper [Western] Cross Timber strata. This well would flow 1½-inch pipe at the ground, but raised 30 inches would only fill an inch pipe; if the well was 8 feet lower it would fill a 2-inch pipe. I gained one-quarter of an inch of water by raising the drilling pipe even with each stratum and pumping them separately to open up the pores for the percolating water. The well is 372 feet deep; depth of first reservoir, 310 feet; next reservoir, 340 feet.

Harry Brothers, who own a flowing well 417 feet deep, 3½ miles west of the city of Dallas, give the following information: "Drilled through blue shale from the surface of ground to the artesian water. We came in contact with a few flat lime rock [*Septaria*] in drilling, but found no water above; water in about 8 or 9 feet of water sand. Below this is hard rock."

In December, 1898, there were thirty-one flowing artesian wells in the city of Dallas. These wells all begin in or near the base of the Austin chalk and show a remarkable similarity of depth and flow.

These wells at Dallas mostly receive their water from the lower of the Woodbine reservoirs, x^2. According to Mr. A. Horton, of Dallas, this reservoir lies about 334 feet below the Upper Woodbine or x^3 reservoir in that city, which is usually struck at a depth of 466 feet. It is said that about 50 feet of sand is usually penetrated before the first flow of the x^2 reservoir is reached.

List of artesian wells from Woodbine reservoir in the city of Dallas, Dallas County, December, 1898.

[Furnished by Mr. E. L. Dalton, assistant city engineer, Dallas.]

No. of well.	Location.	Depth.
1	County Court-House	800
2	Windsor Hotel	797
3	Sanger Brothers	797
4	News Office	797
5	North Texas Bank Building	795
6	Linz Brothers	802
7	Cockrell Building	792
8	McLeod Hotel	793
9	Oriental Hotel	798
10 and 28	Young Men's Christian Association	*a* 816
11	Natatorium	790
12	City Park	790
13	People's Ice Company	806
14	Cotton Mills	805
	do	720
15	Packing House	792
16	S. and L. P. Company	820
17	Lemp's Brewery	836
18	Dallas Ice Factory	837
19 and 20	Sisters' Sanitarium	*a* 855 and 925
21	Dallas Brewery	790
22	Dallas Electric Company	790
23	Dallas Water Works	800

a Two wells.

List of artesian wells from Woodbine reservoir in the city of Dallas, Dallas County, December, 1898—Continued.

No. of wells.	Location.	Depth.
24	Dallas water works	825
25	do	1,000
26	Oak Cliff	767
27	do	767
29	Eureka Laundry	800
30	Block 725	870
31	Bogel's Block, 93	790

Mr. Dalton, city engineer of Dallas, furnishes the following log of the Cotton Mill well in Dallas. The water in this well comes within 25 feet of the surface, and by pumping the well furnished about 200,000 gallons every day. The record is as follows:

SECTION NO. 108.—LOG OF DALLAS COTTON MILL ARTESIAN WELL AT DALLAS.

[Furnished by E. L, Dalton, assistant city engineer.]

	Thickness.	Depth.
	Feet.	*Feet.*
8. Sand and clay (alluvium)	10	10
7. White limestone (Austin)	80	90
6. Blue shale (Eagle Ford)	610	700
5. Water sand (sulphur water) (Woodbine)	5	705
4. Sandstone (x^3)	40	745
3. White clay	10	755
2. Sandstone (x^2)	30	785
1. Sand (x^2)	20	805

Although the Paluxy reservoirs lie about 600 feet beneath the lower Woodbine reservoir and the lowest of the several Trinity reservoirs lie about 500 feet below the Paluxy, we have no positive proof that either of these systems has been penetrated in Dallas County. One well, reported by Mr. Hardie, 957 feet in depth, in northwest Dallas County, may probably reach the Paluxy reservoir. If the well of the Dallas Cotton Mills is 1,300 feet deep, as reported by Mr. Hardie, it reaches within 100 feet of the Paluxy reservoir. The assistant city engineer of Dallas, however, gives the depth of this well at only 805 feet.

There is no reason why these lower reservoirs should be sought in the county, as farmers can obtain sufficient water for their uses from the Woodbine reservoirs. But there is every reason why the city of Dallas should seek them. It is one of the three largest cities in Texas,

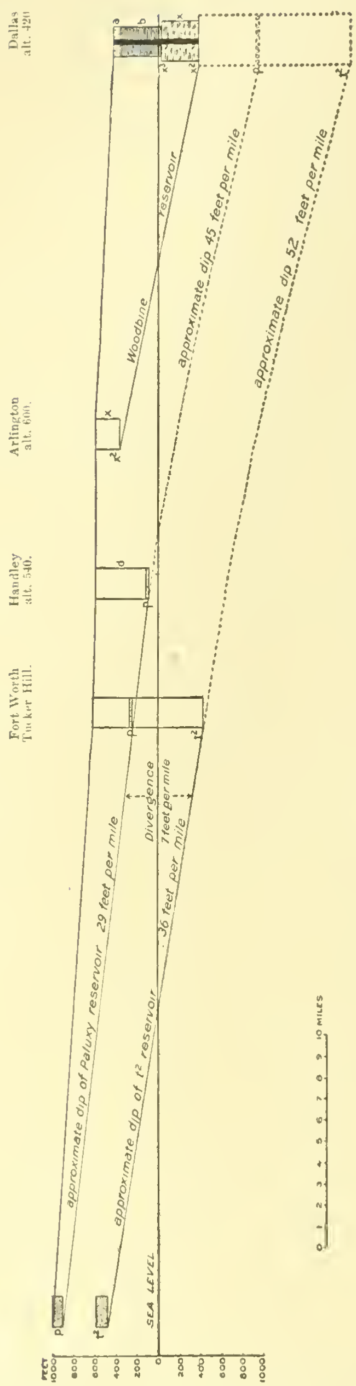


Fig. 76.—Estimate of depths of undeveloped Paluxy and Trinity reservoirs at Dallas, Texas.

with a population of nearly 50,000 inhabitants, and has large manufacturing interests. The Trinity River, from which the city waterworks are largely supplied (although this supply is supplemented by three Woodbine wells), is not one of the purest streams imaginable. Below the city, at a depth of not over 2,200 feet, lies the great Basement reservoir of the Trinity system, which if tapped would give to Dallas wells of far greater volume, purity, and pressure than those possessed by any city in Texas or the United States, except, perhaps, Waco, and they would be fully equal to those of that city.

In fig. 76 an endeavor is made to show approximately the position of the Paluxy and Trinity reservoirs below Dallas and the character of the strata which must be passed through in reaching them. While the estimates of depths may vary within 100 feet or more, the essential facts as shown in the diagrams are true. According to these estimates, the Paluxy reservoir, which is reached at Fort Worth at 300 feet, would be found at a depth of 1,300 feet below Dallas, and the water would have a pressure 140 feet greater than at Fort Worth, which would cause it to flow freely at the surface. The basement Trinity reservoir would be approximately at 2,200 feet, and theoretically it would have a pressure sufficient to raise the water 200 feet above the Texas and Pacific station in the eastern portion of the city of Dallas.

The additional strata to be penetrated beneath the horizon of the Woodbine reservoir of the present wells, which is about 800 feet deep, would be about 550 feet of the calcareous marls and limestones of the Washita division, as exposed in the cuts of the Texas and Pacific Railway between Fort Worth and Aledo, Parker County, to the Paluxy sands, 300 feet of which are penetrated by the Paluxy wells at Fort Worth. Below the Paluxy sands the Glen Rose limestones and marls, with several water reservoirs, would be passed, as in the deep wells at Fort Worth, except that as a whole the limestones would be thicker by the amount of eastward increment of the Glen Rose formation, which is about 200 feet thicker at Dallas than at Fort Worth.

The president of the Oak Cliff Water Company says that in the two flowing wells, 850 feet deep, 1 mile east of Station A, "at about 200 feet sulphur water of good quality and fair quantity was found, and also a trace of petroleum at about the same depth." If this statement is correct the source of water mentioned must be near the middle of the Eagle Ford shale.

On the summit of the White Rock Cliff and in the western part of Dallas County only a few wells have been drilled. Mr. Hamlin furnishes the following notes on a well drilled by him at Cedar Hill for William Bryant, which penetrated only to the upper or x^3 reservoir. (See Pl. LXIII, *G*.)

The Cedar Hill well is on the highest point between Red River and Galveston, on the Gulf, Colorado and Santa Fe Railway, which is locally known as the White Rock Mountain, 320 feet above Dallas, and 350 feet higher than the Mountain Creek Valley. I find the strata east of the Cross Timbers dip toward the east and northeast. We drill through the white rock [Austin chalk], then the blue rock [Austin chalk], then enter the slate and shale formations [Eagle Ford], the same as in the valley. This well reaches the Upper Woodbine reservoir in 15 feet of water sand. I could have gotten two more by going some 75 or 100 feet farther.

To the east of the White Rock Cliff, in the broad Black Prairie region of central and eastern Dallas County, only one flowing well is reported, and this is at Lancaster, where flowing water was obtained at a depth of 1,057 feet. The quantity of water is not enough, but it supplies a 2-inch flow, which is used by the Lancaster Water and Light Company. Lancaster (altitude 519 feet) is very near the limit of height to which the artesian water will rise. At the Orphans' Home, near Arnold Station, which is located only about 50 feet higher, the water rises to within 60 feet of the surface. (See Pl. LXIII, *K*.) The well at this place, as reported by R. C. Buckner, is 1,270 feet deep and supplies 1,200 gallons per hour. The water is used in the steam boilers which run the machinery and electric lights of the institution. Dr. Buckner adds that the water contains soda, salt, sulphur, and iron, and is remarkably wholesome. This is the deepest and the most eastern well that is supposed to reach the Woodbine reservoir in Dallas County.

The well at Ferris, Ellis County, just south of the Dallas County line, is 1,354 feet in depth. There is no reason why similar wells should not be obtained at Garland, Mesquite, and throughout the eastern portion of the county at slightly greater depths.

In studying the well records of Dallas County it is apparent that many of them have been drilled without serious consideration of the geologic conditions. Many of them stopped in the first shallow flows of the x^3 reservoir, where the water is poor. The drilling of others was stopped just above the water reservoirs. The following section illustrates a well of this class.

S. B. Marshall, who owns a well 685 feet deep, 2 miles southeast of Orphans' Home Station, says: "I have mislaid the drill notes, but remember that the log was as follows:"

Section No. 109.—Section of well of S. B. Marshall, 2 miles southeast of Orphans' Home Station, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Soil	8	8
3. Yellow joint clay	20	28
2. Black joint clay	40	68
1. White rock and shale to bottom	617	685

The well was a failure and is not used. It was stopped near the top of the Eagle Ford formation. If it had been drilled 600 feet farther, the Upper Woodbine reservoirs would have been reached, and if had been carried 700 feet farther the basement Woodbine (x^2) reservoir would have afforded an abundant supply.

Concerning the shallower wells of the Mountain Creek Valley in the western part of the county in general, Mr. Hamlin says: "Most of these wells fail, some inside of two years, for what cause I can not tell. Where the water circulates is a soft, porous sand rock, full of small holes, finer than a honeycomb. I have seen it blasted out."

Some of these wells are permanent, as attested by one in the northwestern portion of the county, which, although only 60 feet deep, has been flowing some ten or fifteen years.

We have no positive proof that any well in Dallas County has penetrated to the Paluxy reservoir. Mr. W. J. Borah reports one well, 16 miles northeast from Dallas, which is 975 feet deep. No record of the strata was preserved. If this well goes to the depth stated it probably reaches the Paluxy reservoir.

ELLIS COUNTY.

Ellis County has an area of 965 square miles, and is one of the richest and most fertile of the Black Prairie sub-province. The White Rock scarp passes through the extreme western portion and the surface slopes gradually from the summit of this to the eastward, consisting of gently rolling black prairie lands. Numerous creek valleys indent this sloping plain from northwest to southeast.

The county is underlain by the Woodbine, Paluxy, and Trinity reservoirs, which at Waxahachie have depths of about 940, 1,600, and 2,300 feet, respectively, The chief and most available sources of supply in this county are the reservoirs of the Woodbine system, and these are readily obtainable at depths of from 500 feet at the western margin of the county to about 2,500 feet in the extreme eastern corner.

Artesian development has been quite extensive, and good wells have been obtained in all the principal towns, such as Waxahachie, Italy, Ferris, and Palmer. So far as the writer has been able to ascertain, only two wells have been drilled below the Woodbine reservoirs into the strata of the Washita and Fredericksburg divisions, possibly to the Paluxy sand. These are the wells at Waxahachie, 1,700 feet deep, and at Milford, 1,900 feet deep. The wells all begin at the surface in the Eagle Ford formation, the Austin chalk, or the Taylor marls. The following data concerning the wells have been received:

In the portion of the county west of the White Rock scarp, and in Chambers Creek Valley, wells are obtained at comparatively shallow depths, as shown by the following reports:

J. T. Gaines, of Midlothian, has a well 150 feet deep, and states that there are forty or fifty wells in this locality, and that all yield good soft water. On the low lands the water flows. The surface is black, waxy soil for 3 to 10 feet, with clay foundation. The first water is struck in white sand below a hard cap or sand rock, which is 6 to 36 inches. In some of the wells there seems to be three to four sand strata, and in others there is one.

The postmaster at Midlothian says that the town owns an artesian well.

A. F. Hardie, of Dallas, Dallas County, reports that his well is located in Ellis County and is 213 feet deep. He also says that 3 miles west of Mountain Peak, Ellis County, there are five wells.

Mr. A. J. Stone owns a flowing well 1 mile east of Britton. It is 136 feet deep. This well begins in the base of the Eagle Ford clays and strikes three water reservoirs in the upper part of the Woodbine formation, at depths of 80, 102, and 130 feet.

The following is a section of his well:

SECTION NO. 110.—SECTION OF WELL OF A. J. STONE, 1 MILE EAST OF BRITTON, ELLIS COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
8. Black soil (Eagle Ford)	4	4
7. Gravel (Eagle Ford)	14	18
6. Shaly clay (Eagle Ford)	62	80
5. Thin sand, water bearing (Woodbine)	22	102
4. Blue clay (Woodbine)		
3. Sand (Woodbine)	28	130
2. Clay (Woodbine)		
1. Sand (Woodbine)	6	136

J. H. Pinson, well driller, reports a well drilled by him 1½ miles southeast of Britton post-office. He says:

The first flow was in 15 feet of soft white sand rock and raised the water to 17 feet of surface; the second was in 40 feet of soft white sand rock; the third was in 5 feet of soft white sand rock and brought the water within 10 feet of the surface. The well is 305 feet deep.

