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A Re-Evaluation of the Northern A.W.P. Field, McMullen County, Texas

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ABSTRACT

The A.W.P. is a prolific field that has produced from the Cretaceous Olmos Sandstone since its discovery in 1975. This study focuses on the northern part of the A.W.P. Field, located in McMullen County, Texas. This part of the field was believed to be near the end of its productive life; however, recent activity has produced significant hydrocarbons, prompting a re-evaluation of the potential of the A.W.P. Field. We present the results of a subsurface investigation of two formations within the A.W.P. Field: the Cretaceous Olmos and Paleogene Wilcox-Wales formations. Using well-log correlation, seismic analysis, and production data, we present a complete re-evaluation of the A.W.P. Field. The results of this study show that within the A.W.P. Field the reservoirs thin out in the updip direction (toward the northwest), but maintain a significant thickness, which suggest that the field still has potential for growth. Volumetric analysis reveals that there is remaining resource potential in both the Olmos and Wales formations. In particular, the Wales Formation remains mostly untapped. With recent improvement in unconventional and horizontal drilling and recovery, there is still potential for field growth in the A.W.P. Field.

INTRODUCTION

The calculated growth in the global demand for energy will almost certainly be met through field growth techniques (sensu USGS World Energy Assessment Team, 2000) that utilize improved recovery and reserve additions in extant mature hydrocarbon provinces rather than frontier exploration (Campbell and Laherrere, 1998; Attanasi et al., 1999; Deffeyes, 2005; Benes et al., 2015).

The A.W.P. is a prolific field in McMullen County, Texas, that has produced 110 million barrels of oil (MMBO) and 1227 billion cubic ft of natural gas (BCFG) from the Olmos Sandstone since its discovery in the early 1980s, according to a 2003 U.S. Geological Survey assessment (Condon and Dyman, 2006). The purpose of this study is to perform a comprehensive evaluation of the A.W.P. Field, focusing on a study area located in the northern part of the field. Based on geophysical, geological, and engineering data, we identify the geological structure and stratigraphy, evaluate hydrocarbon production and reserves, and consider the potential for field growth in the Upper Cretaceous Olmos Formation and the Paleogene Wilcox-Wales formation.

STUDY AREA

The A.W.P. Field is located in McMullen County, Texas, approximately 4 to 6 mi southeast of the town of Tilden in the Rio Grande Embayment (Fig. 1). The productive reservoir extends approximately 4 mi east-west and 7 mi north-south (Dennis, 1987; Peard et al., 1991). Early exploration in the A.W.P. Field focused on the Lower Cretaceous formations associated with the Edwards shelf edge (Stuart City Reef). Further exploration revealed the potential of the Olmos Formation. The Olmos Formation is absent on top of the shelf edge, but extends downdip of the reef trend and extends along the reef's strike, defining a shelf/slope transition (Fig. 2). The oil and gas accumulation is stratigraphically controlled. However, the poor and variable reservoir qualities (tight sandstone) of the Olmos lead to mitigated success in this part of the field. Most recently, operators have recognized that the Olmos Formation covers most of the northern part of the field, where the study area is located (Fig. 2). The reservoir is a depletion drive which requires fracture stimulation to be productive (Peard et al., 1991). Recent advances in horizontal drilling, and recovery technologies have revived interest in the A.W.P. Field (Sholtz and Moriarty, 2015).

This study focuses on two formations, the Upper Cretaceous Olmos Formation, and Paleogene Wales sand of the Lower Wilcox Group, both productive within the A.W.P. Field (Fig. 3). In the study area, the Olmos and Wales thicknesses range from 10–52 ft and 29–61 ft, respectively. The subsea total vertical depth (SSTVD) of the Olmos ranges from 8700 to 9244 ft and the depth of the Wales ranges from 5535 to 6194 ft. In the A.W.P. Field, oil has been found in the northern area whereas gas is predominately found in the southern area (Fig. 2). Previous work conducted in the study area suggested that both the Olmos and Wales reservoirs pinched out toward the west, accompanied with a westward decrease in rock quality (Tyler and Ambrose, 1986; Dennis, 1987). However, recent exploration west of the study

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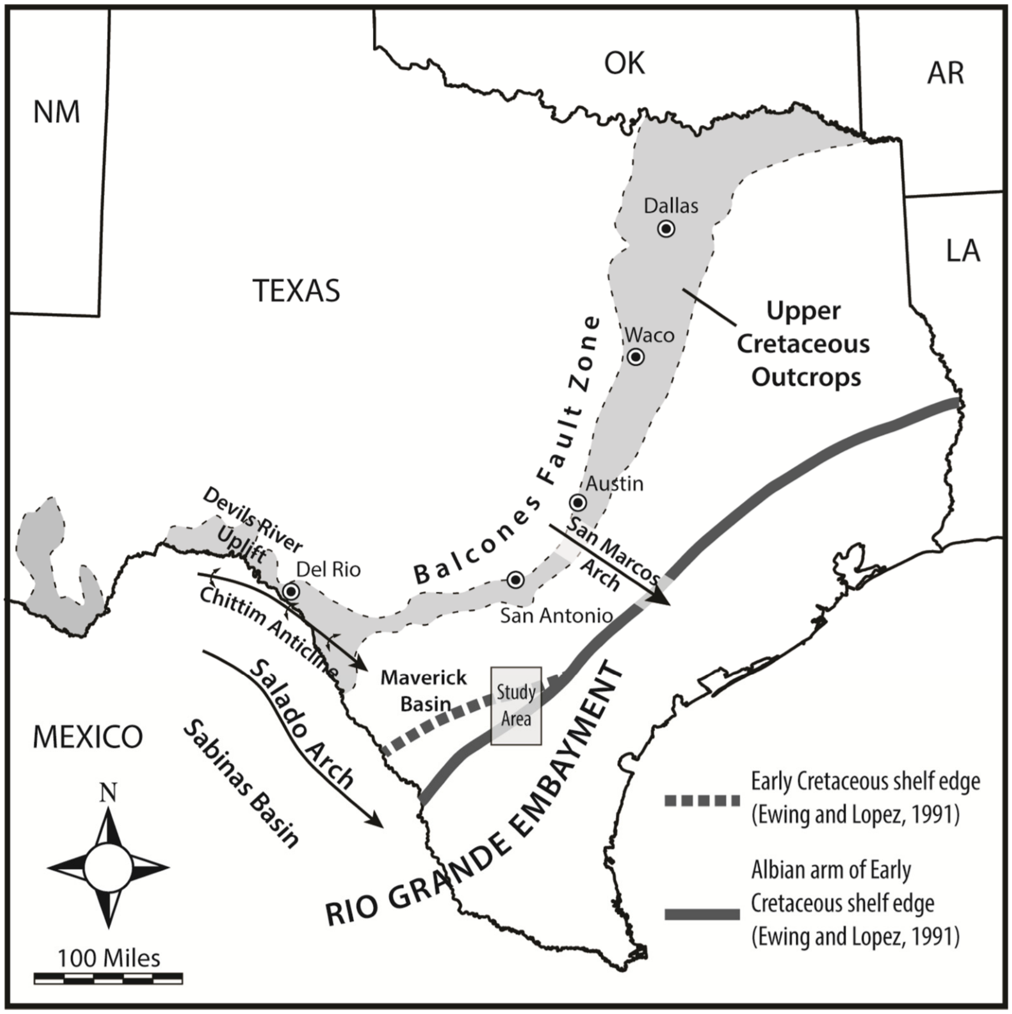

