ENVIRONMENTAL FRAMEWORK, STRUCTURAL EVOLUTION AND PETROLEUM POTENTIAL OF THE CAMBRIAN WILBERNS FORMATION WEST-CENTRAL TEXAS

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By

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ABSTRACT

The Wilberns Formation (Upper Cambrian) in the subsurface of west-central Texas is composed predominantly of sandstone units. Subsurface mapping of the Wilberns shows the sandstones to be persistent throughout most of the study area. Analyses of core samples indicate that the upper portion of the Wilberns Formation consists of a lower sandstone facies overlain by a dolomitic interval. The suite of sedimentary structures present in both facies suggests tidal flat deposition and the electric log signatures are similar to those produced by channel and tidal sand bodies. Thus, it is postulated that the Wilberns Formation was deposed on extensive tidal flats in tidal channels.

The Fort Chadbourne fault system is a linear zone of deformation trending from Sutton County northward into northeastern Nolan County. This structural zone has uplifted and faulted the Wilberns Formation. The presence of en echelon faults and folds as the predominant structures along the Fort Chadbourne system suggests wrench faulting. The orientation of the faults (N-S) and folds (NE-SW) suggests that the wrench system had left lateral

movement produced from compressive forces active during the Ouachita orogeny.

Thin section analyses of core samples produced a general paragenetic sequence for the upper sandstone units of the Wilberns Formation consisting of at least four diagenetic stages as follows:

(1) Burial and compaction leading to reduction of primary porosity and development of quartz overgrowths.

(2) Precipitation of dolomite cement into remaining pore space.

(3) Uplift and exposure leading to dissolution of calcareous materials, resulting in development of secondary porosity.

(4) Re-burial and precipitation of hematite, pyrite and clays as pore lining and pore fill. Hydrocarbon migration probably occurred during this stage.

This sequence of diagenetic events is responsible for the excellent reservoir quality of the sandstone units within the Wilberns Formation; it is found only along the Fort Chabourne fault system.

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INTRODUCTION

Purpose

The Wilberns Formation (Upper Cambrian) is a widespread rock unit in the subsurface throughout most of west-central Texas. In this area, the Wilberns is composed of quartz sandstones overlain by a dolomitic unit which grades upwards into the overlying Ellenburger Group (Ordovician).

The principal tectonic feature, the Fort Chadbourne fault system has given rise to high angle faults with associated anticlinal features. This structuring, believed to have occurred during post-Ordovician time, has improved reservoir quality of the Wilberns Formation along this fault trend.

A better understanding of the nature of the sandstone units within the Wilberns Formation and of the later structural development of the Fort Chadbourne fault system is essential in evaluating Wilberns' petroleum potential. Therefore, the scope of this study is to determine the general depositional origin of the Wilberns sandstones in the study area, to explain the nature and probable origin of the Fort Chadbourne fault system, and to derive a general paragenetic sequence that will account for the reservoir quality of the Wilberns sandstones in the study area.

Location

The area of investigation is in west-central Texas, extending from Sutton and Menard Counties in the south, to King and Knox Counties in the north (Fig. 1).

The Wilberns Formation belongs to the Moore Hollow Group of the Upper Cambrian Croixan series (Fig. 2). It ranges in age from Franconian to Trempealeauan. The Wilberns Formation is separated from the underlying Riley Formation by the Dresbachian-Franconian disconformity and is conformably overlain by the Ellenburger Group.

The major structural feature within the study area is the Fort Chadbourne fault system. Other regional features present are the Concho arch, Eastern Shelf and part of the Midland basin (Fig. 3).

Methods

The methods of investigation used in this study may be categorized into four parts as follows: (1) An extensive review of the literature pertaining to the stratigraphy, origin, and petroleum occurrence of the Wilberns

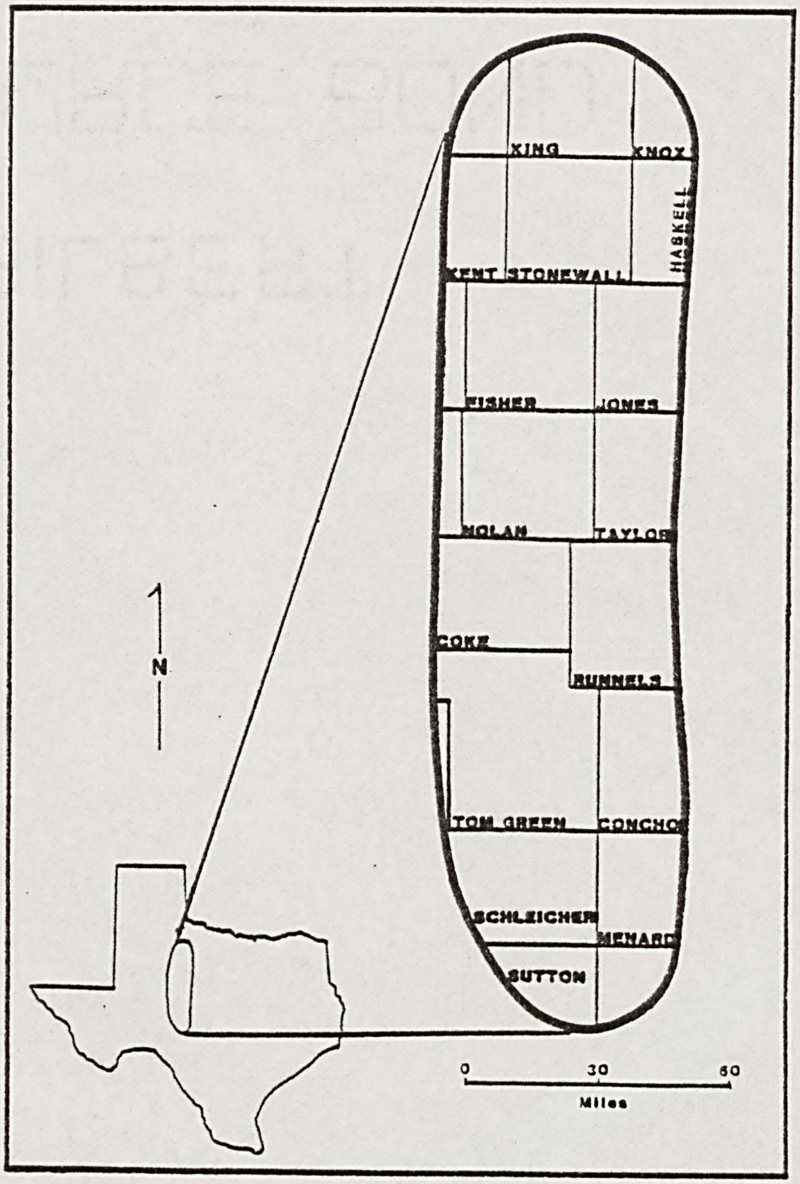


Fig. 1. Location map of study area west-central, Texas.

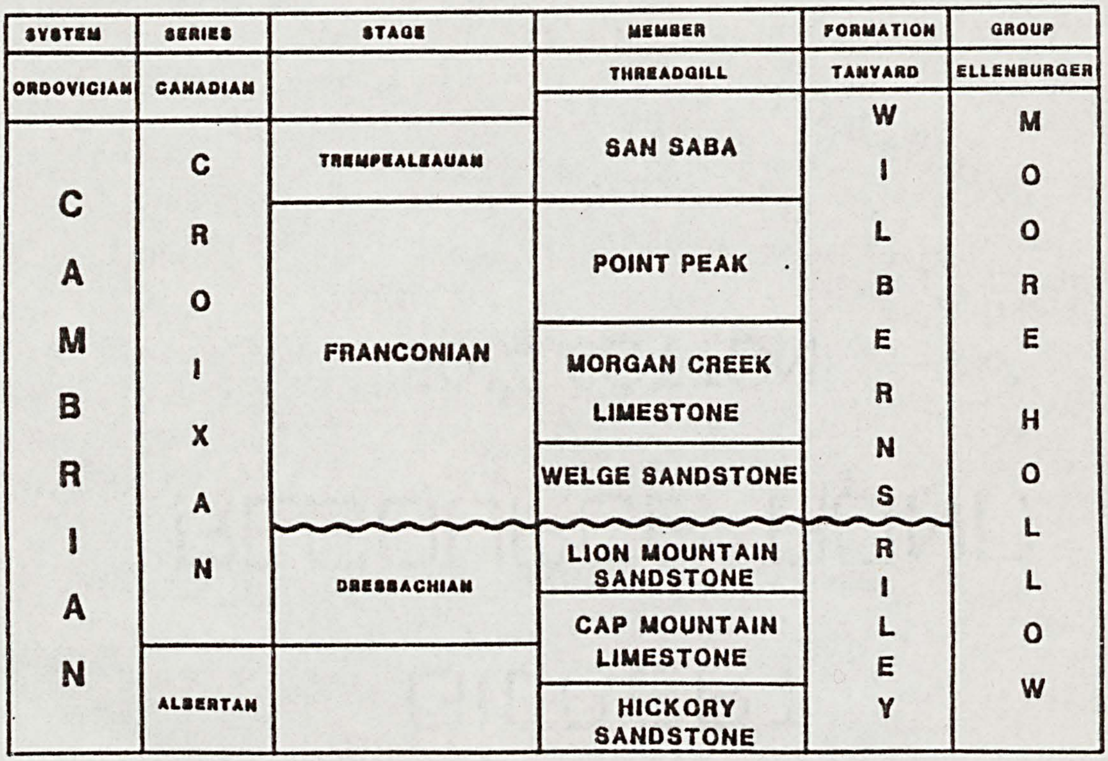


Fig. 2. Stratigraphic column illustrating the position of the Wilberns in relation to overlying and underlying strata (After Bell and Barnes, 1961).

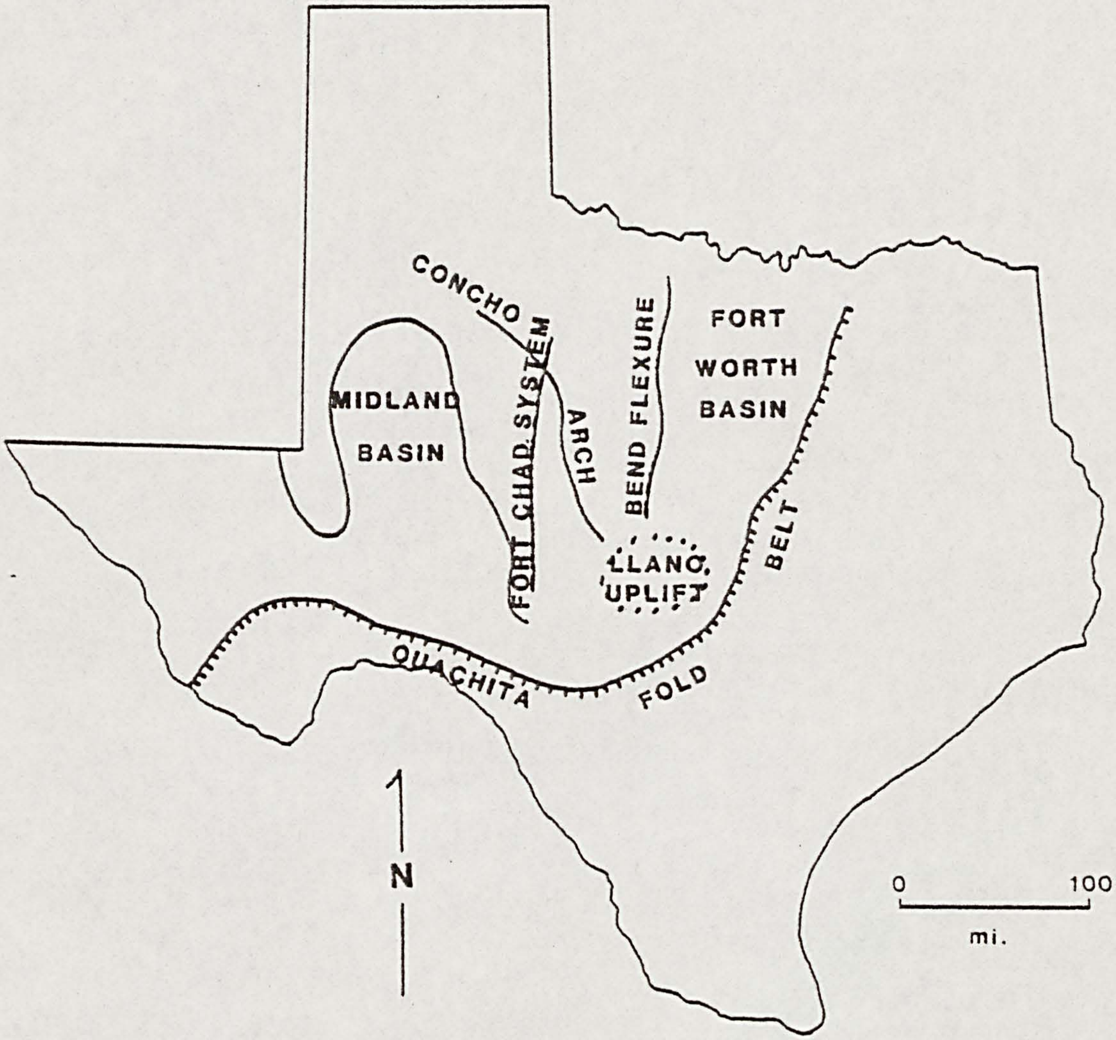


Fig. 3. Structural features of central and west Texas and their position with respect to the study area.