Rollin Thomson, of Bee Creek, says:

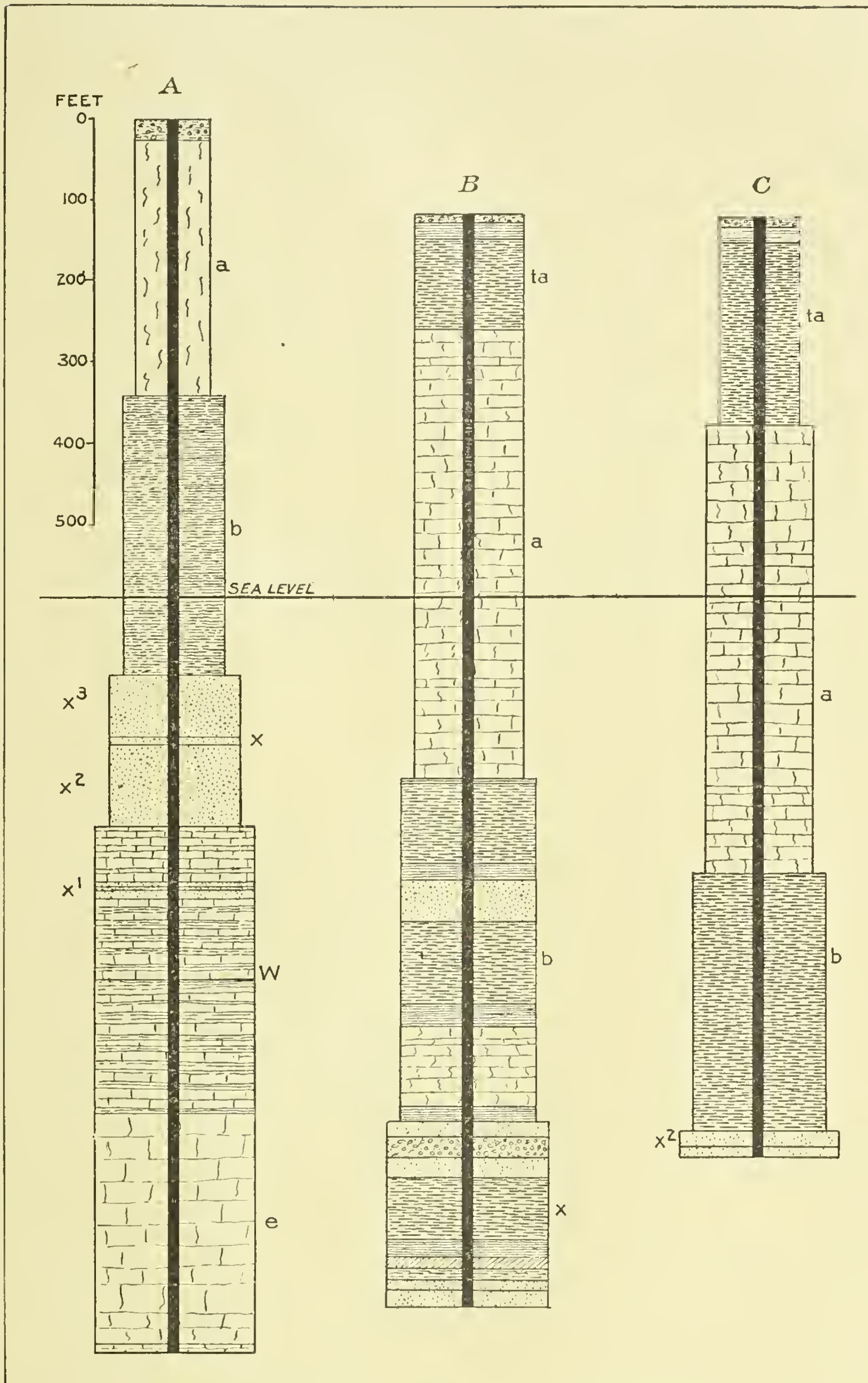
Every one in this county has one or the other sources of water supply. The list of artesian wells could be added to largely in this neighborhood. The artesian wells in this vicinity range from 200 to 350 feet in depth, and most of them flow, some much more copiously than others.

Sides and Hartson report a flowing well 237 feet deep, drilled by them 1 mile northeast from Eyrie and 12 miles west from Waxahachie, in which they passed through soil 10 feet; clay, 35 feet; slaty shale, 174 feet; cap rock, 3 feet; water-bearing sand, 15 feet.

S. E. Hilburn has a flowing well 3 miles northwest from Boz and 9 miles west of Waxahachie, which is 300 feet deep. He gives the following section:

SECTION NO. 111.—SECTION OF WELL OF S. E. HILBURN, 3 MILES NORTHWEST OF BOZ AND 9 MILES WEST OF WAXAHACHIE, ELLIS COUNTY, TEXAS.

	Thickness.	Depth
	Feet.	*Feet.*
3. Black soil	20	20
2. Slate shale	260	280
1. Sand	20	300



WELLS OF ELLIS COUNTY, TEXAS.

A, Waxahachie; *B*, Ferris; *C*, Palmer.

SECTION NO. 112.—SECTION OF WELL OF FRANK VAUGHAN, 18 MILES WEST OF WAXAHACHIE, DRILLED BY SIDES AND HARTSON, ELLIS COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
5. Soil	9	9
4. Gravel and clay	21	30
3. Slate (Eagle Ford)	215	245
2. Cap rock (Eagle Ford)	1.5	246.5
1. Water-bearing sand (Woodbine)	10	256.5

Along the meridian of Waxahachie flowing wells are obtained at depth of about 900 feet. Wells of this section and others have been reported as follows:

Postmaster at Italy reports as follows: "We have one well here 1,400 feet deep, but the water does not flow; have pump in well that furnishes plenty of water. Water comes in 10 feet of top of well."

SECTION NO. 113.—SECTION OF WELL AT WAXAHACHIE, ELLIS COUNTY, TEXAS, DRILLED BY R. H. DEARING.

	Thickness.	Depth.
	Feet.	*Feet.*
11. Soil	22	22
10. White limestone (Austin Chalk)	294	316
9. Shale (Eagle Ford)	284	600
8. Slate (Eagle Ford)	100	700
7. Hard sand rock (Woodbine)	38	738
6. Water sand (Woodbine)	20	758
5. Red sand and shale (Woodbine)	20	778
4. White lime rock (Woodbine)	45	823
3. Hard sand rock (Woodbine)	85	908
2. Water sand (Woodbine)	70	978
1. Blue lime rock (Main Street?)	12	990

SECTION NO. 114.—SECTION OF FLOWING WELL AT WAXAHACHIE, ELLIS COUNTY, TEXAS, BY E. A. DUBOSE, MAYOR OF WAXAHACHIE.

(See Pl. LXIV, *A*.)

	Thickness.	Depth.
	Feet.	*Feet.*
13. Residual soil and gravel	26	26
12. White-lime rock (Austin)	316	342
11. Blue shale (Eagle Ford)	346	688
10. Sand rock (Woodbine)	75	763
9. Water-bearing sand (Woodbine)	9	772
8. Sand rock (Woodbine)	100	872
7. Lime rock with fossils	68	940
6. Water-bearing sand	7	947
5. Sand rock with water	15	962
4. White lime rock	100	1,062
3. White lime rock, alternating with blue shale (Washita and Fredericksburg)	165	1,227
2. White limestone (Washita and Fredericksburg)	284	1,511
1. Blue limestone (Washita and Fredericksburg)	10	1,521

Flows of water were obtained at 772 feet and at 962 feet, supplying 24,000 gallons a day.

G. H. Cunningham's well is located 3 miles east of Boz, and 6 miles southwest of Waxahachie. It is 700 feet deep. He gives the following section:

SECTION NO. 115.—SECTION OF WELL OF G. H. CUNNINGHAM, 3 MILES EAST OF BOZ AND 6 MILES SOUTHWEST OF WAXAHACHIE, ELLIS COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
5. Limestone	285	285
4. Clay shale	50	335
3. Soft, seamy shale and a few hard sand rocks of different thicknesses, from 4 inches to 2 feet	265	600
2. Dark, hard slate shale	100	700
1. Water-bearing sand	----------	----------

The well of Mutz & Cassidy, at Ferris, according to the postmaster, is "the only artesian well there." First flow, 1,120 feet, about 360 gallons an hour; second flow, 1,330 feet, 75 gallons per minute; a fine quality of water, ample to supply all needs of the town. Total depth, 1,360 feet.

The following section is given:

SECTION NO. 116.—SECTION OF ARTESIAN WELL AT FERRIS, ELLIS COUNTY, BY E. A. DUBOSE, MAYOR OF WAXAHACHIE.

(See Pl. LXIV, *B*.)

	Thickness.	Depth.
	Feet.	*Feet.*
21. Black residual soil (Taylor)	12	12
20. Yellow sandy clay subsoil (Taylor)	20	32
19. Blue shale (Taylor)	113	145
18. White and blue limestone interspersed with pyrites (Austin)	555	700
17. Clay (Austin)	5	705
16. Blue shale (Eagle Ford)	100	805
15. Gumbo clay (Eagle Ford)	25	825
14. Quicksand (Eagle Ford)	50	875
13. Blue shale and pyrites (Eagle Ford.)	100	975
12. Gumbo clay (Eagle Ford)	30	1,005
11. Blue limestone (Eagle Ford)	100	1,105
10. Yellow clay (Eagle Ford)	15	1,120
9. Sand rock (Woodbine)	21	1,141
8. Gravel and sand (Woodbine)	25	1,166
7. Hard sandstone (Woodbine)	25	1,191
6. Blue shale (Woodbine)	75	1,266
5. Clay (Woodbine)	20	1,286
4. Hard rock (Woodbine)	15	1,301
3. Blue shale (Woodbine)	15	1,316
2. Sand (Woodbine x^2)	10	1,326
1. White sand with water (Woodbine)	25	1,351

The Palmer Gin and Compress Company, of Palmer, owns a flowing well 1,178 feet deep.

SECTION NO. 117.—SECTION OF WELL AT PALMER, ELLIS COUNTY, DRILLED BY A. F. WILSON.

(Pl. LXIV, *C*.)

	Thickness.	Depth.
	Feet.	*Feet.*
8. Soil and clay (Taylor)	245	245
7. White lime rock (Austin)	470	715
6. Shale (Eagle Ford)	267	982
5. Blue marl (Eagle Ford)	10	992
4. Slate (Eagle Ford)	100	1,092
3. Blue marl (Eagle Ford)	10	1,102
2. Sand rock (Woodbine)	36	1,138
1. Water sand (Woodbine)	16	1,154

A. F. Wilson, well driller, reports a flowing well 975 feet deep, drilled by him 1½ miles west of Boyce and 5½ miles east of Waxahachie; first water at 960 feet. He gives the following record of strata penetrated:

SECTION NO. 118.—SECTION OF WELL 1½ MILES WEST OF BOYCE AND 5½ MILES EAST OF WAXAHACHIE, ELLIS COUNTY, DRILLED BY A. F. WILSON.

	Thickness.	Depth.
	Feet.	*Feet.*
8. Soil and clay	50	50
7. White lime rock (Austin)	492	542
6. Shale (Eagle Ford)	278	820
5. Blue marl (Eagle Ford)	15	835
4. Slate (Eagle Ford)	95	930
3. Sand rock (Woodbine)	20	950
2. Water sand (Woodbine)	10	960
1. Blue marl (Woodbine)	15	975

SECTION NO. 119.—SECTION OF ARTESIAN WELL AT PALMER, TEXAS (ALTITUDE 471 FEET), FURNISHED BY E. A. DUBOSE, MAYOR OF WAXAHACHIE, ELLIS COUNTY, TEXAS.

(Pl. LXIV, *C*.)

	Thickness.	Depth.
	Feet.	*Feet.*
7. Black soil (Taylor)	12	12
6. Clay and sand (Taylor)	20	32
5. Blue shale (Taylor)	227	259
4. White lime rock (Austin)	446	705
3. Blue shale with pyrites, fossils, and concretions (Eagle Ford)	435	1,140
2. Sand (Woodbine)	20	1,160
1. Water-bearing sand at 1,164 feet (Woodbine x^3)	6	1,166

Schedule of wells in Ellis County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water. *a*	Flowing wells. *a*	Quality. *b*	Irrigation. *a*
		Feet.	*Feet.*	*Feet.*				
L. Stone	Britton, $1\frac{1}{4}$ miles east of	300	100	270		×	1, 5	No.
J. H. Pinson	Britton, $1\frac{1}{2}$ miles southeast of.	305	110	160, 290	×	No.	1	No.
A. Stone	Britton, 1 mile east of	136	80	102, 130		×	1	No.
W. P. Brown	Auburn, 1 mile south of	196	135			×	1	×
Sides & Hartson	Eyrie, 1 mile northeast of	237				×	1	
W. G. Clement	Eyrie, 2 miles southeast of	260				×	1	×
J. W. Banks	Eyrie	240				×		
J. A. Berrier	Eryie post-office, 1 mile east of.	270	16	90		×	1	No.
F. Vaughan	Beecreek post-office	257			227	No.	1	
A. J. Fanning	Beecreek, $1\frac{1}{4}$ miles northeast of.	221				×	1	×
J. McCain	Beecreek, 1 mile from	194	16			×	4	No.
Mrs. A. E. Center	Beecreek, $1\frac{1}{2}$ miles east of	218	100			×	1	No.
S. W. Hendrix	Beecreek, 1 mile east of	250	60	190		×	1	×
J. T. Gaines	Midlothian	467	462		×	No.	1	×
J. H. Rutledge	Wyatt, 1 mile southwest of.	200	±25	±194	×	No.	1	No.
J. O. Shoultz	Wyatt, $\frac{1}{2}$ mile north of	280		250	×	No.	1	No.
G. Wilson	Wyatt, 1 mile north of	285			200	No.	1, 9	No.
A. J. Florey	Wyatt	267	200		×	No.	1	No.
D. Rice	Wyatt, $1\frac{1}{2}$ miles northeast of	240				No.	1	
J. T. Gaines, several wells.	Midlothian, 5 miles northwest of.	150	60			×	1	×
G. Wilson	Midlothian	464			×	No.		×
		278				×		
Mrs. Z. T. Huff	Midlothian Peak, 3 miles west of.	258			×	No.	1	No.
S. C. Wise	Mountain Peak	276			100		1	No.
A. F. Hardie (reports)	Mountain Peak, 3 miles west from (5 wells).	200 to 213		20	×	No.	1	No.
Milford Artesian Well Co.	Milford post-office, 100 feet from.	2,018	1,600	1,900		×		No.
R. Aycock	Italy, 300 yards from post-office.	1,400			×	No.	1	No.
R. H. Dearing	Waxahachie	990	758	908		×	1	No.
		1,700	1,100		×			
G. H. Cunningham	Boz, 3 miles east of	700	700		×	No.	1, 8	×
Merchants and Planters' Gin Co.	Palmer post-office, 400 yards from.	1,154	1,144			×	1	No.
Palmer Gin and Compress Co.	Palmer, 750 feet south of	1,178				×	1	No.
Mutz & Cassidy	Ferris	1,360	1,120	1,350		×	1	No.
A. F. Wilson	Boyce, $1\frac{1}{2}$ miles west of	975	960			×	1	No.
T. J. Bales	Boyce, $1\frac{1}{2}$ miles west of	981	500			×	1, 8	No.

