TEXAS WATER COMMISSION

BULLETIN 6216

GEOLOGY AND GROUND-WATER RESOURCES OF KINNEY COUNTY, TEXAS

Prepared in cooperation with the U. S. Geological Survey

December 1962

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OF KINNEY COUNTY, TEXAS

By

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United States Geological Survey

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GEOLOGY AND GROUND-WATER RESOURCES OF KINNEY COUNTY, TEXAS

ABSTRACT

Kinney County is in southwestern Texas, near the west end of the Balcones fault zone. This zone is underlain in part by the Edwards and associated limestones, one of the most productive water-bearing reservoirs in the State. The primary purpose of the investigation in Kinney County was to obtain data on the occurrence of water in this reservoir. Most of the fieldwork was done in 1938-40, but the periodic collection of hydrologic data continued into 1957. The report contains records of 304 wells and 5 springs, drillers' logs of 9 wells, periodic water-level measurements in 28 wells, and chemical analyses of 134 water samples obtained from wells and springs.

Kinney County has an area of 1,391 square miles and in 1950 had a population of 2,668. The climate is semiarid, the average annual precipitation being 22 inches. The northern half of the county is a part of the Edwards Plateau whereas the southern half of the county is a part of the Coastal Plain. The county is drained by the Rio Grande and the Nueces Rivers. Most of the streams are intermittent, but several are perennial.

The county is underlain by a sequence of sedimentary rocks of Cretaceous age. The Glen Rose limestone of the Trinity group of the Comanche series is the oldest formation exposed. It is overlain successively by the Walnut(?) clay, Comanche Peak limestone, Edwards limestone, and Kiamichi formation of the Fredericksburg group, and the Georgetown limestone, Grayson shale, and Buda limestone of the Washita group. Overlying the Comanche series, in ascending order, are the following formations: the Eagle Ford shale and Austin chalk of the Gulf series; the Upson clay, Anacacho limestone, and San Miguel formation of Taylor age; and the Olmos and Escondido formations of the Navarro group. The Uvalde gravel of Pliocene(?) age and the Leona formation and stream alluvium of Quaternary age are present at the surface at places in the county. The Cretaceous or Tertiary igneous rocks, which are nearly all basaltic, have had only a local effect on the sedimentary rocks.

The Cretaceous sedimentary rocks dip south and generally thicken downdip. Most of the formations also thicken to the west, reflecting synclinal deposition in the Rio Grande embayment. In Kinney County, movements in the Balcones fault zone were relatively small, and although there are a large number of small faults, the displacement was formed chiefly by downwarping of the strata. Many small flexures were noted.

The Edwards limestone together with the underlying Comanche Peak limestone and the overlying Kiamichi formation and Georgetown limestone form the major ground-water reservoir, yielding water for domestic, livestock, municipal, and irrigation use. Supplies large enough for irrigation also are obtained in a few places from wells in the Austin chalk and Eagle Ford shale where these formations crop out. The Anacacho limestone, Escondido formation, Uvalde gravel, and stream alluvium yield small supplies to wells.

Recharge to the Edwards and associated limestones is from rainfall on the Edwards Plateau. In the valleys of the West Nueces River and Liveoak Creek, where the streams have cut through the water-bearing limestones into the relatively impermeable Glen Rose limestone, the water table intersects the land surface and the water issues from springs. Downstream, where the streams again flow over the Edwards and associated limestones, the water sinks back into the ground.

No direct method was available for estimating the recharge to the Edwards and associated limestones in Kinney County. It was possible, however, to estimate the recharge to the reservoir in the basin of the West Nueces River by comparing streamflow records for the West Nueces River and the Nueces River in adjoining Uvalde County. The average annual recharge in the basin of the West Nueces River was computed to be roughly 1.4 inches, or about 70,000 acre-feet over the entire basin. The average annual discharge from springs during 1955-56 is estimated to have been about 15,000 acre-feet, and the average annual discharge from wells during the same period was about 4,000 acre-feet. Recharge to the ground-water reservoir greatly exceeds discharge in Kinney County, the water representing the difference being discharged outside the county.

Contour maps of the water surface in the ground-water reservoir for 1937-40 and for 1952 and 1956 show a ground-water divide approximately at the longitude of Brackettville. East of Brackettville the contours indicate that the water moves southeastward and eastward into Uvalde County; west of Brackettville the contours indicate that the water moves southwestward toward the Rio Grande.

The discharge of Las Moras Spring responds rather promptly to rainfall in the northeastern part of the county but is less responsive to rainfall in the north-central and northwestern parts of the county.

Chemical analyses of water samples from wells and springs indicate that the water from the Edwards and associated limestones in the northern part of the county is of good quality and that the water in the southern part of the county may be charged with hydrogen sulfide or may be too highly mineralized for most uses.

GEOLOGY AND GROUND-WATER RESOURCES OF KINNEY COUNTY, TEXAS

INTRODUCTION

Purpose and Scope of the Investigation

The investigation of the geology and ground-water resources of Kinney County, Texas, is part of the general program begun in 1929 by the U. S. Geological Survey in cooperation with the Texas Board of Water Engineers [now the Texas Water Commission] to investigate the ground-water resources of Texas.

Kinney County is near the western end of the Balcones fault zone which extends from north of Austin southwestward to San Antonio and thence westward to Del Rio. (See Figure 1.) This fault zone is nearly coextensive with a belt that is underlain by one of the most productive ground-water reservoirs in the State--the Edwards and associated limestones. The most obvious manifestation of the reservoir--the series of large springs extending from Goodenough Springs near Comstock in Val Verde County to Barton Springs near Austin--was an important factor in determining the locations of the more important towns and cities in the area. The springs form the settings for a series of beautiful parks and the springs furnish water for irrigation and livestock and for municipal, industrial, and recreational uses. Numerous wells tapping the reservoir also supply water for municipal and other uses. In view of the economic and recreational importance of the ground-water supply in this area, a clear understanding of the geology and hydrology of the reservoir is necessary in order to plan for the most advantageous use of the water. This report gives the results of the investigation which was planned primarily to obtain data on the occurrence of ground water in the Edwards and associated limestones in Kinney County. Emphasis was given particularly to the thickness and water-bearing properties of the Edwards and associated limestones and other formations in the county, the amount of recharge and the areas in which it occurs, the movement of the water, and the amount of the discharge and where it occurs.

The investigation in Kinney County was begun in August 1938 and geologic fieldwork was concluded by the authors in 1940. Periodic water-level measurements in observation wells and inventory and sampling of new wells was continued into 1957 by various personnel of the U. S. Geological Survey.

Methods of Investigation

The geology was studied and the outcrop areas of the formations were mapped in the field in part on aerial photographs and in part on topographic and land-survey maps. A land-survey map was used in the northwestern part of the county; consequently, the geologic formations and location of wells in that area are not shown as accurately as in the other parts of the county where photographs or more

Texas Water Commission in cooperation with the U.S. Geological Survey

Figure 1

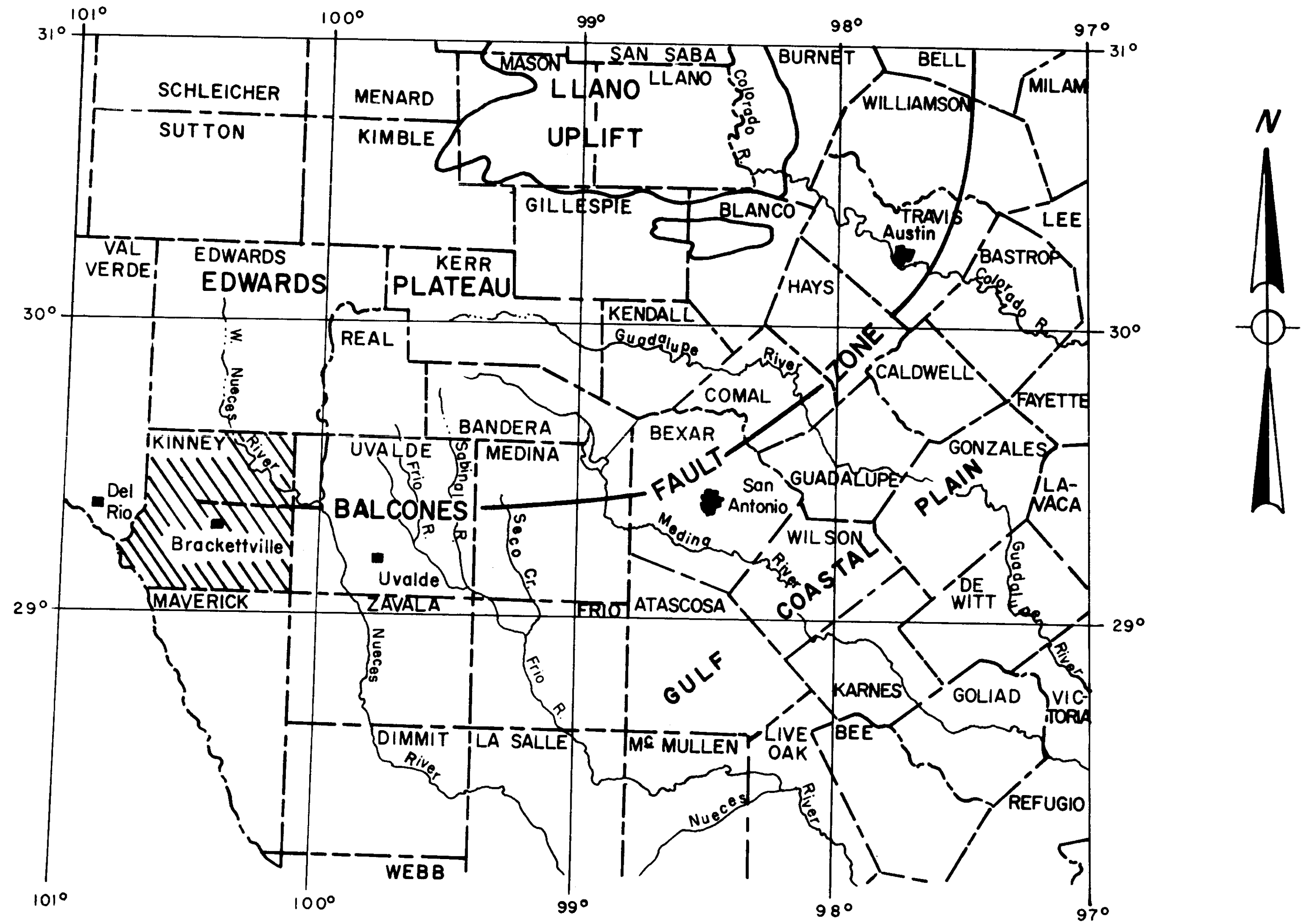

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FIGURE 1.–Map of central Texas showing physiographic provinces and location of Kinney County

detailed maps were available. A base map was constructed and the geology and structure were transferred from the field maps to the base map by a pantograph or an opaque projector. (See Plate 1.)

Several well logs were obtained and studied, and all available samples of well cuttings were examined with a hand lens or a binocular microscope. Geologic sections were measured at several localities, and fossils were collected and sent to Messrs. L. W. Stephenson, J. B. Reeside, Jr., and R. W. Imlay of the U. S. Geological Survey for study and identification. Mr. Stephenson spent about 10 days in the field with the senior author. Samples of igneous rock were collected and identified by Mr. C. S. Ross of the Geological Survey. An unpublished manuscript and geologic map of the Brackett quadrangle, by T. W. Vaughan of the Geological Survey, was used freely during the investigation.

This report contains records of 304 wells and 5 springs (Table 7), drillers' logs for 9 wells (Table 8), periodic water-level measurements in 28 wells (Table 9), and chemical analyses of 134 samples obtained from wells and springs (Table 10). The locations of the wells and springs are shown in Plate 1. In this plate, Kinney County has been divided into areas which are labeled alphabetically; each area embraces one 5-minute quadrangle or part of a 5-minute quadrangle. The wells and springs are numbered consecutively within each area. In Tables 7-10 each well or spring number is preceded by a letter that designates the area in which the well or spring is located. The well numbers used in this report and the numbers used for the same wells in previously published reports are given in Table 6. The chemical analyses were made in the laboratory of the U. S. Geological Survey at Austin.

The altitudes of wells used in drawing the water-level contour map of water in the Edwards and associated limestones for 1937-40 were determined by instrumental leveling, by use of two arenoid altimiters and a recording barograph, or from topographic maps. The altitudes of wells used in drawing the water-level contour maps for 1952 and 1956 were determined by instrumental leveling.

Previous Investigations

A series of exploratory surveys of Texas, some of which crossed Kinney County, was made by the United States Government shortly after Texas was admitted to the Union, and reports on the geology were made by Marcy, Shumard, Marcou, and others. R. T. Hill (1887a) wrote an excellent account and bibliography of the geological reports on Texas prior to 1887, including the reports prepared in connection with the exploratory surveys. The first detailed geologic investigation in the Kinney County area was begun in 1895 by Hill and Vaughan (1898a) with the mapping of the Nueces quadrangle which covers the northeastern part of Kinney County, parts of northwestern Uvalde County, western Real County, and southeastern Edwards County. Vaughan (1900b) mapped the Uvalde quadrangle which lies southeast of the Nueces quadrangle and covers the central part of Uvalde County and a part of northern Zavala County. Vaughan also mapped the geology of the Brackett quadrangle which lies immediately south of the Nueces quadrangle and covers the eastern part of Kinney County and parts of Uvalde, Zavala, and Maverick Counties; his manuscript has not been published but was made available to the writers. These investigations, together with additional information that had been collected, formed the basis for a publication dealing with the geology and ground-water conditions of the Edwards Plateau and the Coastal Plain (Hill and Vaughan, 1898b). Udden (1907) studied and mapped the geology of the lands of the New York-Texas Land Company which includes parts of Val Verde, Kinney, Uvalde, Zavala, Dimmit, and Maverick Counties. In 1919-21 Trowbridge (1923) made a geologic reconnaissance of the Coastal Plain area. However, nearly all the area mapped lies south and southeast of Kinney County. In 1932 a final paper by Trowbridge (1932) on the geology of the Rio Grande Plain was published. Lonsdale (1927) described the geology of the igneous intrusions and extrusions of the area between Austin and Del Rio. Liddle (1930) investigated structural anomalies in southwestern Uvalde County and southeastern Kinney County. Getzendaner (1930) has studied the geology of southwestern Texas for many years and has published some of the data he collected. In 1929-30 Sayre (1936) investigated the geology and ground-water resources of Uvalde and Medina Counties.

Acknowledgments

The writers are grateful to all those who helped them in the course of the investigation. Mr. F. M. Getzendaner of Uvalde, Texas, supplied valuable information relating to the geology of the area, numerous well logs, and other data. Mr. W. N. White, U. S. Geological Survey, was consulted many times during the investigation on problems relating to hydrology. Mr. Marion Badger, County Agent of Kinney County, furnished information concerning wells drilled under the Agricultural Adjustment Administration program. Mr. G. H. Cromack of the Texas Board of Water Engineers [now the Water Commission] located and scheduled many of the water wells and ran instrumental levels to observation wells. Residents of the area willingly allowed the writers access to their properties and supplied information concerning wells and ground water.

GEOGRAPHY

Location and Extent of Area

Kinney County is in southwestern Texas and is bounded on the north by Edwards County, on the east by Uvalde County, on the south by Maverick County, and on the west by Val Verde County and Mexico. (See Figure 1.) Kinney County has an area of 1,391 square miles and in 1950 had a population of 2,668. Brackettville, the county seat and the largest town in the county, had a population of 1,858 in 1950. Spofford, the only other town in the county, had a population of 246 in 1950.

Transportation and Travel Routes

The main line of the Southern Pacific Railroad crosses Kinney County from east to west through Spofford, and a branch line extends south from Spofford to Eagle Pass in Maverick County. Paved Federal, State, and County highways provide automobile access to much of the county. There are also many roads which are passable most of the time.

Agricultural and Industrial Development

The main occupation in Kinney County is stockraising. In the northern part of the county principally sheep and goats are raised, whereas in the southern part cattle is the dominant stock. Some forage crops are grown on small irrigated tracts in the western half of the county.

Considerable quantities of rock asphalt--limestone impregnated with asphalt--have been quarried in southeastern Kinney County and southwestern Uvalde County.

Limestone is quarried and used locally as building stone. Several oil and gas tests have been drilled but none has yielded enough oil or gas for economic production at the time fieldwork for this report was completed.

Climate

The climate in Kinney County is semiarid and, in general, is unsuitable for dryfarming. According to the records of the U. S. Weather Bureau the mean annual precipitation during the period 1921-50 was 22.00 inches at Brackettville, 18.62 inches at Del Rio, and 23.94 inches at Uvalde (for location of towns see Figure 1). By contrast, the average annual precipitation for the period 1947-56 was 17.84 inches at Brackettville, 13.59 inches at Del Rio, and 19.16 inches at Uvalde.

The rainfall which in Kinney County is often torrential may vary considerably from place to place during individual storms, and is unevenly distributed throughout the year. The heaviest rains usually fall in the spring and autumn, and considerably more than half the annual precipitation falls between April and October.

The long-term mean annual temperature is 69.8°F at Del Rio and 70.2°F at Uvalde. The summers generally are hot. The winters are mild, and the temperature is usually well above freezing. The temperature may fall below freezing, however, during occasional cold periods which generally last only a few days. The growing season generally extends from March through November and averages about 275 days.

Precipitation, temperature, and evaporation records collected by the U. S. Weather Bureau are shown graphically in Figures 2 and 3.

Geomorphology

The northern half of Kinney County is a part of the Edwards Plateau, which is a section of the Great Plains; the southern half is a part of the West Gulf Coastal Plain, which is a section of the Coastal Plain (Fenneman, 1914, p. 86). These physiographic divisions are separated in Kinney County by a moderately low escarpment which is known as the Balcones escarpment. (See Figure 1.)

The Edwards Plateau is the southernmost section of the Great Plains, a physiographic province that extends northward into Canada. The plateau is a roughly diamond-shaped area extending about 350 miles from east to west and 225 miles from north to south. It is underlain largely by the Edwards and associated limestones, which are highly resistant to erosion. In its northern and central part the plateau is a broad, level upland about 2,500 feet or more above sea level; the relatively few streams crossing it have cut canyons of moderate depth. Near its southern margin the altitude of the plateau is about 1,600 to 1,900 feet. There numerous streams and their tributaries have cut canyons as much as 400 feet deep, and the plateau surface is dissected into mesas, long narrow ridges, and hills. It is in the southern part of the Edwards Plateau where the surface is rough and hilly that the northern part of Kinney County lies. The soil is generally thin and the vegetation, except for scattered, dense growths of cedar or mountain juniper, is generally sparse.

In eastern Kinney County the plateau slopes abruptly downward to the Coastal Plain--a slope of about 300 to 400 feet in a distance of 3 miles. In western Kinney County the slope is somewhat less steep, but the escarpment is nevertheless pronounced.

Figure 2

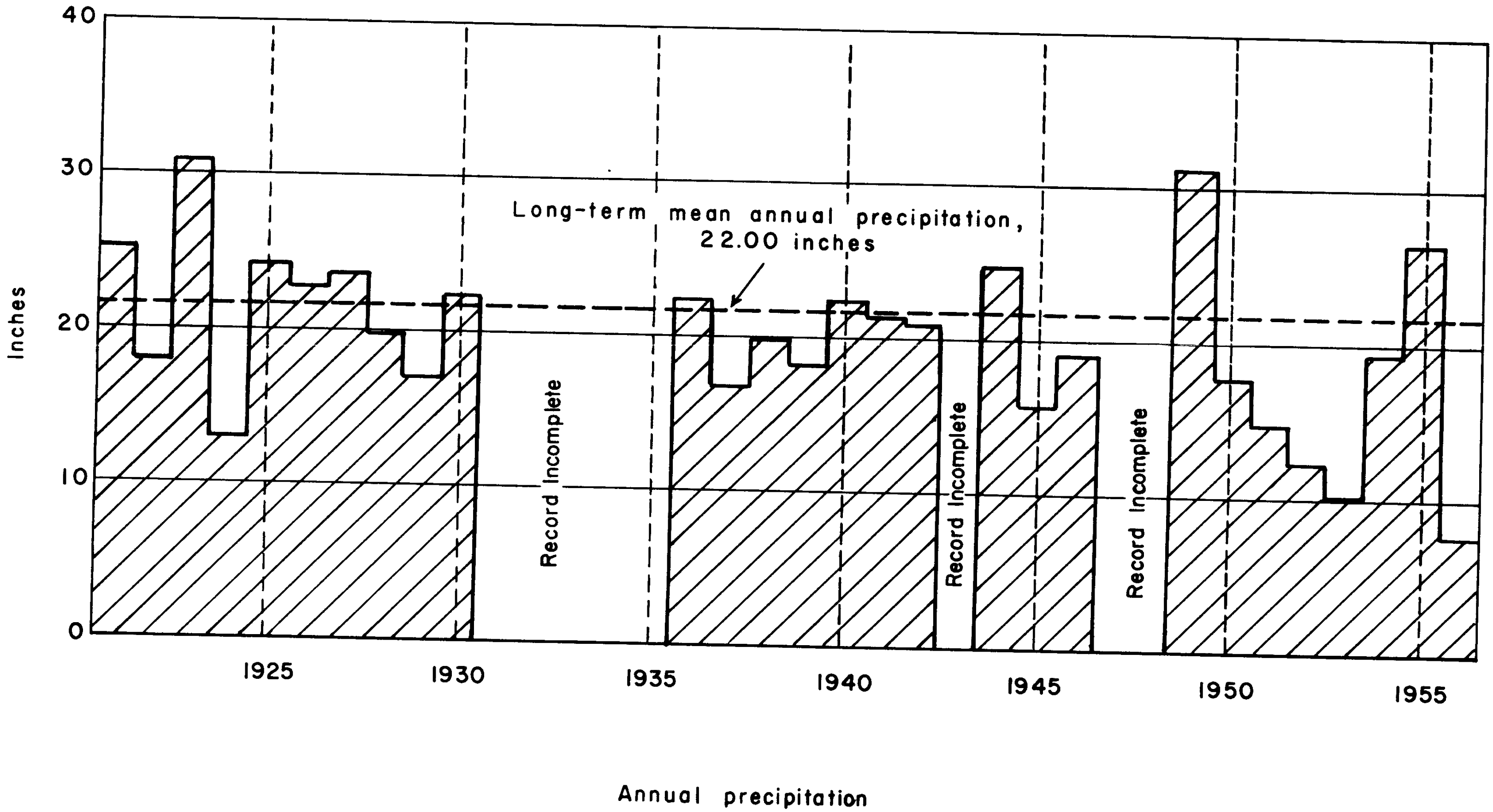

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FIGURE 2.-Precipitation at Brackettville, 1921-56

(Records from U.S. Weather Bureau. The long-term mean is based on records for the period 1921-50)

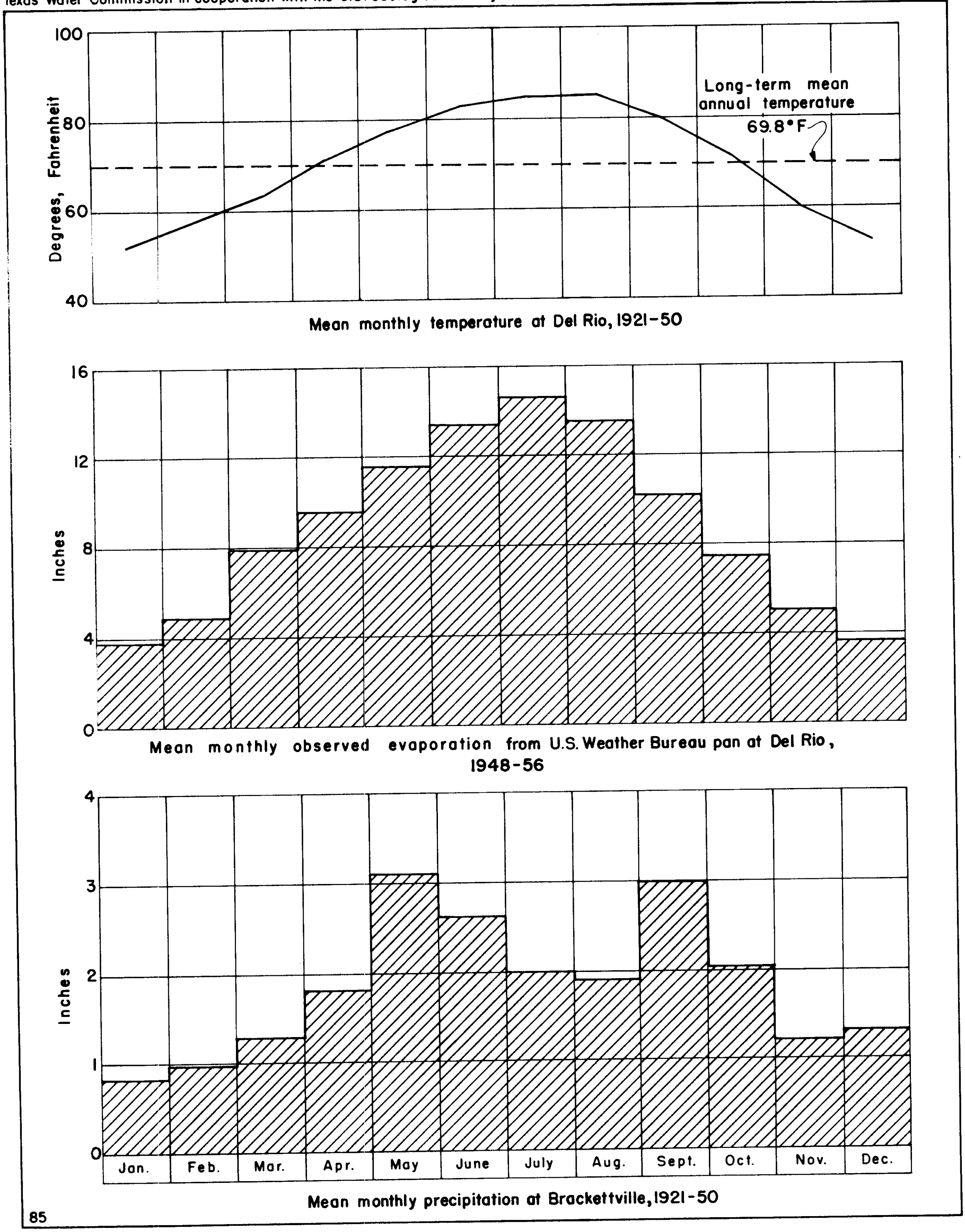

FIGURE 3.–Temperature and evaporation at Del Rio and precipitation at Brackettville
(Records from U.S. Weather Bureau)

The West Gulf Coastal Plain is a section of the Coastal Plain, a province that extends from Cape Cod on the north to Yucatan on the south (Thayer, 1928, p. 165). The relatively low relief of the Coastal Plain in Kinney County contrasts markedly with the rough surface of the Edwards Plateau. In Kinney County the Coastal Plain is underlain chiefly by soft limestone, marl, and shale of Late Cretaceous age. The presence of igneous masses and resistant limestone beds in places results in relatively high hills which stand out sharply above the generally level plain. Examples of such hills are Turkey and Las Moras Mountains, which are 300 to 400 feet high and are formed by igneous bodies, and the Anacacho Mountains, which are about 400 feet high and are formed by the resistant Anacacho limestone. The altitude of the Coastal Plain at its margin near the central part of the county is about 1,200 to 1,300 feet, and at the southern boundary of the county it is about 800 to 900 feet. A broad, level land surface in the southwestern part of the county is underlain by coarse gravel or conglomerate of Pliocene(?) age. East and southeast of Spofford erosion has removed nearly all of this gravel and has formed a low east-facing escarpment which trends nearly north.

At one time the Coastal Plain extended much farther inland. After the movements that accompanied the Balcones faulting, which in Kinney County consisted of minor faulting and monoclinal flexing of the rocks, the deposits of Late Cretaceous age were stripped off and the limestones of Early Cretaceous age were deeply dissected in the Edwards Plateau portion of Kinney County. The material removed by this erosion was deposited on the Coastal Plain at varying distances from the plateau. Gravel was deposited close to the plateau as outwash along the stream channels; erosion following the first outwash of coarse gravel deepened the valleys of the streams in many places along the Coastal Plain and left the ancient gravel deposits high on the interstream divides. Except where these gravel deposits mantle the surface or where resistant rocks crop out, the soil of the Coastal Plain is deep and supports a moderately dense growth of mesquite and other vegetation. Where the soil is thin, the vegetation is sparse and scrubby.

Drainage

Kinney County lies in parts of two major drainage basins, those of the Rio Grande and the Nueces River. The major streams in the county which are in the Rio Grande drainage basin are Sycamore, Mud, Pinto, and Las Moras Creeks, and those in the Nueces drainage basin are Elm (east of Brackettville), Liveoak, and Turkey Creeks, and the West Nueces River.

The Rio Grande, which borders the southwestern part of Kinney County, is a perennial stream that rises far to the northwest. Las Moras Creek is fed by artesian springs some distance below its head and is perennial from the springs to its mouth. The regimen of Mud and Pinto Creeks is similar to that of Las Moras Creek, but the springs that feed them cease to flow after extended periods of drought. The West Nueces River, which is fed by gravity springs from the Edwards and associated limestones, is perennial to the point where the water reenters the limestone. In most stretches of the stream below this point the flow is intermittent, but after storms there may be underflow through the thick deposits of gravel underlying the channel. The underflow feeds a few pools in the channel which remain for a considerable period after surface flow ceases. Liveoak Creek has a small perennial spring-fed flow and has cut its valley through the Edwards limestone and into the Glen Rose limestone or Comanche Peak limestone throughout most of its course in Kinney County. The flow of this creek disappears into the Edwards limestone a short distance east of the county line. Sycamore Creek (in western Kinney County) also flows in some reaches. Like the West Nueces River, however, it generally consists of a series of disconnected pools of water that are fed by underflow. All the other streams in the county are intermittent and contain water only after heavy rains.

Kinney County is well drained. The streams on the Edwards Plateau have developed an intricate drainage pattern, and the plateau has been dissected into numerous high hills and narrow, deep valleys. The gradient of these valleys is relatively steep; for example, the West Nueces River has a gradient of almost 12 feet per mile. The streams on the Coastal Plain lie in shallow, broad valleys having moderate to slight gradients.

Stream piracy has occurred in some places. T. W. Vaughan (unpublished manuscript) suggests that the West Nueces River once flowed through French Creek in Uvalde County to the Nueces River. He says, "It is evident that the West Nueces once flowed into East Nueces through French Creek but has been diverted from its former channel by a stream working northward from a point west of Mustang Waterhole..." French Creek, although of short extent, has a flood plain about 1/2 to 1 mile in width. This is the approximate width of the flood plain of the West Nueces above the point where the stream piracy occurred. For some distance downstream from this point the West Nueces has a relatively narrow flood plain and the sides of the valley are high and steep. Hill and Vaughan (1898a, p. 2) suggest that the West Nueces formerly flowed southward across Kinney County to the Rio Grande, debouching on the plain southwest of Brackettville and depositing the very thick gravel now present in that area.

ROCK FORMATIONS AND THEIR WATER-BEARING PROPERTIES

General Geology

Kinney County is underlain by both sedimentary and igneous rocks. The exposed sedimentary rocks include deposits of Cretaceous, Tertiary(?), and Quaternary age. The Cretaceous rocks were deposited under marine conditions on the eroded surface of Paleozoic rocks, whereas the Tertiary(?) and Quaternary deposits were deposited above sea level. The Cretaceous rocks dip south, in most places at a rate greater than the slope of the land surface; consequently, in going from north to south one progresses up the geologic column. The dip is slight in the northern part of the county, is much greater in the Balcones fault zone, but is moderate south of the fault zone. In general, the thickness of the beds increases to the south and to the west.

The Glen Rose limestone of the Trinity group is the oldest formation exposed in Kinney County. It crops out in the deeper valleys in the northeastern part of the county. Above the Glen Rose are the Comanche Peak and Edwards limestones of the Fredericksburg group, and the Georgetown limestone of the Washita group. All these formations crop out on the Edwards Plateau. In the Devils River area, west of Kinney County, the Georgetown and Edwards limestones are lithologically similar and were described together by Udden (1907, p. 56-60) as the Devils River limestone. The Edwards and Georgetown limestones contain many caves, and in the Balcones fault zone are highly fractured. Exposures of these limestones constitute areas of recharge of ground water.

The Grayson shale, formerly known as the Del Rio clay, overlies the Georgetown limestone. The Grayson confines the water in the underlying limestones. The Buda limestone overlies the Grayson shale and is the uppermost formation of the Washita group. The Eagle Ford shale, Austin chalk, Upson clay, Anacacho limestone, San Miguel formation, Olmos formation, and the Escondido formation overlie the Buda limestone and are exposed in approximately the southern half of the county. The Uvalde gravel of Pliocene(?) age overlies the Cretaceous rocks in the southern part of the county, and Quaternary gravel partly fills the canyons and valleys in the county. Table 1 shows the order of deposition and thickness of the formations in Kinney County and gives a brief description of their lithologic character, topographic expression, and water-supply properties.

