

**THE EFFECTS OF GEOLOGIC STRUCTURE
AND DIAGENESIS ON OIL PRODUCTION IN
UPPER PENNSYLVANIAN AND LOWER PERMIAN
PHYLLOID ALGAL MOUNDS, SOUTHEASTERN
NEW MEXICO**

by

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ABSTRACT

The Bough zones of southeastern New Mexico are made up of phylloid algal mound complexes. Deposition of these mound deposits occurred preferentially on bathymetric highs and on shelfal areas within the study area. This resulted in a heterogeneous distribution of thicker sections within the study area.

Three dominant rock types are found in the studied strata: 1) biomicrites, 2) altered biomicrites, and 3) dolomites. These rock types were able to be identified in thin section but could not be differentiated based on gamma-ray log analysis. This was due to the similar gamma-ray log curves associated with the different rock types.

Diagenesis of these rocks occurred due to exposure to meteoric waters, rising local sea level, and burial. Diagenetic alteration resulted, most notably, in the creation of moldic and vugular porosity. The presence of secondary porosity coupled with the deposition of the mounds in close proximity to source rocks made them good reservoirs.

The most important factors controlling oil production were thickness of the stacked phylloid algal mound deposits and diagenetic history. Oil production within the Bough A and B is higher on the margins of thicker algal mound deposits. This is likely due to dissolution occurring preferentially on the margins of phylloid algal mound complexes. Production from the Bough C does not follow this pattern and must be controlled by some other factor, most likely a different depositional and diagenetic history.

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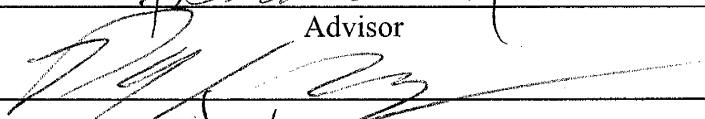
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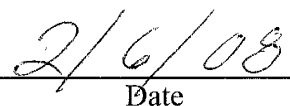
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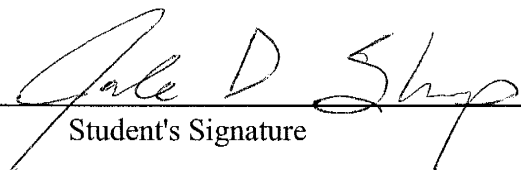




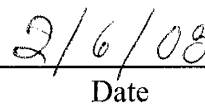


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INTRODUCTION

The subjects of this study are the strata referred to as the Bough zone. This informal stratigraphic unit refers to Late Pennsylvanian to Early Permian strata (Figure 1) in southeastern New Mexico. Core studies show the Bough zone to consist of interbedded carbonate and shale layers. The term, Bough zone, is mostly used in petroleum related studies and refers to strata time equivalent to the Cisco Group and Wolfcamp Limestones of the same area (Figure 1; Cys and Mazzullo, 1985; Cys, 1986; Wahlman, 2001). The Bough zone is commonly referred to on well completion cards, but is rarely mentioned in the literature.

Biogenic carbonate mounds are common through most of the Pennsylvanian-Permian stratigraphic section in the Permian Basin, and can form significant hydrocarbon reservoirs (Kornfeld, 1957). The deposits are classified as phylloid algal mounds due to the inclusion of phylloid algal blades. Most phylloid algae are thought to have had aragonitic skeletal structures which were highly susceptible to alteration by meteoric waters, but a few forms may have had high-Mg calcite (Toomey and Winland, 1973; Scholle and Ulmer-Scholle, 2003). Diagenetic alteration is an important factor in determining the reservoir potential of phylloid algal mounds because most of the porosity and permeability within these types of deposits is secondary (Toomey et al., 1977). During the Late Pennsylvanian, sea level changes

Permian	Wolfcampian	Wolfcamp ls.	Bough A Bough B
	Virgilian		
Pennsylvanian	Missourian	Canyon Gp.	
	Des Moinesian	Strawn Ls.	
	Atokan	Atoka Gp.	
	Morrowan	Morrow Gp.	

