CENOZOIC STRATIGRAPHY AND GEOMORPHOLOGY OF LYNN AND TERRY COUNTIES, TEXAS

by

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CHAPTER I

INTRODUCTION

Location

Lynn and Terry counties, Texas, are in the southeastern part of the Southern High Plains, between 32°57' and 33°24' north latitude and 101°33' and 102°36' west longitude. Each county is about 30 miles square, thus the total area of investigation was approximately 1,800 square miles (Fig. 1).

Topography

With the exception of eight saline lake basins and related dune topography, Lynn and Terry counties are flat to gently rolling, maximum relief outside the large lake basins being approximately 20 feet. The counties have an average slope of 10 to 15 feet per mile to the southeast, the elevation near the northwest corner of Terry County being approximately 3,600 feet and about 2,700 feet in southeast Lynn County.

No present through-flowing drainage exists in Lynn and Terry counties; however, remnant Pleistocene drainage channels such as Lost Draw (northern Terry County) trend east or southeastward (Fig. 2). During wet periods, some drainage will locally occur from one playa basin to another.

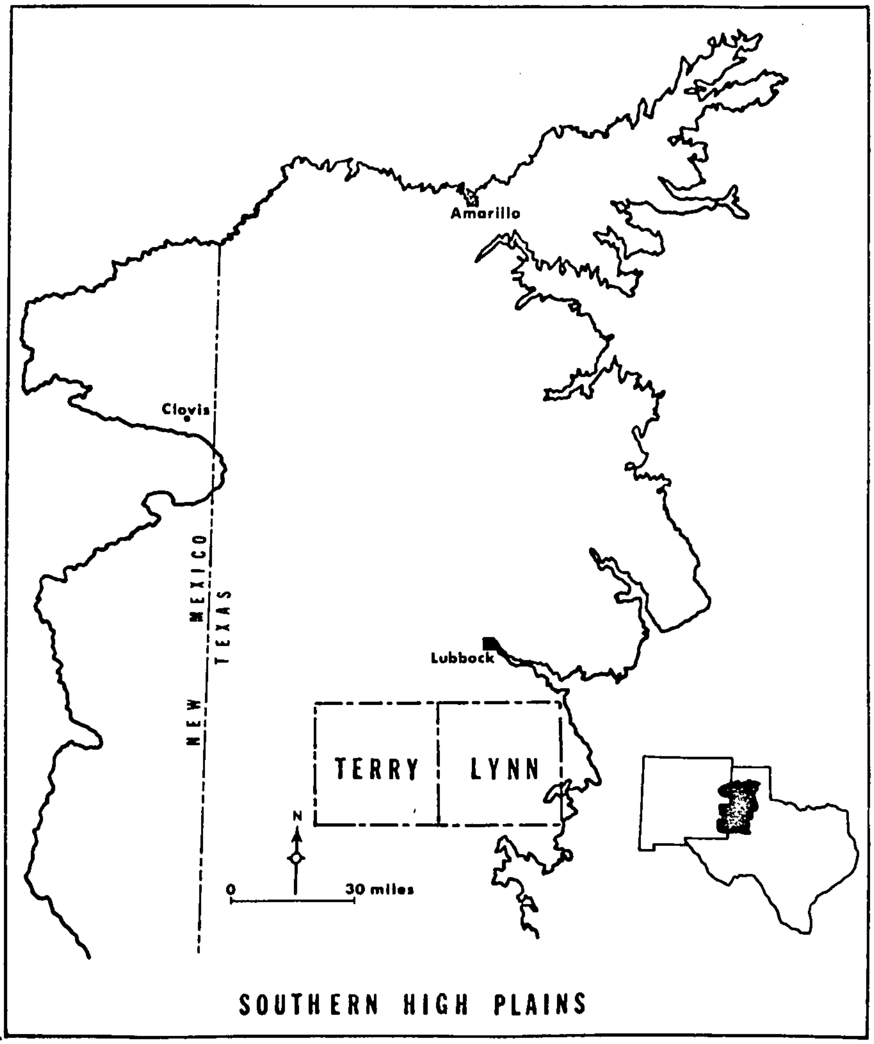

Fig. 1.--Index map of the Southern High Plains, Texas and New Mexico.

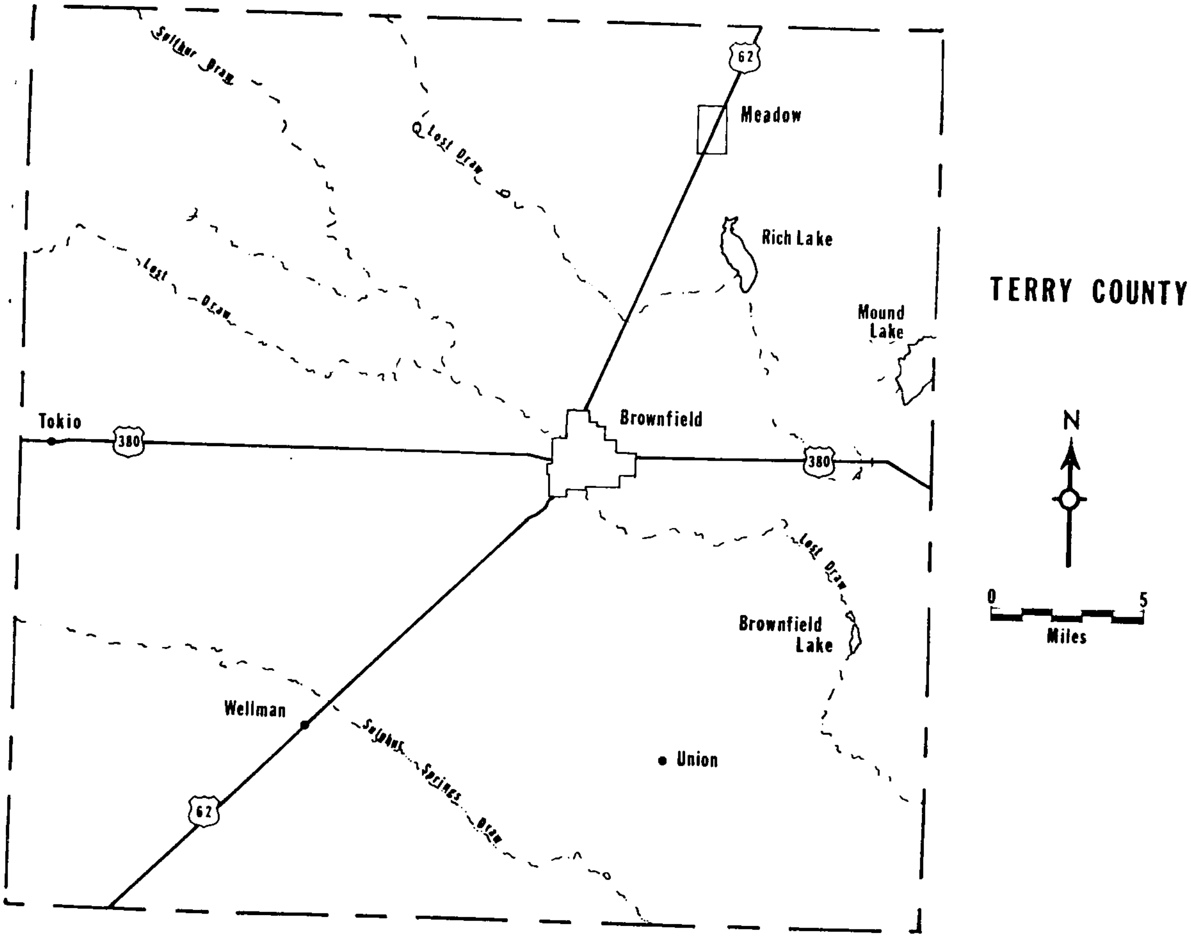

Fig. 2.--Index map of Terry County, Texas.

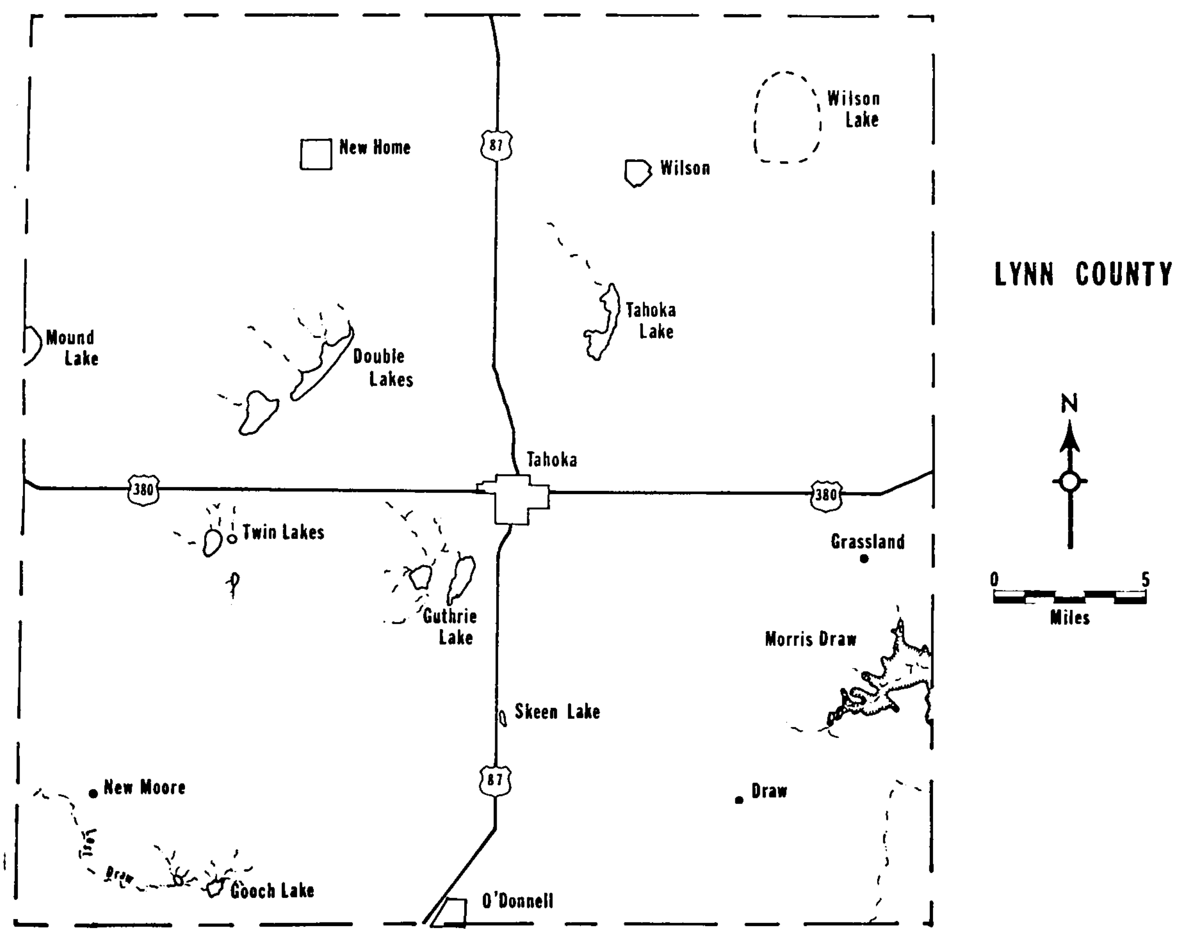

Fig. 3.--Index map of Lynn County, Texas.

Most relief in the two-county area exists because of natural depressions produced by post-Pliocene erosion. Sand dunes associated with the lake basins are responsible for most of the relief except for the erosion of Morris Draw (Spring Creek Canyon) in the southeastern part of Lynn County. Surficial blow sand and Pleistocene cover sands (comprised of sand as well as a high percent of silt and clay) create the gently rolling topography.

Climate

The climate in both Lynn and Terry counties is semi-arid characterized by low precipitation, high evaporation, and a wide temperature range. The mean annual precipitation for a 42-year period (1931-1973) at Tahoka in central Lynn County was 18.37 inches and only 17.70 inches for Brownfield in central Terry County (Local Climatological, Lubbock, Tex., 1973). Mean annual temperature for Tahoka averages approximately 61^{o}F.

The greatest part of the precipitation in Lynn and Terry counties is returned to the atmosphere by evapotranspiration. The average annual rate of evaporation from a free-water surface is approximately 73 inches per year (USDA, 1959); thus, potential annual evaporation is approximately three-and-a-half times greater than the average annual precipitation.

Lynn and Terry counties, like the remainder of the

Southern High Plains, are characterized by strong, persistent winds. The wind direction polygon for Lubbock, Texas, located 30 miles north of Tahoka, shows prevailing summer winds from the south and prevailing winter winds from the southwest. Specifically, wind velocity averages 15.3 miles per hour from the north during January and 16.3 miles per hour from the south during June (Johnson, 1965).

Previous Work and Purpose

G.K. Gilbert (1895) was one of the first to consider the origin of the numerous lake basins on the Southern High Plains, Cummins (1889, 1891, 1892, 1893) studied local stratigraphy, and Gould (1906, 1907) studied the geology and water resources. Cope (1892, 1893) studied vertebrate paleontology in the area but W.D. Johnson (1901) provided the first comprehensive report on the geology of West Texas for the United States Geological Survey (USGS): this was followed by Darton's (1915) study. C.L. Baker (1915) first called attention to the underground water resources of West Texas whereas Sellards and others (1932) were concerned primarily with fossil vertebrates. Melton (1940) included part of the Southern High Plains in his study of paleowind directions as indicated by sand-dune trends. Price (1940, 1944) and later Reeves and Suggs (1964), and Reeves (1970b) discussed the origin of caliche and the Pliocene "caprock" Caliche.

In 1945 Evans and Meade suggested that a record of Pleistocene climatic fluctuations was preserved in the lacustrine stratigraphy of the large natural lake basins of the Southern High Plains. Evans (1949), however, was concerned with the Pliocene Ogallala section, dividing the Ogallala into the lower Couch Formation and the upper Bridwell Formation. Evans (1949) thus unofficially raised the Ogallala to Group rank, but because this work was done before publication of the Stratigraphic Code (1961) the Ogallala is still preferably considered of formational rank, although Group rank is given secondary consideration (Keroher and others, 1961).

Judson (1950) studied the origin of small lake basins in eastern New Mexico and Reeves, in a series of reports during the last several years (1963, 1966a, 1966b, 1968, 1970a, 1972), has documented geneses, morphology, stratigraphy, and paleoclimatology of the Pleistocene lacustrine environment on the Southern High Plains. The clay mineralogy of Pleistocene lacustrine and eolian sediments has been studied by Reeves and Parry (1967), Parry and Reeves (1968), and McLean (1969). Paleoecology of the Southern High Plains, using pollen, vertebrates, and invertebrates, was studied by Green (1961), Hafsten (1961), and Wendorf (1961, 1975). After Wendorf's (1961) study, several investigations (Oldfield and Schoenwetter, 1964; Reeves, 1965, 1966b, 1973; Galloway, 1970) were concerned with Pleistocene climatology on the Southern High Plains. Frye and Leonard (1955, 1957a, 1957b, 1962, 1963, 1964, 1965, 1974) have studied Cenozoic geologic history on the Southern High Plains, correlating Quaternary units with the classic glacial stratigraphy of the central interior United States. Studies currently underway on the Cenozoic of the Southern High Plains are concerned with paleodrainage (Reeves), tephrachronology (Izett), geo-archaeology (Johnson) and clay mineralogy (Lee and Goolsby).

Specifically, Cenozoic geology in Lynn and Terry counties has not been thoroughly investigated, although several local studies have been completed and soil surveys were published by the USDA in 1959 and 1962 respectively. Groundwater resources of Lynn County were studied by Leggat (1952) and a section on groundwater in and around the Slaton channel in northern Lynn County was included in a report by the High Plains Underground Water Conservation District No. 1 (1973). Reeves (1969) studied the Ogallala aquifer in the Rich Lake area, Terry County, and much of Terry County was included on an Ogallala isopachous map by Wyatt (1967). A superficial study of the groundwater in Terry County was included in a report by Wyatt (1968), but no thorough study has ever been conducted.

Evans and Meade (1945) and Reeves (1963) studied geology in the Spring Creek area in Garza and Lynn counties, and such geomorphological features as gas rings (Reeves, 1964), spring pots, and spring necks (Reeves, 1965) associated with large playa basins in Lynn and Terry counties were named for morphological peculiarities. Mound Lake, which straddles the Lynn-Terry County line, was studied by Parry and Reeves (1966, 1968), Leach (1969), and Bates and others (1970). Buchanan (1973) studied the geology of the Double Lakes area in Lynn County.

This investigation of Lynn and Terry counties is primarily concerned with Cenozoic stratigraphy, paleoclimatology and depositional environments, and geomorphology.

CHAPTER II

STRATIGRAPHY

This study deals specifically with rocks of Tertiary and Quaternary age although Triassic and Cretaceous rocks also outcrop at one or more localities in the Lynn-Terry county area. Consequently a brief description of Triassic and Cretaceous stratigraphy is included.

Triassic

McKee and others (1959), and control from oil well logs, show Triassic rocks underlie all of Lynn and Terry counties, ranging in thickness from approximately 1,000 feet in eastern Lynn County to nearly 2,000 feet in western Terry County. The Triassic rocks in the area, termed the Dockum Group (Cummins, 1889; Drake, 1892), consist of deep purplish-red shale and clay, lenticular beds of blue sandy clay, conglomerate, and cross-bedded gray and red micaceous sandstone. Gregory (1972) found fossil evidence indicative of an aquatic floodplain or deltaic environment. The top of the Triassic section is encountered at depths of about 130 feet in southeastern Lynn County and at about 350 feet in the northwestern part of Lynn County where a deep channel was cut through the Cretaceous section.

The only outcrop of the Dockum Group in Lynn and Terry counties is in the southeastern corner of Lynn County along the Double Mountain Fork of the Brazos River (also known as Spring Creek Canyon, Cooper Canyon, and Morris Draw Fig. 3).

The Dockum Group, termed "red beds" by local farmers and drillers, is the aquitard at the base of the Ogallala aquifer for the area north of a line between Portales, New Mexico, and Lubbock, Texas. To the south the Ogallala rests mainly on Cretaceous rocks. In Lynn and Terry counties the only known locality where Triassic units are directly overlain by the Ogallala aquifer is in the previously mentioned channel (Slaton Channel) in the northern extremity of Lynn County.

Cretaceous

Cretaceous rocks in Lynn and Terry counties consist of the Trinity, Fredericksburg, and Washita groups of the Comanche Series (Brand, 1953). The Trinity Group contains the Paluxy Sandstone. The Fredericksburg Group is composed of the Walnut, Comanche Peak, Edwards, and Kiamichi formations, and the Washita Group contains the Duck Creek Shale (Fig. 4).