a × = yes.

b 1, Soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

GRAYSON COUNTY.[1]

Grayson County has an area of 960 square miles. It possesses certain geologic and geographic peculiarities which render the discussion of its artesian conditions somewhat more complex than that of the other counties described. The abrupt border between the Red River and main Texas districts of the geologic and geographic belts of the Black and Grand Prairies runs diagonally northwest and southeast through this county. A line approximately drawn through Cedar Mills, Cook Springs, and Bells separates the two districts, that portion lying north of this line belonging to the Red River district and that lying south belonging to the main Texas belt. Furthermore, in that portion of the county between the line above defined and Red River is a block between two principal fault lines of the Red River fault zone which presents artesian conditions entirely different from either of the districts mentioned. That portion of the county south of the line above mentioned consists of the regular north-south belts of country of the main Texas district, consisting of the Austin chalk belt east of a line drawn through Sherman, Howe, and Van Alstyne, a wide belt of Eagle Ford prairie running westward to Whitesboro, and the sandy prairies of the Woodbine belt in the extreme western portion of the county.

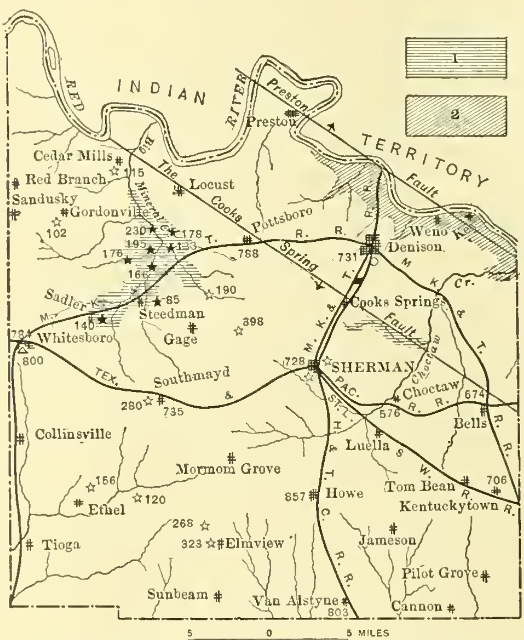


FIG. 77.—Artesian map of Grayson County, Texas. 1, area where flowing wells may be obtained from the Woodbine reservoir; 2, area where flowing wells may be obtained from the Trinity reservoir; ★, flowing wells from Woodbine reservoir; ☆, nonflowing wells from Woodbine reservoir; ○, wells from Trinity reservoir; △, reservoir unknown.

This district consists of a plain with very little coastward slope, although the surface is very undulating in many places, owing to the numerous drainage courses; its extremes of altitude lie between 600 and 850 feet. The highest points of the county in this district from

[1] An excellent topographic map of the northwestern corner of Grayson County has recently been made by the United States Geological Survey.

the western edge to the extreme east are almost in a line horizontally, the variation being only from 800 feet on the western county line to 706 feet at Whitewright on the east. Thus it will be seen that the regional slope is hardly 100 feet in 35 miles. Within this region the strongest relief feature is the incised valley of Big Mineral Creek, which is indented 200 feet below the general summit level. The Austin chalk is exposed in some places near the head of this creek to the west of Sherman.

In the Red River district, or that portion of the county north of a line drawn through Bells, Cook Springs, Pottsboro, and Cedar Mills, the same upland altitudes prevail, but Red River has cut a deep valley which varies from an altitude of 500 feet at the extreme eastern edge of the county to about 590 feet at the western edge of the county, this valley being incised about 300 feet below the highest upland altitudes.

The portion of Grayson County within the faulted zone, which may be called the Denison district, consists of east-west belts of country established upon the various geologic formations from the Woodbine sands (south of Denison) to the Antlers sands (south of Preston), inclusive. The outcrop of each successively lower and lower formation as exposed by the erosion of the Red River Valley produces types of soil differing from place to place. These formations are fully described in the portion of this report devoted to geology.

GEOLOGY.

That portion of the county within the main Texas belt consists at the surface solely of the Upper Cretaceous formations succeeding each other from west to east. The Woodbine formation outcrops at the western line of the county with a thickness of about 500 feet, the Eagle Ford formation constitutes extensive prairies west of Sherman, and the Austin chalk underlies the southeast quarter of the county. The surface formations of the Northern or Red River district, on the other hand, are principally those of the Comanche series, consisting of outcrops of the entire sections from the Paluxy (Antlers) sands to the Woodbine formation, inclusive, as described in detail in the geologic portion of this paper. (See Pl. LXVI.) In the Red River Valley there are also many wide second bottoms of rich alluvial soil.

The whole of the main Texas belt is underlain by the Woodbine, Paluxy, and Trinity reservoirs, the first of which alone is obtainable anywhere within the district at depths of much less than 1,000 feet. None of these have been penetrated as yet by wells except the Woodbine reservoir, although it is probable that the Paluxy reservoir lies about 1,000 feet below the surface at the western edge of the county, about 1,800 feet deep in the longitude of Sherman, and about 2,300 feet deep at the extreme eastern portion of the county. The nearest points at which the basement Trinity reservoir has been penetrated is at Gainesville on the west and Denison on the north. From well sections at these localities the writer estimates that this reservoir is embedded from 2,200 to 2,500 feet in the main Texas belt in the vicinity of Sherman, and hence is practically beyond availability except for municipal and industrial supply. It is doubtful if the water of the Paluxy and Trinity reservoirs will outflow within any portion of the county, except perhaps in the valley of Big Mineral Creek.

The Woodbine reservoir in the portion of the county within the main Texas district is nearest to the surface and is the most practicable and available. It is embedded at depths of from 100 feet at the western edge of the county to 750 feet in the central portion, and not over 1,500 feet at the extreme eastern line. There is only one small area within the entire district where waters from any of the reservoirs will rise to the surface, and this is a small district of less than 10 square miles along the valley of Big Mineral Creek between the Missouri, Kansas and Texas Railway and the Cook Springs fault line and approximately lower in altitude than the 650-foot contour. (See fig. 79, p. 620.)

Owing to the parallel lines of faulting on the north and south sides of the Denison district, the formations in this region as a whole stand some 300 feet higher than those of the main Texas belt to the south and the Red River district to the north.

The artesian conditions of the Denison or Red River district are quite different from those of that portion of the county south of it. The Woodbine sands constitute the surface formation along the narrow belt running eastward from Pottsboro through South Denison to Red River. North of this line the Paluxy and Trinity reservoirs of the Antlers sands are alone available. The Paluxy formation, which outcrops in Marshalls Bluff near Preston, is penetrable at depths of less than 500 feet. The Trinity reservoir, as shown by the log of the well at Denison, elsewhere given, is located at a depth of about 700 feet below Denison.

DEVELOPMENT.

A great many wells in the main Texas belt of this county have penetrated to the Woodbine reservoir, flowing wells being obtained in the valley of Big Mineral Creek, as shown upon the map (fig. 78). Outside of this district these waters will not rise to the surface, but are utilized at Sherman and elsewhere by pumping. The Paluxy and Trinity reservoirs have not been penetrated in this portion of Grayson County.

The following is a list of the artesian wells so far as they have been obtainable:

Schedule of wells in Grayson County, Texas.

WELLS FROM THE WOODBINE RESERVOIR.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow. *a*	Increase. *a*	Quality. *b*
		Feet.	*Feet.*	*Feet.*	*Feet.*			
J. E. Bond	Cedar Mills	115	15	25 or 30	10			1
W. H. Witt	Gordonville, at post-office	102	15	15 to 20				
J. P. Clay	Gage, 2 miles northwest of	190			30			1
G. T. Dorner	Gage, 2½ miles east of	398	300		220			1
J. M. Nicholas	Locust, 3 miles south of	176	90	145		×	×	1
H. L. Poe	Southmayd, ¾ mile west of	+280	190		180			1
	Sadler, 1 mile east of	140	30	60, 80		×		1
H. Eldridge (reports)	Steadman, ½ mile east of	95	80	91		×		1, 8
W. C. Eubank	Sherman, 18 miles northwest of; Red River, 4 miles south of	230	225			×		4
W. H. Dryden	Sherman, 13 miles northwest of	200	150	192	3			1
W. C. Eubank	Sherman, 18 miles northwest of; Red River, 4 miles south of, in Mineral Creek bottom.	480	140	170		×		
Do	do	200	130	155		×		
H. Eldridge (reports)	Pottsboro, 5 miles west of	130	130			×		1, 8
D. Bryant	Pottsboro, 6 miles west of	195	140			×		1
H. Eldridge (reports)	do	166	20	80, 145, 160		×		1
L. Scott	Pottsboro, 7 miles west of	±500	132	154, 176		×		1
E. B. Sizemore (reports).	Elm View	323			+300			1, 8
H. C. Sperry	do	320			220			
J. G. Wheeler	Elm View, 1 mile west of	268			228			1, 8
D. Hunter	Elm View, 3½ miles northwest of	200			80			1
S. A. Schott	Ethel, 4 miles east of	120			×			1
E. B. Sizemore (reports).	Ethel, 1 mile northeast of	156	65	154	80			1
Sherman Ice Co	Sherman	915						
Texas and Pacific Rwy	do	632						
Do	Whitesboro	800						

WELL FROM THE PALUXY-TRINITY RESERVOIRS.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.	Flow. *a*	Increase. *a*	Quality. *b*
C. W. Clark	Denison, 1 mile south of	920	30	100, 560, 625, 707	×			1

a × = yes.

b 1, Soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

Mr. C. W. Clark, of Smithville, Bastrop County, reports a well about 1 mile south of Denison, which he states was bored to a depth of 1,800 feet. The writer possesses a record of this well to the depth of 920 feet, which was obtained from the driller in Denison many years ago, and it is one of the most perfect and valuable logs yet received. It clearly shows that the water-bearing Trinity sands are just 582 feet

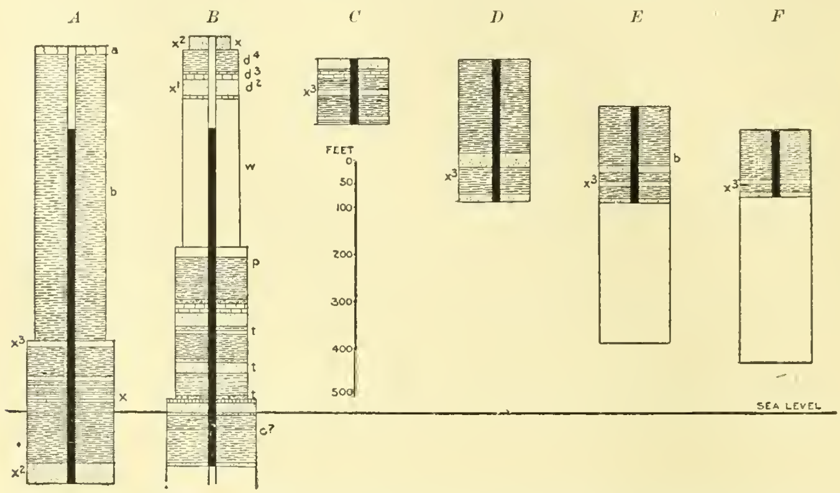


FIG. 78.—Logs of wells in Grayson County, Texas. *A*, Incomplete well at Sherman; *B*, well 1 mile south of Denison; *C*, flowing well 1 mile east of Sadler; *D*, Poe's well, three-fourths mile west of Pottsboro; *E*, Dr. Scott's well, 7 miles west of Pottsboro; *F*, W. C. Eubank's well, Mineral Creek bottom.

below the top of the Main Street limestone at Denison, and that the whole thickness of the Lower Cretaceous below the base of the Woodbine sands is about 632 feet. This is the only log of a well or other record north of Fort Worth by which to approximate these thicknesses in that portion of the Grand Prairie in Texas. The log to a depth of 920 feet is as follows (see fig. 78, *B*):

SECTION NO. 120.—LOG OF A DEEP WELL 1 MILE SOUTH OF DENISON, GRAYSON COUNTY.

[See fig. 78, *B*.]

	Thickness.	Depth.
	Feet.	*Feet.*
23. Soil and clay	5	5
22. Pack sand (Woodbine)	25	30
21. Blue joint clay "soapstone" (Grayson)	50	80
20. Hard fossiliferous Main Street limestone with admixture of sand	3	83
19. Blue clay "soapstone" with various species of Cretaceous fossils and limestones	387	470
18. Blue clay interspersed with frequent strata of fine quicksand (upper part of Antlers sands); water (p)	90	560

SECTION NO. 120.—LOG OF A DEEP WELL 1 MILE SOUTH OF DENISON, GRAYSON COUNTY—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
17. Fine and coarse sand, gravel, and bowlders with water	10	570
16. Very hard blue limestone, fossiliferous	20	590
15. Clean white sand	25	615
14. Thin white clay	3	618
13. Coarse, sharp, white sand; water under pressure rose to within 100 feet of surface	7	625
12. Tough blue clay	50	675
11. Tough white unctuous clay	7	682
10. Fine white sand; water abundant	25	707
9. Yellowish white clay with streaks of sand (water?)	45	752
8. Loose bowlders	10	762
7. Hard gray limestone, thought to be Carboniferous	8	770
6. About 2 feet apparent cavity, balance white sand, with streaks of white clay toward bottom	25	795
5. Yellowish clay, greenish toward bottom, with small lumps of greenish sand rock	15	810
4. Variegated clay, with reddish sand toward bottom	10	820
3. Red rock, composed of red clay or chalk and sand, with small quantity of black sand in upper part of stratum	75	895
2. Bed of small shells	2.5	897.5
1. Red rock, same as above, but without black sand	23	920.5

The last 100 feet of the well was made with drive pipe, which struck a rock so hard it would not go any farther. The well does not flow, but water rose to within 100 feet of the surface, or to an altitude of about 650 feet.