Figure 1 Stratigraphic column of Upper Pennsylvanian and Lower Permian shelf strata, southeast New Mexico. The Bough zone is time equivalent to the upper Cisco Group and lower Wolfcamp limestones. Figure is modified from Broadhead and others (2004).

occurred relatively frequently (Goldstein, 1988). The transition from high-stand to low-stand conditions created optimal diagenetic environments for the phylloid algal mounds by exposing them to a subaerial environment. Depositional settings for these deposits have been inferred by other authors using fossil data, depositional energy evaluations, and modern analogs (such as the calcareous alga *Halimeda*; Toomey and Winland, 1973; Choquette, 1983; Grammar and Eberli, 1998; Wahlman, 2001).

This study uses the correlation of gamma-ray logs from 244 wells to determine the structure and extent of phylloid algal mound deposits over an approximately 500 square mile area in the state of New Mexico (Figure 2) as well as thin sections taken from cores acquired within the study area that show the microscopic properties of these strata. The cores used for petrographic analysis are from two wells, the State DL 1 drilled by Pan American Petroleum Corp. and the Willard Beaty 5 drilled by Skelly Oil Co., which are stored in the core library of the New Mexico Bureau of Geology and Mineral Resources. This information combined with background research into the depositional and diagenetic models for phylloid algal mounds will help to determine what properties make some phylloid algal mounds productive and others nonproductive.



Figure 2 Outline of the state of New Mexico with Lea County outlined in black and the study area highlighted in blue.

METHODS

Well completion card data were acquired from 311 wells within the study area that penetrated the Pennsylvanian section. Information taken from well completion cards includes the lease name, well number, well location, spud date, tops of Wolfcamp and Bough C or Cisco, total depth, initial production, production interval, and field name. Production data was taken from the 2003 Southeast Annual Report (BL Resources, 2003) which reports oil field production data in New Mexico.

This study also uses correlation of 244 gamma-ray logs to determine the structure and extent of phylloid algal mound deposits over a 500 square mile area. The logs are on file in the petroleum records library at the New Mexico Bureau of Geology and Mineral resources on the New Mexico Institute of Mining and Technology campus. Logs were selected if they were from within the study area and penetrated Pennsylvanian strata. The goal was to have one log for every square mile section within the study area, but not every section contained a suitable well log. In sections containing more than one suitable gamma-ray log, each log was studied and the most easily read one was picked for use. Cross sections were made using the top of the Cisco as the datum. This datum was determined by utilizing fusulinid determinations by the late R.V. Hollingsworth (Hollingsworth, undated). Hollingsworth determined fusulinid genera present in drill cuttings of wells in Lea

County. For this project, Hollingsworth's determinations were available for sixteen wells. Hollingsworth determined the top of the Cisco series by identifying the change from Wolfcamp and Bursum fusulinids (*Schwagerina*, *Pseudoschwagerina*, *Schubertella*, *Triticites* and nondescript Wolfcamp and Bursum types) to Virgil fusulinids (nondescript Graham and Thrifty- type *Triticites*). The depth of the top of the Cisco Group, as determined by Hollingsworth, was related to large gamma-ray spikes on the logs taken from the same wells in which he analyzed the cuttings. These sixteen wells were then used as the basis for the correlation of the other 228 well logs. The gamma-ray curve indicating the top of the Cisco Group was correlated to the rest of the picked logs. Large spikes on the gamma-ray logs indicating abrupt changes in lithology were used to correlate the upper boundaries of the individual zones. The depths found through correlation were then used to construct structure contour and isopach maps covering the study area. Five of the eighteen total cross-sections created are located on Plates 1-5 and the other 13 cross-sections were scanned in their original form and are included on a disc found in the back pocket. The five cross-sections were chosen for plates because they cover zones from the study area representing large changes in thickness and elevation of the Bough zone. Maps were created using Microsoft Excel and the Golden Software's Surfer version 8 mapping program. Contour lines were drawn using Surfer's kriging method with default parameters. The longitude, latitude and tops of strata (obtained from cross sections) were used as parameters in creating grid files used by the mapmaking program.