The greatest exposed thickness ($\pm$50 feet) of Cretaceous rocks in Lynn and Terry counties, consisting of the Paluxy Sandstone, Walnut Formation and the Comanche Peak Limestone, is along the Double Mountain Fork of the Brazos River in southeastern Lynn County. The Kiamichi and Edwards formations outcrop in the basin and along the western side of

ERA	SYSTEM	SERIES	GROUP	FORMATION	DESCRIPTION	APPROXIMATE THICKNESS IN FEET
CENOZOIC	QUATERNARY	RECENT			valley alluvium, stabilized and active dunes, black, brown, white saliferous playa silts.	?
					unconformity	
CENOZOIC	QUATERNARY	PLEISTOCENE		LOESS (Peoria?)	loess, yellowish brown to dark brown.	0-10
					unconformity	
CENOZOIC	QUATERNARY	PLEISTOCENE		TAHOKA	sands, gravels, gypsum, thin to podular carbonate lenses, and black (5Y 2/1) to blue-gray (5B 5/1) clays.	35±
					unconformity	
CENOZOIC	QUATERNARY	PLEISTOCENE		DOUBLE LAKES	clay, dark olive gray (5GY 4/1) to black (5Y 2/1) intermittant zones of epsomite and gypsum crystals.	30±
					unconformity	
CENOZOIC	QUATERNARY	PLEISTOCENE		BLACKWATER DRAW	sand, silt, and clay, reddish brown to tan brown eolian, often calcareous in middle and lower part of section.	0-20+
					unconformity	
CENOZOIC	QUATERNARY	PLEISTOCENE		TULE	clay and sand, gray, bentonitic, with thin-bedded, ripple-marked fresh-water limestones.	100
					unconformity	
CENOZOIC	QUATERNARY	PLEISTOCENE		BLANCO	sand and clay, light gray, clays bentonitic, some fresh-water limestone and diatomite.	70±
					unconformity	
CENOZOIC	TERTIARY	PLIOCENE	OGALLALA	BRIDWELL	clay and sand, reddish-brown, coarse channel gravels. "Cap-rock" at top.	155±
					unconformity	
CENOZOIC	TERTIARY	PLIOCENE	OGALLALA	COUCH	sand, pinkish-gray, well sorted, thick basal gravel.	125±
					unconformity	
MESOZOIC	CRETACEOUS	COMANCHE	WASHITA	DUCK CREEK	shale, yellow-brown to dark gray, brown limestone and sandstone. Desmoceras abundant at base.	0-40
					unconformity	
MESOZOIC	CRETACEOUS	COMANCHE	FREDERICKSBURG	KIAMICHI	shale, dark gray to yellow-brown, thin gray to yellow brown limestone and sandstone lentils. Lower oart fossiliferous.	108
MESOZOIC	CRETACEOUS	COMANCHE	FREDERICKSBURG	EDWARDS	limestone, white to yellow-brown, thick to massive-bedded	20-30
MESOZOIC	CRETACEOUS	COMANCHE	FREDERICKSBURG	COMANCHE PEAK	limestone, light gray, thick to massive-bedded, argillaceous, marl interbeds.	50-80
MESOZOIC	CRETACEOUS	COMANCHE	FREDERICKSBURG	WALNUT	shale, light gray, sandy, light gray argillaceous limestone abundant.	8-23
					unconformity	
MESOZOIC	CRETACEOUS	COMANCHE	TRINITY	PALUXY	sand, light gray to purple lenticular quartz gravel beds.	10-25

Fig. 4.--Cretaceous and Cenozoic stratigraphic section of the Southern High Plains (including Lynn and Terry counties). (Modified after Brand, 1953, and Reeves, 1970).

Guthrie Lake southeast of Tahoka, Lynn County. The Kiamichi Formation also outcrops along the southwestern margin of Gooch Lake and the western edge of Tahoka Lake. Both the Kiamichi and Duck Creek formations outcrop along the western margins of Twin Lakes and Double Lakes. Outcrops of the Duck Creek Formation are also located at the northwestern margin of Rich and the western margin of Mound Lake.

As indicated by driller's logs, most of the "fresh water" water wells in Lynn and Terry counties are drilled to either the "yellow shale" (Duck Creek) or the "blue shale" (Kiamichi), the major aquitards underlying the Ogallala aquifer in the two counties. A few wells produce potable water from Cretaceous rocks, but it is likely that such wells are hydrologically linked to the Ogallala aquifer.

Tertiary

Based on several vertebrate faunas (Frye, 1970), the oldest Tertiary deposits of the Southern High Plains are of late Miocene age. The late Tertiary deposits of the High Plains were named the Ogallala Formation by Darton (1899, 1905) after the small town of Ogallala, Nebraska. Evans (1949), on the basis of vertebrates and plant fossils, divided the Ogallala section of the Southern High Plains into the Couch and Bridwell formations thus unofficially raising the Ogallala to Group status. Although Frye and

Leonard found little lithologic continuity along the eastern "Caprock" escarpment of the Southern High Plains, and suggested confining the Ogallala to formational status, Reeves (1970) noticed lithologic similarities to Evans and Meade's (1945) Couch and Bridwell formations along the western "Mescalero" escarpment thus lending credence to Group rank. The widespread regional continuity of the Couch and Bridwell formations is also indicated by clay mineralogy (Goolsby and Lee, 1975), thus the Ogallala is here considered of Group rank.

The Couch Formation, of upper-Miocene and lower-Pliocene age, rests unconformably on Triassic and Cretaceous rocks and is overlain unconformably by the Bridwell Formation. Evans (1974) states that

> ...in most places two members of the formation can be recognized, a basal member composed of cross-bedded sands and gravels occupying very broad comparatively shallow channels, and an upper member composed of well-sorted semi-consolidated calcareous and clayey sands. Distinguishing characteristics of the upper member are its light pinkish-gray color, lack of bedding, homogenous lithology, and imperfect polygonal jointing.... The materials composing the upper member were probably derived from stream deposits, sorted and redeposited by the wind. A zone of secondary calcium carbonate enrichment, with local accumulations of opaline silica, is developed in the uppermost part of the formation. This zone apparently developed as a subsoil beneath the Couch plain which existed for a long time as a stabilized surface before it was buried by sediments of the Bridwell Formation.

The Couch Formation is also characterized by a high percentage of the clay mineral attapulgite which tends to increase upward, being completely absent just above the Couch-Bridwell contact (Lee and Goolsby, 1975; Goolsby and Lee, 1975).

The Bridwell Formation of Middle Pliocene age (Evans, 1974), rests unconformably on the Couch Formation or in places where the Couch is absent, on Cretaceous and Triassic rocks. Evans (1974) states that

> ...the main body of the Bridwell consists of bedded, unconsolidated sands and clays. A thick channel deposit of sand and gravel containing large clay balls is usually present in the base and other more localized channel deposits occur at higher levels in the formation. Secondary calcium carbonate is present in the upper members and is highly concentrated in the remarkable caliche caprock at the top of the formation. The Bridwell is characteristically reddish-brown but the colors grade upward through lighter shades to the gray calcareous zone.

Sediments of the basal Ogallala Group were deposited in topographic lows on the Triassic and Cretaceous unconformity. Valley systems across the plains were filled with fluvial debris by aggrading streams flowing southeastward from the Rocky Mountains, in northern New Mexico (Frye and Leonard, 1959). Reworking by wind action in the intervalley areas and soil formation was common. Caliche accumulation and clay-coated quartz grains within the carbonate horizons are evidence of multiple soil formations upward through the Ogallala section (Wells, 1974).

Reeves (1972) found that the Ogallala section in southeastern New Mexico within 90 miles of the Sacramento

Mountains consists mainly of fine-grained calcareous sand and silt, the only fluvial-appearing sands and gravels being a basal section five to ten feet thick. The predominance of fine-grained sand and the absence of fluvial sand and gravel therefore indicated there was no eastward-flowing streams off of the Sacramento Mountains after early Ogallala time. The first persistent Ogallala fluvial deposits are at San Juan Mesa west of Elida, New Mexico.

The most striking unit within the Ogallala is undoubtedly the "caprock" caliche which forms the escarpment defining the eastern, northern and most of the western boundary of the Southern High Plains. Although the origin of the "caprock" caliche was, for several years, a controversial subject (Lovelace, 1972), many recent studies (Swineford and others, 1958; Reeves, 1970b; Frye and Leonard, 1972) show massive caliches are the long standing product of multiple generations of soil formation, brecciation of the caliche zone, and multiple recementation.

Thickness of the Ogallala Group ranges from a feather edge in the southern extremity of the Southern High Plains where it pinches out over the Cretaceous Edwards Limestone of the Edwards Plateau to over 500 feet in pre-Ogallala topographic lows or within deeply-cut Ogallala stream channels. Regionally the Ogallala section thickens toward the north and east.

The pisolitic character of the "caprock" caliche has been used by some geologists (Frye and Leonard, 1974) to distinguish the Ogallala caliche from younger caliches. Pisolitic structure, however, caused by multiple cycles of brecciation and recementation, occurs in early Pleistocene caliche along Yellowhouse Canyon at Lubbock, Texas, and also at the Wilson Lake locality in Lynn County. Pisolitic caliche also is not necessarily found at the top of the Ogallala caliche, only occurring where the Ogallala has been either exposed or very near surface. Caliche at the top of the Ogallala section along the western escarpment, where westerly winds have deflated the unconsolidated Pleistocene cover (perhaps it never existed), is more likely to contain pisolitic structure than in the eastern part of the Southern High Plains where the Pliocene caliches have been covered by eolian debris. Pisolitic caliche is not uncommon along the eastern Southern High Plains, occurring along the scarp edges of large lake basins such as Guthrie, Double, and Twin lakes among others in Lynn and Terry counties. Clay minerals in the pisolitic caliche are generally poorly crystalline (Frye and others, 1974; Goolsby and Lee, 1975) due perhaps to modification by near surface weathering conditions.

Throughout most of Lynn and Terry counties, sediments of the Ogallala Group unconformably overlie rocks of Cretaceous age; primarily the Duck Creek and Kiamichi formations. Thickness of the Ogallala Group ranges from a feather edge around several of the large lake basins to nearly 300 feet in the Slaton Channel in north-central Lynn County. At the base of the channel, Ogallala gravels lie unconformably on rocks of the Triassic Dockum Group. This steep-walled channel enters Lynn County from Lubbock County to the north where U.S. Highway 87 intersects the county line, trends generally west-east across northern Lynn County, and swings north into Lubbock County about 3 miles west of the intersection of the county line and FM 400 (Fig. 6). Water well logs show the channel cut through approximately 125 feet of Cretaceous limestones and about 75 feet into the underlying Triassic Dockum Group. The lower 100 feet of the Ogallala section within the channel is composed primarily of gravels indicating deposition by a high energy aggrading stream probably originating in the area of the Sangre de Cristo Mountains of northern New Mexico or southern Colorado (based on mineralogical and petrological similarity of the gravels to the rocks comprising this particular mountain range). Gravels reported by drillers in the remaining portion of Lynn and Terry counties are usually confined to the basal 20 feet of the Ogallala section, but have essentially the same siliceous composition. The upper part of the channel fill is typically Ogallala flood-plain and eolian facies, having a normal

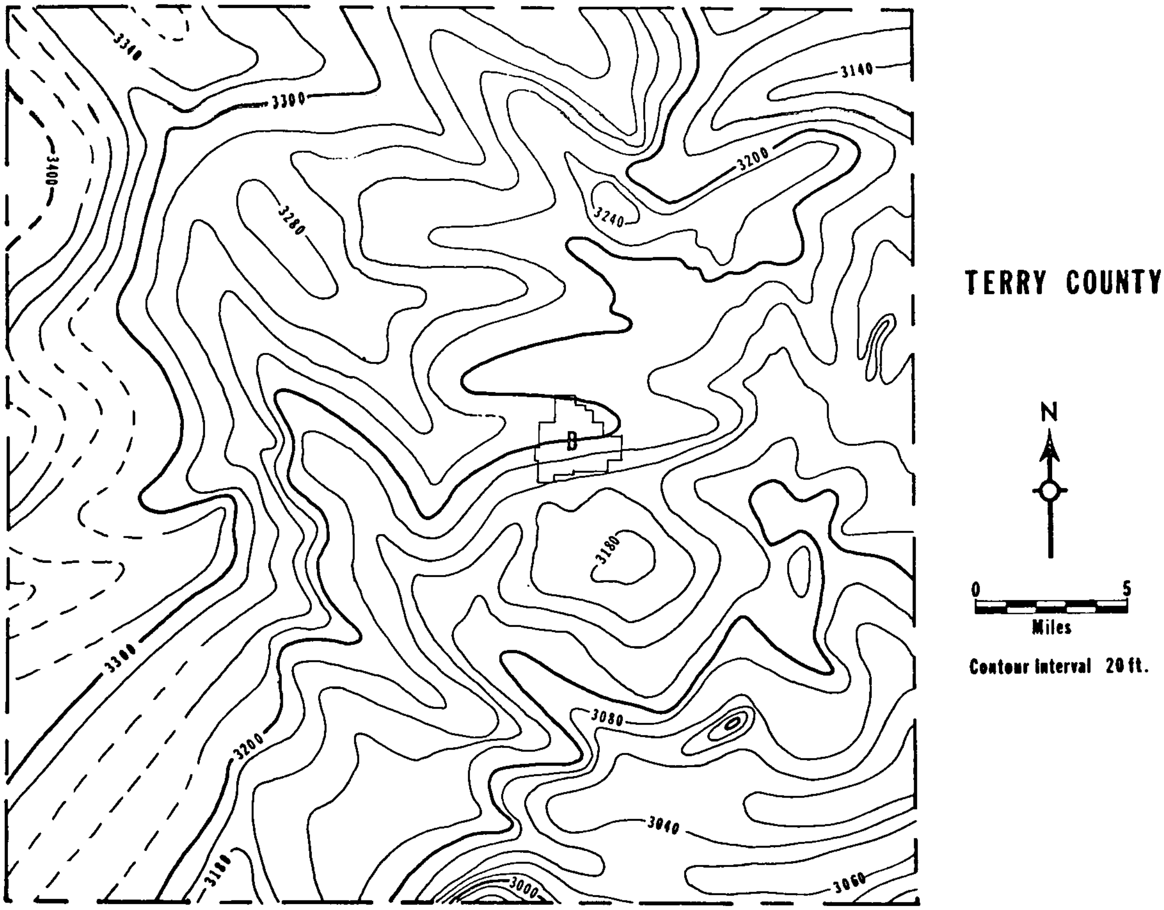

Fig. 5.--Top of Cretaceous (base of Ogallala) contour map, Terry County, Texas.

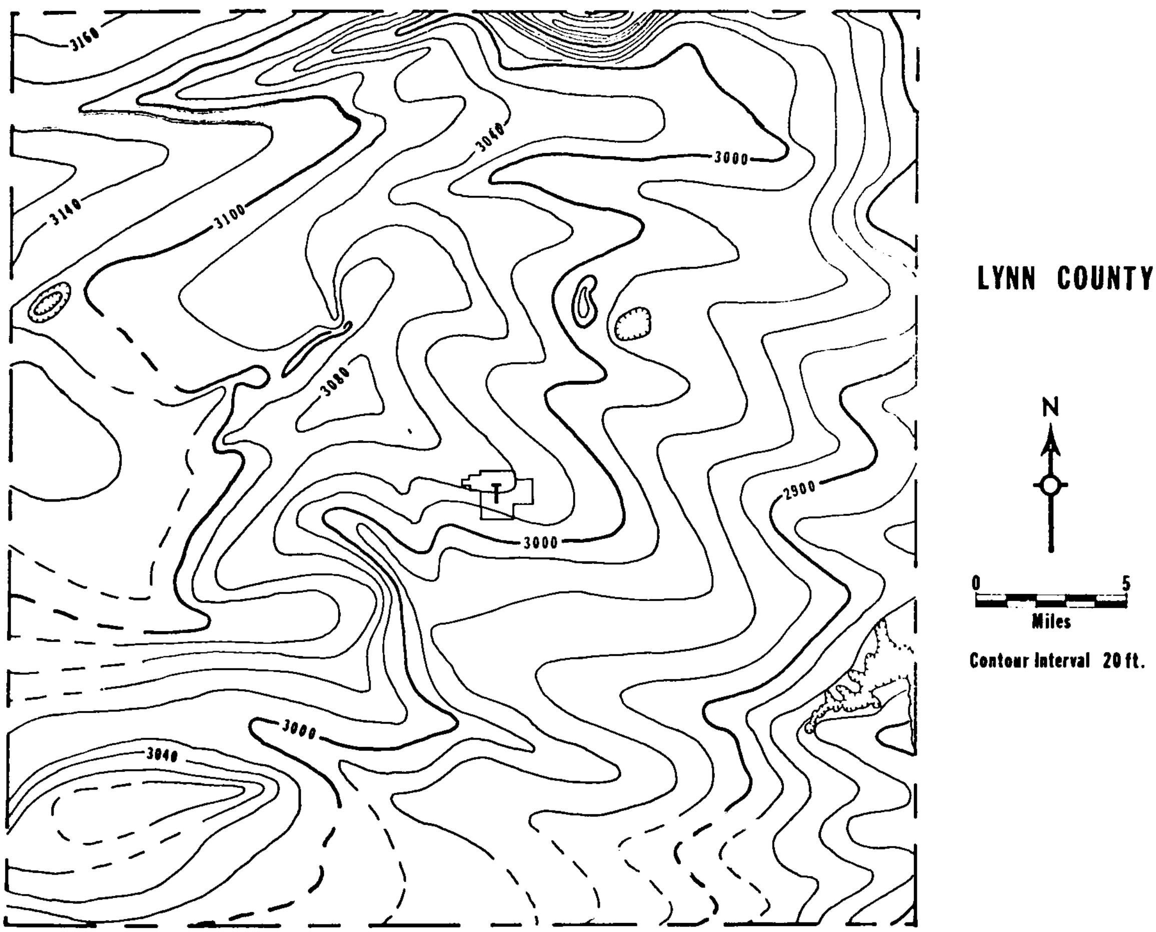

Fig. 6.--Top of Cretaceous (base of Ogallala) contour map, Lynn County, Texas.

thickness of caliche (High Plains Underground Water Conservation District Number 1, 1973). The caliche is more or less level across the valley indicating that the channel was filled, and that the drainage network either shifted or became extinct prior to the end of Pliocene deposition. Slaton Channel gravels are mined commercially where the channel is cut by the westward migrating eastern escarpment northeast of Lynn County in Crosby County. A tributary of the Slaton Channel trends west to east across northwestern Lynn and northeastern Terry counties (Figs. 5 and 6) the main channel turning north into Lubbock County along the present route of U.S. 87.

A channel apparently somewhat similar to the Slaton Channel curves in and out of the south-central part of Terry County (Fig. 5). Maximum depth of wells for which logs were available indicate that the bottom of the channel is approximately 260 feet below the present land surface; hence, the base of the Ogallala here is about twice as deep as in the surrounding area. The small number of available logs and the poor quality of those which are available make a more detailed study of this particular channel difficult.