Figure 1. Structural framework of the Maverick Basin, showing the location of the study area (modified after Barrow et al. [1992] and Condon and Dyman [2006].

area has proven to be successful, which prompted a reevaluation of the remaining potential of the field, presented in this study.

REGIONAL GEOLOGY

The Maverick Basin

The A.W.P. Field is located within the Rio Grande Embayment, a broad synclinal area southwest of the San Marcos Arch that separates Central Texas from the Laramide fold systems of Mexico (Ewing, 1991) (Fig. 1). The Rio Grande Embayment extends into northeastern Mexico (Ewing, 1991; Condon and Dyman, 2006) and is generally aligned with the northwest-trending Precambrian Texas lineament along the Rio Grande River. The A.W.P. Field is situated in a small depression in the Rio Grande Embayment, on top the Edwards reef trend in the county of McMullen, south of the Balcones Fault Zone (Fig. 1). This area of the Rio Grande Embayment is bounded on the northeast by the San Marcos Arch, on the north by the Balcones Fault Zone, and on the west in Mexico by the Salado Arch. Subsidence initiated in the late Early Cretaceous and responded as a foreland basin to Laramide tectonism in the Late Cretaceous to Paleogene. Upper Cretaceous strata in the Maverick Basin display homoclinal dip to the southeast and east-southeast at 50–150 ft/mi (Barrow et al., 1992).

Structure

The A.W.P. Field is in an area of structural dip that is typical for the Gulf Coast (Fig. 4). Dip is, for the most part, in a basinward direction, or south-southeast (Dennis, 1987). The downdip trend overlies the northeast-southwest trend from the Lower Cretaceous shelf edge (Edwards Reef) (Fig. 4). A number of small (generally less than 150 ft of displacement) normal faults cut through the productive strata, and generally trend northeast-southwest and are downthrown to the coast. Faulting is largely the result of the final stages of compaction over the Edwards Reef (Snedden and Kersey, 1982; Pauls et al., 1985; Dennis, 1987; Barrow et al., 1992).

The study area is located in the updip (north) part of the A.W.P. Field (Fig. 2), which is characterized by a homoclinal dip to the southeast at an approximate rate of 140 ft/mi (Snedden and Kersey, 1982; Pauls et al., 1985; Dennis, 1987; Barrow et al., 1992). With no apparent fault-related dip changes (e.g., rollover, dip likely in same direction as fault dip so no upthrown closure, etc.), the trapping of hydrocarbons is likely stratigraphically controlled (Dennis, 1987). The difference in depths of the Olmos and Wales horizons from the updip regions to the downdip regions seems to be dominated by structural dip, rather than large-scale faulting.

Stratigraphy and Depositional Environment

Olmos Formation

The Olmos Formation was deposited during the latest stage of the Cretaceous Period (early Maastrichtian) (Snedden and Jumper, 1990; Trevino et al., 2007) (Fig. 3). The Olmos can be correlated as a continuous unit over the study area. It conformably overlies the San Miguel Formation and is disconformably

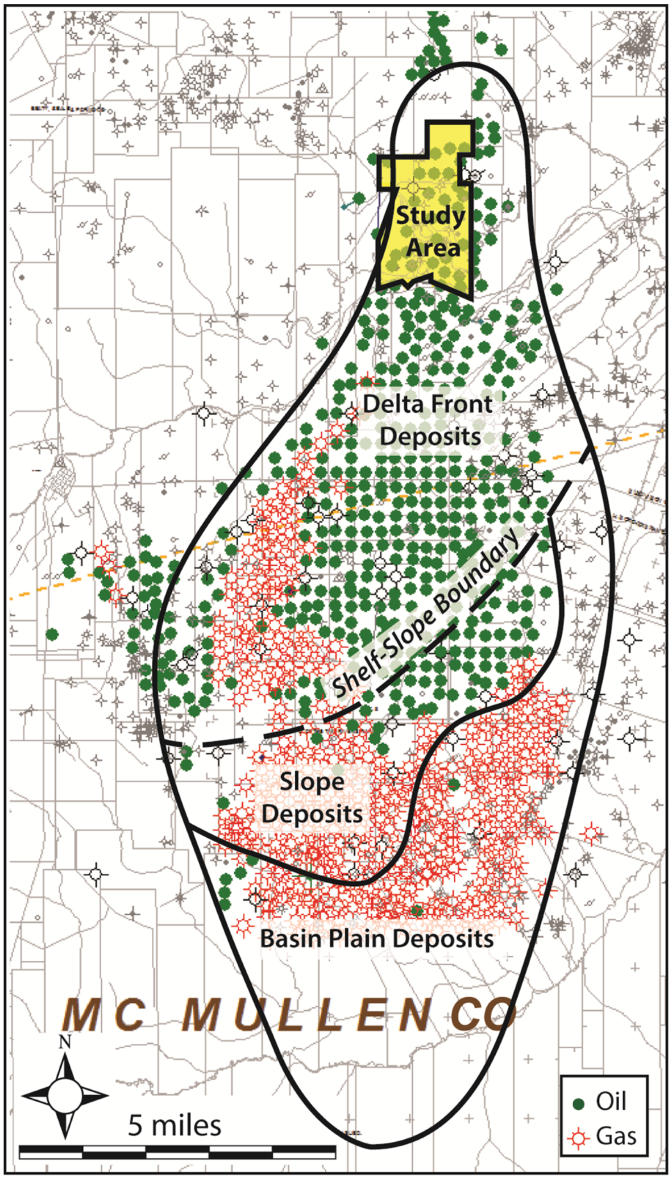

Figure 2. A.W.P. Field (study area in yellow) (modified after Dennis, 1987). There were 1047 well logs available for the A.W.P. Field and relevant to the regional base map, and 41 well logs within the study area. An additional 77 well logs (for a total of 118) were used to complete the detailed work.