Formation. (2) Interpretation of over 200 electric logs in the development of a stratigraphic framework and in constructing subsurface maps. Also, structural and stratigraphic cross sections were prepared using all available electric logs. (3) Description of hand samples, thin sections, and small chips of selected sandstone units were obtained from four cores of wells drilled within the study area. The core descriptions aided in determining depositional environments and relating facies to the electric log signature. Twenty-eight thin sections were cut from selected intervals of the four cores. Point counts of two hundred points each were taken from each thin section in an effort to determine percentages of constituent grains in each sample. Sorting and roundness were determined by the use of templates (Pettijohn, et al., 1973). After thin sections were analyzed, chips of sandstone intervals were taken to be processed by x-ray diffraction. This was done to determine the type of clays present within the sandstones. (4) Available petroleum production information from wells and fields within the study area was used to determine the nature of production of hydrocarbons and to evaluate future exploration potential within the Wilberns Formation.

Previous Works

Very few studies have been made on the stratigraphy and depositional environments of the Wilberns Formation in the subsurface of west-central Texas. However, the Wilberns crops out in the Llano region of Texas where it has been extensively studied. In 1852, Ferdinand Roemer in the appendix of his work on the Cretaceous of Texas, erroneously assigned a Silurian age to the Cambrian strata cropping out in the Llano Region. The following year (1853) Barrande assigned a Cambrian age to Roemer's Silurian rocks of Central Texas by comparing the fossils found there with similar ones in the Cambrian of New York and Wisconsin (Bridge and Girty 1937). Sidney Paige (1911) first described the Wilberns Formation as being predominantly composed of limestones and shales, with the upper third of the formation being mostly shale. Paige placed the Wilberns between the underlying Upper Cambrian Cap Mountain Formation and the Lower Ordovician Ellenburger Group which he believed was unconformable with the Wilberns. Cloud, Barnes, and Bridge (1945) reduced the Cap Mountain Formation to member status and proposed the Riley Formation as the name of Upper Cambrian strata lying below the Wilberns Formation. They also stated that continuous deposition prevailed across the Cambrian-Ordovician boundary. Bridge, Barnes, and Cloud (1947) provided the first complete study of the Upper Cambrian rock units in the Llano region. Barnes, et al. (1959), correlated Upper Cambrian and Lower Ordovician rocks in the subsurface of Texas and southeast New Mexico using cores from wells drilled throughout the area. Correlations made in this study were based on paleontologic, petrographic, physical (electric logs) and chemical (insoluble residue) criteria. Petrographic and mineralogic work on the lower portion of the Wilberns Formation was conducted by Daugherty (1960), Dekker (1966) and Chafetz (1970) in different areas of the Llano region. Bell and Barnes (1961) submitted biostratigraphic evidence for a Dresbachian-Franconian disconformity separating the Riley Formation from the Wilberns Formation. Ahr (1971) described and determined paleoenvironments for the different algal structures in the upper portion of the Wilberns Formation and Chafetz (1973) did the same for these types of structures present in the lower and middle portions of the Wilberns. Barnes and Bell (1977) introduced the Moore Hollow Group for all rock units lying beneath the Ellenburger Group and above the Precambrian in central Texas. Watson (1980) provides a review of the Paleozoic stratigraphy in the Llano Uplift area.

There are few papers dealing with the Fort Chadbourne fault system. Conselman (1954) proposed the name presently used and discussed the nature and possible development of the anticlinal features associated with the faulting. Holmquist (1955) suggests that the structures associated with, what he calls, the Bronte Axis, are related to movement along a reactivated Precambrian zone of weakness. Rall and Rall (1958) describe the Fort Chadbourne fault system in Sutton and Schleicher Counties and discuss the evolution of these structures.

Studies of petroleum production from the Wilberns include Galley (1958) who discussed the nature and possible sources of the hydrocarbons trapped in the Upper Cambrian and Lower Ordovician strata of west-central Texas. Neff (1954), Hayes, et al. (1954), Hayes (1954), Hoffacher (1954), Beaird (1960), Tompkins (1960), and Parrott (1976) report on Cambrian production from fields within the study area.

Acknowledgements

Gratitude goes to Professors Harold Beaver, William Brown and James McAtee for their helpful suggestions and constructive criticism throughout the course of this study. The help received from Roger Sels and Ted Galowski with Amoco in Houston was greatly appreciated. Many thanks go out to my wife Pattina, who helped with the typing of the text and put up with my anxiety attacks.

ENVIRONMENTAL FRAMEWORK

Regional Stratigraphic Setting

The stratigraphy of the Wilberns Formation in the subsurface of west-central Texas is not well known. However, by acquiring a general understanding of the regional stratigraphic relationships for the Wilberns from surface studies conducted in the Llano Uplift region of Texas, its subsurface nature is more clear.

The Wilberns Formation of central Texas unconformably overlies the Riley Formation (Upper Cambrian) and is conformably overlain by the Ellenburger Group (Lower Ordovician). The transgressive sequence making up the Wilberns can be subdivided into four members which, in ascending order, are the Welge Sandstone Member, Morgan Creek Limestone Member, Point Peak Member and San Saba Member (Bell and Barnes, 1954).

The Welge Sandstone Member is a thin, widespread basal sandstone making the encroachment of the Cambrian sea from the southeast after a period of erosion and nondeposition representing the end of Riley time (Dresbachian-Franconian disconformity). Studies by Daugherty (1960), Dekker (1966), and Chafetz (1970) conclude that the Welge represented high energy, shallow marine, near-shore deposition. Northwestward in the subsurface, the Welge maintains its thickness and composition until a point is reached where the overlying Morgan Creek Limestone becomes terrigenous and the two members are indistinguishable (Barnes, 1959).

The Morgan Creek Limestone Member conformably overlies the Welge Sandstone and represents a deepening of the seas. Chafetz (1970) notes that the lower portion of this limestone has more sparite and oolite content than the more micritic and algal-bound upper portion. This relationship suggests a shallowing from high energy shallow marine to intertidal and supratidal environments.

The Point Peak Member consists of calcareous siltstones, intraformational conglomerates and stromatolites ranging from a few layers thick to stromatolitic bioherms. The facies found in this member suggests accumulation on a broad tidal flat (Chafetz, 1970) and the stromatolitic material is thought to have accumulated in sublittoral to lower intertidal conditions based on the mircrostructure of the Algae (Ahr, 1971). Barnes (1959) found the Point Peak Member difficult to discern in the subsurface of west-central Texas since, like the Morgan Creek Limestone below and the San Saba Member above, the Point Peak becomes more terrigenous to the northwest.

The uppermost member of the Wilberns Formation is the San Saba Member which chiefly consists of limestone and dolomite. The algal stromatolites found at the base of this member represent growth in the lower intertidal zone because of striking similarity in morphology that they have with present-day stromatolites growing in the lower intertidal zone of Shark Bay, Australia (Hoffman, 1976). The stromatolites are overlain by sandstone and limestone, both of which become two distinct units of the San Saba west and northwest of the Llano Uplift. In the subsurface of west-central Texas the sandstone unit is probably Cambrian in age while the upper calcareous unit is probably Cambro-Ordovician in age since it is gradational with the lowermost calcareous unit of the Ellenburger Group. Both of these units thin out in a northwestward direction where they lap onto the Precambrian surface (Barnes, 1959).

Nature of the Wilberns Formation

As mentioned previously, the Wilberns Formation in the subsurface of west-central Texas is composed chiefly of sandstone units. An electric log showing a complete section of the Wilberns from the study area examplifies its terrigenous nature (Fig. 4). Plates 9 through 12

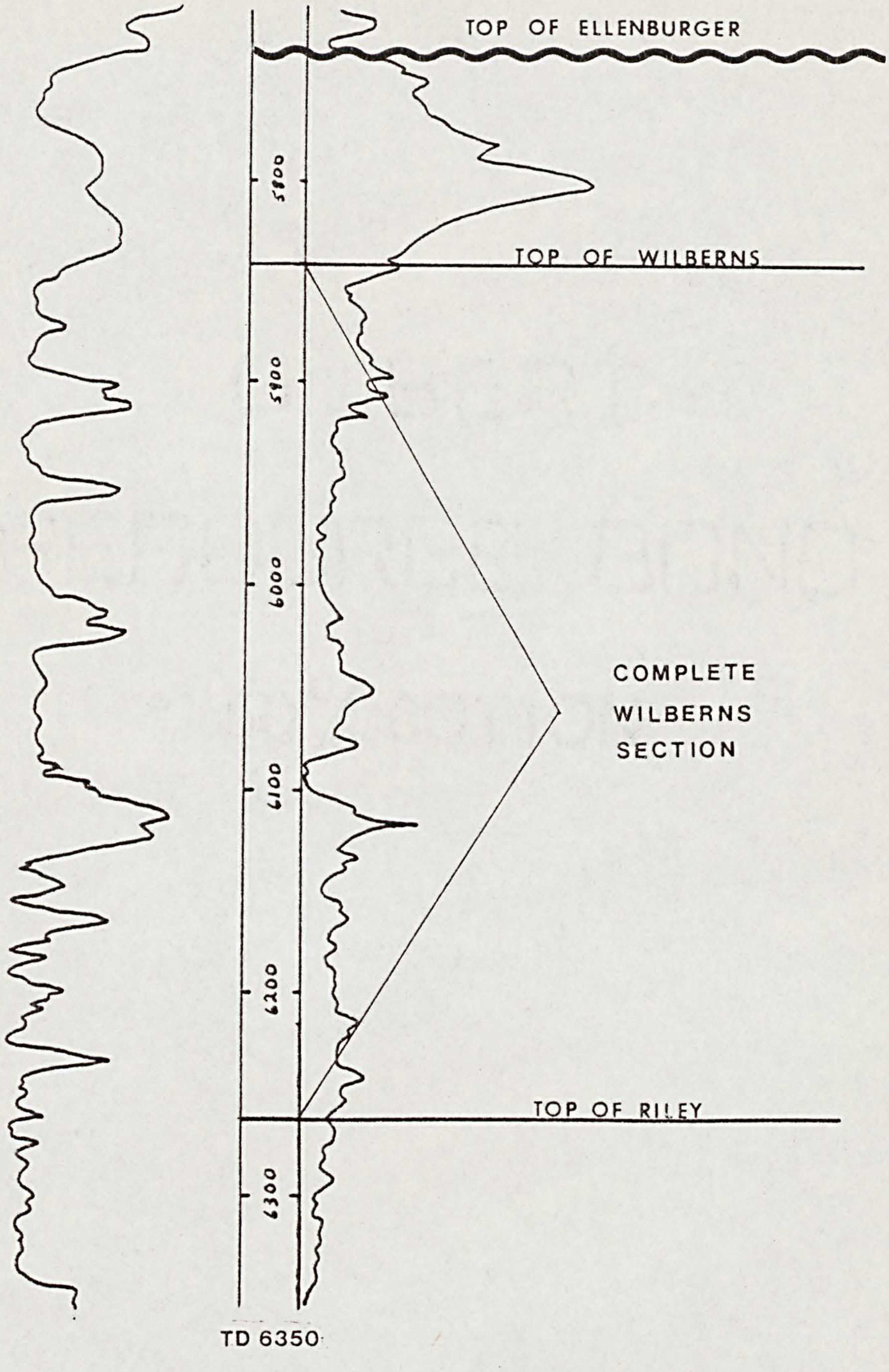


Fig. 4. Electric log signature of complete Wilberns section from Humble #F-90 Odom, Coke County. This shows the terrigenous nature of the Wilberns within the study area.

show the persistent nature of the sandstones of the Wilberns throughout the study area. All lines of section are shown on Plate 1.