Two cores were described in this study. The cores were chosen based on a number of factors, including: whether or not the core was taken from within the study area, whether or not the core was on hand at the core library, whether or not the core intercepted the Pennsylvanian strata, and whether or not gamma-ray logs were available for the intervals represented by the core. These criteria yielded two acceptable cores, which were in turn analyzed. The cores were first separated into units based on their lithologies and sedimentary structures. These units were then described according to their Dunham classification (Dunham, 1962), color, and noticeable visual observations such as color variation or zones of fossil accumulation. Porosity in the core samples was classified using the Choquette and Pray (Choquette and Pray, 1970) system as well as Archie's system (Archie, 1952). Archie's classification gives quantitative porosity values for the core samples whereas the Choquette and Pray system yields more qualitative results, giving insight into the origin of the pore systems.

Seventeen 1 x 2 inch blanks were cut from these cores and made into thin-sections. The depths sampled were chosen by studying the gamma-ray logs taken from the same wells as the core samples. Blanks were taken from depths that had high, low, and medium intensity gamma-ray readings. This allowed petrographic analysis of units showing different log readings and a differentiation of non-sampled units according to gamma-ray log readings. Tulsa Sections, Incorporated in Oklahoma made the thin-sections. The thin-sections were impregnated with blue epoxy for porosity measurements and received a full carbonate stain, which differentiates between calcite, aragonite and dolomite. Petrographic analysis of these

thin sections included descriptions following Folk's classification (Folk, 1962), Dunham's classification (Dunham, 1962), porosity measurements made using comparison to a spot ratio card, cataloguing of porosity types, and cataloguing of general fossil types.

Acetate peels were also made from the core samples. Core samples were prepared by acidizing the cut surface of the core to accentuate the texture. The peels were made by covering the core's cut surface with acetone and then placing a sheet of acetate onto the surface. The acetate conforms to the texture of the rock creating a three-dimensional impression of the rock's surface. Sixty-six peels were taken from the cores. The depths of the peels were chosen by taking peels from depths, both, matching and between depths from which the thin section samples were taken. Peels were used to subdivide the core into three rock types defined by the petrographic analysis of thin sections. Analysis of the acetate peels along with the thin-sections allowed a more thorough delineation of the rock types present in the core. The detailed description of the cores, with 17 thin sections and 66 acetate peels allowed for direct comparison between the defined rock types and gamma-ray log curves.

STUDY AREA

The study area consists of Townships 10 South through 13 South and Ranges 32 East through 35 East. This study area covers approximately 500 square miles in Lea County, New Mexico (Figure 2). The study area is located within the Northwest Shelf Upper Pennsylvanian Carbonate Play of the Permian Basin and completely encompasses the Inbe, Bagley, Bagley North, Hightower East, and Ranger Lake fields (Figure 3). The study area also contains portions of the Baum, Lazy J, Nonombre, Vada, and Cerca fields.

Well completion card data indicate the oldest well utilized in this study was drilled in 1949 in the Hightower Field. Since that time, approximately 3500 wells have been drilled within the study area. Many of these wells produce from the Upper Pennsylvanian and Lower Permian carbonates, but petroleum production within the study area also involves both younger and older strata.

The study area was chosen so that it encompasses areas with a large degree of petroleum production from the Upper Pennsylvanian and Lower Permian Bough zones strata, but also areas with few wells and little or no production. The northern and southern edges, as well as the center of the study area have a high production density from the Upper-Pennsylvanian and Lower-Permian. Lower production density is found between the northern edge and center, as well as between the center

