Petroleum Geology

Middle Wilcox Reservoirs

East-Central Louisiana

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June 2007

1. Geology of the Wilds Distributary Channel Complex Wilcox Group

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ABSTRACT

The Wilds delta comprises a subsurface interval deposited during the transgressive systems tract within Paleocene middle Wilcox time. Because of excellent well coverage through this interval in a four township area of east - central Louisiana, precise mapping based on detailed e-log correlations was possible. Net sand mapping has provided a means of recognizing genetic facies architectures within the Wilds delta. A conventional core collected through the distributary channel portion of the Wilds provided the means of measuring the physical parameters within this thick (50' - 130') channel system.

X-ray radiography of selected intervals, thin section petrography, and detailed petrophysical evaluation indicate that channel fills can differ considerably in architecture within one deltaic system. The data show the Wilds distributary channel to consist mainly of subangular to subrounded, very fine to medium sized quartz grains. Occasional siltstones and shales are interbedded within the sandstone layers; the latter contain flaser bedding, planar laminations and rip-up clasts. Porosity within this predominantly sandstone portion of the channel averages 30%, permeability ranges between 91 and 524 md and average 280 md. Only in those intervals of the channel where the grains are totally cemented by calcite cement are the porosities very low (7%) and permeability is totally lacking. Hydrocarbon accumulations within the Wilds interval in central Louisiana is believed to be the function of stratigraphy, manifested in subtle traps sourced through vertical migration pathways.

INTRODUCTION

Numerous sedimentological studies of the modern Mississippi delta (Fisk et al., 1954; Gagliano, 1965; Morgan, 1970; Coleman, 1973; Penland et al., 1988; Coleman and Roberts, 1990), and studies on smaller deltas such as the Atchafalaya (Roberts et al. 1980; Roberts and van Heerden, 1992), are excellent analogs for a comparison with the thin stacked deltas present in the subsurface in the Paleocene Wilcox of east-central Louisiana (Echols, 1991).

Factors such as river regime, coastal processes and climate, which control the depositional processes within the modern deltaic setting, give rise to a variety of sedimentary facies. Since the facies concept is fundamental to understanding the major and minor components of both modern and ancient deltas, the following generalized definition is applicable: "A facies is a restricted stratigraphic unit, or any genetically related sedimentary deposit, which exhibits lithologic, petrographic, structural, or paleontolgical characteristics significantly different from those of another part of the same unit" (Teichert, 1958).

The lower part of a fluvially dominated delta system such as the Mississippi can be divided into: 1) a lower delta plain marsh distributary channel facies consisting of distributary channel sands, overbank/crevasse splay deposits, interdistributary bay muds, bay fill sands and lignites; 2) a delta front facies with its distributary mouth bars, barrier bar sands, shoal sands and lagoonal muds; and 3) a prodelta facies consisting almost entirely of thinly laminated muddy sediments of marine origin.

Paleocene Wilcox Group researchers in Louisiana (Galloway, 1968; Echols, 1991; Glawe, 1993) and in Texas (Fisher and McGowen, 1967; May and Stonecipher, 1990) have described the principal stratigraphic units of Wilcox deltas by using the facies terminology applied for similar stratigraphic units in modern deltaic analogs. In the present study, a similar approach has been used for the Wilds delta and its associated distributary channels. This study has several advantages: 1) the availability of 1200 well logs in an area of four townships (4N/6E, 5N/6E, 4N/7E, 5N/7E) which provide excellent coverage for detailed mapping of the interval (Figure. 1); 2) the existence of a conventional core sampled through the distributary channel portion of the Wilds delta in the Angelina BBF no.1; and 3) a suite of modern well logs taken in the same well.

The main objective of this study, therefore, is to use these data to present a detailed sedimentological, petrographical and petrophysical description of a "typical" Wilcox distributary channel. Although the Wilds reservoir in the study area is water wet, it is an important oil reservoir in other parts of east-central Louisiana (Corcoran et al., 1994). Also, the results of this study will be critical for determining the feasibility of using the Wilds interval for injecting and disposing of large volumes of produced oil-field brines.

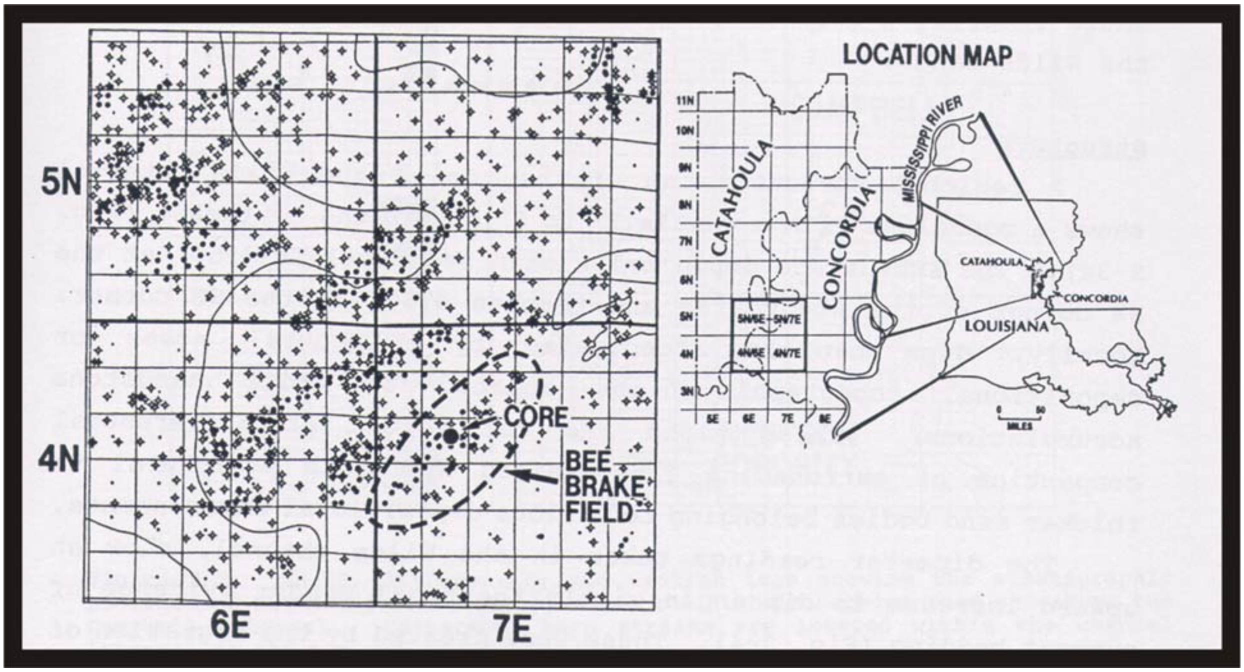

Figure 1: Location map of the four township study area, showing the well coverage and the location of the core taken in the Angelina BBF no. 1 well.

STRATIGRAPHY

In Louisiana, the Wilds deltaic interval overlies the Campbell sandstone, the equivalent of the McKittrick in Mississippi (Echols, 1991). The Wilds sandstone interval itself has no correlative sand equivalent in Mississippi. A Wilds distributary channel system is evidence of a more widespread delta system that formed in Paleocene Middle Wilcox time. A regional transgressive marine shale interval, the Baker Shale systems tract proceeded north and north westward from Mississippi into Louisiana. The developing depositional surface climbed through the Wilds section (Figure. 2). Where underlying concentrations of Wilds distributary channel and bay fill sands were present, the transgression reworked them to produce barrier island arcs, shoals and related offshore sand bodies (Echols, 1991). These deposits are known as the overlying Nichols sandstone (Figure 2). Where the middle Paleocene Baker transgression crossed areas of little or no underlying sand, thin Wilds deposits are overlain by a thick Baker shale interval. This shale acts as a seal to fluids contained in the Wilds sandstone reservoirs.

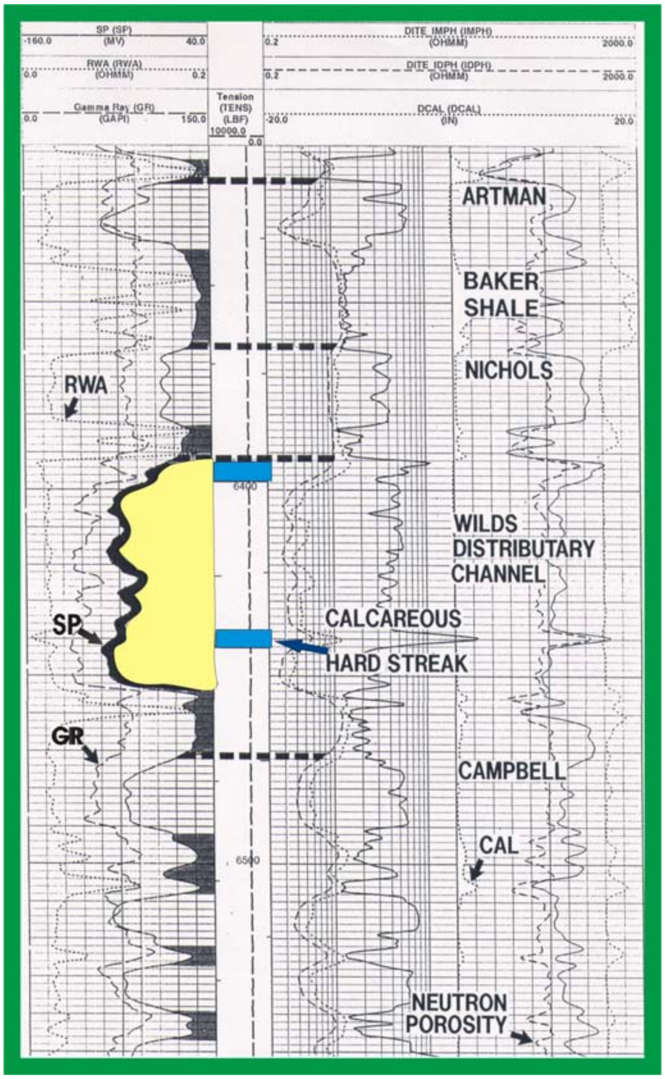

Figure 2: GR/SP, litho-density and neutron logs showing the stratigraphic position of the Wilds distributary channel below the Nichols barrier sand and above the Campbell interval. Calcareous hard streaks are located within the channel interval at the top and near the base.

STRUCTURAL AND NET SAND MAPPING

A regional structure map of the top of the Wilds interval shows a monocline with a gentle 1º to 2º dip to the southeast (Figure. 3A). The subsurface depth below mean sea level is 5250' at the NW corner of the study area and reaches 6750' at the SE corner. Locally, dips can be accentuated by structural noses or depositional topographic highs related to thick sandstone accumulations. These highs are the result of differential compaction of surrounding fine-grained sediments peripheral to thicker sand bodies belonging to various depositional environments. The dipmeter readings taken in the Wilds channel show an upward increase in dip angle within the basal sands, evidence of current bedding (Figure 4). These were created by the migration of sand waves within the channel. In the upper half of the channel fill, the dips are shown to be decreasing upward which depicts the filling of the channel by sand layers that conformed to the shape of the channel (Serra, 1985) .

Genetic facies determinations of stratigraphic units within the Wilds delta were possible from 1) the resulting net sand geometries observed on the net thickness sand map (Figure 3B), 2) certain patterns on the log curves of the old e-logs and the modern log suite, and 3) detailed sedimentological and petrophysical characteristics obtained from the core (Figure 5). Merging these data sets was especially useful in describing the varying facies of the delta. From the net sand map (Figure 3B), the architecture of the distributary channel complex, small crevasse splay deltas, and the widespread overbank bay fill facies are quite obvious. The north - south trending channels have widths that vary from 0.5 to 2.0 miles, and average 1.0 mile. The thickness of the sand filling the channel ranges from 50 to 130 feet and averages 70 feet. Two crevasse splays appear to have developed along the east and southwest sides of the distributary channel complex (Fig. 3B). These breaches through the levees allowed water and sediment to flow out into the interdistributary bay areas where it formed small overbanks or crevasse splay deltas. These cover approximately six square miles each and average 30 feet in thickness. In the numerous interdistributary bays, fine sands, silts and silty shales were deposited. They constitute the widespread overbank bay fill facies that average some 30 feet in thickness.

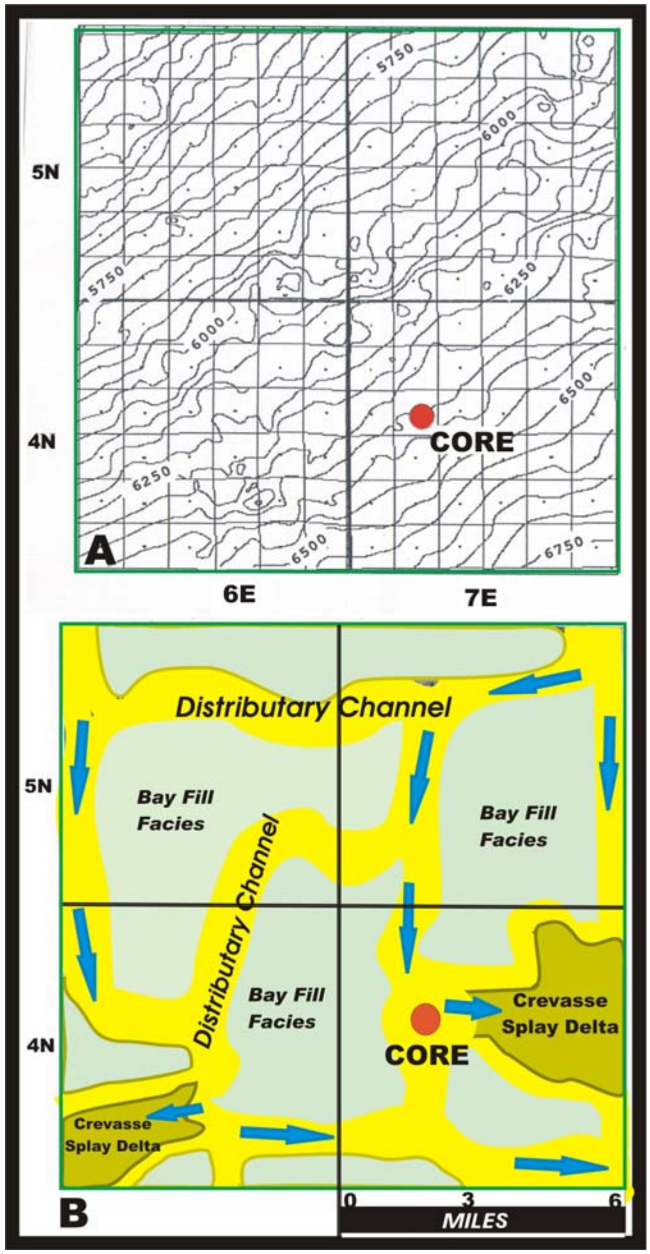

Figure 3: Maps of the Wilds sand: A) Structure on top of the Wilds interval showing a gentle 1° - 2° SE dipping monocline going from -5250' to -6750' below mean sea level (C.I. = 50'); and B) Wilds net sand geometry map depicting the facies architecture of that delta system.