The thickness of the Wilberns decreases to the west and northwest in the study area where it pinches out against Precambrian basement in Dickens and Kent Counties (Pls. 3, 9 and 13). Small localized areas where the Cambrian section is missing in Fisher and Stonewall Counties are believed to be monadnocks on the Precambrian surface (Pl. 3). These erosional remnants are similar to the ones mentioned by Barnes (1959) that occur as buried hills in the Llano region.

Core Analysis

Core samples were obtained from four wells drilled within the study area; their locations are shown on Plate 1. Descriptions of the core samples are found in Appendix II. These cores have also been described by Barnes (1959) who placed them stratigraphically in the upper half of the Wilberns Formation. The ensuing discussion deals with the facies and sedimentary structures observed from the cores studied.

Facies. Two distinct facies can be discerned from the four core samples of the upper portion of the Wilberns Formation; they are: (1) a lower sandstone facies and (2) an upper dolomitic facies. The sandstone facies is present in all four core samples while the upper dolomitic facies was observed only in the Humble #1 Cave and Humble #1 W.C.S.L. of Nolan and Tom Green Counties, respectively. The lack of the dolomitic facies in the other two wells may be related to the extent of erosion incurred during early Pennsylvanian time since these wells are located on the upthrown side of faults of the Fort Chadbourne fault system.

Thin sections cut from the sandstone facies show it to be predominantly composed of quartz arenites with some sublitharenites (Fig. 5). The quartz arenites are fine to coarse grained, well rounded and moderately to well sorted (Fig. 6a). Quartz grains are the dominant mineral constituent of this facies, making up from 86% to 99% of the sandstones. Rock fragments range from less than 1% to 10% and feldspar represents less than 1% to 5% of the sandstone facies. Hematite, pyrite and glauconite are present in minor amounts.

The dolomitic facies is composed of granular dolomite which in some cases is developed into good sized rhombs (Fig. 6b). Silt to medium sized quartz grains are found throughout this facies and constitutes up to 40% of the dolomite.

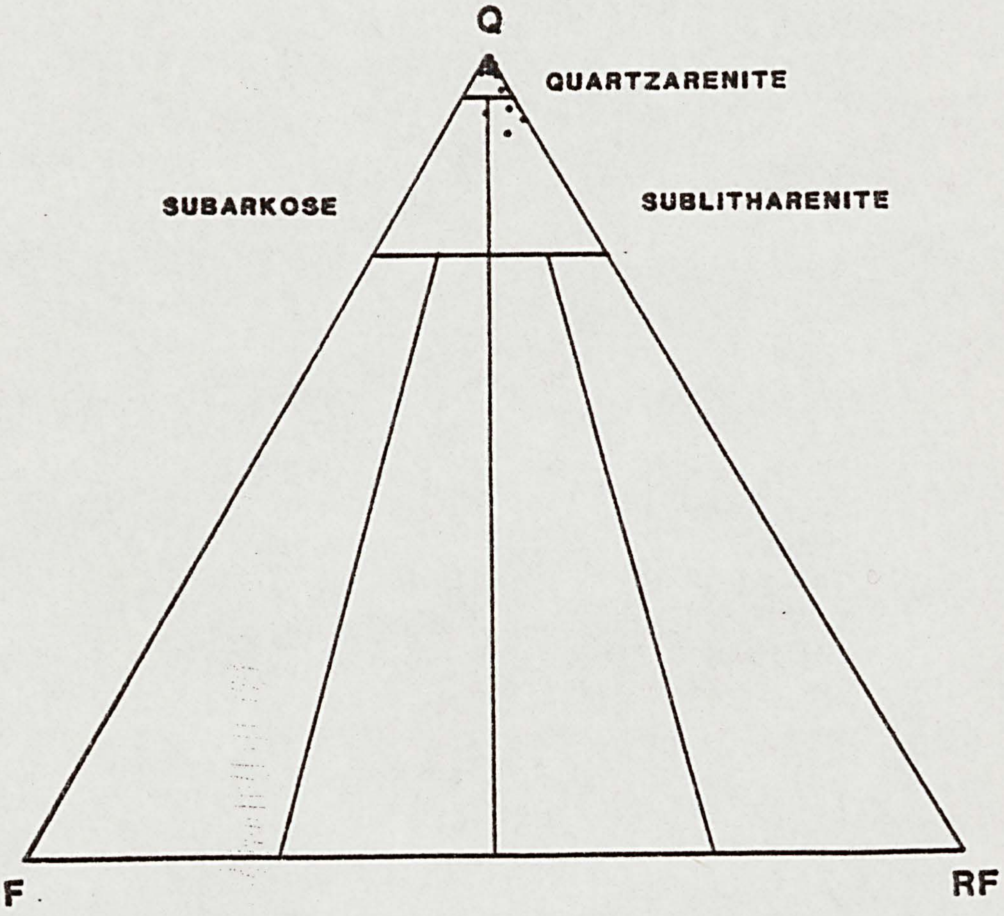


Fig. 5. Sandstone composition of the upper Wilberns sandstone facies. Classification after Folk (1968).

Fig. 6a. U. S. Mining T.X.L. "A" #3, Nolan County (6154 feet). Photomicrograph of the mature textural nature of the Wilberns upper sandstone facies (plane light, 28X).

Fig. 6b. General Crude #1 Cave, Nolan County (6582 feet). Photomicrograph of well developed dolomite rhombs found in the dolomitic facies (plane light, 28X).

Figure 6

a

b

Fig. 7a. U. S. Mining T.X.L. "A" #3, Nolan County (6154 feet).
A portion of the Wilberns upper sandstone facies exhibiting foreset bedding.

Fig. 7b. U. S. Mining T.X.L. "A" #3, Nolan County (6158 feet).
Flaser and lenticular bedding above and below a vertically burrowed horizon.

Fig. 7c. General Crude #1 Cave, Nolan County (6609 feet).
An example of a vertical burrow (Skolithos) found within the sandstone facies.

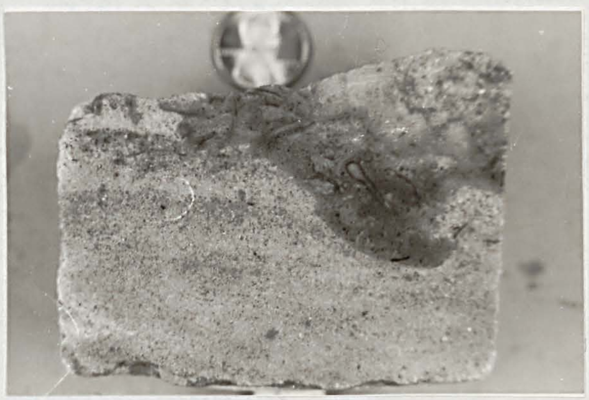
Fig. 7d. General Crude #1 Cave, Nolan County (6608 feet).
Shell material left behind in an infilled burrow.

Figure 7

a

b

c



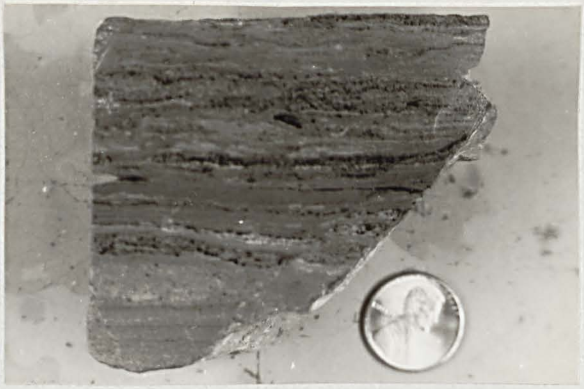
d

Fig. 8a. Kilroy #1 Roberts, Nolan County (6075 feet).
Dark green tidal bedding made up of thin parallel beds of argillaceous materials.

Fig. 8b. General Crude #1 Cave, Nolan County (6610 feet).
Nodules within the sandstone facies which are a probable result of differential compaction of sand and mud.

Fig. 8c. General Crude #1 Cave, Nolan County (6593 feet).
Example of the flat pebble conglomerate found in dolomitic facies.

Figure 8



a

b

c

Sedimentary Structures. Four main types of sedimentary structures are observed within the sandstone facies. Foreset beds are present in the U.S. Smelting T.X.L. "A" #3 (Fig. 7a) and Humble #1 W.C.S.L. wells of Nolan and Tom Green Counties, respectively. Foreset bedding was observed by Barnes (1959) in cores from other wells that penetrated the Wilberns in the study area. Lenticular bedding and flaser bedding are common structures in each core observed (Fig. 7b). Vertical burrows (*Skolithos*) are common throughout the sandstone facies (Fig. 7c and d). Some of the burrowed zones are 20cm in vertical extent. Nodules are present, but are not a common feature within the sandstone facies (Fig. 8a). A thin interbed of argillaceous siltstone exhibiting thin parallel bedding is found in the core from Kilroy #1 Roberts (Fig. 8b).

Flat pebble or intraformational conglomerate is the only structure found of any importance in the dolomitic facies (Fig. 8c). It is believed that this structure is common throughout this facies because it is present in each of the two core samples that have the dolomitic facies.

Electric Log Signature

The electric log signature of the sandstone facies marking the top of the Wilberns Formation is very consistent and characteristic throughout the study area (Pls. 9-12). Figure 9 shows an electric log signature of General Crude #1 Cave, a well from which a core sample was obtained. Comparing this electric log, which shows only the uppermost Wilberns sandstone, with the electric log of a complete Wilberns section (Fig. 4) a similarity of sandstone signatures may be noticed that can be used to infer similar depositional conditions for the sandstones comprising the Wilberns in the study area.

The overall electric log signature for the entire Wilberns section in the study area appears to be mostly sandstone intervals (ranging from 10-60 feet thick) separated by thin shales or calcareous units. Some electric log sandstone signatures show more pronounced shale breaks while signatures from other wells show what appear to be massive sands with poorly developed shale breaks. Also, the sands with well defined shale breaks have increased negative spontaneous potential curves when compared with sands having poor shale breaks. This difference in sandstones is shown in Plate 10 between wells 4 and 13 on the line of cross section.