In the above section the following geologic horizons are recognizable:

	Feet.
22–23. The Dexter sands of the Woodbine formation	35
18–21. The formations of the Washita and Fredericksburg divisions of the Comanche series; No. 20 is the Main Street limestone; No. 21 the Grayson marl	435
8–18. The Antlers sand, or equivalent of the Paluxy and Trinity sands of southern section	292
1– 7. Paleozoic (Carboniferous?) rocks resembling those which outcrop north of Atoka	158
	920

The water reservoirs were as follows:

	Depth from surface.
No. 22. Woodbine (Dexter) (x^2)	30
No. 18. Paluxy (p)	410–560
No. 17	560–570
No. 13	618–625
No. 10	682–707

There are two important deductions that may be drawn from these facts: (1) In regard to the total thickness and depths to water of the Comanche series, and (2) as to the probability of a flowing area north of Denison which would be of great value to that city as a source of city supply. (See fig. 79.)

From the fact that the waters in the deep well 1 mile south of Denison, reported by Mr. Clark, rose to within 50 feet of the surface, or to 650 feet above sea level, it is evident that had this well been located on ground 100 feet lower the water would have reached the surface

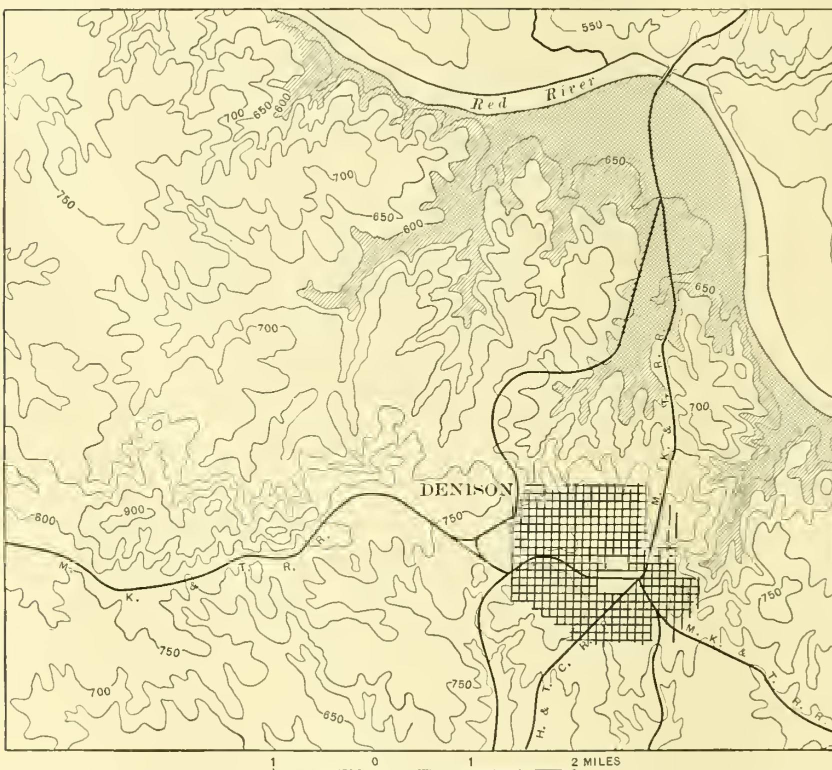


FIG. 79.—Map of area north of Denison, Texas; shaded portion indicates area in which flowing artesian wells can be obtained from the Paluxy system.

and a good flow could have reasonably been expected at any point lower than 600 feet. To the north of Denison, along the slopes of Duck and Choctaw creeks and in the valley of Red River, there is a considerable area below 600 feet where flowing wells could be obtained which could furnish water to be pumped to the city. Furthermore, the wells thus located would be shallower than the one drilled, according to the geologic formation at the surface. At the crossing of Duck Creek by the Missouri, Kansas and Texas Railway, where the formation is the top of the Kiamitia clay, the bottom reservoir encountered in the deep well 1 mile south of Denison should not be over 500 feet below the surface. In the Red River Valley north of the Red River fault, which lies between the Duck Creek and Red River bridge, the Basement reservoirs will deepen again to 750 feet below the river level.

At Sherman and all points south of the Cook Springs fault in the line of strike of Sherman the depth of the Paluxy-Trinity waters will be practically that of the Sherman 915-foot well plus 762 feet of the Denison (Clark) well, or about 1,677 feet below the base of the Austin chalk.

By placing the section of the Sherman well (see fig. 78, p. 618) on top of that of the Denison well, the strata below Sherman will be seen. It is hardly necessary to add that the Paluxy-Trinity waters will not rise to the surface at Sherman or any other point above an altitude of 600 feet. At Whitesboro and other points in the eastern edge of the Eastern Cross Timbers the Basement Trinity water should be about 500 feet nearer the surface, or have a depth of about 1,200 feet. Flows from these lower reservoirs can be obtained wherever the flows from the Woodbine reservoirs are obtainable.

WELLS FROM THE WOODBINE RESERVOIR.

The Woodbine reservoirs have been penetrated at many places south of the Cook Springs fault in the western half of the county between the Eastern Cross Timbers and the Austin chalk belt, and at Sherman, which is situated in and near the base of the Austin chalk. In this district the upper Woodbine reservoirs (x^3) seem to be reached at depths varying from 102 feet at the western border of the county to 632 feet at Sherman, and the lower reservoirs (x^2) at depths of from 480 feet in the western half of the county to 915 feet at Sherman. Unfortunately we possess no logs of the artesian experiments at Whitesboro (800 feet deep) and Sherman (915 feet deep) whereby the exact sequence, depth, distance apart, and inclination of the strata may be determined. There are at least two distinct reservoirs (x^2 and x^3) from 200 to 300 feet apart, but the writer has not been able to secure a single record showing the details of the entire thickness of the Woodbine strata.

It is the writer's opinion that most of the wells, except some of the deepest in Mineral Creek Valley, obtain their water from the upper or x^3 reservoirs of the Lewisville horizon. Mr. J. A. Taff states that "the wells of Mineral Creek Valley were drilled through a part of the Timber Creek [Lewisville] formation [x^3] into the Dexter sand [x^2], from which they receive their flow." Many of the wells to the south show by their records that they have not reached the Dexter sands. The two depths at which the reservoirs were struck at Sherman would indicate that the x^2 and x^3 reservoirs are about 300 feet apart at that place.

All of the Woodbine wells thus far developed, except those at Sherman, begin in the Eagle Ford shales or Woodbine formation, and their logs show only shale and sand, with occasional beds of lignite.

The following details of some of the wells are given: At Whitesboro, on the western edge of the county, near the contact of the Woodbine and Eagle Ford formations, a well was drilled to a depth of 800 feet, but failed to obtain flowing waters owing to the high altitude. This well must have penetrated the entire Woodbine system with its various reservoirs.

In the southwest quarter of the county, south of a line drawn between Whitesboro and Sherman, the Woodbine reservoirs are found beneath the Eagle Ford Prairies at depths of from 100 to 300 feet. The following wells are of this character:

Mr. H. L. Poe, who has a nonflowing well 280 feet in depth located three-quarters of a mile west of Southmayd, gives the following record of strata passed through:

SECTION NO. 121.—SECTION OF WELL OF H. L. POE, LOCATED THREE-FOURTHS MILE WEST OF SOUTHMAYD, GRAYSON COUNTY.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Soil and joint clay	45	45
5. Slate with bituminous smell	145	190
4. Rock, salt water underneath	1.5	191.5
3. Blue sand (x^3)	35	226.5
2. Black soapstone or slate	50	276.5
1. White, water-bearing sand (x^2)	4	280.5

Mr. H. C. Sperry, postmaster at Elmview, gives the following information concerning a well drilled at that place: "Went through soapstone or shale from 20 feet to the bottom, becoming harder and denser as the drill went down to the bottom, where we found a hard rock just above the water, perhaps 6 or 8 inches through said rock. Depth of well, 320 feet. The well does not flow."

SECTION NO. 122.—SECTION OF WELL AT ELMVIEW, GRAYSON COUNTY, TEXAS, REPORTED BY MR. H. C. SPERRY, POSTMASTER.

	Thickness.	Depth.
	Feet.	*Feet.*
3. Blue shale	319	319
2. Hard rock	.5	319.5
1. Water sands	1	320.5

SECTION NO. 123.—SECTION OF WELL 14 MILES SOUTHWEST OF SHERMAN, REPORTED BY E. B. SIZEMORE, WELL DRILLER.

	Thickness.	Depth.
	Feet.	*Feet.*
7. Soil	8	8
6. Clay shale	42	50
5. Black shale	200	250
4. Hard gray shale	63	313
3. Impure blue limestone	2	315
2. Blue pack sand	8	323

The above strata represent the following formations:

2–7. Bituminous clays of Eagle Ford and Woodbine formations.
3. A bed which generally occurs at base of the Eagle Ford.
1. The Lewisville beds of the Woodbine formation.

Mr. G. T. Dorner, who owns a well 2½ miles east of Gage, says: "This well is 398 feet in depth (is not finished). Struck first reservoir at 300 feet. According to other wells east and west of me, may have to go 25 or 30 feet deeper to get plenty of water."

Mr. Dorner also gives the following section of his well:

SECTION NO. 124.—SECTION OF WELL OF G. T. DORNER, 2½ MILES EAST OF GAGE, GRAYSON COUNTY.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Yellow clay	23	23
3. Joint clay and shale	280	303
2. Sandstone (x^3)	3	306
1. Shale	92	398

Mr. E. B. Sizemore, well driller, reports a well drilled by him 18 miles southwest of Sherman, about 1 mile northeast of Ethel: "Went through soil 6 or 8 feet; then struck a yellow clay and went on until I got about 62 feet; then struck a hard lime rock; went 3 feet and into first water and struck a sand and slate; then on until I got about 154 feet and struck water-bearing sand. This is a very strong nonflowing well. The water rose up about 80 or 90 feet, and furnishes 25,000 gallons of water per day."

The following is a section of this well:

SECTION NO. 125.—SECTION OF WELL 18 MILES SOUTHWEST OF SHERMAN, ABOUT 1 MILE NORTHEAST OF ETHEL, REPORTED BY E. B. SIZEMORE, WELL DRILLER.

	Thickness.	Depth.
	Feet.	*Feet.*
5. Soil	8±	8
4. Yellow joint clay	62	70
3. Hard limestone	3	73
2. Sand and clay alternating	81	154
1. Water sand (x^3)	2+	156

Mr. D. Hunter, who owns a well about 3½ miles northwest from Elmview, states that the well has been in use eleven years, and the supply of water is just as strong as when first got it. The total depth of the well is 200 feet.

The following is a section of this well:

SECTION NO. 126.—SECTION OF WELL OF D. HUNTER, ABOUT 3½ MILES NORTHWEST OF ELMVIEW, GRAYSON COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
7. Black waxy soil	6±	6
6. Yellow clay	14±	20
5. Slate rock of a light-blue color, continued	80±	100
4. Fire clay	.5±	100.5
3. Gray shaly clay with many hard balls of pyrites	95	195.5
2. Black clay	2	197.5
1. Hard sand rock of a gray color	3±	200.5

Occasionally the drill passed through small strata of "soapstone" (potter's clay).

To the north of the Texas and Pacific Railway, between Sadler on the west, Pottsboro on the east, and to within 4 or 5 miles of Red River on the north, in the basin of Big Mineral Creek, at altitudes of 650 feet or less, there is an area where seven or eight flowing wells have been obtained from the Woodbine reservoirs. This area follows closely the valley of Big Mineral Creek and its five principal prongs, as shown in fig. 77. The highest of these wells, near Sadler, begins at the base of the Eagle Ford, and the lowest begins in the Woodbine formation.

W. C. Eubank, of Sherman, reports a flowing well 480 feet in depth, owned by himself and others, about 18 miles northwest of Sherman, in Mineral Creek bottom, and 4 miles south of Red River. This well was dug in exploring for coal, the owners having been misled into the enterprise by the occurrence of lignite in the Woodbine formation. Mr. Eubank furnished the following section of this well:

SECTION NO. 127.—SECTION OF WELL OF W. C. EUBANK, LOCATED 18 MILES NORTHWEST OF SHERMAN, IN MINERAL CREEK BOTTOM, GRAYSON COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
6. Alluvial soil	20	20
5. Clay shale	120	140
4. White pack sand	1	141
3. Clay shale	25	166
2. White sandstone	5	171
1. Shale and limestone	309	480

In drilling this well the first flow of water came from about 1 foot of white packsand at 140 feet. At a depth of 165 feet the second flow was encountered on top of No. 4. The sandstone is about 5 feet in thickness. At bottom of said sandstone the third flow was encountered, being the largest flow of the three. The balance of the well, to a depth of 480 feet, furnished no more water. (See fig. 78 *F*.) Mr. Eubank also furnished an analysis of the water from the above well, which is given opposite page 448.

J. M. Nichols owns a flowing well, 176 feet in depth, on low ground 3 miles south of Locust. He says: "Artesian water was first found in this district in 1890, and since then there have been eight wells drilled. Five of these flow, and in the other three the water is near the top. This is the most northern well of the group. Artesian water can be obtained at a depth of 150 feet on low land or in creek bottoms, and upon the prairies at a depth of 200 to 300 feet, but the water will not flow on high land. The reservoirs are from 4 to 50 feet in thickness. One well in this vicinity was drilled 486 feet. An excellent flow [x^3] was obtained at 145 feet, another at 176, then no more was found. In all these wells the water is cold, and is found in a white sand and sand rock."