Except for a dike(?) of nepheline syenite in the northern part of the county, the igneous rocks in Kinney County are basaltic. They have intruded the sedimentary rocks both concordantly and discordantly, but generally have had only a local effect on the structure of the sedimentary rocks.

The Balcones fault zone, which extends from north of Austin southwestward to San Antonio and from San Antonio westward, is represented in the eastern part of Kinney County by folding or increased tilting of the beds and by many normal faults of short extent and small throw. The fault zone practically ends within the county; in the western part of the county only a few small faults are present, and the beds dip gently southward across the line of the fault zone.

Pre-Cretaceous Rocks

The age and structural relations of the pre-Cretaceous rocks in Kinney County are not known. According to Flawn (1956, p. 149, pl. 1) they are either Paleozoic or Precambrian in age. Flawn has drawn a tentative line extending from just south of the northwest corner of the county to just north of the southeast corner. Southwest of this line are highly sheared metamorphic rocks consisting of marble, metaquartzite, slate, and fine-grained schist. Northeast of this line are clastic deposits which have not been subjected to regional metamorphism.

Records are available for eight wells in Kinney County that entered the pre-Cretaceous rocks. They indicate that in general the surface on which the Cretaceous rocks were deposited dips steeply toward the south. The depths at which the eight wells entered the pre-Cretaceous rocks are: well G-1, 2,010 feet; well S-2, 3,430 feet; well T-1, 4,110 feet; well G-2, 1,959 feet; well K-5, 2,740 feet; well U-1, 3,760 feet; well H-1, 2,140 feet; and well T-3, 4,090 feet.

Little is known about the water-bearing properties of the pre-Cretaceous rocks underlying Kinney County. A small amount of salt water reportedly entered well S-2 at a depth of 5,260 feet. In general the pre-Cretaceous rocks are not water bearing, and any water present in them probably is highly mineralized.

Cretaceous System

Pre-Comanche Rocks

No Cretaceous rocks of pre-Comanche age crop out in Kinney County. The Travis Peak formation was long regarded as the oldest formation of Cretaceous age in central Texas because in its type locality in Travis and Burnet Counties (Taff, 1892, p. 295) it is in direct contact with the underlying Paleozoic rocks. It has been shown, however, that a wedge of older strata of Cretaceous age is present between the subsurface extension of the Travis Peak formation (the Pearsall) and the Paleozoic(?) rocks downdip from the outcrop of the Travis Peak.

Imlay (1945) classifies these older strata as the Hosston and Sligo formations and correlated them with the Nuevo Leon and Durango groups of the Coahuila series of Mexico. He also describes the Pearsall formation as the subsurface equivalent of the Travis Peak formation. Lozo and Stricklin (1956, p. 74) recently suggested that the Hosston and Sligo formations are of Comanche age.

Not enough deep wells have been drilled to clarify the stratigraphy of the pre-Comanche rocks in Kinney County. Hazzard (1956, p. 68) reports thicknesses of 575 feet and 145 feet for the Hosston and Sligo, respectively, at well T-1 (Plate 3), but Morey (in Hazzard, 1956, p. 68) reports a combined thickness of only 280 feet for both formations in well S-2 (Table 8), which is about 4 miles from well T-1. Both wells CC-5 and DD-5 were drilled through about 160 feet of the Sligo formation and were bottomed in the Hosston formation after penetrating 855 and 475 feet, respectively, of the Hosston. (See Plate 4.)

Little is known of the water-bearing properties of the Hosston and Sligo formations in Kinney County. The only wells deep enough to reach these formations were drilled as oil tests, and no records were kept of the quality of the water or of the artesian pressure. It seems likely, however, that the formations would yield fresh water in the northern part of the county.

Comanche Series

The Comanche series is divided into three groups which, in ascending order, are the Trinity group, the Fredericksburg group, and the Washita group.

Trinity Group

Travis Peak (Subsurface Pearsall) Formation

The Travis Peak formation, the basal formation of the Comanche series, was named from exposures in the vicinity of Travis Peak post office in western Travis County (Hill, 1901, p. 140).

The Pearsall formation underlies all of Kinney County but does not crop out. As the subsurface extension of the Travis Peak, it underlies the Glen Rose limestone throughout the county. According to Hill and Vaughan (1898b, p. 219) the nearest exposures of the Travis Peak are in the valley of the Colorado River between the mouths of Sycamore and Cypress Creeks in Burnet and Travis Counties. Imlay (1945) states that the Pearsall formation, which long has been recognized in the subsurface by oil geologists, is equivalent to the Travis Peak formation and suggests that the term Travis Peak be confined to the outcrop area.

In the outcrop area the Travis Peak formation consists of "conglomerate, composed of coarse, rounded pebbles of Silurian and Carboniferous limestones, granite, Llano schists, quartz derived from the adjacent Paleozoic rocks, beds of finely cross-bedded pack sand, white siliceous shell breccia resembling the Florida coquina, and some clay" (Hill and Vaughan, 1898b, p. 219). Conglomerate is at the base in most places. Overlying this is a cross-bedded, angular, coarse-grained sand, which is so finely triturated that it resembles what is known in Texas as "pack sand." The thickness of the Travis Peak at the mouth of Hickory Creek, Burnet County, is given as 263 feet.

Table 1--Geologic formations in Kinney County

System	Series	Group	Formation	Range in thickness (feet)	Character of rocks	Topographic expression	Water supply
Quaternary	Recent		Alluvium	0 - 50(?)	Silt, sand, clay, and gravel.	Confined to stream beds.	Furnishes potable water in some valleys, especially in the Edwards Plateau.
	Pleistocene		Leona	0 - 30(?)	Silt and gravel.	Terraces a few feet above stream beds.	Furnishes small quantities of potable water in stream valleys, especially in the West Nueces River Valley.
Tertiary(?)	Pliocene(?)		Uvalde gravel	0 - 75±	Well cemented gravel, caliche, clay, and sandstone.	Broad, flat, high-level plain in southwestern part of the county.	Furnishes potable water in parts of southwestern Kinney County.
Tertiary or Cretaceous			Intrusive igneous rocks	--	Chiefly basalt, but at one exposure the rock is a syenite.	Forms high hills or may be level with the land surface.	Not known to yield potable water to wells.
Cretaceous	Gulf	Navarro	Escondido	Only the basal few feet occurs along a part of the southern edge of the county.	Hard sandstone and shaly clay	Forms low hills or ridges.	Furnishes sufficient water for domestic and livestock purposes on its outcrop in northeastern Maverick County. No wells in Kinney County are known to draw water from this formation.
			Olmos	0 - 50	Friable sandstone and clay.	No distinctive topographic expression.	No wells are known to draw water from this formation in Kinney County.
			San Miguel	0 - 400(?)	Sandstone and calcareous clay.	In general, forms even, featureless surface.	Generally yields small quantities of highly mineralized water.
			Anacacho limestone	0 - 500±	Massive limestone and some clay.	Forms high hills in southeastern part of county.	Furnishes sufficient water in some parts of the Anacacho Mountains for domestic or livestock purposes, but in some parts of this area yields little or no potable water.
			Upson clay	0 - 750±	Clay, marl, and chalky limestone.	Flat, featureless topography.	Not known to yield potable water.
			Austin chalk	0-1,030±	Chalky limestone and marl.	Forms low hills.	Yields sufficient water for irrigation in some parts of its outcrop.
			Eagle Ford shale	0 - 390	Flaggy limestone interbedded with marl and chalky marl.	Forms low hills.	Generally yields small supplies of water in some parts of its outcrop. A few wells yield enough water for irrigation.

(Continued on next page)

Table 1--Geologic formations in Kinney County

System	Series	Group	Formation	Range in thickness (feet)	Character of rocks	Topographic expression	Water supply
Quaternary	Recent		Alluvium	0 - 50(?)	Silt, sand, clay, and gravel.	Confined to stream beds.	Furnishes potable water in some valleys, especially in the Edwards Plateau.
	Pleistocene		Leona	0 - 30(?)	Silt and gravel.	Terraces a few feet above stream beds.	Furnishes small quantities of potable water in stream valleys, especially in the West Nueces River Valley.
Tertiary(?)	Pliocene(?)		Uvalde gravel	0 - 75±	Well cemented gravel, caliche, clay, and sandstone.	Broad, flat, high-level plain in southwestern part of the county.	Furnishes potable water in parts of southwestern Kinney County.
Tertiary or Cretaceous			Intrusive igneous rocks	--	Chiefly basalt, but at one exposure the rock is a syenite.	Forms high hills or may be level with the land surface.	Not known to yield potable water to wells.
Cretaceous	Gulf	Navarro	Escondido	Only the basal few feet occurs along a part of the southern edge of the county.	Hard sandstone and shaly clay	Forms low hills or ridges.	Furnishes sufficient water for domestic and livestock purposes on its outcrop in northeastern Maverick County. No wells in Kinney County are known to draw water from this formation.
			Olmos	0 - 50	Friable sandstone and clay.	No distinctive topographic expression.	No wells are known to draw water from this formation in Kinney County.
			San Miguel	0 - 400(?)	Sandstone and calcareous clay.	In general, forms even, featureless surface.	Generally yields small quantities of highly mineralized water.
			Anacacho limestone	0 - 500±	Massive limestone and some clay.	Forms high hills in southeastern part of county.	Furnishes sufficient water in some parts of the Anacacho Mountains for domestic or livestock purposes, but in some parts of this area yields little or no potable water.
			Upson clay	0 - 750±	Clay, marl, and chalky limestone.	Flat, featureless topography.	Not known to yield potable water.
			Austin chalk	0-1,030±	Chalky limestone and marl.	Forms low hills.	Yields sufficient water for irrigation in some parts of its outcrop.
			Eagle Ford shale	0 - 390	Flaggy limestone interbedded with marl and chalky marl.	Forms low hills.	Generally yields small supplies of water in some parts of its outcrop. A few wells yield enough water for irrigation.

(Continued on next page)

Table 1.--Geologic formations in Kinney County--Continued

System	Series	Group	Formation	Range in thickness (feet)	Character of rocks	Topographic expression	Water supply
Cretaceous	Comanche	Washita	Buda limestone	0 - 119	Fine-textured brittle limestone.	Generally caps low hills.	No wells are known to draw water from this formation.
			Grayson shale	0 - 220	Clay and flaggy arenaceous limestone.	Exposed on slopes of hills capped by Buda limestone; otherwise the surface is flat and featureless.	Does not yield water to wells.
			Georgetown limestone	0 - 550(?)	Chiefly hard massive limestone; contains numerous chert nodules.	Forms high, steep hills where dissected; elsewhere a nearly flat plain.	Generally furnishes large amounts of excellent water. However, in the southern part of the county it yields water containing hydrogen sulfide.
		Fredericksburg	Kiamichi	0 - 200+	Black shale, black and brown limestone, and anhydrite.	Insufficient data to determine if it crops out in Kinney County.	Does not yield potable water.
			Edwards limestone	0 - 575(?)	Not differentiated from Georgetown limestone.	Not differentiated from Georgetown limestone.	Not differentiated from Georgetown limestone.
			Comanche Peak limestone and Walnut(?) clay, undifferentiated	0 - 65	Massive, irregularly bedded limestone and some marl.	Exposed on steep slopes of canyons.	Not differentiated from Edwards limestone.
		Trinity	Glen Rose limestone	1,000-1,700	Limestone and marl.	Exposed in steep slopes in the canyons.	Probably contains only a little water which may be moderately to highly mineralized.
			Travis Peak (Pearsall in subsurface)	160-220	Probably sandstone, shale, and limestone.	Does not crop out in Kinney County.	No wells are known to draw water from this formation in Kinney County.
	Coahuila of Mexico	Nuevo Leon and Durango of Mexico	Sligo and Hosston, undifferentiated	0-1,025+	Probably sand, shale, limestone, and conglomerate.	Do not crop out in Kinney County.	No wells are known to draw water from these formations in Kinney County. They probably contain water, but the quality is not known.
Pre-Cretaceous rocks			?	?	Altered sandstone, shale, and limestone.	Do not crop in Kinney County.	Not known to yield potable water in Kinney County.

The sursurface Pearsall formation consists of limestone, sandstone, and shale. Because only a few oil tests have penetrated this formation in Kinney County, its lithology, thickness, and water-bearing properties are imperfectly known. Well G-2 in the northwestern part of the county is reported to have penetrated 164 feet of the Pearsall. The formation thickens downdip, reaching a maximum known thickness of 220 feet in well DD-5. (See Plate 4.)

Glen Rose Limestone

The Glen Rose limestone was named by Hill (1891b, p. 504-507) from an exposure along the Paluxy River near Glen Rose, Somervell County, Texas. The Travis Peak formation grades upward into the Glen Rose limestone without an apparent break in sedimentation. However, the conditions of sedimentation were gradually changing, the Glen Rose consisting chiefly of clay or marl and thin beds of limestone. The clay or marl is generally bluish gray but weathers light buff. Most of the limestone is impure, and some might be classified as mudstone. Many of the limestone beds are only a few inches thick, but beds 1 to 3 feet thick are exposed along Liveoak Creek. The uppermost Glen Rose is a calcareous clay wherever exposed in the county. Getzendaner (1930, p. 1425) states that in southwestern Uvalde County the Glen Rose consists mainly of limestone with some shale, anhydrite, and a few beds of sand, and that toward the north where shallower water conditions prevailed at the time of deposition, the limestone grades into shale.

The Glen Rose limestone is exposed in the northeastern part of Kinney County where streams have cut through the Edwards and Comanche Peak limestones. (See Plate 1.) It crops out along Liveoak Creek in the West Nueces River valley, along Chalk Creek west of Salmon Peak, and along an unnamed tributary to the West Nueces River southeast of Salmon Peak. The total thickness exposed in Kinney County probably does not exceed 100 feet, but 300 to 350 feet of Glen Rose is exposed in Uvalde County in the Nueces River valley (Sayre, 1936, p. 39).

According to Hill and Vaughan (1898b, p. 255) the total thickness of the Glen Rose limestone at Kerrville is 500 feet. This is the nearest locality to Kinney County where all of the formation is exposed. In the subsurface in Kinney County the Glen Rose limestone thickens downdip toward the south. It is about 1,100 feet thick in well G-2 in the northwestern part of the county, and reaches a maximum recorded thickness of about 1,700 feet in well CC-5 in the south-central part of the county. (See Plates 3 and 4.)

In the stream valleys, where erosion has been fairly rapid, the Glen Rose limestone generally forms steep to vertical banks. Outside the stream valleys, where erosion is less rapid, the hard limestone beds form benches separated by steep slopes, thus resembling terraced slopes.

The Glen Rose is well exposed in northeastern Kinney County on the sides of Casey Mountain which is a small butte capped by the Comanche Peak and Edwards limestones. The gradational contact between the Glen Rose and the Comanche Peak limestones is fairly well exposed here. The section on the following page is present from the top of Casey Mountain down the east slope toward Liveoak Creek.

	Thickness (feet)
Edwards limestone:	
20. Limestone, light-gray, massive, hard; contains Foraminifera	3
19. Limestone, gray to light buff, cavernous	5
18. Limestone, light-gray, massive, cavernous	3
17. Limestone, gray, massive	3
Comanche Peak limestone:	
16. Limestone, gray, argillaceous, irregularly bedded; *Exogyra texana* in middle, *Protocardia* sp. present	30
15. Limestone, gray, hard, forms bench, is nodular but as a unit is massive	15
14. Limestone, gray, very argillaceous; contains many *Exogyra texana*	15
13. Limestone, gray, hard, massive although irregularly bedded, more marly at base; contains many *Exogyra texana*, *Protocardia* sp., and other fossils	5
Glen Rose limestone:	
12. Calcareous clay, light-gray; contains thin beds of mudstone	15
11. Limestone, light-gray to light-buff, argillaceous	3
10. (Covered)	12
9. Limestone, light-gray, argillaceous; forms two beds	4
8. (Covered)	3
7. Limestone, light-gray, argillaceous	4
6. Calcareous clay, light-gray; contains thin beds of finely laminated limestone; some beds appear to contain fossilized mud cracks	15
5. Limestone, light-gray, oölitic(?), nodular; contains an abundance of fossils; forms bench	4
4. Calcareous clay, light-gray, and thin beds of mudstone	10
3. Limestone, buff, hard; forms bench	1
2. Calcareous clay, buff; contains 1-foot limestone bed in middle	7

	Thickness (feet)
1. Limestone, gray, hard, nodular; forms bench------------	3
Total--	160

The Glen Rose limestone is well exposed in the bed of Liveoak Creek for a considerable distance downstream from the measured section. It consists of thin-bedded limestone, marl, and massive beds of nodular limestone; the massive beds are lithologically similar to the Comanche Peak limestone. About 70 feet of the formation, consisting of buff marl and a few beds of impure limestone, is exposed about 1 mile east of the West Nueces River on the south bank of Chalk Creek

The Glen Rose limestone in Kinney County is very fossiliferous, although where exposed the uppermost part contains only microfossils. Dinosaur tracks were noted in the Glen Rose limestone in the bed of a creek a few hundred yards west of Casey Mountain. Some of the characteristic fossils of the Glen Rose are: Palhemiaster comanchei Clark, Pecten (Chlamys) stantoni Hill, Orbitolina texana Roemer, Porocystis globularis Giebel, Tylostoma sp., Arctica sp., Serpula paluxiensis Hill, Nerinea cf. incisa Giebel, and Enallaster aff. obliquatus Clark.

Well drillers generally describe the Glen Rose limestone as "blue clay," but occasionally they report layers of sand. They state that little or no water has been encountered in the formation, and no wells in Kinney County are known positively to draw water from the Glen Rose limestone. It is reported that well F-3 originally yielded a small supply of water that was too highly mineralized for human consumption; this water may have come from the Glen Rose.

The Glen Rose limestone in Kinney County is not likely to be a highly productive water-bearing formation because, in general, the beds are clayey and have a low permeability. They are not readily dissolved by circulation of ground water; and hence, channeling by solution is not likely to be developed on a large scale. It is probable, therefore, that only small supplies could be obtained from wells tapping the formation and that the water would be from moderately to highly mineralized. However, dominantly calcareous beds which have been made porous by weathering or fracturing possibly contain some potable water at and near their outcrop. Some of the sand layers reported in the formation also might yield small amounts of water. Except in the northern part of the county, the Glen Rose lies at too great a depth to warrant drilling into it for a water supply.

Fredericksburg Group

Walnut Clay

The name Walnut clay was applied by Hill (1891b, p. 504-512) to the yellow clay, flaggy limestone, and masses of Exogyra texana Roemer and Gryphaea marcoui Hill and Vaughan exposed near Walnut Springs, Bosque County, Texas.

According to Hill and Vaughan (1898b, p. 226) the Walnut clay is represented along the Colorado River at the northern limit of the Edwards Plateau by 10 to 12 feet of thin, friable, yellow, sandy marl containing a great number of Exogyra texana Roemer.

No beds were seen in Kinney County that could be identified as the Walnut clay. Although a part of the clay regarded to be uppermost Glen Rose may be stratigraphically equivalent to the Walnut, it is lithologically like the clay of the Glen Rose and, at least in its lower part, contains a Glen Rose fauna. Also, no unconformity is apparent between the Glen Rose and the Comanche Peak limestones in Kinney County. Therefore, it is more likely that the Walnut clay, if present, has been included in the lower part of the Comanche Peak limestone. Of interest is a statement by Vaughan, in his unpublished manuscript on the Brackett quadrangle, that the Comanche Peak limestone along the Nueces River is stratigraphically equivalent to two formations north of the Colorado River, the Comanche Peak limestone and the Walnut clay.

Nothing comparable to the Walnut clay is reported in logs of deep wells in the neighboring counties of Uvalde, Maverick, and Val Verde (Getzendaner, 1930, p. 1426).

Comanche Peak Limestone

The Comanche Peak limestone, which conformably overlies the Glen Rose limestone in Kinney County, was named for its exposure at Comanche Peak in central Hood County, Texas (Shumard, 1860, p. 583-585).

The Comanche Peak limestone crops out in deep valleys in the northeastern part of the county. It is exposed at many places in the valley of the West Nueces River between the gaging station and the Laguna-Brackettville road crossing, in the valley of Liveoak Creek, and in the valley of at least one of the smaller streams. Northeastern Kinney County is relatively inaccessible owing to the rough terrain and the absence of roads, and it was not practicable to map it in detail.

In most valleys that have been eroded through the Edwards limestone, the Comanche Peak forms the steep lower slopes of the valley walls. Generally these steep slopes are almost bare of soil and support little vegetation. At Casey Mountain relatively resistant beds in the lower part of the Comanche Peak limestone form a topographic bench.

The Comanche Peak limestone consists chiefly of gray irregularly bedded to nodular thick-bedded limestone, some of which is marly. Where the beds are nodular, thin layers of marl separate the nodules. Although the marl and some of the limestone weather buff, most of the limestone weathers gray. The exposures of Comanche Peak limestone on the east side of the West Nueces River near the mouth of Chalk Creek and in Chalk Creek about 1 mile upstream from the West Nueces River contain a few beds of massive limestone about 1 foot or less in thickness. Some of the limestone beds in the Comanche Peak are lithologically like some of the limestone beds in the upper part of the Glen Rose. In the exposure on Casey Mountain the lower part of the Comanche Peak is more marly than the upper part (see page 17) and seems to grade downward into the Glen Rose.

The thickness of the Comanche Peak limestone, where exposed in the area, is relatively uniform. The formation is 65 feet thick at Casey Mountain and is about 60 feet thick in a bluff 5-1/2 miles north and 3 miles east of the point where the West Nueces River crosses the eastern boundary of Kinney County.

No fossils are known to be solely characteristic of the Comanche Peak limestone. However, the formation generally contains an abundance of *Exogyra texana* Roemer.

No wells in Kinney County are known to obtain water from the Comanche Peak limestone. Many of the successful wells on the Edwards Plateau may have been drilled a short distance into the Comanche Peak, but the water probably enters the well from the basal part of the overlying Edwards limestone. Along the West Nueces River some of the gravity springs issue from the Comanche Peak, but the water probably comes from the Edwards and moves downward through fissures into the Comanche Peak near the point where the springs issue. On the east bank of the West Nueces River at the mouth of Chalk Creek and on the east bank of the West Nueces River 1 mile upstream from the Laguna-Brackettville road, some beds in the Comanche Peak are cavernous. However, it is believed that the cavernous condition does not extend far underground.

Edwards Limestone

Name and Position.--The Edwards limestone, which overlies the Comanche Peak limestone, was named by Hill and Vaughan (1898b, p. 227) for its excellent exposures in Edwards County, Texas.

Areal Outcrop and Surface Features.--The Edwards limestone crops out in the northern part of Kinney County and is the principal rock formation throughout much of the Edwards Plateau. The massive character of its limestone beds and their resistance to erosion is largely responsible for the rugged topography of the plateau area. Excellent exposures of this formation may be seen in most parts of the Edwards Plateau, but the formation is especially well exposed in the canyons of the West Nueces River and its tributaries. These canyons generally have precipitous walls which in places along the West Nueces River rise 200 to 300 feet above the bed of the stream. In the rugged interstream areas the Edwards is exposed in conical-shaped hills, flat-topped buttes, or mesas. (See Plate 2.) Many of these are marked by small benches, or shoulders, formed by the more resistant beds of the limestone.

Many caves and small solutional openings have been formed in the limestone throughout the Edwards Plateau. Some small streamways lead directly into basins containing solutional openings. Moderate-sized caves are common along the West Nueces River, and a cave in northeastern Kinney County is reported to contain swiftly running water. One of the larger caves, Hillcoat Cave, which is a few miles north of Kinney County near the Brackettville-Rock Springs road, was described by Hill and Vaughan (1898a, p. 3).

Erosion has been rapid along the margins of the Edwards Plateau; the slopes are steep, and soil is thin or absent. A few miles back from the edge of the plateau, where erosion has been less rapid, the soil in level areas supports a heavy growth of grass and cedar. On the steeper slopes, cedar, cacti, lechuguilla, sotol, and yucca are predominant.

Lithology.--In Kinney County the Edwards limestone is composed chiefly of massive beds of limestone although near its base the beds are thin and flaggy. (See Plates 5 and 6.) Some of the beds are marly. The formation as a whole is very resistant to erosion. The predominant color of the unweathered limestone is light gray, but it ranges from a very light gray to nearly black. Most of the beds weather to a gray hard limestone which rings under the blows of a hammer, but the more marly beds weather to a cream color or light buff and are rather soft. Some of the limestone beds are coarsely crystalline, but some are so finely crystalline that they resemble lithographic stone. Nearly all the limestone in the Edwards is rather pure, although a few beds are somewhat clayey or sandy and some contain small pyrite concretions. Although most beds are almost barren of fossils, some are very fossiliferous and may be reef deposits.

Chert is abundant in some parts of the formation. Chert concretions in the massive limestone beds are tubular, oval, or irregularly shaped, ranging from a few inches to 2 feet in diameter. Beds of chert 1 to 3 inches thick extend several feet laterally in the thin-bedded zone of the Edwards. Most of the chert is dark gray to black, but some is pink or blue.

Gypsum is reported in the outcrop of the Edwards in Kinney County (Sellards, Baker, and others, 1934, p. 627), but none was seen by the writers.

Petroliferous limestone in a thin-bedded zone on the Edwards Plateau also has been reported.[1] Although no petroliferous limestone was seen in place, one large fragment was found in the float in the bed of the West Nueces River about 6 miles downstream from Edwards County. Mr. Slator reports that asphaltic beds were penetrated in the drilling of a well on his ranch near the north edge of Kinney County, approximately 5 miles west of the West Nueces River.

In its outcrop in Kinney County, the Edwards limestone may be divided into five somewhat ill-defined zones. The lowest, or first, zone consists of about 75 feet of massive light-gray crystalline limestone. The base and lower part of this zone is marked by massive crystalline light-gray beds of limestone containing abundant minute round bodies (coprolites?) and many Foraminifera. In places the basal bed contains small patches of darker colored limestone which appear to be pieces of Comanche Peak limestone that were reworked by water when the basal bed of the Edwards limestone was deposited. This suggests an unconformity between the Comanche Peak and the Edwards. The sharp change in lithology between the two formations also suggests an unconformity, as do the fragments of silicified wood in the base of the Edwards limestone in northeastern Uvalde, southern Edwards, and southern Real Counties (Getzendaner, 1930, p. 1427). On the other hand, the writers noted no indication of deep channeling or of an undulating contact in the several places in Kinney County where they examined the contact of the two formations. As Getzendaner points out, the presence of petrified wood does not necessarily indicate that trees grew where their fossilized remains are found; they may have floated out from some distant land, possibly the Llano-Burnet area.

The base of the Edwards limestone is well exposed on the east bank of the West Nueces River, about 1 mile upstream from the Laguna-Brackettville road crossing. (See Plate 7.) The following section was measured at this locality:

	Thickness (feet)	(inches)
Edwards limestone:		
15. Limestone, thin-bedded, flaggy-------------------	10	
14. Limestone, gray, massive, subcrystalline; poorly exposed-----------------------------------	40	
13. Limestone, gray to dark gray, hard, massive-------	5	

[1] Vaughan, T. W., Description of the Brackett quadrangle: U. S. Geol. Survey unpublished manuscript, p. 57.

	Thickness (feet)	(inches)
12. Limestone, gray, massive, hard; contains an abundance of high-spired gastropods------------	3	
11. Limestone, gray, hard, irregularly bedded--------	1	
10. Marl---	0	2
9. Limestone, gray, hard, massive; contains many Foraminifera------------------------------------	2	7
8. Marl---	0	2
7. Limestone, gray, hard, massive; contains Foraminifera------------------------------------	2	3
6. Limestone, gray, hard, massive------------------	1	2
5. Limestone, gray, hard, brittle; contains an abundance of Foraminifera----------------------	0	9
4. Limestone, gray, hard, brittle------------------	1	
3. Limestone, gray, hard, massive, brittle; contains an abundance of Foraminifera----------	1	4
2. Marl---	0	2
Comanche Peak limestone:		
1. Limestone, dark-gray to gray, hard, irregularly bedded; contains many *Exogyra texana* Roemer----	10	
Base of Comanche Peak limestone not exposed.		
Total--	78	7

Samples of beds 3, 5, 7, and 9 were submitted to Lloyd G. Henbest of the U. S. Geological Survey for examination. His report is as follows:

> Bed 9. Like the samples described below, the rock in this sample is composed of small bodies that resemble oölites, at first glance, and are crowded as close as they can be. The spaces between these grains are filled with clear calcite. About a third or a half of the grains are porcellaneous shells of *Quinqueloculina*, *Triloculina*, *Nummoloculina*, *Vidalina*, *Planispirina* or a closely related new genus, and other Miliolidae and Ophthalmidiidae. About a fourth of the grains are recognizable as possibly related to other Foraminifera.
>
> Bed 7. Fauna resembles that in beds 3 and 9. Foraminifera compose a large share of rock material.
>
> Bed 5. Fauna similar to that in beds 3 and 9. About three-fourths or more of the grains are Foraminifera.

BASE OF THE EDWARDS LIMESTONE IN EAST BANK OF WEST NUECES RIVER, 1 MILE NORTH OF LAGUNA-BRACKETTVILLE ROAD. BASE OF THE EDWARDS IS AT HAMMER HEAD

Bed 3. (Basal bed of Edwards limestone.) This limestone contains a great abundance of Quinqueloculina, Cornuspira, Vidalina, Nummoloculina, and other Miliolidae and Ophthalmidiidae. Other indeterminable and undescribed Foraminifera are present. Coprolitic(?) bodies that stain deeply are common. Foraminiferal remains compose about a fourth to a third of the rock material. Some areas were found where nearly all of the grains are shells of Foraminifera. Other areas of dense limestone contain larger shell fragments, more grains of unidentifiable origin and less abundance of foraminiferal shells.

A sample of the basal bed of the Edwards limestone was collected also at an outcrop in the West Nueces River, about 1-1/2 miles above the Laguna-Brackettville road crossing. Mr. Henbest's report on this was as follows:

> This collection resembles those described above. Nearly all the grains in this rock are fossil Foraminifera. In addition to the known and apparently unnamed genera listed above, I found a single, small shell fragment that may possibly belong to Dictyoconus or Orbitolina. I find no oölites, though many of the grains appear to have algaloid coverings.

The following section measured from the top of Salmon Peak west to Chalk Creek shows the lithology and thickness of the first zone as well as the second, third, and part of the fourth zones of the Edwards limestone.

	Thickness (feet)
Edwards limestone:	
Fourth zone	
7. Limestone, light-gray, massive, crystalline; contains nodular chert------------------	60
Third zone	
6. Limestone, light-gray to cream, chalky, massive-bedded; semicrystalline in the lower part------------------	80
5. Limestone, light-gray to cream, massive-bedded, hard, dense, fine-textured, brittle; contains black spots of manganese. Large Gryphaea sp. present about 30 feet above base. Basal bed is a dense gray limestone containing angular pieces of dark-gray limestone------------------	90
Second zone	
4. Limestone, gray to dark-gray, flaggy, hard, dense to finely crystalline; some like lithographic stone; weathers light buff; contains angular chert 25 feet below top. Bedded chert and Gryphaea sp. from 30 to 65 feet below top. Upper part supports a heavy growth of vegetation that forms a distinct band on the hillsides------------------	115

	Thickness (feet)
First zone	
3. Limestone, light-gray, massive, fossiliferous; contains many nodules and nodules of chert-----------	30
2. Limestone, light-gray, massive, dense, crystalline; high-spired gastropods present 35 feet below top. Lowermost beds are gray and massive and contain an abundance of small bodies that may be Foraminifera----	50
Comanche Peak limestone:	
1. Limestone, dark-gray, irregularly bedded---------------	10
Base of Comanche Peak not exposed.	___
Total--	435

The second zone of the Edwards limestone is represented by bed 4 in the Salmon Peak section. It is a zone of partly flaggy, gray limestone that contains bedded chert and many specimens of Gryphaea. (See Plate 6.) Thin beds of marl are interbedded with the thin beds of limestone, many of which are so finely crystalline that they resemble lithographic stone. Most of the chert beds are 1 to 2 inches thick and are continuous for several feet. Even on steep slopes a part of the second zone supports a heavy growth of vegetation which is an excellent key horizon in the northeastern part of the county. Although cavernous the second zone does not appear to be as much so as the other zones in the Edwards limestone. (See Plate 6.)

The lithology of the second zone is shown in beds 2 to 6 in the following section, which is exposed on the north side of a high hill 1 mile east of the West Nueces River and about one-half a mile south of the Laguna-Brackettville road.