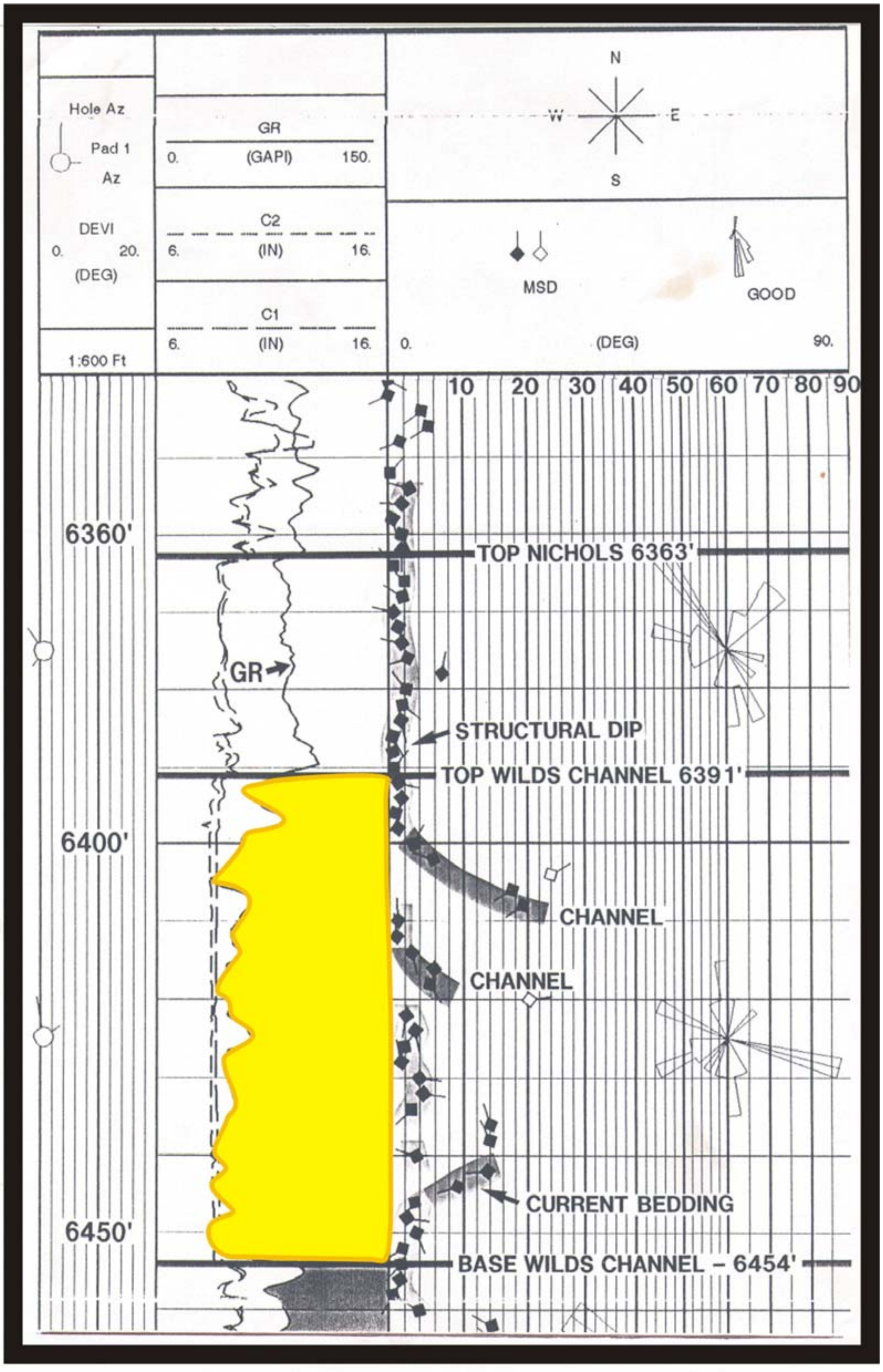

Figure 4: Dipmeter through the Wilds channel showing basal current bedding by an upward increase in dip angle. Toward the upper part of the interval there is an upward decrease in dips as sand fills the channel.

DISTRIBUTARY CHANNEL LITHOFACIES

The ± 63' interval (6391'3" - 6453' 11") of the core penetrated a distributary channel that forms an integral part of the Wilds deltaic complex. The channel cut into an interdistributary bay deposit consisting of laminated siltstones (Figure. 5). The base of the Wilds channel consists of a well sorted, fine to medium grained (0.22-0.27 mm), predominantly subangular to subrounded quartz sandstone. Accessory components consist of plagioclase, muscovite, zircon, and opaque minerals (hematite and magnetite) (Figure 6). Current ripple lamination in the form of low-angle dipping foreset bedding, and horizontal planar laminations are the principal sedimentary structures observed on x-ray radiographs of this section of the core (Figures 6).

Moving up through the channel fill, the sandstone exhibits variations in grain size from medium (0.24 - 0.29 mm) to interbedded intervals of subangular to subrounded coarse grained sandstones. Variations in mineralogy are minor. Flaser bedding and small current ripples are the predominant sedimentary structures throughout. Erosional contacts and thin shale lamina that separate the more massive sandstone layers reflect pulsating channel filling. Occasional siltstone layers (6410') and silty shale intervals (6399') were deposited within the channel when the flow regime diminished (Figure 5). Two intervals, consisting of very fine-grained calcareous ($CaCO_3$) cemented sandstone, were observed within the channel. These are: 1) an interval with planar laminations and parallel wavy bedding (6438'-6441) and 2) one without observable sedimentary structures at the top of the channel between 6392' and 6394'. The calcite cement is believed to have precipitated from interstitial fluids associated with marine conditions as the distributary channel approached the coast. Although located within the channel, these calcareous sandstone intervals were probably cemented in much the same manner as "beach rock" commonly found near the fresh-marine water interface along sandy marine shorelines.

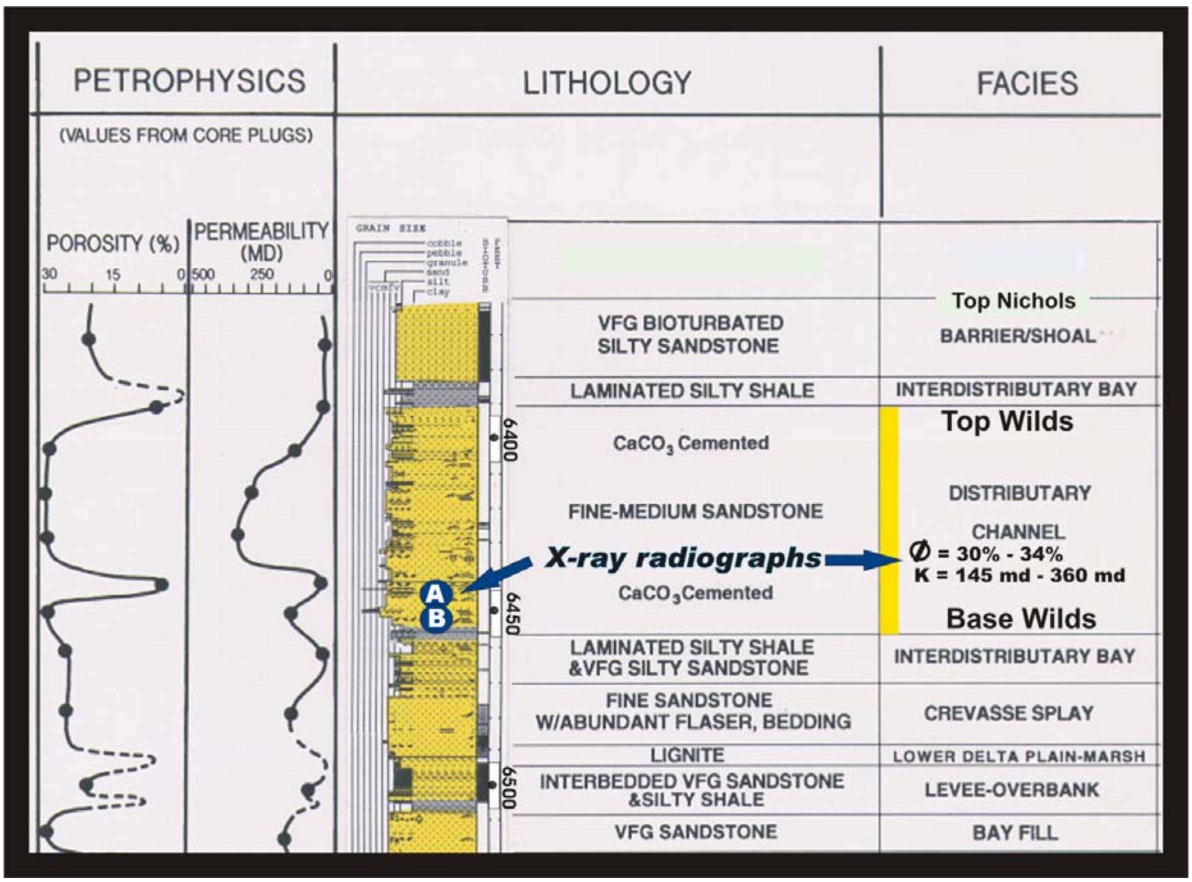

***Figure 5:** Core description of the Wilds channel presenting lithology, sedimentary structures, porosity and permeability values throughout the interval. Two calcareous ($CaCO_3$) cemented sandstone layers can be observed, one at the surface and the other near the basal portion of the channel.*

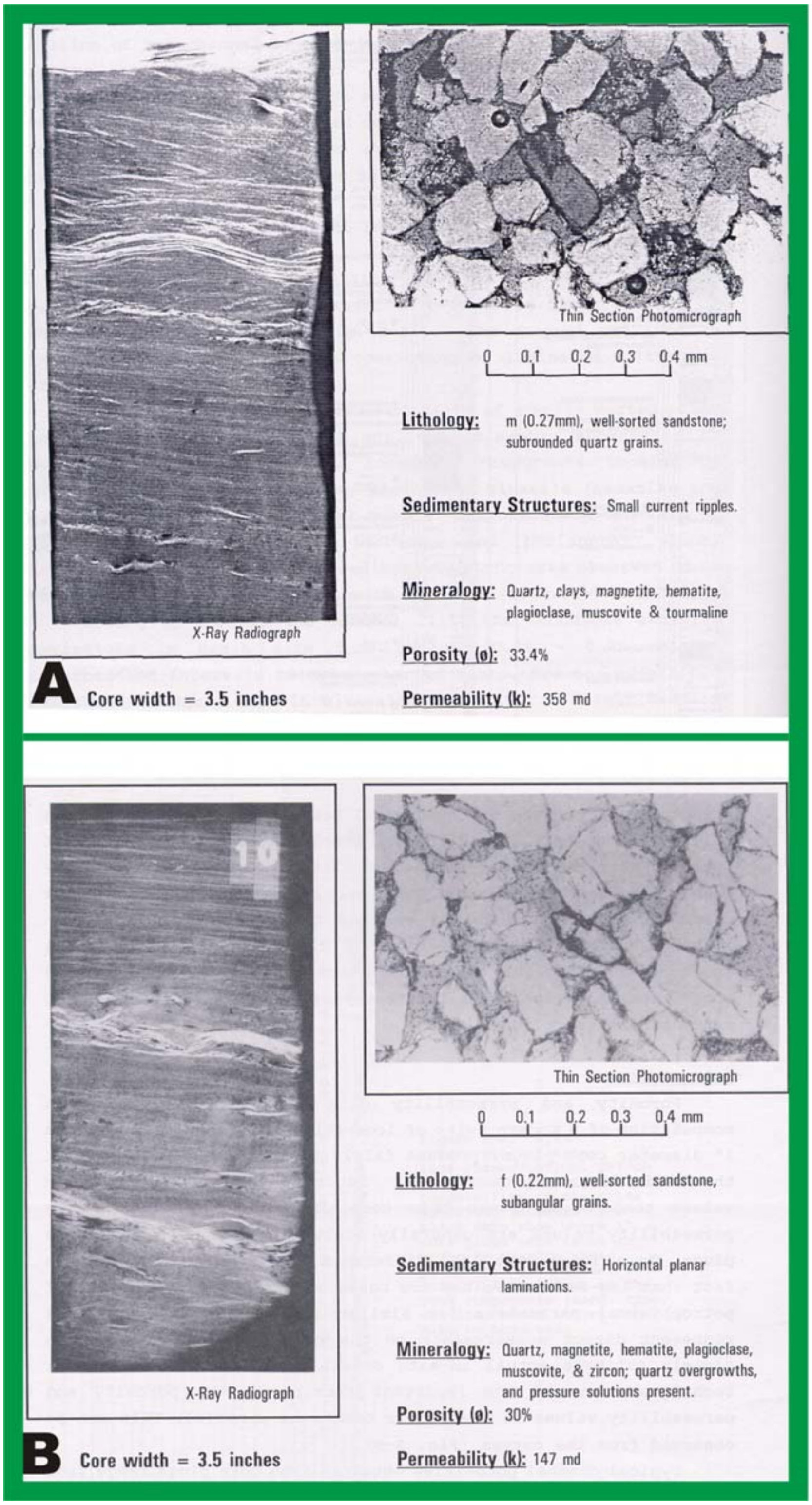

Figure 6: (A) X-ray radiograph (6442' 11" - 6443' 7") showing current ripple and parallel lamination. The photomicrograph shows grain size, angularity and excellent pore/perm values consistent with a distributary channel facies. (B) X-ray radiograph (6450' 3" - 6450' 10") showing horizontal planar laminations as the main sedimentary structure. Photomicrograph shows grain size, angularity and excellent porosity typical of distributary channel sands.

PETROPHYSICS

Porosity and permeability data derived from the Elan computation of a modern suite of logs and from numerous 1" diameter plugs taken from the core, produce fairly constant values throughout the Wilds distributary channel. Figure 6 shows log porosity values tend to be lower than core plug values, whereas log permeability values are generally higher than those of the core plugs. The difference can be attributed to the fact that log-derived values are based on estimates of a number of petrophysical parameters for similar rocks. Core plug values represent direct measurements on the rock itself and thus more closely estimate actual in-situ conditions. For both analytical techniques, one of the important factors in the porosity and permeability values is that their trends be parallel (Figure 7).