Several other channels which are usually wider but not as deeply cut as the Slaton Channel trend northwest-southeast through Terry County and west to east through Lynn

County. Figures 5, 6, 17 and 18 illustrate that all of the large lake basins in the two-county area are either within or closely associated with one of the basal Ogallala channels and that most are located on the east side of Cretaceous topographic highs. Age of the channels is unknown. However, well logs usually indicate several feet of "caprock" caliche over the channels, thus they must predate the climaxing Ogallala caliche.

Lithologic maps illustrating the percentage of clay, sand, and gravel within the Ogallala Group in Terry County are shown in Figures 7, 8, and 9. Similar maps for Lynn County were not constructed due to insufficient data.

An aggrading stream of moderately-high energy entered the east side of Terry County between 5 and 10 miles north of Tokio, trending east, northeast (Fig. 7). At a point approximately 9 miles northwest of Brownfield, the stream turned south near the present northern city limits of Brownfield and continued south for about 12 miles where it turned to the northwest passing into Lynn County, 3 to 6 miles south of Mound Lake (Fig. 7). Interestingly, the gravel and clay contents in the Ogallala section around Rich and Mound lakes are low (Figs. 7 and 9), a like situation occurring in Lynn County in the Double Lakes area.

Figure 8 shows that the areas of high sand content

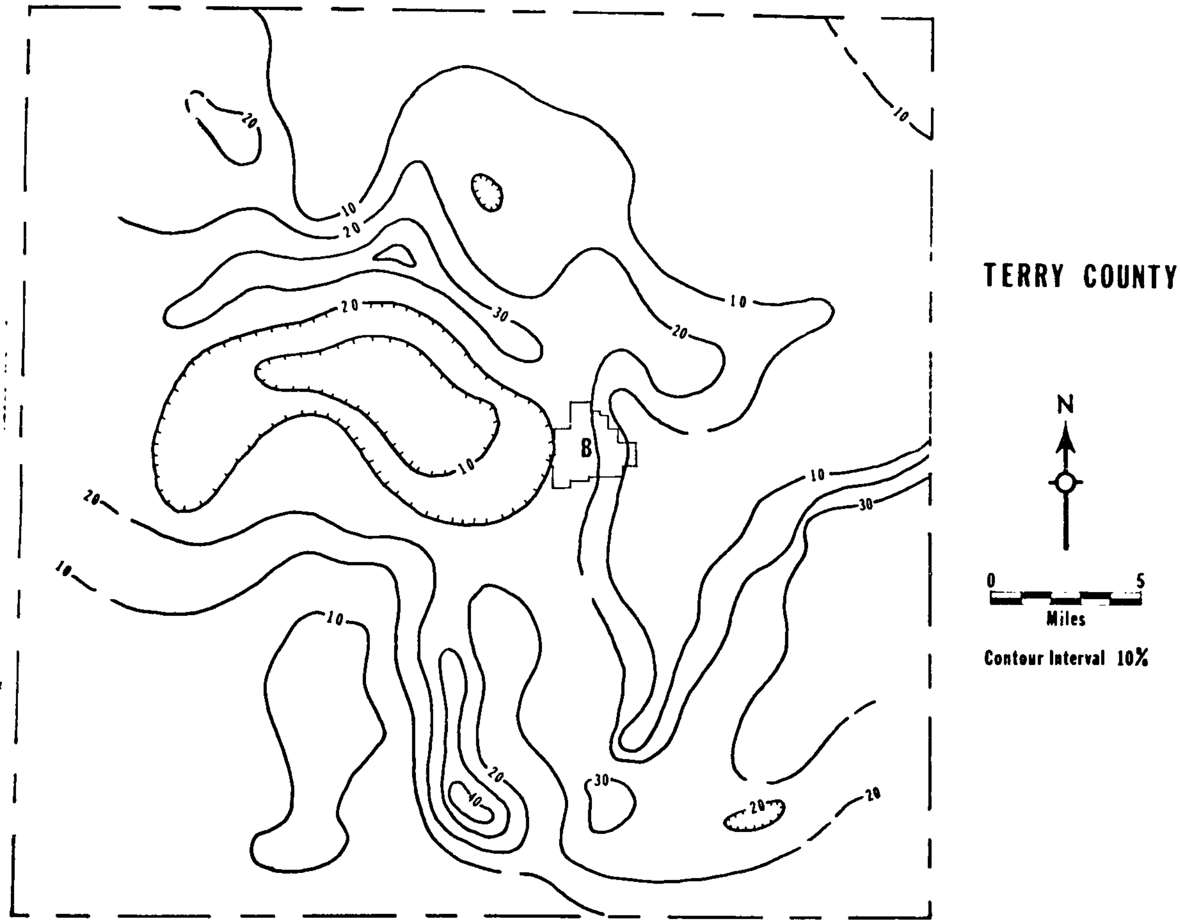

Fig. 7.--Lithofacies contour map of the Ogallala Group in Terry County, Texas, indicating percent gravel.

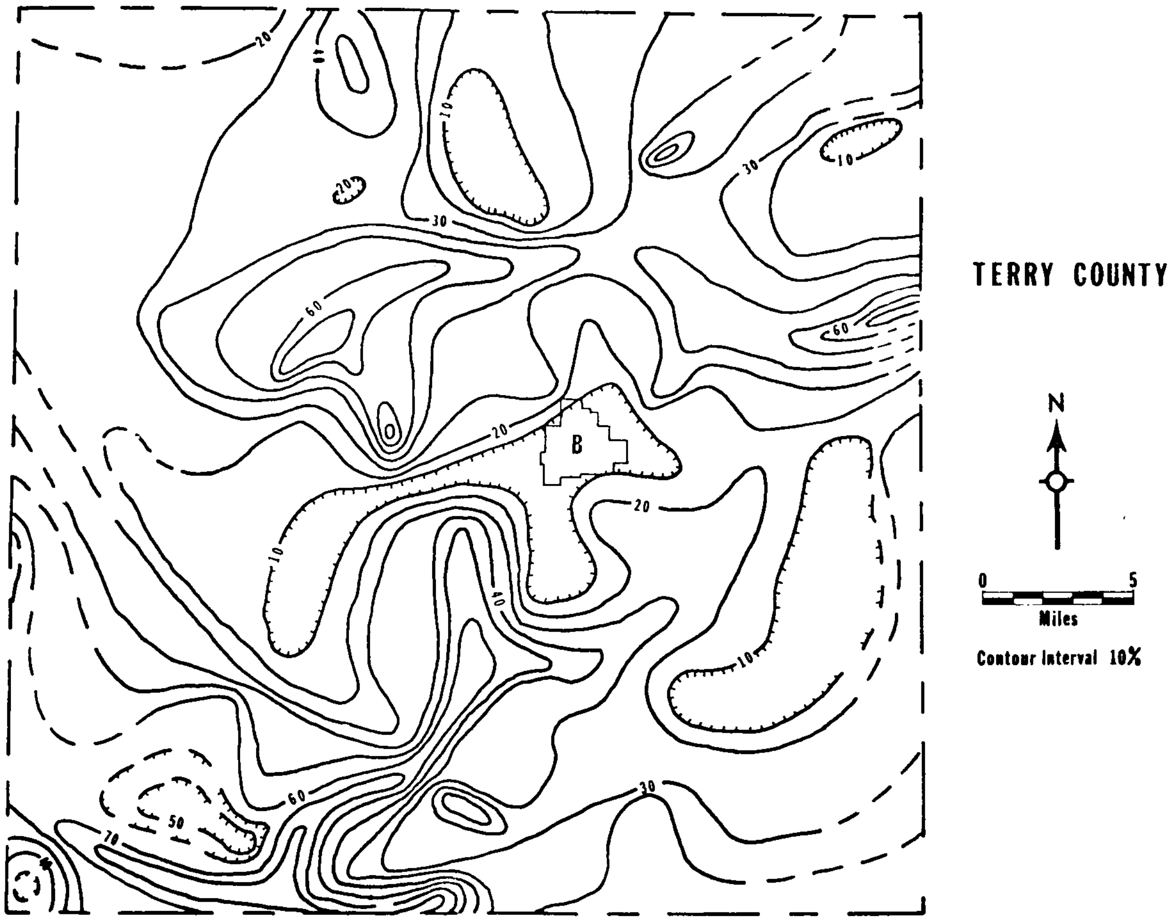

Fig. 8.--Lithofacies contour map of the Ogallala Group in Terry County, Texas, indicating percent sand.

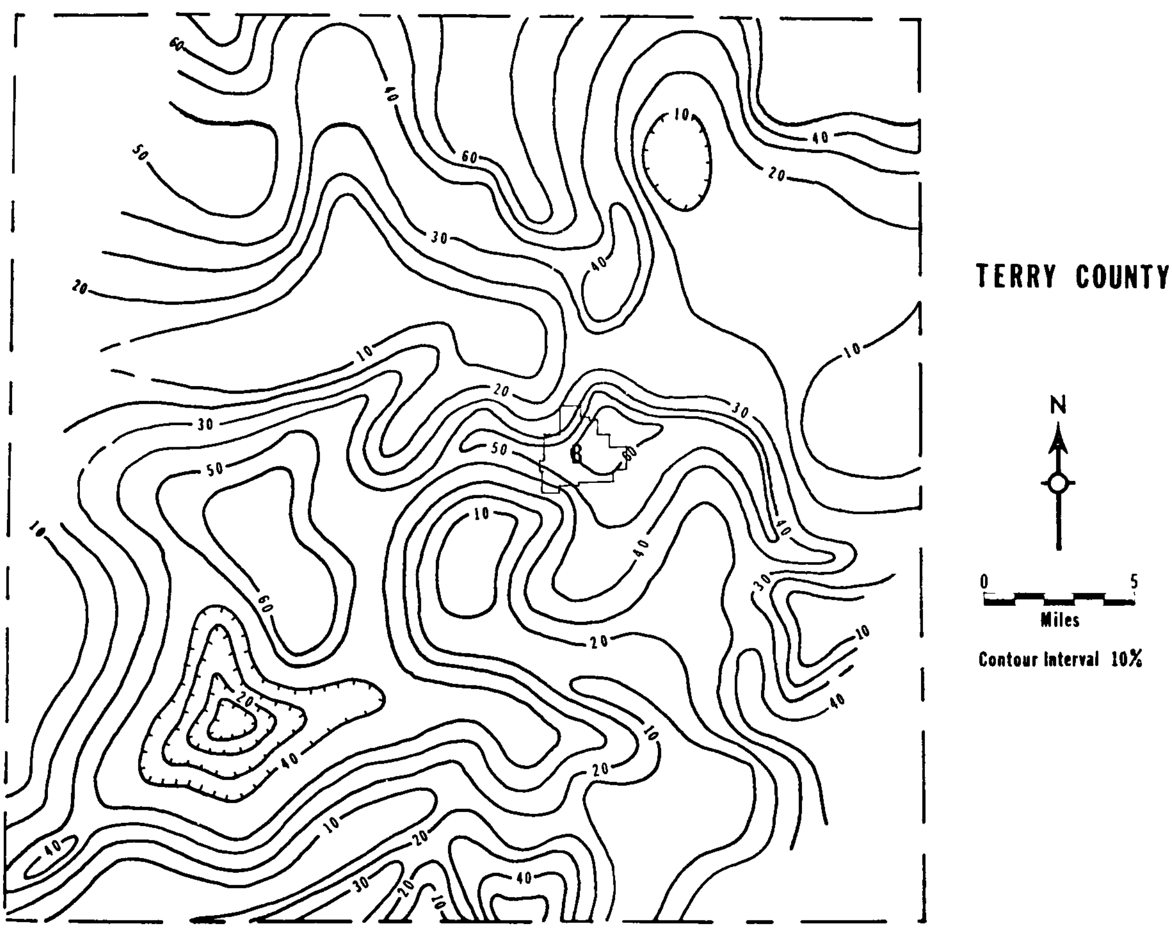

Fig. 9.--Lithofacies contour map of the Ogallala Group in Terry County, Texas, indicating percent clay.

trend southwest-northeast, perhaps indicating a southwest prevailing wind direction during Ogallala time. Reeves (personal communication, 1975) found a similar sand trend for the Ogallala during reconnaissance lithologic mapping over the entire Southern High Plains. Clay percentages are highest in northern Terry County, again probably due to the prevailing wind direction during Ogallala time. Reeves (personal communication, 1975) also found clay percentages in the Ogallala section increasing to the northeast.

Isopachous maps of the Ogallala Group in Lynn and Terry counties (Figs. 10 and 11) were prepared to help in understanding the relationship between the Ogallala section, underlying Mesozoic rocks, overlying Quaternary sediments, area geomorphology, and groundwater quality (and quantity). Both the Ogallala isopachous maps and the map of the base of the Ogallala show the locations of pre-Ogallala drainage channels and Cretaceous topographic highs. Figures 10 and 11 show the Ogallala section is thin around the large lake basins, being absent beneath all of the present large playas. The Ogallala section is also absent south of Morris Draw and northeast of Wilson where older, early Pleistocene (?) lake basins have been filled (Fig. 11). Drilling indicates at least 75 feet of lacustrine fill south of Morris Draw and 70 feet northeast of Wilson.

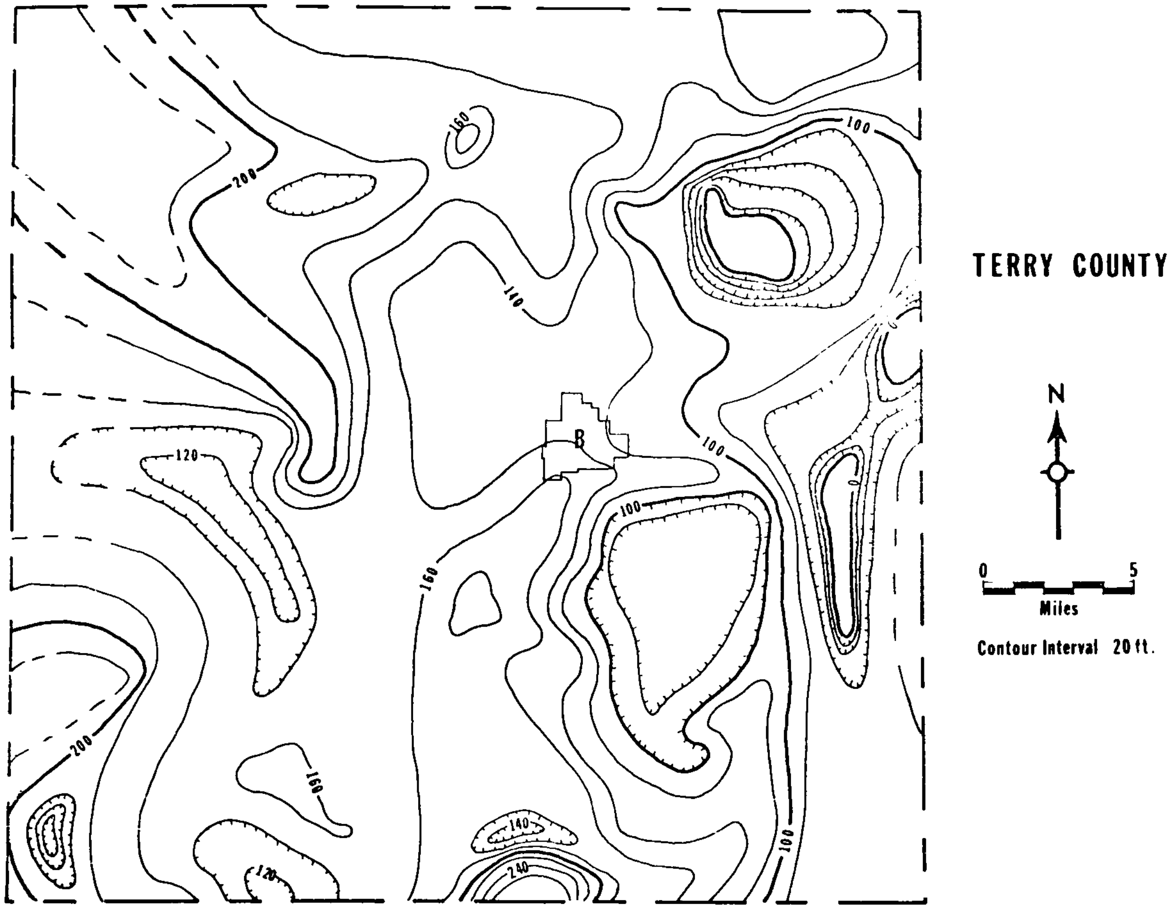

Fig. 10.--Ogallala isopachous map of Terry County, Texas.

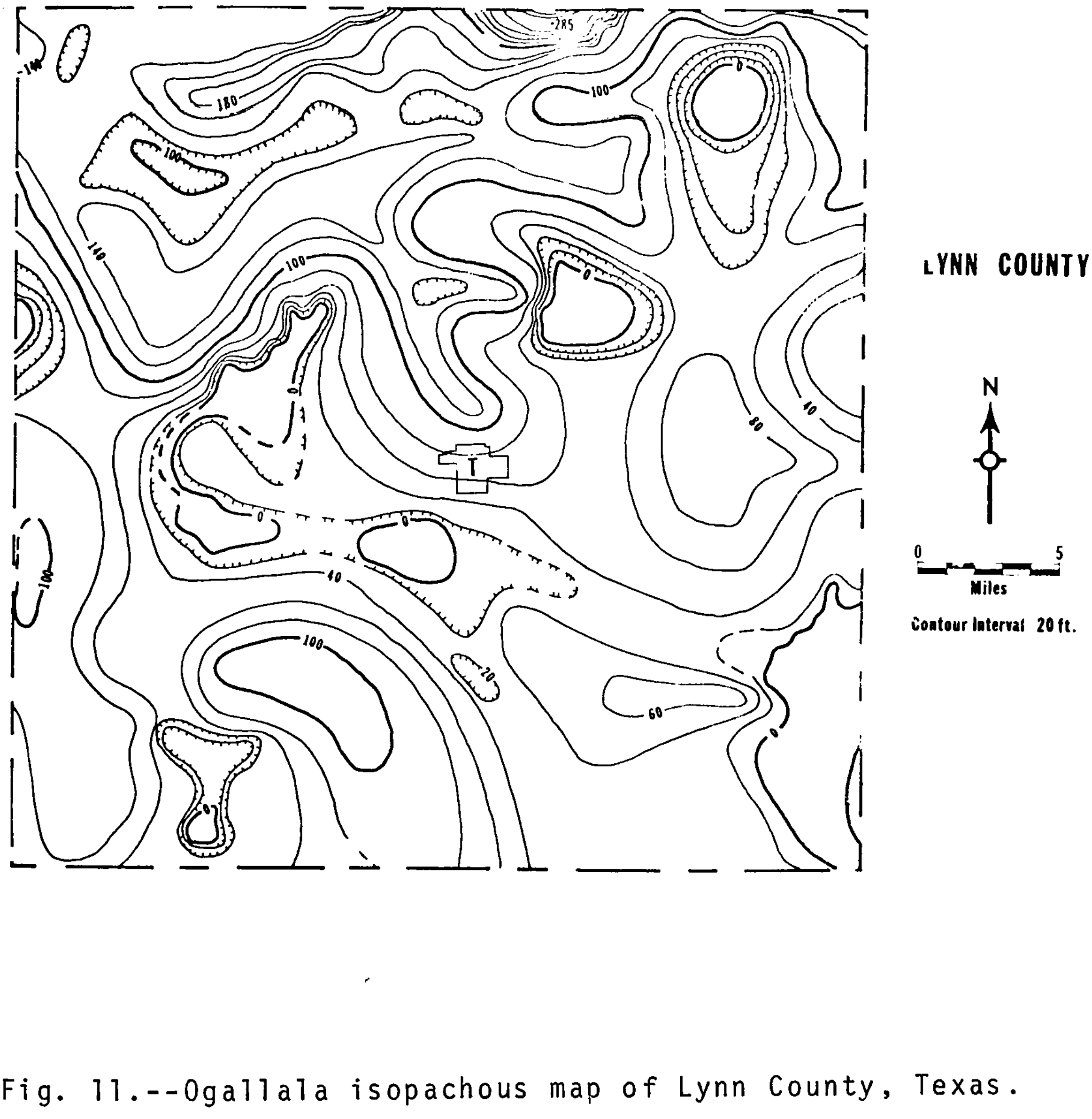

Fig. 11.--Ogallala isopachous map of Lynn County, Texas.