The most feasible explanation for this variance in electric log signature between sandstones from different wells lies in the type of drilling muds used in these wells. Two of the greatest controls on the shape and

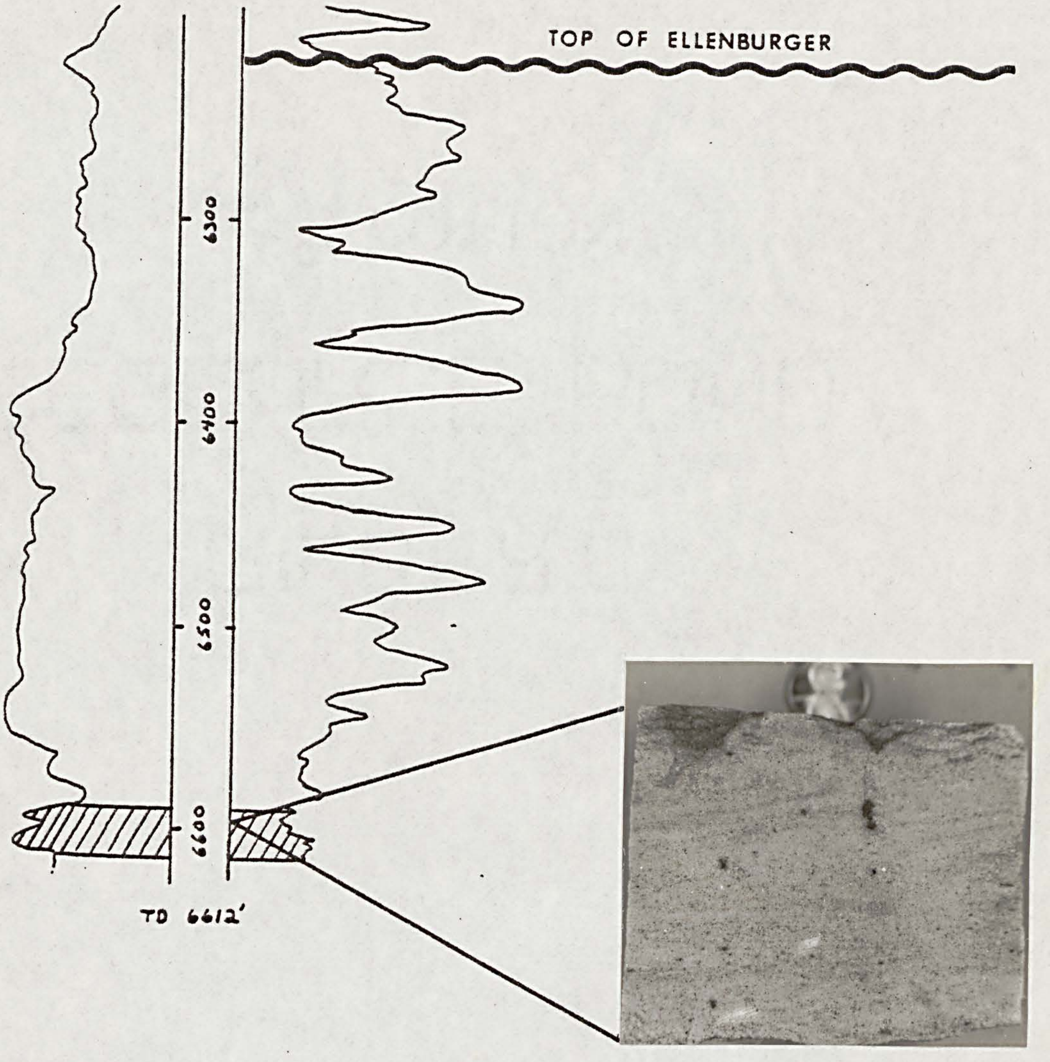


Fig. 9. Electric log signature of General Crude #1 Cave, Nolan County. The upper sandstone facies (shaded) of the Wilberns Formation is emphasized on this E-log. Comparison of this log character with the adjacent core interval (6595 feet) illustrates the type of lithology that generates this characteristic E-log signature of the Wilberns throughout the study area.

amplitude of spontaneous potential curves are: (1) thickness and true resistivity of the permeable bed and (2) resistivity of the drilling mud (Doll, 1948). Figure 10 shows the variations of spontaneous potential curves when the resistivities of the permeable strata (R_t) and drilling mud (R_m) are equal and when the drilling mud has a higher resistivity than the permeable strata. It can be noted that a better defined spontaneous potential curve is developed when $R_t=R_m$. Therefore, electric log signatures of the Wilberns section having well developed sandstones and shale breaks were probably produced in wells that were drilled with a mud having a resistivity close or equal to that of the Wilberns sandstones penetrated. The electric logs having poor definition of sandstones and shale breaks were probably obtained from wells in which the drilling mud used had a much greater resistivity than the sandstones.

Depositional Environment

From the observations presented in the previous portions of this section, a general environmental framework can be postulated. This is done for the most part by comparison of the core samples with similar recent and ancient environments that have been documented. Although

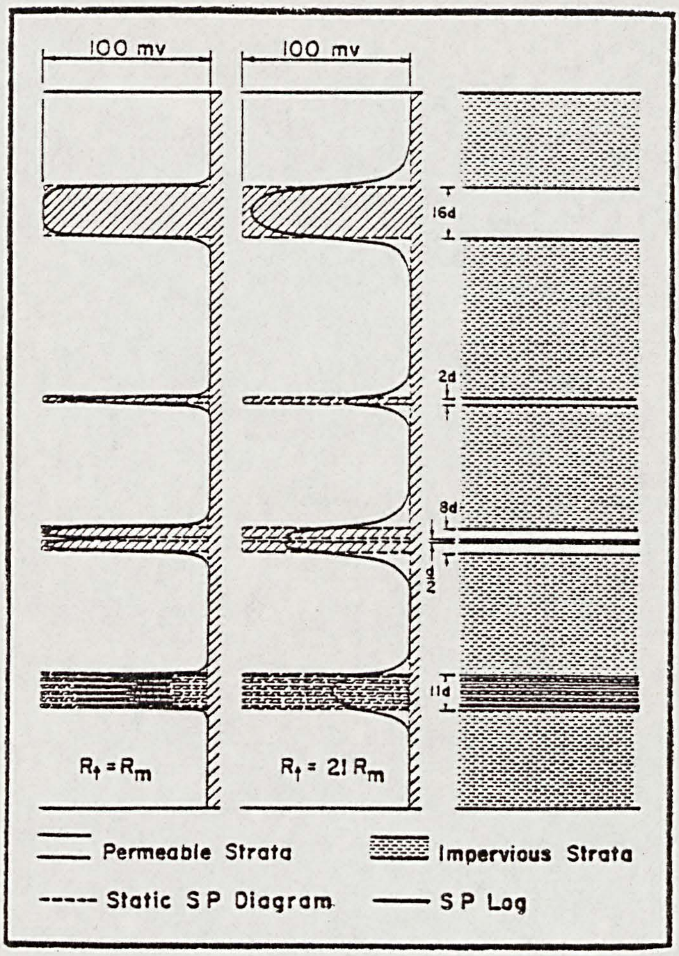


Fig. 10. This figure shows the variation in SP character as a function of thickness of the permeable strata and differences in the resistivities of the drilling mud and the permeable strata. SP kick is greater and has better definition when the drilling mud and permeable beds have similar resistivities (Schlumberger, 1972, p. 9).

no single feature of the Wilberns can pin point a specific depositional environment, it is the combination of characteristics that will narrow down the environmental framework of these Cambrian sandstones.

Sedimentary structures believed to be common in the sandstone facies of the upper Wilberns are foreset bedding, lenticular and flaser bedding, burrows, nodules, interbeds of thin parallel bedded argillaceous siltstone and the flat pebble conglomerates from the dolomitic facies. These features are common in a tidal flat environment.

Studies by Reineck (1975) and Klein (1977) provide descriptions of the types of sedimentary structures forming in modern tidal flats. Foreset beds, lenticular and flaser beds are found to be commonly produced in tidal channels of the subtidal zone. Bioturbation is common in the intertidal zone and the vertical burrows (Skolithus) observed in this study are of probable intertidal origin (Seilacher, 1977). Pseudonodules formed on tidal flats where differential loading of sand occurs on top of water saturated muds is the most likely origin of the nodules observed in the Wilberns (Klein, 1977). Mudcracks forming on the supratidal flats are the probable source for the flat pebble conglomerates of the dolomitic facies.

The interbeds of thin parallel bedded argillaceous siltstone are comparable to Reineck and Wunderlich's (1968) tidal bedding which consists of couplets of sand and mud deposited during a tidal cycle.

The mature quartz arenitic nature of the sandstone facies of the Wilberns Formation also favors a tidally dominated depositional setting. Mack (1978) showed that a great deal of transportation is essential in the destruction of feldspar grains and rock fragments to produce a quartz rich sandstone. In tidal channels the sand is transported back and forth through the channel before final deposition. This reworking of sediment over long distances in a depositionally restricted site (i.e. tidal channel system) combined with the frequent wetting and drying of sediments common in intertidal environments results in the abrasion and consequent reduction of mechanically unstable grains (Swett, Klein and Smit, 1971). This great amount of transport within a restricted area will lead to a high degree of rounding of quartz grains which is one of many characteristics of a tidally deposited sandstone (Balays and Klein, 1972).

The electric log signature of the Wilberns section in the study area suggests a possible tidal channel origin. The comparability of these sandstone signatures with documented signatures of tidal and channel sandstones (Galloway and Brown, 1972; Selley, 1978; Merkel, 1979; and Weimar, Howard and Lindsay, 1981) suggests a similar depositional origin.

Studies on ancient tidal sandstones by Swett, Klein and Smit (1971), Klein (1973), Jansa (1975) and King and Chafetz (1983) based their tidal origin on sedimentary structures and sandstone textures that were similar to the ones observed in this study. It appears that the Wilberns Formation in west-central Texas is the result of extensive tidal flat deposition in view of the following facts.

Tidal channel deposits are the most likely tidal flat deposit to be preserved in the rock record since they are accumulated on the subtidal portion of the tidal flat. A thin veneer of intertidal flat shale may be deposited on top of a tidal channel deposit and, if preserved, may account for the thin shale breaks observed on the electric log signature of the Wilberns sandstone units. Tidal channels are very dynamic and shift their positions constantly through time, depositing appreciable amounts of sand onto the tidal flat. Thickness of the channel sands is directly related to depth of the channels. In the North Sea tidal flats on the German coast, tidal channels may scour to depths of 45 feet (Weimar, Howard and Lindsay, 1981).

All of these characteristics of tidal channel deposition can easily explain the dominance of sandstone units, the thin shale breaks, the thickness of sandstones, and the widespread nature of the sandstone units within the Wilberns Formation. Therefore, it is postulated that the Wilberns Formation of west-central Texas was accumulated on a tidal flat of broad expanse and relatively low relief similar to the present day tidal flats along the North Sea coast of Germany.

By the end of Cambrian time most of the source for the sediments (Texas Craton) was leveled off and with the start of the transgression marking the beginning of early Ordovician time carbonate deposition prevailed (Lockman-Balk, 1973). The dolomitic facies noted in the uppermost part of the Wilberns probably represents the transition from upper Cambrian clastic deposition to lower Ordovician carbonate deposition.

STRUCTURAL EVOLUTION

Tectonic Setting

Establishment of the structures affecting the Wilberns Formation in west-central Texas occurred as a result of the complex tectonic regime that occupied this area from late Mississippian well into Permian time. The driving mechanism behind all of this activity was probably the Quachita Orogeny which resulted from closing of the proto-Atlantic by collision of the North and South American plates.

Regional features in the study area that were formed in response to the plate collision are the Fort Chadbourne fault system, Concho arch, and the eastern portion of the Midland basin and the northern portion of the Val Verde basin (Fig. 11). The Concho arch is part of the stable region between the Fort Worth basin to the east and the Midland basin to the west (Rall and Rall, 1958). The truncation of the Ellenburger Group along the Concho arch suggests that initial uplift occurred soon after Ordovician time with subsidence of the arch taking place during late Pennsylvanian time (Cheney and Goss, 1952).

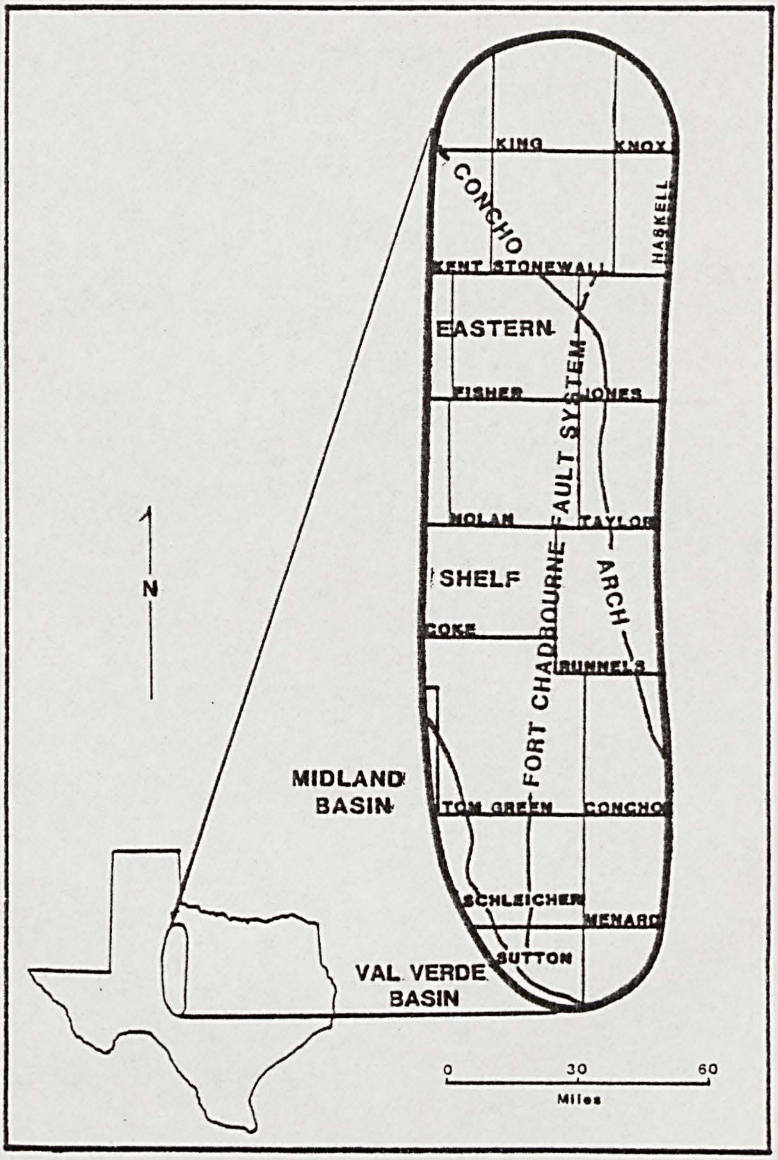


Fig. 11. Tectonic features within the study area. Structures of major importance in this study are found along the Fort Chadbourne fault system.