Dr. Scott, of Pottsboro, says that the artesian wells flow great quantities of soft water accompanied by a trace of oil.

Mr. H. Eldridge, who has drilled many of these wells, says: "The stratigraphy is about the same in all of them. What we find in one we generally find in others. The strata of slate or shale between the water reservoirs of sand runs from 10 to 80 and 120 feet in thickness. Between these we find thin rock from 6 inches to 1 foot, with blue sand under the rock from 2 to 10 feet in depth." He reports the following flowing wells:

"Flowing well one-half mile east of Steedman; total depth, 95 feet; water at 80, 91, and 95 feet. A second well 140 feet deep, 1 mile east of Sadler, 15 miles west and 3 miles north of Sherman. Water found at 30, 60, 80, and 130 feet. This well began flowing at a depth of 60 feet, where the x^3 reservoir is reached."

Mr. Eldridge gives the following record of strata (see fig. 78, *C*):

SECTION No. 128.—SECTION OF WELL DRILLED BY H. ELDRIDGE 1 MILE EAST OF SADLER, 15 MILES WEST, 3 MILES NORTH, OF SHERMAN, GRAYSON COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
10. Soil and clay	8	8
9. White, loose sand	12	20
8. Shale	6	26
7. Rock	1	27
6. Sand with water under rock	5	32
5. Shale	43	75
4. White sand (x^3) with water and sandy shale	55	130
3. Water sand at 130 feet 2. Lignite, 2 feet 1. Potters clay	10	140

There is a flowing well, 166 feet in depth, 6 miles west of Pottsboro. Water was struck at 20, 80, 145, and 160 feet. This well is near Big Mineral Creek, just above high-water mark. There is another flowing well, 130 feet in depth, 5 miles west from Pottsboro. This one penetrated 130 feet of clay and shale. The drill broke through shale into the water reservoir, the tools falling about 2 feet. This well is on high ground, certainly near the level of fountain head.

SECTION No. 129.—SECTION OF FLOWING WELL 5 MILES WEST FROM POTTSBORO, REPORTED BY H. ELDRIDGE.

	Thickness.	Depth.
	Feet.	*Feet.*
3. Clay	30	30
2. Shale	100	130
1. Sand	2	132

Dr. L. A. Scott, of Pottsboro, reports a flowing well 7 miles west of Pottsboro which is about 500 feet deep. (See fig. 78, *E*.) Water was struck at 132, 154, and 176 feet. The water from this well was pronounced remarkably pure by the State chemist at Austin.

J. E. Bond, near Cedar Mills, gives the following section showing material penetrated in his well at that place, which is entirely in the Woodbine formation.

SECTION NO. 130.—SECTION OF WELL OF J. E. BOND, AT CEDAR MILLS, GRAYSON COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Red sand, top soil	3	3
3. Ferruginous sandstone	8±	11
2. Alternations of red sand and joint clay	100	111
1. White sand	4	115

Little development seems to have been done in the eastern half of Grayson County in the region underlain by the Austin chalk and later Upper Cretaceous formations. At least we have been able to obtain data concerning such wells only at Sherman in this district, and even these are of a meager nature. The geologic conditions are excellent in this portion of the county for obtaining good nonflowing wells which will rise approximately to within 100 feet of the surface at depths varying from 900 to 2,000 feet.

At Sherman two wells are reported at depths of 613 and 915 feet. From the writer's acquaintance with the geologic formations, he is of the opinion that these figures represent the depths of the upper and lower Woodbine reservoirs x^2 and x^3. In general 600 and 900 feet would approximately represent the depths of those reservoirs below the base of the Austin chalk throughout Grayson County, Sherman being located within a few feet of the base of that formation.

THE RED RIVER COUNTIES.

The group of counties constituting the Red River division of our geologic map (see Pl. LXVI) consists of Black Prairie uplands and timbered stream valleys and bottoms. The Black Prairie upland constitutes a high divide of sublevel or gently rolling agricultural land, which drains northward toward Red River and southward toward Sulphur.

The geologic formation of these counties consists of soft marls, chalks, clays, and occasional sands of the Upper Cretaceous series. The Woodbine formation outcrops irregularly along Red River, as shown upon the map, while the higher formations succeed each other southward, so that along the southern margins of these counties the uppermost layers of the Upper Cretaceous constitute the surface formation. The Cretaceous formations are covered by a deep regolith of rich black soil, which makes it difficult to always determine their exact stratigraphic position.

These counties are underlain by the Lower Cretaceous reservoirs in the Antlers sand representing the combined Trinity and Paluxy, by perhaps some additional arenaceous reservoirs which have developed in the formations of the Washita division in this portion of their extent, and by the Woodbine reservoirs. There can be no doubt that the artesian reservoirs beneath this district are thick and well supplied with water, but the hydrostatic head is lacking to raise these waters to the surface of the high Black Prairies, which stand at an altitude of from 500 to 600 feet above the sea, and are higher than the catchment areas of the underlying artesian reservoirs to the northward in Indian Territory. Hence water will not rise to the surface in the Black Prairie portion of these counties.

Deep artesian well experiments have been made at Clarksville, Paris, Honey Grove, and Bonham, near the center of each of these counties, and the results of these borings are sufficient to show that the available artesian reservoirs are deeply embedded and that the water has not sufficient head to raise it to the surface of the most populous portions of the counties.

It is more than probable that in these counties flowing water may be obtained along the valley of Red River, which is on an average about 200 or 300 feet lower than the high divide above mentioned.

The profiles on Pl. LXVII show the lack of fall in the slope of the surface away from these catchment areas in the Red River counties. The artesian experiments at Bonham, Clarksville, and Paris all show that the waters of the reservoirs when tapped will not rise to the top of the black-land divide between Red River and Sulphur Fork.

LAMAR COUNTY.

From the profiles of the Gulf, Colorado and Santa Fe and St. Louis and San Francisco railways, which run directly north from Paris across the whole outcrop of strata constituting the artesian system, it is evident that the catchment area of the Antlers sands to the northward in Indian Territory is topographically lower in altitude than Paris, and hence flowing wells should not be expected at the latter place. The same can be said of the Woodbine reservoirs, which outcrop along both sides of the valley of Red River.

The Paris Water Works have made a strong endeavor to thoroughly exploit the artesian reservoirs beneath that city, and thanks to Messrs. W. F. Gill and John A. Porter, detailed sections of the drilling and specimens have been supplied the writer. Inasmuch as these data contribute most valuable information concerning the geological formation and underlying artesian reservoirs of the whole belt of Red River counties, the section is published in detail.

SECTION NO. 131.—SECTION OF THE ARTESIAN WELL AT PARIS, TEXAS, 2½ MILES EAST BY SOUTH OF THE CITY. ALTITUDE, 495 FEET. DRILLED FOR THE PARIS WATER WORKS COMPANY.

(See fig. 80.)

	Thickness.	Depth.
	Feet.	*Feet.*
26. Residual soil and sandy clay formation	60	60
25. Pack sand	20	80
24. Blue marl (Eagle Ford)	420	500
23. Lighter colored marl (Eagle Ford)	100	600
22. Gray sand rock (Eagle Ford)	50	650
21. Marl (Woodbine)	125	775
20. Sand rock (Woodbine)	8	783
19. Marl (Woodbine)	175	958
18. Gray sand rock (Woodbine)	25	983
17. Marl (Woodbine)	66	1,049
16. Gray sand rock (Woodbine)	31	1,080
15. Marl (Woodbine)	33	1,113
14. Red sand rock (Woodbine)	52	1,165
13. Red sand mixed with pipe clay (Woodbine)	6	1,171
12. Calcareous sand, almost white (Woodbine)	105	1,276
11. Unrecorded (Woodbine or possibly Denison)	39	1,315
10. Marly lime and sand (Woodbine or possibly Denison)	33	1,348
9. Sand rock (Woodbine or possibly Denison)	39	1,387
8. Loose sand (Woodbine or possibly Denison)	25	1,412
7. Gravel (Woodbine or possibly Denison)	8	1,420
6. Sand Marl with shell casts Ten inches of shell rock Layers of limestone and marl Shell casts in marl Alternating limestone and marl	130	1,550
Unrecorded	100	1,650
5. Grayish friable sandstone (Washita)	35	1,685
4. Impure argillaceous limestone with fossils	15	1,700
3. Impure limestone with *Gryphæa washitaensis*	10	1,710
2. White limestone, resembling Goodland limestone	15	1,725
1. Hard arenaceous limestone with *Pecten* and *Anomia*	+1	1,726

In this well five small water reservoirs were encountered in the first 110 feet. Nearly 500 feet of marls were then passed through, when a strong flow of briny water, which rose to within 110 feet of the surface, was reached. This probably comes from the gray sand rock, No. 22, which is the first sand bed in a series of alternating sands and marls encountered between the depths of 600 and 1,276 feet, and representing in a general way the Woodbine reservoir. This group of strata, 676 feet in thickness, contains six beds of sand. The next water was encountered in the sand bed, No. 20, at a depth of 775 feet. This water was also salty, and rose to within 100 feet of the surface. A third flow in this group of strata was reached at 958 feet. This was also salty, and rose to within 75 feet of the surface. At 1,049 feet in the gray sand rock, No. 16, a fourth flow of water was encountered which was lighter in volume than the others and rose to within 30 feet of the surface. At 1,350 feet a fifth flow of water was reached in this group of strata, which was very strong in volume and rose to within 6 feet of the surface. The quality of this water was unknown, as the salty waters from above were mixed with it. This stratum, No. 9, probably represents the Basement reservoir of the Woodbine formation, which is so prolific of artesian wells to the southward, and water would undoubtedly rise to the surface at points in Lamar County 10 feet lower than the well. Below this water the well penetrated the Washita division of the Comanche series for a distance of 305 feet, and the last core received was from the Goodland limestone, showing conclusively that the well had not penetrated to the deeper and more prolific reservoirs of the Trinity division.

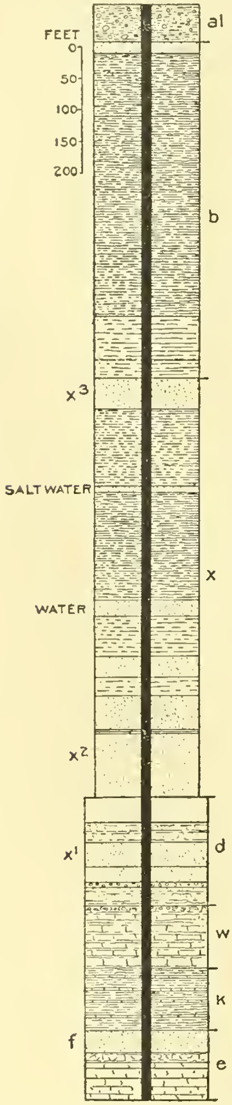


FIG. 80.—Well at Paris, Texas. (For explanation of symbols see Pl. XVI, p. 110.)

Where the well is drilled the ground is about 80 feet lower than the square in the city, and the water from the heavy vein of sand comes to within 5 feet of the surface. The supply is inexhaustible. The well was an experiment. Much caving of the clays occurred. In the light of the experiences of this well, another well should be drilled with proper precautions for cutting off the salty flows of the upper Woodbine reservoirs by casing and continuing at least 300 feet farther into the Trinity reservoirs.

It will be seen from an examination of the log and figure (see fig. 80) that this well struck several artesian reservoirs in the Woodbine formation, and also in the Washita division of the Comanche series. The reservoirs have not heretofore been positively recognized in other wells, although a study of the formations shows that the beds of the Washita division are gradually passing into clays and sands in this direction. The lowest core sent from this well was a piece of limestone which was undoubtedly the Goodland limestone of the Fredericksburg division, showing that the Trinity and Paluxy reservoirs had not yet been penetrated.

At Paris a supply of water is found near the surface in sandy layers of the Upper Cretaceous, but the water does not flow. The following section of the well of the Texas Midland Railway Company at Paris, Texas, kindly furnished by Mr. E. H. R. Green, president of the company, illustrates this shallow reservoir:

Section No. 132.—Section of well of the Texas Midland Railway Company, at Paris, Lamar County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
4. Residual soil, grading into sand and clay	18	18
3. Black sand, water bearing, yielding 12,000 gallons of water a day	15	33
2. Hard barren pack sand	12	45
1. Top of upper portion of the barren joint clays	28	73

RED RIVER COUNTY.

At Clarksville the city corporation four or five years ago made an effort for artesian water. The well was drilled to a depth of 1,050 feet and the water rose to within 10 feet of the top. When water was first struck it is said that it spouted out at the surface, but it quickly subsided to its present position. Clarksville is 442 feet above sea level, and this experiment demonstrates that water will rise in wells in this region to the altitude of 440 feet.

If the pressure of the well was sufficient to cause the water to flow at Clarksville, good flowing wells should be obtained with increasing pressure in the slopes of Red River Valley to the north of the town as one descends toward the river. Mr. S. J. Wright, who owns a well on the bank of Red River opposite the mouth of Kiamitia River, contributes the following data, which may be of value:

The well is 300 feet deep. The surface formation is near the contact of the Upper and Lower Cretaceous. The well was bored in 1892. At 30 feet below the surface soft shell and limestone rock of the

Washita division, about 10 to 15 feet thick, was struck; then came 3 to 6 feet of black gummy clay, impervious to water. This would decompose and harden, and crumble off when brought in contact with air. The shell rock and black clay continued in consecutive alternating strata down to 300 feet without a drop of water; at times it was intermixed with pyrites of iron. At 300 feet the entire formation changed and the hard white pack sand of the Comanche series was found, from which the artesian water rushed up the hole, causing the hard and crumbling clay to cave into the hole and upon the top of the drill, and from this muck he could never extract it.

The source of this water is about 30 miles to the north. The strata dip south under the towns of Paris and Clarksville, 30 miles distant each. This is corroborated by a natural artesian flow bursting out 5 and 6 miles north of the mouth of the Kiamitia, consisting of immense springs, bottomless so far as measured, which come up through fissures. They are five in number, two of which are chalybeate. These flow into Gates Creek, which runs into the Kiamitia River at its mouth.

The locality at which these artesian springs burst forth is enhanced in interest by what are known as the "Witches' Holes." These are perpendicular and slanting openings in the earth upon high ground, disclosing an immense supply of pure, clear, sweet water, always at the same height or elevation, and never varying or freezing, full of fish, and bottomless. If piped, these springs would rise 100 feet from the present level of issue.