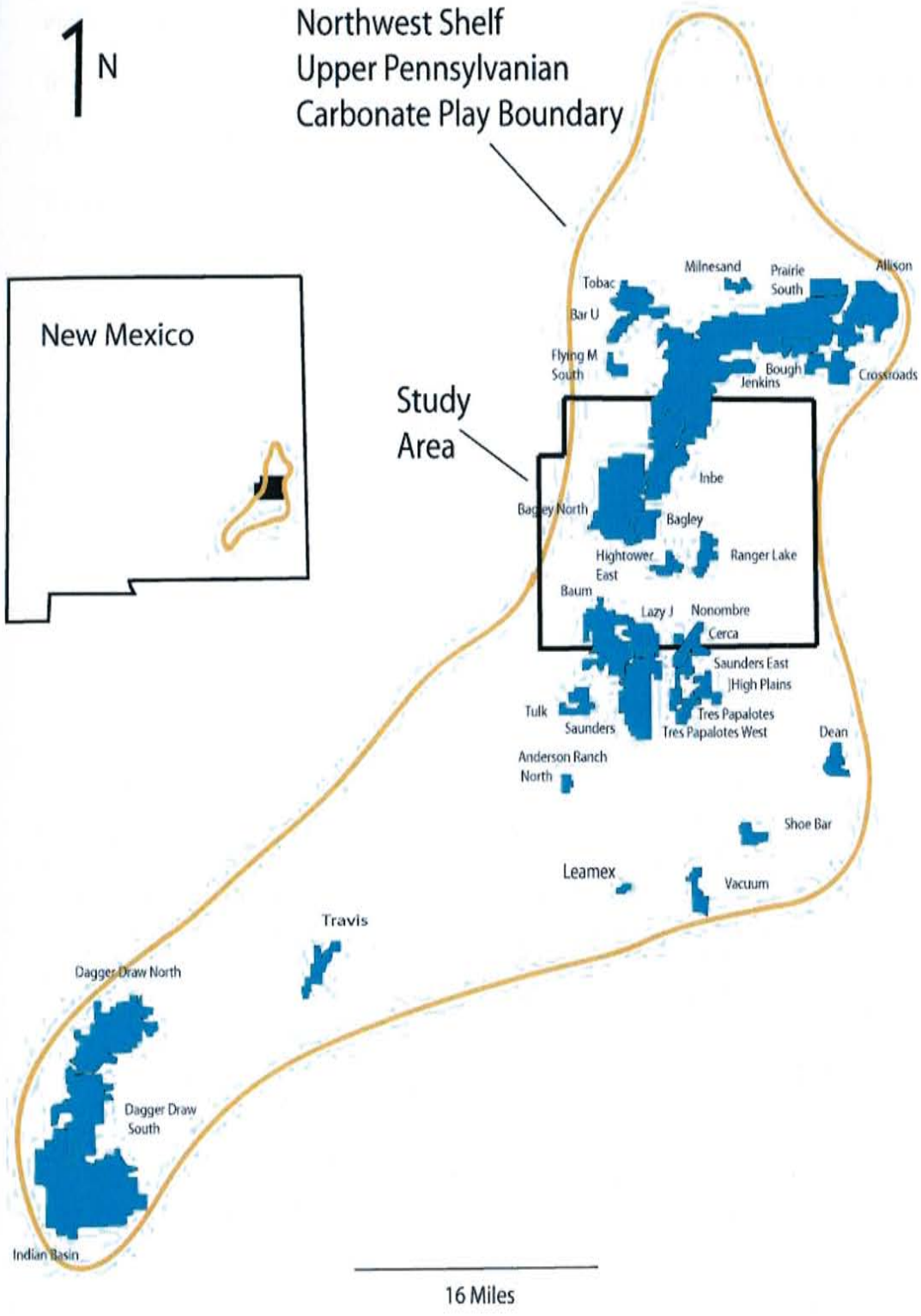


Figure 3 Map of the Northwest Shelf Upper Carbonate Play with the study area outlined in black. A reference map is present showing the position within New Mexico. Map modified from Broadhead et al. (2001).

and southern edge. There is also a lack of production on the east and west sides of the study area. In choosing this area the differences between the productive Upper-Pennsylvanian and Lower-Permian strata could be examined and any differences explained.

BACKGROUND INFORMATION

PHYLLOID ALGAE

The term “phylloid algae” refers to late-Paleozoic, platy, calcareous algae (Pray and Wray, 1963). Figure 4 shows an artist’s reconstruction of two forms of phylloid algae. The term was first used by Pray and Wray (1963) to describe the growth form of leaf-like algae (Grammar and Eberli, 1998). Some of the more common and extensively studied genera include *Ivanovia* and *Eugonophyllum*. These algae had an aragonitic skeleton which was commonly altered through various diagenetic processes that will be discussed later. In thin section, phylloid algae blades have several characteristic features. These include filled primary tubules, irregular shapes and sizes, and a flared end (Figure 5; Scholle and Ulmer-Scholle, 2003). The algae were photosynthetic; therefore they needed to live in the photic zone. This excludes them from growing in deep waters. No phylloid algae grow in modern times, but they are similar to modern squamariacean red algae or codiacean green algae, especially the calcareous alga *Halimeda* (Toomey and Winland, 1973; Kirkland et al., 1991; Grammar and Eberli, 1998; Scholle and Ulmer-Scholle, 2003). Phylloid algae are similar to modern *Halimeda* because of their commonly aragonitic skeletal structure and their aggradational growth habit (Grammar and Eberli, 1998).