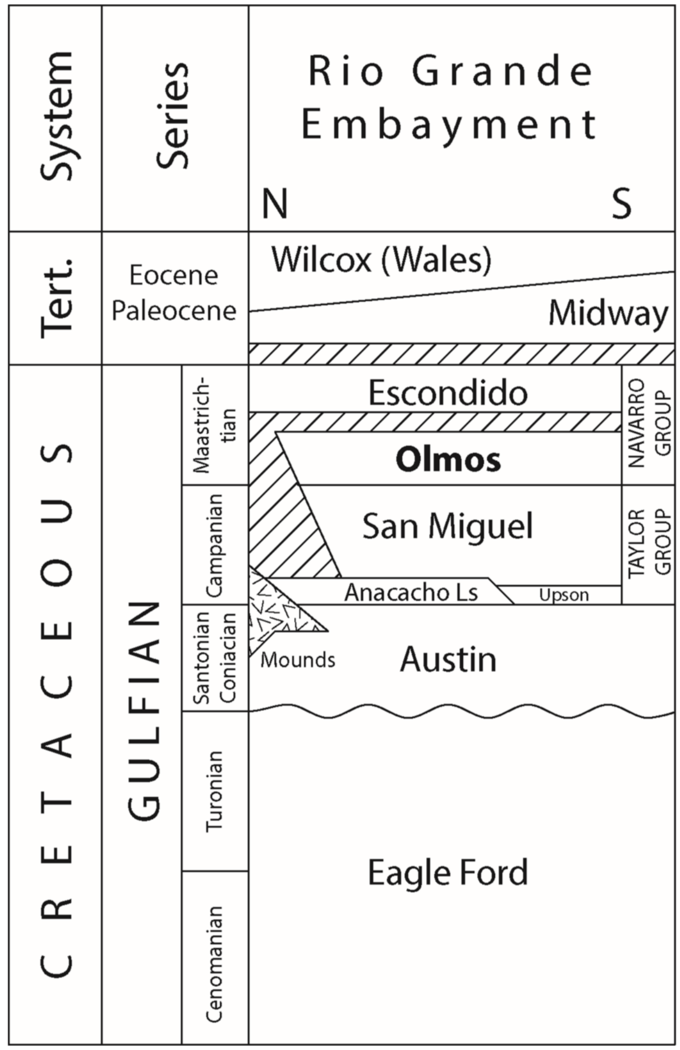

Figure 3. Stratigraphic column of the A.W.P. Field (modified after Ewing [1991] and Condon and Dyman [2006]).

overlain by the Escondido Formation (Fig. 3). Siliciclastic sedimentation succeeded early Late Cretaceous carbonate deposition that culminated in the widespread accumulation of the Austin Chalk and correlative unit of the Anacacho, a slightly limy shale or marl in the A.W.P. Field (Barrow et al., 1992). Siliciclastic influx into the Rio Grande Embayment was initiated in response to Laramide tectonic deformation to the west and northwest (Trevino et al., 2007). Uplift of the northern margin of the Maverick Basin prior to the deposition of the Escondido Formation led to erosion and truncation of the Olmos and San Miguel formations.

The Olmos Formation and underlying San Miguel Formation share similar characteristics. In the Maverick Basin, the Olmos Formation was deposited in two distinct depocenters associated with a northwestern and northern source (Tyler and Ambrose, 1986). In the A.W.P. Field, the northern source fed deltaic sands that prograded from the north and accumulated along the shelf edge (Fig. 2). Faulting on basinward dipping fault parallel to the shelf edge caused the sands to fail and slump down the shelf-edge slope, where sands were redeposited on the slope and at the base of the slope in sheets (Tyler and Ambrose, 1986; Dennis, 1987; Condon and Dyman, 2006). This environment of deposition gave rise to sand accumulations in three distinct depositional settings within the A.W.P. Field: (1) deltaic sand deposits on the updip side of the slope; (2) slope or proximal ramp deposits; and (3) a series of marine sand sheets with local, lens-like buildups sometimes called 'offshore bars' in the downdip parts of the eastern Rio Grande Embayment (Tyler and Ambrose, 1986; Dennis, 1987; Snedden and Jumper, 1990; Barrow et al., 1992; Condon and Dyman, 2006).

In the study area, the environment of deposition of the Olmos is neritic to open marine during the Late Cretaceous (Snedden and Kersey, 1982; Dennis, 1987; Trevino et al., 2007). The Olmos assemblage in the A.W.P. Field is primarily a stratigraphic accumulation in which the Olmos reservoirs are truncated updip by an unconformity and overlain by impermeable shale (Tyler and Ambrose, 1986). The Olmos has been divided into five distinct porous members, or lobes (Tyler and Ambrose, 1986; Dennis, 1987). The reservoir rock is a very fine grained to fine grained sandstone (Dennis, 1987). The Olmos is sealed by the overlaying marine shale of the Escondido Formation (Dennis, 1987).

The Olmos can be divided in two stratigraphic units: Olmos A (upper) and Olmos B (lower), that contribute to the production