FANNIN COUNTY.

In Fannin County, area about 1,000 square miles, several costly well experiments have been made upon the high prairie lands, but few or no details can be secured concerning these experiments. These wells were apparently drilled without scientific direction or consultation of any kind.

The postmaster at Honey Grove states that Honey Grove has a non-flowing artesian well 1,700 feet deep which furnishes plenty of water, but the water is so strongly mineral it can not be used, even for stock, without mixing with pure water.

The postmaster at Ladonia says that several years ago a private stock company was formed and bored an artesian well 1,035 feet deep and did not strike even a "seep." This well should have been continued into the Woodbine reservoir. He states that his own observation is that there are no artesian wells or springs in this community.

At Bonham a well is said to have been drilled 1,500 feet without obtaining water.

The postmaster at Trenton reports an artesian well belonging to J. R. Merritt. No particulars are given, however.

The postmaster at Gover says: "There was an unsuccessful attempt to sink an artesian well 8 miles west of here, but never could get a flow."

G. N. Parker, postmaster at Ivanhoe, near Red River, near the outcrop of the Woodbine formation, says:

> The geological formation in my immediate neighborhood is very peculiar. Wells are from 40 to 80 feet deep in this locality. The water is found in sand or gravel; in a few instances water is found in a slate or soapstone. Some of our wells are sulphurous or brackish; sometimes a well is found whose water is offensive after the well has been used a while. These features of the wells are found occasionally within a few yards of each other. The formation passed through in putting down a well alternates from clay to sand. The sand is full of what we call clay balls, which are round or worn smooth by having been rolled about by running water.

COLLIN COUNTY.

Collin County has an area of 866 square miles. This county presents artesian conditions similar to the Main Texas belt as described in Grayson County. No topographic survey has been made, but the county consists mostly of what is locally described in Texas as high black land prairie of the Eagle Ford, Austin, and Taylor belts, which succeed one another eastward. The White Rock Scarp runs north and south through the county close to its western border. Its summit has an altitude of 850 to 900 feet in this region. From this scarp the country slopes to the east and southeast to about 650 feet at the southeast corner. This sloping upland plain is drained by the north and south ramifying headwaters of the East Fork of Trinity River, which are not indented much over 100 feet beneath the general summit level.

The geologic formations of the county (see Pl. LXVI) consist, in ascending order, of the Eagle Ford formation along its western line, a broad belt of the Austin chalk occupying most of the western half, and the Taylor marls the eastern half. The entire area of the county is underlain by the Woodbine, Paluxy, and Trinity reservoirs. The Woodbine reservoir is embedded at depths of from 300 to 400 feet along the western border to 1,500 feet beneath the surface at the eastern county line. It is approximately 960 feet deep at McKinney, in the central portion of the county. The Paluxy and Trinity reservoirs are much more deeply embedded; the former increases from 1,000 feet beneath the surface along the western boundary to over 2,000 feet at the east. The basement Trinity reservoir must be from 2,200 to 2,500 feet deep at McKinney, in the center of the county. While it is barely possible that flowing wells may be obtained from all these reservoirs in such portions of the county as are below 600 feet in altitude, in most of the area the waters will not rise to the surface.

Schedule of wells in Collin County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water.a	Flowing wells.	Quality.b	Irrigation.a
		Feet.	*Feet.*	*Feet.*				
B. Warner	Frankford, 2 miles southwest from.	442	442	......	50	No.	3	×
......	McKinney	1,860	960	1,150	890	No.	1	....
W. B. Smith	Rockhill, 2 miles west of	370	360	......	300	No.	1	....
A. Machard	Rockhill, 1½ miles northwest of.	395	......	......	300	No.	1, 4, 8	...
M. White	In Big Elm River Flats, 5 miles west of Lebanon.	400	......	......	300	No.	5, 8	...
J. Greenwood	Prosper, ¾ mile east of	660	638	652	416	Yes	1	....
Mr. Shipley	Prosper, ¼ mile from	470	462	......		No.	1	....
J. W. Bryant	Celina	470	460	......	325	No.	1, 4, 8	...
W. H. Butts	Celina, 1 mile west of	400	30	370	300	No.	1	....
H. F. Doyle	Celina, 1½ miles southwest of.	388	375	......	75	No.	1	....

a × = yes.

b 1, Soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil, 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

Only one experimental well has been drilled within the upland area of the main Black Prairie, and this penetrated the Paluxy and Trinity reservoirs. This was at McKinney, the county seat, which has an altitude of 552 feet. A well 1,860 feet deep was bored at this place. The Woodbine reservoir was struck at a depth of 960 feet, the Paluxy at 1,150 feet, and the Trinity reservoirs at 1,860 feet. Soft water was obtained from the latter reservoirs which rose to within 70 feet of the surface, or to an altitude of 482 feet, which is lower than any point in the county.

In that portion of the county lying west of the White Rock Scarp there are many wells from 500 to 600 feet deep which begin in the Eagle Ford clays and secure nonflowing water from the Woodbine reservoirs.

The postmaster at Allen writes: "There are no artesian wells in this neighborhood. But one effort has been made in this community to obtain artesian water. A depth of 1,400 feet was made, but no water was obtained, and the work was abandoned."

The postmaster at Shepton says: "There are no artesian wells in this immediate vicinity. At Renner and Frankford, 3 to 5 miles from Shepton, there are several wells 400 to 500 feet, the water getting farther down as you go east. This is black waxy soil underlain with what is called white rock. The location is near White Rock Creek."

B. Warner, who owns a well 442 feet deep 2 miles southwest of Frankford, says that the drill passed through about 15 feet of clay, the rest being blue shale, until water was struck in sand.

W. H. Butts, who owns a well 400 feet deep 1 mile west of Celina post-office, reports the sinking of a good many wells there, and that the strata seemed to get deeper to the east, perhaps 100 feet to the mile; all soft water.

H. F. Doyle, who owns a well 388 feet deep 1½ miles southwest of Celina, says: "It is 30 feet to slate rock, then after 200 feet get some sand, then harder rock and shale; just above the water there is a hard sand rock 6 or 7 feet thick. Found water in white sand, which was 12 or 15 feet thick."

John Bryant has a well 470 feet deep located in town of Celina, and gives the following section:

Section No. 133.—Section of Well of John Bryant, at Celina.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	6	6
Joint clay	12	18
Dark-gray or black slate	450	468
Sand	2	470

"This is very soft and easily handled. Below this slate you strike a soft sand rock (Woodbine), in which you always find good soft water in inexhaustible quantities. Have drilled many of these wells in Collin and Grayson counties, and find the same thing in all."

Postmaster at Celina says: "Have deep wells, but don't flow. They range from 200 to 480 feet. Have one in our little town 480 feet deep; the water is pumped by windmills."

A. Machard, who owns a well 395 feet deep 1½ miles northwest of Rockhill, says: "After passing through the soil about 15 feet we strike soapstone (clay), and when we get through that we always get plenty of water."

W. B. Smith, who has a well 370 feet deep 2 miles west of Rockhill, gives the following section:

Section No. 134.—Section of well of W. B. Smith 2 miles west of Rockhill, Collin County, Texas.

	Thickness.	Depth.
	Feet.	*Feet.*
Black soil	20	20
Hard slate, with occasional hard rock	2±	22
Sand rock	6±	28
Fine white sand	10	38
Clay	322	360

EASTERN BORDER COUNTIES.

In Hunt, Kaufman, Navarro, Falls, and Milam counties, along the eastern border of the Black Prairie, there are certain peculiar artesian conditions. The Trinity, Paluxy, and other reservoirs of the Comanche series are too deeply embedded to be practically available. The Woodbine reservoirs, however, are available at depths of from 1,500 to 3,000 feet in the counties named, except Falls County.

In general, these counties are sublevel areas of prairie covered with dense black calcareous soil. The round divides seldom rise over 200 feet above the streamways. Geologically they are underlain to depths of from 1,000 to 2,000 feet by the formations of the Upper Cretaceous series, which have a gentle and uniform inclination to the east. On the east they are overlain by the Tertiary formations, the artesian conditions of which are not within the province of this paper.

In each of the counties mentioned deep artesian borings have been made at one or more localities which in a general way demonstrate the artesian conditions mentioned.

The eastern portion of these counties is underlain by local reservoirs composed of the sands of the Navarro formation, which afford the water supply of Terrell. Inasmuch as the outcrop of these reservoirs extends through the eastern half of these counties, they are too slightly embedded to have serious artesian possibilities within the region under discussion, but in the East Texas Timber Belt, to the eastward, they ought to be available for deep-seated wells.

Another important economic feature of this tier of counties is the occurrence of oil and gas in paying quantities in the shales of the Upper Cretaceous series. The oil at Corsicana has proved to be of commercial value and quantity, as will be further described.

HUNT COUNTY.

Hunt County has an area of 720 square miles. It is a typical black prairie country, having little topographic relief other than gently rolling prairie. The highest altitudes are at Celeste (658 feet) and Wolfe (682 feet). The county is underlain by all the Cretaceous artesian reservoirs, but these are at great depths beneath all of it. The Woodbine reservoirs are from 2,000 to 2,500 feet and the Trinity reservoirs from 500 to 1,000 feet deeper; hence no artesian wells could be expected here, except at great depth and expense.

The geologic formations in this county are the Taylor and Navarro beds of the Upper Cretaceous. We have only one imperfect record of an artesian experiment. This is a brief log of a well at Commerce, as given by Mr. H. G. Johnston. The well was a failure from a practical standpoint, and no data were furnished concerning the quantity or rise of water.

SECTION NO. 135.—LOG OF WELL AT COMMERCE, HUNT COUNTY, TEXAS, BY H. G. JOHNSTON.

	Thickness.	Depth.
	Feet.	*Feet.*
Marl	1,550	1,550
Austin chalk	400	1,950
Eagle Ford shale	400	2,350
Woodbine	40	2,390

KAUFMAN COUNTY.

Kaufman County has an area of 825 square miles. Except along the eastern border and in the valley of the Trinity, which forms the southwestern border, the surface is mostly upland black and black sandy prairie. It is underlain by the uppermost Cretaceous formations in the western two-thirds of the county and the Eocene along a belt corresponding to the eastern third. It is underlain by all the artesian reservoirs of the Cretaceous system, but these are very deeply embedded. The Woodbine reservoirs are probably 2.500 feet deep in the longitude of Terrell and Kaufman.

Along the eastern margin of the Black Prairie water is obtained at shallow depths from the arenaceous beds of the uppermost Cretaceous, but this does not rise to the surface.

One costly experiment has been made in this county to determine the availability of the artesian supply. This was the well drilled by the State of Texas at the insane asylum near Terrell to a depth of about 2,500 or 2,600 feet. We have the record of this well to a depth of 2,113 feet, where it was stopped for a time fully 600 feet above the upper Woodbine reservoirs. A newspaper clipping states that this well was afterwards continued to 2,500 feet, and that abundant water, 85,000 gallons per hour, is obtained by deep pumps. As has been the case with all the State wells, no records have been published or are to be procured for the benefit of the public. This well alone cost $30,000.

SECTION NO. 136.—PARTIAL SECTION OF DRILL HOLE AT STATE INSANE ASYLUM AT TERRELL, KAUFMAN COUNTY, TEXAS.

(See Pl. LXIII, *L*.)

	Thickness.	Depth.
	Feet.	*Feet.*
14. Soil	15	15
13. Joint clay	31	46
12. Rock	10	56
11. Sand (Terrell reservoir)	20	76
10. Shales and clay (Navarro)	185	261
9. Soft rock (Navarro)	10	271
8. Blue shale (Navarro)	340	611
7. Rock (Navarro)	8	619
6. Blue shale (Navarro)	484	1,103
5. Rock (Navarro)	8	1,111
4. Blue shale (Taylor)	600	1,711
3. Solid rock (Austin)	195	1,906
2. Lignite (Austin)	12	1,918
1. Lime rock (Austin)	195	2,113

At 1,280 feet traces of gas and oil were seen in probably the same horizon at which oil is obtained at Corsicana. At 1,900 feet the drill passed through 8 feet of lignite and some salt deposits.

The postmaster at Lawndale says that all efforts at getting water have failed. It is a good country but for scarcity of water.

Mr. E. H. Green, president of the Texas Midland Railway Company, has kindly furnished the following section of the well drilled by his company at Terrell. This section illustrates the nature of the water-bearing sands of the Navarro division along the eastern margin of the Black Prairie, which have been previously alluded to as the Terrell or Navarro reservoir.

SECTION NO. 137.—SECTION OF WELL OF THE TEXAS MIDLAND RAILWAY COMPANY AT TERRELL, KAUFMAN COUNTY, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
Black waxy soil grading downward into yellow clay marl	10	10
Bluish pack sand	6	16
Blue pack sand containing small water-yielding layers	34	50
Water-yielding sands	10	60

This well yields 40,000 or 50,000 gallons every twenty-four hours.

The well of M. A. Joy is located in the city of Terrell. It is 173 feet deep; depth to first water, 42 feet; to other waters, 85 and 135 feet. It is nonflowing, but the water rises above level at which it was reached, furnishing 150,000 gallons daily. It contains magnesia.

The well of A. P. Lowrie, 3 miles east of Poetry, is 216 feet deep; depth of first water, 70 feet; to other waters, 126 feet. It is nonflowing, but the water rises 136 feet and furnishes plenty of good, wholesome water. Calvin Dorsey, well driller, gives the following section:

SECTION NO. 138.—SECTION OF WELL OF A. P. LOWRIE, 3 MILES EAST OF POETRY, KAUFMAN COUNTY, TEXAS, BY CALVIN DORSEY.

	Thickness.	Depth.
	Feet.	*Feet.*
Joint clay	65	65
Black clay	70	135
Gray sand rock	.5	135.5
Black clay	78	213
Gray sand rock	3	216
Water that rose 100 feet		

The well of J. A. C. Howell, situated in town of Poetry, is 110 feet deep; depth of first water, 30 feet; to other waters, 40 feet. It is nonflowing. The water is used for running steam gin. Calvin Dorsey, the driller, gives the following section:

SECTION NO. 139.—SECTION OF WELL OF J. A. C. HOWELL, AT POETRY, KAUFMAN COUNTY, TEXAS, BY CALVIN DORSEY.