The Midland basin began downwarping rapidly during middle and late Pennsylvanian time (Rall and Rall, 1958). Between the Midland basin and Concho arch existed the broad and shallow eastern shelf. The shelf-slope break into the Midland and Val Verde basins is expressed by the tightening of contour lines as shown on Plates 3 and 4.

All of these features involve warping of the Cambrian section in some way except for the Fort Chadbourne fault system which cuts through the Cambrian strata. The rest of this discussion is dedicated to describing and defining the nature of this fault system.

Fort Chadbourne Fault System

Counselman (1954) first described this fault system as a narrow zone of deformation extending well over 100 miles north to south from northeastern Jones County southward into Sutton County. The faults are found mostly to the west of the Concho arch. In northeastern Jones County the Fort Chadbourne fault system crosses the Concho arch. Northwestward of this intersection, faults affecting lower Paleozoic strata are oriented in a more east-west direction (Pls. 2, 3 and 4) and were probably influenced by the structuring that formed the Matador and Red River uplifts to the north (Tompkins, 1960).

Movement along the Fort Chadbourne fault system may have been initiated as early as Silurian time, although major movement did not occur until early (Atokan) Pennsylvanian time. Lack of upper Mississippian and lower Pennsylvanian sediments on the upthrown side of the faults substantiates the timing of movement mentioned. The presence of the Caddo Limestone (lower Strawn) lying directly on top of the truncated surfaces of the upthrown side of the faults suggests a decrease in the intensity of uplift. Minor reactivation of these deep seated faults during the later part of Strawn time and well into Canyon time caused low anticlinal folds to be formed in these strata. Movement along the Fort Chadbourne fault system ceased in Permian time (Conselman, 1954).

Type of Structures

The Fort Chadbourne fault system is made up of extremely high angled faults with anticlines and minor elements associated with the structural trend. Observations on the characteristics of these structures will assist in determining the origin of the Fort Chadbourne fault system.

High Angle Faults. The faults comprising the Fort Chadbourne system are of a high angled nature and occur as en echelon features along a linear zone trending essentially north to south from northeastern Nolan County to central Sutton County (Pl. 4). The fault planes are believed to be nearly vertical because none of the many wells drilled along this zone are known to have cut a fault (Sels, pers. comm.). The west sides of the major faults are upthrown and vertical displacement ranges between 400 to 800 feet throughout most of the fault trend. On both the structure contour maps and structural cross sections, faults are shown to have inferred lateral movement. The reason for this will be discussed later in this section.

Anticlines. Along the west side of each fault within the Fort Chadbourne system there occurs an accompanying anticlinal structure. Each anticline appears to have been cut obliquely by the high angle fault. The folds are in en echelon arrangement and are shown to have an axial trend of north-northeast through this narrow zone of deformation.

Conselman (1954) and Parrott (1976) both show the presence of minor fault slices and down-dropped wedges that appear to have sheared the upthrown sides of the faults and are oriented at acute angles to the main trend.

Structural Origin

The problem of determining the structural regime in which the Fort Chadbourne fault system formed has not been adequately explained. The reason for this is a lack of available seismic data from the area and because very few studies have dealt with the Fort Chadbourne system. In view of the structural information presented in this study it is proposed that the Fort Chadbourne fault system formed as a result of wrench fault deformation. The following evidence is given to substantiate this proposal.

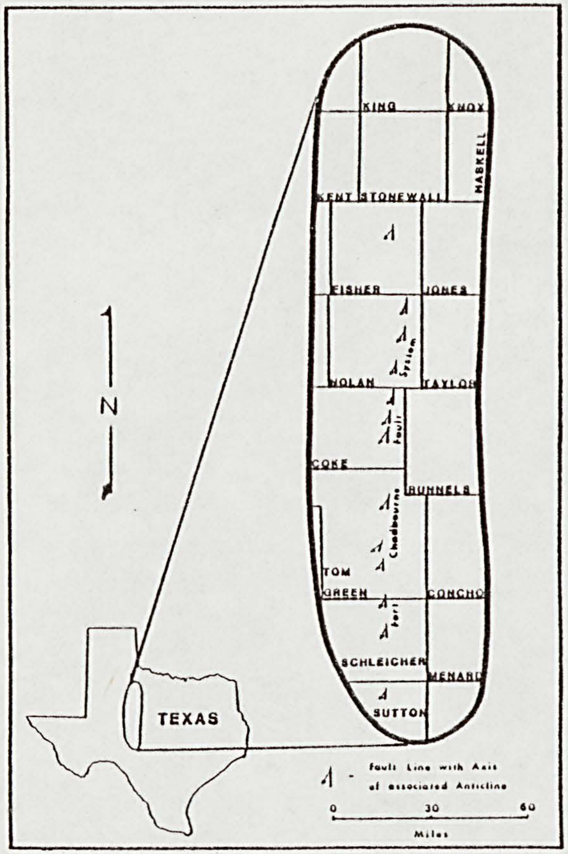
The most supportive evidence in favor of a wrench system origin is the presence of the en echelon folds which are cut obliquely by left lateral en echelon faults. These en echelon structures occur along a linear zone that extends for over 100 miles north-south. Wilcox, Harding and Seely (1973) showed en echelon folds to be important features in early wrench development and with continued wrenching en echelon strike-slip faults will cut the folds. En echelon structures confined to a persistent linear zone are considered to be characteristic of wrenching, especially in cases where lateral offset data is not available, as in this study (Harding and Lowell, 1979).

The minor faults oriented to the southwest at acute angles to the main fault trend are similar to the horst and graben slices associated with the en echelon folds of the Newport-Inglewood wrench zone in California (Harding, 1973).

The interpretation of normal movement along the main faults of the Fort Chadbourne system (Pls. 6, 7 and 8) is not entirely in opposition to a wrench system origin. The high angled nature of the faults are characteristic of strike-slip faults, and normal and reverse displacements are common along the high angle fault planes of strike-slip faults (Harding, 1973 and Wilcox, Harding and Seely, 1973). The high angle of the Fort Chadbourne fault planes may also be explained by the speculation that these faults are formed by reactivation of planes of weakness along a late Precambrian upwarp (Holmquist, 1955). These zones of weakness within the late Precambrian basement may have been formed as a result of rifting. When reactivated in middle to late Paleozoic time these old rifts resulted in high angle faults with normal movement and horizontal movement developed due to the influence of the wrenching that occurred during this time. This may explain the basement involvement observed along the Fort Chadbourne fault system as shown in Plate 2 and mentioned in Conselman (1954).

The final consideration is whether or not a wrench system such as the one proposed, could have developed under the tectonic conditions which prevailed during the time of the development of the Fort Chadbourne fault system. During the suturing of the North and South American plates, convergence was from the southeast as shown by Thomas (1977). Knowing the direction of compressional force (convergence), which gave rise to the structures formed within the study area, the strain ellipsoid for a left lateral wrench system (Fig. 12) can be applied. This shows the similarity in alignment of the faults and folds along the Fort Chadbourne system with those of a hypothetical left lateral wrench system.

There are problems in interpreting a left lateral wrench fault origin to the Ford Chadbourne fault system. Lack of en enchelon folds on the eastern side of the fault zone and the alignment of some faults and folds along the zone of deformation are not totally consistent with structures anticipated in the classical strike-slip model under the proposed regional tectonic setting (Fig. 12). These apparent inconsistencies may result from the regional approach used in this study; therefore, it is suggested that future studies be made of smaller areas within this region, utilizing all well control and mapping individual structures in detail. Such an approach



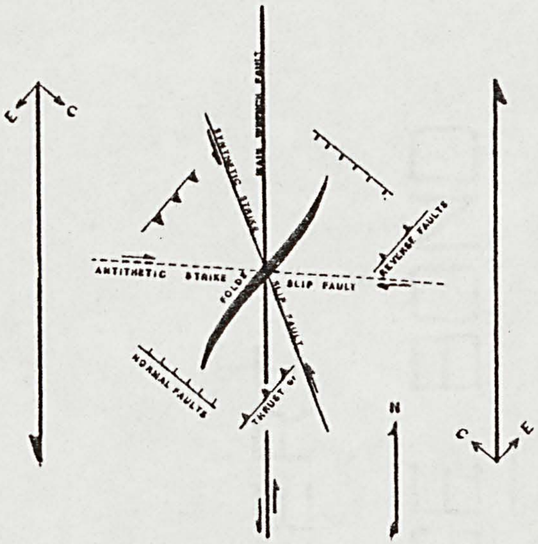


Fig. 12. Comparison showing the similarity in alignment the faults and associated anticlines of the Fort Chadbourne fault system (left) have with the same structures produced in a left lateral wrench fault system model as a result of compression from the southeast (right, After Harding, 1974).

would yield more accurate orientations of the individual structural features. Also, if seismic sections along the Fort Chadbourne fault system were made available for study, the direction of dip of the high angle fault planes might be better understood and such a differentiation of strike slip, normal, and reverse faults would more closely control the orientations of the strain ellipsoid.

The Fort Chadbourne fault system formed on the Texas recess which was a tectonically stable area located between the highly deformed Ouachita salient to the north and Marathon salient to the south. Since the sedimentary rocks on the Texas recess are more competent than the thick basinal sediments found in the salients, compression of the rocks in the study area resulted in narrow belts of deformation with basement involvement (Thomas, 1977). Therefore, it is probable that the narrow zone of left lateral wrench fault deformation comprising the Fort Chadbourne system evolved from the tectonic conditions which prevailed during late Paleozoic time.

PETROLEUM POTENTIAL

Introduction

The Wilberns Formation is productive of hydrocarbons within the study area. More specifically, the only hydrocarbon accumulations produced out of the Wilberns in this area occur locally along the trend of en echelon folds of the Fort Chadbourne fault system (Pl. 3). It appears that post-depositional faulting has enhanced the overall reservoir potential of the sandstones within the Wilberns Formation of west-central Texas.

In this portion of the study, diagenetic features of upper units of the Wilberns sandstones are described. This information suggests a viable paragenesis of the sandstones which will account for their reservoir potential. Also, the nature of the hydrocarbon production from the Wilberns in proven fields will be considered.

Sandstone Composition

Thin sections of the upper sandstone unit within the Wilberns reveal that they are composed of mostly quartz grains with small amounts of feldspar and rock fragments. The majority of grains are well rounded and the overall sorting is moderately good. The quartz grains are mostly monocrystalline. Microcline is the dominant feldspar observed. Chert, igneous and metamorphic fragments make up the rock fragments found in the sandstones (Fig. 13a).

Cementing Materials

Secondary Quartz

The most common cementing agent in the upper sandstone unit of the Wilberns Formation is quartz overgrowths. These overgrowths are detected by use of "dust" lines marking boundaries between quartz grain and overgrowth, concavo-convex nature of quartz grain contacts with adjacent quartz grains and euhedral nature of some quartz grains (Fig. 13b).