Figure 4 Artist's (Robert B. Hailey) reconstruction of a complex, cuplike phylloid algae (A) and the phylloid algae *Eugonophyllum* (B) with internal morphology and outer plates shown (Cross and Klosterman, 1981; figure from Scholle and Ulmer-Scholle, 2003).

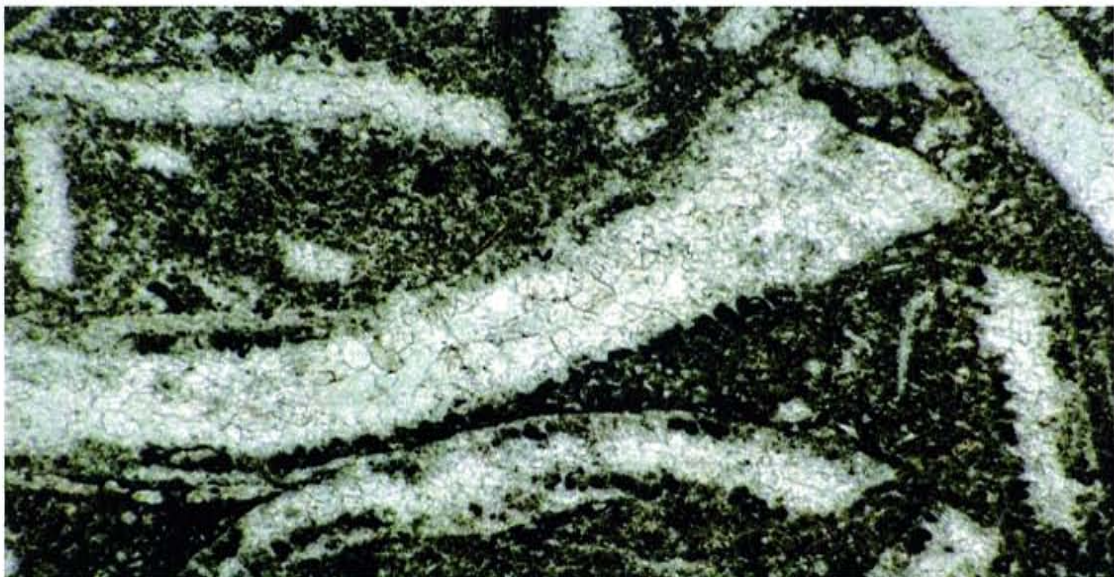


Figure 5 Thin section (horizontal axis is 4.5 mm) showing characteristic features of phylloid algae including flared end, irregular grain sizes and shapes, and filled tubules on the grain margin (from Scholle and Ulmer-Scholle, 2003).

Phylloid algae were prominent bioherm builders in west Texas and eastern New Mexico from the Middle Pennsylvanian through the Early Permian (Wolfcampian; Wahlman, 2001). The mounds formed by phylloid algae were usually flat-bottomed, dome shaped, and reached thicknesses of 30 meters (Grammar and Eberli, 1998). Their growth habit can be described as gregarious. They had a high reproductive and growth rate, which meant they could form a growth community very rapidly (Wahlman, 2001).

DEPOSITIONAL ENVIRONMENT

Phylloid algal mounds were most likely deposited in moderate energy, shallow-marine platform environments (Grammar and Eberli, 1998). The algae preferred to grow in water depths close to 10 meters (Toomey and Winland, 1973; Mazzullo and Cys, 1979). Ancient mounds are often found containing fossils of other common shallow-marine biota including fenestrate bryozoans, crinoids, brachiopods, gastropods, and fusulinids (Toomey and Winland, 1973; Wahlman, 2001). The mounds also show evidence of frequent subaerial exposure caused by local sea-level falls, suggesting a shallow-marine environment (Choquette, 1983). Ancient mounds often contain lenses of reworked sediment such as intragrainstones, biopackstones and phylloid algal packstones (Mazzullo and Cys, 1979). Choquette (1983) describes a common breccia facies that suggests break-up due to storm action. This serves as further evidence of shallow-marine environments of deposition.