Typical channel porosities obtained from core plugs range from 23.5 to 34% and average 30%. At a microscopic scale these excellent porosities and lack thereof are quite obvious in thin sections (Figures. 6 & 8). The typical channel permeability ranges from 91 to 524 md and average 280 md. Within the calcareous cemented sandstone intervals at the top of the channel and near the base, the porosities average 7% with no corresponding permeability. A photomicrograph of the calcareous interval shows that calcite filled all the pore space. Within these intervals a minor amount of porosity can be attributed to hairline fractures (Figure 8).

The calcareous cemented sandstone intervals or "hard streaks" are clearly discernable on the neutron porosity (CNL) curve where it decreases notably and on the density curve (LDT) where it increases slightly (Figure 2). On the low resolution old e-logs, such highly resistive hard calcareous sandstones could be mistakenly interpreted as oil sands. Overall, if unfractured, these calcareous intervals are sufficiently tight to act as seals to fluid migration from underlying reservoirs.

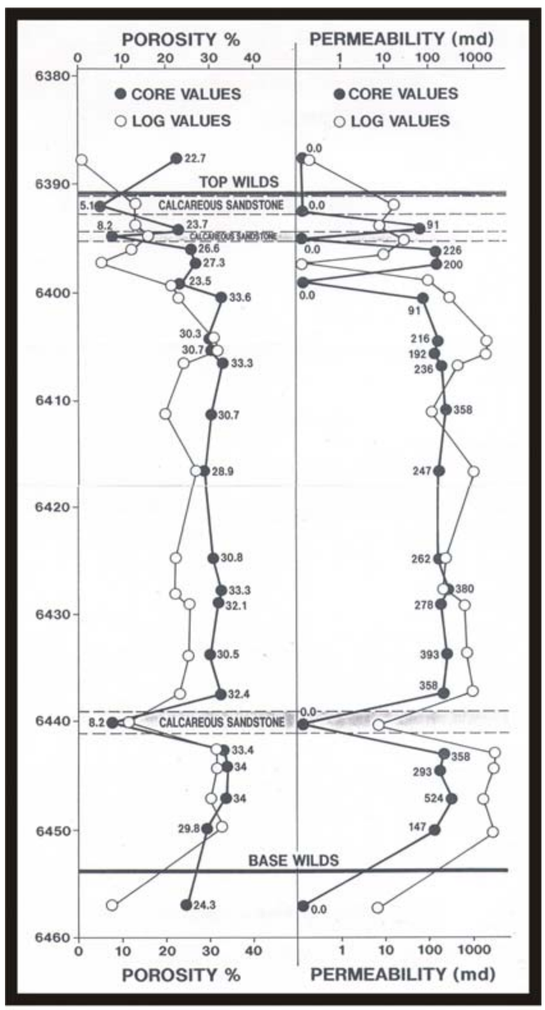

Figure 7: Porosity and permeability measurements within the Wilds distributary channel showing comparison between core plug and e- log values for both parameters.

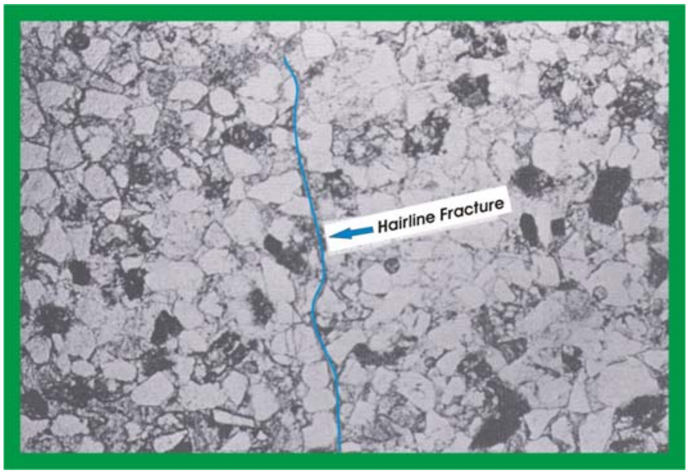

Figure 8: Photomicrograph of the calcareous cemented interval within the Wilds channel. Pores are completely filled with calcite cement. Any porosity observed in the calcareous sandstones can be attributed to hairline fractures.

HYDROCARBON OCCURRENCE

A considerable amount of oil has been produced from the Wilds reservoir eight miles to the north of the study area in the Wildville field (T7N-R6E) (Corcoran et al., 1994). Discovered in 1953, this field has produced 3.25 million barrels. In order to explain the presence of oil in certain areas of the unstructured Wilds deltaic system and not in others, stratigraphic details, trapping mechanisms, and migration pathways must be understood.

Recent structural and geochemical evidence indicates that hydrocarbons found in Wilcox reservoirs such as the Wilds sandstones were emplaced by vertical migration along wrench faults and associated fracture zones from underlying Cretaceous and Jurassic source rocks (Zimmerman, 1993; Echols et al., 1994) (Figure 9). Once it reaches such a sandy interval as the Wilds distributary channel system, the oil migrates laterally and up-dip over short distances along gently dipping strata (1º - 2º) until it accumulates, mainly in stratigraphic traps. In areas where the overlying Nichols and Artman sands have eroded channels and are in contact with the Wilds interval, they may have drained the oil from below through a process termed stratigraphic capture (Echols and Goddard, 1992). This appears to have occurred in the study area three miles to the west and northwest of the core location where the Nichols-Artman barrier complex forms prolific oil producers in the Lake Curry Field.

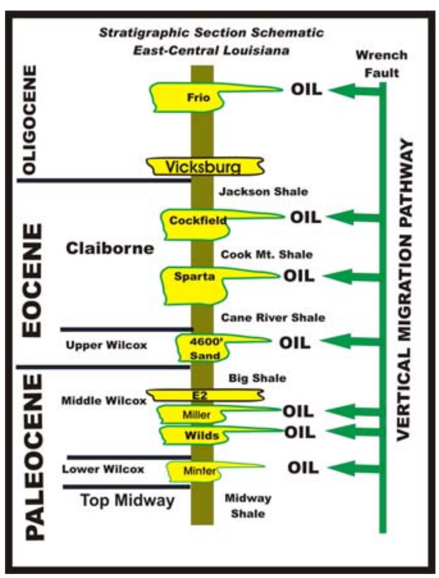

Figure 9: Model showing that wrench faults can serve as vertical migration pathways for Mesozoic sourced oils found in Tertiary reservoirs.

CONCLUSIONS

The Wilds distributary channel complex forms part of a more widespread deltaic interval within the Paleocene Wilcox Group of thin stacked deltas. The distributary channel itself is a 63' thick interval consisting of fine to medium grained well-sorted sandstone that has cut into an interdistributary bay deposit. In the channel layers, flaser bedding, small current ripples and horizontal planer laminations are the predominant sedimentary structures. Thin shale laminae, siltstone and silty shale intervals can be observed in the cored sectioned separating the thick sandstone layers. Typical channel porosities average 30%, ranging between 24 and 34%. Permeabilities range from 91 to 524 md and average 280 md. In calcareous cemented sandstone intervals where the calcite pore-filling is nearly complete, minor porosities of 7% can be attributed to hairline fractures. Unfractured, these impermeable hardstreaks make excellent seals to underlying reservoirs. Hydrocarbon accumulations in Wilds reservoirs have been well documented. The fluids were capable of reaching these shallow Paleocene intervals by migrating vertically up wrench faults and associated fracture zones from underlying Jurassic source rocks.

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2. Reservoir Characterization

of the

Wilcox Miller Sandstone

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June 2007

ABSTRACT

The Paleocene Middle Wilcox interval in east-central Louisiana typically consists of 15 major, easily correlatable sandstone bodies; six of which are oil producers. Of these, the Miller sandstone is one of the important reservoirs within this 800-ft interval. From 1959 to the present it has produced approximately 1.1 million barrels of 40° to 49° API gravity oil within the four township study area (4N/6E, 4N/7E, 5N/6E, 5N/7E). The depositional framework of the sandstone bodies was determined from detailed correlation and mapping, using 1007 E-logs in a 144 square mile area. The Miller sands are interpreted as distributary channels and associated overbank bay fill facies deposited in a lower delta plain setting. This is evident from the detailed net sandstone geometry and overlying lignite that caps the Miller reservoir throughout the study area.

Stratigraphically trapped oil in the distributary channel system and associated facies is believed to have originated in the underlying source rocks; then subsequently, it moved vertically up to its present position through faults and several levels of communicated sandstone bodies (stratigraphic capture). The extremely low southeastwardly dip (< 1°) was sufficient to permit lateral movement of oil within the Miller reservoir where it is trapped in depositionally higher sandstone layers or against shale.

INTRODUCTION

Reservoir heterogeneities in a deltaic system, such as the one that characterizes the Middle Wilcox in east-central Louisiana, are the result primarily of 1) structural features, 2) depositional processes responsible for facies variations, and 3) diagenesis resulting from the physical, chemical and biological processes that occurred during subsequent basin subsidence. Structural features in the Middle Wilcox deltaic reservoirs in east central Louisiana are lacking. Any syndepositional and/or post depositional deformation which may have occurred was minor and thus believed to be an unimportant factor to the recovery potential in these reservoirs. For this reason, the reservoirs in the study area can be considered unstructured.

Diagenesis was always believed to be a major factor influencing the producibility of the Middle Wilcox reservoirs. Therefore, the effects of diagenesis on reservoir heterogeneities were the subject of detailed studies at Louisiana State University's Basin Research Institute (BRI) in the early 1990s (Williams et al., 1991; Ferrell and Melancon, 1992). Diagenesis research formed a fundamental part of a two year Wilcox integrated study and core project at BRI (Schenewerk et al., 1994; Goddard, 1995).

The objective of this study was to determine the depositional facies characteristics of the Miller reservoir through detailed net sand and structural mapping at regional and reservoir scales. A secondary objective was to try to explain the relationship of facies variations to oil movement and accumulation. The Miller sand was considered an ideal candidate for detailed mapping for the following reasons: (1) there is adequate well control in the producing areas; (2) it is easily correlatable on the electric logs on a regional scale; (3) its scattered production needed to be explained; and (4) there may be room for additional infill drilling or enough remaining oil in the known producing areas for successful secondary recovery projects.

LOCATION OF THE STUDY AREA

Four townships comprise the study area (4N/6E, 4N/7E, 5N/6E, & 5N/7E), located in Concordia and Catahoula parishes in east-central Louisiana (Figure 1). About 1,200 wells have been drilled in this 144-square mile area. The majority of these barely penetrated the Lower Wilcox, just below the Minter Sand, and only 2 wells reached the Cretaceous below the Midway Group. The first Miller sand producer was drilled in 1959. Since then a total of 27 wells have produced from this sand at twelve scattered areas throughout the four townships. The producing interval averages 10 feet in thickness. Initial production rates vary between 6 and 122 barrels of oil per day (BOPD) and average 54 BOPD.

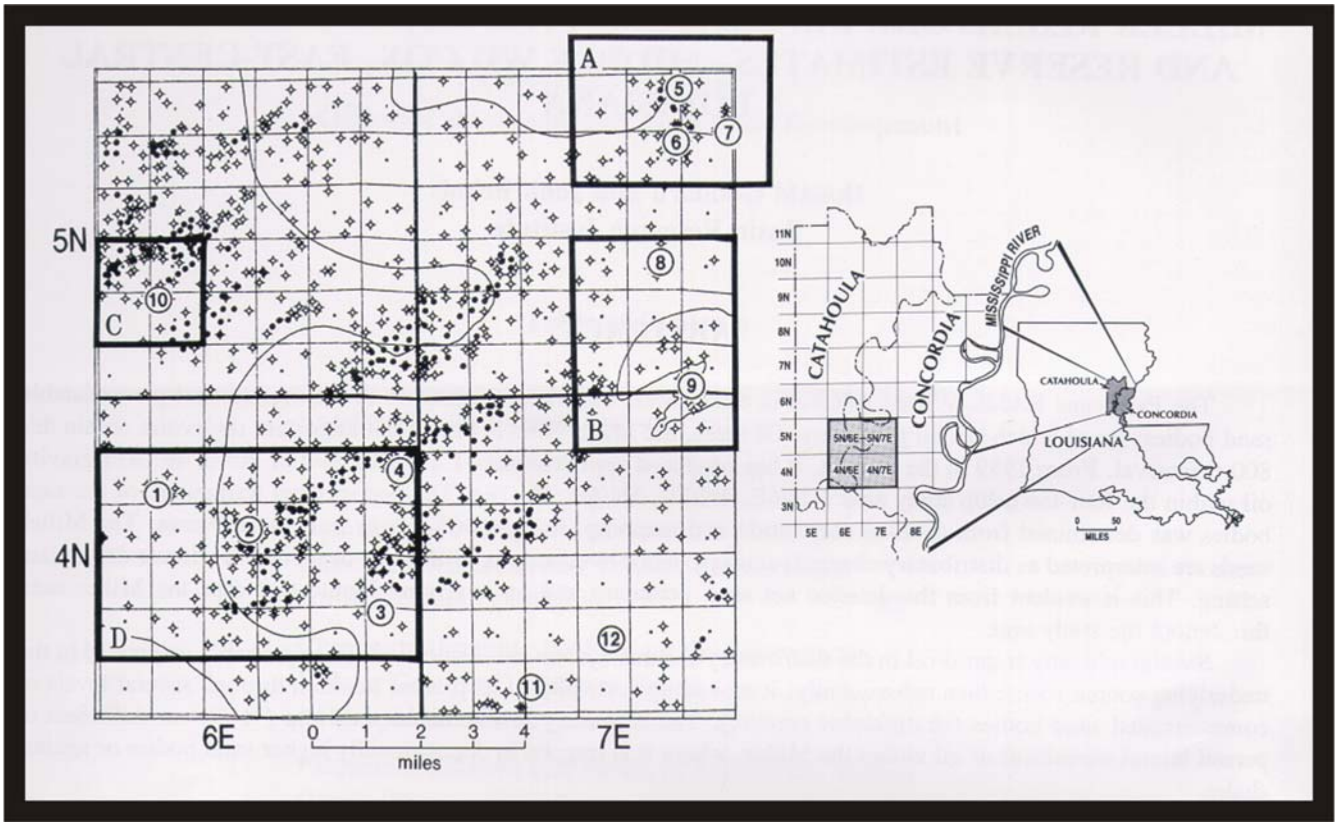

Figure 1: Location map of the four township study area showing the well coverage and the main Miller reservoir producing areas (1 to 12).