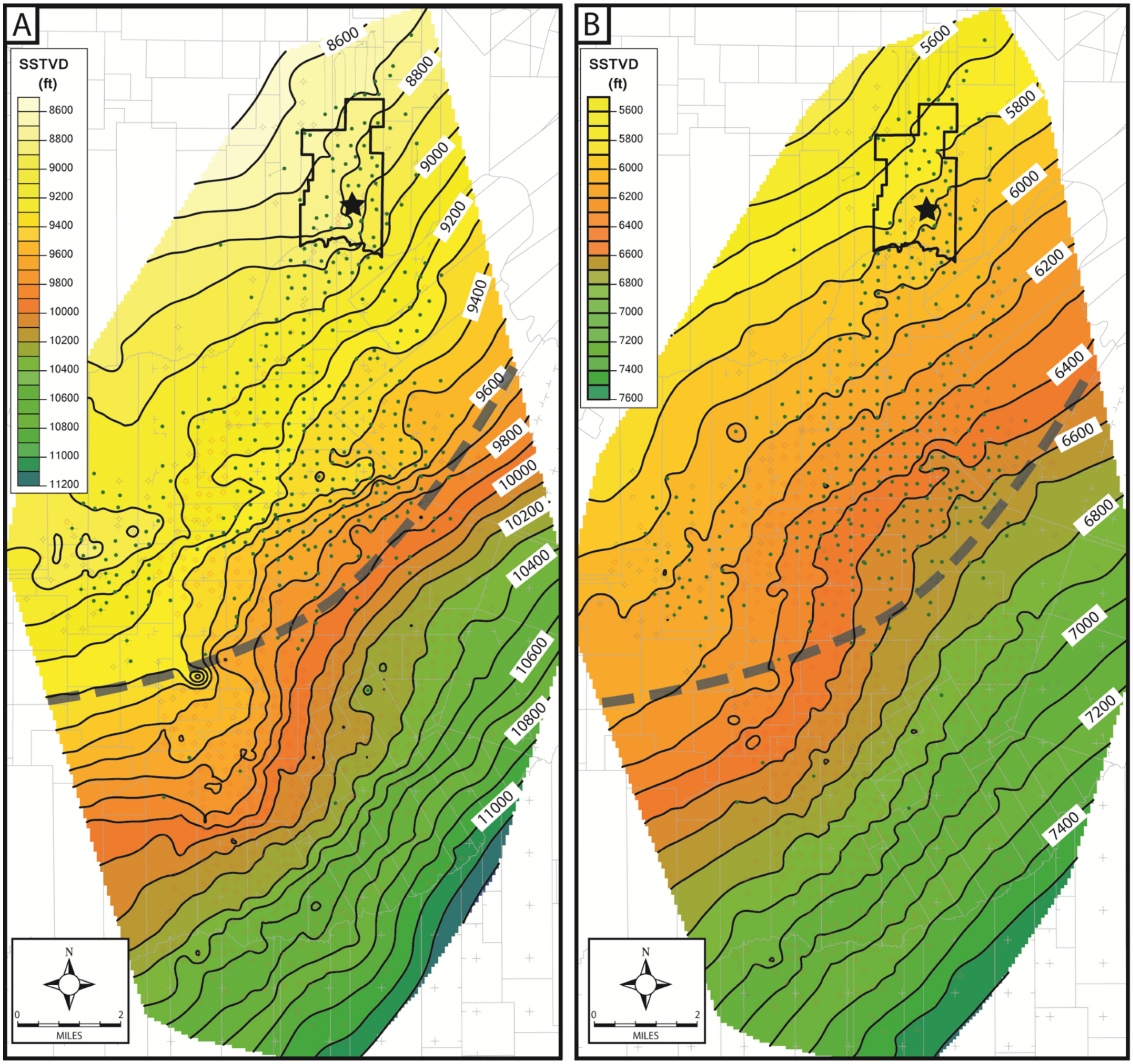

Figure 4. Structural contour maps of the top of the (A) Olmos and (B) Wales formations, showing the structural dip of both formations in the basinward direction (toward the southeast). Dashed line represents the shelf/slope boundary. SSTVD = subsea true vertical depth.

in northern A.W.P. Field (Travis, 1985). Olmos A consists of up to four sand members that overlie the Olmos B, a silty, very fine grained member having less permeability and porosity (Dennis, 1987). The two units are separated by a 12 ft to 20 ft thick shale unit (Dennis, 1987). Each porous member of the Olmos A is separated by a shale member 2 ft to 10 ft thick (Dennis, 1987). The shale beds have been interpreted to represent periods of transgression or a decrease in the supply of sediment load (Dennis, 1987).

Wales Formation

The Wales Formation is part of the Paleogene Lower Wilcox Group (Phornprapha et al., 1992; Breyer et al., 2001), and was deposited in two separate depositional systems (Phornprapha et al., 1992). The first comprises sands deposited in a marine setting, below wave base in open water, offering up regressive sheet sand bodies landward (Coppinger and Shultz, 1983; Phornprapha et al., 1992). The second was by the development of deltaic distributary sands filling channels, and ultimately truncating the earlier marine deposits (Coppinger and Shultz, 1983). Eight sands, B1–B8, comprise the Wales sand interval (Phornprapha et al., 1992); however within the A.W.P. Field and the study area, only the B1 and B2 sands are found, and only limited information regarding the Wales is available. The lower sand body, 'Wales lobe A,' has produced hydrocarbons, while 'Wales lobe B' has produced nothing but water, and well logs indicate that it is indeed wet throughout the study area.

Petrophysics

In the A.W.P. Field, the porosity of the Olmos reservoir ranges from 10–28% as measured by density log curves and averages 18% for the productive interval (Dennis, 1987). The total thickness of the productive interval ranges from 15 to 50 ft in the updip part of the field and 50 to 110 ft in the downdip extension (Dennis, 1987). The Olmos thins to the north-northwest but maintains its reservoir quality. The Olmos gradually loses its porosity and permeability to the south-southeast, or downdip, but maintains bed thickness (Dennis, 1987). The permeability of the Olmos reservoir decreases gradationally from 1 millidarcy updip to 0.01 millidarcies downdip due to an increase in clay content in the sediment deposited basinward (Dennis, 1987).

Current wells producing from the Olmos are characterized by a steep production decline. The subsurface data show that there are many faults that cut the Olmos Formation, but do not break the continuity of hydrocarbon migration. Most faults are contained in an interval from approximately 1000 ft above to approximately 100 ft beneath the Olmos Formation (Dennis, 1987). The Olmos is a tight sandstone, and is similar to unconventional shale reservoirs, which require hydraulic fracturing.

The Wales Formation has been subject to little investigation within the A.W.P. Field. In productive wells, our preliminary data show that porosity in the Wales reservoir ranges from 8–18% as measured by density log curves and averages 14% within the study area; net thickness of the productive interval ranges from 5–18 ft with little consistency.

METHODOLOGY

Data Acquisition

There were 1047 well logs available for the A.W.P. Field and relevant to the regional base map, and 41 well logs within the study area. An additional 77 well logs (for a total of 118) were used to complete the detailed work within the study area. These additional wells were selected based on their log curve (especially spontaneous potential and gamma ray) quality, and whether or not at least one of the formations of interest was fully penetrated. Well logs that were unreadable or very shallow, with a subsea true vertical depth of 4500 ft or less were not selected for study. Selected wells were quality controlled, edited, corrected when necessary, and imported into Petra®.

Correlation Framework

The Thetford #3 well (White Oak Operating Company LLC), located near the center of the study area (Fig. 4), was chosen as the type log for this project to aid with stratigraphic identification. Detailed correlations were made of the tops and bases of the Olmos Formation and Wales Formation throughout the entire A.W.P. Field in order to display the basinward structural dip (Fig. 4).

Eight supplemental correlation markers were added to the Olmos and Wales Formation markers, to follow the structure with depth in order to add more detail and use the series of markers as quality control points. These markers average 645 ft in depth of separation, and were chosen based on distinct characteristics on the type log permitting correlation throughout the study area. These distinct characteristics are either: (1) spikes in the conductivity curve, (2) significant spikes in the resistivity curve, or (3) a distinct showing on the spontaneous potential curve. By adding these markers we were able to investigate changes in strike and dip of the formations throughout the study area, assist in identifying faults, and eventually produce gross sand isopach maps for the Olmos and Wales formations (Figs. 5 and 6).