Due to phylloid algae's growth habit they were able to dominate shallow-marine shelves and shelf-margin areas (Toomey and Winland, 1973; Wahlman,

2001). This domination often led to a lack of biodiversity within the mound environment. After sea-level rises the phylloid algae could set up their communities more quickly and efficiently than other more advanced equilibrium communities such as bryozoan mounds (Wahlman, 2001). The accretionary growth of these algal mounds was able to keep pace with the frequent sea-level rises of the time (Grammar and Eberli, 1998).

MOUND GROWTH AND EVOLUTION

Facies analysis and description concerning phylloid algal mounds cannot be discussed without first discussing a theory concerning the growth and evolution of the mounds. The lack of internal sediment and bafflestone fabric of many mound complexes indicates the mounds are accretionary features and not just sediment dumps (Grammar and Eberli, 1998). Phylloid algal mound growth occurred in stages (Toomey and Winland, 1973; Toomey et al., 1977). Toomey and others (1977) described a “simple” normal sequence of growth consisting of three phases. These were the foundation phase, constructional framework phase and, finally, a climax boundstone phase. Mound growth could be halted by local sea level changes which either drowned the mound in deeper water or exposed it subaerially. Since mound growth could stop during any phase, one or more of these phases may be missing in individual mound sequences.

The foundation phase was the phase in which the alga started to grow on a hard substrate. The phylloid algae preferred a growth area with slight bathymetric relief (Marquis and Laury, 1989) and were able to maintain the relief of an area due

to their gregarious growth habit (Toomey and Winland, 1973). This implies that the algae were able to sustain their own preferred growth environment.

The substrate, to which the algae attached, could be organic (Toomey et al., 1977) or inorganic (Mazzullo and Cys, 1979). Examples of an organic substrate include large shelled invertebrate fossils, such as bivalves. The inorganic substrate consisted of lithified lime mud and marine shale (Choquette, 1983) or the products of calcareous precipitation on the sea-floor (Doherty et al., 2002). Mazzullo and Cys (1979) found that aragonitic and calcitic botryoids precipitated on the seafloor or on fallen phylloid algal blades and formed a framework which has its pore space partially filled in with local sediments and aragonitic cement. This formed a substrate to which the phylloid algae could attach.

The construction phase was a stage of prolific phylloid algal growth. This phase is also of economic significance, because primary and secondary porosity and permeability are best developed in the sediments that were deposited during this phase of mound growth (Toomey et al., 1977). Primary porosity was developed due to the sheltering of open spaces from sediment in-fill after the alga died and their irregularly shaped plates fell onto the mound (Wahlman, 2001). The phylloid algae grew up from the substrate and trapped sediment. As currents or waves passed through the algae, their energy was decreased, sediment fell out of suspension and was deposited around the plates (Toomey et al., 1977). Secondary porosity was created because of the chemical instability of aragonitic phylloid algal blades, which led to dissolution and recrystallization when exposed to meteoric waters (Kirkland et al., 1991). The preferential dissolution of aragonite over calcite created the

commonly observed moldic and vugular porosity of the lithified phylloid algal deposits. The inferred upright growth habit of the algae was based on observations made by Toomey and Winland (1973). These include the bilateral symmetry of the internal structure of the algae, particularly the identical character of the pillar-like uticles of the outer layers of the opposing walls, and encrustation of the outer walls by carbonate. Encrustation by foraminifers and cyanobacteria is commonly observed (Schatzinger, 1983). This would also have contributed to the framework and overall sedimentation and mound growth.

The climax boundstone phase was the final stage of mound growth. This stage occurred as the phylloid algal growth reached wave base and began to become encrusted by masses of tubular foraminifers and other organisms (Toomey et al., 1977). This growth phase was accountable for the uppermost facies assemblage and contained the most commonly altered mound facies. Figure 6 illustrates mound morphology in relation to the three growth phases.

The last phase of growth would be halted if the mound was either raised tectonically above sea-level or if sea-level lowered enough to expose the top of the mound. The mound could have been submerged after subaerial exposure and growth would start back up at either the constructional phase or the climax stage. This process could be repeated multiple times over the course of one mound's growth (Mazzullo and Cys, 1979).