Maximum thickness of the Ogallala Group in the study area is about 300 feet in the Slaton Channel and in an unnamed channel along the southcentral Terry County line. The Ogallala section thickens regionally toward the northern part of the study area, being 100 to 150 feet thick in northern Lynn County and over 200 feet in northwestern Terry County.

Quaternary

Early Pleistocene

Early Pleistocene sediments on the Southern High Plains are represented by the Blanco and Tule formations; however, no Blancan-aged sediments are known from the investigated area, the nearest being along Yellowhouse Canyon in Lubbock County.

In the Lynn-Terry County area the earliest Pleistocene sediments dated thus far are the Spring Creek beds in the vicinity of Morris Draw (Fig. 3). Evans and Meade (1945), based on vertebrate fauna and Frye and Leonard (1957) using invertebrates, considered the Spring Creek beds to be equivalent to the Tule Formation of Kansan age. Reeves (1963), however, suggested that the Spring Creek beds may, in part, be of Nebraskan age, a suggestion supported by Pierce's (1975) study of the sedimentology, stratigraphy, and invertebrate fossils. Pierce (1975) found paleontologic evidence that the volcanic ash (geographically located in "Dead Negro Draw" along the Lynn-Garza County line) in the Spring Creek beds correlates with the Tsankawi ash, radio-metrically dated at 1.1 M.Y. B.P. (Izett and others, 1972), thus confirming a Nebraskan-Aftonian age. The Spring Creek beds consist of "light greenish, yellowish, and white clays, red to tan to white sands, occasional thin fresh-water limestones, caliche, and conglomerate lentils" (Reeves, 1963).

The Wilson Lake sediments, located within a gentle topographic low about five miles east-northeast of Wilson, Texas, (Fig. 3) range in thickness up to about 70 feet. The sediments exposed in several caliche pits in the area are predominantly white, fresh-water limestones (Fig. 12). The limestones and associated clays are highly fractured due to expansion and contraction of expandable clay minerals and solution and redeposition of calcium carbonate (Fig. 13). Solution along the fractures cause the limestones to be very porous and permeable.

No definitive fossil remains or volcanic ash lenses have been found in the Wilson Lake sediments, thus age is unknown. However, the relatively-thin (two to three feet thick), but extremely well-developed pisolitic caliche which formed in the overlying eolean sediments of the Blackwater Draw Formation of Illinoian age (Reeves, 1970a, 1972, 1975), indicates a pre-Illinoian age for the Wilson

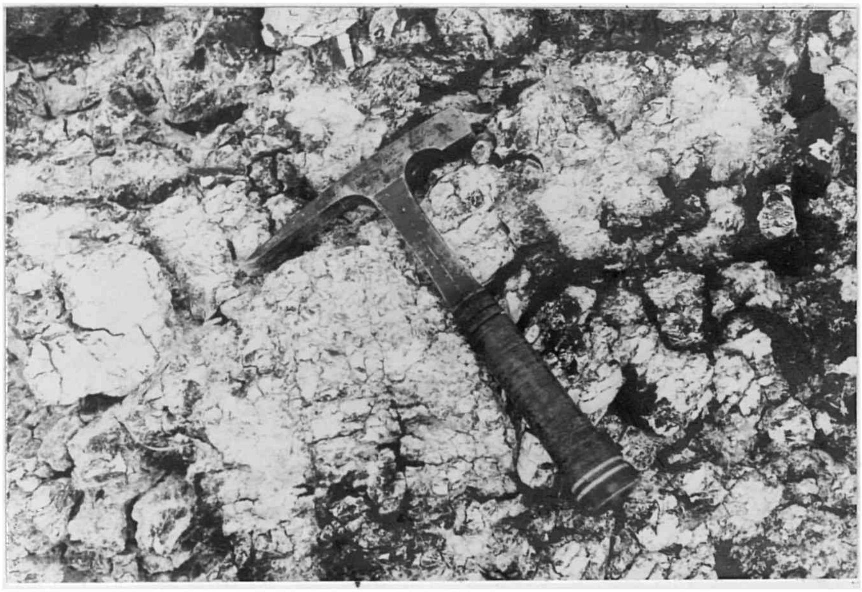

Fig. 12.--Wilson Lake beds. Mineral composition of this particular facies is approximately 35 percent calcite, 20 percent dolomite, 25 percent sepiolite and 20 percent smectite. Manganese oxide is the black staining material.

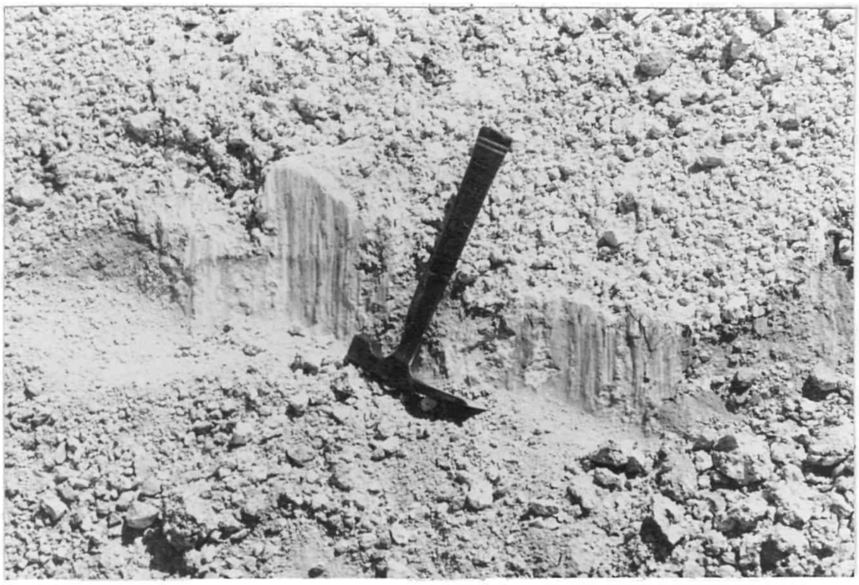

Fig. 13.--A slickenside surface within a Wilson Lake carbonate (95 percent calcite), incidating expansion due possibly to swelling clay minerals (smectite) within the section and/or secondary calcification.

Lake deposits. The Wilson Lake deposits lie directly on dark Cretaceous shales over most of the area, although the lacustrine sediments do onlap Ogallala sands and gravels near the basin edges.

The mineralogy-petrology of the Wilson Lake beds have been studied by x-ray diffraction, petrographic microscopy, and to a small extent, transmission electron microscopy. Petrographic study reveals that the bulk of exposed sediments is composed of micritic limestone with an average grain size less than one micron (Fig. 14). Most of the deposits are chemical precipitates rather than detrital materials; however, localized pods of clayey sands from a fraction of an inch to several feet across are widely scattered within the precipitates. The clay minerals within these pods are poorly-crystalline smectites, illites, smectite-illite (interstratified) and kaolinite similar to clay minerals found in the soils of the Southern High Plains (Allen and others, 1972) indicating probable translocation from overlying soils. Small voids in the carbonate above 20 feet are not usually filled with any type of material (Fig. 14) but below ±20 feet, the voids are often filled by silica which in thin section exhibits a lacy, box-work-type structure (Fig. 15) indicative of tridymite; x-ray diffraction of the silica indicates part tridymite and part amorphous. With increased void and

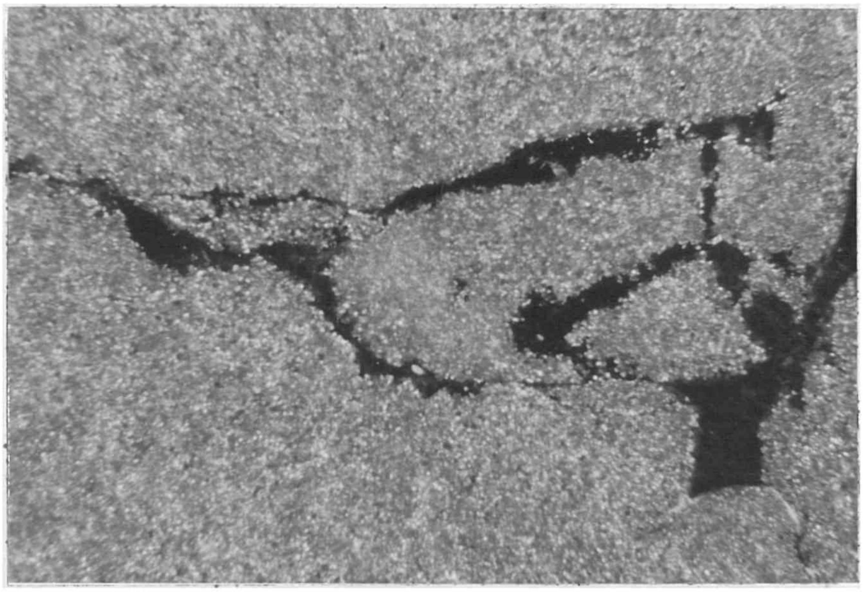

Fig. 14.--Typical micritic texture of a Wilson Lake carbonate above -20 feet. Notice little or no void filling. (Photomicrograph)

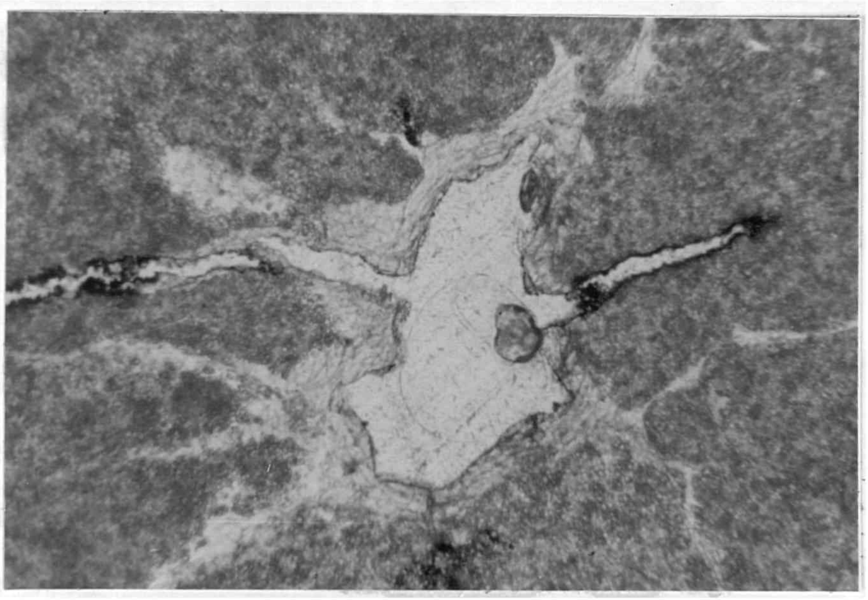

Fig. 15.--Solution void, within a Wilson Lake carbonate below -20 feet, partially filled with silica. X-ray diffraction data indicates the silica is predominantly tridymite. (Photomicrograph)

fracture filling below ±20 feet, in what appears in hand specimen and thin section to be the same limestone, the carbonate to silica ratio decreases from about 20 to 1 at the sharp, but undulating contact, to about 5 to 1. Interestingly, above this contact the clay minerals (sepiolite and trioctahedral smectites, which will be discussed in a later section) are highly crystalline, but below, the clays, where present, are weakly crystalline (Fig. 16). Tridymite peaks are prevalent even within the less than 2 micron fraction of the insoluble residues of the carbonate below about 20 feet. The contact between the siliceous and non-siliceous carbonates apparently represents the effect of a post-depositional, stable, water table. The vadose zone existed as a stable environment for magnesium-rich clay minerals whereas the phreatic zone allowed breakdown of the clay minerals. Certainly the hydrologic continuity of the ground water within the Wilson Lake deposits with Ogallala ground water is considered a contributing factor to the high silica content in the Wilson Lake sediments from the water table downward. (Farmers in the area claim the water table, though it may fluctuate during time of heavy rain or extreme downdraw by irrigation, does not significantly fluctuate from about 20 to 30 feet below the surface for any significant length of time.) Ash deposition at the contact could explain the increased silica content in a thin strata; however, well logs indicate the silica is continuous to the base of the sediments. Ash deposition also would not explain the difference in clay crystallinity.

The small amount of dolomite detected (sepiolite content is very high in the same samples) within the Wilson deposits is interspersed with the dominant calcite. The grain size of both the minerals is similar and both are considered primary precipitates. (For discussions concerning primary dolomites within lacustrine sediments of the Southern High Plains, see Reeves and Parry, 1965; Reeves and Parry, 1967; Leach, 1969; and Bates and others, 1970.)

Late Pleistocene

Continental glaciation during Illinoian time extended further south in several areas than during previous stages (Frye and Leonard, 1965), but the ice sheets were thin and the climate moderate compared to either Kansan or Wisconsin time (Frye, 1973). Reeves (1975) states that the absence of lacustrine sediments, and presence of the eolian Blackwater Draw Formation, required a semi-arid to arid climatic regime during Illinoian time on the Southern High Plains. It was during this general time period that the present large lake basins were formed.

The "reddish-brown to tan brown" Illinoian eolian deposit was informally named the "cover sands" by Frye and

Leonard (1957b), Reeves (1975) formally proposing the name Blackwater Draw Formation from the type area on the west side of Blackwater Draw a few miles west of New Deal, Texas.

The Blackwater Draw Formation is principally fine sand to sandy clay loam, the surface being a yellowish-red (5 YR 5/6:4/6) to a reddish-brown (5 YR 4/4:3/4). Regionally (across the Southern High Plains), the upper part of the formation ranges between 5 and 7.5 YR, whereas the lower part ranges from 2.5 to 4 YR. Reeves (1975) states that "the Blackwater Draw Formation increases from a feather-edge in southeastern New Mexico to at least 88 feet toward the northeast, thus measurement of the type section is meaningless."

The Blackwater Draw Formation, capped by so-called "Sangamonian soil" (Frye and Leonard, 1957b) is exposed over most of Terry and Lynn counties with the exception of north and eastern Lynn County (Fig. 20). Thickness of the Blackwater Draw Formation averages about 10 feet in the study area.

The Double Lakes Formation, named by Reeves (1975) for its occurrence in the Double Lakes basin in central Lynn County (Fig. 3), is of early Wisconsin age. No complete sections of the Double Lakes Formation are known in the study area; the description in Appendix A is from the 74-foot core taken at the Double Lakes type locality: the Double Lakes Formation occurring in the -33 to -71-foot interval (Appendix A) is composed predominantly of dark olive gray (5 GY 4/1) to olive gray (5 GY 6/1) dense clay with intermittent zones of small epsomite and gypsum crystals and occasional individual gypsum rosetts. Very fine sand sporadically occurs in the clays in the -48 to -55-foot interval.