	Thickness (feet)
Edwards limestone:	
Fourth zone	
11. Limestone, fine-texured, semicrystalline, massive; contains large nodules of chert and gastropods at same horizons---------------------------------------	75
10. Limestone, light-gray, massive; contains irregularly shaped chert nodules--------------------------------	5
9. Limestone, light-gray, fine-textured, chalky, massive; contains chert nodules------------------------------	60
Third zone	
8. Limestone, fine-textured, chalky----------------------	55

	Thickness (feet)
7. Limestone, light-gray, very fine-textured; appears lithologically like the Buda limestone. The basal bed contains patches of gray limestone	100
Second zone	
6. Limestone, very light gray to gray, flaggy	15
5. Limestone, very light gray to gray, flaggy; contains fragmental chert. A dense growth of vegetation occurs at the base of this bed	20
4. Limestone, very light gray to gray, flaggy; contains chert. Dense growth of vegetation at the top of this bed	20
3. Limestone, flaggy; contains <u>Gryphaea</u> at base	5
2. Limestone, flaggy; contains abundant <u>Gryphaea</u> at base	45
First zone	
1. Limestone, poorly exposed; probably flaggy in part	25
Total	425

The third zone of the Edwards limestone consists of about 155 to 170 feet of light-gray massive semicrystalline limestone which is very fine textured and brittle in the lower part and chalky in the upper part. Some of the beds in the lower part are similar in appearance to the Buda limestone. In the Salmon Peak section the limestone in the lower part of this zone contains black manganese dendrites; large specimens of <u>Gryphaea</u> are present in both the lower and upper parts. The basal bed contains what appears to be pieces of limestone that are darker than the matrix. This suggests an unconformity at this horizon.

The fourth zone consists of about 130 to 140 feet of light-gray chalky massive limestone that contains many chert nodules. This zone is well exposed on the west bank of the West Nueces River, about 8 miles downstream from the Laguna-Brackettville road crossing. A section at this locality is as follows:

	Thickness (feet)
Edwards limestone:	
Fifth zone	
4. Limestone, light-gray, fine-textured, massive, chalky; weathers gray	12
Fourth zone	
3. Limestone, light-gray, chalky; contains many nodules of chert	128

	Thickness (feet)
Third zone	
2. Limestone, light-gray, chalky-------------------------	25
1. Limestone, light-gray, very fine-textured, brittle------	85
Base of section not exposed.	
Total--	250

The fifth, or uppermost, zone of the Edwards limestone is composed of about 75 feet of light-gray massive subcrystalline limestone which contains no chert. This zone was seen only in the following section, which is exposed along the West Nueces River about 11 miles downstream from the Laguna-Brackettville road crossing.

	Thickness (feet)
Georgetown limestone:	
10. Limestone, marly; contains many limonitic fossils; _Kingena_ _wacoensis_ Roemer abundant--------------------	5
9. Limestone, light-gray, marly; weathers buff-------------	5
8. Limestone, light-gray with bluish spots, hard, brittle, poorly exposed; contains many limonitic segregations. Large echinoids abundant----------------------------	5
7. Covered--	5
6. Limestone, bluish-gray, hard, brittle, very fine-textured; contains a few limonitic segregations-------	13
5. Limestone, gray, fine-textured; weathers brown; contains small spherical bodies (oölites?); contains _Kingena_ _wacoensis_ Roemer and _Pecten_ sp.---------------	10
4. Limestone, light-gray, subcrystalline, massive, pure; contains small spherical bodies (oölites?)------------	10
3. Limestone, light-gray, hard, massive, subcrystalline; contains small spherical bodies (oölites?)------------	2
Edwards limestone:	
Fifth zone	
2. Limestone, light-gray, subcrystalline, massive-----------	75

	Thickness (feet)
Fourth zone	
1. Limestone, light-gray, massive, subcrystalline; contains many nodules of chert------------------------	20
Total--	150

The beds above bed 2 in the preceding section contain small spherical bodies which some geologists (Plummer, 1931, p. 112-118) refer to as oölites. These small spherical bodies are common in the Georgetown limestone. Adkins (in Sellards, Adkins, and Plummer, 1932, p. 365) notes that similar structures apparently are present in rocks of other ages "but their abundance suggests the Washita age of the containing rock." In the preceding section, bed 2 was classified as Edwards because it contains none of the small spherical bodies such as are present in the overlying beds. Further study may show that bed 2 and perhaps several of the underlying beds, here included in the Edwards limestone, are of Washita age.

Thickness.--The maximum thickness of the Edwards limestone, determined by compiling sections measured in northeastern and eastern Kinney County and western Uvalde County, is about 575 feet. This figure may be in error because the exact determination of the contact between the Edwards limestone and the overlying formation is subject to controversy. (See pages 30 and 32.) The Edwards probably is rather uniform in thickness along the strike in Kinney County.

Fossil Content.--Among the many fossils in the Edwards limestone are the distinctive aberrant mollusks *Monopleura*, *Radiolites*, and *Requienia*. These have been given the more general name of rudistids and are believed to indicate shallow-water environment. Other fossils collected in the West Nueces River canyon are *Gryphaea* cf. *marcoui* Hill and Vaughan, *Plicatula* sp., *Oxytropidoceras*(?) sp., and undetermined oysters.

Water-Bearing Properties.--The Edwards limestone, together with the underlying Comanche Peak limestone and the overlying Georgetown limestone, is the most important water-bearing unit in a region of several thousand square miles in west-central Texas. This region includes the Edwards Plateau and a belt of varying width on the Coastal Plain south and southeast of the plateau. In the western part of this region the Georgetown limestone is similar in lithology to the Edwards and is several hundred feet thick. The Georgetown supplies water to several springs in the valley of the Devils River west of Kinney County. The Comanche Peak limestone also is lithologically similar to the Edwards limestone and is the source of several springs in Kinney County. Although the Edwards probably is the source of most of the water supplied to both springs and wells in Kinney County, the entire Comanche Peak and the lower part of the Georgetown may constitute a part of the reservoir and in places may yield some water. Inasmuch as well drillers do not distinguish these formations, the term "Edwards and associated limestones" is used in this report to designate the ground-water reservoir (aquifer) in the three formations. The Kiamichi formation, which is between the Edwards and Georgetown limestones in the southern part of the county, also is included in this reservoir.

In Kinney County the Edwards and associated limestones are the source of many springs, both on the Edwards Plateau and on the Coastal Plain. They also supply water to most of the wells in the northern half of the county.

Where streams have eroded through or nearly through the Edwards limestone on the Edwards Plateau, most of the springs issue at or near the base of the Edwards limestone near its contact with the Comanche Peak limestone. The contact is exposed in several places along the West Nueces River and its tributary Liveoak Creek. (See Plate 8A.) Schwandner Spring (F-1), the largest spring on the plateau in Kinney County, is in the valley of the West Nueces River. It issues from one large opening in the Edwards limestone in the side of a bluff, considerably above the Comanche Peak limestone. (See Plate 8B.)

The two largest springs in Kinney County are Las Moras and Pinto Springs (V-7 and O-1). (See Plate 9.) These and Mud Spring (G-6) are in the Coastal Plain where the Edwards and associated limestones are some distance below the land surface. The water rises along fault or fracture planes that probably have been enlarged by solution. Records of the discharge of Las Moras, Pinto, and Mud Springs are given in the section entitled "Discharge from the Reservoir" (page 76).

In most places on the Edwards Plateau, wells drilled into the Edwards and associated limestones encounter water near the base of the aquifer in sufficient quantities for livestock and domestic use. In some localities, however, the rocks are too dense to yield water or the base of the rock unit is above the water table. For example, two wells in the northern part of Kinney County, about 1-1/2 miles south of the Edwards County boundary and about 4 miles east of the West Nueces River, are reported to have been drilled through the Edwards and associated limestones without encountering water. None of the wells on the plateau is known to yield a large quantity of water.

South of their outcrop on the Coastal Plain, the Edwards and associated limestones contain water under artesian pressure. In this part of Kinney County, the water level in wells that tap the Edwards and associated limestones is above the top of this aquifer; and in topographically low places, the wells flow.

In the northern part of the county nearly all of the wells that tap the Edwards and associated limestones discharge potable water; whereas in the southern part of the county, approximately one-third of the wells that tap the aquifer discharge water that smells strongly of hydrogen sulfide and generally is moderately to highly mineralized. (See Figure 15.) A possible explanation for the difference in water quality may be that the solutional openings in the limestone in the southern part of the county are less fully developed, making the ground-water circulation correspondingly less than in the northern part of the county.

Most of the wells that tap the Edwards and associated limestones on the Coastal Plain discharge less than 10 gpm (gallons per minute). These wells are equipped with pumps that are powered by windmills or small gasoline engines. It is believed that some of these wells would discharge much more water if they were equipped with pumps of larger capacity. Wells V-23, U-14, U-15, and AA-10, which were drilled to obtain irrigation supplies, are equipped with pumps of large capacities and are reported to discharge 750, 800, 1,500, and 320 gpm, respectively. Other wells, however, have a low specific capacity and are incapable of delivering much water. For example, the water level in well FF-7 reportedly is lowered about 350 feet when the well is discharging only 2 gpm. This well is in the Anacacho Mountains in the southeastern part of the county where the circulation of ground water in the Edwards and associated limestones probably is small.

The flow from well BB-2 is reported to have been about 1,000 gpm in 1915, shortly after the well was drilled. However, the flow was only about 200 gpm in 1940. The decline in the discharge probably was caused chiefly by a reduction in the effective diameter of the well due to incrustation of the casing. The incrusting material is yellow and probably contains some sulfur. It is seen in the casing at the top of the well and in the flume that conducts the water away from the well. (See Plate 10.)

Solutional Openings.--The Edwards limestone and, to a lesser extent, the Georgetown limestone transmit water only through fractures and interconnected openings formed by solution. The rocks themselves are practically impermeable.

Some solutional openings in the Edwards limestone may have been formed by circulating water during the period after the Edwards was deposited and before the Georgetown limestone was laid down. The contact of the Edwards limestone with the Georgetown limestone is an unconformity in some parts of the Balcones fault zone, but it has not been established whether this unconformity extends into Kinney County. According to Sellards, Adkins, and Plummer (1932, p. 360), the unconformity represents a time when the area stood above sea level. Some solutional openings may have been formed also during later periods of erosion--for example, the period of erosion between the Cretaceous and Tertiary periods. However, it seems likely that the major development of solutional openings occurred after the Balcones faulting which provided an extensive system of fissures that greatly facilitated the circulation of ground water and made openings along which ground water could reach the surface and discharge through springs. Hence, a circulatory system was established in which water entered the formation in the outcrop area and moved downdip to points of discharge through springs.

Although limestone is nearly insoluble in distilled water, it is relatively soluble in water containing carbon dioxide. Rain falling on the surface of the earth absorbs some carbon dioxide from the air. Adams and Swinnerton (1937, p. 505) state that under ordinary conditions rain picks up enough carbon dioxide from the atmosphere to dissolve about 63 parts of calcium carbonate per million parts of water. Because the water in the Edwards limestone in Kinney County generally contains calcium bicarbonate equivalent to more than 200 ppm (parts per million) of calcium carbonate, Adams and Swinnerton conclude that the additional carbon dioxide that is needed for the water to dissolve more than 63 ppm of calcium carbonate is picked up as the water passed through the soil.

Some idea of the extent of the solvent action may be obtained from the following example. The average of the available measurements through 1941 of the discharge of Las Moras, Pinto, and Mud Springs is about 30.5 cubic feet a second, or about 962 million cubic feet a year. The dissolved solids in samples of water from the three springs averages 263 ppm. Assuming that the precipitation that enters the aquifer contains no dissolved mineral matter and that the specific gravity of the rock material is 2.6, it is evident that the springs are discharging about 100 cubic feet of dissolved rock material for each million cubic feet of water. On this basis the amount of rock material dissolved and discharged by the springs is about 97,000 cubic feet a year. As subsurface streams developed, they may have captured other streams by piracy, thereby causing some of the former discharge points (springs) to go dry. A dry hole in the Buda limestone on the W. C. Belcher ranch, 5-1/2 miles northwest of Brackettville, appears to have been a spring at one time. (See Plate 11.) Nearby are thick beds of caliche. The hole has been filled with soil and debris nearly to the land surface, but a heavy growth of trees near the hole may indicate that some water still is being discharged from the Edwards limestone into younger formations and is within the reach of the roots of the trees.

Kiamichi Formation

The Kiamichi formation was named by Hill (1891b, p. 504, 515) for the black marly clay and hard yellow limestone that overlies the Goodland limestone (Edwards equivalent) and underlies the Duck Creek formation (Georgetown equivalent) in Choctaw County, Oklahoma. Hill placed the Kiamichi in the Washita group, but since then the U. S. Geological Survey has classified the formation as part of the Fredericksburg group.

A series of beds that were penetrated in the drilling of deep wells in Kinney County have been correlated with the Kiamichi formation by Imlay (1945, p. 1420) and oil-company geologists working in the area. The beds are a little more than 200 feet thick and consist principally of black shale, black and brown limestone which may be petroliferous, and anhydrites. Vaughan[2] reports thin-bedded petroliferous limestone and Sellards, Baker, and others (1934, p. 627) report gypsum in the outcrop in Kinney County, but these were not seen by the writers. The subsurface beds cannot be correlated definitely with the outcropping beds until a greater number of detailed well logs become available. Their position in the subsurface, however, indicates that the overlying Georgetown limestone is considerably thicker than the underlying Edwards limestone.

According to the driller's log of well S-2 (Table 8), "sulfur water" was encountered in black shale which probably is of Kiamichi age. The Kiamichi formation is not known to yield potable water to wells in Kinney County.

Washita Group

Georgetown Limestone

The name Georgetown limestone was proposed by R. T. Hill "from its occurrence at Georgetown, Williamson County, Texas" (Vaughan, 1900b, p. 1-2). It is the equivalent in part of the Fort Worth limestone of Hill (1889, p. XIV, XXI, XXII). Adkins (1924, p. 38-40) states that in McLennan County the Georgetown is composed of seven mappable members which, in descending order, are: Mainstreet, Pawpaw, Weno, Denton, Fort Worth, Duck Creek, and Kiamichi. He also states that these members thin and lose their identity toward the south. Hill and Vaughan (1898b, p. 235) state that in the Colorado River section "the [Fort Worth] formation does not exceed 75 feet in thickness...Southwestward, toward Brackett, it becomes less and less distinguishable from the underlying Edwards limestone...So far as the question of artesian waters is concerned, it would be better to consider it as the upper 70 feet of the Edwards limestone rather than as an independent formation." In the area between San Antonio and Uvalde, the Georgetown is represented by 50 feet or less of beds composed at the base of massive limestone and grading upward into marl (Sayre, 1936, p. 50-51). Westward from Uvalde County the limestone thickens considerably and is lithologically so similar to the underlying Edwards that it probably can be distinguished from the latter only by fossils. About 15 miles west of Kinney County, thick beds of limestone that include both the Georgetown and the Edwards form the walls of the Devils River canyon. Udden (1907, p. 56-60) applied the term "Devils' River limestone" to the entire section.

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[2] *Ibid*.

VIEW OF WELL BB-2 AND FLUME ABOUT 10 MILES SOUTHWEST ON BRACKETTVILLE,
SHOWING DEPOSITS CONTAINING SULFUR ON FLUME

SOLUTION HOLE IN BUDA LIMESTONE, 5-1/2 MILES NORTHWEST OF BRACKETTVILLE.
POSSIBLY A SPRING ONCE ISSUED FROM THIS HOLE

In most places the contact between the top of the Georgetown limestone and the overlying Grayson shale can be mapped easily. (See Plate 12.) The beds that are known to be of Georgetown age crop out in a belt that crosses Kinney County in a northwesterly direction from near the mouth of the West Nueces River. The tops of many of the high hills in the northwestern and north-central parts of the county, which formerly were believed to consist of Edwards limestone, may be composed of the Georgetown limestone. The actual contact of the Georgetown with the Edwards is imperfectly known because the two formations are lithologically similar. Hence, although the outcrop area is well defined on the south, its northern limits are uncertain in many parts of the county. The areas underlain by beds that are known to be Georgetown generally do not have much topographic relief, and in most places the soil contains cobbles and boulders of Georgetown limestone. The vegetation on the outcrop of the Georgetown is similar, in general, to the vegetation on the Edwards limestone.

In the eastern part of Kinney County (see section given on page 26) the known Georgetown limestone consists of very fine-textured, massive, nodular, light-gray limestone intercalated with thin beds of marl that weather buff. The limestone contains a relatively large amount of pyrite which on exposure to weathering has altered to limonite. Minute spherical bodies that may be oölites are present in some of these beds.

Much of the Georgetown limestone, at this locality as well as in other parts of the area, is lithologically similar to the Buda limestone, the uppermost formation in the Washita group. Although, in general, the Georgetown contains more iron oxide and is not as brittle as the Buda, the limestone in many isolated outcrops cannot be identified as one or the other.

North and northwest of Brackettville are limestones which field relations indicate to be of Georgetown age. These beds contain rudistids and are similar to the rudistid-bearing facies in the Edwards limestone. One such outcrop is a few hundred yards south of well J-4, which is about 10-3/4 miles north of Brackettville. At this locality, a coarsely crystalline bed of limestone containing rudistids is in contact with the Grayson shale, which overlies the Georgetown and underlies the Buda. The contact forms a straight line and probably is a fault. If it is a fault, aerial photographs indicate it to be of short extent; furthermore, the throw probably is not great enough to bring the Edwards in contact with the Grayson shale. Rudistid-bearing limestones are present a few feet below the Grayson shale in several localities north of Brackettville and also in northwestern Kinney County near well A-4. Although the Georgetown limestone is not exposed well enough to permit the tracing of individual beds across the county, it is apparent that the rudistid-bearing limestone beds present in the Georgetown in the north-central and northwestern parts of the county do not extend to the extreme eastern part.

Stanton (1928, p. 406-407) discussed the lithology of the Georgetown as follows:

> In southwest Texas in the Edwards Plateau and westward to Devils River, Pecos River, and beyond, mistakes have been made in the past in drawing the boundary between the Fredericksburg and the Washita, and there is still difficulty in placing isolated outcrops or in referring small collections of fossils to their proper stratigraphic position because the peculiar lithology and the reef faunal facies of the Edwards recurs in the Washita near the top of the Georgetown limestone and, according to Adkins, at another level between that and the Edwards. This condition is

> particularly evident in the Edwards Plateau near Brackettville on the southern border and near Rock Springs at the summit of the plateau and in the gorges of Devils River and Pecos River near their mouths.
>
> The true stratigraphic relations of these limestones in the vicinity of Del Rio were recognized some years ago by Udden, who named the massive limestone of the Edwards aspect along the Devils River, the Devils River limestone and stated that it includes the equivalent of the Georgetown limestone and is therefore, in part, of Washita age. A similar development in the Fort Stockton region has been recorded by Hill (1921, p. 190-191) and Adkins (1927). I wish to record from my own observations that the entire thickness of limestone in the gorge of Devils River at the crossing of the Comstock road and for some miles above is of Georgetown age. At the top, just beneath the Del Rio clay (Grayson shale), the limestone contains the recurrent reef facies of the Edwards fauna including _Chondrodonta_, _Caprinula_, and numerous specimens of Nerinea, while beds at the bottom of the gorge yield _Hemiaster elegans_, _Ostrea carinata_, and _Pervinquieria leonensis_. In the Brackettville quadrangle also the Del Rio clay rests directly on massive limestones of the Edwards type containing _Caprinula_ and _Nerinea_, and even on top of the Edwards Plateau at Rock Springs a few feet of Del Rio clay with _Exogyra arietina_ rests on the same massive limestone and is overlain by a thin remnant of Buda limestone, which is the actual top of the Comanche series.

Because of the difficulties involved without faunal studies in differentiating these formations, the Georgetown and the Edwards limestone are mapped as one unit on Plate 1.

The beds along the West Nueces River that can be definitely assigned to the Georgetown are at least 50 feet thick. Tentatively, the base of the Georgetown was placed at the bottom of the lowest bed containing abundant spherical bodies which, according to Adkins, characterize the Georgetown but not the Edwards.

The thickness of the formation in western Kinney County is not known, but in the Devils River region in Val Verde County paleontological evidence indicates that the thickness is considerably more than 200 feet. The following species of Washita age were collected near the upper end of Lake Walk in Val Verde County; they were found at lake level, at least 300 feet below the base of the Grayson shale: _Kingena wacoensis_ Roemer, _Pecten_ (_Neithea_) sp., _Gryphaea cf. G. washitaensis_ Hill, _Hemiaster_? sp., _Cymatoceras texanum_ (Shumard), _Hamites_? sp., _Pervinquieria_ sp., and _Prohysteroceras cf. P. austinense_ (Roemer). The presence of _Pervinquieria_ sp. and _Prohysteroceras_ indicates early Washita age. The Georgetown limestone probably thickens downdip in Kinney County. Imlay (1945, p. 1420) reported that well S-2 was drilled through about 550 feet of Georgetown.

The upper marly part of the Georgetown in places contains an abundance of _Kingena wacoensis_ (Roemer), _Pecten_ sp., _Protocardia cf. P. texana_ (Conrad), _Lima_? sp., _Ostrea (Lopha)_ sp., _Engonoceras_ sp., and numerous other invertebrates. The lower massive limestone part of the formation is less fossiliferous, but contains similar genera. Some of the rudistid forms that characterize the Edwards recur in the Georgetown. However, many of the other fossils are restricted to the Georgetown or first appear in the Georgetown; for example, _Hemiaster calvini_ Clark, _Prophysteroceras_, and _Ostrea carinata_ Lamarck. Where fossils are present it generally is not difficult to identify the Georgetown.

The Georgetown limestone is not known to be water bearing in any part of Kinney County. In the lower reaches of the Devils River in Val Verde County, however, where the Georgetown includes a great thickness of massive limestone lithologically similar to the Edwards limestone, numerous springs issue from solutional openings in the Georgetown. Possibly caverns exist in the Georgetown in the north-central and northwestern parts of Kinney County where much of the formation is massive limestone. If detailed logs and cuttings from existing wells in this area were available, it might be found that the Georgetown is an important aquifer. Inasmuch as it is not possible to distinguish the Edwards and Georgetown limestones except by detailed paleontologic investigations, the ground-water reservoir in the two formations and the Comanche Peak limestone will be considered as a unit called the "Edwards and associated limestones."

Grayson Shale

The Grayson shale, formerly known as the Del Rio clay, was named for numerous outcrops in Grayson County, Texas (Cragin, 1894, p. 43-48). It conformably overlies the Georgetown limestone.

The Grayson shale crops out as a narrow band a quarter of a mile to about a mile and a half wide trending slightly north of west across Kinney County from about the midpoint of the eastern boundary to a point about 4 miles south of the northwestern corner of the county. The upper part of the Grayson shale, protected from erosion by the overlying resistant Buda limestone, is well exposed in a nearly continuous abrupt north-facing escarpment and in isolated hills lying north of this escarpment. In most places the lower part of the Grayson forms gently sloping or flat surfaces (Plate 13A) and generally is covered by soil or alluvium. Very little vegetation grows on the steep slopes of the upper part of the shale, but an abundance of grass, mesquite, cactus, and catsclaw and other chaparral grows on the flat or gently sloping surface of the lower part of the formation. The thick vegetation and deep soil on the outcrop of the Grayson shale is in marked contrast to the sparse vegetation and thin soil in areas underlain by the Georgetown limestone and greatly facilitates the mapping of the outcrop of the Grayson.

The Grayson shale in Kinney County consists of bluish-gray clay and thin flaggy beds of gray sandy subcrystalline limestone which weathers to brown or greenish brown. Some of the flaggy limestone beds are finely laminated and in this respect resemble some of the flaggy limestone beds of the Eagle Ford shale. The proportion of limestone increases toward the west. The Grayson contains large numbers of <u>Exogyra arientina</u> Roemer, a small ramshorn-shaped oyster, which in some places are cemented into calcareous layers from 1 to 4 inches thick. It also contains a considerable amount of pyrite which oxidizes to iron oxide upon exposure and is responsible for the dominant brownish color of the weathered rock. Gypsum is common in the outcrop area near Mustang Waterhole in Uvalde County, and selenite was seen interspersed with clay in the south bank of the West Nueces River in western Uvalde County.

The following section shows the typical lithology of the Grayson shale in Kinney County. The section is on E. Webb ranch, 7 miles northeast of Brackettville and 0.3 mile east of Silver Lake Road.

	Thickness (feet)
Buda limestone:	
3. Limestone, light-gray, fine-textured, nodular, massive----------	20
Grayson shale:	
2. Clay, buff to brown; contains thin beds of laminated sandy limestone that apparently are not fossiliferous----------	15
1. Clay, buff, and flaggy sandy limestone. _Exogyra arietina_ Roemer abundant in limestone at the top. Some of the limestone beds contain no fossils, but others are very fossiliferous. Some of the limestone beds are thinly laminated----------	35
Total----------	70

The following section on the escarpment south of Pinto Creek near the Brackettville-Rock Springs road, about 7 miles north of Brackettville, was measured by Vaughan[3].

	Thickness (feet)
Buda limestone:	
2. Limestone, hard, showing faint brownish blotches on fractured surface; contains _Alectryonia carinata_ Lamarck and _Pecten_ sp.----------	20
Grayson shale:	
1. Clay, laminated, arenaceous, calcareous, containing slabs in which _Exogyra arietina_ Roemer is very abundant. Other fossils are "_Nodosaria_" _texana_ Conrad and _Pecten_ sp.----------	20
Total----------	40

The Grayson shale is well known to most of the well drillers of the area mainly because of their difficulty in drilling it. The clay, when wet, is very sticky, and it is difficult to pull out the drill unless the hole is cased as drilling proceeds.

The Grayson shale thickens toward the south and the west. Where exposed in the eastern part of the county, it is about 60 feet thick and in the northwestern part of the county it is about 70 feet thick. In the subsurface it is about

[3] _Ibid._, p. 70.

155 feet thick in well EE-2 in the east-central part of the county, but thickens to 220 feet in well II-2 in the southwestern part of the county. (See Plate 4.)

The Grayson shale is very fossiliferous and in places contains great numbers of Exogyra arietina Roemer, Gryphaea mucronata Gabb, and "Nodosaria" texana Conrad. In some places Exogyra arietina Roemer are extremely abundant and form limestone beds as much as 6 inches thick. Many Exogyra arietina Roemer weather out easily, and well preserved specimens are common in the soil or weathered surface in the outcrop area.

Fossils collected from the Grayson 7 miles northeast of Brackettville are as follows: Exogyra arietina Roemer, Pecten (Neithea) texanus Roemer, Plicatula sp., and Gervilliopsis sp.

The Grayson shale is not known to yield water to wells in Kinney County, and because it is chiefly clay, attempts to obtain water from the Grayson are very likely to be unsuccessful. In a large part of the county the relatively impermeable clay confines the water in the underlying limestones.

Buda Limestone

The Buda limestone was named for the town of Buda in Hays County, Texas (Vaughan, 1900a, p. 18). It overlies the Grayson shale and marks the top of the Washita group.

The Buda crops out in a narrow belt a quarter of a mile to about 4 miles wide extending from the south bank of the West Nueces River near the midpoint of the eastern boundary of the county to the northwestern part of the county. It crops out also in several isolated outliers north of the main outcrop belt, notably Turkey and Pinto Mountains. The Buda limestone is rather resistant to erosion; and because it is underlain by the easily eroded Grayson shale, it forms the cap of a prominent northfacing escarpment. (See Plate 13A.)

In general, only the lower part of the Buda is present in the escarpment. Back from the escarpment the outcrop area of the Buda is marked by low hills and rather shallow valleys, and the soil is thin or lacking. The Buda limestone supports a variety of vegetation in which scrub oak and other chaparral predominate. The change from the vegetation typical of the Grayson shale outcrop area to that of the Buda limestone outcrop area is sharp and distinct, and the contact between the two formations is located easily in most places by this sudden change. (See Plate 13A.)

The Buda limestone consists of light-gray, irregularly bedded, massive, hard, rather pure, very fine textured limestone containing a few thin marly layers. When struck with a hammer the limestone shatters into many angular pieces having smooth or slightly conchoidal shiny faces. The limestone is traversed by many minute veins of calcite. It also contains numerous specks which grade from red to black. The specks are believed to be a glauconite coating on the Foraminifera which are abundant in the rock (Sayre, 1936, p. 52). The Buda as a whole weathers gray to light gray, but the thin marl layers weather buff and in many places stain the limestone.

The lithology of the Buda limestone is indicated by the following section, on the east side of Sycamore Creek, 1/2 mile upstream from Herbst ranch house and about 1-1/2 miles south of the Southern Pacific Railroad. (See Plate 13B.)

	Thickness (feet)
Buda limestone:	
15. Limestone, light-gray, irregularly bedded; has small brown specks on fresh surface	3
14. Same as above	3
13. Limestone, light-gray, irregularly bedded; has small brown specks on fresh surface and contains small veinlets of calcite	2
12. Limestone, nodular, irregularly bedded; contains thin layers of marl between the nodules	2
11. Limestone, light-gray, irregularly bedded, fine textured, porcelaneous	3
10. Same as above	3
9. Limestone, light-gray, irregularly bedded, fine textured, porcelaneous, softer at base; contains segregations of softer material	3
8. Same as above	3
7. Limestone, light-gray, irregularly bedded, porcelaneous	3
6. Same as above but less resistant	3
5. Limestone, light-gray, irregularly bedded, porcelaneous; fragment of <u>Inoceramus</u> sp.(?) noted; forms three beds	$3\frac{1}{2}$
4. Same as above but forms two beds	2
3. Limestone, light-gray, irregularly bedded; not as lustrous as above beds; marl present between irregular layers of limestone	$2\frac{1}{2}$
2. Same as above	3
1. Same as above	$1\frac{1}{2}$
Total	$40\frac{1}{2}$

On the outcrop at Turkey Mountain the Buda limestone is approximately 65 feet thick. Although the Buda is fairly uniform in thickness along the strike in the subsurface, it almost doubles in thickness in the county downdip toward the south. (See Plates 3 and 4.) The maximum recorded thickness is 119 feet in well GG-1. Getzendaner (1930, p. 1428) states that the Buda is 180 feet thick on the Indio ranch in Maverick County.

Few fossils were found in the Buda limestone in Kinney County. A few Foraminifera were seen and only two macrofossils, Stoliczkaia(?) sp. and Pleurotomaria sp., were collected.

The Buda limestone, in general, is relatively impermeable, and it is not known to yield water to wells. In a few places on and near the outcrop, however, joints may yield small amounts of water. During wet periods a small amount of water seeps from the contact of the Buda limestone and Grayson shale about 100 feet east of the Nolan-Postell ranch house.

Gulf Series

Eagle Ford Shale

The Eagle Ford shale was named for the exposures at Eagle Ford, Dallas County, Texas (Hill, 1887b, p. 298). In Kinney County it lies unconformably on the Buda limestone and is the basal formation of the Gulf series.

The Eagle Ford shale crops out in a belt which extends from the south side of the West Nueces River at the eastern boundary of the county northwest to Brackettville and thence westward to the western boundary of the county. (See Plate 1.) At the eastern boundary of the county the outcrop is about 2 miles wide and directly westward its width varies from 1 mile to about 6 miles, depending chiefly upon the topography and geologic structure. The width of the outcrop in the vicinity of well O-11, northwest of Brackettville, is less than 1 mile, but west of well O-11 the width increases to about 6 miles and is fairly uniform to the Carta Valley road. West of this road the outcrop widens abruptly, and along Sycamore Creek it is about 18 miles wide. This widening probably is due partly to an increase in the thickness of the formation and partly to an unwarping of the rocks into a broad anticline which extends from near Del Rio eastward into Kinney County. Sycamore Creek, which crosses this anticline, has eroded through the Eagle Ford shale and has exposed the underlying Buda limestone for a distance of about 7 miles in the bed of the creek.

In most places the outcrop of the Eagle Ford shale is characterized by low hills and shallow valleys, but in some of the stream valleys the formation stands up in steep banks and moderately high cliffs. Of the many outliers of the Eagle Ford north of the main outcrop, some probably were preserved from erosion by downfaulting, as in the low hill on the Rock Springs road about 5 miles north of Brackettville, but others were preserved because they were overlain by hard igneous rock, as in Turkey and Pinto Mountains.

The soil on the Eagle Ford shale generally supports a heavy growth of vegetation, composed chiefly of guajillo. The type and density of vegetation sharply differentiates the outcrop of the Eagle Ford from that of the underlying Buda limestone. (See Plate 14.)