Seismic Interpretation

The structure of the study area was investigated using a 3D seismic survey in order to identify faults and constrain the lateral continuity of the horizons. The seismic data are proprietary and belong to Seitel Data Ltd., and will not be displayed. However, we present seismic interpretation maps highlighting the structure within the study area. The analysis of the 3D seismic data revealed the presence of 15 faults within the study area (Fig. 7). Seven faults cross the top of the Olmos (Fig. 7A), and four faults cross the top of the Wales (Fig. 7B). None of the faults cut through both the Olmos and Wales horizons. The seismic data also reveal that both the Olmos and Wales are continuous throughout the study area, and exhibit a consistent dip rate of approximately 120–150 ft/mi for both formations.

DISCUSSION OF THE SUBSURFACE GEOLOGY

Structure

The fieldwide subsurface maps of the top of the Olmos (Fig. 4A) and Wales (Fig. 4B) show a homogeneous dip toward the Gulf Coast. The top of the Olmos shows a steepening in the central portion of the field, which may be related to differential compaction and/or faulting caused by the Cretaceous Edwards shelf edge.

Seismic interpretation reveals that faults within the study area extend laterally between 2000 and 7000 ft, with vertical penetration lengths ranging from 300 to 2000 ft, associated with 30 to 60 ft of offset (Fig. 7). The faults strike northeast-southwest, and have an average dip of ~45°, which is consistent with regional strike and dip of faults in South Texas (Collins, 1987).

Isopach Maps

The top and bottom of the Olmos and Wales formations were correlated across the entire A.W.P. Field in order to produce full regional gross sand isopach maps of the Olmos (Fig. 5A) and the Wales (Fig. 5B) formations. The regional Olmos gross sand isopach map shows that the thickest zone of deposition trends north-south through the center of the field. The regional gross sand Wales isopach map shows a consistent thickening of the sands to the south.

In the study area, three net sand isopach maps were created: a single net sand isopach map for the Olmos Formation (Fig. 6A) and two separate net sand isopach maps for the Wales Formation titled lobe A (Fig. 6B) and lobe B (Fig. 6C). The net sand isopach maps were created by selecting areas of sand and eliminating areas of shale in each well log in order to visualize the sand thickness.

The Olmos net sand isopach (Fig. 6A) reveals that the primary sand thickness is located at the center of the study area, thickening from the north (source area) to the south as it approaches the Edwards Reef trend and continuing downdip, which could be an indication of a channel deposit. Throughout the rest of the mapped area, the net thickness of the Olmos is somewhat sporadic, and shows a slight thickening to the east. With better well control further north and south, we would expect to see similar channel deposits.

In the Wales net sand isopach maps (Figs. 6B and 6C), the thickness of lobe A shows a lot of variability, while lobe B is more consistent, showing possibly a much broader and conforming delta. To illustrate which wells contain the productive zones, a production map was computed (Fig. 8).

Volumetric Calculations

Within the study area, productive wells and intervals were investigated in order to define the net pay thickness and porosity

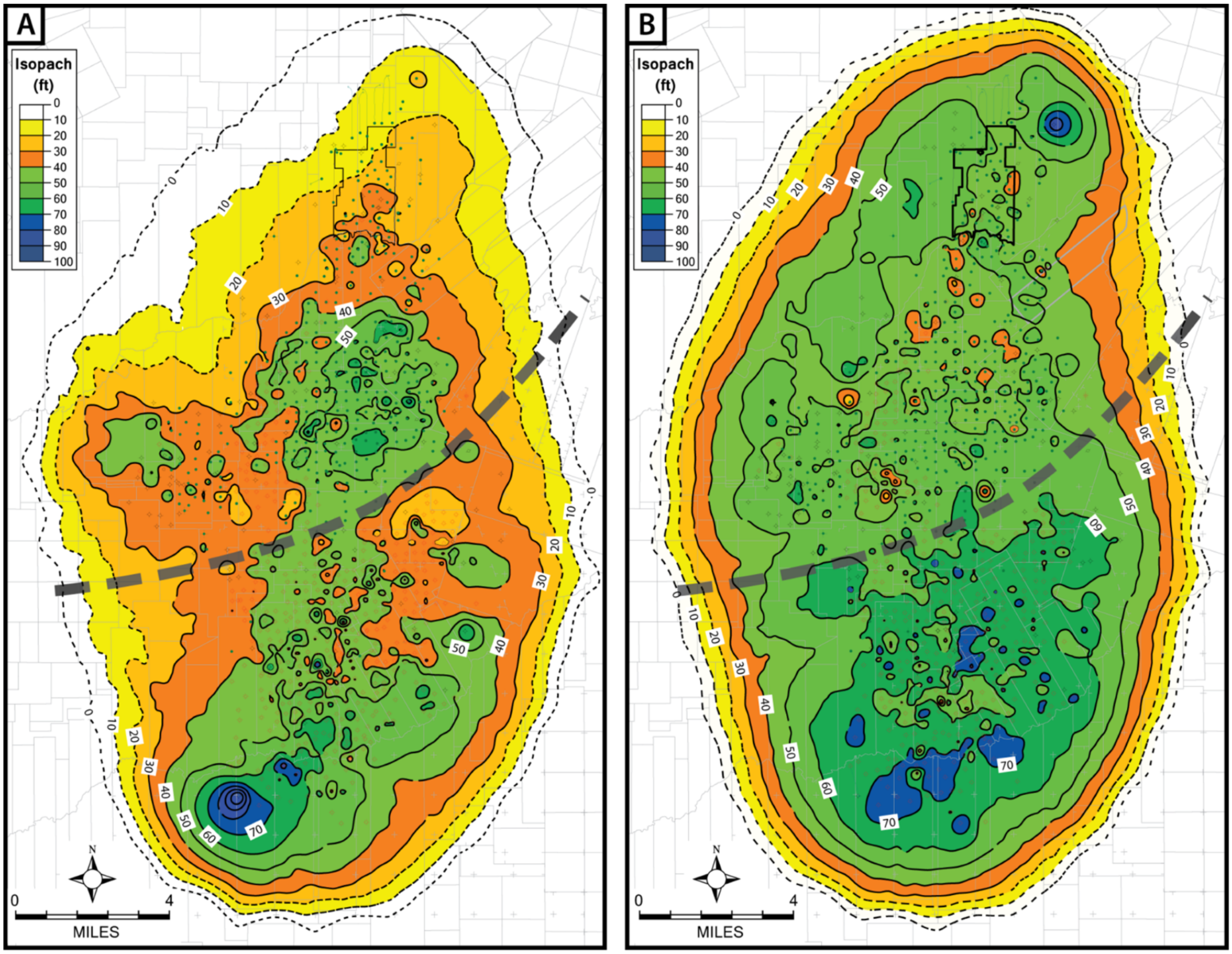

Figure 5. (A) Olmos and (B) Wales gross sand regional isopach maps. Dashed line represents the shelf/slope boundary. Although the peripheral thinning illustrated is most likely an artifact of the contouring algorithm due to the absence of data along the field periphery, evidence does suggest that some thinning exists both westward and eastward.