STRATIGRAPHY

The stratigraphy of the entire Wilcox Group in Louisiana has been described as consisting of alternating sandstone and shale and occasional lignite beds of Paleocene-Eocene age and deposited on top of the Paleocene Midway Group. The upper boundary of the Wilcox is formed by the Eocene Tallahata Formation (Galloway, 1968; Echols, 1991). The reservoir of interest in this study is the Miller sandstone located within the Middle Wilcox between the Big Shale (5000'-6000') and the E5 sandstone interval (5600’) (Figure. 2).

The sandstone names used in the subsurface Middle Wilcox in the study area are those published by the Shreveport Geological Society (1961) and redescribed by Echols (1991). Superjacent to the Minter Sands is a series of deltaic sand bodies (C7, E5, PLS, Baker, Campbell and Wilds) which are present in a 250 foot interval. Each is overlain by an occasional 1' to 3' thick lignite seam followed by a 10' to 20' thick transgressive shale. The depositional nature of the ±100 foot interval between the Wilds and C5/Turner sand indicates that it is transgressive and includes the Nichols and Artman transgressive barrier sands (Echols, 1991). The remaining sand bodies (Yakey, Miller, Tew Lake, and E2) are all capped by lignite and believed to have been deposited in a lower delta plain environment (Goddard and Echols, 1992). The cyclic depositional model for this Paleocene Middle Wilcox interval can be observed in Figure 3. Finally, the A1 sand located below the Big Shale was the last sand deposited in the Middle Wilcox within the Big Shale transgressive event.

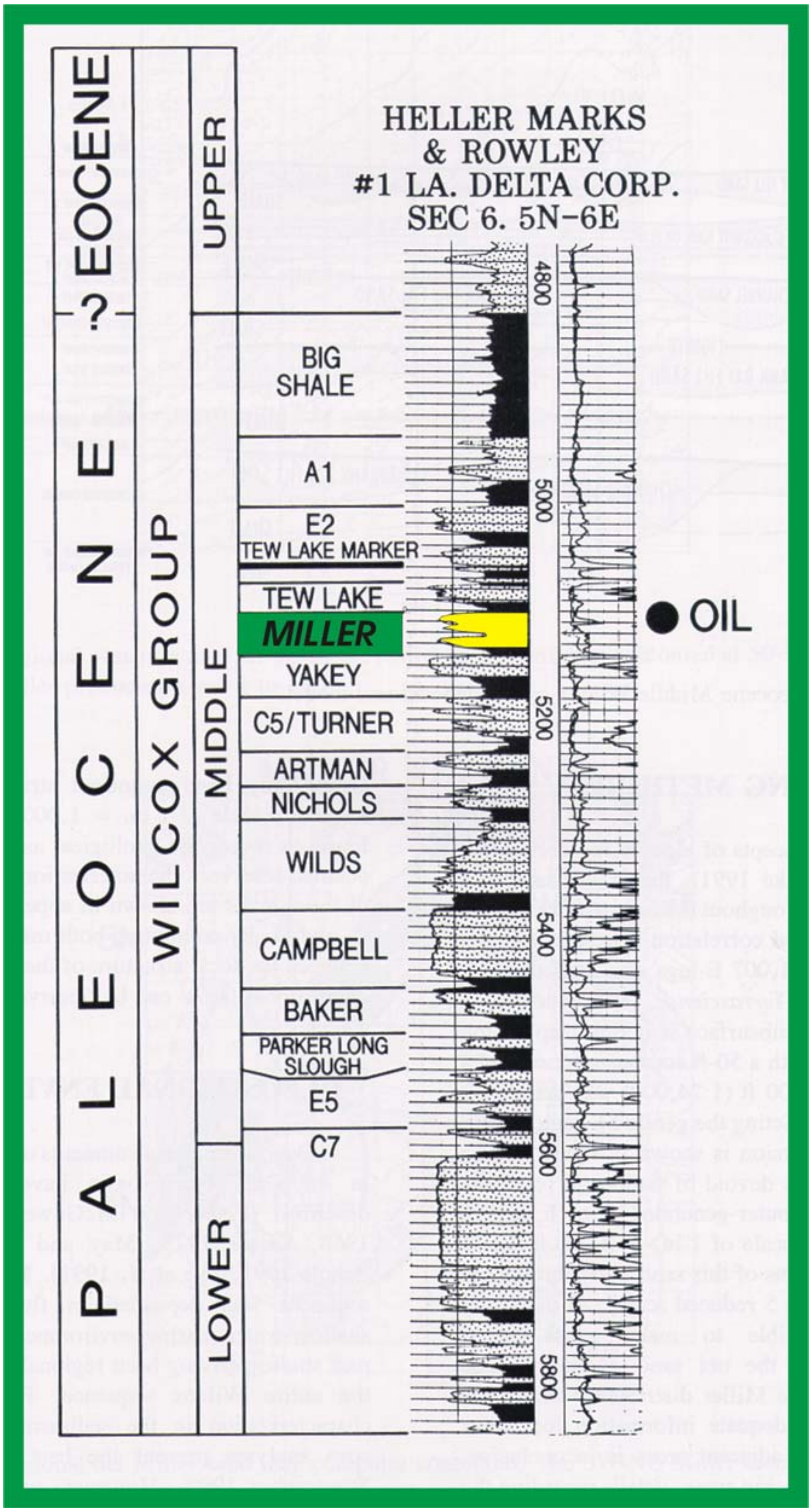

Figure 2: A representative e-log and stratigraphy showing the Miller reservoir within the Wilcox Group.

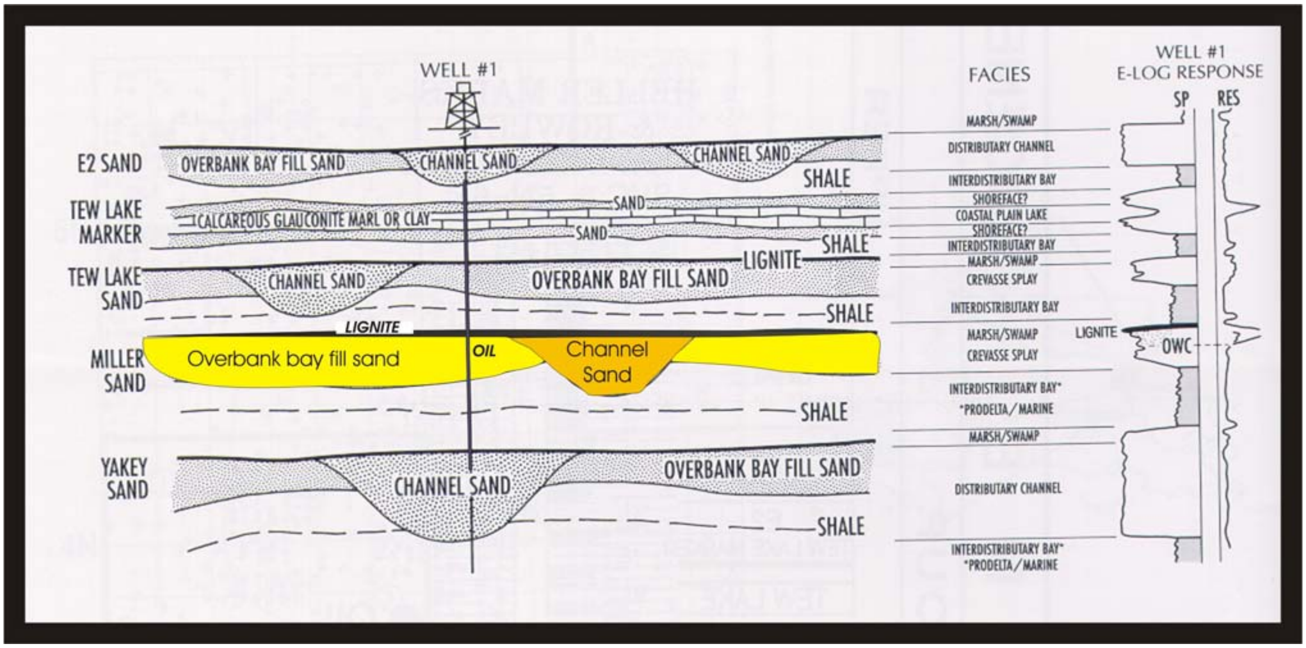

Figure 3: A model of the Middle Wilcox showing cyclic deposition within a deltaic environment.

MAPPING METHODS

Using basic concepts of electric log correlation (Tearpock and Bischke, 1991), the Miller sand was easily correlatable throughout the four township area. After completing the detailed correlation, the sand top and thickness data from 1007 E-logs was loaded into a mapping data file (TERRASCIENCE). Subsequently, a computer generated subsurface structure map on top of the Miller sandstone with a 50' contour interval and a scale of 1" = 2000' (1:24000) was obtained. It was found to be adequate for depicting the gentle SE regional dip of 1 degree (Figure 4A). It can be observed that the four township area is devoid of faults and relatively unstructured. A computer generated isopach map of the Miller sand at a scale of 1" = 2000' shows the thickness variations of this sand body throughout the study area (Figure 4B). At the larger scales, it is possible to make gross facies interpretations from the net sand geometry. The northeast trend of the Miller distributary channel is obvious. However, adequate information for facies determination in the adjacent areas is not conclusive. Also, in the oil producing areas, details regarding the Miller reservoir are difficult to ascertain. For these areas, only hand contoured structure and isopach maps at a scale of 1" = 1000' (1:12000), were found to reveal the geological aspects necessary for detailed reservoir characterization. Versions of these maps are shown in Appendix I, maps A, B, C and D. By combining both maps, the relationship between the local structure of the Miller sand and its depositional facies can be observed.

DEPOSITIONAL ENVIRONMENTS

Depositional environments of the Wilcox Group in the Gulf Coast Basin have been thoroughly described (Fisher and McGowen, 1967; Galloway, 1968; Kaiser, 1978; May and Stonecipher, 1990; Echols, 1991; Tye et al., 1991). Most workers agree that the sediments were deposited in fluvial, deltaic and shallow water marine environments. Many of these past studies, having been regional in scope, included the entire Wilcox sequence. For detailed facies characterization within the sedimentary environments, core analyses present the best results (May and Stonecipher, 1990, Goddard, 1995). However, where core data is not available, detailed structural and net sand mapping of individual sand bodies provides adequate information for facies identification.

The geometry of the Miller sandstone bodies observed on the regional isopach map (Figure 4B) and the relationship of the deposits to the overlying lignite gives evidence of a lower delta plain setting for these sediments (Goddard and Echols, 1992). Having established the depositional environment with a reasonably high degree of confidence, it can be observed that the principal feature crossing the study area is a NE-SW trending distributary channel. The gap in the continuity of the Miller channel can be attributed to scouring by the overlying Tew Lake distributary channel (Echols and Goddard, 1992). The width of the Miller distributary channel averages 1.5 miles and reaches a maximum sand thickness just over 100 feet. A number of crevasses formed along the length of the principal Miller channel. These breaches through the levees, shown in Figure 4B, allowed water and sediments to flow out into the overbank and interdistributary bay areas. Secondary channels and crevasse-splay deltas developed (see maps Appendix I). These features formed the principal conduits for sediment transport and constitute the overbank and bay fill facies. With widths of approximately 0.5 miles and thicknesses of 20 to 30 feet, dimensions of these sand bodies are considerably smaller than the distributary channel.

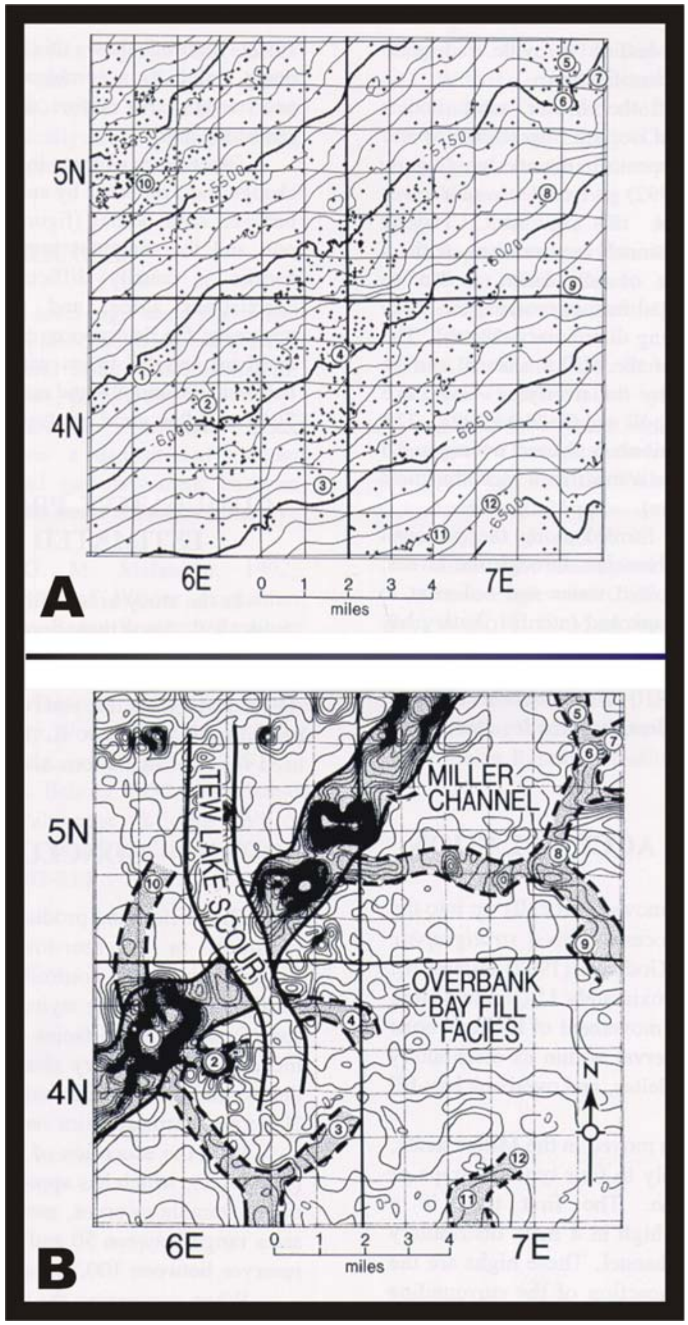

Figure 4: The regional structure map on top of the Miller sandstone, contoured at 50- ft interval, shows the 12 producing areas (A). A regional computer contoured net sand map (B) shows a main SW-NE distributary channel, smaller secondary channels and overbank bay fill facies.