In fresh exposures the Eagle Ford consists chiefly of petroliferous dark-gray to black irregularly bedded chalky limestone and marl, and gray and bluish-gray flaggy crystalline limestone interbedded with dark-gray marl. Some of the flaggy limestone is finely banded with brown and black lines, and most of the marl is composed of laminae only a fraction of an inch thick. Most of the formation weathers buff, but much of the marl generally weathers to a bright orange and various shades of red. Although the flaggy limestone generally weathers to a rich brown, some of it weathers to a dirty gray.

The uppermost Eagle Ford shale contains a few feet of massive to irregularly bedded light-gray chalky limestone containing thin marl beds. In many respects these beds resemble the overlying Austin chalk. Below the chalky limestone and thin marl beds in the uppermost Eagle Ford is a section of flaggy crystalline limestone. These limestones are interbedded with thin layers of marl which vary considerably in thickness. On Las Moras Mountain, according to Vaughan[4], this section is about 1 foot thick; on U. S. Highway 90 about 10 miles east of Brackettville, it is about 12 feet thick. This section is underlain by irregularly bedded, clayey, chalky limestone interbedded with marl; the section is about 100 feet thick in the central part of the county. Many of the chalky limestone beds are similar to beds in the Austin chalk, but for the most part they are not as brittle or hard as the typical limestones of the Austin. In general, the lower 50 feet of the Eagle Ford consists of hard massive crystalline limestone flags which are as much as 2 feet thick and are separated by thin beds of marl.

The following section of the Eagle Ford was measured at the west side of Las Moras Mountain (measured by T. W. Vaughan):

	Thickness (feet)
Igneous intrusive:	
12. Basalt; indurated limestone either rests on or is included in the basalt at 30 and 20 feet above the lower contact------------------------------------	130
Austin chalk:	
11. Chalk, white, bedded; contains <u>Inoceramus</u> sp.-----------	80
Eagle Ford shale:	
10. Limestone flags, hard, yellowish-gray, like those near the base of the Eagle Ford shale----------------	1 (?)
9. Chalk, soft, yellow, and soft marly chalk; some firmer beds--	25
8. Marly beds with one hard flaggy layer near the middle---	2
7. Chalk, yellow, marly; at the top there is a firmer bed 1 foot thick---	10
6. Marl and interbedded yellowish-laminated chalk----------	60
5. Marl--	10
4. Limestone flags, hard, yellowish-gray, 1 to 4 inches thick, grouped in beds about 1 foot thick; these beds beds are separated by marly layers 1 to 3 feet thick--	20

[4] Vaughan, <u>op</u>. <u>cit</u>.

	Thickness (feet)
3. Limestone flags, hard, brownish-yellow or brownish-gray, 2 to 6 inches thick, separated by marly layers. The flags show fine lamination or banding on the transverse surface; most of the marly material is brick-red and breaks into thin flakes, 1/16 to 1/4 inch thick----------------------------------	40
2. Marl, soft, yellow, calcareous-------------------------	$\frac{1}{4}$ to 1
Buda limestone:	
1. Limestone, indistinctly bedded, nodular, cracked. The upper surface is undulate with humps as much as 1-1/2 inches high, and from 2 to 6 inches across. The humps may be oblong or in the form of rounded ridges. The nodular character of the limestone suggests that the irregularities of its upper surface may not be due to erosion, but there is no transition to the Eagle Ford shale. The change from one formation to the other is abrupt-----	6
Total--	385

A generalized section along the south side of U. S. Highway 90, about 10 miles east of Brackettville, is as follows:

	Thickness (feet)
Austin chalk:	
4. Limestone, relatively thick-bedded, chalky; contains many <u>Inoceramus</u> sp.----------------------------------	10
Eagle Ford shale:	
3. Limestone, flaggy, thin-bedded, semicrystalline, interbedded with thin beds of marl. Each bed is only a few inches thick--------------------------	8
2. Limestone, semicrystalline, flaggy; flags thicker than those in 3--------------------------------------	3 to 4
1. Limestone, irregularly-bedded, chalky and clayey, interbedded with marl. The limestone beds are nodular and apparently lenticular; they contain calcitized echinoids---	50 +
Total--	72 +

The Eagle Ford is well exposed along Sycamore Creek in western Kinney County. In one exposure all of the shale in the formation is slightly petroliferous and one bed contains bentonite. A section measured at this locality, on the west side of Sycamore Creek, about 1 mile above the mouth of Mud Creek, is as follows:

	Thickness (feet)
Uvalde gravel:	
Gravel	10
Eagle Ford shale:	
Shale, dark-gray to black	5
Shale, dark-gray, silty	½
Shale, black	1½
Bentonite, impure	½
Shale, black; contains thin lenses of silty shale	10
Total	27½

In well X-5 the drill cuttings from the Eagle Ford shale contained a small amount of bentonitic material but consisted principally of rather hard gray shale or marl which contained small specks of darker material.

The contact of the Eagle Ford shale with the Buda limestone is exposed at many localities in Kinney County. (See Plate 14.) Below the contact is the light-gray, fine-textured, irregularly bedded limestone of the Buda; above the contact are the semicrystalline limestone flags and interbedded marls of the Eagle Ford. Where observed, the surface of contact is nearly smooth, the maximum undulation being 1 to 2 inches. No indications were seen of an unconformity between the two formations other than the slightly undulating surface and the abrupt change in lithology. In most places the basal bed of the Eagle Ford is a relatively massive semicrystalline sandy limestone, thicker than most of the overlying limestone beds. However, in one exposure on the south side of the Mey ranch about 12 miles northwest of Brackettville, the basal bed is sandstone.

Vaughan[5] measured 169 feet of the Eagle Ford shale on the west side of Las Moras Mountain. (See page 38.) On the east side of Las Moras Mountain the Eagle Ford is 150 feet thick; however, this apparent difference in thickness may be due to the difficulty in determining the top of the formation, which at this locality is obscured by a thick mantle of detrital material. In the subsurface in Kinney County the Eagle Ford is about 320 feet thick in the east-central part of the county and about 390 feet thick in the western part. (See Plate 4.)

According to Sayre (1936, p. 54) the Eagle Ford is 30 feet thick where it crops out in Medina County and 75 feet thick where it crops out in Uvalde County. It is apparent, therefore, that the Eagle Ford thickens considerably downdip to the south and also toward the axis of the Rio Grande embayment to the west.

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[5] Ibid.

The Eagle Ford shale contains abundant Inoceramus sp. and various ammonites and echinoids. A zone of ammonites, most of which are less than one-half inch in diameter, is present near the base of the formation.

The Eagle Ford shale is a source of water supply only in and near the outcrop area. The shale itself is nearly impermeable, but open joints in the shale store water and transmit it to the pumped wells. Most of the wells discharge only enough water for domestic use and the watering of livestock, but a few that were drilled through one or more large fractures discharge enough water for irrigation. Well O-4 is reported to have discharged 600 gallons per minute during a pumping test, and well O-3 is reported to have discharged 780 gallons per minute. It is not known whether such large discharges could be maintained throughout a long period of pumping. Well M-7, which is believed to obtain water from the Eagle Ford, is reported to discharge 1,000 gallons per minute but also is reported to "go dry."

Austin Chalk

The Austin chalk, which unconformably overlies the Eagle Ford shale, was named for the exposures at Austin, Texas, and was first described by Roemer (1852, p. 11-15). It crops out in a broad east-west band that extends across the southern part of Kinney County. The outcrop is about 4 miles wide in the eastern part of the county, but is nearly 15 miles wide in the southwestern part. Las Moras and Elm Mountains are outliers of the Austin chalk, a layer of resistant igneous rock having retarded erosion of the underlying relatively soft chalk. Two other outliers are in downfaulted blocks.

The outcropping beds of Austin chalk generally are covered by secondary lime deposits (caliche) in the eastern part of Kinney County and by alluvial deposits in the southwestern part of the county. The outcrop area consists of low hills and moderately level surfaces, but in a few places relatively deep gullies have been cut into the chalk. The formation supports a fairly dense growth of scrub oak, cenizo, and guajillo.

In its outcrop area the Austin chalk consists of massive beds of hard light-gray limestone in the lower part and buff to white relatively thin-bedded soft chalky limestone and marl in the upper part. Concretions of pyrite are common, and where exposed the pyrite is generally oxidized to iron oxide which stains the limestone or marl brown to buff.

In many places the limestone at the base of the Austin chalk is similar to that at the top of the Eagle Ford shale. Hence, although the contact generally can be located within a few feet by the contrast between the upper flaggy section of the Eagle Ford and the lower massive limestone section of the Austin, the contact can be located exactly only in unusually good exposures. The beds near the contact of the Eagle Ford shale and Austin chalk are exposed fairly well on the east side of Arenosa Creek, about 11 miles southeast of Brackettville and about 1 mile south of U. S. Highway 90. Within a few feet vertically, the beds change from thin flags of crystalline limestone typical of the Eagle Ford to a hard light-gray chalky limestone that contains many specimens of Inoceramus sp. and undoubtedly is Austin chalk. At this locality, a small topographic bench has been formed at or near the contact of the Eagle Ford shale and the Austin chalk.

The Eagle Ford-Austin contact is well exposed on the east bank of Pinto Creek, 0.6 mile southwest of U. S. Highway 277. (See Plate 15A.) A section measured at this locality is as follows:

	Thickness (feet)
Austin chalk:	
10. Limestone, massive, chalky, light-gray; interbedded with thin beds of marl	50
9. Marl, contains small irregularly shaped pebbles of limestone	$\frac{1}{4}$
Eagle Ford shale:	
8. Limestone, chalky, light-gray; surface is very irregular; contains worm borings filled with softer material that extends from top of bed downward as much as 10 inches; contains ammonites	$1\frac{1}{2}$
7. Marl, thin-bedded, chalky; contains ammonites	$\frac{1}{4}$
6. Limestone, chalky, clayey; contains ammonites	$\frac{1}{2}$
5. Marl, thin-bedded, light-gray; weathers buff; contains ammonites	2
4. Limestone, clayey	$\frac{1}{2}$
3. Marl	$\frac{1}{2}$
2. Limestone, subcrystalline, irregularly bedded, flaggy, interbedded with marl; some of the limestone beds pinch out within a short distance. Most of the limestone flags are 3 inches or less in thickness; thin-shelled Inoceramus sp. near top	7
1. (Covered to edge of water in Pinto Creek)	10
Total	$72\frac{1}{2}$

Because the worm borings in bed 8 and the limestone pebbles in bed 9 probably indicate an unconformity, bed 9 is believed to represent the lowermost bed of the Austin chalk.

The lower part of the Austin chalk is well exposed in a quarry a few hundred yards south of Las Moras Spring. (See Plate 15B.) Here the beds are rather massive and consist of light-gray chalky limestone separated by very thin layers of marl. These massive beds are characteristic of the lower part of the Austin in the outcrop in Kinney County.

Flaggy beds of limestone are present in the lower part of the Austin chalk in southwestern Kinney County on the Herbst Ranch. These flags are not as coarsely crystalline nor as brittle as the limestone flags in the Eagle Ford. According to Adkins (in Sellards, Adkins, and Plummer, 1932, p. 440-441) they may represent the flaggy limestone facies that is present in the Austin chalk from Val Verde County westward to beyond Terlingua in Brewster County.

The upper part of the Austin chalk is more clayey and thinner bedded than the lower part. It contains beds of impure limestone interbedded with marl or chalky clay. Most of the marl is chalky, but a few of the beds are similar to the marl of the overlying rocks. These upper beds of the Austin are well exposed in the area north and northeast of the west end of the Anacacho Mountains and in Agua de Fuera Creek north of Spofford.

Stephenson (1937, p. 133, 134) has subdivided the upper one-fourth of the typical Austin chalk in Travis County into five faunal zones. These zones in ascending order are the *Inoceramus undulato-plicatus* Roemer zone, 100 feet or more below the top of the chalk; the *Gryphaea wratheri* Stephenson zone, closely above the preceding zone; the *Exogyra tigrina* Stephenson zone, about 40 feet below below the top of the chalk, the *Ostrea centerensis* Stephenson zone, about 30 feet below the top of the chalk, and the *Ostrea travisana* Stephenson zone, about 10 feet below the top of the chalk.

In January 1941, Dr. Stephenson and the senior author examined the section of beds exposed in Agua de Fuera Creek, 2 miles north of Spofford. A section measured at this locality is as follows:

	Thickness (feet)	Thickness (inches)
Uvalde gravel:		
8. Caliche, very light gray, fine-textured, massive-bedded; grades into gravel upstream and downstream----------------------------------	20	
Austin chalk:		
7. Marl, gray, weathers buff; contains crinoid stems and *Inoceramus* prisms--------------------	8	
6. Limestone, clayey, glauconitic; weathers light buff; contains *Ostrea centerensis* Stephenson---		4
5. Marl, sandy, gray; weathers buff-----------------	3	
4. Limestone, clayey, glauconitic, light-gray, massive-bedded; weathers buff; more marly at base; contains *Exogyra tigrina* Stephenson at top and *Baculites* sp., *Inoceramus* prisms, and *Exogyra laeviuscula* Roemer near base-------	3	
3. Limestone, light-gray, massive-bedded; *Inoceramus* sp. abundant at top and small specimens of *Gryphaea aucella* Roemer present near base---------------------------------------	12	
2. Marl; contains *Gryphaea aucella* Roemer-----------		3
1. Limestone, chalky, light-gray; contains abundant *Gryphaea aucella* Roemer------------------------	1	
Total--	47	7

Inasmuch as the *Ostrea centerensis* Stephenson zone is about 30 feet below the top of the Austin chalk in Travis County, bed 7 in the above section probably is near or at the top of the Austin. Specimens of *Ostrea travisana* Stephenson found in the float a few hundred feet downstream from this locality indicate that the zone bearing the name of this oyster is nearby, probably at about its normal position above the *Ostrea centerensis* Stephenson zone.

The *Exogyra tigrina* Stephenson and *Ostrea travisana* Stephenson zones were seen on the south side of U. S. Highway 277, 0.3 mile east of Tequesquite Creek and at the west side of Tequesquite Creek about one-fourth of a mile north of U. S. Highway 277 in Maverick County. At these localities *Exogyra tigrina* Stephenson is in a rather massive chalky limestone about 2 feet thick. Large numbers of *Exogyra laeviuscula* Roemer are in and below this bed.

In Kinney County the thickness of the Austin chalk ranges from 0 to at least 1,030 feet. It increases westward toward the axis of the Rio Grande embayment. (See Plate 4.) The thickness of Austin chalk penetrated in the drilling of wells EE-2 and II-2 was 580 feet and 1,030 feet, respectively. Because both these wells are within the outcrop area of the Austin chalk, the original full thickness of the formation at the sites of these wells was somewhat greater. (See Plate 1.)

Fossils collected from the Austin chalk in Kinney County have not been studied systematically. The upper, very fossiliferous part of the formation includes such species as: *Inoceramus undulato-plicatus* Roemer, *Exogyra ponderosa* Roemer, *Exogyra laeviuscula* Roemer, *Gryphaea aucella* Roemer, *Baculites asper* Morton, *Texanites texanus* (Roemer), and *Barroisiceras dentato-carinatus* (Roemer).

The Austin chalk is the second most important aquifer in Kinney County. Records were obtained for 84 wells in Kinney County that obtain part or all of their water from it. Although most of these wells discharge enough water for only domestic or livestock purposes, 13 of them discharge sufficient water for irrigation. Of the 13, all are in the western half of the county, all are in the outcrop of the Austin, and 11 obtain water from the lower part of the Austin.

The water in the Austin appears to be contained in solutional openings and fractures which vary in size and number from place to place. The largest opening seen was in the bottom of a small stream channel 4-1/2 miles west of Brackettville, about one-half mile south of U. S. Highway 90 and one-third mile southeast of well V-14. (See Plate 16.) The opening is about 8 feet long, 3 to 4 feet wide, and at least 40 feet deep; it connects at the bottom with a north-trending passageway. It is reported that practically all the water that runs down the small channel goes into the opening, even during heavy rains.

The success of a water well drilled in the Austin chalk is governed chiefly on the number and size of openings that are encountered in the drilling of the well. In most of the wells the drawdown is large even though the discharge is small, indicating that the wells were not drilled through any large openings. For example, at well V-12, which is 135 feet deep, the water level recovered 9 feet during 70 minutes after the cessation of pumping 2 or 3 gallons per minute. On the other hand, well V-14, which is 50 feet from well V-12 and is only 50 feet deep, was drilled through several caverns and is reported to yield as much as 500 gallons per minute.

The largest discharge reported for a well in the Austin chalk was the 2,000 gallons per minute from well V-19. This well has a specific capacity of 71 gallons per minute per foot of drawdown. Two other wells, V-20 and V-21, which discharged 1,200 and 1,250 gallons per minute have specific capacities of 92 and 96 gallons per minute per foot of drawdown, respectively. In contrast, a number of unsuccessful wells have been drilled in the Austin chalk in Kinney County. Wells V-10 and V-26 did not yield enough water for livestock use, and it is reported that little or no water was encountered in the drilling of wells as deep as 400 feet between Elm Creek (east of Brackettville) and Agua de Fuera Creek, a short distance south of U. S. Highway 90. Apparently these wells were not drilled through solutional openings or fractures large enough to yield appreciable quantities of water.

Measurements of the water level in three observation wells in the Austin chalk in Kinney County have been made periodically since the late 1930's. (See Table 9.) The water level in wells V-14 and V-10, which are in the central part of the county, have fluctuated only slightly, and the net change in water level from 1938 to 1957 was slight. In the eastern part of the county in well FF-6, however, the water level has declined gradually and in March 1956 it was 20 feet below the level measured in March 1938.

Taylor Marl Equivalents

The name Taylor marl was applied by Hill (1892, p. 73) to a sequence of chalky clays in central Texas. The sequence is 1,200 feet thick and contains abundant *Exogyra ponderosa* Roemer. In Kinney County, the beds of Taylor age are represented by the Upson clay, the Anacacho limestone, and the San Miguel formation. The Anacacho limestone, which is present only in the eastern part of the county, is equivalent in part to the Upson clay, which is present only in the central and western parts of the county.

Upson Clay

The Upson clay was named for its exposure near the old Upson post office in Maverick County, Texas (Dumble, 1892, p. 224).

The Upson, which overlies the Austin chalk, crops out as a broad belt extending from the west end of the Anacacho Mountains southwestward to the Kinney-Maverick County line. Because it is overlain by the Uvalde gravel throughout much of this area, good exposures are rare. The Upson is easily eroded and in its area of outcrop generally forms a gently rolling to flat surface lying at a relatively low topographic level. In a few localities where streams have cut into it, the Upson is exposed in steep banks because the relatively resistant overlying Uvalde gravel protects it from erosion.

The soil developed on the Upson supports a rather heavy growth of mesquite, grass, cacti, and chaparral.

On Agua de Fuera Creek, from 1.5 miles northeast of Spofford downstream to the Southern Pacific Railroad, the Upson is not well exposed but probably consists chiefly of clay. Greenish-gray clay is exposed in Agua de Fuera Creek a few hundred yards south of the Southern Pacific Railroad, and greenish-gray clay that weathers buff is present above the marly chalk of late Austin age and beneath the Anacacho limestone at the west end of the Anacacho Mountains. In some localities the Upson contains thin seams of gypsum, and Udden (1907, p. 68) reports finding crystals of barite as well as the gypsum.

A section measured at the west end of the Anacacho Mountains, on the east bank of Elm Creek, 0.9 mile south of the Southern Pacific Railroad bridge over Elm Creek, is as follows:

	Thickness (feet)
Anacacho limestone:	
5. Limestone, thin-bedded; weathers buff------------------	5
4. Limestone, gray, massive; weathers buff----------------	8
3. Limestone, thin-bedded, very clayey; interbedded with marl--	10
Upson clay:	
2. Clay, greenish-gray; weathers buff---------------------	40
Austin chalk:	
1. Limestone, chalky, glauconitic, clayey, gray; contains phosphatized fossils and pebbles of phosphate---------	1
Total--	64

The Upson clay (bed 2) thins northward to the northwest corner of the Anacacho Mountains, and within a few miles it grades laterally northeastward into the Anacacho limestone. Throughout the Anacacho Mountains lenses of clay similar to the Upson are present at the base and at higher horizons in the Anacacho limestone; such clay lenses are believed not to be continuous with the Upson clay.

Thick beds of Upson clay containing Exogyra ponderosa Roemer are exposed in Elm Creek from 2.2 to 2.7 miles north of Maverick County. A few thin lenses of fossiliferous sandstone are present in the clay. Farther downstream the sediments are chiefly sandstone and interbedded marl which probably are of San Miguel age.

As much as 20 feet of clay which weathers buff is exposed south of the Anacacho Mountains in Strickland Creek about 3 miles north of Maverick County. The clay contains abundant Exogyra ponderosa Roemer.

The thickness of the Upson could not be determined by measuring sections. Udden (1907, p. 69) estimates its thickness as nearly 500 feet, his estimate being based on the dip of the formation along the Rio Grande and the width of the outcrop.

The Upson clay in Agua de Fuera Creek northeast of Spofford dips about 5° to the S. 30° E., and about 2 miles north of Maverick County in the west bank of the Agua de Fuera Creek it dips about 30° to the S. 30° E. The average dip of the Upson in the intervening stretch cannot be determined because the formation is too poorly exposed. In the absence of additional direct data, the average dip of the Upson was assumed to be the same as the regional dip of the Eagle Ford shale. The average dip of the Eagle Ford was determined by subtracting the altitude of the top of the Eagle Ford[6] in the W. A. Stephens Clamp No. 1 oil test (about 6-1/2 miles southeast of Spofford) from the altitude of the top of the Eagle Ford at Las Moras Spring. It was found that the dip is approximately 130 feet per mile, or

[6] Determined from data furnished by Mr. F. M. Getzendaner, Uvalde, Texas.

about 1-1/2 degrees. It is believed that these two points form a line approximately perpendicular to the general strike of the formations. Using 1-1/2 degrees for the average dip and the width of the outcrop of the Upson on Agua de Fuera Creek, the thickness of the Upson was computed to be about 750 feet.

The most common macrofossil in the Upson clay is the large oyster, Exogyra ponderosa Roemer. Ostrea saltillensis Bose, O. falcata Morton, O. panda Morton, Anomia argentaria Morton, and Cyprimeria depressa (Conrad) also have been identified from the formation.

Drillers report that several wells have been drilled into the Upson clay in its outcrop area, but all were dry or discharged only small amounts of highly mineralized water. The thin sandstone beds in the formation are lenticular, and if they contain water it probably is highly mineralized. In the area south and east of Spofford the ranchers construct earthen tanks on the outcrop of the Upson to impound storm water for domestic and livestock use.

Anacacho Limestone

The Anacacho limestone was named for its excellent exposure in the Anacacho Mountains in southeastern Kinney County (Hill and Vaughan, 1898b, p. 240-241). It unconformably overlies the Austin chalk, and the lower part is equivalent stratigraphically to the Upson clay and the upper part to the San Miguel formation.

The Anacacho limestone crops out in an area of about 50 square miles in the southeastern part of Kinney County. The resistant limestone caps the east-trending, north-facing escarpment which extends from the vicinity of Cline in Uvalde County westward to central Kinney County. This escarpment together with the highly dissected country to the south is known as the Anacacho Mountains. (See Plate 17A.) Deep canyons such as Mustang Canyon, Chilipotin Canyon, and Juan Canyon have been cut into the limestone. The formation supports a relatively heavy growth of cacti, guajillo, and scrub oak and other chaparral.

Nearly closed topographic basins called "fry-pan valleys" are an interesting feature of the outcrop area of the Anacacho. These valleys were so named by the cowboys because of their resemblance in shape to a frying pan (Hill and Vaughan, 1898b, p. 255). The wider or flaring upstream part of the valley constitutes the body or pan part of the fry pan, and the constricted downstream part of the valley forms the handle of the pan. The best examples of fry-pan valleys are Little Fry-Pan Valley and Big Fry-Pan Valley about 1/2 mile and 1-1/2 miles northeast of the Altizer ranch house, respectively.

The Anacacho limestone consists mostly of massive beds of hard subcrystalline limestone, many of which are composed chiefly of fragments of fossils. The limestone is bluish-gray but generally weathers dark to light buff. The weathered surface of some of the massive beds is characterized by miniature hills and valleys. (See Plate 17B.) Layers of clay are interbedded with the limestone beds. Although the clay layers generally are thin, they may thicken or pinch out in a short distance. Some of the limestone beds also change rapidly in lithologic character. A well-formed crystal of quartz was noted in a small cavity in a limestone bed on the north side of the Anacacho Mountains, about 6 miles northeast of the Anacacho ranch house.

The following section was measured by Hill and Vaughan (1898b, p. 241) at the northeastern corner of the Anacacho Mountains in Kinney County. According to Hill and Vaughan, the measurements are only approximately correct.

	Thickness (feet)
Anacacho limestone:	
8. Scarp-making rock, forming the top of the hill. It is hard, yellow, subcrystalline limestone. In the top a species of Alectryonia was found. About 30 feet below the top, great numbers of _Gryphaea vesicularis_ (Lamarck) occur firmly embedded	60
7. Softer limestone: _b_, Soft, yellow, marly limestone, containing a large species of Cardium, 50 feet; _a_, soft, white, chalky limestone, containing a species of Turritella with three prominent revolving striae on each whorl (_T. trilira_ Conrad ?), 30 feet; total	80
6. Hard limestone ledges. The upper 30 feet is brownish, and contains great numbers of _Exogyra ponderosa_ Roemer firmly embedded near the top. The next lower 20 feet is a yellowish granular limestone with glauconitic specks. This bed forms a platform on the east end of the Anacacho Mountains	70
5. Ledges of yellow, ferruginous, not very hard, subcrystalline limestone, forming the lower scarp on the east end of the hill	30
4. Slope. The upper part is composed of marly limestone and the lower part of yellow marls with fragments of a very large coarsely corrugated _Inoceramus_	20
3. Yellowish limestone, weathering into nodular chunks, iron stained along the weathering cracks. Contains some poorly preserved fossils _Trigonia_(?) sp., _Mactra_ sp., and a finely-ribbed species of _Lima_	10
2. Soft material containing fragments of a very large species of _Inoceramus_	5
1. Thin, very hard, brown, siliceous ledge	3 or 4
Total Anacacho limestone	279
Austin chalk:	
3. Hard brownish limestone, containing many _Gryphaea aucella_ Roemer	5
2. Hard chalky limestone	10
1. Unexposed to bottom of arroyo	20
Total Austin chalk	35

Sandstone is interbedded with limestone in the Anacacho on a small outlier 1 mile west of Uvalde County and 0.6 mile south of the Southern Pacific Railroad. A section at this locality is as follows:

	Thickness (feet)
Anacacho limestone:	
3. Sandstone, calcareous, brown, hard, massive-------------	4
2. Clay, buff. Contains near base, large pieces of calcite as much as 3 inches thick and 12 inches in length and width; the calcite is prismatic and is marked by approximately parallel shallow depressions--	10
Austin chalk:	
1. Limestone, chalky, light-gray; surface is undulate; contains Gryphaea aucella Roemer 29 feet below top----	40
Total--	54

As shown in the preceding section, the clay that overlies the Austin chalk contains thick slabs of prismatic calcite near its base. Similar slabs are present at the same horizon at the northeastern part of the Anacacho Mountains. Some of the calcite resembles parts of a large Inoceramus sp., but the prisms are not as well defined as those that generally occur in Inoceramus shells. One piece was found in which calcitic material protruded as small dikes in the parallel depressions that mark the surface of the calcite slabs.

At the east side of the Anacacho Mountains the Anacacho limestone contains lenticular beds of clay at several horizons. The clay is similar to the Upson clay.

A section at the contact between the Anacacho limestone and the Austin chalk, 1.6 miles east of Kinney County and 1.8 miles south of Cline in Uvalde County is as follows:

	Thickness (feet)	Thickness (inches)
Anacacho limestone:		
4. Clay; weathers buff------------------------------	5	
3. Limestone, glauconitic, coarse-textured, gray; contains small specimens of Gryphaea aucella Roemer--------------------------------	4	
Austin chalk:		
2. Marl, gray to buff; contains worm borings (?) and pebbles of glauconitic limestone-----------		10

	Thickness (feet)	(inches)
1. Limestone, glauconitic, chalky, light-gray; contains Gryphaea aucella Roemer, Exogyra ponderosa Roemer, ammonites, and Inoceramus sp.----------------------------------	50	
Total---	59	10

The Gryphaea aucella Roemer in bed 3 may be reworked from the Austin chalk and redeposited in the Anacacho limestone. The suggestion of worm borings in bed 2 indicates an unconformable relation between the Austin and the Anacacho. The absence of the Ostrea travisana Stephenson, Ostrea centerensis Stephenson, and Exogyra tigrina Stephenson zones in the Austin chalk at this locality and at the eastern part of the Anacacho Mountains in Kinney County, and their presence in the Austin chalk in Agua de Fuera Creek northeast of Spofford indicates that the contact of the Austin chalk with the overlying rocks of Taylor age is unconformable.

In a poorly exposed section 8 miles west of Uvalde County and 2 miles south of the Southern Pacific Railroad, 155 feet of Anacacho overlies about 100 feet of beds consisting chiefly of gray chalky limestone of Austin(?) age. A section at this locality is as follows:

	Thickness (feet)
Anacacho limestone:	
18. Limestone, finely crystalline, dark-brown, hard, massive; forms topographic bench----------------------	22
17. Limestone, chalky, soft; weathers light buff------------	12
16. Limestone, dark-brown, hard, massive; forms topographic bench-------------------------------------	3
15. Limestone, chalky, soft; weathers light buff------------	8
14. Covered--	5
13. Limestone, dark-brown, hard, massive; forms topographic bench-------------------------------------	2
12. Limestone, chalky, clayey, soft------------------------	10
11. Limestone, finely crystalline, light-buff, hard, massive; contains large Inoceramus sp.; forms topographic bench-------------------------------------	5
10. Marl, chalky, soft, grading to marly chalk; weathers light buff; softer at base------------------	10
9. Covered slope; marl on slope---------------------------	20

		Thickness (feet)
	8. Limestone, finely crystalline, very hard, light-buff, massive; forms topographic bench	18
	7. Limestone, chalky, hard, gray; weathers light buff	15
	6. Limestone, chalky, clayey, soft, gray; weathers light buff; forms slope	25
Austin(?) chalk:		
	5. Limestone, chalky, gray, soft; forms slope	15
	4. Covered	80
	3. Limestone, chalky, gray	5
	2. Covered	30
Austin chalk:		
	1. Limestone, chalky, gray; weathers light buff; contains large *Inoceramus* sp., ammonites, *Exogyra ponderosa* Roemer, and echinoids	5
	Total	290

Beds of the Anacacho limestone and Austin chalk are distributed erratically in an area about 150 yards in diameter on the south bank of Elm Creek, about 0.4 mile north of U. S. Highway 90 and about 7 miles north of the Anacacho Mountains. The beds in this small area are highly fractured and tilted at high angles. Because the area is surrounded by limestone of early Austin age, it is believed that the beds in this locality have been dropped down and preserved from erosion by the collapse of a cavern. At this locality the Anacacho limestone is a hard buff sandy limestone which contains *Exogyra ponderosa* var. *erraticostata* Stephenson. Abundant quartz pebbles, some as much as one-half inch in diameter, are embedded in the sandy limestone. Beds of Austin chalk containing *Exogyra ponderosa* Roemer and *Gryphaea aucella* Roemer are associated with and underlie the beds of sandy limestone. The beds of sandy limestone probably are fragments of the basal bed of the Anacacho limestone, indicating that an interval of erosion immediately preceded deposition of the Anacacho limestone. The same conclusion is drawn from the absence of the upper zones of the Austin chalk in the eastern part of the Anacacho Mountains.

The Anacacho limestone probably was formed as a reef. It is strongly crossbedded at the west end of the Anacacho Mountains; it is composed largely of shell fragments; and it abuts, rather than grades into, the Upson clay and San Miguel formation.

Asphalt in the Anacacho limestone in southwestern Uvalde and southeastern Kinney Counties was mined extensively for several years. As far as could be determined, however, the mines in Kinney County were abandoned prior to 1939. Sellards (in Sellards, Baker, and others, 1934, p. 253) states that the asphalt was formed when heat from igneous intrusions distilled the asphaltic tar out of underlying bituminous sediments. Sellards further states that the Anacacho contains the largest body of asphaltic limestone known; it probably is rivaled only by the deposits in the Lebanon region of Syria.

The total thickness of the Anacacho limestone could not be measured; however, it was estimated to be about 400 to 500 feet. As determined from a topographic map, the difference in altitude between the Austin-Anacacho contact at the east end of the Anacacho Mountains and the top of one of the highest peaks in the Anacacho Mountains, about 1-1/2 miles west, is about 350 feet. Because these two points are approximately on the strike of the formation, the Anacacho must be at least that thick. However, beds of the Anacacho younger than those on top of the peak crop out to the south; thus, the full thickness of the formation is greater than 350 feet. Udden (1907, p. 70) gives a thickness of about 400 feet for the Anacacho limestone, and Vaughan[7] states that the thickness of the Anacacho limestone is a little more than 400 feet.