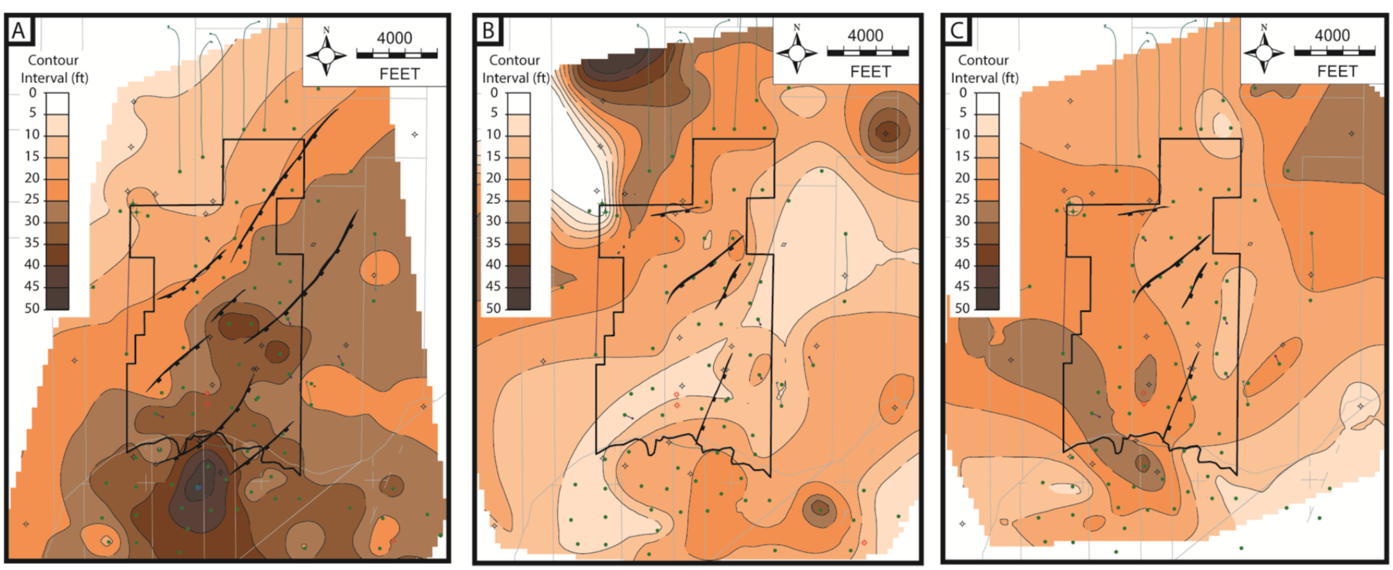

Figure 6. Net sand isopach maps of the study area of the (A) Olmos, (B) Wales lobe A, and (C) Wales lobe B.

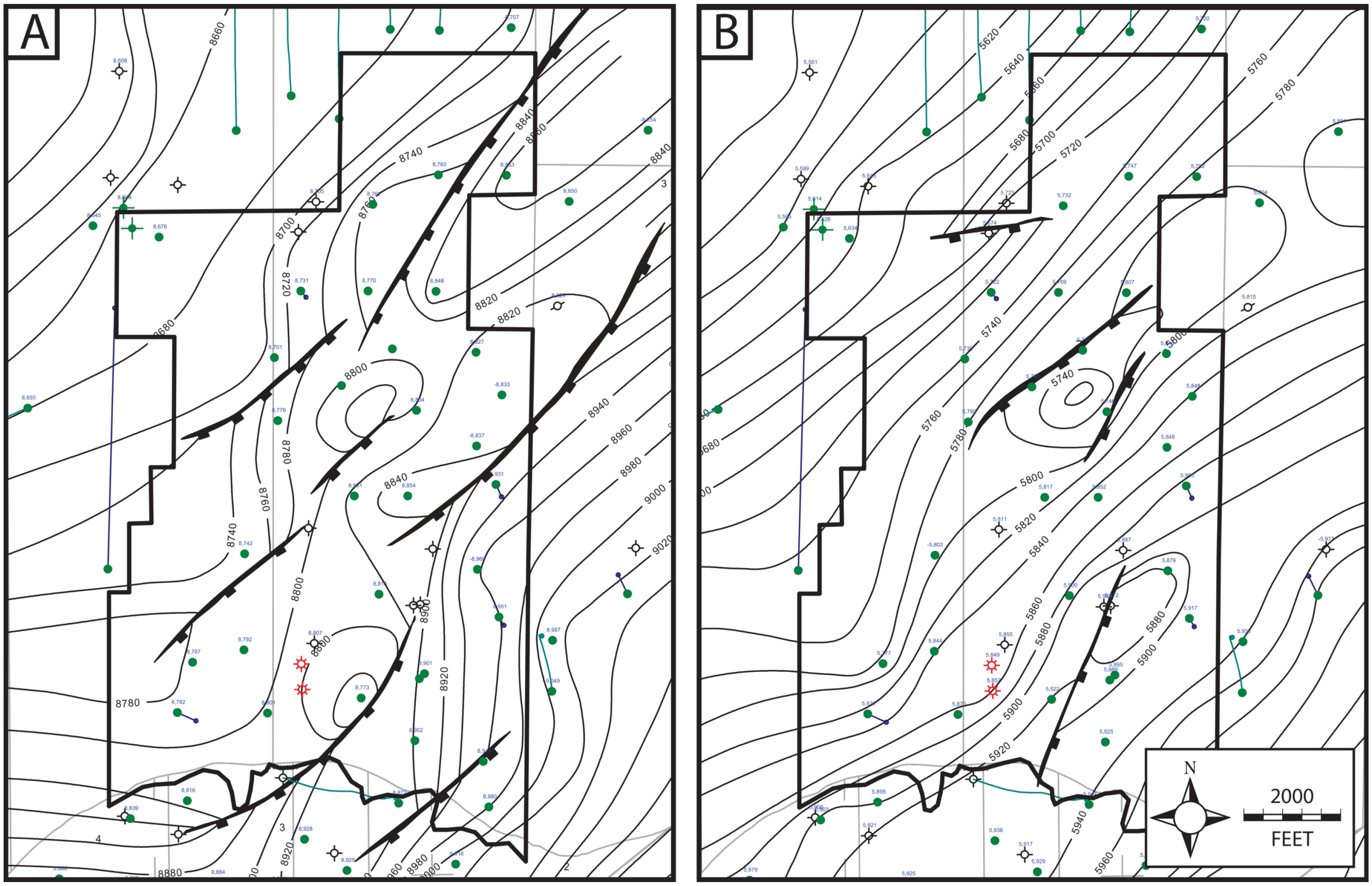

Figure 7. Structure contour maps of the top of the (A) Olmos and (B) Wales formations, using a 20 ft contour interval. Contour values are subsea true vertical depth (SSTVD) in ft. Seven faults cross the top of the Olmos (Fig. 7A), and four faults cross the top of the Wales (Fig. 7B). None of the faults cut through both the Olmos and Wales. Seismic interpretation reveals that faults within the study area extend laterally between 2000 and 7000 ft, with vertical penetration lengths ranging from 300 to 2000 ft, associated with 30 to 60 ft of offset horizons.