HYDROCARBON ACCUMULATION

Hydrocarbons have moved vertically up into the Miller reservoir through a process termed "stratigraphic capture" by Echols and Goddard (1992). A regional SE dip of approximately 1 degree was sufficient to allow lateral movement of hydrocarbons throughout the Miller interval within its distributary channels, crevasse splay deltas and overbank bay fill facies (Figure 5).

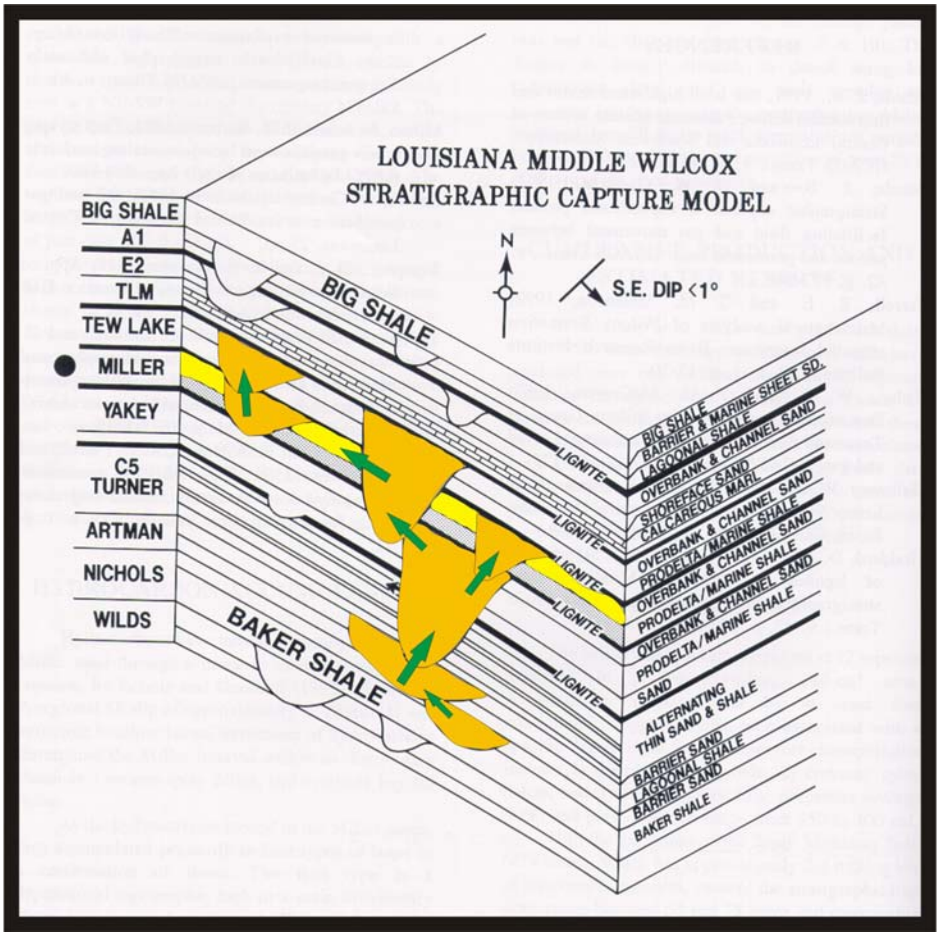

Figure 5: The stratigraphic capture model shows how the hydrocarbons move vertically and laterally through distributary sandstone channels and overbank-bay fill facies.

As the hydrocarbons moved within the Miller reservoir they accumulated primarily in four types of traps or a combination of these. The first type is a depositional topographic high within a main distributary channel or a secondary channel. These highs are the result of differential compaction of the surrounding sediments outside the thick sand channels. Commonly referred to as structural/stratigraphic traps in the Wilcox, similar traps have recently been termed "compaction anticlines" (Milton and Bertram, 1992). Figure 6A shows this type of trap in the Miller being sealed by a combination of overlying lignite and transgressive marine shale which drape over the sandstone high.

The other types of traps in the Miller are the facies-change trap reflected by subtle permeability barriers between sand bodies (Figure 6B), the channel pinch-out and the shale-out trap (Figures 7A & 7B). The former is usually difficult to detect using log correlations alone and side wall samples are necessary for determining the permeability. Miller overbank bay-fill facies with permeability ranging between 200 and 400 millidarcies and porosity averaging 30% are often the better producers.

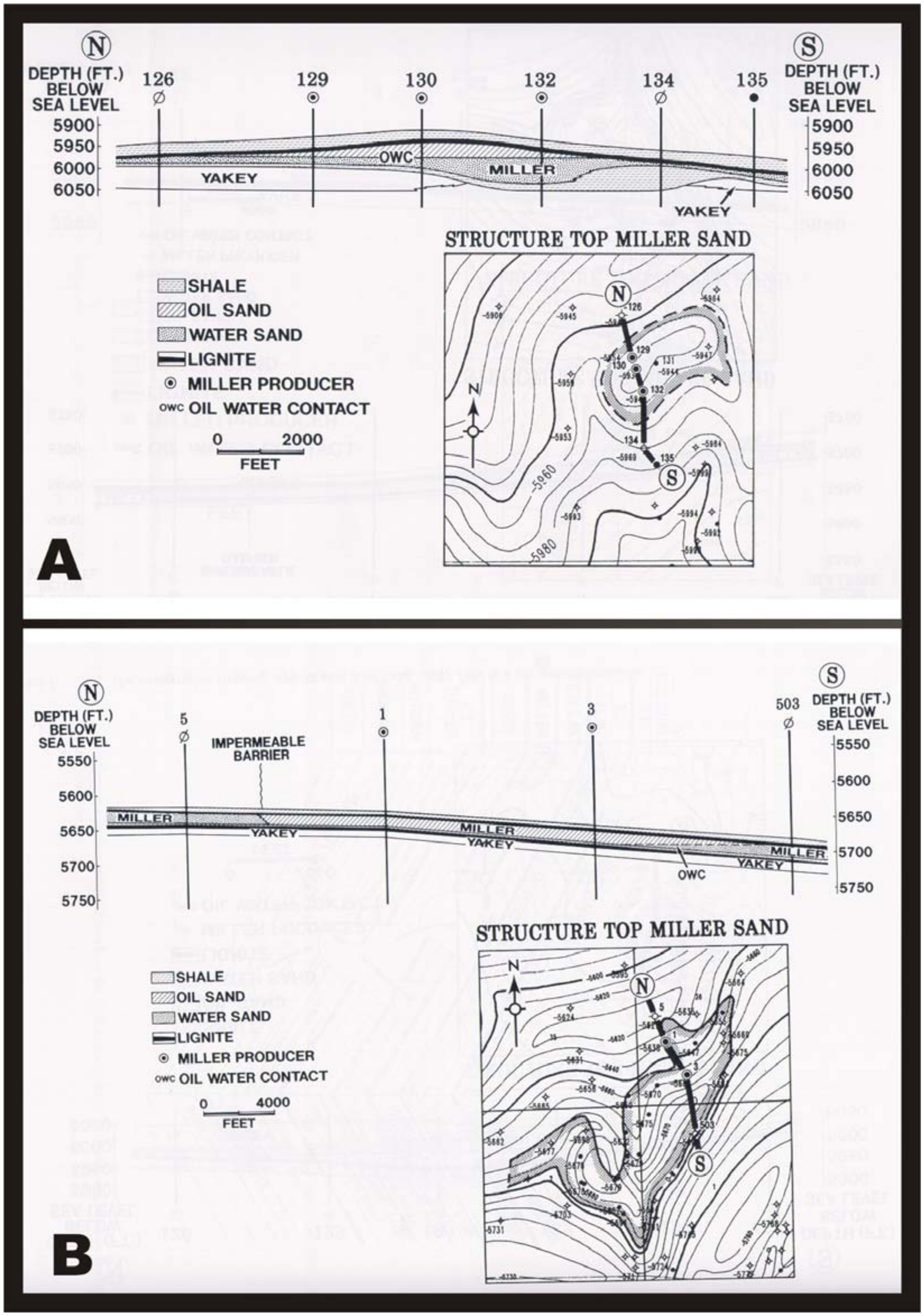

Figure 6: The stratigraphic trapping style in area 2 of Lake Curry field is a compaction anticline (A). The trapping style in area 4 of South Monterey field is a facies change that gives rise to an impermeable barrier (B).

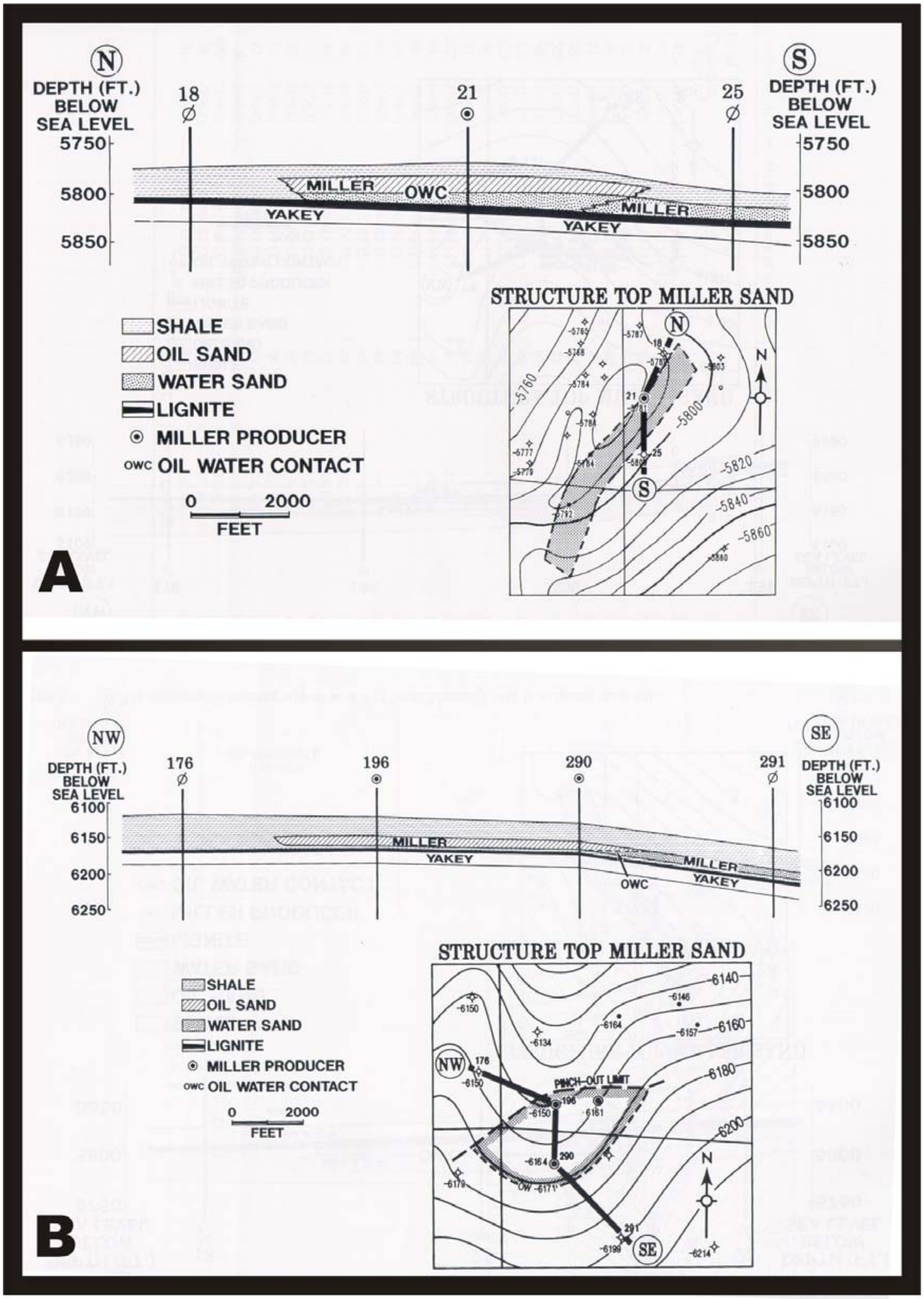

Figure 7: The straigraphic trapping style in area 6 of South Monterey field is a channel shale-out (A). The trapping style of area 3 of Bee Brake field is an updip shale-out (B).

RESERVOIR PARAMETERS

Water saturation for the Miller reservoir was estimated using the Archie equation:

$$Sw = \sqrt{\frac{F \times Rw}{Rt}}$$

Average porosity (Ø) of the Miller reservoir is 30% and because the typical formation factor (F) is given as $0.81/Ø^2$, the formation factor for the Miller is equal to 0.81/0.09 or 9. Water resistivity (Rw) for the Miller sandstone saturated with 80,000ppm is 0.02 (average Wilcox Rw) and the true formation resistivity obtained form the e-log is 1.5 Ω. Therefore, water saturation (Sw) is equal to: $\sqrt{\frac{9 \times 0.2}{1.5}} = 0.346$ or approximately 35%.

In the study area, the depths below the surface to the reservoir range from approximately 5600' in the northwest to 6200' in the southeast sector. The Miller sandstone reservoir produces in the small and large distributary channels, varying in thickness from only 4 feet to 12 feet, and averaging 10 feet.. Reservoir pressure for different depths of the Miller reservoir can be estimated by multiplying an approximate pressure gradient of 0.466 psi/ft times the depth. In the study area, pressures range between 2500 psi and 2850 psi and average 2675 psi.

The reservoir temperature for different depths is 1.2°F/100 ft (temperature gradient) x depth (ft) + 65°F.
In the study area, the temperature ranges from 131º to 140°F and averages 136°F.

The gravity of Miller reservoir oils range from 39 to 49° API and average 44° API with solution gas –oil ratios (GOR) typically averaging 200 Ft^3 per barrel. Because the drive mechanism in the Miller reservoir is a strong water drive, recovery factors for these light oils tend to be high, around 45%.

Based on the reservoir conditions given above, a formation volume factor (Bo) of 1.35 is estimated.

CUMULATIVE PRODUCTION AND ESTIMATED RESERVES

In the study area, production from Miller sandstone reservoirs dates from 1959. Since then, some 27 wells have produced approximately 1.16 million barrels of oil (MMBO) at twelve localities throughout the 144 square mile area (Figure 1) (Table 1). Reserve calculations have been made on these isolated pockets of production, each associated with a specific type of trap (Figures 6 & 7) (Table 2). Using a basic data sheet for estimating oil reserves (Table 3), giving an average depth to the Miller reservoir and applying the reservoir parameters in the previous chapter, recoverable oil reserves in an area of 981 acres are estimated at approximately 4.94 MMBO. Therefore, remaining recoverable reserves of about 3.78 MMBO are still available in the Miller reservoir in this area of Concordia Parish.