The fossils of the Anacacho limestone in Kinney County have not been systematically collected and studied. The formation is more richly fossiliferous to the east in Uvalde and Medina Counties. Some of the more common species are *Exogyra ponderosa* Roemer, *Cardium* (*Pachycardium*) *spillmani* Conrad, *Turritella trilira* Conrad, and *Baculites asper* Morton.

In many places in Kinney County the Anacacho limestone yields enough water to wells for domestic or livestock purposes. Several springs issue from the formation in the Anacacho Mountains; spring LL-1 at the western end of the Anacacho Mountains discharges about 10 gallons per minute. About 0.6 mile west of the Altizer ranch house, an ephemeral spring issues at or near the contact of the Anacacho and the overlying San Miguel formation. This spring is reported to have a large discharge during periods of heavy rainfall.

Water in the Anacacho limestone is contained in solutional openings and in open fractures above clay beds. Therefore, in areas where fractures and solutional openings in the Anacacho are uncommon, most attempts to obtain water from it have been unsuccessful. Among the wells drilled without encountering water are well FF-7 and well FF-11, both of which were drilled completely through the formation.

San Miguel Formation

The San Miguel formation was named for its exposure near the abandoned village of San Miguel in Maverick County, Texas (Dumble, 1892, p. 224-230). It overlies the Upson clay and probably is equivalent stratigraphically to the upper part of the Anacacho limestone.

Some geologists have considered the San Miguel formation to be of Taylor age, and others have considered it to be of Navarro age. Vanderpool (1930, p. 252-258) believes the microfauna of the San Miguel and the stratigraphic break between the San Miguel and the underlying Upson clay indicate the San Miguel is of Navarro age. On the other hand, Stephenson (1931, p. 793-798) concludes that macrofauna in the San Miguel indicates late Taylor age. The U. S. Geological Survey also considers the San Miguel to be of late Taylor age. If known, the field relationship of the San Miguel formation to the Anacacho limestone could throw considerable

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[7] Vaughan, p. 84.

light on the age problem; but unfortunately, the contact between these formations is poorly exposed in Kinney County.

The San Miguel is exposed in southeastern Kinney County south and southwest of the Anacacho Mountains. Although the surface of the outcrop area is almost level, a few small hills stand above the level of the general land surface. Peloncillo Peak, one of these hills, is capped by hard sandstone beds of San Miguel age and by the Uvalde gravel.

Vegetation growing in the outcrop area of the San Miguel consists of a rather sparse growth, chiefly mesquite, chaparral, cacti, and grasses.

The San Miguel formation consists chiefly of hard calcareous sandstone and sandy limestone interbedded with clay. These materials are gray on fresh exposure but weather to a yellowish, greenish, or brownish tint. Much of the clay is similar to the Upson clay, and some of the sandy limestone resembles some of the beds in the Anacacho limestone. Many of the sandstone beds are fossiliferous.

Hard sandstone beds that dip about 3° SE. are fairly well exposed on the west side of Agua de Fuera Creek from the Maverick County line to about 2 miles north of the line. Some of the sandstone beds are as much as 2 feet thick and are very fossiliferous, containing small oysters, *Pecten* sp., other pelecypods, and many gastropods. The San Miguel is not exposed well enough for its base to be determined accurately; however, an exposure on Agua de Fuera Creek, a short distance downstream from an exposure of typical clay of Upson age, probably is near the base of the San Miguel. This exposure is on the west side of Agua de Fuera Creek, 1.9 miles north of Maverick County and 2.7 miles east of the branch line of the Southern Pacific Railroad which extends from Spofford to Eagle Pass. A geologic section at this locality is as follows:

	Thickness (feet)	Thickness (inches)
Uvalde gravel:		
6. Conglomerate, composed mainly of cobbles of limestone, quartzite, and igneous rock firmly cemented into a calcareous matrix-------	10	
San Miguel formation:		
5. Clay(?), sandy; poorly exposed------------------	8	
4. Sandstone, fine-grained, light-buff, friable; contains lenses of harder well-cemented sandstone and concretionary masses of hard dark-brown sandstone-------------------------	25	
3. Limestone, sandy, semicrystalline, dense, hard, brown; contains fossil oysters, pelecypods, small *Pecten* sp.-----------------------------		6
2. Sandstone, calcareous, light-gray, soft, fossiliferous--------------------------------		6
1. Clay, sandy-------------------------------------	10	
Total--	54	

The surface of bed 1 has a relief of about 1 foot in a horizontal distance of 5 feet; thus, the thickness of bed 2 varies by about the same amount.

Sandstone beds in the San Miguel are exposed on Peloncillo Peak where they are overlain by about 10 feet of Uvalde gravel. The sandstone beds at this locality are hard and consist in part of concretionary masses of sandstone as much as 6 feet long and 2 feet thick. Hard massive sandstone beds, probably in the San Miguel, are exposed in Elm Creek about 1-1/2 miles north of Maverick County. The beds in the creek a short distance north of this locality consists chiefly of clay with a few thin sandstone layers, and they probably are in the Upson.

Soft fossiliferous sandstone of San Miguel age is exposed about 1.4 miles north of Maverick County on Chapote Creek at the lower end of Peloncillo Peak. Thick beds of Upson clay are exposed from about 3 to 3-1/2 miles north of Maverick County on Strickland Creek. The beds between these exposures are covered; hence the contact on Plate 1 was drawn arbitrarily at about the midpoint between the two localities. Interbedded clayey sandstone and clay of the San Miguel are exposed on the east side of Chapote Creek, about 0.8 mile north of Maverick County. The sandstone beds contain calcareous geodes which are lined with quartz crystals. (See Plate 18A.) A specimen of *Placenticeras* sp. and several specimens of *Hamulus* sp. were observed at this locality.

On the east bank of Muela Creek, 1.6 miles north of Maverick County, sandy semicrystalline limestone, probably of the San Miguel formation, is exposed and apparently is in fault contact with the Anacacho limestone. (See Plate 18B.) Hence, the stratigraphic relations between the San Miguel and the Anacacho at this locality cannot be determined from the outcrops.

Near the Altizer ranch house the outcrop of the Anacacho limestone ends rather abruptly along a line that trends approximately east; the line is marked by a heavy growth of vegetation. It seems probable that the resistant Anacacho limestone would be exposed if it were present south of this line. Although the beds south of the line are so poorly exposed they cannot be identified, the field relationships suggest a fault. No further evidence of faulting was found. Conceivably, however, the straight-line contact might be caused by an abrupt change in facies from the Anacacho limestone on the north to the softer beds of the San Miguel on the south. Such an abrupt change in facies might cause ground water in the Anacacho to rise to the surface along the line between the limestone and the more impermeable beds of the San Miguel formation. The water would account for the heavy growth of vegetation along the line and also the presence of the wet weather spring 0.6 mile west of the Altizer ranch house. (See page 52.)

The thickness of the San Miguel formation was not measured because good exposures are lacking. Udden (1907, p. 73) gives the thickness of the San Miguel on Elm Creek as slightly more than 400 feet.

Stephenson (1931, p. 793-800) has given a detailed discussion of the faunal content of the San Miguel formation. Fossil species collected from the San Miguel by the writers during this investigation include: *Ostrea saltillensis* Bose, *Pecten simplicius* Conrad, *Cymella* cf *C. bella* (Conrad), *Turritella quadrilira* Johnson, and unidentified species belonging to the genera *Idonearca* (large), *Anomia*, *Cardium* (large), *Pugnellus* (large), and *Paladmete*.

The San Miguel is a poor source of water supply. Although the formation contains many sandstone beds, they are too impermeable to transmit large amounts of water. Mr. Mon Fenley of Uvalde reported that he drilled several wells between Elm Creek and Peloncillo Peak, about 2 to 3 miles north of the county line, and all the wells except one were dry. One of the wells yielded a small amount of water from a "sand rock," but the yield was too small for ranch purposes.

Well LL-3 probably draws water from the San Miguel. The water contains hydrogen sulfide, but livestock drink it. Well MM-7, which draws from the San Miguel, yields barely enough water for domestic use. The water level lowers considerably when the well is pumped and recovers very slowly when pumping ceases. Wells MM-3, MM-4, and MM-6 yield sufficient water for livestock, but the water is too highly mineralized for human consumption.

Navarro Group

The Navarro group in Kinney County is composed of the Olmos and Escondido formations. The Olmos consists of nonmarine sediments and according to Stephenson (1931, p. 798) partly fills the stratigraphic gap between the Taylor and Navarro rocks. The Escondido is the youngest formation of the Cretaceous system in this area.

Olmos Formation

The Olmos formation was named for the Olmos flag station and for Olmos Creek in Maverick County, Texas (Stephenson, 1927, p. 14). It is composed of nonmarine rocks which overlie the San Miguel and underlie the Escondido.

According to the Geologic Map of Texas published by the U. S. Geological Survey in 1937, the Olmos formation crops out at the Rio Grande near Eagle Pass in Maverick County and extends northeastward to about north-central Maverick County where it apparently pinches out. Stephenson (1927, p. 14) described the Olmos in Maverick County as consisting of greenish-gray shaly clay and fine sandy clay. Irregularly interbedded with the clay are fine to coarse greenish-gray thin-bedded to massive more or less crossbedded soft to hard sandstone and seams of coal and lignite. Some layers of the sandstone are ripple-marked. Samples of sandstone collected from the formation near Eagle Pass were examined by C. S. Ross, who reported that the sandstone is composed in part of waterlaid fragments of volcanic rock. The Olmos in Maverick County contains large pieces of silicified wood.

Gray to buff friable sandstone interbedded with gray clay crops out in the southernmost part of Kinney County in the west prong of Chaparrosa Creek, about one-half mile north of Maverick County and 4-1/2 to 5-1/2 miles west of Uvalde County. The beds are poorly exposed; hence, they could not be examined in detail. No macrofossils were found other than pieces of silicified wood as much as 2 feet in length and 1 foot in diameter. In order to determine whether this silicified wood was of the same age as that in the Olmos near Eagle Pass, specimens were collected from both localities by L. W. Stephenson and the senior author. These specimens were examined and compared by R. W. Brown, U. S. Geological Survey, who made the following report:

> 8905. Eastward flowing branch of Chaparrosa Creek, just north of Maverick-Kinney County line and 4-1/2 to 5-1/2 miles west of the SE corner of Kinney County, Texas.
>
> Coniferous wood, species not identified.
> *Palmoxylon* sp.
> Dicotyledonous wood, species not identified.
>
> Age: Very probably Cretaceous.

8906. Field north of abandoned mine of International Coal Mines Co., 2 miles north of Eagle Pass, Texas.

Coniferous wood, same as above.
Dicotyledonous wood, same as above.

Age: Cretaceous. Olmos formation.

8907. Small branch of Elm Creek, 3.9 miles NW of Eagle Pass, near Highway 85, Texas.

Coniferous wood, same as above.
Dicotyledonous wood, same as above.

Age: Cretaceous. Olmos formation.

In the foregoing collections, the fossil woods, although they have not been specifically identified, can nevertheless be identified as identical on the basis of their cellular structures. The coniferous wood is of the type commonly described as Cupressinoxylon and the dicotyledonous wood is like that usually referred to Laurinoxylon. These types of wood range upward from the Cretaceous into the later Eocene. The Palmoxylon is also a type of wood common from the Upper Cretaceous onward. However, the collection from locality 8905 is judged to be very likely of the same age as those from localities 8906 and 8907, because (1) the species are identical, (2) the strata are apparently at the same stratigraphic level, and (3) the occurrence of fossil wood at or near the same stratigraphic level in a local area points to simultaneity of similar conditions favoring silicification of wood.

South of the west prong of Chaparrosa Creek, the land surface rises to low hills capped by hard resistant sandstone beds in the Escondido formation. Thus the beds containing the silicified wood are at the stratigraphic position of the Olmos. In view of this fact and Brown's report, it is believed that these beds represent the Olmos.

The beds that are considered to belong to the Olmos formation could not be measured because of poor exposures. It is apparent from the topography and distribution of the younger and older formations, however, that the thickness of the Olmos in Kinney County is less than 50 feet.

No wells in Kinney County are known to draw water from the Olmos formation. Although some of the friable sandstone beds appear to be permeable enough to take in and transmit water, they may be lenticular and therefore not conducive to free circulation of water.

Escondido Formation

The Escondido formation was named for its exposure on the Escondido River below Eagle Pass, Maverick County, Texas (Dumble, 1892, p. 227). The Escondido in Kinney County unconformably overlies beds of Olmos age and is the youngest formation of the Cretaceous system.

No exposures of the Escondido formation were seen in Kinney County. However, the Escondido is exposed in Maverick County about 5 miles west of the southeastern corner of Kinney County and is believed to extend a short distance northward into Kinney County. The beds of hard sandstones in the Escondido are very resistant to erosion and in most places form relatively high ridges or hills.

Only the basal few feet of the Escondido are present in Kinney County. Where exposed in the northeastern part of Maverick County, however, the Escondido is composed of hard calcareous brown sandstone and shaly clay. Many of the beds are fossiliferous. Fragments of Ostrea cortex Conrad locally form beds of breccia several feet thick.

No wells in Kinney County draw water from the Escondido. However, several wells draw from the Escondido where it crops out on the Davidson ranch in Maverick County about 7 to 8 miles west of Zavala County and about 1 to 3 miles south of Kinney County. These wells are reported to discharge enough water for ranch purposes. About 0.8 mile west of Zavala County and 2.4 miles south of Kinney County, a well that draws from the Escondido discharges enough water for irrigation. This well also is on the outcrop of the formation. It is reported that the water fills fractures in the hard sandstone beds; the fractures probably extend over only a small area.

Tertiary(?) System

Rocks of the Tertiary and Quaternary systems are present in Kinney County and are described below, but they are not shown on Plate 1 because it was deemed more desirable to show the boundaries of the bedrock formations upon which they rest than to show their distribution.

Pliocene(?) Series

Uvalde Gravel

The Uvalde gravel was named for the coarse alluvial deposits that are present on the divides in the Coastal Plain area in Uvalde and Medina Counties (Hill, 1891a, p. 366-370).

The Uvalde gravel mantles the Cretaceous rocks throughout most of southern Kinney County west of the Anacacho Mountains. Its surface is a nearly smooth plain that slopes gently south-southwestward. The formation probably extends as far north as U. S. Highway 90 and possibly farther, but north of the highway it is poorly exposed in most places and apparently merges with Quaternary sediments. Agua de Fuera Creek has cut its valley completely through the Uvalde; east of the creek and north of the Southern Pacific Railroad the formation caps only the divides between the southward-flowing streams.

According to Vaughan[8], the highest point on the surface of the Uvalde gravel between Brackettville and Spofford is about 1,150 feet, and the altitude of the gravel at the southern margin of the quadrangle is about 950 feet. The altitude of the surface of the Uvalde gravel at the eastward-facing escarpment on the west side of Agua de Fuera Creek is about 960 feet, and north of the Southern Pacific

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[8] Ibid., p. 99.

Railroad between Spofford and the west end of the Anacacho Mountains the altitude is about 1,000 feet. On Peloncillo Peak, about 5 miles east of the eastward-facing escarpment on Agua de Fuera Creek, the surface of a gravel which contains pebbles and cobbles of acidic igneous rocks, and which is similar to the Uvalde gravel west of Agua de Fuera Creek, is about 1,000 feet above mean sea level.

In Kinney County the Uvalde gravel is composed primarily of well-cemented pebbles and cobbles of limestone, chert, and acidic igneous rocks, caliche, clay, and calcareous sandstone. In a few places cobbles of purplish quartzite and brown jasper were noticed. On the east bank of Agua de Fuera Creek, about 2-1/2 miles north of the Southern Pacific Railroad, is several feet of very light gray massive-bedded caliche containing only a few pebbles of quartz. Clay, conglomerate, and hard sandstone of the Uvalde are exposed at Tequesquite Spring (HH-8; see Plate 19). Sandstone and clay of the Uvalde also are exposed on the west side of Sycamore Creek at U. S. Highway 277.

In discussing the origin of the Uvalde gravel in Uvalde and Medina Counties, Sayre (1936, p. 66-67) stated:

> During most of the Tertiary period the area north of the Cretaceous-Eocene contact was exposed to weathering and erosion, so that by the end of this time the area was reduced to base level, and a deep soil was developed. In the Edwards limestone area the limestone at the surface was pretty thoroughly dissolved, but the chert in the limestone was left as residual nodules in the soil. Late in Pliocene time or perhaps early in Pleistocene time the first movement of the Balcones faulting occurred, and the Edwards Plateau was uplifted. As a result the streams, their carrying power increased by the increase of the gradient, moved large quantities of material from the Edwards Plateau. The finer material was carried far downstream. The coarser, predominantly chert gravel was spread out as alluvial fans south of the Balcones fault for a distance of many miles and was later covered by silt. Erosion has removed most of the gravel and cut valleys into the ancient plain, leaving the gravel-capped divides as remnants. The gravel and silt capping the divides constitute the Uvalde gravel.

Most of the Uvalde gravel in Kinney County was derived from the Edwards limestone. However, the presence of cobbles of acidic igneous rock unlike any of the native igneous rock in the county suggests that at least a part of the Uvalde may have been transported from considerable distance, possibly from the Trans-Pecos area in west Texas. Getzendaner (1931, p. 129) found round acidic igneous pebbles on the ridges south of Cuevas Creek in the southern part of Maverick County which he concluded came from the Trans-Pecos area south of Alpine or from the Burro Mountains in northern Mexico. Purplish quartzite pebbles were found much farther north than the pebbles of acidic igneous rock; thus it seems possible that the quartzite pebbles may have come from the Llano uplift region in central Texas.

The average and maximum thicknesses of the Uvalde gravel are difficult to determine because good exposures are rare. About 10 feet of the Uvalde gravel is exposed on Peloncillo Peak and along the eastward-facing escarpment on the west side of Agua de Fuera Creek. According to the drillers' logs, wells S-2 and BB-1 were drilled through about 25 feet of brown gravel and about 50 feet of caliche and gravel, respectively. These sediments probably are of Uvalde age. In well HH-7, near the southwestern corner of the county, sand and gravel were reported to a depth of 66 feet. The Uvalde gravel probably ranges in thickness from 0 to as much as 75 feet in Kinney County.

Little is known about the water-bearing properties of the Uvalde gravel in Kinney County. Logs are available for only a few wells drilled through the Uvalde. Furthermore, the gravel is underlain by the Austin chalk in a considerable part of this area, and it is not possible to determine whether wells draw water from the Austin chalk or the Uvalde gravel. For example, it is reported that water in sand and gravel was encountered at a depth of 65 feet in the drilling of well HH-7. However, the well was drilled to a depth of 94 feet, and very possibly part of the water discharged by the well is from the Austin chalk. In several places, however, the Uvalde is known to yield sufficient water for domestic or livestock use. Tequesquite Spring (HH-8; Plate 19) issues from the Uvalde gravel, and wells BB-7, II-1, II-3, and II-4 probably draw from the Uvalde. Water seeps out of the Uvalde gravel on the north bank of Mud Creek a short distance above its confluence with Sycamore Creek.

Quaternary System

Pleistocene Series

Leona Formation

In its type locality along the Leona River in Uvalde County, Texas, the Leona formation consists of fine calcareous silt grading downward into coarse gravel. As originally described by Hill and Vaughan (1898b, p. 253-254, 275-276), it includes the unconsolidated deposits underlying the flood plain of the Nueces and Leona Rivers and the similar deposits underlying the bordering wide terrace. These deposits are below the level of the Uvalde gravel and extend westward from Uvalde to the Nueces River.

In Kinney County the boundary between the Leona formation and the Uvalde gravel is indefinite because the two formations merge upstream and are composed of practically the same material. In the present investigation no attempt was made to map the area underlain by the Leona formation.

Vaughan[9] states that the Leona formation

> ...forms the high terrace above the present flood plain deposits and below the surface of the Uvalde gravel. Near the streams it stands 30 feet or more above the stream beds but it reaches elevations of 70 or 100 feet above the streams along the margins of the valleys. Where it is typically developed it occupies a position intermediate in height between that of the Uvalde gravel and that of the present flood plain, but as the canyons are approached the surface of the Leona formation rises more rapidly than that of the Uvalde causing a mergence in the height of the two surfaces.

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[9] Vaughan, op. cit.

> Topographically, the areas occupied by the Leona formation are very level, forming open prairies upon which mesquite bushes, the principal shrub, are sometimes thickly crowded together. Within the Brackett quadrangle it extends up the canyons of the East and West Nueces, and the extensive areas of alluvium occurring along the creeks near the southern margin and southwestern corner of the quadrangle are probably referable to it. It extends along the valley of Chacon Creek, up Agua de Fuera Creek and along Elm Creek at the west end of the Anacacho Mountains.

In Kinney County the Leona formation underlies the broad terrace that borders the flood plain of the Rio Grande. It also underlies the narrower terraces in the valleys of Sycamore and Las Moras Creeks. Northwest of Brackettville the Leona probably underlies most of the broad plains adjacent to the streams.

According to Sayre (1936, p. 68),

> The deposition of the Uvalde gravel was followed by a period of erosion during which streams cut valleys into the Reynosa (Uvalde) and then began to widen these valleys to their present width. A second uplift of the plateau or possibly a change in climatic conditions gave new life and erosive power to the streams, and again large quantities of gravel were moved along and spread out as alluvial fans just south of the Balcones escarpment and carried down the streams to cover the floors of the valley. This gravel was largely limestone, because the period between the first uplift, which caused the deposition of the Uvalde, and the second uplift or change in climatic conditions, which caused the deposition of the Leona, was too short for weathering to produce a residual soil containing chert in the Edwards limestone area. Consequently the Edwards limestone was attacked by erosion directly, and a limestone gravel resulted. A period without uplift has followed, and streams have cut into the present terrace of Leona age and are now spreading and reworking the gravel over their flood plains.

The gravel south of the Anacacho Mountains and east of Agua de Fuera Creek probably is the Leona formation. It lies at a lower level and seems to have been derived from the extensive body of gravel believed to be the Uvalde gravel. The Pleistocene gravel deposits are thin and appear to be alluvial fans extending southward from the Anacacho Mountains.

In Kinney County the Leona formation is composed of silt and gravel with lesser amounts of caliche. The gravel consists largely of limestone. The Leona is well exposed as an extensive body of gravel, silt, and caliche in the vicinity of Pinto Springs, between Pinto and Elm Creeks. A fragment of a tooth, probably from a large mammal related to the elephant family, was the only fossil found in the Leona. The site of the find was on a tributary of Chaparrosa Creek, about 5 miles west of the southeastern corner of Kinney County and about one-half mile north of Maverick County.

The exact thickness of the Leona formation in Kinney County could not be measured. The maximum thickness is estimated to be about 30 feet near the streams. Toward the margins of the valleys the formation thins to a featheredge.

The Leona formation is known to yield water to wells in some parts of the county. However, it was not always possible to determine whether the wells obtained water from the Leona formation or the Recent alluvium. For this reason, the water-bearing properties of the two formations are discussed together under the Recent series, and in Table 7 the "water-bearing unit" for wells drawing from both formations is shown as Quaternary.

Recent Series

Practically all the stream valleys in Kinney County contain alluvium which probably is of Recent age. The alluvium consists of silt, sand, clay, and gravel. The streambed of the West Nueces River contains cobbles and boulders derived chiefly from the Edwards limestone. (See Plate 20.) Sycamore Creek at the west edge of Kinney County likewise contains large deposits of limestone cobbles and boulders of Recent age. Most of the youthful streams draining the Edwards Plateau contain considerable quantities of gravel derived from the Edwards Plateau. Likewise, many of the streams draining the Anacacho Mountains contain cobbles and boulders of limestone derived from the Anacacho limestone.

The exact thickness of the alluvium in Kinney County could not be measured. The alluvium underlying the bed of the West Nueces River may be as much as 50 feet thick.

Much of the Recent gravel in the valleys of the West Nueces River and Sycamore Creek probably is water-bearing, and in both valleys many pools of surface water normally are connected only by underflow through the Recent alluvium. According to Sayre (1936, p. 70) the deposits underlying the several smaller terraces below the Leona terrace along the Nueces River yield water to wells.

The Leona formation and Recent alluvium yield water to many wells. Most wells are dug wells, and they yield sufficient water for livestock or domestic use. Because of the thinness of the sediments, however, some wells are reported to go dry during severe droughts. (See wells E-7 and L-4 in Table 7.) Well E-3, a drilled well, draws from stream gravel and is reported to have been bailed at 20 gallons per minute without a noticeable lowering of the water level.

Igneous Rocks

Igneous intrusions are common along the Balcones fault zone between Austin and Del Rio. These igneous masses were studied and described by Lonsdale (1927).

The igneous rocks in Kinney County crop out on both the Edwards Plateau and the Coastal Plain. All are intruded into Cretaceous rocks, some being concordant and others discordant with the bedding planes. Most of the igneous masses form high hills, but a few are practically level with the surrounding land surface. In most places the soil developed on the igneous rocks supports a heavy growth of guajillo, chaparral, cacti, and grasses.

The structural position or type of occurrence of the igneous masses is difficult to determine because in most places the contact between the igneous rock and the intruded sedimentary rock is covered by detrital material. However, at a few localities the rocks are exposed well enough for the type of occurrence to be established with reasonable certainty. At some localities the magma intruded the Cretaceous rocks and spread laterally between the bedding planes to form sheet-like bodies called sills. Erosion has left only isolated remnants of the sills.

All the important exposures of igneous rocks in Kinney County are shown on Plate 1 and are described below. Petrologic descriptions are by C. S. Ross of the U. S. Geological Survey.

Las Moras Mountain, 3-1/2 Miles North of Brackettville

The basalt that caps Las Moras Mountain probably is an erosional remnant of a sill. (See Plate 21A.) The basalt is about 95 feet thick and its contact with the underlying Austin chalk is a nearly level plane. The Austin chalk at the contact has been metamorphosed to a hard dark-gray finely crystalline limestone. Igneous rock probably capped the small hill on the west side of Las Moras Mountain but was removed by erosion.

Hill 1-1/2 Miles North of Las Moras Mountain

The 90 feet of basalt which caps this hill overlies the lower part of the Eagle Ford shale. The structural position of the igneous rock could not be determined because the contact of the basalt with the sedimentary rock is not well exposed. According to Vaughan[10] this mass of igneous rock appears to be a boss (an irregular knoblike mass).

A sample of basalt from this hill contains phenocrysts of olivine and magnetite. The groundmass is composed of euhedral augite grains in a nearly isotropic matrix of material that probably is altered nepheline. The rock may be best classified as a nepheline basalt.

Hill South Side of Pinto Creek, 7 Miles North of Brackettville

The basalt capping this hill is about 15 feet thick and overlies the Eagle Ford shale[11]. The Eagle Ford is metamorphosed near its contact with the igneous rock and has a "baked" appearance. Because the contact of the igneous rock and the sedimentary rocks forms a nearly level plane, the igneous rock is believed to be an erosional remnant of a sill or possibly of a laccolith (an intrusive mass that has domed up the overlying rocks).

A sample of igneous rock from this hill contains phenocrysts of augite and olivine in a groundmass of augite, calcic feldspar, nepheline, and magnetite. The feldspar is in larger grains and is more abundant than in the sample obtained from the hill 1-1/2 miles north of Las Moras Mountain. A little brown biotite is present. The rock may best be classified as a nepheline basalt.

Pinto Mountain, 8-3/4 Miles North of Brackettville

Basalt about 100 feet thick caps the two peaks of Pinto Mountain and at one time probably also covered the small hill on the north side of Pinto Mountain. (See Plate 21B.) The Eagle Ford immediately underlying the basalt on the north

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10/ *Ibid.*, p. 114.
11/ *Ibid.*, p. 113.

side of Pinto Mountain is metamorphosed and has a "baked" appearance. The contact of the igneous rock and the underlying sedimentary rock is not well exposed, but in general it seems to be about level. The igneous rock is probably an erosional remnant of a sill which intruded the Eagle Ford.

A sample of igneous rock from Pinto Mountain is petrologically similar to the sample obtained from the hill on the south side of Pinto Creek.

Elm Mountain, 7 Miles
East of Brackettville

The basalt capping Elm Mountain overlies the lower part of the Austin chalk. On the south side of the hill the basalt is about 10 feet thick, and on the north side it is about 40 feet thick. On the south side of the hill the basalt and the Austin chalk form a straight-line contact trending about N. 68° E. Because the contact between the basalt and the Austin chalk is about 30 feet lower on the north side of the hill than on the south side, and the contact on the south side of the hill forms a straight line, the rocks seem to have been faulted with the downthrown side on the north. The Austin chalk close to the contact of the basalt has been baked and altered to a dark-gray brittle crystalline limestone. The structural position of the igneous rock at Elm Mountain could not be determined, but apparently the basalt is an erosional remnant of a sill.

A sample of the igneous rock from Elm Mountain is similar to the sample from the exposure 9 miles northeast of Brackettville, but the magnetite is in larger grains. It contains a small amount of very fine-grained interstitial nepheline, but plagioclase is absent. The rock may best be classified as a nepheline basalt.

Igneous Mass on Peterson Ranch
About 9 Miles Northeast of
Brackettville

This mass of basalt (shown northeast of well Q-1 on Plate 1) has been eroded practically to the level of the surrounding land surface and forms a nearly circular ground pattern. Where the contact of the igneous rock with sedimentary rock is exposed, the igneous rock is in contact with the Eagle Ford shale. On the northwest and west side, however, the igneous rock appears to be in contact with a block of coarsely crystalline limestone that is considered to be either the Edwards or Georgetown limestone. (See Figure 4.) Only a few feet of Eagle Ford shale lies between the basalt and the Buda limestone. The Eagle Ford is apparently in normal contact with the Buda limestone except on the north side of the mass where the Eagle Ford is in fault contact with the Grayson shale. Where exposed, the Eagle Ford shale and Buda limestone dip toward the igneous mass. The block of Edwards or Georgetown limestone on the west and northwest side of the basalt obviously is not in normal formation sequence because it overlies the Eagle Ford shale.

The structural attitude of the adjacent Cretaceous rocks suggests that when the magma ceased its upward movement the roof of sedimentary rocks collapsed as they were not able to support their own weight. Thus the beds at the sides of the igneous body dip inward toward the center of the mass. The block of Edwards or Georgetown limestone at the west and northwest side of the basalt probably was dislodged by the stopping action of the magma and carried upward and "frozen" at its present position. (See geologic section in Figure 4.) Owing to the subcircular ground pattern of the igneous body and to the probability that it intrudes the

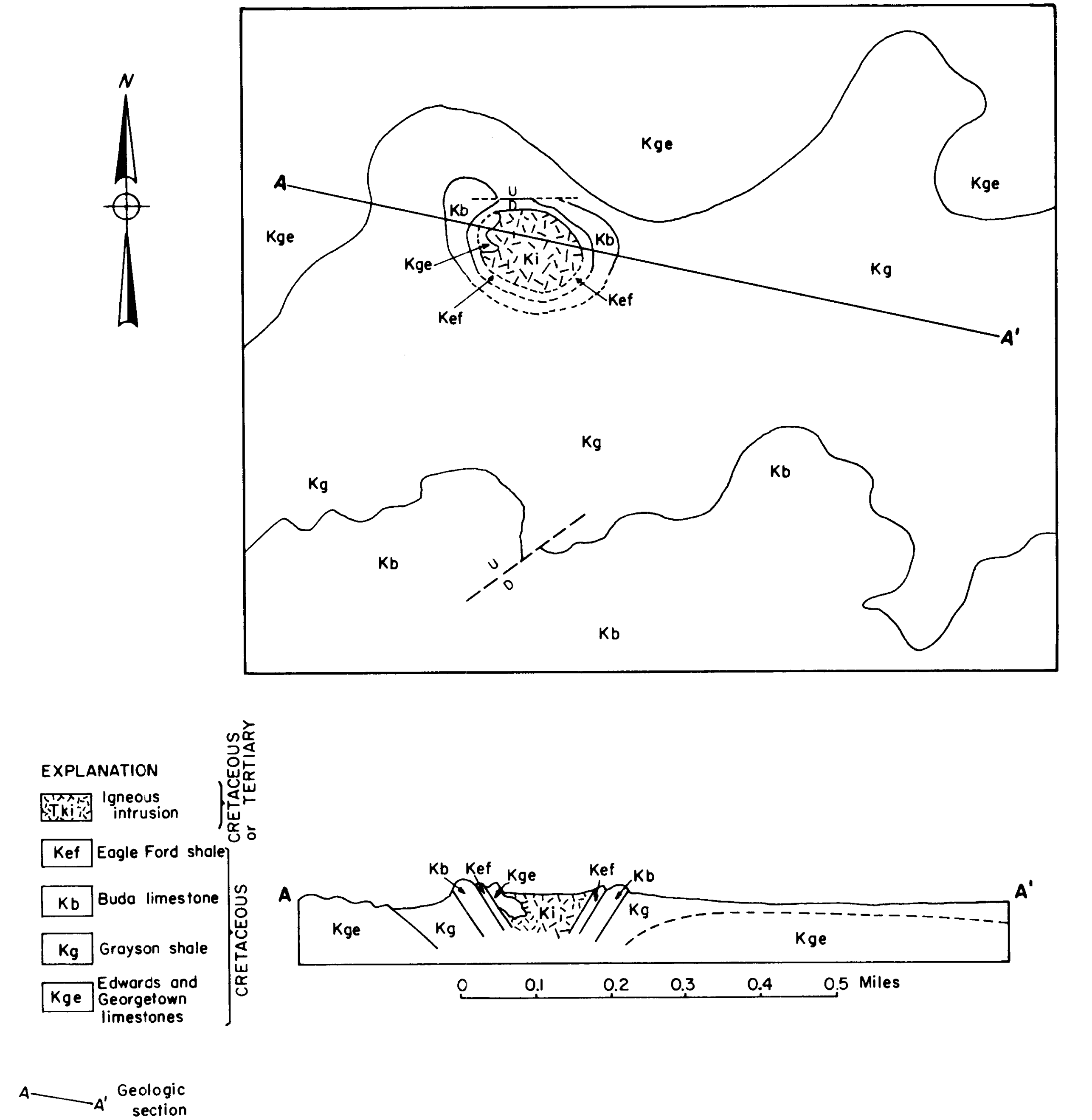

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FIGURE 4.- Areal geology in vicinity of igneous intrusion on Peterson Ranch, 8.8 miles northeast of Brackettville Post Office, and hypothetical section through the intrusion

Cretaceous rocks across bedding planes, it seems proper to classify this igneous mass as a boss.