Dolomite

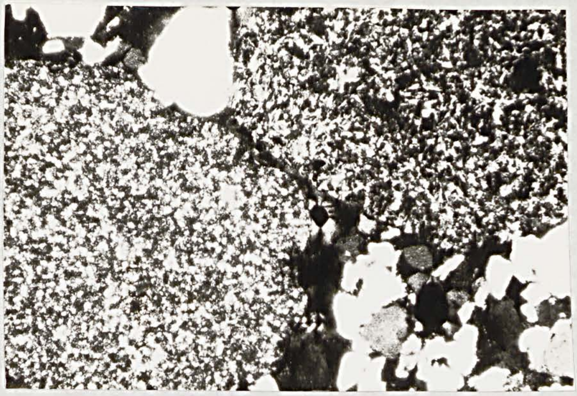
Staining of hand samples of the sandstone with potassium ferricyanide revealed the presence of ferroan dolomite cement in certain areas. Thin section observation showed the dolomite cement to be poikilotopic (Fig. 13c). In some places a fine grained dolomitic matrix separates quartz grains from each other (Fig. 14a). This

Fig. 13a. U.S. Mining T.X.L. "A" #3, Nolan County (6144 feet).
Photomicrograph of a chert rock fragment (lower left) and an igneous rock fragment (upper right) (crossed nicols, 75X).

Fig. 13b. Humble #1 W.C.S.L., Tom Green County (6096 feet).
Photomicrograph of well developed quartz overgrowths. This figure shows quartz grain (a) and overgrowth (b) separated by a "dust" line. Concavo-convex overgrowth contacts (c) are formed where adjacent overgrowths run together (plane light, 75X).

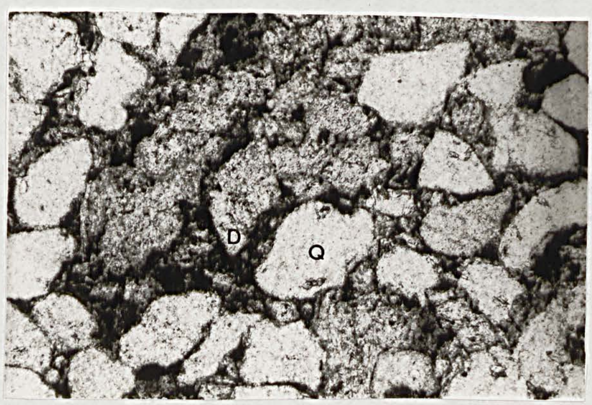
Fig. 13c. U.S. Mining T.X.L. "A" #3, Nolan County (6144 feet).
Photomicrograph of poikilotopic dolomite cement (D) in contact with and surrounding quartz grains (Q) (plane light, 75X).

Figure 13



a

b



c

microcrystalline dolomite may be a syndepositional constitutent of the sandstones.

Hematite

A reddish to dark opaque mineral present in the sandstones is believed to be hematite. It acts as a pore lining in some areas and completely infills porosity in other areas (Fig. 15a). In some cases even the poikilotopic dolomite cement is stained slightly red by hematite.

Clays

Authigenic clays are found as pore linings and plugs. Attempts to identify these clay minerals by use of X-ray diffraction methods provided inconclusive results.

Pyrite

Minute amounts of pyrite are present as pore filling material within the sandstones.

Porosity

Porosity in the Wilberns upper sandstone unit is almost completely secondary and ranges from less than 1% to 15.5% in the various sandstone samples observed. Dissolution of grains appears to be the cause of the secondary porosity. Features of dissolution (Schmidt and

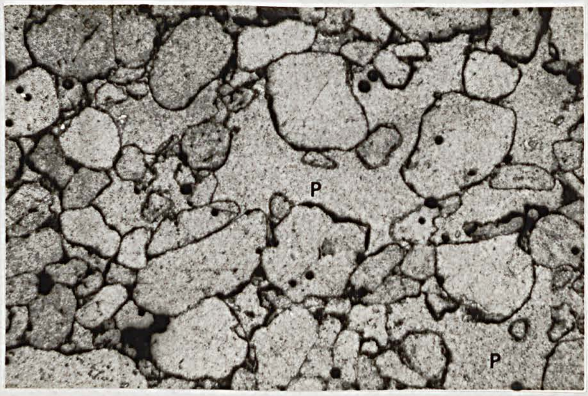
Fig. 14a. General Crude #1 Cave, Nolan County (6601 feet).
Photomicrograph of a contact between sand with a microcrystalline dolomitic matrix and sand free of matrix (plane light, 28X).

Fig. 14b. and c. Humble #1 W.C.S.L., Tom Green County (6086 and 6097 feet).
Both photomicrographs show the type of secondary porosity developed in the sandstone facies of the Wilberns Formation. Oversized pore space (P) and grains that appear to be "floating" in the pore are features of dissolution (plane light, 28X).

Figure 14

a

b



c

Fig. 15a. Humble #1 W.C.S.L., Tom Green County (6086 feet).
Photomicrograph of secondary porosity (P) which is in part infilled by opaque hematitic material (plane light, 28X).

Fig. 15b. U.S. Mining T.X.L. "A" #3, Nolan County (6147 feet).
Photomicrograph of remnant primary porosity (P) which has not been completely destroyed by compaction and quartz overgrowth development (plane light, 28X).

Figure 15

a

b

McDonald, 1979) found in the sandstone units are the oversized nature of the pore space and the presence of "floating" quartz grains observed in the pores (Fig. 14b and c). A possible example of remnant intergranular primary porosity is shown in Figure 15b. This is believed to be remnant primary porosity because of the small size of the pore spaces which appear to be almost completely choked off by euhedral quartz overgrowths.

Paragenesis

After initial deposition, the upper sandstone unit of the Wilberns Formation appears to have experienced at least four separate diagenetic events. Each event is a result of chemical changes that occur within the formation waters through time, due to mixing. Since most rock forming minerals, especially silicates and carbonates, are sensitive to change in pH (Walker, 1962; Runnels, 1969 and Friedman, 1975) the four different diagenetic stages have been plotted on a pH/solubility graph for quartz and calcite as shown on Figure 16. This gives a general feeling for the condition of the formation waters during each stage.

First Stage. The first stage is marked by the beginning of quartz overgrowths. Most of the overgrowths

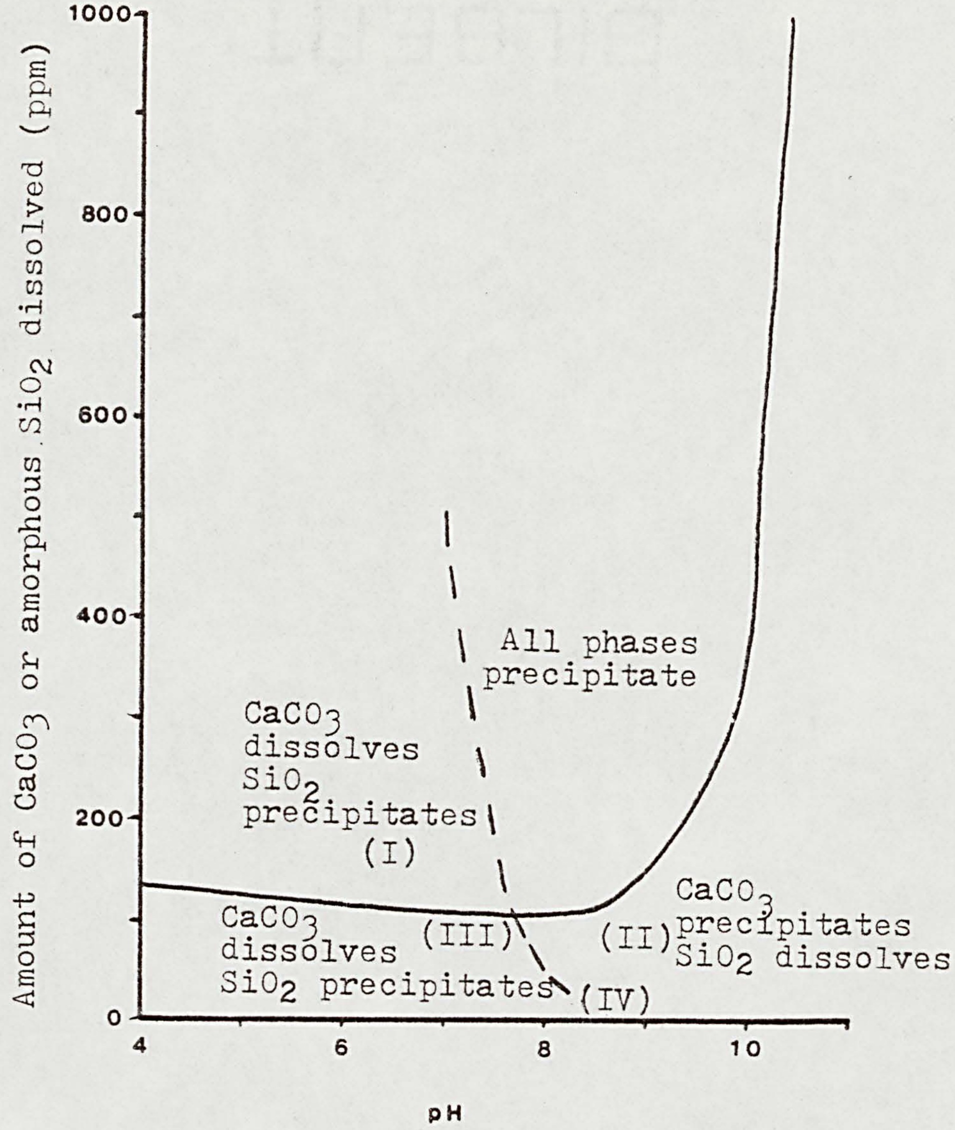


Fig. 16. Graphic representation of solubility of $CaCO_3$ and SiO_2 in water (25°C) with respect to pH. The solid line is the SiO_2 solubility curve and the dashed line is the $CaCO_3$ solubility curve. Roman numerals (I-IV) represent the formation water conditions believed to have been prevalent during each of the four diagenetic stages experienced by the Wilberns sandstone facies (Graph after Friedman, 1975).

are well developed and many are euhedral to subhedral. This suggests that the quartz overgrowths were developed in acidic formation waters having a high concentration of silica ions. The lack of any materials inhibiting quartz overgrowth development suggests conditions were continuous until the next diagenetic phase.

Second Stage. Precipitation of dolomitic cement occurred during the second diagenetic stage. The poikilotopic dolomite cement formed in direct contact with the quartz grains and overgrowths of the first stage and for this reason is believed to have directly followed the precipitation of quartz overgrowths stage. The precipitation of poikilotopic dolomite cement into remaining pore spaces suggests a change in formation waters from acidic to basic. The origin of calcium ions may have been from the microcrystalline dolomitic material initially deposited with the sandstone in some places or from downward percolating waters from the overlying Ellenburger carbonates.

Third Stage. Extensive uplift along the Fort Chadbourne fault system leads to the beginning of the third diagenetic stage. During this period the sandstone units on the upthrown sides of the faults were very close to the surface and even exposed in areas of extreme uplift (Pl. 4). In this position the sandstones were exposed to the downward percolation of meteroric waters. These slightly acidic waters dissolved varying amounts of the calcareous cement and matrix, leaving behind oversized pore spaces (Schmidt and McDonald, 1979).

Fourth Stage. Stage four began sometime after movement of the fault system ceased and upper Paleozoic sediments covered the tops of the uplifted areas. During this stage hematite, pyrite and possibly authigenic clay minerals precipitated and lined or completely filled some of the newly formed pore spaces. In some cases during this stage hydrocarbon migration into the porous sandstone unit may have occurred. This would have limited the precipitation of minerals within the pore spaces in a manner similar to that described by Webb (1974) where the presence of hydrocarbons in Cretaceous sandstones in Wyoming appear to have inhibited authigenic clay growth.

Reservoir Potential

The reservoir potential of the Wilberns sandstones is a function of the extent of dissolution porosity formed. Since this type of porosity developed during stage three of the paragenetic sequence, two factors undoubtedly influenced the amount of dissolution porosity developed. This would have a direct effect on the reservoir quality of the sandstone.