CONCLUSIONS

The Miller sandstone reservoir produces light oil at twelve localities within a four township 144 square mile area. The accumulation is controlled by at least 4 different stratigraphic trapping styles, each associated with a specific depositional facies. Reservoir characteristics include 1) distributary channels, 2) crevasse splay deltas and 3) overbank bay fills; porosity averages 30% and permeability ranges from 150 to 400 md. With the exception of the South Monterey Field (479 acres) with approximately 2.4 million barrels of recoverable reserves, most of the stratigraphic trap sizes range between 50 to 75 acres and with recoverable reserves between 100,000 to 450,000 barrels.

When comparing the cumulative production of some of these Miller reservoirs against the estimated recoverable reserves, it becomes obvious that a considerable amount of oil remains to be produced from these mature fields. This fact, together with today's oil price ($65+/barrel) and the shallow depths (5600'-6200'), make these Miller reservoirs ecomically attractive targets using present day drilling and production technologies.

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Table 1. Miller production from wells in the study area.

Well	Initial Production (BOPD)		Perforated Interval (Feet)	Grav(API)	Cumulative Production (Bls)	Status
21	85	(1976)	5836-40 (4')	45	29,083	P & A (1980)
56	90	(1990)	6007-17 (10')	47	4,322	Shut in
129	20	(1967)	6011-12 (1')	47	6,982	P & A (1969)
130	35	(1984)	5985-92 (7')	47	7,684	P & A (1991)
131	46	(1977)	5999-02 (3')	49	13,079	P & A (1980)
132	24	(1964)	6008-13 (5')	47	17,748	P & A (1968)
196	50	(1983)	6211-18 (7')	48	131,300	flowing
219	60	(1977)	5806-15 (9')	44	13,792	P & A (1980)
458	110	(1988)	6505-10 (5')	43	2,720	P & A (1990)
479	96	(1979)	6461-63 (2')	45	83,654	P & A (1980)
501	33	(1959)	5800-05 (5')	43	11,034	P & A (1963)
510	122	(1976)	5840-44 (4')	45	55,007	P & A (1982)
514	45	(1965)	5736-39 (3')	47	45,880	P & A (1969)
515	82	(1964)	5734-36 (2')	40	27,952	P & A (1967)
516	14	(1964)	5830-32 (2')	40	865	P & A (1965)
518	65	(1960)	5748-52 (4')	44	54,921	P & A (1964)
519	20	(1963)	5743-48 (5')	45	3,835	P & A (1963)
520	70	(1963)	5803-06 (3')	49	126,764	P & A (1980)
521	80	(1964)	5749-51 (2')	43	55,038	P & A (1968)
527	50	(1961)	5742-45 (3')	44	35,022	P & A (1965)
529	60	(1961)	5751-54 (3')	45	20,998	P & A (1965)
563	52	(1964)	5792-95 (3')	46	81,101	P & A (1975)
564	42	(1964)	5786-92 (6')	49	124,420	P & A (1971)
567	6	(1965)	5796-5802 (6')	42	6	P & A (1965)
629	100	(1977)	5961-69 (8')	43	115,427	P & A (1988)
716	35	(1964)	6180-82 (2')	46	27,883	P & A (1967)
1037	70	(1981)	5512-15 (3')	39	+60,000	shut in
				TOTAL	1,156,517 barrels	

Table 2. Miller Reservoir Reserve Estimates

AREA	FIELD	LOCATION	RECOVERABLE OIL (STB)	CUMULATIVE PRODUCTION (bbl)	% OF STB PRODUCED	NO. OF WELLS	YEARS	TRAP TYPE
1.	DISC BOOK	SEC 8 4N-6E	186,200	13,792	7	1	1977-80	CHANNEL SHALE-OUT
2.	LAKE CURRY	SEC 16 4N-6E	210,000	45,493	22	4	1964-84	COMPACTION ANTICLINE
3.	BEE BRAKE	SEC 24 4N-6E	355,000	131,300	37	3	1983-PRESENT	UPDIP SHALE-OUT
4.	NORTH BEE BRAKE	SEC 12 4N-6E	65,000	4,322	7	1	1990-92	COMPACTION ANTICLINE
5.	SOUTH. MONTEREY	SEC 11 5N-7E	2, 395,000	>450,000	18	14	1959-80	DEPOSITIONAL FACIES CHANGE
6.	SOUTH MONTEREY	SEC 11 5N-7E	453,000	205,521	45	2	1964-75	COMPACTION ANTICLINE
7.	SOUTH MONTEREY	SEC 1 5N-7E	100,000	84,090	84	2	1976-82	CHANNEL SHALE-OUT
8.	WYCHES	SEC 23 5N-7E	300,000	115,427	38	1	1977-88	COMPACTION ANTICLINE
9.	WILD COW BAYOU	SEC 36 5N-7E	682,000	27,883	4	1	1964-67	COMPACTION ANTICLINE
10.	FOSTER RIDGE	SEC 29 5N-6E	60,000	+60,000	100	1	1981-85	UPDIP SHALE-OUT

Table 3

ESTIMATED OIL RESERVES

Field: Concordia Parish Study Area **Reservoir: MILLER**

Datum……	**5900 (Feet)**
Porosity (%)……	**30 %**
Average Connate Water (SW)……	**35 %**
1 – Connate Water (So)……	**65 %**
Reservoir Pressure (BHP) (0.466 psi/ft)……	**2675 psi**
Reservoir Temperature (BHT)……	**136 (° F)**
Oil Gravity……	**44 (° API)**
Formation Volume Factor (Bo)……	**1.35**

OIL IN PLACE (OIP): $\dfrac{7758 \times (\text{Porosity})(1\text{-connate water})}{(B_o)}$

$\dfrac{7758\ (0.3)\ (1-0.35)}{(B_o\ 1.35)}$ …… **1,121 STB.AC-FT**

Recovery Factor (RF) (Water drive mechanism :)…… **45 %**

Recoverable Oil / AC- FT: **OIP X RF** …… **504 STB/ac-ft**
(1121) (0.45)

Recoverable Oil: (Acres) (Net Pay -feet) (STB/AC-FT)…… **4,944,249 STB**
(981) (10) (504)

4.94 Million Barrels

3. Organic Geochemistry

of Wilcox

Shale, Coal, and Oils

Concordia Parish, Louisiana.

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LSU Center for Energy Studies

June 2007

ABSTRACT

Results of an organic geochemical study of Middle and Lower Wilcox rocks and oils from a conventional core taken in Concordia Parish, Louisiana, helped determine the potential organic facies thermal maturity and enabled oil-rock correlations. The geochemical techniques applied included: (1) total organic carbon (TOC) and Rock-Eval analyses; (2) visual kerogen analysis for vitrinite reflectance and kerogen typing; (3) whole extract gas chromatography (gc); 4) whole oil gc; (5) pyrolysis-gas chromatography (py-gc) of S_1 and S_2 , and (5) gas chromatography-mass spectrometry (gc/ms) of saturate biomarkers on rock and oil samples. Kerogen microscopy shows a 0.44% R_o mean reflectance for both the coals and the shales and places the coals within the thermally immature lignite - subbituminous rank. Based on the results of the TOC and Rock-Eval analyses, the rock samples were subdivided into four groups according to variations in TOC, hydrogen indices (HI), oxygen indices (OI), and kerogen type.

Results of the kerogen petrography analyses indicate that coals and shales are petrographically different, in that the coals contain much smaller amounts of structured lipids and no amorphous kerogen. The maceral contents of the coals suggest they were deposited in a lower delta plain environment in fresh water marsh and swamp facies. Within the four groups of rock, percentages of amorphous kerogen in the shales as well as kerogen types vary greatly within the sampled interval, with some having adequate potential for oil generation, some could generate gas and others with no oil and gas generating potential whatsoever.

Pyrolysis - gas chromatography (py-gc) S_2 data suggest that the coals are capable of generating highly paraffinic crude oils at adequate maturity, whereas the shales would generate less waxy crude oils when mature. Also, the S_2 py-gc chromatograms of the shales indicate they are all similar regarding their organic matter constituents.

Gas chromatography-mass spectrometry (gc/ms) analyses on saturate biomarkers (terpane m/z 191) show a close similarity among the coal and shale samples. One of the pentacyclic terpane peaks shows a bionomoretane representing terrigenous organic matter. Major contributors to some of the peaks are probably C30 demethylated hopanes which also indicate a contribution of terrigenous organic matter. The biomarker analyses of these samples also showed very low thermal maturities in agreement with the measured values of about 0.44% (mean value).

Terpane (m/z 191) and sterane (m/z 217) distributions from the biomarker analyses on oil samples within different intervals in the Minter reservoir are very similar, indicating the same organic matter and thermal maturity for both. Also, the terpane distribution in the oils indicates they are quite different from the coals and shales adjacent to the reservoir. The GC/MS data on the oils indicate they are mature and derived from a shaly source rock containing mixed organic matter with bacterial, algal, and terrigenous components. Equilibrium values in hopane isomerization (56%) and those in sterane isomerization (57%) of the oils indicate thermal maturities close to peak oil generation at 0.80 - 0.90% R_o.

Whole extract gas chromatograms show similarities between the coals and shales in that that they are immature and contain essentially terrestrial organic matter. However, the Minter oils were expelled at a thermal maturity of about 0.80 - 0.90 R_o and totally lack any correlation with the coals and shales.

INTRODUCTION

Organic geochemical studies of Paleocene-Eocene Wilcox rocks (shale and coal) in the Gulf Coast Basin flourished between 1987 and 1992 (Gregory, 1987; 1991; Walters et al. 1988; Mukhopadhyay 1989a, 1989b; Wenger et al. 1989; Sassen et al. 1988, 1990a, 1990b; Chinn et al., 1990; Chinn, 1992). For the most part, these were regional studies with two principal objectives: 1) to locate and determine the sourcing potential of Wilcox shale and coals and 2) to explain the origin of the hydrocarbons found in the Wilcox reservoirs. This early work was followed by a study of Wilcox lignite from central and north Louisiana aimed at determining their sourcing potential and found them to be similar to Texas Wilcox coals (Mukhopadhyay, 1989; Goddard et al. 1992). Being geochemically similar and thermally immature, they are of lignite subbituminous rank. Because of their organic richness, they can be considered potential source rocks capable of generating crude oils at adequate thermal maturity. The organic geochemical results from the Wilcox shales indicate that variations throughout the Wilcox Group are minor. The central and northern Gulf Coast

Wilcox shales are thermally immature and incapable of sourcing crude oils. However, in the southern Gulf Coast, organic rich Wilcox shales are thermally mature and, in part, responsible for sourcing the Wilcox reservoirs in south Louisiana and Texas (Chinn, 1992).

As part of a detailed sedimentological, geochemical, petrophysical, and petroleum engineering study of the Bee Brake Field in east-central Louisiana, a continuous 510 foot conventional core was taken in the Angelina BBF No. 1 well (Schenewerk et al., 1994, Goddard, 1995) (Figure 1). The core was sampled in several middle and lower Wilcox shale and coal intervals for organic and geochemical analyses. Oil samples from the productive Minter interval were also analyzed geochemically. The objectives of this detailed organic geochemical study were the following: (1) determine organic matter and depositional variations within the cored interval; (2) determine the thermal maturity of the shales and coals; (3) identify the organic maturities and organic facies of the source rock for the Minter oil and (4) use the results of this study for oil-oil and oil-source rock correlation comparisons with data from previous regional studies.

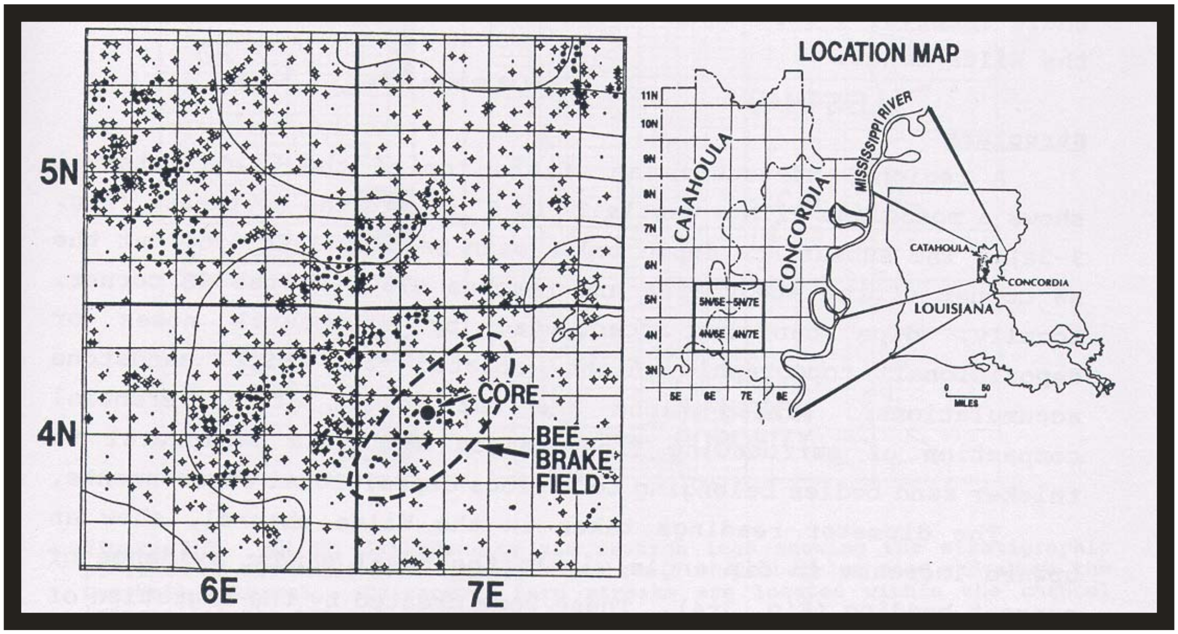

Figure 1: Location map showing where the core was taken in Bee Brake Field in Concordia Parish.