A sample from this igneous mass contains phenocrysts of olivine and augite in a fine-grained groundmass of augite, plagioclase, nepheline, and magnetite. Augite is dominant over the sparse plagioclase. A very fine-grained material between the augite in the groundmass is nepheline. The rock may best be classified as a nepheline basalt.

Palmer Hill, 5-1/2 Miles
Southeast of Brackettville, at
South Side of U. S. Highway 90

Palmer Hill is capped by basalt that is in contact with the lower part of the Austin chalk. The basalt probably was present at one time on the hill about one-half mile north of Palmer Hill because in places the chalk at the surface of this hill is baked and somewhat altered in appearance. In general, the Austin chalk is is rather flat lying, but in localized areas near Palmer Hill it is tilted gently to strongly in different directions. Because the contact of the basalt and the Austin chalk is poorly exposed, the type of occurrence of igneous rock could not be determined. Lonsdale (1927, p. 13) considered the basalt at this locality to be a remnant of a sill.

A sample of the igneous rock at Palmer Hill contains phenocrysts of olivine and lesser amounts of augite (pigeonite type) in a groundmass of augite, plagioclase, magnetite, and a little biotite. The rock is very similar to a sample obtained from the nepheline basalt exposed on the Peterson Ranch about 9 miles northeast of Brackettville, but is coarser grained and slightly more feldspathic. Nepheline fills spaces between the augite and plagioclase of the groundmass.

Igneous Mass About 1 Mile
West of Elm Creek on U. S.
Highway 90

This body of basalt is about one-half mile northwest of the center of Palmer Hill. The basalt forms an approximate rectangle about 200 yards long and about 50 yards wide and is about level with the surrounding land surface. It trends about N. 15° W. and is in contact with the Eagle Ford shale on all sides at the land surface. The rectangular shape of this igneous body suggests that it may be a dike.

Igneous Rock 7.7 Miles South of
the North County Line and 4.7 Miles
West of the East County Line, About
0.2 Mile North of the Old Tularosa
Post Office

This igneous body is poorly exposed but probably is rather extensive. Aerial photographs show that a narrow zone of heavy vegetation extends about 6 miles S. 75° W. and about 1 mile N. 60° E. from the igneous body. The ground surface in this zone is partly covered by baked limestone, quartz, and limonite. Where the igneous rock is exposed, it is in contact with Edwards limestone and the Edwards has been baked and metamorphosed to a dark-gray coarsely crystalline limestone. However, some of the limestone has a "sugary" texture and is lighter colored. It seems reasonably certain that the igneous rock is a dike which is only partly exposed at the land surface. This is the only igneous mass seen on the Edwards Plateau in Kinney County.

A sample of the igneous rock from this exposure is composed of altered plagioclase, augite (pigeonite type), green hornblende, magnetite, and probably nepheline. The augite is fresh and the green hornblende nearly so, but most of the feldspar is altered to an isotropic mass. The nepheline(?) is completely altered to a fibrous aggregate. The secondary materials probably consist in part of zeolites. The rock originally may have been a nepheline syenite.

Turkey Mountain, 13.5 Miles East
of Brackettville and 5.3 Miles
West of Uvalde County

Turkey Mountain, the highest igneous hill in Kinney County, stands about 400 feet above the surrounding land surface and is capped by about 200 feet of basalt. The contact of the basalt with the underlying Eagle Ford shale is poorly exposed, and consequently the thickness of the basalt could not be determined accurately. Vaughan[12] reports that basalt crops out in a ravine on the southwest side of the hill. The altitude of the outcrop is 1,480 feet or 320 feet below the top of the hill; however, the basalt possibly has slumped from a higher level. Lonsdale (1927, p. 14) considers the basalt at Turkey Mountain to be an erosional remnant of a sill.

Well R-6, 1 mile northeast of the center of Turkey Mountain, was drilled through 150 feet of basalt. The well is in a zone of thick vegetation less than 100 yards wide and about 3 miles long. (See Plate 22.) This zone trends about N. 60° E., and from it smaller zones of thick vegetation branch off to the northeast, east, and south. The Edwards limestone is exposed a short distance northeast and south of well R-6. In the exposure east of the well, the Edwards limestone has been metamorphosed and has a baked appearance, being dark gray and crystalline. The zones of thick vegetation may overlie dikes that have intruded the Edwards limestone.

Other igneous masses are doubtlessly present in Kinney County, but erosion has not yet removed the rock that covers them or they are mantled by alluvium. According to Vaughan[13], a well about 3 miles southwest of Turkey Mountain on the east fork of Elm Creek was drilled through amygdaloidal basalt and into the underlying Edwards limestone, which is cavernous and water bearing.

Evidence indicates that considerable igneous activity occurred in the area of the Balcones fault zone during the Cretaceous period, possibly as early as Eagle Ford time. Bentonite is present in the Eagle Ford shale in Kinney County, but it may not be related to the volcanic activity of the area inasmuch as volcanic ash may be transported long distances. In this general area, however, deposits of sedimentary serpentine are present in the Eagle Ford shale, Austin chalk, and the beds of Taylor age. Hence it appears that at least some of the igneous masses were formed in the early part of the Late Cretaceous and existed as islands during the deposition of the Eagle Ford, Austin, and sediments of Taylor age.

The youngest formation intruded by igneous rock in Kinney County is the Austin chalk. However, in Uvalde County the youngest formation intruded by igneous rock is the Escondido formation (Sayre, 1936, p. 27). Evidently, therefore,

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[12] Ibid., p. 116.
[13] Ibid.

some igneous intrusion took place either during the deposition of the Escondido formation or after the Escondido was laid down. It appears then that at least some of the igneous activity occurred at the end of the Cretaceous period or possibly early in the Tertiary period.

Structural Geology

Although, in general, the geologic structure in Kinney County is relatively simple, in detail it is somewhat complex. The average dip of the strata is about 80 feet per mile to the south or southeast, but in some places the dip differs considerably within a short distance, and in other places it has been reversed. In places faulting breaks the continuity of the beds, and in other places structural movements associated with the intrusion of igneous masses or the collapse of underground caverns have warped and tilted the strata. The overall structural relations are shown in four cross sections (Plates 2, 3, and 4) across the county along the lines A-A', B-B', C-C', and D-D', which are shown on the geologic map (Plate 1).

In the northern part of Kinney County the southward dip of the strata is only a few feet per mile, but along a line a few miles north of Brackettville the dip abruptly increases to more than 100 feet per mile. Because of the greater dip, the Edwards and associated limestones, which are exposed on the Edwards Plateau, are progressively deeper beneath the land surface in a southward direction and they are replaced at the surface by less resistant younger beds. Since the flexure occurred, erosion has removed the younger rocks more rapidly than it has the Edwards and associated limestones and has produced the southward-facing Balcones escarpment. This escarpment forms the boundary between the Edwards Plateau and the Coastal Plain. In Kinney County the earth movements that caused the flexure were relatively slight; and although faults are numerous, they are of small extent and displacement. East of Kinney County the earth movements were much stronger, and the Balcones escarpment nearly coincides with a series of faults of large throw.

Kinney County lies in the northern part of the Rio Grande embayment, a geosyncline that existed during Cretaceous and part of Cenozoic time (Sellards, Baker, and others, 1934, p. 40-41). The marked westward thickening of some of the Cretaceous rocks in Kinney County (Plate 4) indicates that the axis of the embayment lies west of Kinney County.

During the course of the investigation, many small flexures were noted. A broad low syncline trends northward near the Laguna-Brackettville road crossing on the West Nueces River. The flaggy-bedded section of the Edwards limestone is exposed at river level near the crossing but is higher both to the east and to the west. According to Deussen (1924, p. 127) the Uvalde-Kinney County line is close to a gently southward-pitching syncline.

An anticline named the Brackett anticline by F. M. Getzendaner trends northeast from the vicinity of well W-1, approximately 2 miles north of Brackettville. It crosses the Silver Lake road just north of Las Moras Mountain and extends beyond well P-2 for a total distance of at least 10 miles. The Buda limestone is exposed in the vicinity of well P-9 in a narrow strip nearly 2 miles long and extending northeastward across the Rock Springs-Brackettville road. The outcrop is surrounded by the outcrop of the Eagle Ford shale. Doubtless the Buda limestone was exposed here by erosion of the crest of the Brackett anticline. The outlier of Buda limestone and Grayson shale to the west of the Silver Lake road about 10 miles north of Brackettville is on the northwest flank of this anticline, and the long northeast-trending tongue of the Buda limestone capped in part by Eagle Ford shale, which lies between Pinto and Elm Creeks, also may be on the flank of the Brackett anticline.

Another anticlinal structure trends north-northeastward through a point on U. S. Highway 90 about 9 miles east of Brackettville. The Eagle Ford shale crops out much farther south in this locality than in the adjacent areas to the east and west. The rocks dip eastward on the east side of Arenosa Creek, which is apparently on the east flank of the structure. The Eagle Ford-Austin contact is exposed near U. S. Highway 90 on the east side of Arenosa Creek at an altitude of about 1,120 feet, and about 3 miles due west of this point the contact is at an altitude of about 1,100 feet. However, between these two localities the Eagle Ford shale crops out at an altitude of as high as 1,175 feet.

About 4 miles north of the Laguna-Brackettville road, in the valley of Liveoak Creek, the rocks dip gently to the north. This reversal of the general southward dip probably indicates a northeasterly trending anticline.

A broad anticline described by Stephenson (1922) extends eastward from Del Rio in Val Verde County into western Kinney County. At the Kinney-Val Verde County line, near the Southern Pacific Railroad bridge, the rock strata dip to the north and the Buda limestone is exposed in Sycamore Creek. North and south of this exposure of Buda, the Eagle Ford shale crops out in the bed of Sycamore Creek. A syncline probably lies north of this anticline, crossing Sycamore Creek about 1 mile north of the Southern Pacific Railroad.

Between U. S. Highway 277 and the Rio Grande, an anticline trends northwest approximately parallel with the Rio Grande. The anticline is indicated by the northward-dipping Austin chalk in Sycamore and Pinto Creeks near Highway 277. In Pinto Creek, south of Highway 277, the Eagle Ford shale is exposed as an inlier within the Austin chalk. (See Plate 1.)

In places north of the west end of the Anacacho Mountains the Austin chalk dips slightly to the north, indicating a reversal of dip and possibly an anticlinal structure. Small structural anomalies are present in the Anacacho Mountains also.

Within the Eagle Ford shale are many folds not more than a few feet wide. Most of the folds seen by the writers were on nearly flat exposures of the Eagle Ford; however, a few were seen in vertical exposures also. (See Plate 23A.) These miniature anticlines may be a result of differential compaction of the sediments or, possibly, of the wetting and consequent expansion of bentonitic material in the Eagle Ford.

Most of the sill-like intrusions do not appear to have greatly affected the structure of the rocks even in the immediate vicinity of the intrusive body. However, the intrusion near well Q-1 on the Peterson Ranch, 8.8 miles northeast of Brackettville, is an exception to the general rule. Here the structure of the rocks has been greatly altered and the deposits into which the igneous rocks were intruded appear to have slumped into the igneous mass. (See Figure 4.)

The steep dips of the rock strata around the sides of Turkey Mountain may be the result of slumping rather than structural deformation.

These are many small faults in Kinney County. All the faults are normal, and most are less than a mile long. (See Plate 1.) The intersection of most of the fault planes with the land surface is a straight line; however, the intersection of a few of the faults curves slightly. The downthrown side of most faults is on the southeast, but some of the faults are downthrown on the northwest. The throw ranges from a few feet to about 75 feet. The vegetation along the fault planes is generally denser than in the surrounding areas; therefore, many faults may be detected by the differences in vegetation. (See Plate 23B.)

The orientation of the faults mapped is shown in Figure 5. Of the 112 faults mapped all except 9 trend in a northeasterly direction, and more than half trend between N. 45° E. and N. 80° E. Although other faults certainly are present but were not mapped, the orientation shown in Figure 5 probably is representative of the general orientation of all of the faults in the area.

Most of the faults probably are tension faults resulting from a relative subsidence of the area to the southeast. However, some of the faults may have been formed by the collapse of caverns in the Edwards limestone. For example, on the east bank of the West Nueces River, about 17-1/2 miles northeast of Brackettville, a block of Grayson shale and Buda limestone was dropped to a level at least 300 feet below the top of the Edwards limestone. On the south side of Elm Creek, about 6 miles east of Brackettville and 0.5 mile north of U. S. Highway 90, a block of Anacacho limestone surrounded by Austin chalk is present at a level near the base of the Austin chalk. The beds are highly fractured and dip at high angles; consequently it is reasonably certain that the Anacacho limestone was dropped into a large cavern probably developed in the Edwards limestone or the Austin chalk.

On the Peterson ranch, about 10 miles northeast of Brackettville and about 0.6 mile south of the Laguna-Brackettville road, Eagle Ford shale is exposed in the center of a large subcircular depression with Buda limestone exposed around the sides at a higher altitude. (See Plate 24.) The beds around most of the perimeter dip toward the center of the depression; in some places the beds are faulted. This depression also probably was caused by the collapse of a solutional cavern in the underlying Edwards limestone.

GROUND WATER

General Principles of the Occurrence of Ground Water

Below a level known as the "water table," water fills the pore spaces, fissures, and cavities in the soil or rocks beneath the surface of the earth. The total volume of these openings in relation to the total volume of the material is called the porosity. In uncemented rocks such as the Uvalde gravel or the Leona formation, these openings consist of the interstices between the individual particles that constitute the rock. In igneous intrusives, and in strongly cemented or compacted rocks, such as the Edwards and associated limestones, Grayson shale, Austin chalk, and Upson clay, the openings consist chiefly of cavities formed by solution and of cracks and fissures formed by earth movements or by contraction due to cooling. In some rocks, such as the Grayson shale, Upson clay, and the igneous intrusives, the openings are very small. Such rocks are said to be relatively impermeable. Other rocks, such as the Edwards and associated limestones and Austin chalk, have larger openings, and water can move more rapidly through them than through those with smaller openings. These rocks are said to be permeable, and they are the rocks that yield water to wells and springs. The capacity of the rocks or soil to transmit water is called its permeability.

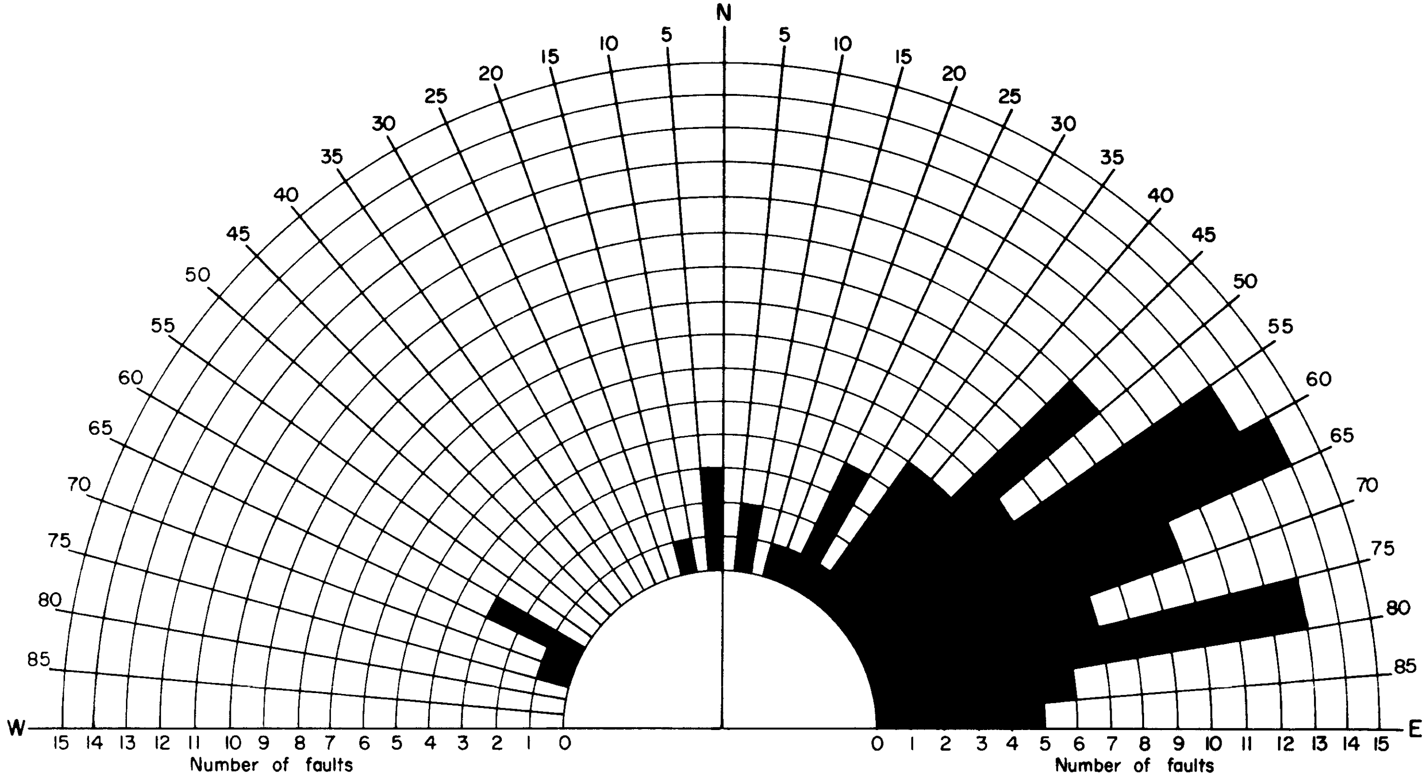

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FIGURE 5.—Orientation of faults mapped in Kinney County

The outer part of the earth may be divided with respect to subsurface water into a zone of saturation and a zone of aeration. The zone of saturation is the zone in which the rocks are saturated with water under pressure equal to or greater than atmospheric pressure. The zone of aeration is the zone in which the interstices in the rocks are not, except temporarily, filled with water. The zone of aeration extends from the surface to a specific level below which all rocks are saturated. The openings in this zone are filled partly with atmospheric gases but also may contain much water suspended above the zone of saturation. Water is held in the zone of aeration by forces of molecular attraction, generally called "capillarity," acting against the pull of gravity.

The water available to wells occurs in the zone of saturation, and a well sunk into that zone will receive water from the saturated permeable rock. Where the top of the zone of saturation is in a permeable rock, the water table is defined by the level at which the water stands in wells.

Under water-table conditions the water is confined to the water-bearing material by an impermeable bed at the base of the water-bearing material. Where water-bearing material is confined at both the top and bottom by relatively impermeable beds and where the hydraulic head in the aquifer is sufficient to cause the water level in wells that tap the aquifer to stand above the top of the water-bearing bed, the water is said to be under artesian conditions. The water within an aquifer may be under water-table conditions in some places and under artesian conditions in other places. For example, precipitation enters the Edwards and associated limestones where they crop out, moves downward to the zone of saturation, and then moves downdip within the zone of saturation. Thus, in the outcrop area the water is under water-table conditions. Downdip, however, where the zone of saturation is overlain by a confining bed, the water is under artesian conditions.

Where the land surface intersects the water table, the water issues from the permeable water-bearing material in springs and seeps. These are called gravity springs and seeps. An artesian spring is one whose water issues naturally under artesian head through a fissure or other opening in the confining bed which overlies the aquifer. Tequesquite Spring (HH-8) is an example of a gravity spring and Las Moras Spring (V-7) is an example of an artesian spring. (See Plate 19 and Figure 6.)

The Uvalde gravel, the Leona formation, and the Recent alluvium in the southwestern part of the county contain water under water-table conditions. Where the Austin chalk crops out it also contains water under water-table conditions, but in the central and southern part of the outcrop, some of the deeper water-bearing beds in the Austin may contain water under artesian head.

Ground Water in the Edwards and Associated Limestones

The Edwards and associated limestones constitute the principal ground-water reservoir in Kinney County. It is a water-table reservoir in the outcrop area on the Edwards Plateau where the water is confined only at the bottom by the relatively impermeable Glen Rose limestone, and it is an artesian reservoir on the Coastal Plain where the water is confined at the bottom by the Glen Rose and at the top by the Grayson shale and younger formations. The depth to water is governed largely by the topography. On the higher hills in the Edwards Plateau the water table is as much as 300 feet or a little more below the land surface, but in some of the deeper valleys the water table intersects the land surface and water issues in seeps and springs. In the Coastal Plain the water level in wells that

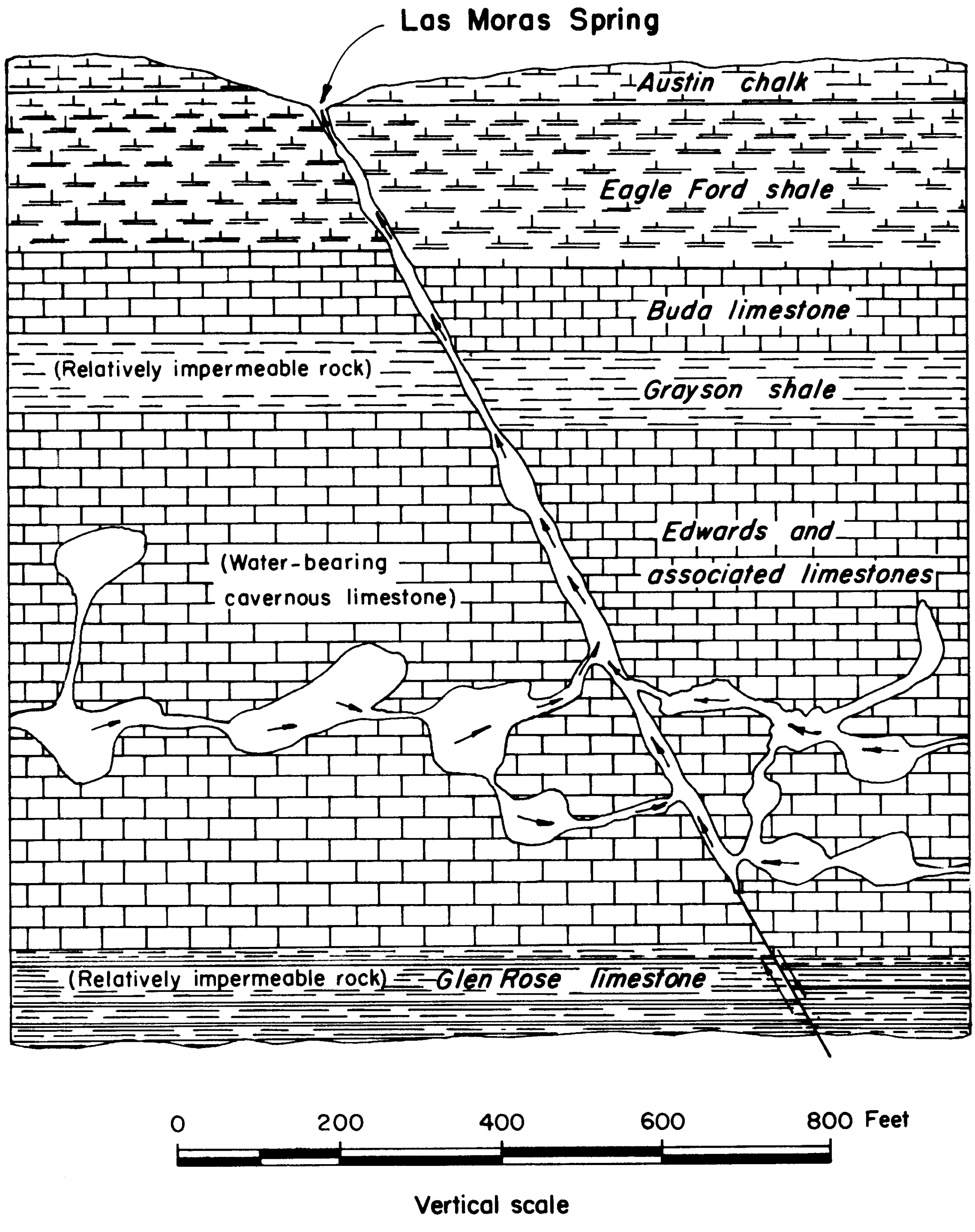

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FIGURE 6. - Hypothetical section at Las Moras Spring, looking northeast

tap the Edwards and associated limestones is above the top of the limestones; in some topographically low areas the wells flow.

On the Edwards Plateau east of Kinney County the Nueces, Frio, Sabinal, and Medina Rivers and other smaller streams have cut their valleys through the Edwards and associated limestones and are flowing on the Glen Rose limestone. As a result, ground water escapes from the reservoir on the plateau, issuing from the limestone in springs or seeps along the stream valleys at or near the contact with the underlying confining beds. The ground water maintains a perennial base flow in the streams until they reach the outcrop of the Edwards and associated limestones. There all the base flow, together with a large part of the flood flow, sinks into these limestones. Recharge to the aquifer in this manner in Uvalde and Medina Counties is discussed by Sayre (1936), Livingston, Sayre, and White (1936), Holt (1956), and Petitt and George (1956).

In contrast to the conditions on the plateau east of Kinney County, only a small part of the water that enters the outcrop area of the Edwards and associated limestones on the Edwards Plateau in Kinney County reappears at the surface in the county. Only Liveoak Creek and the West Nueces River have cut through the Edwards and associated limestones on the Edwards Plateau in Kinney County. The regimen of Liveoak Creek is similar to that of the streams in Uvalde and Medina Counties. The West Nueces River, however, has cut completely through the Edwards and associated limestones in only a few stretches. Water issues from the limestone in these stretches and flows at the surface until it reaches a stretch where the limestone is below the bed of the stream; there the water reenters the limestone. Consequently, most of the water that enters the Edwards and associated limestones reservoir in the area drained by the West Nueces moves downdip as underflow into the artesian part of the reservoir. In Kinney County none of the streams on the plateau west of the West Nueces River have eroded their channels to the water table in the Edwards and associated limestones.

Recharge to the Reservoir

In Kinney County the outcrop of the Edwards and associated limestones is practically coextensive with the Edwards Plateau. It occupies the northern third of the county and nearly all of Edwards County which adjoins Kinney County to the north. In most of this area in both counties the principal source of recharge to the aquifer is the direct infiltration of rainfall into the reservoir.

The plateau is deeply dissected; the slopes are moderate to steep, and the soil is thin or lacking. Solutional openings and fissures are abundant, particularly on the slopes and in the beds of streams. In many places small drainageways lead into these openings. Consequently, water enters the limestone rather readily. Conditions are especially favorable for recharge near the southern margin of the plateau where the rocks dip more steeply and the numerous fractures and small faults associated with the Balcones fault zone admit rain and surface runoff into the limestone. (See Plate 25.) In many parts of the plateau, however, the limestone contains few fractures or solutional openings, and the opportunity for recharge is small.

Recharge on the Edwards Plateau is dependent both on the amount and on the intensity of rainfall during individual storms. The water of light rains largely evaporates. Much of the water of heavier rains enters the ground directly or by way of stream channels; only the most intense storms produce runoff that leaves the plateau. When the rainfall has replenished the soil moisture to field capacity, the additional water infiltrates into the limestone through fractures, honeycombed surficial rocks, holes produced by roots, and the burrows of animals.

Since the start of the investigation in 1938, water-level measurements have been made periodically in numerous wells in the outcrop of the Edwards and associated limestones in Kinney County. These records are valuable for indicating the time when recharge took place, the area affected, and the relative amount of recharge from time to time in one place. The water-level measurements are given in Table 9 and discussed in the section on pages 82 to 93 entitled "Fluctuations of Water Levels and Spring Discharge."

Although the recharge to the Edwards and associated limestones in the Edwards Plateau in Kinney County cannot be computed directly, some idea of its magnitude was obtained from an analysis of stream discharge records of the West Nueces and the Nueces Rivers. The West Nueces drains about half the area of the plateau in Kinney and Edwards Counties, and the Nueces River drains a slightly larger area in Uvalde, Edwards, and Real Counties. (See Figure 7.)

The rate of runoff from the plateau to the Nueces River differs greatly from that to the West Nueces River. The Nueces carries a perennial flow of large average volume and frequent flood flows, whereas the West Nueces is dry in most of its course and only the largest floods reach its mouth. The discharge of the two streams is measured at gaging stations maintained by the U. S. Geological Survey. The gaging station on the Nueces is at Laguna, Uvalde County, and that on the West Nueces is northeast of Brackettville, Kinney County. (See Figure 7.) The gaging station on the Nueces has been in operation since October 1923, and the Brackettville station has been in operation since September 1939 except for the period October 1950 to April 1956.

Above the Laguna station in a stretch having a length of about 35 miles and a width ranging from 1 to 5 miles, the valley of the Nueces River has cut through the Edwards and associated limestones into the nearly impermeable Glen Rose limestone. In this stretch the river receives large quantities of water from springs that discharge near the contact of the Edwards and associated limestones and the underlying confining bed. The discharge from the springs, together with the storm water, is measured at the gaging station at Laguna. In contrast, the West Nueces River flows on the Edwards and associated limestones along most of its course. Ground water enters the stream in the few places where it has cut below the water table in the Edwards and associated limestones, but the amount is small and most of it reenters the aquifer before reaching the gaging station near Brackettville.

The discharge of the Nueces River at Laguna, drainage area 764 square miles, and of the West Nueces River near Brackettville, drainage area 700 square miles, is given in the table on page 76.