POST-DEPOSITIONAL ALTERATION

The aragonite formed by the algae is unstable over geologic time periods and has been thoroughly replaced and recrystallized in many instances (Toomey and

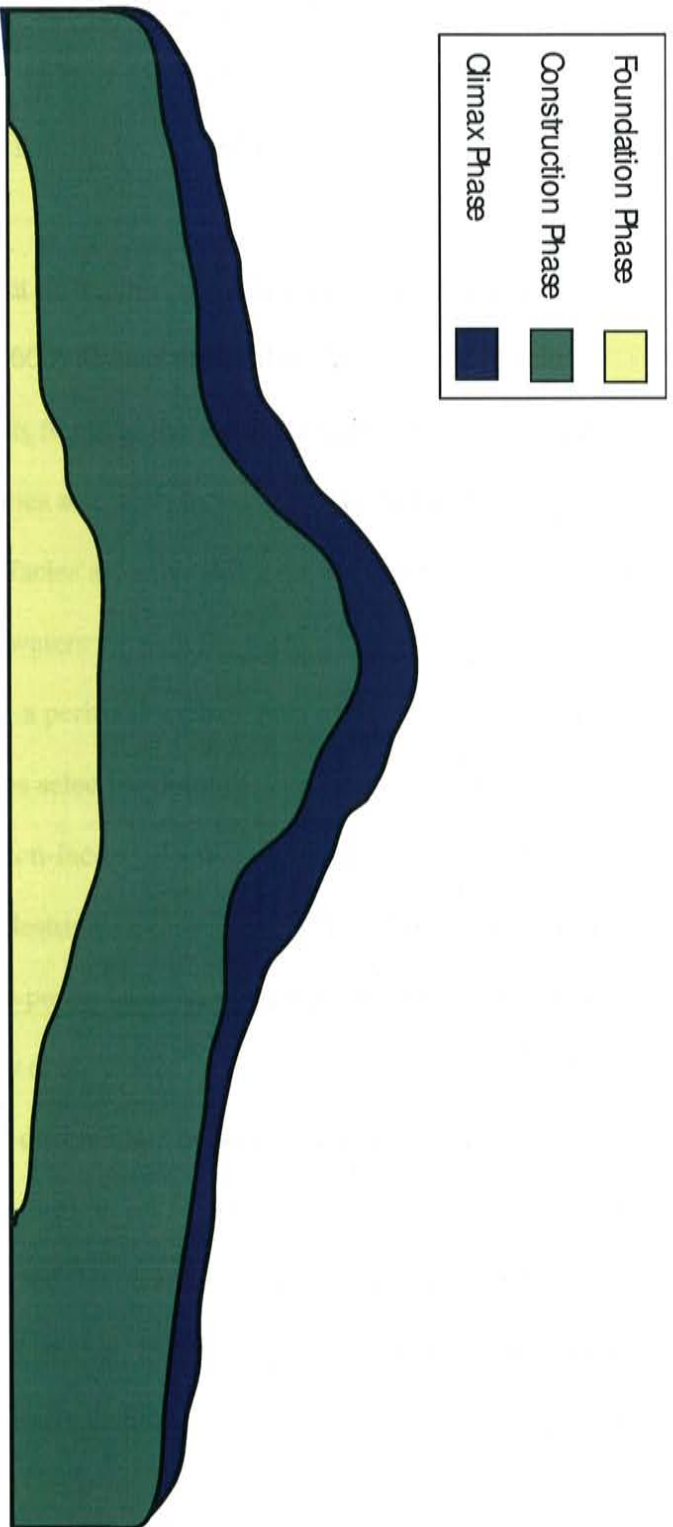


Figure 6 Graphical representation of mound morphology with growth phases differentiated. Growth based on Toomey et al. (1977) simple growth phases. Mound height is in the tens of meters.

Winland, 1973; Kirkland et al., 1991). Aragonite was replaced and recrystallized as isopachous bladed non-ferroan finely crystalline spar, coarsely crystalline mosaics of divergent-radial pseudospar, and multiple forms of dolomite (Mazzullo and Cys, 1979; Marquis and Laury, 1989; Kirkland et al., 1991; Soreghan et al., 2000; Doherty et al., 2002).