METHODOLOGY

Twenty-six rock samples from seven coal and nineteen shale beds were selected for analyses from Middle to Lower Wilcox core interval between 6361'3" and 6871'8" (e-log depths) (Figure 2). Also, one crude oil sample from the productive Minter reservoir in the lower Angelina sandstone at 6756'-6758' and an oil extract from the upper Bee Brake sandstone at 6744' were analyzed. The following organic geochemical techniques were used in the analysis of the rocks and oils: (1) Total organic carbon (TOC) and Rock-Eval analyses were completed on all twenty-six rock samples; (2) visual kerogen analysis techniques were employed for vitrinite reflectance and kerogen typing of twenty-two rock samples; (3) whole extract gas chromatography (gc) on fifteen samples and whole oil gc on two oils were performed to help determine the potential organic facies thermal maturity and for oil-rock correlations; (4) pyrolysis-gas chromatography (py-gc) of S_1 and S_2 from six samples, and (5) gas chromatography-mass spectrometry (gc/ms) of saturate biomarkers from five rock samples and 2 oil samples, (Table 1).

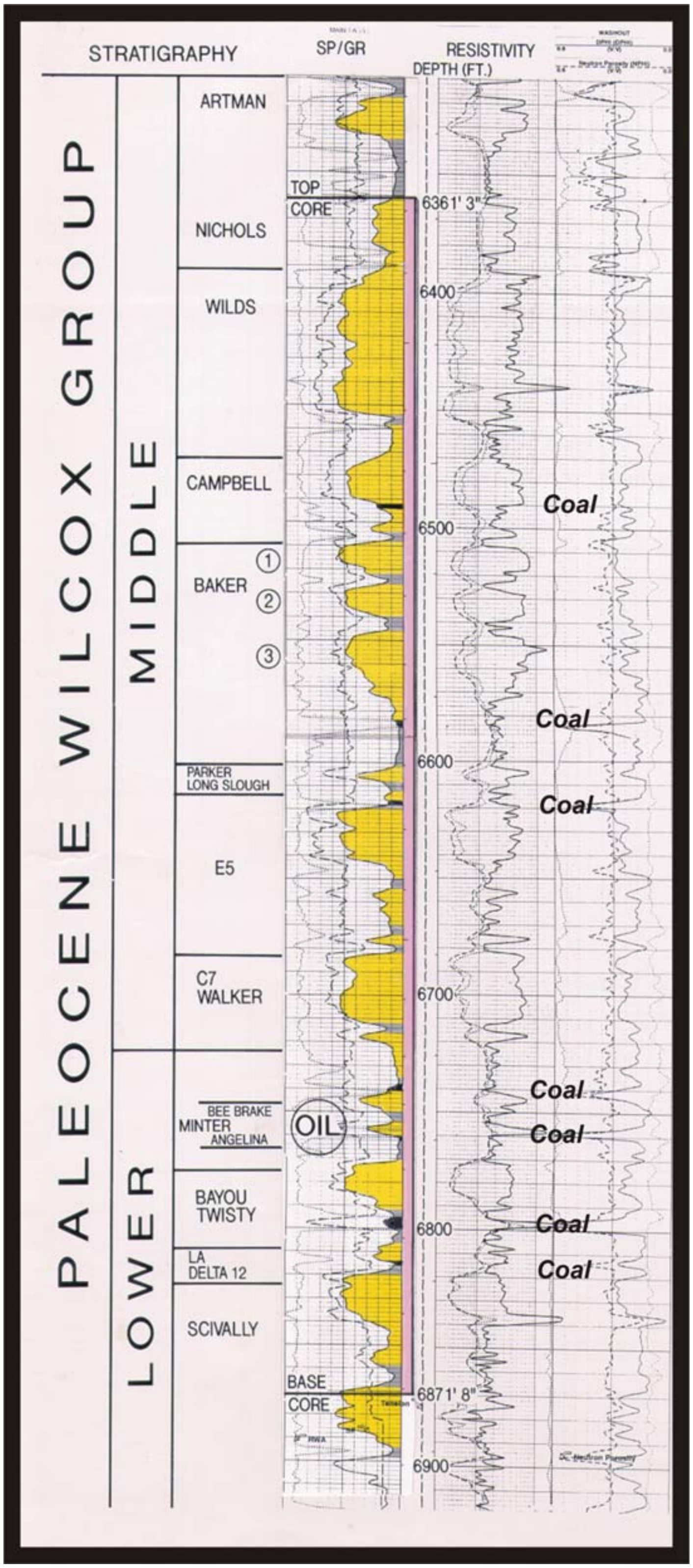

Figure 2: The cored interval in the Angelina BBF No.1 well between 6361' 3' and 6871' 8' showing the coal layers and the Minter reservoir from which the oil samples were selected.

TOC ROCK-EVAL PYROLYSIS

Based on the results of the TOC and Rock-Eval analyses (Table 2) the rock samples could be subdivided into the following four groups:

Group 1 consists of all the coals and four organic rich shales with TOC's between 7.15 and 27.17 (6525', 6648', 6770' and 6824'). These have high hydrogen indices (HI) and low oxygen indices (OI), suggesting deposition in oxygen-poor waters. On the Van Krevelen plot they are of mixed type II and III kerogen (Figure 3).

Group 2 consists of shales from 6455.25' and 6593', which have moderate HI's (223-276), moderate OI's (73-127 and high TOC's of 3.04 and 4.80 wt. %. They are composed of mixed types II and III kerogen (Figure 3).

Group 3 consists of shales (6363', 6541', 6674' and 6795') with maximum TOC's of 1.53 wt. % low HI's (86-130) and low to moderate OI's (35-101). These shales are composed of mixed type III and IV kerogens capable of generating some gas.

Group 4 consists of six shales (6384', 6386', 6499', 6507', 6732' and 6864') with a maximum TOC of 1.9 wt. % and low HI's (similar to Group 3), but possessing much higher OI's (188-527). These shales contain types III and IV kerogen (Figure 3) deposited under oxic conditions and having the potential of generating some gas.

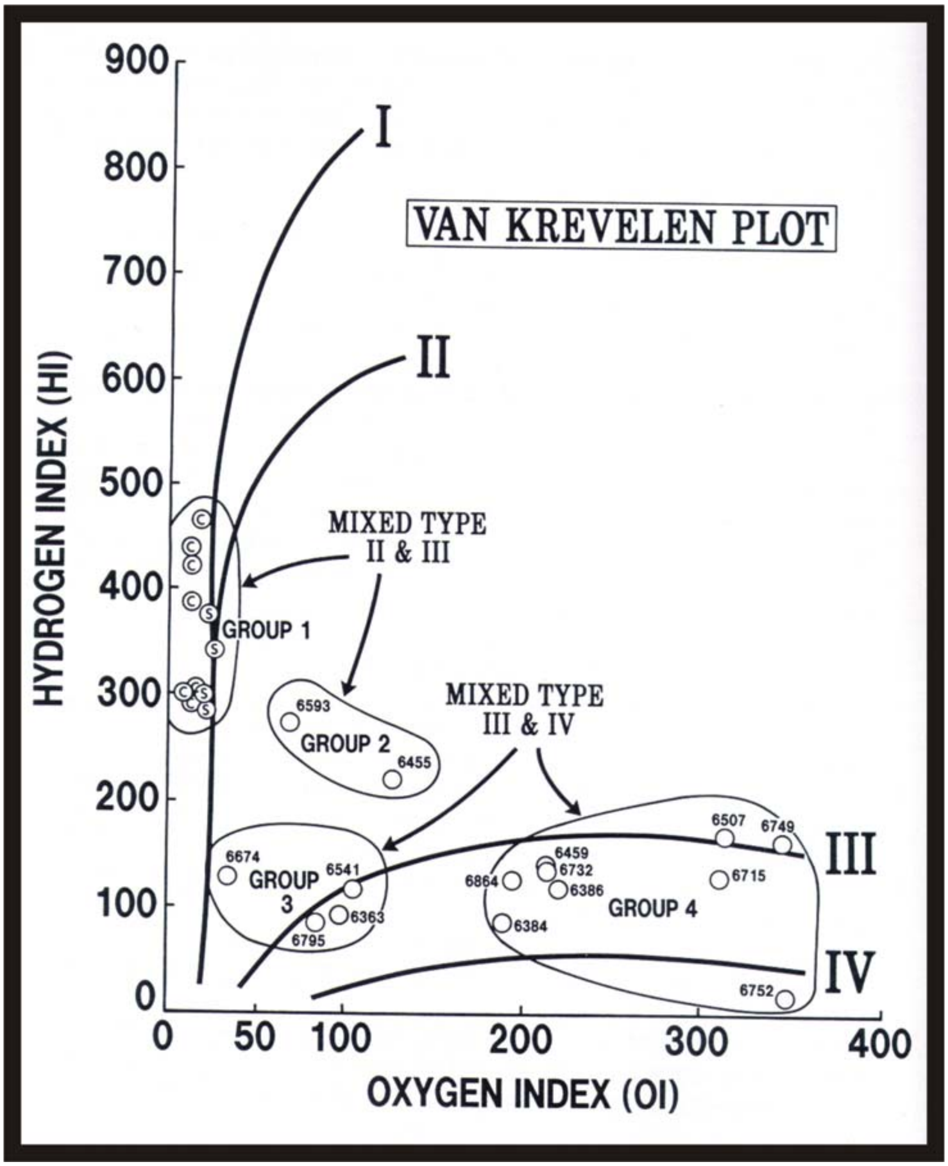

Figure 3: The Van Krevelen diagram showing the division of the Kerogen types into four groups.

KEROGEN PETROGRAPHY

Results from the kerogen microscopy show a 0.44% R_o mean reflectance for both the coals and the shales. The reflectance data places the coals within the thermally immature lignite - subbituminous rank.

Group 1 coals and shales are petrographically different. The coals contain 5 to 15% structured lipids comprised mainly of resinite and sporinite with subordinate liptodetrinite and cutinite. Desmocollinite, a lipid-rich vitrinite (VL) is prominant in all these coals. Amorphous kerogen is absent in the coals. The shales, however, have 10 to 75% amorphous kerogen but less structured lipids and lipid-rich vitrinite when compared to the coals. The amorphous kerogen in the shales is hydrogen rich, thus having good potential for oil generation.

Group 2 shales contain 50 to 85% amorphous kerogen, 10% structured lipids and little or no lipid-rich vitrinite. The kerogens have low oil and gas generating potential.

Group 3 shales contain 45 to 80% amorphous kerogen and low content of structured lipids and lipid-rich vitrinite (5% or less). The kerogens could generate some gas.

Group 4 shales have high (50 to 90%) amorphous kerogen content, small amounts of structural lipids, but lipid-rich vitrinite is absent. The kerogen could generate some gas. The maceral contents of the coals suggest they were deposited in a lower delta plain environment in the following facies:

6492' - marsh
6584'6" - wet forest swamp
6619' - low lying marshy land
6742'6" - low lying marshy land
6758' - fresh water reed swamp
6798' - low lying marshy land
6814' - fresh water reed swamp

PYROLYSIS - GAS CHROMATOGRAPHY

Pyrolysis - gas chromatography (py-gc) of S_1 and S_2 was carried out on two coal and four shale samples (Table 1). The S_2 py-gc data suggest that the two coals (6492' and 6619') are capable of generating highly paraffinic crude oils at adequate maturity. On the other hand, the shales would generate less waxy crude oils when mature. Also, the S_2 py-gc chromatograms of the shales (6507' and 6770') indicate they are all similar, suggesting they have similar organic matter constituents. The high waxy components observed in the S_2 py-gc of the coals (Figure 4 A) correlate with the high (35-50%) lipid-rich vitrinite content. The shales, however, do not exhibit high C25+ waxy components in the S_2 py-gc chromatograms (Figure 4 A).

GAS CHROMATOGRAPHY - MASS SPECTROMETRY (SATURATE BIOMARKERS - ROCKS)

Gas chromatography-mass spectrometry (gc/ms) analyses on saturate biomarkers were made on two coals (6492' - 6619') and three shales (Table 1). Terpane (m/z 191) data show a close similarity among the samples. Of the pentacyclic terpane peaks marked 1, 2, 3 and 4, peak 2 has the highest concentration. It is a bionomoretane representing terrigenous organic matter (Figure 4 B). Major contributors to peaks 3 and 4 are probably C30 demethylated hopanes which also indicate a contribution of terrigenous organic matter. The biomarker analyses of these samples also showed that their thermal maturities were very low and in agreement with the measured values of about 0.44% (mean value).

GAS CHROMATOGRAPHY - MASS SPECTROMETRY (SATURATE BIOMARKERS - OILS)

Biomarker analyses on an oil sample from the Angelina sand and an oil extract from the overlying Bee Brake sand were carried out to evaluate their biologically derived compounds. Terpane (m/z 191) and sterane (m/z 217) distributions show that the samples are very similar, indicating the same organic matter and thermal maturity for both. Also, the terpane distribution and the lack of the 4 peaks in the oils indicate they are quite different from the coals and shales that are stratigraphically near the Minter reservoir (Figure 4 B). The total % composition and terpane (m/z 191) ratios clearly indicate the differences between the oil and the surrounding rocks. The GC/MS data on the oils indicate that they are mature and derived from a shaly source rock containing mixed organic matter with bacterial, algal, and terrigenous components. Equilibrium values in hopane isomerization (56%) and those in sterane isomerization (57%) of the oils indicate thermal maturities close to peak oil generation at 0.80 - 0.90% R_o.