The total discharge of the West Nueces River at the gaging station near Brackettville during the 11 years of record was only about 16 percent of the discharge of the Nueces River at Laguna, despite the fact that there is little difference in the size of the drainage areas above the gages. During the 11-year period of continuous record from the station near Brackettville, all flow (neglecting losses by evapotranspiration) except that from two floods entered the limestone as recharge to the underground reservoir before reaching the mouth of the West Nueces River. An unmeasured flow was observed near the mouth when a flow of 11,500 second-feet was measured on June 25, 1948 at the station. Flow near the mouth was observed again between February 23 and 26, 1949, when the average daily flows at the station were 9,030, 2,970, 12,400, and 2,150 second-feet. The largest measured flow at the station prior to 1948 was 2,040 second-feet on October 8, 1946. The flow at the mouth during the floods of 1948 and 1949

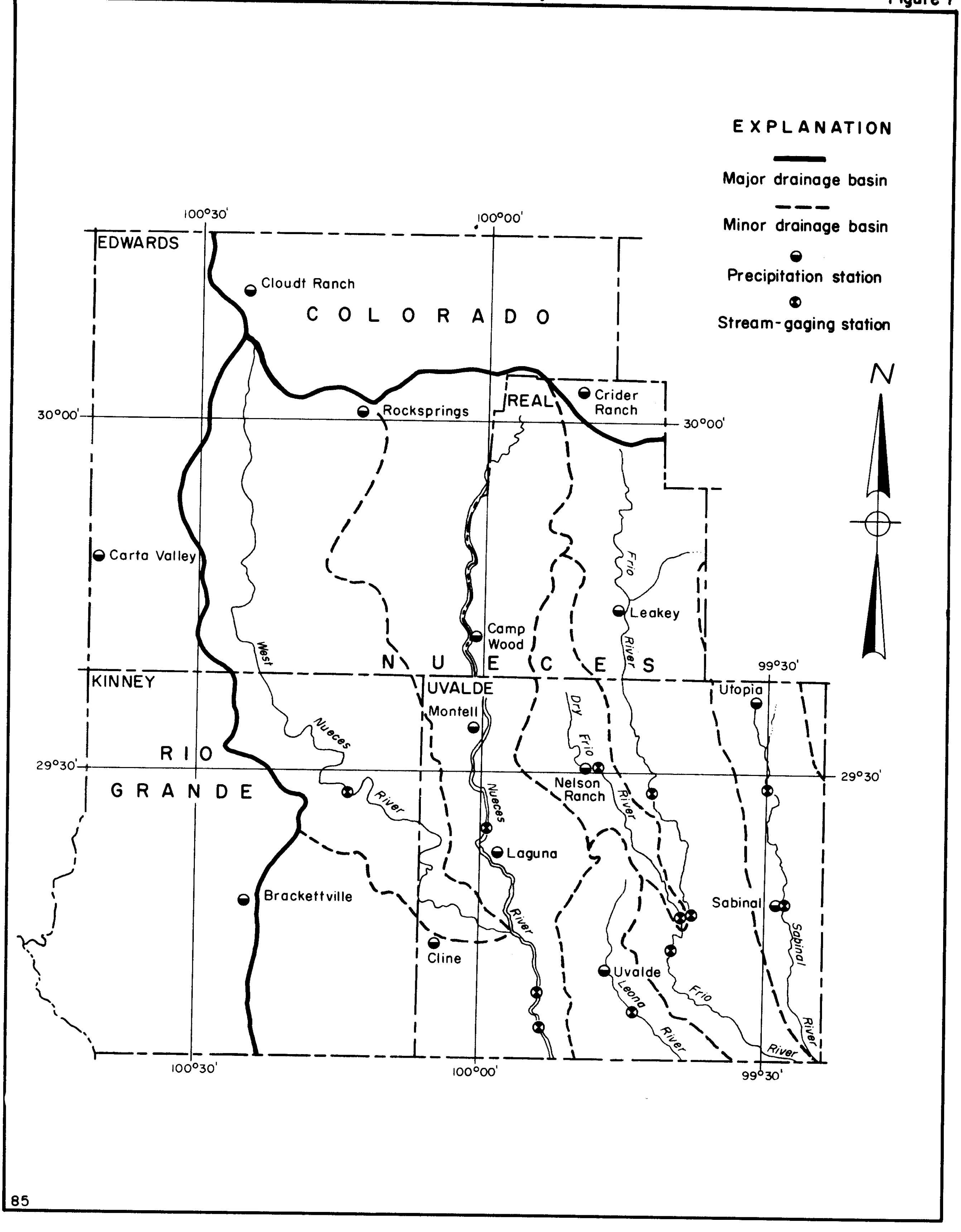

FIGURE 7.- Map of Kinney County and adjacent area showing stream-gaging stations and drainage basins

Table 2.--Discharge of the Nueces and West Nueces Rivers, water years* 1940 to 1950

Water Year	Nueces River at Laguna (acre-feet)	West Nueces River near Brackettville (acre-feet)
1940	77,500	10,200
1941	68,100	203
1942	80,400	109
1943	78,200	3,880
1944	57,300	14
1945	47,600	14
1946	42,600	36
1947	96,300	10,100
1948	40,700	25,500
1949	21,600	58,300
1950	61,600	36
Total	671,900	108,392
Average annual	61,100	9,850

*The 12-month period ending September 30 each year is called the water year.

was estimated by subtracting this flow from the daily flows. Accordingly, the estimated flow at the mouth for the water years 1948 and 1949 was 19,000 and 37,000 acre-feet. These data suggest that the recharge per unit area of the West Nueces River basin above its mouth (area, about 930 square miles) would approximately equal the difference in runoff per unit area of the Nueces River at Laguna and the West Nueces at its mouth. Accordingly, the average recharge per square mile for the 11 years of record would be

$$\left[\frac{61,100}{764}\right] - \left[\frac{56,000/11}{930}\right] = 75 \text{ acre-feet.}$$

This is equivalent to about 70,000 acre-feet or an average of 1.4 inches over the entire West Nueces River basin. Because the portion of the West Nueces basin in Kinney County is about half the total area of the basin, and because that portion of the basin occupies about half the area of the Edwards Plateau in Kinney County, the recharge to the reservoir in Kinney County is of about the same magnitude--roughly 70,000 acre-feet per year. This estimate of recharge may be materially in error because it is based principally on the following assumptions, which are not wholly true: (1) The surface-water divides and the ground-water divides coincide; (2) the rainfall in the Nueces and West Nueces basins is the same; (3) average evapotranspiration rates are the same in both basins; and (4) withdrawals by man are negligible. Nevertheless, the errors caused by deviation from the assumptions cannot be great enough to destroy the validity of the figure if it is considered as only an indication of the correct order of magnitude.

Discharge from the Reservoir

Discharge in Kinney County

In Kinney County water is discharged from the Edwards and associated limestones chiefly through artesian springs. A relatively small amount is discharged through wells, and a considerable amount of water moves underground toward the east or west and is discharged outside the county.

Las Moras, Pinto, and Mud Springs issue on the Coastal Plain. The water rises along channels formed by faults or fractures which provide a conduit from the Edwards and associated limestones to the land surface. Figure 6 shows a schematic section of the channel at Las Moras Spring (V-7).

Las Moras Spring is the largest spring in Kinney County. The water issues into a large pool. At times part of the water is discharged from the spring pool into a swimming pool or is pumped for public supply at Brackettville; the remainder is conveyed to Las Moras Creek by a concrete spillway. (See Plate 9A.) Table 3 gives the results of the measurements of the discharge, in cubic feet per second (cfs), of Las Moras Spring through the spillway gate into the canal leading to Las Moras Creek.

Table 3.--Discharge of Las Moras Spring, December 1895 to September 1956

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
Dec. 23, 1895	21	May 16, 1941	37.5	Sept.20, 1944	31.7
June 30, 1899	60	June 18	27.0	Oct. 10	30.4
Sept. 1900	51	July 22	21.4	Nov. 22	15.2
Sept. 1902	11	Aug. 29	15.4	Jan. 9, 1945	11.9
Mar. 14, 1904	28	Sept.26	16.6	Feb. 17	25.0
Aug. 1905	14	Oct. 27	36.8	Apr. 1	14.4
Apr. 1906	18	Dec. 14	13.8	May 11	10.8
Sept. 1910	14	Jan. 27, 1942	10.9	June 14	9.30
Nov. 1911	8.4	Mar. 14	9.92	July 21	5.67
Apr. 8, 1925	9.34	Apr. 20	10.0	Sept. 9	5.97
July 30, 1928	5.79	May 30	10.6	Oct. 22	10.9
Nov. 4, 1938	20.3	June 18	8.46	Dec. 3	8.31
Feb. 5, 1939	15.2	July 20	8.24	Jan. 10, 1946	9.01
Mar. 12	14.0	Aug. 20	7.65	Feb. 16	8.16
Apr. 26	12.4	Sept.21	29.9	Apr. 2	7.00
June 5	11.4	Oct. 27	40.9	May 6	9.96
Aug. 8	43.2	Dec. 14	29.7	June 7	12.4
Sept.20	26.4	Jan. 31, 1943	16.3	July 11	13.3
Oct. 31	42.2	Mar. 8	13.4	Aug. 21	12.6
Dec. 15	26.1	Apr. 27	11.2	Oct. 8	35.7
Jan. 25, 1940	19.1	June 4	26.8	Oct. 26	42.1
Mar. 15	15.0	July 12	14.5	Dec. 6	35.1
Apr. 27	12.4	Aug. 23	9.07	Jan. 16, 1947	22.0
May 30	26.1	Sept.28	11.5	Feb. 26	35.7
June 24	19.9	Oct. 12	23.2	Apr. 3	25.7
July 24	33.5	Dec. 2	11.6	May 8	30.4
Aug. 22	21.4	Jan. 17, 1944	18.9	June 23	41.4
Sept.19	11.8	Feb. 23	13.6	July 30	43.5
Oct. 15	15.7	Mar. 30	22.6	Sept.10	30.6
Nov. 26	12.1	May 5	13.4	Oct. 22	21.6
Jan. 12, 1941	11.7	June 20	33.2	Nov. 24	16.5
Feb. 26	11.2	July 6	18.6	Jan. 12, 1948	15.4
Apr. 13	15.0	Aug. 11	9.56	Feb. 20	13.5

(Continued on next page)

Table 3.--Discharge of Las Moras Spring, December 1895 to September 1956--Continued

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
Mar. 26, 1948	10.6	Mar. 24, 1950	16.4	Aug. 22, 1953	5.53
May 7	10.6	Apr. 26	13.3	Nov. 15	17.2
June 14	9.72	May 20	12.7	Jan. 19, 1954	9.83
July 27	30.9	June 27	13.5	Mar. 31	7.93
Aug. 31	11.9	Aug. 9	12.8	May 13	23.2
Oct. 9	9.61	Sept.22	10.1	July 28	42.1
Nov. 20	9.20	Feb. 8, 1951	8.02	Oct. 16	30.0
Dec. 17	8.80	Apr. 21	8.14	Jan. 5, 1955	18.9
Feb. 7, 1949	10.6	June 28	5.91	Jan. 10	15.9
Mar. 5	48.5	Aug. 28	5.72	Mar. 25	11.6
Apr. 13	42.9	Nov. 29	7.58	June 8	8.01
May 24	30.8	Feb. 15, 1952	6.85	Aug. 19	35.1
June 25	19.4	Apr. 30	12.3	Oct. 25	42.1
Aug. 2	18.6	Aug. 1	9.72	Mar. 14, 1956	11.1
Sept.23	40.3	Sept. 9	6.29	May 23	8.70
Nov. 4	43.4	Nov. 15	5.49	July 10	6.56
Dec. 9	39.6	Jan. 29, 1953	5.28	Aug. 15	4.91
Jan. 13, 1950	23.7	Apr. 25	8.27	Sept.25	5.36
Feb. 17	18.1	July 17	2.84		

The average of the measurements in Table 3 is 23.1 cfs. The largest discharge recorded was 60 cfs on June 30, 1899, and the smallest was 2.84 cfs on July 17, 1953. The average of the measurements from January 1955 to September 1956, however, is only 15.3 cfs, or about 11,000 acre-feet per year. Field observations show that the discharge of the spring fluctuates quickly in response to precipitation. The discharge is affected also by the raising or lowering of the gates at the swimming pool and at the entrance to the spillway canal. These manipulations affect the level of the spring pool and change the head against which the water rises to the surface, thus affecting the discharge to some extent. The effect, however, is small.

Pinto Springs (O-1) 9-1/4 miles north of Brackettville, issues into the bed of Pinto Creek. (See Plate 9B.) Table 4 gives the results of 19 measurements of the flow of Pinto Springs which were made from February 1939 to August 1953.

Table 4.--Miscellaneous measurements of discharge of Pinto Springs, February 1939 to August 1953

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
Feb. 6, 1939	5.17	Dec. 15, 1939	8.83	Aug. 22, 1940	6.85
Mar. 12	4.46	Jan. 25, 1940	7.19	Sept.19	4.92
Apr. 26	2.13	Mar. 15	4.45	Oct. 15	3.80
June 5	.70	Apr. 26	5.06	Sept. 9, 1952	3.59
Aug. 11*	7.77	May 30	5.98	Aug. 21, 1953	.0
Sept.19	7.27	June 27	6.14		
Oct. 30	7.70	July 24	7.81		

*Site of measuring section changed on this date.

Prior to August 11, 1939, the discharge measurements of Pinto Springs were made at a measuring section on Pinto Creek at some distance below the spring. Upon investigation, it was found that an appreciable amount of water was lost by seepage, transpiration, and evaporation between the spring and the point of measurement. Therefore, on August 11, 1939, a new measuring section was selected above the original one, and it is believed that from that date practically all of the water discharged by the spring at the time of measurement is represented in the gaging records.

Mud Spring (G-6) is 16-1/4 miles northwest of Brackettville and issues into the bed of Mud Creek. Table 5 gives the results of 19 measurements made at Mud Spring from February 1939 to August 1953.

Table 5.--Miscellaneous measurements of discharge of Mud Spring, February 1939 to August 1953

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
Feb. 6, 1939	7.58	Dec. 15, 1939	4.50	July 24, 1940	2.72
Mar. 12	5.17	Jan. 25, 1940	3.54	Aug. 22	2.81
Apr. 26	2.87	Mar. 15	1.84	Sept.19	2.02
June 5	1.84	Apr. 26	1.27	Oct. 15	.96
Aug. 11	2.63	May 30	2.03	Sept. 8, 1952	.00
Sept.19	3.25	June 24	2.03	Aug. 21, 1953	.00
Oct. 30	3.37				

According to Mr. Ed Mey, owner, Mud Spring flowed most of the time during the 25-year period 1916-40; it ceased flowing during 1917, for several months in 1928, and for 1 month in 1930. No flow was observed when the spring was visited on October 8, 1952 and August 21, 1953.

Concurrent measurements of the discharge of Las Moras, Pinto, and Mud Springs were made at 12 times during the period September 1939 through October 1940. These discharge measurements indicate that the combined discharge of the three springs was about 23,000 acre-feet per year. The discharge of Las Moras Spring represented about 73 percent of the total discharge. If the factor of 73 percent is applied to the average of 11 discharge measurements from Las Moras Spring during the period 1955-56, the average annual discharge of all three springs for this period is estimated to have been about 15,000 acre-feet. Graphs showing the discharge of Las Moras, Pinto, and Mud Springs are given in Figure 8.

Windmills pump most of the wells that draw water from the Edwards and associated limestones in Kinney County. The average discharge per well is small, and the water is used largely for livestock and domestic purposes. Turbines pump a few wells that supply water for irrigation; the largest yield reported was 750 gpm from well V-23. The combined discharge of about 200 wells pumping from the Edwards and associated limestones is estimated to be about 2,000 acre-feet per year. Approximately the same amount of water is discharged from the Edwards and associated limestones through flowing wells. The total discharge from wells that tap the Edwards and associated limestones in Kinney County during 1955-56, therefore, was estimated to be at the rate of about 4,000 acre-feet per year. Thus the annual discharge through wells and artesian springs in the county from the Edwards and associated limestones in 1955-56 was about 19,000 acre-feet.

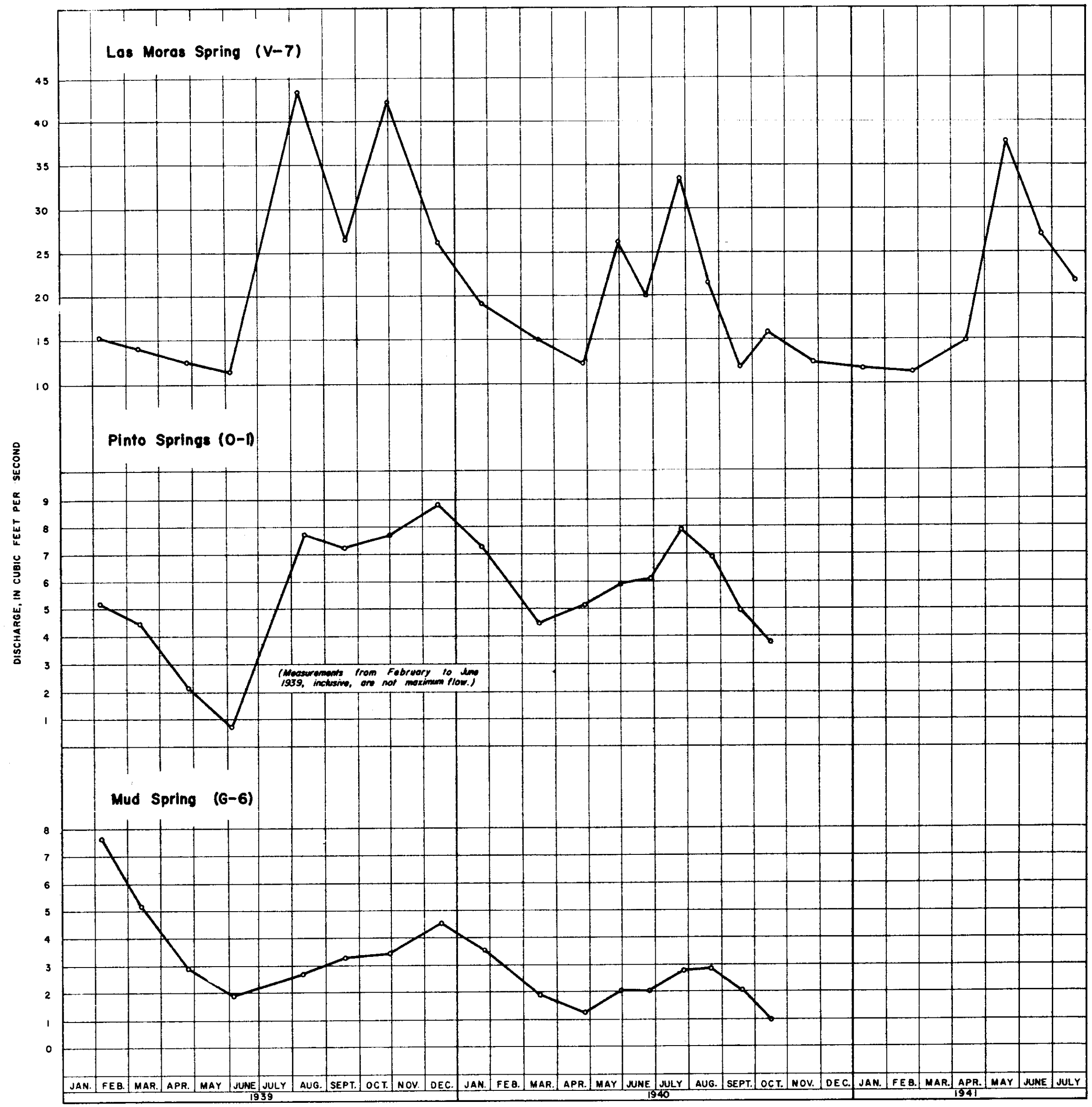

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FIGURE 8.-Fluctuations in discharge of Las Moras, Pinto, and Mud Springs

Discharge Outside Kinney County

The average annual recharge to the Edwards and associated limestones in Kinney County is estimated (page 76) to be about 70,000 acre-feet, and the average annual discharge through wells and springs probably is about 20,000 acre-feet. Thus about 50,000 acre-feet a year, less an unknown but relatively small amount discharged by evapotranspiration, is discharged from Kinney County by underflow.

Contour maps showing the altitude of the water surface in the Edwards and associated limestones indicate that the water is leaving Kinney County across both the eastern and western boundaries. (See Figures 9, 10, and 11.) In Val Verde County most of the discharge from the Edwards and associated limestones is through San Felipe Springs, which is about 1 mile east of Del Rio and 11 miles west of the Kinney County line. The average annual discharge of this spring during 1931-53 was about 42,000 acre-feet (International Boundary and Water Commission, United States and Mexico, 1953, p. 27).

Although most of the discharge from the Edwards and associated limestones east of Kinney County has been through springs along the Balcones fault zone, discharge through wells has been increasing and from 1954 to 1956 it exceeded the discharge through springs. In 1956 the discharge in Uvalde County, which was entirely through wells, was estimated to be about 60,000 acre-feet, and the total discharge through wells and springs in the region from Uvalde County eastward to Hays County was estimated to be about 365,000 acre-feet.

Movement of Ground Water

The water in an aquifer moves in the direction of the hydraulic gradient, and the direction of movement can be determined if the shape and slope of the water surface can be mapped accurately. The Edwards and associated limestones are not homogeneous; they contain openings that range in size from minute cracks in which there are large losses of head to caverns through which the water moves freely. In light of this, and due to the lack of intensive development in the county, the water surface cannot be mapped in sufficient detail to show all the details of movement; in fact, one of the most important phases of movement out of Kinney County is not shown by the generalized piezometric contours in Figures 9 through 11, as discussed further below.

Figures 9, 10, and 11 show contours on the water surface in the Edwards and associated limestones in Kinney County in 1937-40, 1952, and 1956. The overall pattern of the contours is essentially the same in all the figures. In the outcrop area on the Edwards Plateau the contours have an eastward trend, indicating that the water in the outcrop area moves downdip in the limestone toward the south. The contours south of the plateau show a ground-water divide in the longitude of Brackettville. The contours east of Brackettville indicate that the water moves southeastward and eastward into Uvalde County. Petitt and George (1956, p. 59-63) have shown that this movement continues toward the east as far as Hays County. West of Brackettville the contours indicate that the water moves southwestward toward the Rio Grande. The altitude of the water surface in central Kinney County near Brackettville is about 1,100 feet, and at San Felipe Spring in Val Verde County, the major point of discharge from the limestone aquifer, the altitude is about 950 feet.

Although the generalized contours on the water surface in the central part of Kinney County indicate that the water is moving toward the south, part of the water is not moving at right angles to the contours. The prompt increases in the discharge of Las Moras Spring in response to rainfall in the outcrop area of the Edwards and associated limestones suggest that zones of well-developed solution channels extend from the spring northward to the outcrop area. Similar zones of solution channels may be inferred between Pinto and Mud Springs and the outcrop area north of them. Eastward-trending zones of solution channels probably are developed along the dominantly eastward-trending faults of the Balcones fault system, the fault planes having been enlarged by solution. This condition is illustrated schematically in Figure 12, in which, for simplicity, faults are not shown. If, as seems likely, the channels developed in the east-west direction are larger than those developed in the north-south direction, an equal volume of water would require less gradient to move in the east-west direction than in the north-south direction. Although the gradient "appears" to be chiefly southward in the central part of Kinney County, it is probable that the greater volume of water is moving eastward nearly parallel with the trend of the regional, generalized contours. If a sufficient number of control points were available for use in constructing a detailed contour map, the contours may cross the larger solution channels at right angles to the direction of flow, or nearly north-south.

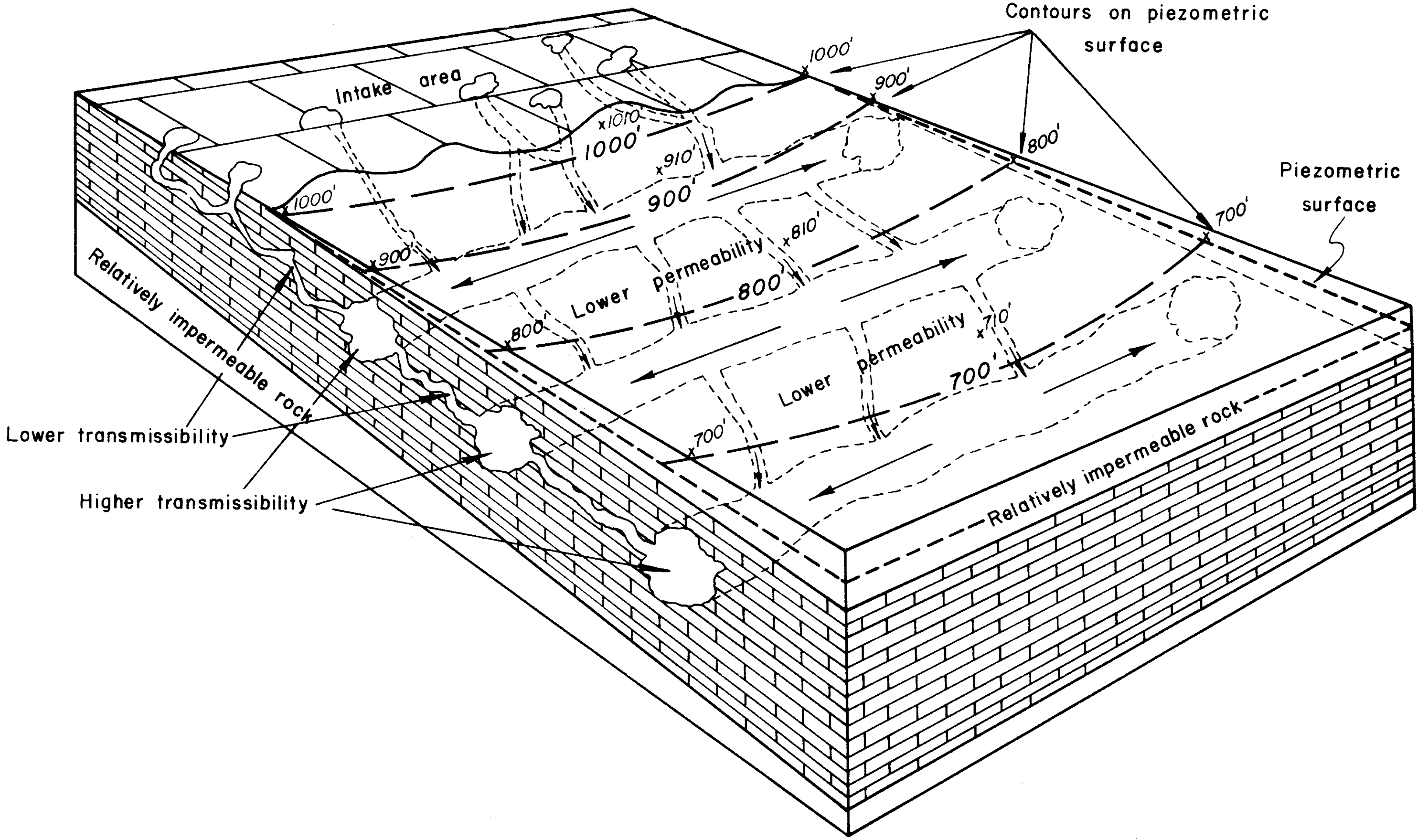
Only a small part of the water in the Edwards and associated limestones is believed to move downdip beyond the artesian springs. A few miles south of the springs, the water in the Edwards and associated limestones contains hydrogen sulfide, and farther downdip the water is highly mineralized. (See Figure 15, page 95.) The high mineralization of the water suggests that movement of the water is negligible owing to the low permeability of the limestone.

Fluctuations of Water Levels and Spring Discharge

Periodic water-level measurements for 32 wells in the Edwards and associated limestones in Kinney County are given in Table 9. Figures 13 and 14 show graphically the measurements for 6 of the wells during the period from January 1939 to August 1941. After 1941, measurements were made only at irregular intervals. Well W-2 was equipped with an automatic water-stage recorder, and an almost continuous record of the water level was obtained from January 1939 to August 1941. Plate 26 shows this record graphically, together with records of the precipitation at Brackettville and at Montell, Uvalde County. Measurements of the discharge of Las Moras, Pinto, and Mud Springs are given in Tables 3, 4, and 5 and shown graphically in Figure 8.

The rate of discharge from springs is related to changes in water levels in the ground-water reservoir; the higher the stage, the greater the flow from the springs. Those water-level fluctuations in wells in or near the outcrop of the Edwards and associated limestones that correlate closely with fluctuations in the discharge of springs indicate which part of the outcrop provides the principal source of recharge to the spring. For example, the close correlation between fluctuations in the discharge of Pinto Springs and the water-level fluctuations in well I-9 (Figures 14 and 8) suggests that a principal source of recharge to the springs is the outcrop in the Pinto Creek watershed. Similarly, the correlation between Mud Spring and well G-5 suggests that a principal source of recharge to the spring is the outcrop area northeast of Mud Spring; and the correlation between Las Moras Spring and well P-1 (Figures 13 and 8) suggests that the outcrop in the Elm Creek watershed is a principal source of recharge to the spring.

Water levels in wells in Kinney County fluctuate with changes in the ratio of recharge to discharge; thus they reflect changes of storage in the ground-water reservoir. When the rate of recharge to an area exceeds the rate of discharge from it, the water level in a well in that area rises, indicating an increase in



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FIGUGE 12.- Hypothetical diagram showing how water in the cavernous Edwards and associated limestones may flow approximately parallel with the trend of the regional contours on the piezometric surface

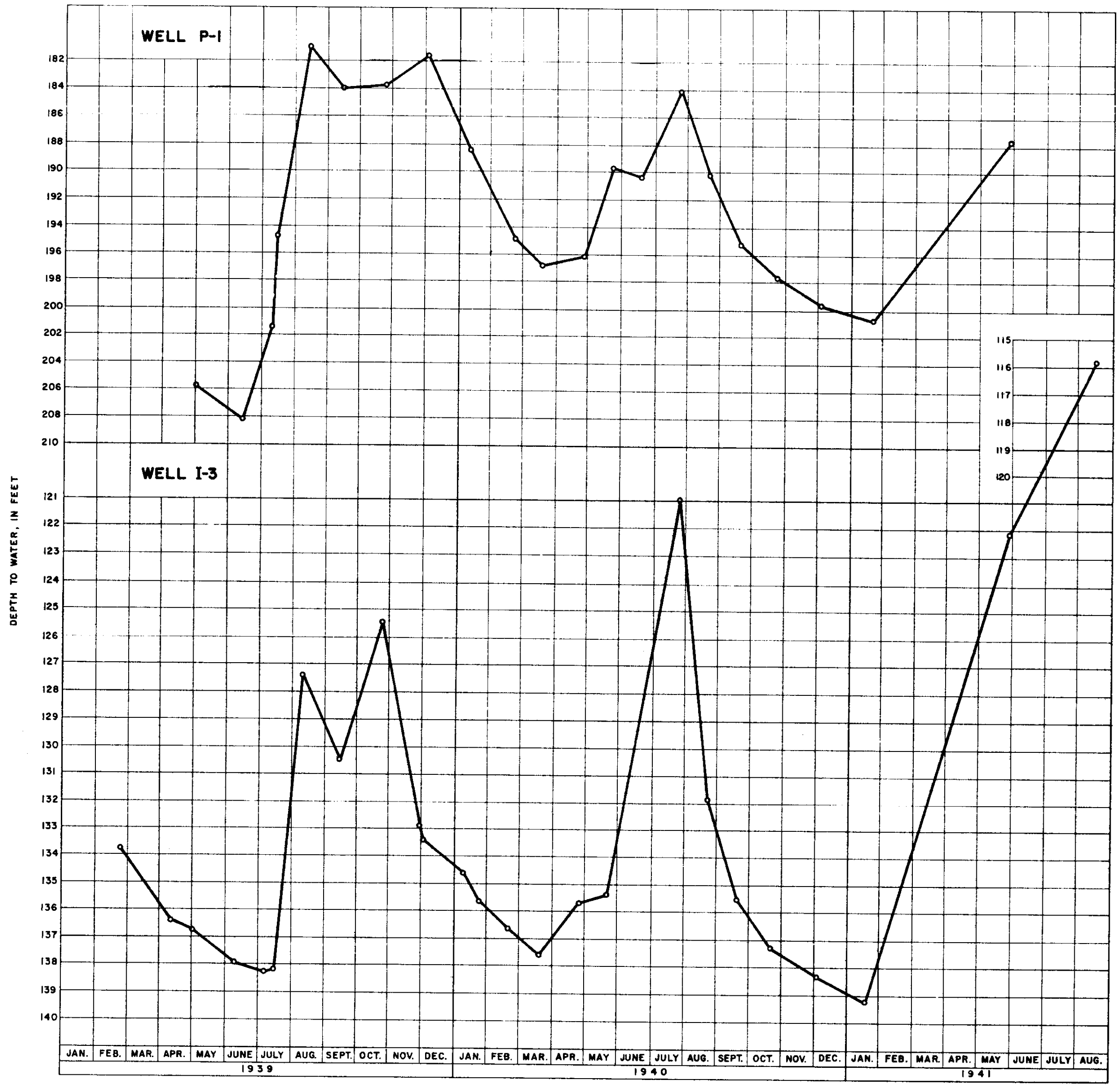

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FIGURE 13. - Fluctuations of water levels in wells P-1 and I-3

Texas Water Commission in cooperation with the U. S. Geological Survey

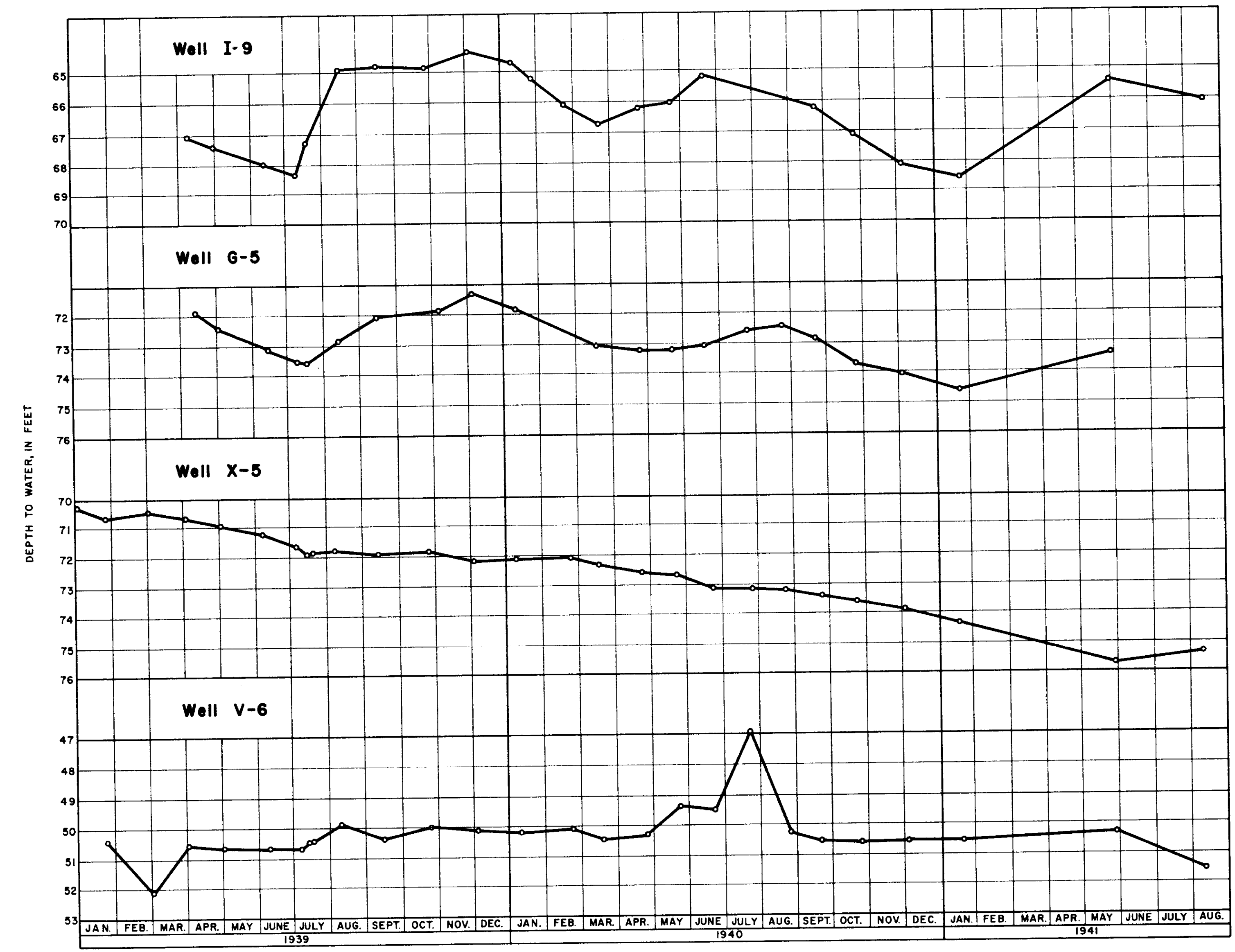

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FIGURE 14.-Fluctuations of water levels in wells I-9, G-5, X-5, and V-6

storage. Conversely, when the rate of discharge exceeds the rate of recharge, the water level declines, indicating a decrease in storage.