The upper part of the Double Lakes Formation in the Brownfield, Rich, Gooch (sometimes referred to as Frost), Mound, and Cedar (Dawson County) depressions contains sodium sulfate deposits, although relative chemistry and concentrations vary (Reeves, 1975). Only sporadic crystals are present in the type section (Double Lakes Core), whereas the Double Lakes section at Rich Lake contains three zones of astrakonite ($Na_2Mg(SO_4)_2 \cdot 4H_2O$) intermixed with dark clays. Ten miles south of Rich Lake, and on the same drainage, the Brownfield basin contains 19 feet of clear, crystalline mirabalite ($Na_2SO_4 \cdot 10\ H_2O$) with epsomite ($Mg\ SO_4 \cdot 7\ H_2O$) (Reeves, 1975); concentrated deposits occurring along the Lost Draw drainage. Haynes (1975) thought the bedded salts at Rich Lake of post-Tahoka age, yet they have been drilled beneath the Tahoka Formation (upper Wisconsin age) in the center of the present playa (Reeves, 1971). Peripherial strata of the same age do not contain the salts due to facies changes (Reeves, 1975). A 51-foot core from the center of Rich Lake revealed ± 10 feet of Recent fill resting on the salt bed of the Double Lakes

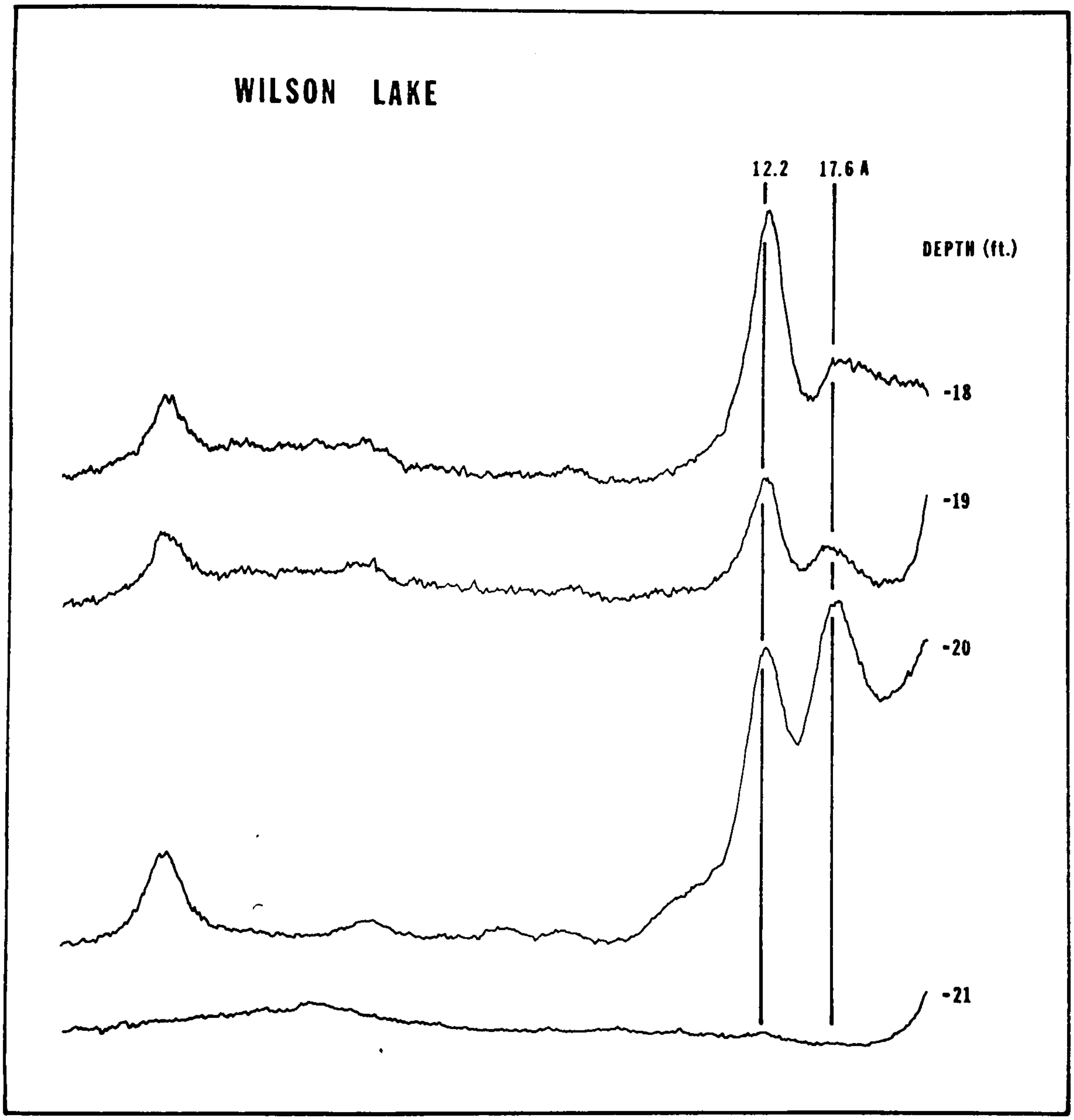

Fig. 16.--X-ray diffraction patterns of sodium saturated-glycolated clay (carbonates removed by treatment with pH.5 buffered Na-acetate) of the Wilson Lake deposits at the distances specified below the present land surface. Notice the abrupt change in clay crystallinity between -20 and -21 feet.

Formation (Appendix B). Salty, light brownish-gray (2.5 Y 6/2) to dark greenish-gray (5 GY 4/1) clays are predominant from -10 to -20 feet. Below 20 feet the dense clays are dark, greenish-gray (10 GY 4/1) to black (5 Y 2/1) with intermittent zones of oxidized sands; abundant gypsum crystals occurring at -50 feet. The thickest sections of the Double Lakes Formation are usually located near or beneath the post-Tahoka dunes which fringe the eastern sides of all the large, late-Pleistocene basins.

The Tahoka Formation was named by Evans and Meade (1945) from lacustrine deposits in the Tahoka Lake basin in central Lynn County (Fig. 3). The term "Tahoka" was used for lacustrine beds of early Wisconsin age (Frye, 1973; Frye and Leonard, 1965) on the Southern High Plains, but Wendorf (1961) limited the Tahokan pollen interval to the period 22,500-15,000 years B.P. Reeves (1968, 1972), on the basis of radiocarbon dates, correlated the Tahoka Formation to the Woodfordian glacial stade of the central United States (24,000 to 14,000 years B.P.), stating that "Tahokan sediments are of late Wisconsin age only, representing deposition from the last permanent lake sustained on the Southern High Plains by the last major glacial advance in the mid-continent region."

Tahokan sediments outcrop around all of the present large playas of the pluvial lake basins and completely fill many of the small basins in Lynn and Terry counties as well as throughout the Southern High Plains. Essentially, the Tahoka beds consist of sands, gravels, gypsum, thin to podular carbonate lenses, and black (5 Y 2/1) to blue gray 5 B 5/1) clays. Saline facies represent deposition toward basin centers during dry periods, thus have been largely deflated; however, remnants still exist on the islands in Mound, Rich, and Cedar lakes. The carbonate lenses, as thin one to two-inch thick beds or irregularly-shaped pods several feet thick, formed along shore and around springs respectively (Reeves and Parry, 1965, 1967; Bates and others, 1970; Reeves, 1975). The clay facies, which is most typical of present Tahokan outcrops, was deposited over much of the lake bottom during periods of permanent water. Carbonates in the Tahoka Formation, by x-ray analysis, are primarily dolomicrites or dolomitic sands and/or clays, rather than limestones as reported by Wendorf (1961) and Wendorf and Hester (1975).

The upper part of the Tahoka Formation is characterized by the thin Vigo Park Dolomite, which, although only a few inches thick, is recognizable within many basins throughout the Southern High Plains. Because of the wideapread occurrence of the Vigo Park Dolomite on the Southern High Plains and in other areas, Reeves (1970) divided the Tahoka Formation into the lower Rich Lake Member and the overlying Brownfield Lake Member, the respective type areas being at Rich Lake and Brownfield Lake in Terry County (Fig. 2). The Vigo Park Dolomite marks the top of the Rich Lake Member and the base is marked by the top of the Rich Lake Dolomite.

Typically, only the upper part of the shoreward facies of the Rich Lake Member is exposed (the central basin facies was deflated during post-Tahoka time or is covered by post-Tahokan deflated debris); however, cores and selected pits reveal a lighology dominated by gray (N/4) to black (N/7) clays. The Brownfield Lake Member typically consists of yellowish-gray (5 Y 8/1 to 5 Y 7/2) to grayish-yellow (2.5 Y 7/2) clay, often with yellowish-gray (5 Y 8/1) fine-grained sand, the sand content increasing toward the ancient shorelines.

The northeastern part of the Southern High Plains is covered by a thin, dusky yellowish-brown (10 YR 2/2) to dark brown (7.4 R 5/4) loess which was tentatively correlated to the Peoria (?) of Kansas (Frye and Leonard, 1965; Reeves, 1972). The loess which, in places, mantles Tahokan sediment (Reeves, 1975), ranges in thickness from a featheredge to nearly 10 feet in the northeastern part of the Southern High Plains. Reeves (1975) shows the Peoria (?) loess extends into the eastern third of Lynn County, the contact between the Blackwater Draw Formation and the (Peoria?) loess coinciding with the contact between brown to reddish-brown (7.5 YR 4/3 to 5 YR 4/3) and reddish-gray (5 YR 5/2) soils (Amarillo, Acuff).

CHAPTER III

GEOMORPHOLOGY

Lake Basins

Over 19,000 small, randomly-scattered basins occur on the Southern High Plains (Texas Water Development Board, 1965); Lynn and Terry counties having about 865 and 572, respectively. Several theories concerning the origin of these small, natural depressions, ranging from less than one acre to over 500 acres, and exhibiting generally less than 20 feet of relief, have been postulated. For example, Gilbert (1895) suggested wind deflation but Johnson (1901), Baker (1915), Elias (1931), Theis (1932), Patton (1935), Smith (1940), and Frye and Schoff (1942) considered solution of underlying salts followed by surface collapse more likely. Differential subsidence has also been suggested (Johnson, 1901; Frye, 1945) as well as solution in the "caprock" caliche (Price, 1940) and zoological factors (Darton, 1915). Judson (1950), however, supported Gilbert's (1895) original suggestion of wind deflation, particularly for the small depressions near San Jon, New Mexico. Reeves (1966a, 1970a, 1972) finds the small depressions polygenetic, but does maintain that deflation and unequal deposition of Pleistocene eolian sand account for most although solution and ungulatory action have also been locally important.

Reeves (1966a, 1970a) grouped the lake basins of the Southern High Plains into eight classes based primarily on degree of filling and absence or presence of the Pliocene "caprock" caliche (Table 1). The eight large lake basins in the Lynn-Terry County area (Tahoka, Guthrie, Gooch, Twin, Double, Mound, Rich, Brownfield) are Type Eight basins with the possible exception of Mound Lake. Reeves (1969) states that the

> ...presence of basal Ogallala gravels well above the present playa of Mound Lake and the elevation of the Ogallala east of Mound Lake suggests that Mound was never buried by Ogallala sediments. In fact, Pliocene lacustrine strata in the Ogallala along the west side of Mound Lake suggests that the basin may have existed in pre-Pleistocene time.

Reeves (1970c) noted that the large linear basins are predominantly located along ancient drainage channels, at the intersection of regional lineaments, and on the eastern sides of buried Cretaceous highs (Figs. 5 and 6). All of the large lake basins in the Lynn-Terry county area contain late Pleistocene (Wisconsin) and Holocene sediments: Tahokan aged deposits outcrop around the periphery of the present playa and beneath dunal material along the east flanks. To generalize, all of the large lake basins in the investigated area exhibit (1) central saline playas, (2) high-level lacustrine terraces, (3) thick lacustrine sections beneath present playas, (4) remnant abandoned shorelines, and (5) associated shoreline features. The Guthrie basin (Fig. 3) is an exception in that the present playa

TABLE 1

CLASSIFICATION OF NATURAL BASINS ON THE SOUTHERN HIGH PLAINS*

"Caprock" caliche present beneath basin:

Type 1 - Holocene deflation basins

Type 2 - Pre-Holocene but post-Tahoka basins

Type 3 - Pre-Tahoka basins

"Caprock" caliche not present beneath basin:

Type 4 - Early Pleistocene basins associated with drainage channels: no evidence of solution

Type 5 - Late Pleistocene basins associated with drainage channels: no evidence of solution

Type 6 - Late Pleistocene basins associated with drainage channels: evidence of solution

Type 7 - Late Pleistocene basins not associated with drainage channels

Type 8 - Late Pleistocene but pre-Tahoka basins associated with drainage channels

*(From Reeves, 1970).

has formed on the Edwards Limestone at the south end, but about 8 feet of Recent deflation debris covering the Edwards Limestone at the north end.

The average trend of the present playas in the Tahoka, Guthrie, Double, and Mound depressions is N 35° E. The Brownfield playa, which is nearly filled with lacustrine and eolian debris, trends N-S, probably due to the influence of the Lost Draw drainage. Rich playa, which trends N 40° W, also seems to be reflecting the trend of the ancient drainage channel. Playas in Twin and Gooch basins are nearly round (Table 2). No consistent shape or orientation of the basins themselves is apparent (Table 2), due to the differential lateral erosion and subsequent infilling by surrounding eolian debris.

During the last pluvial maximum (Tahokan time) the eight large basins in the investigated area contained at least 78 square miles of permanent water, based on planimeter measurement of the present strand lines of the Tahoka Clay and abandoned shorelines (Table 2 and Figs. 17 and 18).

No significant shoreline features of other than Recent age were observed associated with the large Pleistocene lake basins in the study area, probably because of eolian cover and age. Reeves (1970a) states that "Ancient beaches, on the downwind sides of the basins, are commonly marked by ancient transverse dune ridges, but the only bar and wave-cut terraces known exist on the west side of Guthrie Lake..."

TABLE 2

QUANTITATIVE RELATIONS OF LARGE PLUVIAL LAKE BASINS IN LYNN AND TERRY COUNTIES, TEXAS

BASIN	SHAPE: Length/Width Playa	Basin	TREND Playa	Basin	AREA (Sq. Mi.) Playa	Basin	SHORELINE Playa	Basin	MAXIMUM FILL (Ft.) (Approx.)	GENESIS
Brownfield	3.75	5.67	N-S	N-S	0.38	15.0	3.0	21.0	85+	Stream
Double (T-Bar)	8.33	2.69	N45E	N45E	1.84	13.5	11.4	25.8	55	Stream
Guthrie	2.97	2.29	N35E	N-W	1.14	13.1	4.7	27.1	45(?)	Stream
Mound	2.17	1.91	N35E	N35E	1.72	5.1	6.3	13.8	55+	Stream
Rich	5.60	1.00	N40W	--	0.66	6.3	4.5	18.2	70	Stream
Tahoka	7.00	4.50	N20E	N25W	1.12	8.50	7.0	26.5	40	Stream
Twin (Three Lakes)	1.00	2.70	--	N50W	0.36	7.1	2.0	17.2	?	Stream
Gooch (Frost)	1.00	2.0	--	N30W	0.25	9.5	2.5	19.0	?	Stream

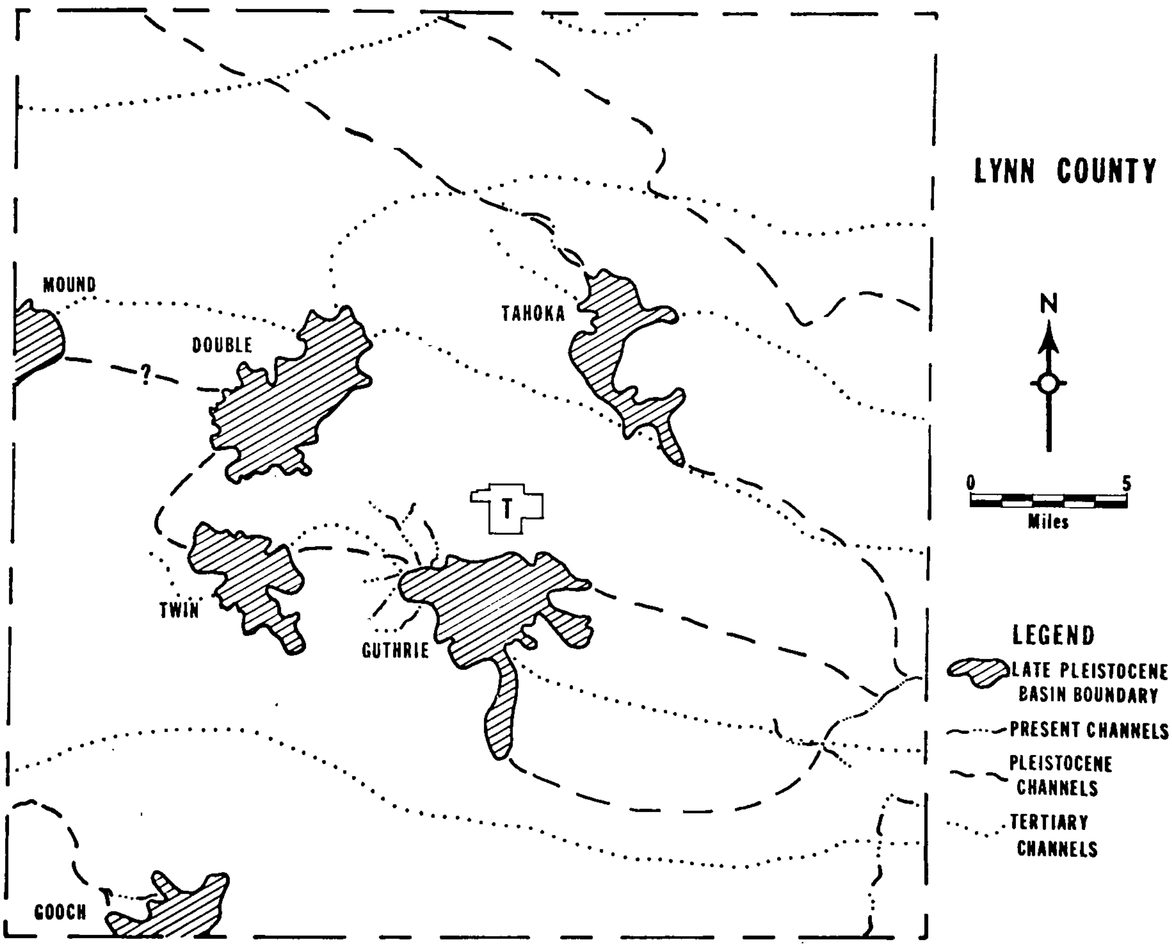

Fig. 17.--Pliocene-Pleistocene drainage channels and areas covered by large late-Pleistocene lakes, Terry County, Texas.

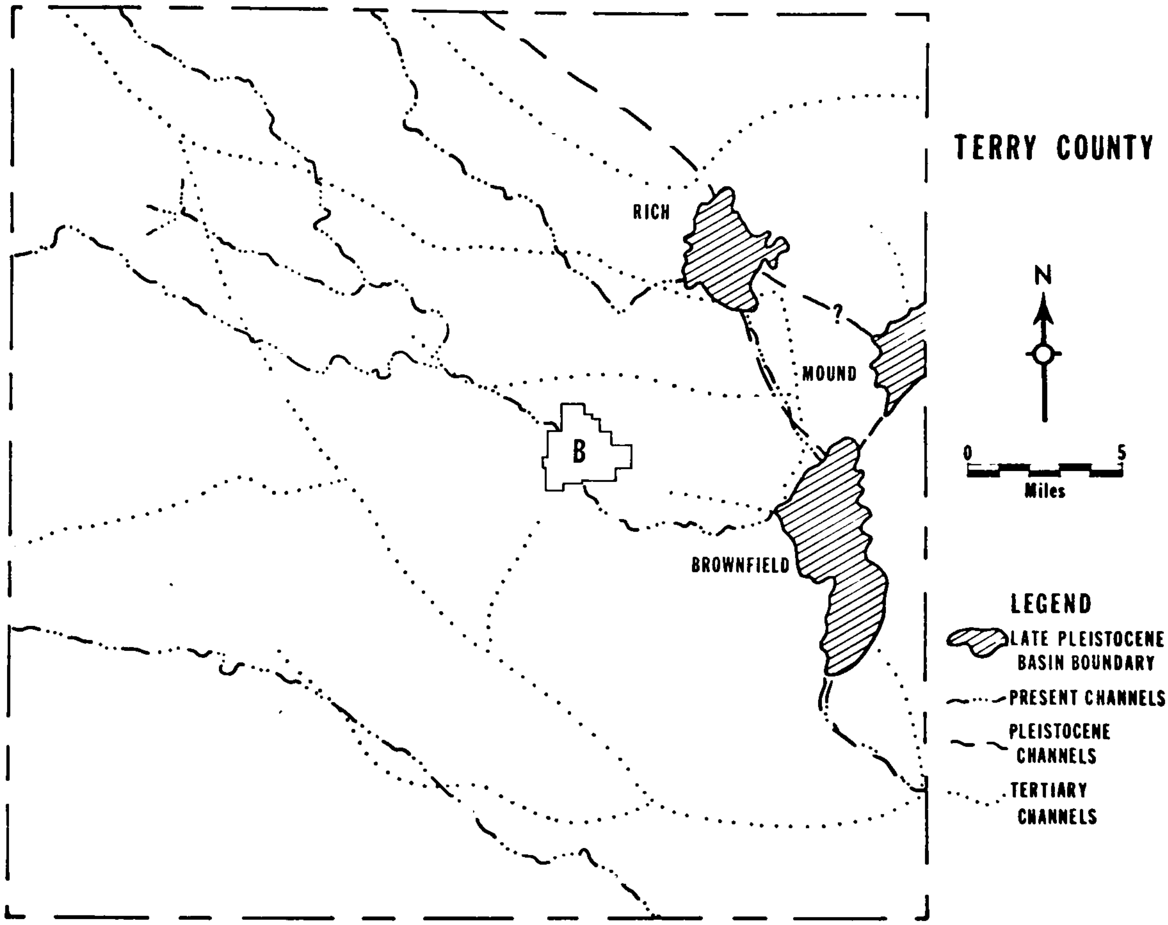

Fig. 18.--Pliocene-Pleistocene drainage channels and areas covered by large late-Pleistocene lakes, Terry County, Texas.