percentages for each well (Fig. 8). The productive intervals are from the Olmos Formation and the Wales lobe A only. The Olmos Formation net pay thickness ranges from 15–39 ft, with an average of 27 ft, and from 4–18 ft, with an average of 9 ft, for the Wales Formation. The porosity ranges from 16–28%, with an average of 21% for the Olmos Formation, and from 14–26%, with an average of 18% for the Wales Formation. Porosity in the study area is on the higher end of the range of porosity than in the rest of the field. .

Based on production data, the estimated ultimate recovery (EUR) and drainage radius was defined for each well (Fig. 9). Historically, the A.W.P. Field has an oil recovery factor of 20% and a gas recovery factor of 60% (P. Hart, 2015, personal communication); the same recovery factors were used in this study (Figs. 9A and 9B). For the Wales Formation, there is a significant lack of well log data and consistency of production, however taking into account the information available, the same 20% oil recovery map and 60% gas recovery factor was used (Figs. 9C and 9D).

We estimated the original oil in place (OOIP) using the following relationship:

$$OOIP = \left[\frac{7758 \cdot \phi \cdot (1 - S_w)}{Formation\,Volume\,Factor} \right] \cdot Net\ Bulk\ Volume$$

where OOIP is in barrels of oil (bbl), ϕ is the porosity determined from well logs, Sw is the water saturation, and 7758 is the standard conversion factor in bbl/ac. Net bulk volume (in ac-ft) is derived from drainage area times net pay thickness. The formation volume factor was predetermined at 3.1795 (P. Hart, 2015, personal communication). Then, we assumed that the estimated ultimate recovery (EUR) of oil is equal the recoverable oil in place (ROIP), where the ROIP is equal to the OOIP multiplied by the recovery factor.

Estimated original gas in place (OGIP) was determined using the following relationship:

$$OGIP = OOIP \cdot Initial\ GOR / 1{,}000{,}000$$

where OGIP is in millions of cubic ft (MMCF), initial gas-oil ratio (GOR) is 2200 standard cubic ft (scf)/bbl (P. Hart, 2015, personal communication). Recoverable gas (in MMCF) was obtained by multiplying OGIP by the gas recovery factor (60%), and remaining gas was obtained from the difference between recoverable gas and the cumulative produced gas (from production data).

The recovery maps show that the Olmos Formation still has remaining resource potential, especially in the western part of the study area (Fig. 9). The Wales Formation remains almost entirely untapped. Ultimately, drilling a well specifically for the Wales Formation would be high risk due to the poor knowledge of this formation in the A.W.P. Field. However, the Wales Formation could be logged while drilling to the Olmos Formation. Potential in-fill production may be possible based on distribution of prior drilling.

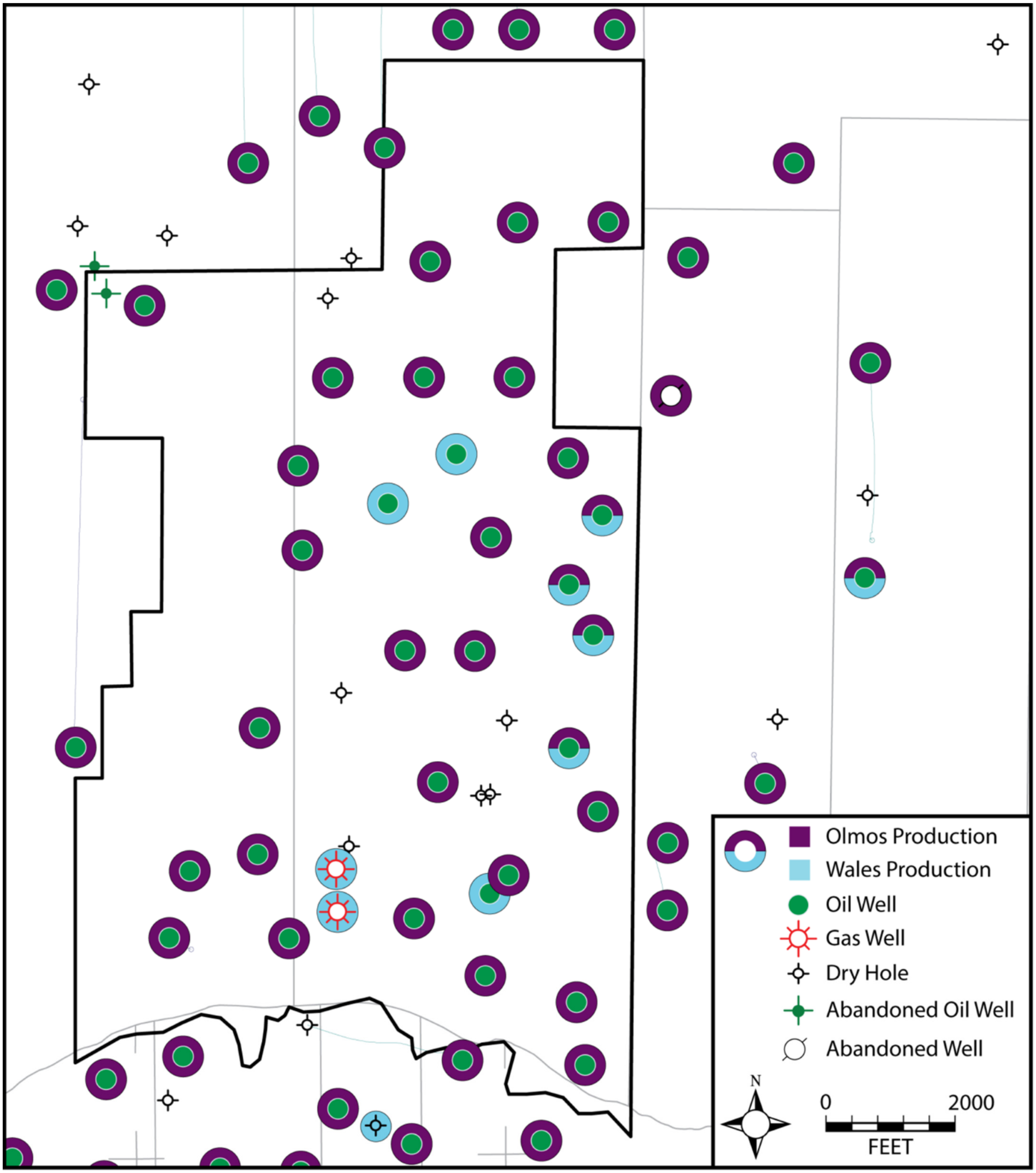

Figure 8. Production map. Productive wells and intervals were investigated in order to define the net pay thickness and porosity percentages for each well.