The hydrographs in Figures 13 and 14 show that the water levels in different parts of the reservoir display different characteristics. Water levels in wells P-1 and I-3 show rapid rises of comparatively large magnitude in response to periods of heavy precipitation (Figure 13 and Plate 26), suggesting that the wells are close to areas of recharge. In contrast, wells V-6 and X-5 (Figure 14) show much less response. The lack of response may be the result of poor hydraulic connection, which dampens the effects of close proximity to an area of large discharge, or may be due to the dampening effect of distance from the area of recharge.

Plate 26 shows that the water level in well W-2 responds promptly to storms of more than 1 inch of rainfall.

No direct relationship has been established between the amount of precipitation and the magnitude of water-level rise in wells in Kinney County because of several factors. The rainfall records may not be representative of rainfall in the principal recharge area, and varying conditions of rainfall intensity and distribution of evapotranspiration and of soil moisture effect the rainfall-recharge ratio. Also, unit rises of water levels may vary with the changing stages of the reservoir. However, in general, Figures 13, 14, and Plate 26 show that storage is greatest during the summer, corresponding with the period of heaviest precipitation.

In general, the flow at Las Moras Spring responds rather promptly to heavy rains at Montell, but at times a considerable lag occurs. The spring appears less responsive to rainfall on the north-central and northwestern parts of the county. The heaviest rain during the period of concurrent water-level record in Kinney County fell during a period of about 19 hours on June 23-24, 1948, and affected an area in western Kinney County, southwestern Edwards County, and eastern Val Verde County. About 8 inches was recorded at Brackettville, and at the center of the storm in northwestern Kinney County the U. S. Weather Bureau estimated that the total was about 24 inches. The rain was comparatively light in the northeastern part of Kinney County, as indicated by a recorded fall of only 1.27 inches at Camp Wood in southwestern Real County. This rain produced the largest recorded runoff of storm water in the West Nueces River during the period 1939 to 1949; and the runoff to the Rio Grande, largely through Sycamore Creek, produced floods all the way to the mouth of the river. The flow of the Nueces River was practically unaffected, however. The storm of June 23-24 caused an increase in the discharge of Las Moras Spring--30.9 cfs being recorded on July 27 compared with 9.72 cfs on June 14--but the discharge decreased quickly, was only 11.9 cfs on August 31, and continued low for several months thereafter. Obviously, therefore, the recharge from this storm was relatively small in the area from which the spring discharge was derived. Two reasons for this are possible: (1) The spring is fed for the most part by water that enters the ground-water reservoir in areas on the plateau northeast of the spring where the rainfall during the storm was light and not in areas northwest of the spring where the rainfall was very heavy. This possibility is supported by the fact that over the years the fluctuations in the discharge of the spring generally correlated more closely with the rainfall at Montell and Camp Wood to the northeast than they did with the rainfall at Brackettville and at Del Rio to the west. (2) The storm of June 23-24, although of great intensity, was of brief duration, and little opportunity was afforded for the percolation of the storm water into the soil and rocks. Most of the storm water ran off into the streams. The water level in well M-2, an observation well within the area of heaviest rainfall, was higher on August 10 than it was on

April 20, but the difference was only 1.5 feet. (See Table 9.) The water level in well M-14 at the southern border of the area of heaviest rainfall declined sharply between the April and August measurements. Water levels in wells north of Brackettville rose between the April and August measurements, but water levels in wells in the northeastern part of the county declined.

QUALITY OF WATER

The suitability of a water for various uses is determined largely by the kind and amount of dissolved mineral matter that the water contains. The mineral matter is dissolved principally from the soil and rocks through which the water passes, and consequently the differences in the chemical character of the ground water reflect in a general way differences in the geologic formations with which the water has had contact. The concentrations of the chemical constituents commonly are expressed in parts per million; a part per million (ppm) is one unit weight of constituent in one million unit weights of sample.

Samples of water were obtained from 130 wells and 4 springs in Kinney County. The wells and springs that were sampled are shown by bars over the location numbers on Plate 1, and the results of the analyses of the samples are given in Table 10. Figure 15 shows the geographical distribution of the wells that were sampled and the results of analyses of water from the Edwards and associated limestones and the Austin chalk, the principal and the next most important aquifer in Kinney County. Most of the samples were collected in the period 1937-39; a few were collected in the period 1945-48, and two were collected in 1957. The analyses were made in the laboratory of the U. S. Geological Survey at Austin, Texas.

Various standards have been proposed from time to time for use in evaluating water for drinking. The U. S. Public Health Service (1946) has established standards for drinking water used on common carriers in interstate commerce. The recommended maximum concentrations for certain of the chemical constituents, according to these standards, are listed below. The standards have been widely adopted by State and municipal authorities; however, in many places water is used in which the concentrations exceed those listed.

Iron (Fe) and Manganese (Mn) together should not exceed 0.3 ppm (parts per million).

Magnesium (Mg) should not exceed 125 ppm.

Sulfate (SO_4) should not exceed 250 ppm.

Chloride (Cl) should not exceed 250 ppm.

Fluoride (F) must not exceed 1.5 ppm.

Dissolved solids should not exceed 500 ppm; however, if such water is not available, a dissolved-solids content of 1,000 ppm may be permitted.

In appraising the quality of water for irrigation, both the concentration and the composition of dissolved constituents should be considered. The chemical characteristics that appear to be most important in evaluating the quality of water in Kinney County are: (1) total concentration of soluble salts (an index to the salinity hazard); (2) relative proportion of sodium to other cations (an index to the sodium hazard); and (3) concentration of boron. In the one water sample analyzed for boron (well O-9), the concentration was low (0.05 ppm), and water samples from Uvalde County likewise have low concentrations of boron. Most crops grown in Kinney County are relatively insensitive to high concentrations of boron, and therefore boron probably is not a problem.

A system of classification commonly used for judging the quality of a water for irrigation has been proposed by the U. S. Salinity Laboratory Staff (1954, p. 69-82). The salinity hazard is measured by the electrical conductivity of the water and the sodium hazard is measured by the sodium-adsorption ratio (SAR). (See Table 10.)

The relative importance of the dissolved constituents is dependent upon the degree to which they accumulate in the soil. Kelley (1951, p. 95-99) cited areas having an average annual precipitation of about 18 inches in which salts did not accumulate in the soil. Wilcox (1955, p. 15), a member of the U. S. Salinity Laboratory, stated that the system of classification of irrigation waters proposed by the laboratory staff "is not directly applicable to supplemental waters used in areas of relatively high rainfall." Thus, in Kinney County where the average annual precipitation exceeds 20 inches, the system of classification probably is not directly applicable. However, Wilcox (1955, p. 16) indicated that water generally may be used safely for supplemental irrigation if its conductivity is less than 2,250 micromhos per centimeter at 25°C and its SAR is less than 14. Each individual situation should be appraised when consideration is being given to irrigating with water in which the specific conductance and SAR exceed these limits, or where soil and drainage conditions are unfavorable, or when the crop to be grown is especially sensitive to the hazards of sodium and salinity.

Edwards and Associated Limestones

The water in and close to the outcrop area of the Edwards and associated limestones is generally of good quality, except that it is hard. In 37 samples collected from wells and springs that produce from this aquifer, the dissolved solids ranged from 154 to 2,550 ppm (parts per million) and averaged 480 ppm. The chloride concentration was generally less than 50 ppm, but was 130 and 104 ppm in the samples from wells Y-5 and K-4. Fluoride content was determined in 24 of the samples. It was less than 1 ppm in 22 of the samples, but in the sample from well P-6 it was 1.7 ppm, and in the sample from well BB-2 it was 2.3 ppm. The predominant constituent in most of the samples was calcium bicarbonate, the ratio of bicarbonate to sulfate being generally at least 10 to 1. In most of the samples the sulfate content was less than 100 ppm. In some, however, the sulfate content was nearly equal to the bicarbonate, and in a few the sulfate content exceeded the bicarbonate.

The water from some of the wells contained hydrogen sulfide, which probably was formed chiefly by the reduction of the anhydrite ($CaSO_4$) in the limestone by hydrocarbons. The hydrogen sulfide is released when the water is exposed to the air, and no attempt was made to determine the amount of hydrogen sulfide that originally was present in the water. The waters containing the hydrogen sulfide generally are fairly highly mineralized and most have a high sulfate content. Nearly all of the samples containing hydrogen sulfide were from wells in the southern part of the county. The approximate boundary between water free of hydrogen sulfide and water containing hydrogen sulfide or having a concentration of dissolved solids exceeding 1,000 ppm is shown on Figure 15. Some of the wells south of the boundary have large yields of water that has a low content of dissolved solids and is suitable for irrigation although the water contains hydrogen sulfide.

Eagle Ford Shale

The water from the Eagle Ford shale is generally somewhat more highly mineralized than the water from the Edwards and associated limestones. Of 12 samples of water from the Eagle Ford shale, the amount of dissolved solids, determined in 9 of the samples, ranged from 299 to 1,020 ppm and averaged 580 ppm. The total hardness in 11 samples ranged from 282 to 608 ppm and averaged 416 ppm. Calcium bicarbonate was the predominant dissolved constituent in all the samples except those from wells V-4 and W-8. The water from some of the wells in the Eagle Ford shale contained hydrogen sulfide, and in general the water from the Eagle Ford contained a larger proportion of sulfate than the water from the Edwards and associated limestones.

Austin Chalk

Analyses were made of 27 samples of water from wells in the Austin chalk. The dissolved solids, determined in 19 of the samples, ranged from 351 to 956 ppm and averaged 498 ppm. The hardness--determined in 26 of the samples--ranged from 175 to 658 ppm and averaged 376 ppm. Calcium bicarbonate was the chief dissolved constituent in all the samples, and the sulfate generally was less than 100 ppm. Chloride was less than 100 ppm in all except 5 of the samples. In the 5 samples it ranged from 105 to 315 ppm.

Anacacho Limestone

In 4 samples collected from wells in the Anacacho limestone the dissolved solids ranged from 439 to 619 ppm and averaged 541 ppm. The hardness ranged from 57 to 382 ppm and averaged 279 ppm. In the 4 samples in which fluoride was determined, the fluoride content was less than 1.5 ppm.

San Miguel Formation

Only 2 samples (wells JJ-2 and MM-3) were obtained from the San Miguel formation. Analyses showed the water to be highly mineralized, containing a predominance of sodium chloride.

Uvalde Gravel

The dissolved solids content in 5 samples from the Uvalde gravel ranged from 155 to 617 ppm and averaged 372 ppm. The total hardness ranged from 117 to 360 ppm and averaged 257 ppm. Calcium bicarbonate was the predominant dissolved constituent.

Quaternary Gravel

The water from Quaternary gravel is generally of good quality. In 5 samples (wells K-1, O-6, O-7, O-8, and O-12) the dissolved solids content ranged from 157 to 366 ppm and averaged 278 ppm. The total hardness ranged from 117 to 348 ppm and averaged 247 ppm. Calcium bicarbonate was the chief dissolved constituent in all the samples.

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*Name of Agency changed to Texas Water Commission January 30, 1962.

Table 8.--Drillers' logs of wells in Kinney County1/

Well G-1, partial log

Owner: Prosser & Walker. Driller: Havoline Oil Co. Asterisk (*) means formation top is from P. T. Flawn, Bureau of Economic Geology, University of Texas.

	Thickness (feet)	Depth (feet)
Grayson shale:		
Lime	10	10
Clay, yellow	10	20
Edwards and associated limestones:		
Lime, gray, hard	5	25
Lime, yellow	15	40
Lime, white	25	65
Lime, gray	45	110
Lime, gray, hard	110	220
Lime, gray, soft	80	300
Lime, grayish, white	50	350
Lime, sandy, gray, soft; show of gas	35	385
Lime, medium sandy	30	415
Lime, sandy, gray, hard	5	420
Lime, sandy, gray; show of oil	30	450
Lime, white	25	475
Sand, gray; hole full of water	10	485
Lime, gray, hard	5	490
Lime, black, hard, saturated with oil	10	500
Lime, dark-colored hard	15	515
Lime, blue, hard	5	520
Lime, dark-colored; and slate	10	530
Lime, dark-brown, hard	45	575
Lime, dark-gray; shells	7	582
Lime, cherty, gray, hard	3	585
Lime, gray	10	595
Lime, gray, sea shells	15	610
Lime, gray, hard	20	630
Lime, sandy, gray; contains sea shells	18	648
Lime, gray	57	705
Lime, brown, hard	25	730
Lime, gray	80	810
Slate, white, soft	5	815
Lime, gray	125	940
Lime, brown, hard	20	960

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1/ Formation tops are by U. S. Geological Survey unless stated otherwise.

Table 8.--Drillers' logs of wells in Kinney County--Continued

Well G-1--Continued

	Thickness (feet)	Depth (feet)
Glen Rose limestone, Pearsall, Sligo, and Hosston formations:		
Slate, gray, soft ----	7	967
Lime, gray, hard -----	93	1,060
Slate, gray, soft ----	15	1,075
Lime, gray, hard -----	10	1,085
Slate, blue, soft ----	45	1,130
Lime, brown, hard ----	24	1,154
Slate, gray ----------	6	1,160
Lime, gray, very hard-	3	1,163
Slate, gray, soft, alternating with seams of white gypsum ----	35	1,198
Lime, brown ----------	30	1,228
Slate, gray, soft ----	2	1,230
Lime, brown, hard ----	8	1,238
Lime, gray, hard -----	10	1,248
Slate, blue, soft ----	3	1,251
Lime, gray -----------	133	1,384
Lime, gray, hard -----	3	1,387
Slate, dark-gray -----	26	1,413
Lime, gray -----------	12	1,425
Slate, gray ----------	9	1,434
Gypsum, white --------	4	1,438
Lime, brown, hard ----	7	1,445
Slate, brown, hard ---	3	1,448
Lime, brown ----------	16	1,464
Lime, blue, hard -----	4	1,468
Lime, dark-gray, hard; show of gas --------	26	1,494
Lime, gray, hard -----	24	1,518
Slate, dark ----------	3	1,521
Lime, soft gray and conglomeratic sand -	10	1,531
Lime, brown, and sand; yellow water; show of gas -------------	17	1,548
Slate, dark-gray -----	3	1,551
Lime, brown, hard ----	14	1,565
Lime, dark-gray, hard-	22	1,587
Lime, sandy, gray, hard ---------------	57	1,644
Lime, sandy, conglomeratic, hard ---------	8	1,652
Lime, gray to dark-gray ---------------	90	1,742
Sand, conglomeratic, white to gray, soft; hole full of water -	20	1,762
Lime, gray, hard -----	28	1,790
Sand, dark-gray, hard; show of oil --------	8	1,798
Lime, gray, hard -----	14	1,812
Sand, gray -----------	20	1,832
Sand, gray, hard, sharp; good show of oil ---	20	1,852

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Table 8.--Drillers' logs of wells in Kinney County--Continued

	Thickness (feet)	Depth (feet)
Well G-1--Continued		
Lime, sandy, gray	19	1,871
Slate, gray	1	1,872
Lime, sharp sandy, gray, hard	35	1,907
Slate, gray	2	1,909
Lime, sandy, gray, hard	6	1,915
Slate, gray, soft	5	1,920
Sand, gray; contains 18-inch layer of rock asphalt	13	1,933
Lime, gray, hard	14	1,947
Shale, blue	2	1,949
Sand, brown	3	1,952
Lime, gray	12	1,964
Lime, sandy, gray, hard	11	1,975
Lime, white, hard	12	1,987
Lime, gray, hard	12	1,999
*Pre-Cretaceous rocks:		2,010
Lime, crystalline, light-gray	51	2,050
Lime, crystalline, cream-colored and opaque pinkish-gray	53	2,103
Shale, gray	38	2,141
Lime, pinkish colored	11	2,152
Lime, crystalline, pink; contains a few crystals of pyrite	11	2,163
Lime, crystalline light-gray	19	2,182
Lime, finely crystalline; stained red-brown from iron; full of fine iron shavings; small percent quartz sand	38	2,220
Lime, crystalline, dark-gray	27	2,247
No record	13	2,260
Lime, crystalline	27	2,287
Limestone, crystalline, slightly sandy, black; about 5 percent cream-colored crystalline lime	71	2,358
Lime, crystalline, dark-gray	50	2,408
Sandstone, brown	47	2,455
Sand, light-tan	8	2,463
Calcite and some silica, black or gray material with calcite form of pyrite	27	2,490
Calcite, black	10	2,500
Sand, highly iron stained a red-brown	140	2,640
Sand	25	2,665
Sand, about 50 percent calcite, black streaked, about 50 percent	10	2,675
Quartzite, dolomitic, similarly splotched	155	2,830
TOTAL DEPTH		4,381

Table 8.--Drillers' logs of wells in Kinney County--Continued

Well S-2

Owner: J. F. Beidler. Driller: Magnolia Oil Co. Asterisk (*) means formation top is by P. S. Morey, Bureau of Economic Geology, University of Texas.

	Thickness (feet)	Depth (feet)
Uvalde gravel:		
Gravel, brown --------	25	25
Eagle Ford shale:		
Shale, blue, soft ----	56	81
Shell, lime, hard ----	7	88
Shale, blue, soft ----	57	145
Shale, gray, hard ----	45	190
*Buda limestone:		190
Lime, white, soft ----	100	290
*Grayson shale:		290
Shale, blue, soft ----	60	350
Shale, gray, hard ----	93	443
*Edwards and associated limestone:		430
Lime shells ----------	22	465
Lime, white, hard ----	35	500
Lime, black, very hard	455	955
Lime shells, hard ----	31	986
Granite, hard --------	9	995
Lime, black, hard ----	22	1,017
Lime, gray, soft -----	13	1,030
Lime shells ----------	40	1,070
Shale, black, hard ---	10	1,080
(1 barrel sulphur water an hour at 1,095 feet)		
Lime, sandy, hard ----	30	1,110
Lime, black ----------	98	1,208
(10 barrels sulphur water an hour at 1,250 to 1,260 feet)		
Lime shells ----------	52	1,260
(2 barrels sulphur water an hour at 1,330 to 1,332 feet)		
*Glen Rose limestone:		1,330
Lime, gray, hard -----	170	1,430
Shale, gray, soft ----	20	1,450
Lime, white, hard ----	18	1,468
Shale, gray, hard ----	22	1,490
Lime, gray -----------	20	1,510
Lime shells ----------	725	2,235
Lime, black ----------	85	2,320
Lime, gray -----------	120	2,440
Lime, black ----------	10	2,450
(Hole full of salt water at 2,440 to 2,450 feet)		
Lime, gray -----------	90	2,540
Sand, hard; water ----	62	2,602
Lime, gray, hard -----	93	2,695

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Table 8.--Drillers' logs of wells in Kinney County--Continued

Well S-2--Continued

	Thickness (feet)	Depth (feet)
Lime, sandy ----------	115	2,810
Shale, white, soft ---	5	2,815
Lime, sandy, hard ----	15	2,830
Shells, sandy, hard, sharp --------------	25	2,855
Lime, sandy, hard ----	15	2,870
Shale, sandy, soft ---	30	2,900
Lime, sandy, hard ----	20	2,920
Shale, sandy, soft ---	15	2,935
Lime, sandy, hard ----	15	2,950
*Pearsall formation:		2,960
Shale and gypsum, soft ---------------	13	2,963
Sand, gray, hard, sharp --------------	15	2,978
Shale, sandy, soft ---	8	2,986
Lime, sandy, hard ----	24	3,010
Shale, sandy, soft ---	10	3,020
Lime, sandy, hard ----	15	3,035
Sand, brown, soft ----	18	3,053
Lime, sandy, hard ----	7	3,060
Shale, soft ----------	40	3,100
*Sligo formation:		3,150
Shale, sandy, soft ---	68	3,168
*Hosston formation:		3,190
Shale, soft ----------	32	3,200
Lime, dark-colored, hard ---------------	10	3,210
Lime shells, hard ----	98	3,308
Red beds, soft -------	17	3,325
Sand, red, hard ------	5	3,330
Red beds, soft -------	60	3,390
*Pre-Cretaceous rocks:		3,430
Lime, sandy, hard ----	88	3,478
Shale, black, soft ---	9	3,487
Lime, sandy, hard ----	38	3,525
Lime, red, hard ------	20	3,545
Lime, sandy, hard, sharp --------------	18	3,563
Shells, sandy, soft --	1,440	5,003
Red beds, hard -------	2	5,005
(½ barrel salt water per hour at 5,250 to 5,253 feet)		
Sand, gray -----------	275	5,280

Well X-5

Owner: Geo. Crystall. Driller: Geo. Crystall.

	Thickness (feet)	Depth (feet)
Eagle Ford shale:		
No record ------------	55	55
Shale, bluish-gray ---	5	60
Shale, gray with small light-gray spots; contains some bentonite ----------	5	65
Shale, gray with small light-gray spots ---	6	71
Shale, gray with small light-gray spots; also some sandy limestone ----------	19	90
Shale, gray with small light-gray spots; contains some bentonite ----------	20	110
Shale, gray with small light-gray spots ---	20	130
Shale, gray with small light-gray spots, some sandy limestone, pyrite, and a small amount of light-gray fine-textured limestone ----------	20	150
Buda limestone:		
Limestone, light-gray-	15	165
No record ------------	10	175
Limestone, light-gray-	35	210
Limestone, light-gray; fragments of calcite ------------	25	235
No record ------------	30	265
Grayson shale:		
Shale, bluish-gray; contains pyrite and shell fragments ----	5	270
Clay ----------------	103	373
Edwards and associated limestones:		
Limestone, white -----	27	400
Limestone, fine-textured, light-gray --	10	410
Limestone, fine-textured, light-gray; some light-blue shale, and some with small black specks and pyrite -------------	50	460
Limestone reported ---	54	514

Table 8.--Drillers' logs of wells in Kinney County--Continued

Well BB-1

Owner: Gaebler Bros. Driller: Bob Rose.

	Thickness (feet)	Depth (feet)
Uvalde gravel:		
Caliche, light-gray, soft ---------------	30	30
Limestone, pebbles ---	10	40
No record ------------	5	45
Limestone pebbles ----	5	50
Austin chalk and Eagle Ford shale:		
Limestone, chalky, light-buff, soft ---	10	60
No record ------------	5	65
Limestone, gray, hard-	25	90
No record ------------	10	100
Limestone, gray, hard-	20	120
No record ------------	10	130
Limestone, gray to dark-gray ----------	20	150
Limestone, gray ------	10	160
No record ------------	5	165
Limestone, gray ------	10	175
Limestone, gray to dark-gray ----------	5	180
No record ------------	55	235
Limestone, gray; small amount of dark-gray limestone ----------	25	260
Limestone, gray to dark-gray ---------------	5	265
Limestone, gray to very dark gray -----	10	275
Limestone, gray to dark-gray ----------	5	280
Limestone, light-gray-	5	285
Limestone, light-gray; a small amount of dark-gray limestone-	5	290
Limestone, light-gray-	10	300

Well EE-2

Owner: R. W. Morrison

	Thickness (feet)	Depth (feet)
Austin chalk:		
No record ------------	80	80
Chalk ----------------	350	430
Limestone, shaley, dark-colored -------	10	440
Chalk ----------------	140	580
Eagle Ford shale:		
Shale, dark-gray -----	20	600
Shale, chalky --------	20	620
Shale, black ---------	285	905

(Continued on next page)

Well EE-2--Continued

	Thickness (feet)	Depth (feet)
Buda limestone:		
Limestone	90	995
Grayson shale:		
Mud	5	1,000
Clay	150	1,150
Edwards and associated limestones:		
Limestone, white	10	1,160
Limestone, chalky, white	50	1,210
Shale	20	1,230
Limestone, gray	190	1,420
No record	80	1,500
Limestone, buff	30	1,530
TOTAL DEPTH		3,600

Well FF-7

Owner: Judge Brice. Driller: T. J. Hiney.

	Thickness (feet)	Depth (feet)
Anacacho limestone, Austin chalk, and Eagle Ford shale:		
Clay, calcareous, gray; contains small specks of black material, some bentonite and shell fragments	122	122
Limestone, fine-textured, light-gray; contains small specks of black materials, some gray calcareous clay and shell fragments	88	210
Limestone, fine-textured, light-gray; contains small specks of black material, some gray calcareous clay, shell fragments and bentonite	30	240
Limestone, fine-textured, light-gray; contains relatively large specks of black materials, pyrite shell fragments and gray calcareous clay	15	255
Limestone, fine-textured, light-gray	140	395
Limestone fine-textured, light-gray to gray	5	400
Limestone, fine-textured, light-gray to gray; contains some dark gray to black calcareous shale	12	412
Shale, dark-gray to black; contains small amount of light gray limestone	68	480

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Well FF-7--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Limestone, fine-textured, light-gray --	35	515	Buda limestone:		
Limestone, clayey, gray to dark-gray; contains limestone, shell ---	195	710	Limestone, fine-textured, light-gray --	28	990
Shale, calcareous, gray to dark-gray; contains shell fragments ----------	30	740	Limestone, fine-textured, chalky, light-gray ---------------	50	1,040
Limestone, light-gray-	35	775	Grayson shale, Edwards and associated limestones:		
Shale, very calcareous, dark-gray -----------	8	783	Clay, slightly calcareous, dark-gray; contains pyrite ----	65	1,105
Shale, calcareous, gray, with dark-gray spots-	179	962	No record ------------	315	1,420

Well FF-15

Owner: Louis L. Farr.

Anacacho limestone:			Limestone, gray (water at base) -----------	40	140
Limestone, yellow ----	40	40	Shale, blue ----------	40	180
Clay, yellow (water seep at bottom) -----	60	100	Limestone, broken, gray (water) -------	26	206

Well GG-1

Owner: J. E. White. Driller: Lloyd Oil Co.

Cenozoic gravel:			Austin chalk:		
Soil -----------------	3	3	Lime, gray (2 barrels of water an hour) --	79	103
Clay, light-colored --	6	9	Lime, gray -----------	2	105
Gravel (little fresh water) -------------	10	19	Shale, blue ----------	2	107
Clay, yellow ---------	5	24	Lime, gray -----------	25	132

(Continued on next page)

Table 8.--Drillers' logs of wells in Kinney County--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Well GG-1--Continued					
Shale, light-brown ---	3	135	Shale, light-brown ---	6	629
Lime, gray (hole caving a little)-----------	38	173	Shale, brown, hard; contains pyrite ----	5	634
Lime, gray -----------	66	239	Buda limestone:		
Eagle Ford shale:			Lime, white, hard ----	119	753
Shale, light-brown ---	16	255	Grayson shale:		
Lime, hard -----------	1	256	Shale, blue, soft ----	42	795
Shale, light-brown ---	14	270	Shale, blue, soft (hole dry) ---------	125	920
Lime, gray, hard -----	1	271	Shale, blue ----------	10	930
Shale, light-brown, soft ---------------	29	300	Shale, gray ----------	15	945
Lime, gray, hard -----	15	315	Edwards and associated limestones and Glen Rose limestone:		
Shale, white, hard ---	19	334	Lime, gray -----------	195	1,140
(Little show of water; about 2 bailers an hour at 338 feet) --	16	350	Lime -----------------	2	1,142
Shale, light-brown, soft ---------------	25	375	Lime, hard gray ------	252	1,394
Shale, blue, hard ----	35	410	Lime, soft -----------	2	1,396
Shale, light-brown, soft ---------------	50	460	Lime, hard gray ------	43	1,439
Shale, blue, hard ----	15	475	Lime, soft gray ------	4	1,443
Shale, light-brown, soft ---------------	35	510	Lime, hard gray ------	85	1,528
Shale, dark-brown ----	40	550	Lime, black, quartz --	70	1,598
Shale, sandy, dark-brown --------------	71	621	Lime, hard black -----	77	1,675
Lime, white, hard ----	2	623	Lime, sandy ----------	36	1,711
			Lime, black ----------	16	1,727
			Lime, brown ----------	16	1,743

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Table 8.--Drillers' logs of wells in Kinney County--Continued

Well GG-1--Continued

	Thickness (feet)	Depth (feet)
Lime, black	49	1,792
Lime, gray	15	1,807
(4 barrels of water an hour)		
Lime, gray (hole full of water)	20	1,827
Lime	38	1,865
Sand, water (flow 200 gallons an hour)	10	1,875
Sand, hard gray	32	1,907
Lime, hard gray	81	1,988
Lime, hard blue	5	1,993
Lime, hard brown	56	2,049
Lime, hard gray	69	2,118
Lime and shale	28	2,146
Lime, hard gray	6	2,152
Lime, hard brown	22	2,174
Lime, hard gray	11	2,185
Lime, hard blue	24	2,209
Lime, hard brown	32	2,241
Lime, hard gray	8	2,249
Lime, hard brown	4	2,253
Lime, hard gray	31	2,284
Lime, hard brown	26	2,310
Lime, hard blue	291	2,601
Lime, hard gray	18	2,619
Shale, hard blue	15	2,634
Lime, hard brown	42	2,676
Lime and shale	10	2,686
Lime, hard brown	83	2,769
Lime, hard gray	147	2,916
Lime, hard brown	105	3,021

Well MM-5

Owner: E. H. Schmidt. Driller: -- Strippling.

	Thickness (feet)	Depth (feet)
Tertiary rocks:		
Soil, red sandy loam	2	2
Subsoil, sandy clay, light red	3	5
No record	5	10
Shale, sandy, white	15	25
Sand, shaley, white	10	35
Sand, shaley, yellow	5	40
Sand, shaley, light-yellow or gray	15	55
Sand, fine, shaley, blue	25	80
Shale, dark-colored	15	95
Shale, sandy, blue	15	110

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Table 8.--Drillers' logs of wells in Kinney County--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Well MM-5--Continued					
Sand, blue, and sandstone showing slight traces of dead asphalt. (Bailed water at $12\frac{1}{2}$ gallons a minute) ------------	20	130	Shale, blue ----------	22	160
Sand, shaley, gray ---	8	138	Sand, shaley, blue ---	18	178
			Tertiary and Navarro rocks:		
			Shale, sandy, blue ---	72	250