	Thickness.	Depth.
	Feet.	*Feet.*
Joint clay	20	20
Black clay	9	29
Water in sand		
Black clay	40	69
Sand rock with water	1	70
Black clay rest of the way	40	110

James Gale reports that his well is located 350 yards from Tona post-office. It is 160 feet deep; is nonflowing, the water rising about 130 feet. The water is soft, and any quantity can be obtained. After passing through the siliceous rock the shaft dropped 14 feet in water below rock.

SECTION NO. 140.—SECTION OF WELL OF JAMES GALE, AT TONA, TEXAS.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	30	30
Yellow joint clay	90	120
Black clay	20	140
Rock, gray sandstone	9	149
Black waxy clay	10	159
Rock, siliceous	1	160

The postmaster at Colquitt informs the writer that they can not get water there unless they go about 200 or 300 feet, and then it is always limy or has a brackish taste and can not be used for drinking purposes.

No returns have been received from the southern half of the county.

Schedule of wells in Kaufman County, Texas.

Owner.	Location.	Total depth.	Depth to first water.	Other waters.	Rise of water. *a*	Flowing wells.	Quality. *b*
		Feet.	*Feet.*	*Feet.*			
L. Mason	Poetry, 4 miles from	145	60	....	10 feet from top.	No.	2
A. P. Lowrie	Poetry, 3 miles east of	216	70	126	136	No.	2
J. A. C. Howell	Poetry	110	30	40	×	No.	2
E. H. R. Green	Tona, 300 feet northeast of post-office.	150	....	....	....	No.	1
J. Gale	Tona post-office, 350 yards south of,	160	....	....	130	No.	1
M. A. Joy	Terrell	173	42	{ 85 135 }	×	No.	......
C. Dorsey	......do	100	40	30	....	No.	......
Insane asylum well	Near Terrell	2,600	....	....	....	No.	......

a × = yes.
b 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, contains alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

NAVARRO COUNTY.

Navarro County has an area of 1,030 square miles. The surface consists entirely of gently rolling black prairie varying in altitude from 640 feet at Frost, near the western corner of the county, to about 300 feet along the valley of the Trinity, which constitutes the eastern border.

The surface formations consists mostly of the sands and clays of the Navarro division of the Upper Cretaceous along the eastern margin of the county and the Taylor marls and Austin chalk in the western portion. The county is underlain by the Trinity, Paluxy, and Woodbine reservoirs. The latter alone need be considered in relation to artesian water, inasmuch as it contains an abundant supply, while the Paluxy and Trinity reservoirs are too deeply embedded to be available. The top of the Woodbine reservoir at the western corner of the county is about 1,000 feet below sea level. At Corsicana it is 2,500 feet, and at the eastern corner of the county probably 3,000 feet.

Deep wells drilled at Corsicana have demonstrated the character of the strata and the availability of the water supply. We have reports of three flowing artesian wells at Corsicana and one 3 miles west of the city. The following section of the second well drilled in Corsicana is furnished by Mr. H. G. Johnson.

SECTION NO. 141.—SECTION OF ARTESIAN WELL NO. 2, AT CORSICANA, TEXAS, DRILLED BY H. G. JOHNSON, COMPLETED DECEMBER, 1895.

(See Pl. LIX, *P*.)

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy marl and clay	1,050	1,050
Marl and clay	500	1,550
Chalky blue and white limestone	430	1,980
Blue-black shale	420	2,400
Water-bearing sand (Woodbine)	60	2,460
Blue clay	27	2,487
Sand	8	2,495
Shale	20	2,515

This well flows 280,000 gallons per day, and has a pressure of 38 pounds. The temperature of the well is 126° F.

Judging from the sections of the Woodbine formation in the wells in Hill County to the westward, the Corsicana wells do not entirely penetrate that formation, but derive their waters from the upper reservoirs. The upper 1,550 feet of this well represent the combined Navarro and Taylor formations. In the first well oil was encountered at 1,040 feet, but no oil was met with in well No. 2. The discovery of oil in the first well led to the sinking of numerous wells to the oil horizon in the vicinity of Corsicana, and this Survey, through the agency of Mr. James L. Autry, employed a driller to keep a minute section of one of the oil wells.[1] This section, made up from specimens

[1] It is not within the province of this paper to discuss oil wells. At Corsicana 642 oil wells had been drilled up to the close of 1899, producing about 1,282,869 barrels of oil. The production of the Corsicana oil fields is fully treated in the annual reports on Mineral Resources published by this Survey.

taken at intervals of 10 feet, gives the exact character of the strata of the upper 1,050 feet of the deep wells. It is as follows:

Section No. 142.—Section of an oil well of the American Well and Prospecting Company, Lot 1, Block 42, City of Corsicana.

	Depth. Feet.
Light-colored clay free from grit; gypsum, small quartz pebbles, jasper; pebble very fine and scarce	35
Fine unctuous light-gray clay, same as preceding; no grit	45
Do	55
Do	65
Fine-grained sand; white quartz and glauconite. One small pebble of feldspar.	75
Do	85
Black sandy clay, small jasper and quartz fragments and pieces of nacreous fossils. Pebble very fine and scarce	95
Do	105
Black sandy clay, small jasper and quartz fragments and pieces of nacreous fossils. Pebble very fine and scarce; angular piece of broken flint, small fossils, more glauconite than in preceding	115
Black sandy clay, small jasper and quartz fragments and pieces of nacreous fossils. Pebble very fine and scarce; a little clay and less glauconite	125
Exceedingly fine-grained sand, glauconite, becoming rare; light-gray color	135
Do	145
Still light gray and very fine sand	155
Do	165
Do	175
Do	185
Sandy clay, dark-gray color, very little grit	195
Do	205
Laminated clays and sediments accompanied by very fine grit	215
Laminated clays and sediments accompanied by very fine grit; trace of fossil shell	225
Do	235
Laminated clays and sediments accompanied by very fine grit; trace of fossil shell; stiff argillaceous clay with shells; blackish-gray color, slight grit, continuation of preceding	245
As above, less grit, slightly lighter color	255
Arenaceous clay, sand, very fine and about equal proportions with the clay	265
Arenaceous clay, sand, very fine and about equal proportions with the clay; exceedingly fine grit	275
Do	285
Arenaceous clay, sand, very fine and about equal proportions with the clay; exceedingly fine grit; nacreous shell fragments	295
Arenaceous clay, sand, very fine and about equal proportions with the clay; exceedingly fine grit; nacreous shell fragments; grit decreasing	305
Arenaceous clay	315
Arenaceous clay; shell fragments	325
Do	335
Do	345
Arenaceous clay; shell fragments; clay increasing in proportion to grit	355
Arenaceous clay; shell fragments; clay increasing in proportion to grit; still gritty glauconitic clays	365
Do	375

	Depth. Feet.
Arenaceous clay; shell fragments; clay increasing in proportion to grit; still gritty glauconitic clays; grit decreasing	385
Clay	395
Clay; slightly gypsiferous	405
Clay; slightly gypsiferous; grit decreasing	415
Clay; slightly gypsiferous; grit decreasing; grit almost imperceptible	425
Blue clays, grit almost imperceptible	435
Lumpy clay, one fine grain of gravel	445
Gritty clay	455
Do	465
Do	475
Do	485
Do	495
Do	505
Do	515
Do	525
Clays continue; a very little grit	535
Do	545
Flaky clays, still gritty	555
Gritty clays	565
Do	575
Do	585
Purer clays; grit almost imperceptible	595
Do	605
Clays; barest suspicion of grit	615
Do	625
Do	635
A little more grit	645
Grit almost imperceptible	655
Fine, greasy, black clay; bituminous, very earthy and loamy	665
Do	675
Do	685
Fine, greasy, black clay, bituminous, very earthy and loamy; lighter colored; no grit	695
Decided change to light-colored clays again; free from grit	705
Light-gray clays; free from grit	715
Do	725
Do	735
Do	745
Do	755
Change to black, slightly arenaceous, earthy clay again	765
Do	775
Lighter-colored clay again	785
Bituminous black earth again; very little grit	795
Do	805
Lighter clays; no bituminous matter	815
Lumpy clays, getting dark again	825
Lighter joint clays	835
Do	845
Gritty, light-colored clays	855
Do	865
Light slate-colored clays; slightly gritty	875

	Depth. Feet.
Light clays; very slightly gritty	885
Do	895
Do	905
Do	915
Very little grit	925
Clays slightly darker in color, slate color; slightest possible grit	935
Do	945
Bituminous, earthy clay again	955
Light slate-colored clay again; barest trace of grit	965
Do	975
Darker-colored clay, slightly bituminous; laminated	985
Do	995
Laminated, dark-colored clay	1,005
Clays slightly lighter in color	1,015
Decidedly arenaceous	1,020
Do	1,025
Decidedly arenaceous clay	1,035
Fine arenaceous material increasing	1,040
Arenaceous clay material	1,045
Bluish clays; less gritty	1,050

A careful study of these sample borings will show that the clays are all of a sandy and arenaceous nature, distinguishing the Navarro formation from the Taylor formation, thereby contributing valuable knowledge concerning the thickness of these two formations in this portion of Texas.

The well at the Orphans' Home, 3 miles west of Corsicana, is 2,300 feet in depth. Similar wells should be obtained throughout this county to the west of Corsicana at constantly decreasing depths.

Schedule of wells in Navarro County.

Owner.	Exact location.	Total depth.	Surface formation.	Water formation.	Flowing well.	Irrigation.
J. E. Whiteselle	In Corsicana	2,487	G.	x	Yes.	No.
Corsicana Water Co	In Corsicana (2 wells)	2,477	G.	x	Yes.	......
Orphans' Home	3 miles west of Corsicana	2,300	G.	x	Yes.	......

FALLS COUNTY.

This county has an area of 770 square miles. The relief consists of an upland plain, as shown in the western portion, which has been intensely dissected by the broad and deeply cut valley of the Brazos River. The extreme eastern portion of the county lies within the Tertiary area, a central north-south belt is occupied by alluvial formations of the Brazos Valley, and the western half is typical black Cretaceous prairie, underlain by the Navarro and Taylor formations of the Upper Cretaceous series.

The county is underlain by the Trinity and Paluxy reservoirs, which are deeply embedded at depths of from 2,000 feet on the western border of the county to 4,000 feet on the eastern. So far as we can ascertain, only one artesian experiment has been made in this county, but this is one of the most important and instructive artesian drillings in the Black Prairie region, as well as one of the deepest artesian wells in the United States. This well is situated at Marlin, altitude 394 feet above sea level, and is 3,330 feet in depth. The well was drilled by the city at a cost of $30,000. It flows about 80,000 gallons of water a day, having a temperature of 147° F. and a pressure of 97 pounds to the square inch.

The water is mineral in character (see analysis, p. 448) and is used for medicinal and advertising purposes. This well penetrates nearly the entire Cretaceous series. Like many other great undertakings of the kind in Texas, no accurate section of this well was kept. H. G. Johnson, who drilled it, has kindly furnished the following brief log:

SECTION NO. 143.—SECTION OF DEEP WELL AT MARLIN, FALLS COUNTY, TEXAS, FROM NOTES BY H. G. JOHNSON, WELL DRILLER.

(See Pl. LVIII, *P*.)

	Thickness.	Depth.
	Feet.	*Feet.*
Blue marl (Navarro and Taylor)	1,150	1,150
Chalky limestone (Austin)	200	1,350
Blue clay (Eagle Ford)	100	1,450
Limestone (Buda and Del Rio)	125	1,575
Blue clay (Buda and Del Rio)	77	1,652
White limestone (Georgetown and Edwards)	338	1,990
Shelly limestone and clay (Walnut)	200	2,190
Limestones (Glen Rose)	1,000	3,190
A little sand, first flow	10	3,200
Shaly limestone (Trinity?)	100	3,300
Sand, with water	20 to 30	3,330

MILAM COUNTY.

Only the western half of Milam County lies within the Cretaceous area, and the artesian reservoirs are embedded from 2,000 to 5,000 feet beneath this county, and hence are practically unavailable. In the eastern portion of the county artesian wells are obtained from the Tertiary series, but these do not lie within the province discussed in this paper. At Thorndale, on the western border of the county, a costly artesian experiment was made. A hole drilled 1,700 feet was entirely through the blue marls of the Upper Cretaceous, not even reaching the Austin chalk.

Schedule of wells in Milam County, Texas.

Owner.	Exact location.	Total depth.	Depth to first water.	Depth to other waters.	Rise of water.	Flowing wells.	Quality. *a*	Irrigation.
		Feet.	*Feet.*	*Feet.*				
W. S. Caruthers	Thorndale	1,790						
A. E. Brady	Maysfield	1,356	850	1,150	×		1, 3	
T. J. Estes	Baileyville, 3½ miles west of.	831	500 and 600		×	No.	3	No.
A. J. Raymond	Branchville, 300 yards of.	700	250		×	No.	1	No.
J. A. Peele	Branchville, 4 miles east of.	530	200	320				No.

a 1, soft and potable; 2, hard; 3, salty; 4, contains sulphur; 5, contains iron; 6, contains oil; 7, contains lime; 8, contains soda; 9, alkali; 10, contains potash; 11, contains alum; 12, contains magnesia.

AREAS OF THE COUNTIES OF THE BLACK AND GRAND PRAIRIES, AND ALTITUDES THEREIN.

AREAS OF COUNTIES.

County	Square miles.	County	Square miles.	County	Square miles.
Bell	1,093	Grayson	960	Montague	976
Bosque	1,007	Hamilton	849	Navarro	1,030
Burnet	992	Hill	986	Parker	866
Collin	866	Hood	424	Red River	900
Comanche	954	Hunt	870	Rockwall	151
Cooke	928	Johnson	725	Somervell	191
Coryell	1,065	Kaufman	825	Tarrant	897
Dallas	859	Lamar	900	Travis	1,040
Denton	972	Lampasas	723	Williamson	1,148
Ellis	965	Limestone	954	Wise	893
Erath	1,091	McLennan	1,055		
Falls	770	Milam	1,036	Total	31,597
Fannin	940	Mills	696		

ALTITUDES, ARRANGED BY COUNTIES.