The "bar" on the west side of Guthrie Lake appears to be composed largely of siliceous gravels (Ogallala?), thus may be fluvial rather than lacustrine, particularly in view of its elevation only 50 feet below the Plains surface. The "wave cut terraces," also at about the same respective elevation, are cut into Cretaceous rocks, thus both features may be remnants of the Pleistocene stream channel along which the Guthrie basin formed.

Absence of early Pleistocene sediments, but presence of the Lower Wisconsin Double Lakes Formation, indicates that basins in the study area (Figs. 2, 3) formed in post-Kansan but pre-Wisconsin time, thus must represent the effects of Illinoian deflation. Groundwater recharge of the Southern High Plains, except by local precipitation, effectively ceased when the ancient Portales River and other associated easterly and southeasterly flowing streams were pirated by the Pecos River drainage during late Kansan or Yarmouthian time (Reeves, 1972). Subsequent lowering of the water table during the Yarmouthian-Illinoian-Sangamonian interval simultaneously lowered the deflation base level. The large basins were formed mainly on the down-slope, east side of Cretaceous highs where Pleistocene streams had been forced to meander into soft Ogallala sediments. In these meandering areas considerable sand was originally deposited which was susceptible to deflation once the stream ceased flowing and the local water table dropped.

Reeves (1970c, 1971), from a lineament analysis of the Southern High Plains from high-altitude photo mosaics, finds that the trend of the early Pleistocene stream channels was apparently structurally controlled and that the late Pleistocene basins occur at the junction of two or more of the lineaments. Reeves (1971) states "the major northeast-southwest lineament east of Lubbock has at least 7 large pluvial lake basins along its 240-mile trace (Blanco, Wood Ranch, Tahoka, Guthrie, Frost, Cedar-McKenzie, and Shafter basins)" a list to which Wilson Lake can now be added.

Deflation of the Ogallala sands where the caliche "caprock" had been breached, but where the stream had not yet begun meandering to any significant degree, produced the less-spectacular basins in the study area. These basins are much larger than the typical small deflation basins, and have a linear trend, but fail to exhibit any associated Cretaceous outcrops and rest on several feet of Ogallala sands. A good example in the study area is a relatively-large lake basin about 8 miles north of Grassland (1 mile west of Gordon, Texas).

Closely associated with the large basins in Lynn and Terry counties are transverse dunes which represent prolonged deflationary periods. The dunal debris, consisting mainly of gypsum, sand, clay and silt, was deflated from the adjacent playas, thus ancient transverse dunes now often one-half to one mile east of the present playa shorelines mark ancient abandoned shorelines, and earlier lake levels.

Melton (1940), investigating sand dunes in the northern part of the Southern High Plains, distinguished three separate dune series. Series I dunes were formed during the last 5,000 years by winds from the south-southwest; Series II dunes were formed during the period 5,000 to 15,000 years B.P. by winds from the southwest, and Series III dunes were formed over 15,000 years B.P. by winds from the northwest. Reeves (1965, 1970a), however, found that winds forming the Series II dunes were predominantly from the northwest rather than from the southwest as suggested by Melton (1940).

The youngest dunes associated with the large pluvial lake basins are located immediately next to the present playas. These dunes, which are seldom over 20 feet high, are active and support little vegetation (primarily scattered bunch grass), and correlate with Melton's (1940) Series I dunes. Reeves (1970a) states that "all Series I dunes exhibit a wave-cut terrace 5 to 10 feet above the present playa levels." This terrace, which occurs on all Series I dunes in the study area, appears young, thus probably represents a recent water level of unknown date.

Series II dunes rest on the Tahoka Formation, primarily along the eastern and southeastern sides of the present playas, thus were formed by post-Tahokan winds blowing predominantly from the west and northwest. Core and drill holes on Series II dunes in Double Lakes basin and island remnants in Cedar (Dawson County), Rich, and Mound Lakes indicate up to 20 feet of Tahoka clay has been deflated from present playas, some of which served as source material for the Series II dunes.

The oldest dunes associated with the large basins in the study area are southeast of the Series II dunes. The area between the Series II dunes and the older, low, subdued dunes which Reeves (1965) correlated with Melton's (1940) Series III dunes, is usually a flat lacustrine terrace underlain by Tahoka Clay and the Double Lakes Formation. Series III dunes, which are not present on all basins, indicate prevailing winds from the west and northwest.

The Tahoka Clay strand line follows the front edge of the Series III dunes indicating that they were formed before deposition of the Tahoka Formation by deflation of pre-Tahokan strata. A test hole drilled (by John Buchanan, John Hawley, and C.C. Reeves, Jr.) on a Series III dune at Double Lakes showed only 3.5 feet of deflated lacustrine sediments overlying orange and reddish-brown (5 YR 5/4-6/4 and 7.5 YR 7/4) sandy clays, interpreted by Buchanan (1973) as the Bridwell Formation. Thus Series III dunes may be representative of only a short deflationary period following deposition of the Double Lakes Formation.

Reeves (1970a) discusses the origin of smaller scale geomorphic features such as spring pots, spring necks, spring mounds and phreatophyte mounds as well as associated sedimentary structures (gas rings, cross bedding and hoof-prints) associated with the lake basins on the Southern High Plains.

Drainage

Late Pleistocene drainage channels are still evident in the study area (Figs. 2 and 3). Drainage from Rich to Brownfield to Gooch Lake basins still occurs during periods of abnormally high precipitation and drainage from Tahoka Lake to Morris Draw area has occurred during historic times. Earlier drainage channels, however, are difficult to establish except by extensive drilling. For example, drainage between Double Lakes south into the Twin Lakes (Three Lakes) area is only faintly suggested by contours on the 7½ minute Double Lakes sheet, yet was proven by the sedimentary section (and related clay mineralogy) recently drilled by the USGS.

Usually, Pleistocene drainage channels trend southeast, but at the Tahoka, Guthrie, Double, Brownfield basins, and possibly Mound Lake, the old drainage channels turn south-southwest (Figs. 17 and 18) suggesting structural control as proposed by Reeves (1970c, 1971).

Soils

According to the new soil classification scheme now used by the United States Soil Conservation Service (Soil Survey Staff, 1972), soils covering the largest part of the investigated area belong to the Paleustalf great soil group, primarily mapped by the Soil Conservation Service as the Amarillo-Brownfield soil association. The term Paleustalf indicates soils reddish in color with an argillic horizon (therefore mature) formed in subhumid to semiarid climates. The Paleustalf soils in Lynn and Terry counties are forming on the Blackwater Draw Formation of Illinoian age.

The dominant soils in the north and east parts of Lynn County are Paleustolls (primarily the Acuff soil series), forming on a thin mantle of (Peoria?) loess (Reeves, 1975) overlying the Blackwater Draw Formation. Paleustolls differ from Paleustalfs in that they contain more organic debris and are thus somewhat more fertile.

Other soils in the investigated area are often formed on parent material of local derivation. Soils mapped as the Portales-Drake association by the Soil Conservation Service are formed on deflated lacustrine deposits and are rich in carbonates and soluble salts, thus soil survey maps may be of some value in detecting buried lacustrine basins. The Mansker-Potter soil association occurs along drainage systems and is also formed on previously exposed Pliocene "caprock" caliche. The Tivoli soil series is largely restricted to active dunes which may be remnant materials

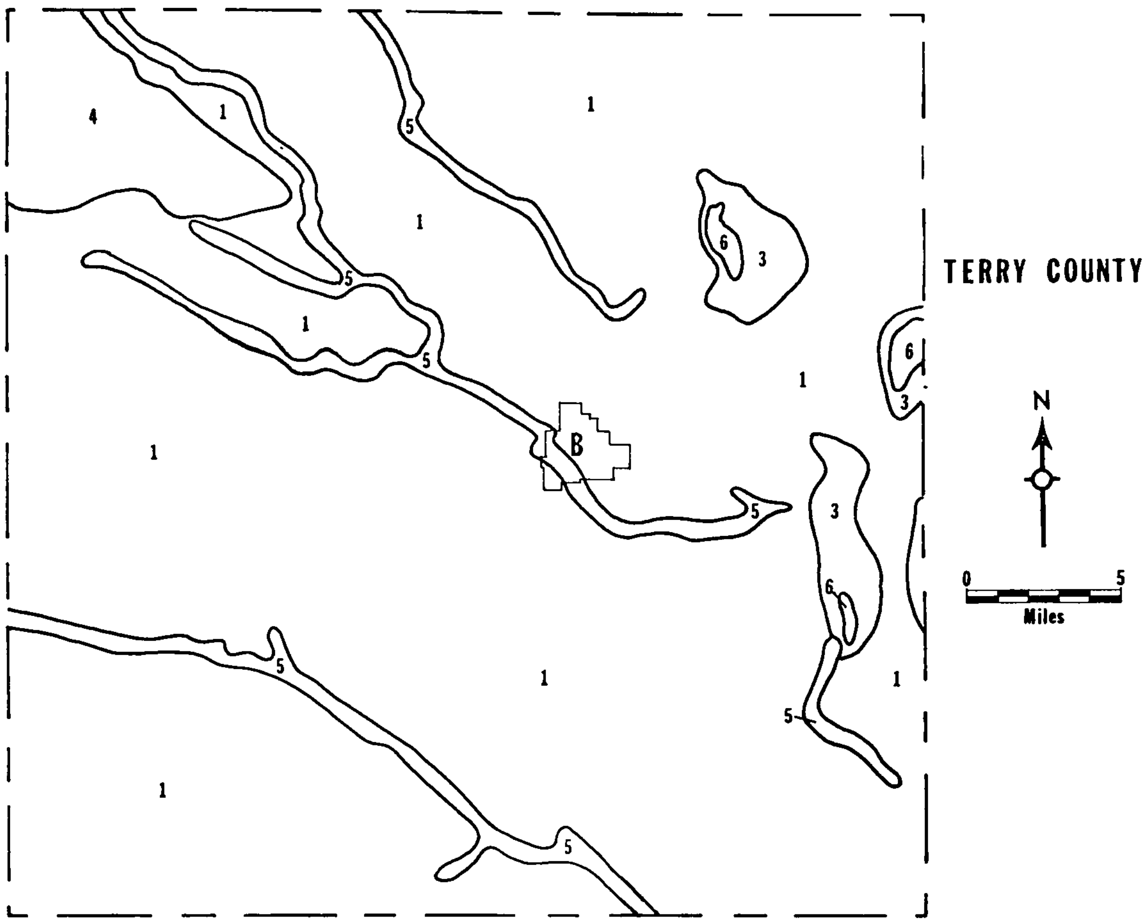

Fig. 19.--Generalized soil map of Terry County, Texas. (Modified from Sanders, 1962)

1 = Aridic Paleustalfs (Amarillo-Brownfield) formed on the Blackwater Draw Formation.

2 = Aridic Paleustolls (Acuff series) forming on the (Peoria?) Loess which overlies the Blackwater Draw Formation.

3 = Mixed, Aridic Calciustolls and Typic Usorthents (Portales-Drake) forming primarily on lacustrine associated sediments.

4 = Typic Ustisamments (Tivoli series) forming on dunal debris (primarily quartz sands).

5 = Mixed, shallow soils forming on eroded (or eroding) surfaces.

6 = Udic Pelusterts (Randall series) forming on lacustrine clays.

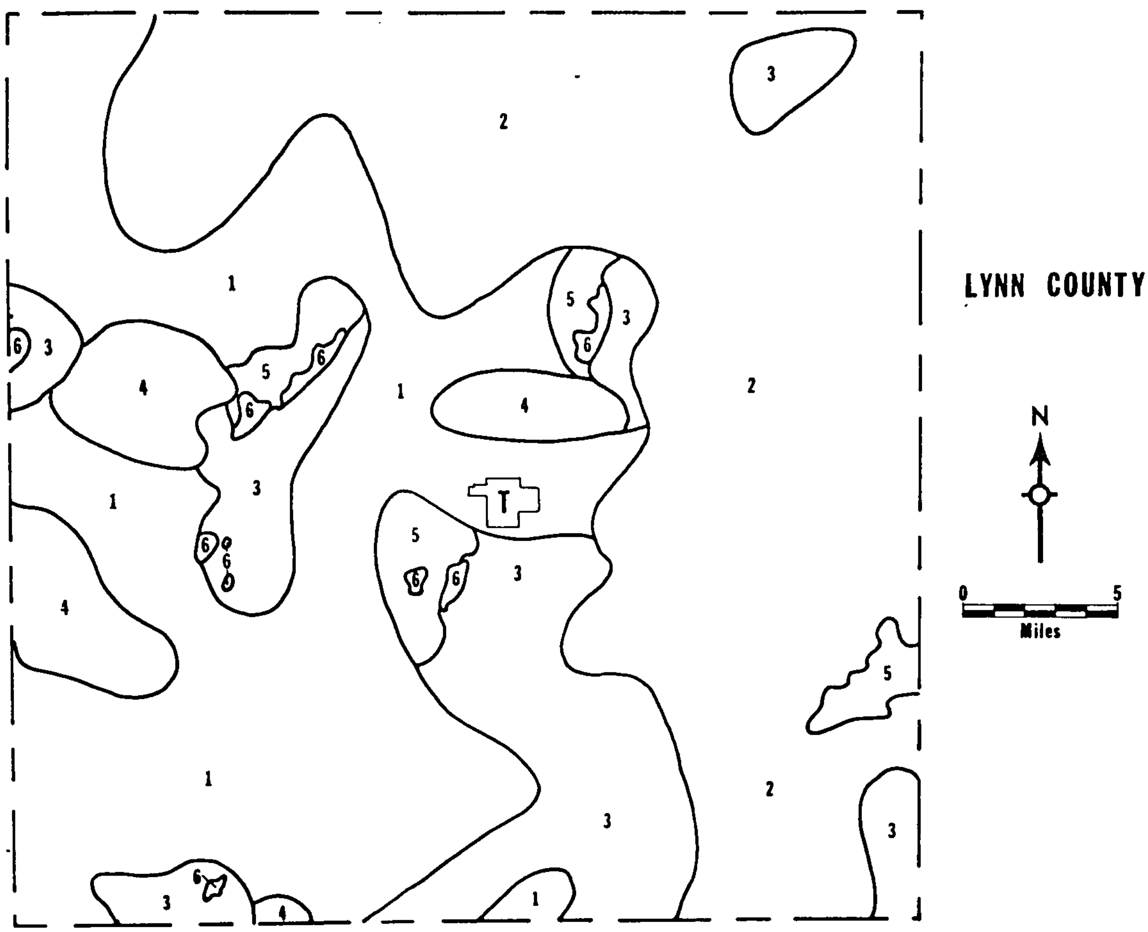

Fig. 20.--Generalized soil map of Lynn County, Texas. (Modified from Mowery and McKee, 1959)

1 = Aridic Paleustalfs (Amarillo-Brownfield) formed on the Blackwater Draw Formation.

2 = Aridic Paleustolls (Acuff series) forming on the (Peoria?) Loess which overlies the Blackwater Draw Formation.

3 = Mixed, Aridic Calciustolls and Typic Usorthents (Portales-Drake) forming primarily on lacustrine associated sediments.

4 = Typic Ustisamments (Tivoli series) forming on dunal debris (primarily quartz sand).

5 = Mixed, shallow soils forming on eroded (or eroding) surfaces.

6 = Udic Pelusterts (Randall series) forming on lacustrine clays.

deflated from Pleistocene drainage channels. The Randall soil or the Randall clay is a Pellustert, a gray soil very rich in swelling clays (smectites) formed from lacustrine clays within present playas (Figs. 19 and 20).

CHAPTER IV

CLAY MINERALOGY AND PALEOCLIMATOLOGY

Recently studies of clay mineralogy from Ogallala outcrops (Frye and others, 1974; Lee and Goolsby, 1975; Goolsby and Lee, 1975) show that well-crystallized magnesium-rich clay minerals, particularly sepiolite and attapulgite, increase toward the top of practically all Ogallala sections studied. The magnesium-rich clay minerals are unstable in a leaching environment, thus their increasing abundance toward the top of the Ogallala Group indicates a progressively drying climate prevailed throughout Ogallala time. This climatic interpretation is also substantiated by fossil evidence (Frye and Leonard, 1957). A limited study by Lee and Goolsby (1975) of clay mineralogy in the Ogallala Group along the eastern escarpment of the Southern High Plains suggests two or more wet-dry cycles occurred (Tables 3, 4 and 5). Data from the Crosbyton section (Table 4) indicates three wet-dry cycles; however, inspection of samples C_2 and C_3 by electron microscopy (Fig. 21) shows the morphology exhibited by the clays is similar to the morphology of trioctahedral smectites which are rich in magnesium. Thus, even though C_2 and C_3 are smectite-rich, and thus appear to represent a wetter climate, chemically they are similar to sepiolite and attapulgite,

TABLE 3

CLAY MINERALOGY OF AN OGALLALA SECTION NEAR POST, TEXAS*

SAMPLE NO.	LITHOLOGY	DISTANCE BELOW TOP OF SECTION	M	I	K	A	S	CLAY ZONES (FRYE, et al, 1974)
Post Section								
P_1	dense, massive caliche	0.3	22	(5)	0	48	25	3
P_2	cemented sand	7.0	30	(5)	0	65	0	2
P_3	weakly cemented sand	18.0	18	(5)	0	77	0	2
P_4	shaly silt and clay	25.0	77	14	2	7	0	1
P_5	sand, gravel, Triassic frag.	31.0	80	15	5	Tr	0	1
P_6	sand, gravel Triassic frag.	42.0	91	8	1	0	0	1
P_7	cemented sand	47.0	14	(5)	0	81	0	2
P_8	massive sand-clay	70.0	81	16	4	Tr	0	1

*Clay mineral data (determined by semi-quantitative methods of x-ray diffraction pattern analysis employed by H.D. Glass, Illinois Geological Survey) from an exposed section of the Ogallala Group along the eastern "caprock" escarpment west of Post, Texas.