First, the amount of dolomite cement or matrix present within the sandstone unit is important because it will have an effect on the permeability developed after dissolution. If the calcareous material is interconnected within the sandstone, then the porosity developed upon dissolution will be interconnected, resulting in the development of good permeability. Alternately, poor permeability will result from the dissolution of isolated calcareous material, leaving isolated pore spaces (Pittman, 1979). The interconnection of dolomite cement or matrix predominantes within the upper Wilberns (Fig. 13c and 14a), which after dissolution may produce oversized pores with "floating" grains (Fig. 14 a, b).

The other factor controlling the dissolution porosity developed in this case is the tectonic position of the sandstone unit and the duration of exposure in that position. For example, if the sandstone unit is in a position whereby it is on the upthrown side of a fault and/or on the crestal portion of the associated anticlinal structure, the chances of developing extensive dissolution porosity are good because the sandstone is almost certain to be exposed to surface conditions in this position. In contrast, the same sandstone unit placed in a structurally stable position may not develop dissolution porosity as extensively, if at all.

Both of these factors indicate the importance of the depositional history and later structural history of a sandstone in determining its potential as a hydrocarbon reservoir. Therefore, sandstone units of the Wilberns Formation that have been affected by the faulting and folding associated with the Fort Chadbourne fault system, such as the sandstones described in this study, appear to have excellent reservoir potential. This is supported by the evidence that various wells penetrating these sandstone units along the Fort Chadbourne fault system have produced significant amounts of hydrocarbons.

Average Cambrian production information (Fig. 17) was determined by use of data provided by Neff (1954), Hoffacker (1960) and Parrott (1976) from White Flat, Hylton Northwest and Dora North fields in Nolan County and from sparse scout tickets of wells producing from the Cambrian. It is speculated here that the hydrocarbons within the Wilberns sandstone reservoirs were sourced from an overlying Pennsylvanian unit. During Fort Chadbourne faulting, the Wilberns Formation was placed adjacent to or slightly updip from this younger source rock and hydrocarbons migrated updip along the fault plane into the sandstone reservoir. Galley (1958) believed

IP = 628 BOPD

GRAVITY = 49.6° API

GOR = 845:1

RANGE OF DEPTH TO TOP OF PAY = 5530′-6161′

Fig. 17. Average production information for the Wilberns Formation along the Fort Chadbourne fault system in Nolan and Coke Counties.

that the source for the upper Cambrian oil production in this area was from Ordovician and Pennsylvanian strata on the eastern flank of the Midland Basin. This is viable speculation because the anticlinal features are cut by faults to the east and die out to the west making it possible for hydrocarbons generated from younger rocks to migrate updip into the older Cambrian strata at the crest of the fold. Both of these migration paths are shown in Figure 18. Again this emphasizes that Cambrian production in the study area is chiefly, if not totally, controlled by the structures created during the development of the Fort Chadbourne fault system.

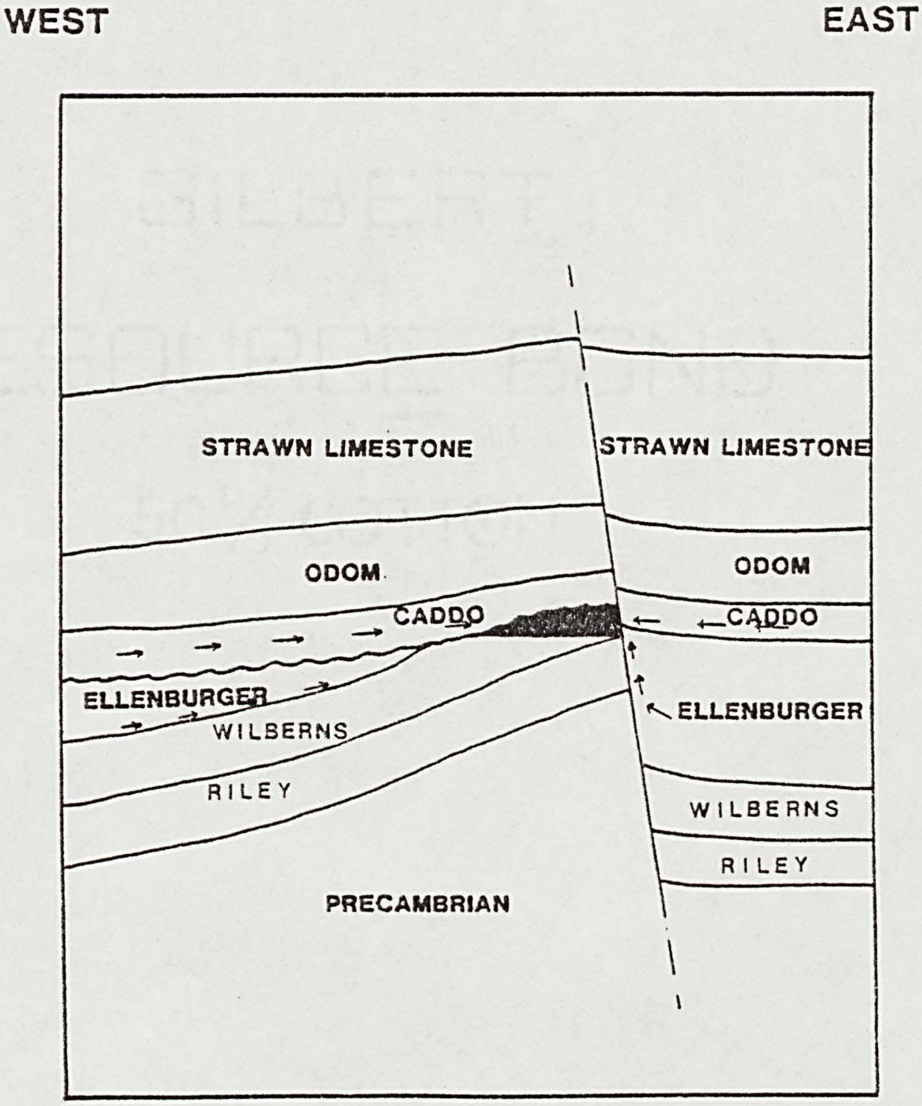


Fig. 18. Diagrammatic representation of the probable hydrocarbon migration pathways into the Wilberns reservoirs from younger source rocks. Migration paths are shown by arrows and the hydrocarbons are shown to be sourced from the Ellenburger (lower Ordovician) and Caddo (middle Pennsylvanian) units.

CONCLUSIONS

1. Electric log information shows that the sandstone units of the Wilberns Formation are persistent throughout the study area and pinch out onto the Precambrian surface to the west and northwest of the study area.

2. A sandstone facies and dolomitic facies are found in the core samples of the upper portion of the Wilberns Formation.

3. The sandstone facies is mostly made up of quartz arenites and sublitharenites with minor shale breaks; the dolomitic facies is composed of granular dolomite.

4. The presence of foreset beds, flaser and lenticular bedding, *Skolithos* burrows, nodules, and flat pebble conglomerates within the upper portion of the Wilberns suggests deposition on a tidal flat. The electric log signature of the Wilberns sandstone units is similar to signatures produced by channel and tidal sand bodies. The sandstone units belonging to the Wilberns Formation in west-central Texas are probably the result of clastic sedimentation on a broad tidal flat upon which an extensive network of tidal channels served as the transporting pathway. Upper Cambrian clastic deposition in this area gradually gave way to Lower Ordovician carbonate deposition and this transition is represented by the dolomitic facies.

5. The Fort Chadbourne fault system is a linear zone of deformation composed of northward trending en echelon high angle faults which obliquely cut through north to northeastward trending en echelon folds.

6. The alignment of the en echelon structures of the Fort Chadbourne system suggests they were produced from a left lateral wrench system which formed as a result of the compressional forces generated during the Ouachita orogeny.

7. Hydrocarbon production from the Wilberns Formation is restricted to the linear trend of the Fort Chadbourne fault system.

8. The upper sandstone unit of the Wilberns Formation appears to have undergone four distinct diagenetic stages. The paragenesis consists of an early phase of quartz overgrowth development followed by a phase of precipitation of dolomite cement. Uplift by the sandstone along the Fort Chadbourne trend caused dissolution of calcareous material, creating secondary porosity. The final stage gave rise to the precipitation of hematite, pyrite and authigenic clays which line and fill pore spaces in some areas.

9. Reservoir potential of the Wilberns sandstone units depends on the interconnection of secondary pore space for good permeability and the extent to which the units were exposed to uplift along the Fort Chadbourne fault system so as to develop secondary porosity.

10. Younger overlying strata are believed to be the source for the hydrocarbons produced from the Cambrian sandstone reservoirs. One possible path is migration updip along the main fault plane from younger sediments on the downthrown side to the east. The other path may have been migration updip from the west into the closure formed by the en echelon folds.

11. Further exploration should be concentrated along the linear Fort Chadbourne system with emphasis on finding small scale structures that are commonly associated with wrench faulting.

APPENDIX I

Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Coke	1	Sun Oil Company	#1 Millican	2014	7826
	2	Union Oil Company	#1 McCutcheon	1921	6742
	3	Humble Oil Company	#1 Weaver	2180	6987
	4	Humble Oil Company	#F-90 Odom	2042	6350
	5	M & M Production Company	#1 Luttrell	1847	6010
	6	Humble Oil Company	#3 Butner	1901	5611
	7	Hickok & Reynolds	#1 Warren	1821	5530
	8	Hickok & Reynolds	#1 Rawlings	1831	5802
	9	Gulf Oil Corp.	#1-A Simpson	2226	7532
	10	Amerada Petroleum	#1 March Ranch	2338	7454
	11	Katz Exploration	#1 Copeland	2154	7047
	12	Stanolind Oil Company	#1 Nicholas	2091	6906
	13	Humble Oil Company	#10 Odom	2039	6712
	14	Murray Petroleum	#1 Nora Gee	2614	8341
	15	Norsworthy	#1 Mims	2457	8005
	16	Richard King	#1 Counts	2173	7353
Concho	1	Union Oil Company	#1 Campbell	1717	5850
	2	Progress Petroleum	#2 Speck	1983	4367
	3	Belcher	#1-A Loveless	2000	3592
	4	Holland Oil	#1 Hartgrove	1650	3797
	5	Eltex	#1 Roberts	1980	4070

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Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Concho	6	Wooley	#1 Sims	1694	4283
Dickens	1	Livermore	#1 Bird	2551	8384
	2	Placid Oil Company	#1 Goen	2744	8468
	3	Humble Oil Company	#1-G Matador	2741	8248
	4	Placid Oil Company	#1 Hughes	2311	7949
	5	Humble Oil Company	#3 Matador	2404	7737
	6	Humble Oil Company	#2-F Matador	2196	7538
	7	Norsworthy	#1 Burleson	2027	7511
	8	National Assoc. Petroleum	#1 Blackwell	2912	8387
Fisher	1	Lion Oil Company	#1 Lanning	1953	6156
	2	Gulf Oil Corp.	#1 Roberts	2130	7381
	3	Texas Crude Oil Company	#1 Cochran	2147	7379
	4	Humble Oil Company	#1 Crowley	1964	7084
	5	Norsworthy	#1 Cave	2115	7127
	6	Norsworthy	#1 Park	2072	7106
	7	Mid-Continent	#1 Leeper	2116	7010
	8	Lloyd Smith, Inc.	#1 Rives	1992	6875
	9	Texas Pacific	#1 Johnson	1782	6375
	11	General Crude	#1 Parker	1948	7015
	12	General Crude	#12 Flannigan	1808	6746
	13	Texaco	#1-C Stevens	1924	6315