	Feet.
Brown County:	
Blanket	1,601
Brownwood	1,343
Indian Mountain	1,600
Zephyr	1,501
Burnet County:	
Bald Mountain	1,239
Bertram	1,268
Burnet	1,295
Fairland	980
Granite Mountain	877
Marble Falls	771
Niggerhead Peak	1,313
Burnet County—Continued.	
Post Mountain	1,556
Potato Top Peak	1,570
Collin County:	
Allen	664
Anna	719
Copeville	551
Farmersville	636
Josephine	619
McKinney	612
Melissa	692
Nevada	648
Plano	692

	Feet.
Collin County—Continued.	
Renner	702
Wylie	546
Comanche County:	
Comanche	1,358
Fleming	1,296
Proctor	1,209
Brazos County:	
Bryan	371
College Station	350
Millican	300
Wellborn	322
Cooke County:	
Gainesville	730
Lindsay	786
Muenster	964
Myra	916
Valley View	712
Woodbine	762
Coryell County:	
Coperas Cove	1,092
Gatesville	795
Dallas County:	
Carrollton	441
Coppell	550
Dallas	422
Duncanville	729
Eagle Ford	432
Farmers Branch	458
Garland	536
Grand Prairie	519
Hutchins	470
Lancaster	519
Letot	436
Mesquite	483
Oak Cliff	450
Reinhardt	537
Richardson	632
Rowlett	503
Sachse	545
Trinity Mills	452
Wilmer	475
Denton County:	
Argyle	662
Aubrey	681
Denton	621
Garza	579
Justin	642
Krum	718
Lewisville	477
Mustang	717
Pilotpoint	683
Ponder	733
Roanoke	651
Sanger	664
Erath County:	
Bluffdale	880
Dublin	1,466
Harbin	1,282
Immermere	1,067
Stephenville	1,283
Falls County:	
Gurley	382
Lott	522
Marlin	394
Reagan	385
Rosebud	391
Travis	455
Fannin County:	
Bailey	602
Bonham	566
Dial	500
Dodd	669
Ector	650
Honey Grove	660
Ladonia	620
Leonard	708
Randolph	559
Trenton	754
Windom	692
Grayson County:	
Bells	674
Choctaw	577
Collinsville	750
Cook's Springs	600
Denison	723
Howe	858
Kentuckytown	706
Marshalls Bluff	700
Pottsboro	761
Preston, on Red River, northwest of Denison	575
Sherman	720
Southmayd	735
Tioga	671
Tom Bean	712
Van Alstyne	803
Whitesboro	784
Whitewright	744
Summit of Iron Ore Knobs, near Aylshire switch	900
Hamilton County:	
Hico	1,007
Star Mountain	1,600
Hill County:	
Abbott	710
Blum	582
Hillsboro	627
Hubbard	638
Itasca	711

	Feet.
Hill County—Continued.	
Kerby	715
Lakenon	702
Mertens	544
Mountcalm	598
Hood County:	
Comanche Peak	1,200
Cresson	1,049
Granbury	698
Tolar	1,013
Hunt County:	
Caddo Mills	529
Campbell	369
Celeste	658
Commerce	558
Dixon	502
Fairlie	589
Greenville	552
Kingston	631
Lone Oak	555
Merit	646
Neyland	592
Quinlan	519
Roberts	495
Wolfe	682
Johnson County:	
Alvarado	700
Burleson	715
Cleburne	758
Egan	838
Godley	903
Grandview	702
Joshua	924
Rio Vista	795
Venus	660
Kaufman County:	
Elmo	496
Forney	465
Kaufman	448
Lawrence	462
Rosser	368
Scurry	446
Terrell	509
Lamar County:	
Ambia	544
Arthur	473
Blossom	530
Brookston	588
High	579
Howland	505
Paris	567
Petty	612
Roxton	499
Lampasas County:	
Castle Peak	1,552

	Feet.
Lampasas County—Continued.	
Flat Top Peak	1,541
Kempner	879
Kinchelo Peak	1,433
Lampasas	1,026
Lometa	1,489
Limestone County:	
Groesbeck	480
Kosse	503
Mexia	537
Thornton	499
McLennan County:	
Axtell	534
Bruceville	598
Crawford	687
Eddy	682
Elm Mott	527
Hewitt	654
Lorena	600
McGregor	713
Moody	783
Norwood	388
Ritchie	672
South Bosque	540
Waco	400
West	645
Milam County:	
Benarnold	392
Buckholts	523
Burlington	421
Cameron	393
Gause	376
Milano	497
Minerva	399
Rockdale	469
Mills County:	
Antelope Gap	1,488
Goldthwaite	1,581
Mullin	1,431
Montague County:	
Bonita	929
Bowie	1,113
Nocona	930
Ringgold	886
St. Jo	1,146
Stoneburg	930
Sunset	982
Navarro County:	
Angus	447
Barry	513
Corsicana	426
Dawson	493
Frost	535
Kerens	376
Mann	450

Navarro County—Continued.	Feet.
Powell	390
Purdon	405
Rice	473
Richland	377
Palo Pinto County:	
Brazos	800
Gordon	955
Strawn	991
Wolf Mountain	1,300
Parker County:	
Aledo	873
Anneta	846
Lambert	1,135
Millsap	811
Parsons	1,174
Reno	545
Weatherford	1,010
Red River County:	
Anona	370
Bagwell	476
Clarksville	442
Davenport	806
Detroit	482
Rockwall County:	
Fate	577
Rockwall	545
Royse City	547
San Saba County:	
San Saba Peak	1,712
Round Mountain	1,835
Tarrant County:	
Arlington	607
Benbrook	657
Crowley	764
Ferguson	348
Fort Worth	599
Grapevine	670
Handley	581
Haslet	693
Keller	703
Kennedale	600
Mansfield	587

Tarrant County—Continued.	Feet.
Saginaw	719
Smithfield	679
Watauga	605
Webb	630
Travis County:	
Austin	480
Beecaves	960
Carl	357
Cedar Valley	1,081
Creedmoor	638
Garfield	494
Littig	465
McNeil	835
Manchaca	705
Manor	537
Oakhill	814
Post Oak Ridge	1,250
Watters	707
Webberville	406
Williamson County:	
Bartlett	611
Cedarpark	820
Circleville	537
Coupland	526
Georgetown	753
Granger	539
Leander	980
Libertyhill	1,040
Roundrock	720
Taylor	556
Wise County:	
Alvord	860
Boyd	714
Bridgeport	749
Chico	938
Cowen	862
Decatur	1,047
Newark	688
Paradise	749
Park Springs	952
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ADVERTISEMENT.

[Twenty-first Annual Report, Part VII.]

The statute approved March 3, 1879, establishing the United States Geological Survey, contains the following provisions:

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization; and the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

Except in those cases in which an extra number of any special memoir or report has been supplied to the Survey by resolution of Congress, or has been ordered by the Secretary of the Interior, this office has no copies for gratuitous distribution.

ANNUAL REPORTS.

I. First Annual Report of the United States Geological Survey, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Second Annual Report of the United States Geological Survey, 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 62 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883–'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

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XVI. Sixteenth Annual Report of the United States Geological Survey, 1894–'95, Charles D. Walcott, Director. 1895. (Part I, 1896.) 8°. 4 pt. xxii, 910 pp., 117 pl. and maps; xix, 598 pp., 43 pl. and maps; xv, 646 pp., 23 pl.; xix, 735 pp., 6 pl.

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MONOGRAPHS.

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II. Tertiary History of the Grand Cañon District, with Atlas, by Clarence E. Dutton, Capt., U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.00.

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Each folio contains topographic, geologic, economic, and structural maps, together with textual descriptions and explanations, and is designated by the name of a principal town or of a prominent natural feature within the district.

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Under the law a copy of each folio is sent to certain public libraries and educational institutions. The remainder are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly. Prepayment is obligatory. The folios ready for distribution are here listed.

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
1	Livingston	Montana	110°–111°	45°–46°	3,354	25
2	Ringgold	Georgia, Tennessee	85°–85° 30′	34° 30′–35°	980	25
3	Placerville	California	120° 30′–121°	38° 30′–39°	932	25
4	Kingston *a*	Tennessee	84° 30′–85°	35° 30′–36°	969	25
5	Sacramento	California	121°–121° 30′	38° 30′–39°	932	25
6	Chattanooga *a*	Tennessee	85°–85° 30′	35°–35° 30′	975	25
7	Pikes Peak *a*	Colorado	105°–105° 30′	38° 30′–39°	932	25
8	Sewanee	Tennessee	85° 30′–86°	35°–35° 30′	975	25
9	Anthracite-Crested Butte. *a*	Colorado	106° 45′–107° 15′	38° 45′–39°	465	50
10	Harpers Ferry	Virginia, West Va, Maryland	77° 30′–78°	39°–39° 30′	925	25
11	Jackson	California	120° 30′–121°	38°–38° 30′	938	25
12	Estillville	Virginia, Kentucky, Tennessee	82° 30′–83°	36° 30′–37°	957	25
13	Fredericksburg	Maryland, Virginia	77°–77° 30′	38°–38° 30′	938	25
14	Staunton	Virginia, West Va	79°–79° 30′	38°–38° 30′	938	25
15	Lassen Peak	California	121°–122°	40°–41°	3,634	25
16	Knoxville	Tennessee, N. Carolina	83° 30′–84°	35° 30′–36°	925	25
17	Marysville	California	121° 30′–122°	39°–39° 30′	925	25
18	Smartsville	California	121°–121° 30′	39°–39° 30′	925	25
19	Stevenson	Alabama, Georgia, Tennessee	85° 30′–86°	34° 30′–35°	980	25
20	Cleveland	Tennessee	84° 30′–85°	35°–35° 30′	975	25
21	Pikeville	Tennessee	85°–85° 30′	35° 30′–36°	969	25
22	McMinnville	Tennessee	85° 30′–86°	35° 30′–36°	969	25

a Out of stock.

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
23	Nomini	Maryland. / Virginia	76° 30′–77°	38°–38° 30′	938	25
24	Three Forks	Montana	111°–112°	45°–46°	3,354	50
25	Loudon	Tennessee	84°–84° 30′	35° 30′–36°	969	25
26	Pocahontas	Virginia / West Va	81°–81° 30′	37°–37° 30′	951	25
27	Morristown	Tennessee	83°–83° 30′	36°–36° 30′	963	25
28	Piedmont	Maryland. / West Va	79°–79° 30′	39°–39° 30′	925	25
29	Nevada City:					
	Nevada City	California	121° 00′ 25″–121° 03′ 45″	39° 13′ 50″–39° 17′ 16″	11.65	50
	Grass Valley	California	121° 01′ 35″–121° 05′ 04″	39° 10′ 22″–39° 13′ 50″	12.09	50
	Banner Hill	California	120° 57′ 05″–121° 00′ 25″	39° 13′ 50″–39° 17′ 16″	11.65	50
30	Yellowstone National Park: Gallatin, Canyon, Shoshone, Lake'	Wyoming	110°–111°	44°–45°	3,412	75
31	Pyramid Peak	California	120°–120° 30′	44°–45°	932	25
32	Franklin	Virginia / West Va	79°–79° 30′	38° 30′–39°	932	25
33	Briceville	Tennessee	84°–84° 30′	36°–36° 30′	963	25
34	Buckhannon	West Va	80°–80° 30′	38° 30′–39°	932	25
35	Gadsden	Alabama	86°–86° 30′	34°–34° 30′	986	25
36	Pueblo	Colorado	104° 30′–105°	38°–38° 30′	938	50
37	Downieville	California	120° 30′–121°	39° 30′–40°	919	25
38	Butte Special	Montana	112° 29′ 30″–112° 36′ 42″	45° 59′ 28″–46° 02′ 54″	22.80	50
39	Truckee	California	120°–120° 30′	39°–39° 30′	925	25
40	Wartburg	Tennessee	84° 30′–85°	36°–36° 30′	963	25
41	Sonora	California	120°–120° 30′	37° 30′–38°	944	25
42	Nueces	Texas	100°–100° 30′	29° 30′–30°	1,035	25
43	Bidwell Bar	California	121°–121° 30′	39° 30′–40°	918	25
44	Tazewell	Virginia / West Va	81° 30′–82°	37°–37° 30′	950	25
45	Boise	Idaho	116°–116° 30′	43° 30′–44°	864	25
46	Richmond	Kentucky	84°–84° 30′	37° 30′–38°	944	25
47	London	Kentucky	84°–84° 30′	37°–37° 30′	950	25
48	Tenmile District Special.	Colorado	106° 8′–106° 16′	39° 22′ 30″–39° 30′ 30″	55	25
49	Roseburg	Oregon	123°–123° 30′	43°–43° 30′	871	25
50	Holyoke	Mass / Conn	72° 30′–73°	42°–42° 30′	885	50
51	Big Trees	California	120°–120° 30′	38°–38° 30′	938	25
52	Absaroka: Crandall, Ishawooa	Wyoming	109° 30′–110°	44°–44° 30′	1,706	25
53	Standingstone	Tennessee	85°–85° 30′	36°–36° 30′	963	25
54	Tacoma	Washington	122°–122° 30′	47°–47° 30′	812	25
55	Fort Benton	Montana	110°–111°	47°–48°	3,273	25
56	Little Belt Mts	Montana	110°–111°	46°–47°	3,295	25
57	Telluride	Colorado	107° 45′–108°	37° 45′–38°	236	25
58	Elmoro	Colorado	104°–104° 30′	37°–37° 30′	950	25
59	Bristol	Virginia / Tennessee	82°–82° 30′	36° 30′–37°	957	25
60	La Plata	Colorado	108°–108° 15′	37° 15′–37° 30′	237	25
61	Monterey	Virginia / West Va	79° 30′–80°	38°–38° 30′	938	25
62	Menominee Special	Michigan	(a NW.-SE. area, about	22 m. long, 6½ wide)	150	25
63	Mother Lode	California	(a NW.-SE. rectangle,	70 m. long, 6¾ wide)	455	50
64	Uvalde	Texas	99° 30′–100°	29°–29° 30′	1,040	25
65	Tintic Special	Utah	111° 55′–112° 10′	39° 45′–40°	229	25
66	Colfax	California	120° 30′–121°	39°–39° 30′	925	25
67	Danville	Illinois / Indiana	87° 30′–87° 45′	40°–40° 15′	228	25
68	Walsenburg	Colorado	104° 30′–105°	37° 30′–38°	944	25
69	Huntington	West Va / Ohio	82°–82° 30′	38°–38° 30′	938	25
70	Washington	Maryland / Dist. of Columbia / Virginia	76° 45′–77° 15′	38° 45′–39°	465	50
71	Spanish Peaks	Colorado	104° 30′–105°	37°–37° 30′	950	25