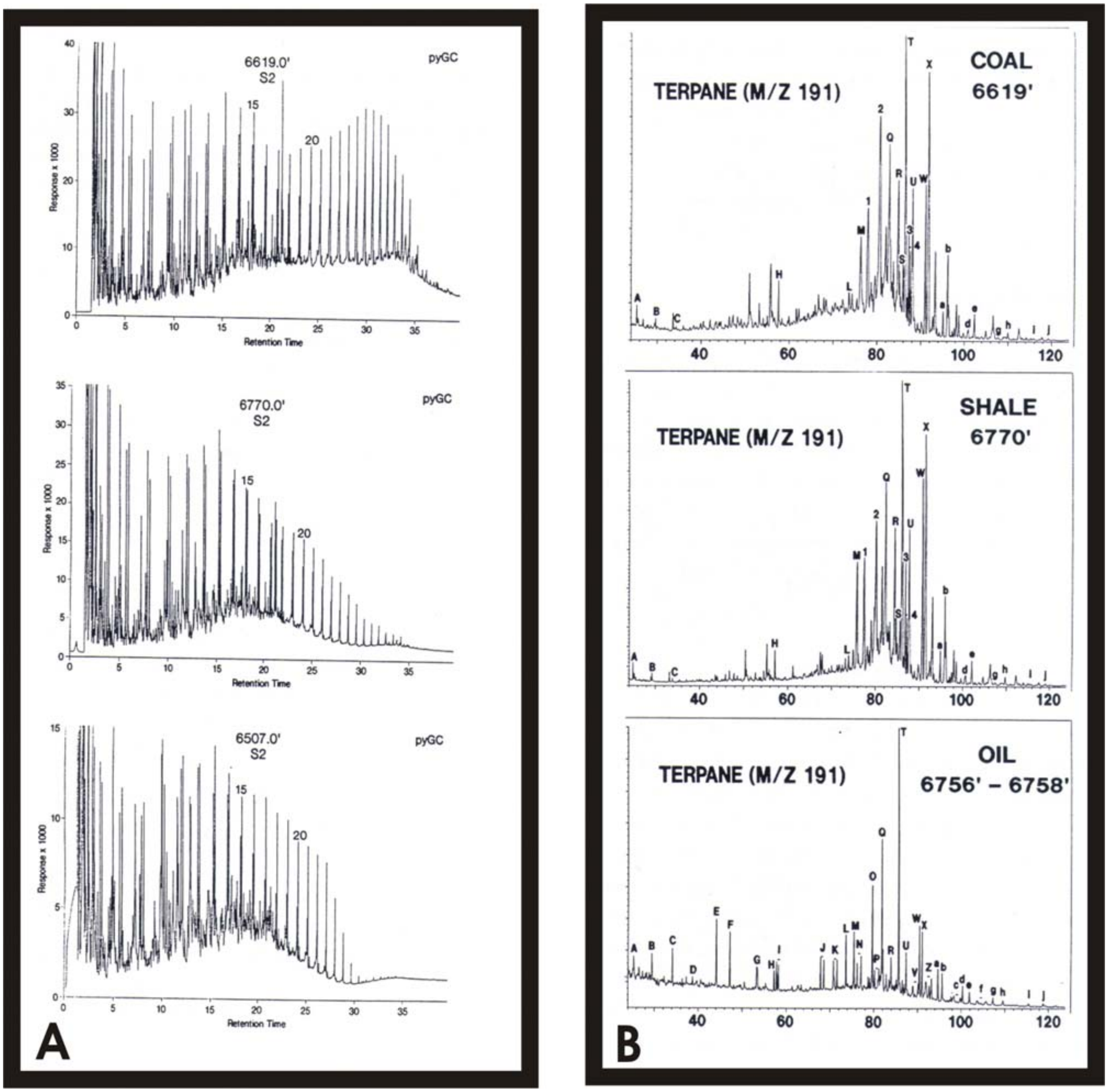

Figure 4: (A) The pyrolysis gas chromatogram (S2) of a coal (6619') and two shales (6770' & 6507') indicate that the shales do not exhibit the high C25+ waxy components of the coal. In (B) the gc-ms analysis of terpanes (m/z -191) in the coal, shale, and oil samples shows that the oil is quite different from the rocks.

WHOLE EXTRACT AND WHOLE OIL GC

Whole extract gas chromatograms of 7 coals and 9 shales indicate that they are immature and contain essentially terrestrial organic matter. Whole oil gas chromatograms of the Minter oils (Angelina and Bee Brake) are very similar with a minor but significant presence of C_{25+} n-alkanes. This suggests the source rock consisted of mixed organics with significant terrigenous components. The oils were expelled at a thermal maturity of about 0.80 - 0.90 R_o equivalent. The chromatograms in Figure 5 show the similarities between the shale and coal and their definite lack of correlation with the Minter oil.

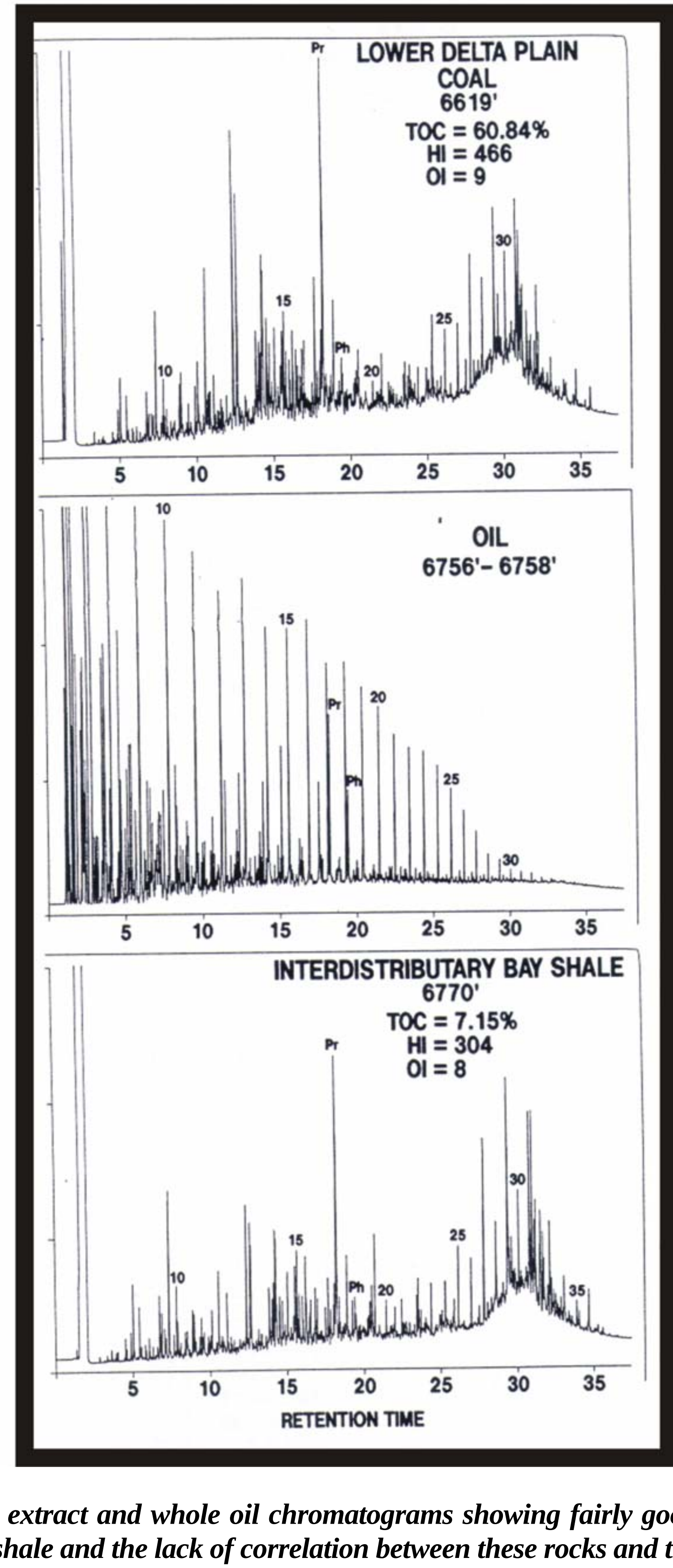

Figure 5: Whole extract and whole oil chromatograms showing fairly good correlation between the coal and the shale and the lack of correlation between these rocks and the oil.

CONCLUSIONS

The core interval (6361'3" - 6871'8") from the Angelina BBF No. 1 Well, Bee Brake Field, Louisiana contains several thin beds of immature (mean reflectance 0.44% R_o), coals and organic-rich to organic-lean shales with dominant terrigenous organic matter constituents. Based on TOC values and amorphous kerogen content these samples could be separated into four groups. The strata represent middle and early Wilcox deposition in a lower delta plain environment. Reflectance data places the coals within the lignite-subbituminous rank. The coals (6492', 6584'5", 6619', 6742'5", 6758', 6798' and 6814') and organic-rich shales (6525', 6648', 6770' and 6824') contain oil-prone Type II-III kerogen capable of generating oil at adequate maturity. Kerogen petrography data support their deposition on a lower delta plain. These types of coals usually have high gelification indices and low tissue preservation indices and are commonly deposited in oxygen poor waters in fern-marsh and limno-telmatic subenvironments of the lower delta plain. Moderately organic-rich shales at 6455'3" and 6593', contain immature, mixed Type II-III kerogen with a type III emphasis. These shales have the potential of generating small amounts of oil and some gas at adequate maturities. Organic-lean shales at 6363', 6384', 6386', 6459'5", 6499', 6507', 6541', 6674', 6732', 6795' and 6864' are immature with low HI indices and Type III-IV kerogen. These shales, which occur as interdistributary bay deposits of the lower delta plain, are capable of expelling some gas when mature and seem to reflect more oxic depositional conditions. This conclusion is based on kerogen petrography Rock-eval, py-gc (S_2) and saturate-gc/ms data, the decrease in kerogen quality (HI), and TOC content.

The organic geochemical results indicate that oil in the Minter reservoir was sourced by a mixed organic facies with a thermal maturity of 0.80 - 0.90% R_o (Figure 6). These characteristics are quite different from those of the immature (0.44% R_o) surrounding Wilcox rocks. From this, the most plausible conclusion is that these Wilcox oils originated in older source rocks and not within the chronostratigraphic Wilcox itself.

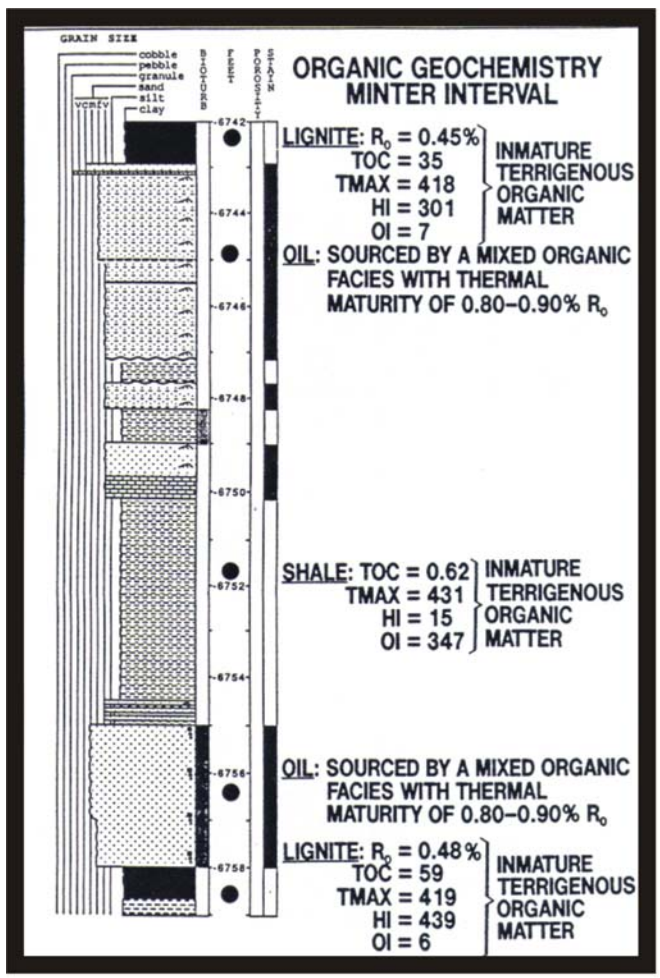

Figure 6: Organic geochemical results of the coals, shales and oils within the Minter reservoir.

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TABLE 1: Shale, coal and oil samples from Angelina BBF No. 1 well.

Depth (Feet)	Sample	TOC Rock Eval	Kerogen Petrography	Whole Extracxt & Oil GC	Pyrolysis GC	GC Mass Spec & Biomarkers
6363'	Shale	X	X			
6384'	Shale	X	-			
6386'	Shale	X	X	X		
6455'3"	Shale	X	X	X	X	X
6459'5"	Shale	X	-	-		
6492'	Coal	X	X	X	X	X
6499'	Shale	X	X	-		
6507'	Shale	X	X	X	X	
6525'	Shale	X	X	X	X	X
6541'	Shale	X	X	-		
6584'5"	Coal	X	X	-		
6593'	Shale	X	X	X		
6619'	Coal	X	X	X	X	X
6648'	Shale	X	X	X		
6674'	Shale	X	X	-		
6715'	Shale	X	-	-		
6732'	Shale	X	X	X		
6742'5"	Coal	X	X	X		
6744'	Oil	-	-	X		X
6752'	Shale	X	-			
6756'	Oil	-	-	X		X
6758'	Coal	X	X	X		
6770'	Shale	X	X	X	X	X
6795'	Shale	X	X	-		
6798'	Coal	X	X	X		
6814'	Shale	X	X	X		
6824'	Shale	X	X	X		
6864'	Shale	X	X	-		

Table 2
Total Organic Carbon (TOC) and Rock-Eval Pyrolisis Data
Angelina BBF No. 1 Well

SAMPLE	DEPTH (Feet)	TOC	S1	S2	S3	TMAX	HI	OI
Shale 1	6363.0	0.93	0.20	0.82	0.91	426	88	98
" 2	6384.0	0.89	0.21	0.82	1.67	430	92	188
" 3	6386.0	0.91	0.30	1.09	2.00	430	120	220
" 4	6455.3	3.04	0.41	6.79	3.85	428	223	127
" 5	6459.5	0.76	0.31	1.02	1.62	435	134	213
Coal 6	6492.0	63.28	22.78	265.92	3.62	415	420	6
Shale 7	6499.0	1.08	0.07	1.76	5.69	431	163	527
" 8	6507.0	1.90	0.10	3.23	5.96	431	170	314
" 9	6525.0	11.95	1.24	34.14	1.20	415	286	10
" 10	6541.0	1.53	0.06	1.88	1.55	433	123	101
Coal 11	6584.5	60.59	11.20	234.80	3.40	416	388	6
Shale 12	6593.0	4.80	0.41	13.24	3.50	425	276	73
Coal 13	6619.0	60.84	13.90	283.57	5.35	419	466	9
Shale 14	6648.0	7.65	0.80	28.80	0.87	422	376	11
" 15	6674.0	1.00	0.09	1.30	0.35	426	130	35
" 16	6715.0	0.47	0.05	0.62	1.46	529	132	311
" 17	6732.0	1.03	0.13	1.43	2.21	428	139	215
Coal 18	6742.5	35.06	12.52	105.49	2.39	418	301	7
Shale 19	6752.0	0.62	0.05	0.09	2.15	431	15	347
Coal 20	6758.0	59.36	25.25	260.50	3.81	419	439	6
Shale 21	6770.0	7.15	0.65	21.77	0.60	425	304	8
" 22	6795.0	0.99	0.03	0.85	0.86	432	86	87
Coal 23	6798.0	66.71	9.60	199.80	7.00	412	300	10
" 24	6814.0	69.97	11.75	210.74	3.20	420	301	5
Shale 25	6824.0	27.17	5.33	92.62	3.28	414	341	12
" 26	6864.0	1.02	0.08	1.36	1.95	430	133	191