CONCLUSION

The Olmos Formation in the study area is a muddy sandstone that was deposited in an offshore environment, compacted and cemented to become a low permeability reservoir rock. The Wales Formation in the study area is made up of two clean, thin stinger sands separated by a 20–30 ft shale unit, and thick large shale bodies above and below the formation.

Seismic analysis concludes that the A.W.P. Field presents a steady basinward dip direction, typical of this area of the Gulf Coast. Log correlations and subsurface mapping show that the reservoirs are continuous over the study area, but thin eastward

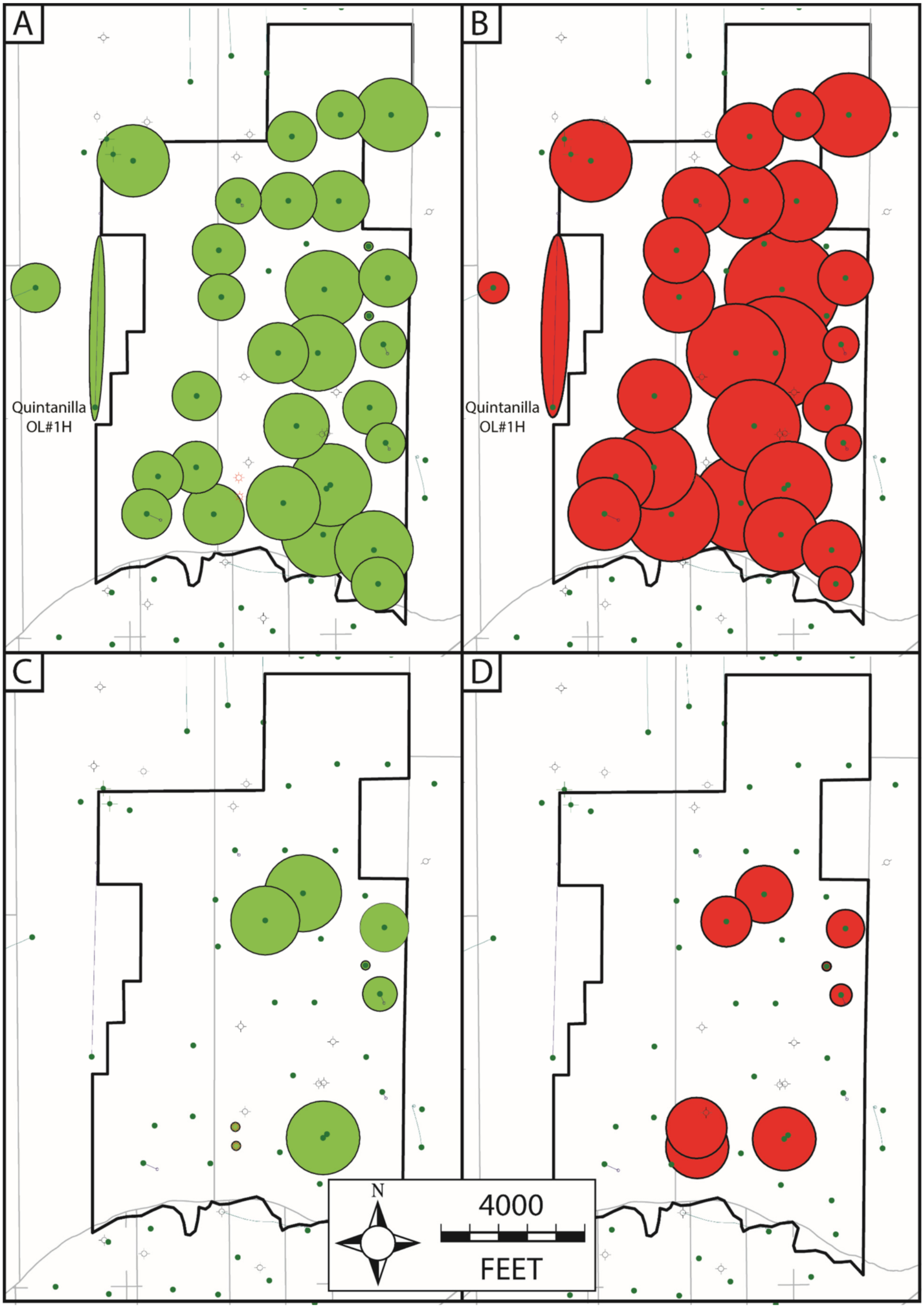

Figure 9. 20% oil and 60% gas recovery maps of the (A, B) Olmos and Wales (C, D), respectively. Based on production data, the estimated ultimate recovery (EUR) and drainage radius was defined for each well using an oil and gas recovery factor of 20% and 60%, respectively.

and westward. Normal faults are present throughout the study area, generally parallel with strike and dipping to the southeast. These short-length faults bound to stratal sections of Wilcox and Olmos are probably due to volume reduction during compaction. The Olmos and Wales depositional dip direction and angle are consistent with that of the general regional dip, suggesting that faulting and location of the reef has little effect on the general dip of the formations. Seismic analysis shows that no faults extend far enough to cross both the Olmos and the Wales Formation. Faults vary in lengths and extent throughout the area. The dip of the faults is consistent with that of the Gulf Coast.

Within the study area both the Olmos and Wales formations are pressure depletion stratigraphic reservoirs. While some wells have produced significant water, there is no correlation between water and hydrocarbon output that shows any signs of water drive.

The results of this study show that within the A.W.P. Field, although the reservoirs thin out in the updip direction (toward the northwest), they certainly maintain a significant thickness, contrary to previous interpretations, which suggest that the field still has potential for growth. Volumetric analysis reveals that there is remaining resource potential in both the Olmos and Wales formations. In particular, the Wales Formation remains mostly untapped. With recent improvement in unconventional and horizontal well technologies, the life of the A.W.P. Field could be significantly extended.

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