APPENDIX I Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Fisher	14	General Crude	#1 Akins	2227	7508
	15	Lion Oil Company	#1 Huddleson	1973	5942
	16	Sojourner Drilling Company	#1 Deere	1847	6269
	17	Tex-Harvey Oil Company	#1 Dozier	1916	6391
	18	R. L. Adkins	#1 Floyd	1906	6110
	19	HLH Petroleum	#13-1 Shipley	1911	6084
	20	Joseph O'Neill	#10-1 Harvey	2119	6732
Haskell	1	Woodward	#1 Campbell	1395	5798
	2	Hunter Estate	#1 Christian	1479	6120
	3	Van-Grisso Oil Company	#1 Adkins	1636	6461
	4	McLean, et. al.	#1 Lambert	1632	6161
	5	Evans Production Company	#1 Scott Estate	1473	5332
	6	Danciger Oil	#8 Bogard	1628	6335
	7	Skelly Oil Company	#1 Stewart	1462	5821
	8	Originala Petroleum Corp.	#1 Avis	1655	7018
Irion	1	Atlantic Refining Co.	#1 Noelke	2326	7657
	2	Shell Oil Company	#1 Tankersley Estate	2333	8357
Jones	1	Rhodes Drilling Company	#1 Reddin	1857	6010
	2	Davis Drilling Company	#1 Wagstaff Estate	1852	6048
	3	Crown Central Petroleum	#14 Brown	1852	5851
	4	Buchanan, et. al.	#1 Swann	1924	5927

APPENDIX I Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Jones	5	Paul C. Teas	#1 Brothers	1886	6120
	6	J. C. Hunter	#1-C Minter	1664	5470
	7	Miami Operating Company	#1 Gregory	1816	6086
	8	Walsh & Watts	#6 Canon	1796	5848
	9	Paul C. Teas	#3 Fleming	1888	6241
Kent	1	Superior Oil Company	#8-194 Wood	2165	7907
	2	General Crude	#1-82 Jones	2151	7685
	3	General Crude	#1 Jones	2036	7589
	4	Slick-Moorman	#1 Wallace	2183	7787
	5	Hamon	#1 Girard Trust	2163	7763
	6	Welch Estate	#1Sorelle	1984	7125
	7	Sun Oil Company	#1-A Wallace	2093	7318
	8	Ralph Lowe	#1 Frost	2174	7445
	9	Big Spring Exploration	#1 Hardin	1932	7151
Kimble	1	Humble Oil Company	#1 Woodward	2112	3027
	2	Irwin	#1 Kothman	2193	3963
King	1	Continental Oil Company	#1 Martin	1847	7173
	2	Helmerich & Payne	#1 Gillespie	1796	6802
	3	Gulf Oil Company	#1 Masterson Estate	1758	6647
	4	Superior Oil Company	#2 Pitchfork	2024	7045
	5	Humble Oil Company	#1 Ross	1772	6600

APPENDIX I

Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
King	6	Frank Wood	#1 Parramore	1737	6603
	7	The Ohio Oil Company	#1 Pitchfork	1945	6976
	8	The Ohio Oil Company	#1 Burnett Estate	1846	6438
	9	McAlester	#1 McGee	1965	6843
	10	Youngblood & Youngblood	#1 Martin	1752	6680
	11	Humble Oil Company	#43 Bateman Estate	1723	6635
	12	Humble Oil Company	#70 Bateman Estate	1781	6325
Knox	1	Skelly Oil Company	#1 Price	1469	6928
	2	Seaboard Oil Company	#1 Big Four Ranch	1650	7039
	3	Roark, Hooker & Hill	#1 Alexander Estate	1432	6296
	4	Union Oil Company	#1 Beavers Estate	1480	6518
	5	Tom Medders	#1 Davis	1404	6440
Menard	1	Wayne Allison	#1-A Volkmann	2320	4344
	2	Naylor Oil Company	#1 Nasworthy	2323	3893
	4	King Resources	#1 Murr	2395	4317
	5	Deep Rock Oil Corp.	#1 Bevans	2218	5149
	6	American Republic	#1 Bradford	2054	2743
	7	Phillips Petroleum	#1 Meta	2035	3947
	8	Tucker Drilling Company	#2 Rogers	2313	4610
Mitchell	1	Humble Oil Company	#1 Pratt	2293	8127
	2	Great Western Drilling	#1 Baumann	2264	7856
	3	Sun Oil Company	#2 Ellwood	2122	8655

APPENDIX I Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Nolan	1	Skelly Oil Company	#1 Bradberry	2350	6913
	2	Norsworthy	#1 Jordan	2211	6953
	3	Honolulu Oil Company	#2 Spires	2594	7625
	4	Sun Oil Company	#1 Everett	2200	6937
	5	Sun Oil Company	#1 Cooper	2280	7395
	6	Gem Oil Company	#1 Howard	2316	7383
	7	Moore & Moore Drilling	#1 Lee	2493	6501
	8	Skelly Oil Company	#1 Cooper	2385	7360
	9	Choya Drilling Company	#1 Wimberly	2413	7666
	10	Fisher-Webb	#1 Norris	2403	7176
	11	Suburban Propane Gas Corp.	#1 Pierce	2602	6969
	12	Dow Chemical Company	#1 Hughes	2342	7164
	13	Superior Oil Company	#4-30 Kinard	2370	7011
	14	American Trading Company	#1 Little	2004	5696
	15	Hunt Oil Company	#1-44 Boyd	2524	7079
	16	U.S. Smelting and Refining	T.X.L. "A" #3	2490	6159
	17	Lebus-Warner & Luttrell	#1 Wimberley	2513	7008
	18	General Crude	#1 Cave	2523	6612
	19	Kilroy Company	#1 Roberts	2504	6120
	20	Seaboard Oil Corp.	#1 Earwood	2408	6890
	21	Champlin Petroleum Company	#1 Sears-Boyd	2446	6598

APPENDIX I

Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Runnels	1	Western Drilling Company	#1 Gross	1755	5432
	2	Gulf Oil Company	#1 Puckett	2039	5846
	3	Richardson & Bass	#1 Cook	1765	6315
	4	Superior Oil Company	#1 McDowell	1900	6307
	5	N. P. Powell	#A-8 Odom	1952	6205
	6	Western Drilling Company	#1 Smith	1817	5737
	7	American Trading Company	#1 McShan	1709	4583
	8	Slick Oil Company	#1 Mabee	1729	5038
	9	Slick Oil Company	#1 Gulley	1725	4916
Schleicher	1	Taylor Oil & Gas Company	#1 Judkins	2218	6620
	2	Continental Oil Company	#1 Moore	2514	8616
	3	Stanolind Oil Company	#1 Hill	2412	8202
	4	Hunt Oil Company	#1 King	2376	6101
	5	Stanolind Oil Company	#1 Williams	2511	8090
	6	Sinclair Oil Company	#1 McLatchy	2237	7420
	7	Humble Oil Company	#1 Stanford	2447	9029
	8	Stanolind Oil Company	#1 West	2461	8214
	9	R. W. Berry	#1 Thomerson	2412	5751
	10	Atlantic Richfield Company	#1 Roberts	2405	7741
	11	Taylor Oil & Gas Company	#1 Webster	2311	5597
	12	Geo. E. Day	#1 McBurnett	2276	6363

APPENDIX I

Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Schleicher	13	Abercrombie	#1 Meador	2506	8196
	14	J. A. Chapman	#1 Robinson	2317	6512
	15	Ralph Lowe	#1 Reynolds	2376	6051
	16	Norsworthy	#1-A Powell	2244	5135
	17	J. S. Woodward	#1 Thomson Estate	2383	7191
	18	Delta Gulf Drilling	#1 Boyd	2328	5255
Stonewall	1	Continental Oil Company	#1 Nichols	2002	7108
	2	McLean & Tompkins	#1-A Trammel	1671	5928
	3	Norsworthy	#1 Green	1725	6707
	4	Norsworthy	#1 Craft	1724	6697
	5	Sun Oil Company	#1 Branch	1869	6951
	6	Honolulu Oil Corp.	#1 Baugh	1893	6902
	7	Humphrey & Sons	#1 Gibson	1928	7028
	8	Continental Oil Company	#1 Springer	1915	6940
	9	Hamon	#1 Harris Hospital	1987	6860
	10	Texas Pacific	#1 Winters	1828	6604
	11	Continental Oil Company	#1 Carothers	1686	6685
	12	Rancho Oil Company	#1 Gholson	1616	6685
	13	American Trading Company	#1 Lindhorst	1838	6900
	14	Kimball Production Company	#1-203	1747	6912
	15	Riddle Oil Company	#1 Patterson	1777	6578

APPENDIX I

Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Stonewall	16	Rowan & Hope	#1 Berry	1747	6704
	17	Johnson	#1 Brinkley	1705	6462
	18	Mizel	#1 Henson	1837	6000
	19	Kadane and Sons	#1 Peacock	1766	6713
Sutton	1	Skelly Oil Company	#1 Reiley	2457	5557
	2	C.P. Burton	#1 Miers	2254	7845
	3	Humble Oil Company	#2 Mayer	2309	9814
	4	Humble Oil Company	#1 North Branch Gas	2312	7546
	5	Continental Oil Company	#2 Mayer	2127	9844
	6	Sinclair Oil & Gas Company	#1 Mittel	2339	7115
	7	Ralph Lowe	#1 Allison	2326	7919
	8	Hamon & Norsworthy	#1 Meckal	2237	8219
Taylor	1	Humble Oil Company	#1 Norwood	2439	6226
	2	Kirk	#1 Motz	2450	6390
	3	Lion Oil Company	#1 Bartee	2244	6190
	4	Humble Oil Company	#1 Ellinger	2122	6166
Tom Green	1	George Strake	#1-A Rust	1985	5821
	2	Plymouth Oil Company	#2 Green	2153	5660
	3	Texaco	#1 Edwards	1880	5945
	4	Texaco	#1 Garmon	1836	5505
	5	M.E. Davis	#1 Jones	2021	6147

APPENDIX I

Well Names

County	Well Symbol	Operator	Lease	DF (ft)	TD (ft)
Tom Green	6	C.L. McMahon	#1 Johnson	2034	5634
	7	Palmer Oil Company	#1 Oats	1886	5796
	8	Richardson Oil Company	#1 Schwartz	1849	7168
	9	Honolulu Oil Corp.	#1 Nasworthy	1930	7688
	10	Gray Wolf	#1 Field	2203	8091
	11	Stanolind	#1-E Johnson	2103	6974
	12	Skelly Oil Company	#1 Turner	2135	8049
	13	Paul C. Teas	#1 Brown	2055	6123
	14	Shell Oil Company	#1 Johnson	1841	5375
	15	Stanolind	#1 Johnson	2136	5812
	16	Tennessee Production Co.	#1 Hrncir	1901	6601
	17	Humble Oil Company	#1 Washington CSL	1955	6359
	18	Lone Star Production Co.	#1 Feldman	2354	6273
	19	Plymouth Oil Company	#1 Johnson	1889	6348
	20	George Strake	#1-C Winterbotham	2545	8013
	21	Republic Natural Gas	#1 Johnson	2148	6274
	22	Bridwell Oil Company	#1 Robbins	1941	6501
	23	Ohio Oil Company	#1 Bryant	2062	7006
	24	Bridwell Oil Company	#1 Farr	2184	7286

APPENDIX II--CORE DESCRIPTIONS

County	Well Name	Sample	Description
Nolan	U. S. Mining T. X. L. "A" #3	6139-6162	Quartz arenite- gray to reddish tan, fine to medium grained, moderately to well sorted, hematitic and glauconitic, lenticular and flaser bedding, mottling of silt and clay with fine sand, bioturbation zones with _Skolithos_ type burrows, planar and foreset bedding at base of interval.
Nolan	Kilroy Company #1 Roberts	6070-6120	Quartz arenite to sublitharenite- light olive gray, fine to coarse grained, friable, moderately to well sorted, hematite and pyrite sparse, wavy glauconitic laminae, and interbedded argillaceous siltstone exhibiting thin parallel bedding.
Nolan	General Crude #1 Cave	6582-6596	Granular dolomite- gray to tan, yellow mottled zones, vugular, silicified breccia, and flat pebble conglomerate.

APPENDIX II--CORE DESCRIPTIONS

County	Well Name	Sample	Description
Nolan	General Crude #1 Cave	6597-6612	Quartz arenite- light gray to tan, fine to coarse grained, moderately to well sorted, glauconitic shale lens, lenticular and flaser bedding, mottles, nodules, and zones of <u>Skolithos</u> bioturbation.
Tom Green	Humble #1 Washington County School Lands	6079-6084	Silty dolomite- medium gray to light brown, flat pebble conglomerate, mottled, boudinage compaction features, and algal laminations.
		6085-6100	Quartz arenite- light reddish brown, fine to coarse grained, well sorted, hematitic and glauconitic, flaser and lenticular bedding, bioturbated zones, and planar and foreset bedding in lower part of interval.

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