TABLE 4

CLAY MINERALOGY OF AN OGALLALA SECTION NEAR CROSBYTON, TEXAS*

SAMPLE NO.	LITHOLOGY	DISTANCE BELOW TOP OF SECTION	M	I	K	A	S	CLAY ZONES (FRYE, et al, 1974)
Crosbyton Sec.								
C_1	platy caliche	0.3	Tr	(5)	0	Tr	95	3
C_2	cemented sand	10.0	95	(5)	0	Tr	Tr	1
C_3	weakly cemented sand	18.0	95	(5)	0	0	0	1
C_4	weakly cemented shaly sand	25.0	75	14	1	10	0	1-2
C_5	shaly silt and clay	35.0	65	15	2	18	0	2
C_6	thin caliche	53.0	6	(5)	0	89	0	2
C_7	caliche mottled sand	68.0	30	(5)	4	61	0	2
C_8	sand	106.0	95	3	2	0	0	1
C_9	jointed sand	118.0	58	(5)	4	33	0	2
C_{10}	sand and gravel	185.0	93	(5)	2	0	0	1

*Clay mineral data (determined by semi-quantitative methods of x-ray diffraction pattern analysis employed by H.D. Glass, Illinois Geological Survey) from an exposed section of the Ogallala Group along the "caprock" west side of Blanco Canyon east of Crosbyton, Texas.

TABLE 5

CLAY MINERALOGY OF AN OGALLALA SECTION NEAR FLOYDADA, TEXAS*

SAMPLE NO.	LITHOLOGY	DISTANCE BELOW TOP OF SECTION	M	I	K	A	S	CLAY ZONES (FRYE, et al, 1974)
Floydada Sec.								
F_1	platy caliche	0.3	24	(5)	Tr	71	0	2
F_2	blocky, sandy caliche	12.0	17	(5)	1	77	0	2
F_3	shaly silt and clay	20.0	65	16	4	15	0	2
F_4	weakly cemented sand	36.0	37	(5)	1	57	0	2
F_5	weakly cemented sand	53.0	27	22	1	49	0	2
F_6	weakly cemented sand	102.0	60	18	1	21	0	2
F_7	gravelly, cobbly sand	110.0	76	10	2	12	0	1-2
F_8	sand and gravel	125.0	94	(5)	1	0	0	1

*Clay mineral data (determined by semi-quantitative methods of x-ray diffraction pattern analysis employed by H.D. Glass, Illinois Geological Survey) from an exposed section of the Ogallala Group along the eastern "caprock" escarpment northwest of Floydada, Texas.

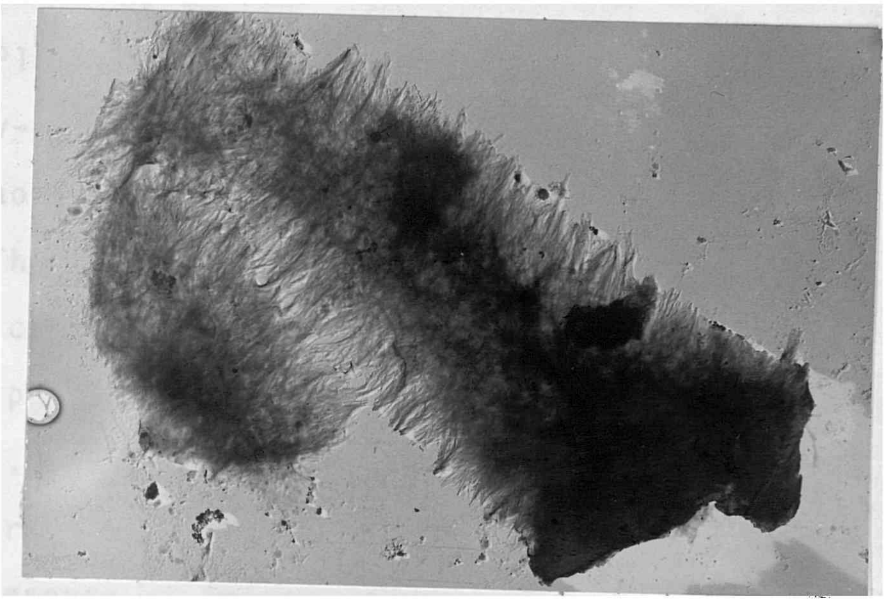

Fig. 21.--Fibrous (trioctahedral) smectite from sample C2 (see Table 4). (Transmission electron Photomicrograph)

and probably also indicative of a dry climate.

Quaternary units (such as the Blackwater Draw Formation) in Lynn and Terry counties are often similar in color and carbonate content to Ogallala sediments, thus are often difficult to distinguish from Ogallala sediments in drill or core samples. However, the clay minerals in soils and most Pleistocene lacustrine sediments of the Southern High Plains (Allen and others, 1972) are comprised of poorly-crystalline smectite, illite, interstratified clays, and kaolinite, thus are distinctive from Ogallala clays.

The principal clay in most early Pleistocene lacustrine carbonates on the Southern High Plains, including the type Blanco Beds, Blancan deposits along Yellowhouse Canyon, Spring Creek beds, and Tule equivalents, is sepiolite or attapulgite or both (McLean, 1969; Pierce, 1973). The presence of these acicular clays in the lacustrine sediments, associated with calcite or dolomite or both, indicates deposition in an alkaline environment; but, such environments do not fit the concept of deposition during supposed early Pleistocene pluvial climates. More surface (and subsurface) water was available on the Southern High Plains during the early Pleistocene than at present due to permanent or semi-permanent streams draining east from water sources in the Southern Rocky Mountains. Under conditions which existed before the Pecos River captured eastward-flowing drainage during mid-Pleistocene time (Reeves, 1970, 1972), permanent and/or semi-permanent lakes existed on the Southern High Plains, all associated with early Pleistocene drainage. Evaporation of the lake waters concentrated alkaline ions causing precipitation of carbonates (calcite and dolomite) and eventually the formation of magnesium-rich clay minerals.

Only two clay minerals, smectite and sepiolite, have been detected in the Wilson Lake carbonates, the overall content of both becoming high in samples with dolomite. This association, the fibrous morphology (Fig. 21) of the smectite (indicated by electron microscopic work furnished by Rod Pease, Geochemist, Sun Oil Company) and the high magnesium content of a similar smectite from sediments on the Southern High Plains (chemistry furnished by Roger Lee, Texas Tech Unviersity graduate student), indicates that the smectite in the Wilson Lake carbonates is probably a magnesium-rich trioctahedral smectite, and thus also indicative of deposition under an arid environment.

Data collected by Parry and Reeves (1968) and by Goolsby (unpublished manuscript, 1973) shows that the predominant clay minerals in the Double Lakes Formation of early Wisconsin age are smectites, illites, interstratified illite-smectite and kaolinite. Sepiolite is rare in the

Double Lakes Formation and attapulgite is absent. Carbonate lenses do not occur in organic-rich clays of the Double Lakes Formation but may exist in the shoreward facies. The Double Lakes core does contain some dolomitic clays and some of the clays exhibit a trace of sepiolite (Appendix A).

The high content of kaolinite in the Double Lakes Formation indicates a wet climatic regime and permanent water existed during deposition of the clays, thus supporting Reeves' (1973, 1975) contention that early Wisconsin time on the Southern High Plains was pluvial in the classic sense. Cryophylic salts, such as epsomite, of the upper Double Lakes Formation in several of the lake basins indicates not only a wet but a cold climate during mid-Wisconsin time (Reeves, 1975).

The sepiolite traces and dolomitic content of the clays in the Double Lakes Formation at the type locality do not occur in Double Lakes clays in the other large basins cored to date. Presence of sepiolite and dolomite in the clays of the Double Lakes basin resulted from the early blockage of the Pleistocene drainage channel along which the basin formed, thus restricting the amount of fresh water entering Double Lakes.

Thin beds of dolomites (Rich Lake Dolomite and Vigo Park Dolomite) and dolomitic clays within the Tahoka Formation contain sepiolite and are thus indicative of dry periods during early Tahokan and late Tahokan time. However for the most part Tahoka clays are illite, smectite, and interstratified illite-smectite (Parry and Reeves, 1968), indicating permanent water. Pollen data (Wendorf, 1961) and invertebrates (Pierce, 1975) indicate a cool, wet climate prevailed during Tahokan time.

Large dunes fringing the lake basins, the predominance of sepiolite in the poorly-crystalline clay fraction and associated dolomite and gypsum in the upper few feet of the playa sediments indicate that dry climates have prevailed since the end of Tahokan time. Evidence for short-lived, wet-dry fluctuations, however, does occur in select areas (Compton, 1975).

CHAPTER V

GROUND WATER IN THE OGALLALA GROUP

Ogallala ground water was first used for irrigation in Lynn County at Grassland (Fig. 3) in the early 1930's, but extensive development of irrigated farming did not begin until after World War II. By 1950, approximately 300 irrigation wells were in use in Lynn County (Leggat, 1952), subsequent records (High Plains Underground Water Conservation District Number 1; Leggat, 1952) indicating that about 2,500 irrigation wells have been in use at one time or another in Lynn County during the past 25 years (an average of more than two and two-thirds irrigation wells per square mile). Data for Terry County is not readily available due to invalidation of the South Plains Water District.

Water of desirable quality and quantity for irrigation is very rare or absent in the vicinity of the large lake basins. This is due primarily to thinning and absence of the Ogallala aquifer over the Cretaceous highs on which the basins are formed (Figs. 5 and 6). Ground water that may be present is usually of poor quality due to saline lacustrine sediments.

The best irrigation wells in the Lynn-Terry County area are located in the center of the Slaton Channel in northern Lynn County. Unfortunately, wells bordering the channel lost production due to drawdown of the water into the channel by long range pumping of large-volume wells. Regionally, most wells in the two-county area (with the exception of some in the deepest channels) are usually less than 4 inches in diameter. Progressively larger areas, particularly in Lynn County, are being forced to dry-land farming because of depletion of the Ogallala ground water.

Data collected from Ogallala producing water wells during the late 60's and early 70's by the Texas Water Quality Board and Dr. W.D. Miller (deceased), Texas Tech University, was used to construct contour maps for nitrate, chloride, and total dissolved solids in the investigated area (Figs. 22-27). Wells which may be producing from Cretaceous rocks have been indicated on the maps.

Ogallala ground water tested from 90 evenly distributed wells in Lynn County has an average nitrate content of 27 p.p.m. (slightly lower for Terry County) whereas the average nitrate content in Ogallala groundwater from 83 wells in Hale County (30 miles north of Lynn and Terry counties) was only 3.0 p.p.m. With the exception of the "sand dune" area in Lamb, Baily, and Hockley counties all the ground water north of Lynn and Terry counties is comparatively low in nitrate content. No natural source for nitrate is known on the Southern High Plains; therefore, the high nitrate content of Ogallala ground water is assumed a result of either sewage effluent or agricultural practices on the sandy, permiable soils in the area, although a natural nitrate source may have been overlooked. Figures 22 and 23 show that the high nitrate areas underlie sandy soil areas, thus contamination by agricultural fertilizers is suspected. The soils are usually sandy and the Ogallala is very thin in the area of Double, Twin, and Guthrie lakes, but nitrate in the ground water is low due to the absence of agricultural activity (land is used for grazing). The notable exception is the high concentration of nitrates in Ogallala ground water around Tahoka Lake. Regionally, nitrate concentration in the Ogallala ground water increases from north to south in the study area.

The chloride and total dissolved solids of Ogallala ground water are higher in Lynn and Terry counties than in most other areas of the Southern High Plains, with the exception of areas surrounding large saline lake basins in Lamb, Baily, and Hockley counties. The close relationship between the large saline lake basins and high chloride and total dissolved solids is illustrated by Figures 24 through 27. Chlorides and total dissolved solids, as nitrates, increase from north to south in the study area. I suspect the decrease in water quality from north to south in the study area may be directly related to, or the result of, the increase in sand content of the Ogallala (Fig. 8) and

Fig. 22.--Contour map of the nitrate content in Ogallala ground water, Terry County, Texas.

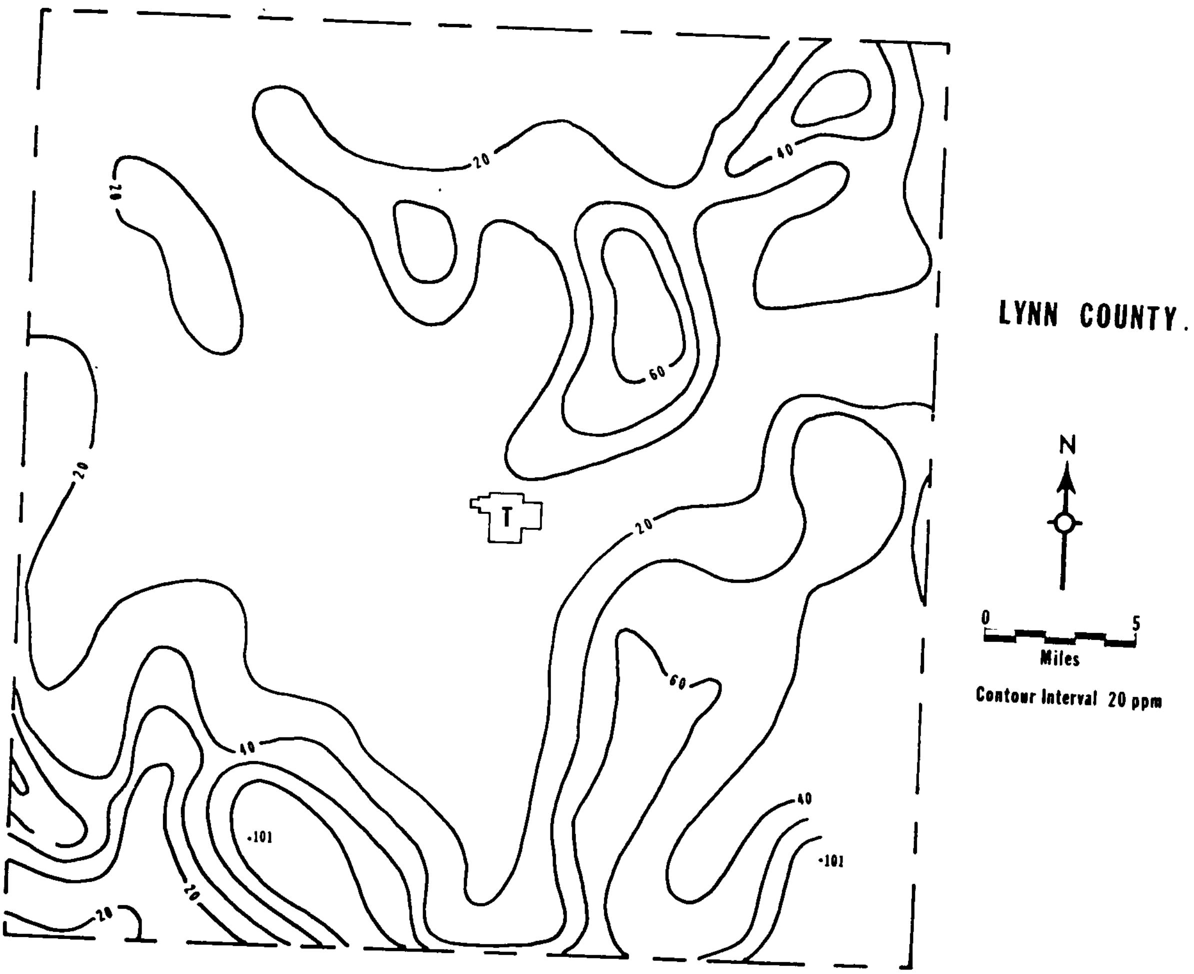

Fig. 23.--Contour map of the nitrate content in Ogallala ground water, Lynn County, Texas.

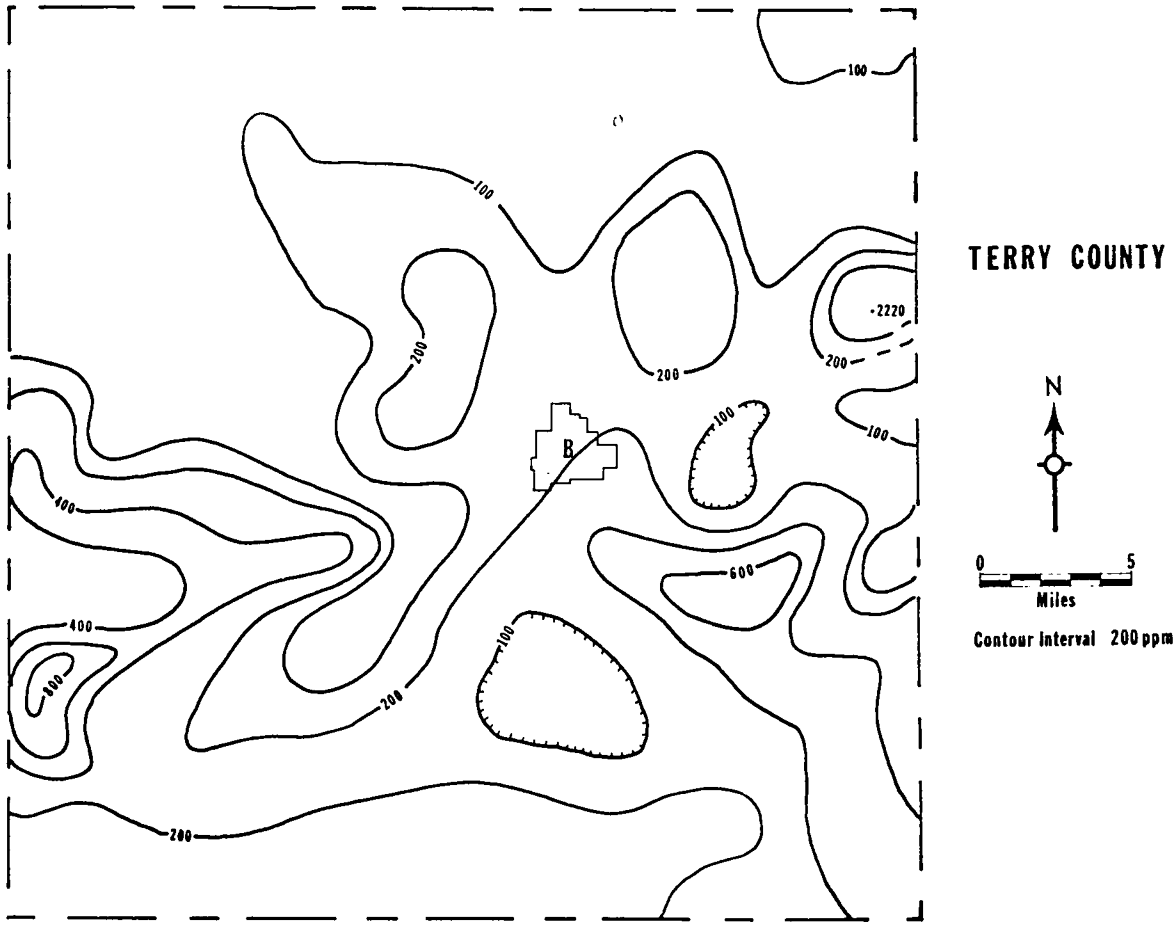

Fig. 24.--Contour map of the chloride content in Ogallala ground water, Terry County, Texas.

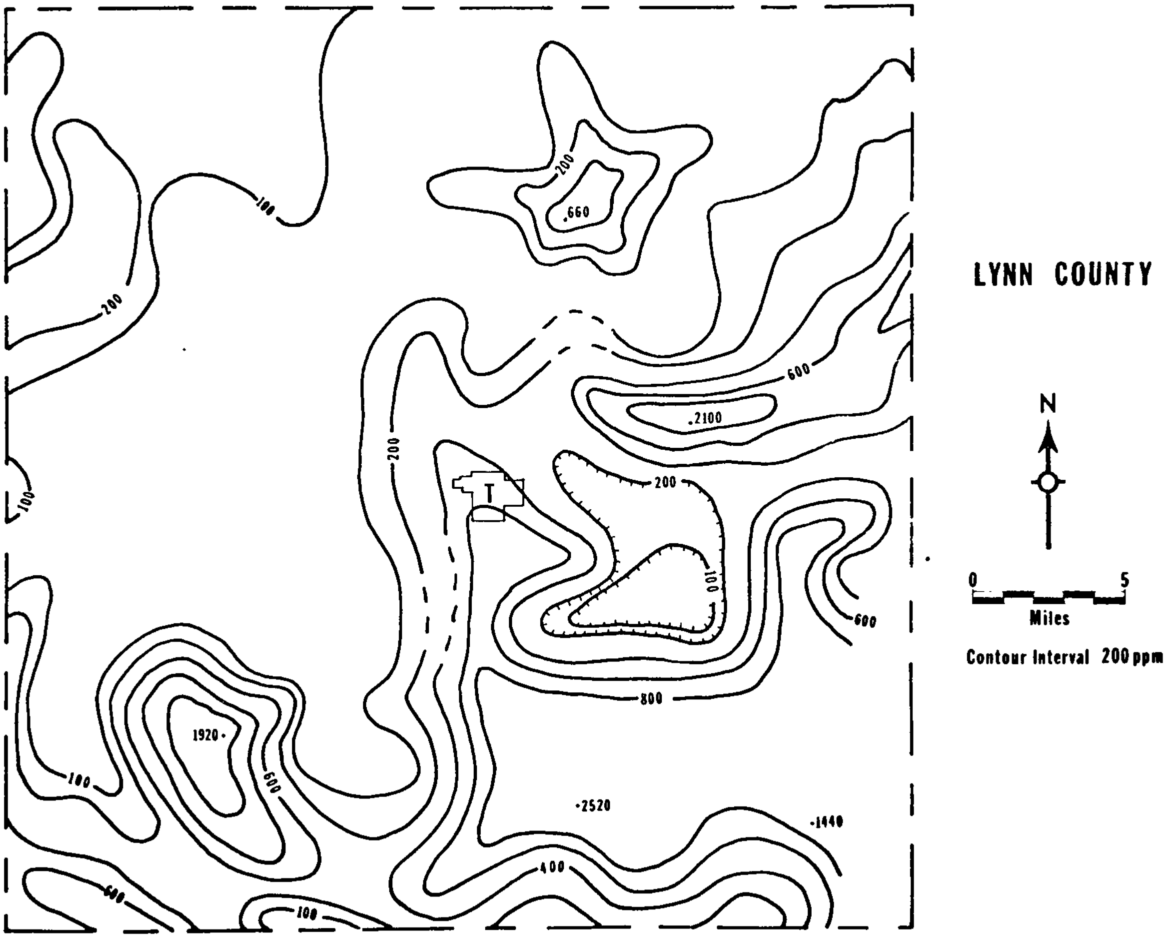

Fig. 25.--Contour map of the chloride content in Ogallala ground water, Lynn County, Texas.

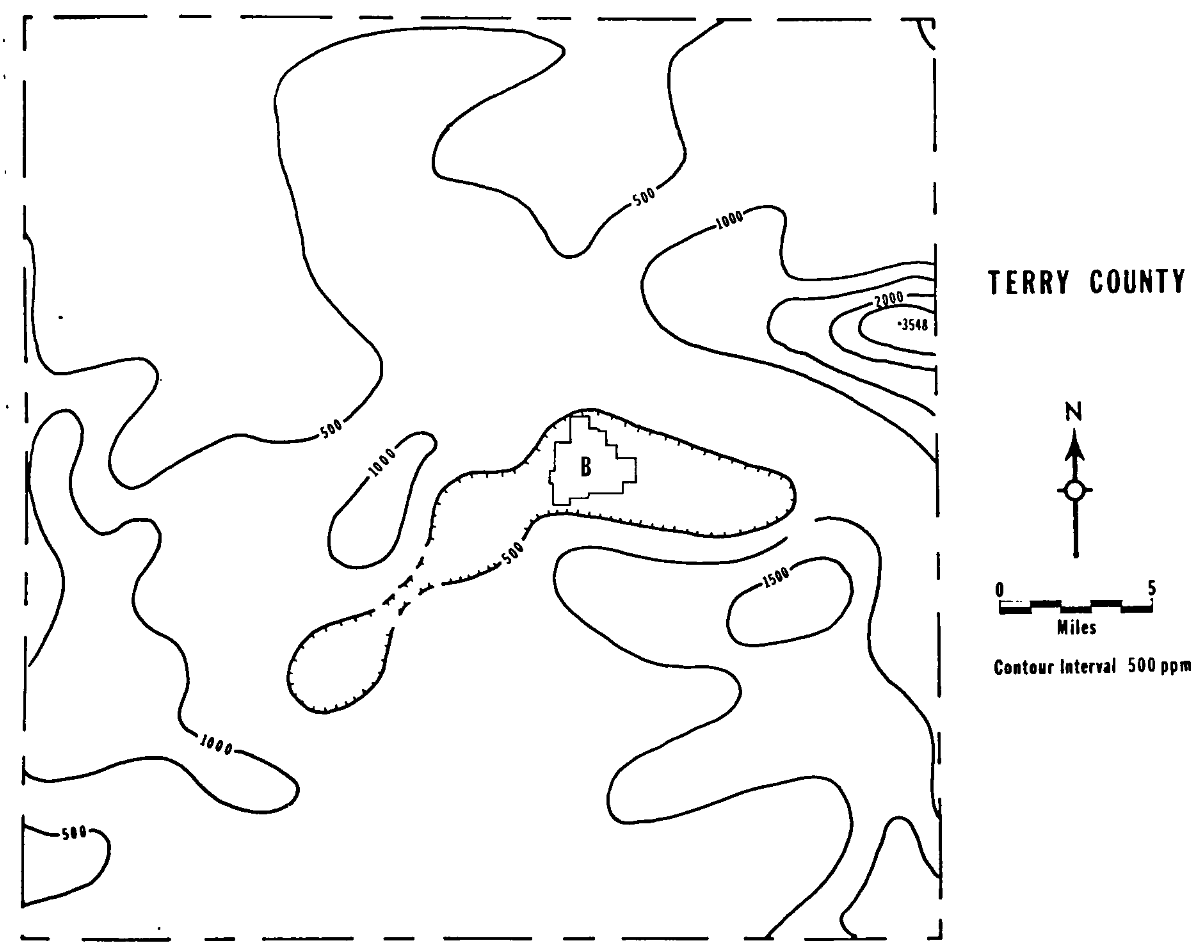

Fig. 26.--Contour map of the total dissolved solids in Ogallala ground water, Terry County, Texas.

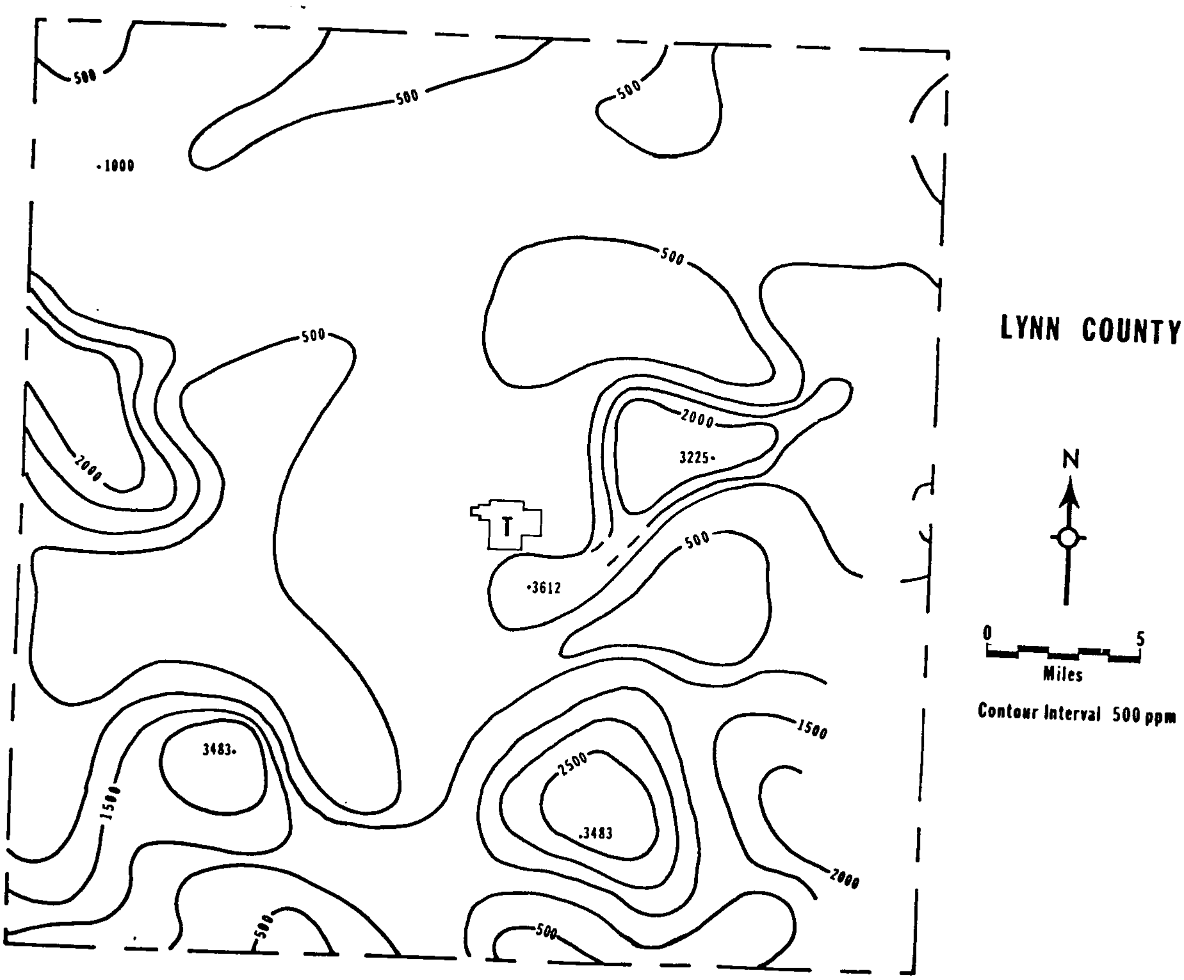

Fig. 27.--Contour map of the total dissolved solids in Ogallala ground water, Lynn County, Texas.

the corresponding clay decrease from north to south in the area (Fig. 9), coupled with the thinning of the Ogallala section also from north to south (Figs. 10 and 11). The thicker, clay-rich section has a greater capacity for filtering (adsorbing) contaminants from the infiltrating water.

CHAPTER VI

CONCLUSIONS

Cenozoic rock units in the Lynn-Terry County area consist of: 1) the Pliocene Ogallala Group comprised of the Couch and Bridwell formations, 2) the localized early to mid-Pleistocene Wilson Lake and Spring Creek beds, 3) the extensive, but relatively-thin Blackwater Draw Formation (Illinoian age), 4) the Double Lakes and Tahoka formations of Wisconsin age, and 5) the thin, late Wisconsin loess (Peoria?) which covers much of eastern Lynn County.

Clay mineralogy indicates that a progressively dryer climate more or less prevailed throughout Ogallala time, culminating in formation of the widespread "caprock" caliche. Clay mineralogy indicates a short-lived, somewhat-moister climate prevailed during early Bridwell time, but this may have been of only local significance.

Although lower Pleistocene sediments are not recognized in the investigated area, Kansan-Yarmouthian deposits and invertebrates in southwest Lynn County suggest a wet climate characterized Kansan time, whereas a semiarid climate occurred during Yarmouthian time. Illinoian time on the Southern High Plains was characterized by semiarid to arid conditions which allowed widespread eolian deposition. Wisconsin time was also very wet with precipitation/runoff exceeding evaporation/infiltration. The eight large lakes which occurred in the Lynn-Terry county area during Wisconsin time had a combined water area of at least 78 square miles (this estimate is not inclusive of thousands of smaller lakes existing at that time).

Formation of the large open basins took place along Tertiary-early Pleistocene drainage channels where meandering occurred on Cretaceous topographic highs. Blocking of the narrow parts of the channels by Illinoian eolian deposits then closed the basins which, throughout most of Wisconsin time, contained permanent water. The basins were partially filled with the early Wisconsin Double Lakes Formation and the late Wisconsin Tahoka Formation, the Tahoka clay representing deposits from the last permanent lakes which existed on the Southern High Plains.

During the last ±12,000 years the Southern High Plains has undergone severe deflation. The large lake basins have been incised by winds blowing either to the southeast or northeast. Depth to which deflation has occurred in individual basins has been controlled by the local groundwater level which, in turn, has been controlled (since capture of the east-flowing drainage and before extensive irrigation) by climatic factors.

Water quality within the Ogallala aquifer is a reflection of overall thickness and lithology of the Ogallala Group. The best quality ground water occurs along deep Ogallala channels in the northern part of the study area, whereas the poorest quality water occurs around old Pleistocene lake basins. The older, early Pleistocene lacustrine fills, such as found at Wilson Lake and Spring Creek, exert local influences on groundwater quality. Nitrate content of the ground water in the area of Wilson Lake is high probably due to the permeability of the Wilson Lake carbonates which extend to within one to three feet of the land surface in an area of extensive cultivation.

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APPENDIX A

DOUBLE LAKES CORE

Depth in Feet	Description	Unit
0-17	Sand	DII
17-23	Sand, clayey, dull yellow-orange (10 YR 7/2) calcareous, gypsum threads	
23-28	Clay, sandy light gray (10 YR 7/1) calcareous, gypsum threads. Scattered bits of charcoal	Q+
28-33	Clay, sandy, dull yellow-orange (10 YR 6/2) thin beds of sand and of gypsum crystals	
33-37	Clay, grayish-yellow (2.5 Y 7/2) calcareous, gypsum crystals abundant, scattered epsomite	
37-41	Sandy, loam, grayish-yellow (2.5 Y 7/2) with scattered orange mottling	
41-45	Clay, gray (N/6) darkening near lower portion to (N/4)	
45-52	Clay, olive gray (56 Y 6/1)	Qdl
52-55	Sand, very fine, dark olive gray (5 GY 4/1) to olive gray (5 GY 6/1), with common gypsum rosettes	
55-63	Clay, light olive gray (5 GY 7/1) to dark greenish-gray (5 G r/1) abundant gypsum crystals	
63-72	Clay, olive gray (5 GY 5/1) very abundant crystals, some thin sand units	
72-74	Shale, brownish-black (2.5 Y 3/1) to black (5 Y/21)	Kki

Depth in Feet	Clay Minerals[1]	Carbonate Content[2]
0-17	I-Sm, S, I very poorly crystalline	D very high
17-23	I-Sm, S, I, K very poorly crystalline	D very high
23-28	S, I, K very poorly crystalline	D very high
28-33	I, S, K very poorly crystalline	D = C very high
33-37	Sm, S, I, K poorly crystalline	D very high
37-41	S, I, Sm, K poorly crystalline	D very high
41-45	Sm, S, I, K poorly crystalline	D very high
45-52	Sm, I, I-Sm, K	D = low
52-55	I, I-Sm, K	D = low
55-63	Sm, S, I, K	D = high
63-72	I, Sm, S, K	D = low-high
72-74	Sm, I, K very highly crystalline	None

[1]Clay minerals are listed in order of magnitude.

[2]Carbonate content in the clay fraction.

I = illite, S = sepiolite, Sm = smectite, K = kaolinite,

D = dolomite, C = càlcite, I-Sm - interstratified, illite-smectite

APPENDIX B

RICH LAKE CORE

Depth in Feet	Description	Unit
0-10	Clay, light brownish-gray (5 YR 6/1) scattered layers of gypsum mesh, calcareous	Recent
10-20	Clay, medium gray (N/5) to dark greenish-gray (5 G 4/1), abundant astrakamite, randomly scattered gypsum crystals	
20-25	Clay, medium gray (N/5) to grayish-green (10 GY 5/2)	
25-28	Clay, medium gray (N/5) to light olive (10 Y 5/4), scattered astrakanite and gypsum crystals	Qd1
28-32	Clay, medium-dark gray (N/4), to brownish-black (5 YR 2/1) very few gypsum crystals	
32-40	Clay, dark gray (N/3) with moderate olive brown streaks (5 Y 4/4), few gypsum crystals	
40-47	Clay, dense, shaly, very dark gray (5 Y 3/0) to black (5 Y 2/1)	
47-51	Clay, dark olive gray (5 Y 4/1) to medium-dark gray (N/4), abundant gypsum crystals, calcareous	

Depth in Feet	Clay Minerals[1]	Carbonate Content[2]
0-10	S, I-Sm, Sm very poorly crystalline	C = low
10-20	S, I-Sm, I, K poorly crystalline	C = low
20-25	I, K, Sm	none
25-28	Sm, I, K	none
28-32	Sm, I, K	none
32-40	Sm, K, I	none
40-47	Sm, K, I	none
47-51	Sm, I, K	C = moderate

[1]Clay minerals are listed in order of magnitude.

[2]Carbonate content in clay fraction.

I = illite, S = sepiolite, Sm = smectite, K = kaolinite,

D = dolomite, C = calcite, I-Sm = interstratified, illite-smectite

APPENDIX C

METHOD FOR DETERMINING CLAY MINERAL PERCENTAGES

The samples were prepared and analyzed by x-ray diffraction methods employed by Glass and others (1973). The height of the diffraction peak above the background was then measured on log scale recording paper. Values obtained by height measurement were multiplied by factors of one for montmorillonite, two for kaolinite, and three for attapulgite, sepiolite, and illite. The resulting values for all the clay minerals within the samples were then totaled and the individual values for each clay mineral divided by the total value, thus obtaining the percentage of each clay mineral represented (H.D. Glass, written communication, 1974).