Dolomitization occurred at different stages during the evolution of phylloid algal mounds. Soreghan et al. (2000) discuss three different types of dolomite observed in phylloid algal mounds found in the western Orogrande Basin of New Mexico. These types are non-facies selective, facies selective and burial-stage dolomite. Formation of the non-facies selective dolomite occurred during sea level rise and subsequent reflux of seawaters through the rock. Facies selective dolomite occurred while the mound was in a peritidal environment after either a lowering of sea-level or tectonic uplift. Facies selective dolomite is a fine to medium grained fabric preserving dolomite, and non-facies selective dolomite is fine to medium grained and is commonly fabric destructive (Soreghan et al., 2000). Facies selective and non-facies selective dolomite percentages increase near the tops of sequences within the algal mounds (Doherty et al., 2002).

Mazzullo and Cys (1979) differentiate between baroque dolomite and non-baroque dolomite. Baroque dolomite can act as cement or a replacement mineral and is characterized by its warped crystal lattice and markedly undulose extinction when viewed in thin section (Radke and Mathis, 1980). This type of dolomite is commonly found in the mound core facies. Baroque dolomite could have replaced mosaics of

pseudospar and the aragonitic botryoids found in some of the phylloid algal mound facies (Mazzullo and Cys, 1979).

Void filling by cement is also an important diagenetic process.

Dolomitization, internal brecciation and dissolution increase permeability (Roylance, 1990). The filling of pores and voids in the rock by secondary cements act to decrease permeability. Equant non-ferroan spar cement fills voids after secondary dissolution of the algal material (Mazzullo and Cys, 1979; Marquis and Laury, 1989).

Diagenetic alteration is as important, or more important, to the final lithologic characteristics of the deposit than the physical processes that lead to the original deposition of phylloid algal mounds (Ball et al., 1977). Thorough recrystallization occurs after mound deposition. Many of the petrographic characteristics (e.g. dolomite, sparry and micritic cement) of the mound were shaped by diagenetic processes. The porosity and permeability of these mounds is in large part due to meteoric water migrating through the existing framework and creating moldic, vugular, interparticle and fracture porosity (Schatzinger, 1983). Porosity and permeability can also be attributed to the development of extremely fine intercrystalline pores during recrystallization (Toomey and Winland, 1973).

STRATIGRAPHY

This study describes Upper Pennsylvanian and Lower Permian age limestones and mudstones of the Northwest Shelf informally correlated as the Bough zones (Cys, 1986). This zone of shelfal carbonates has been informally subdivided into the Bough A, B, C, and D strata and the top of the Bough C is considered to be time equivalent to the top of the Cisco Group. The exact ages of the separate Bough zones are a matter of some contention (Broadhead et al., 2004). The most recent studies indicate the top of the Cisco Group, defined in this study as the boundary between Bursum fusulinids and Virgil fusulinids, is located below the Pennsylvanian-Permian boundary (Wahlman and King, 2002). The Bough zones range in thickness within the study area from 190-400 feet (Plates 1-5 and Appendix D). The Bough zones overlie the thick (0-1300 ft.) Missourian-age Canyon limestones, described by Meyer (1966) to consist of white to light-brown, fine grained, chalky, fossiliferous limestones with gray and red shale interbeds. The Bough zones are overlain by thick (250-1300 ft.) Wolfcampian-age fossiliferous limestones described by Meyer (1966) as light-brown to tan, fine to medium-grained.

Core analysis related to this study show the Bough zones to be made up of lithologies associated with stacked phylloid algal mounds. These include wackestones and packstones containing phylloid algae fossils, as well as crystalline

limestones and thin shale beds. In many cases the shale layers have been deformed during burial and are in the form of large solution seams and mud diapirs.

These core analyses indicate the Bough zones are almost completely made up of limestone with thin shale beds (inches thick) making up the siliciclastic portion.

Figures 7 and 8 show stratigraphic columns of the cores, and detailed core descriptions can be found in Appendix A. Cores described for this study have significant thicknesses of section that are missing. This may be due to a large shale component or extremely porous and permeable sections which were exceptionally fragile.

Gamma-ray log analysis may also be used to interpret lithology in the Bough zone. Rock types with higher levels of radiation, such as shales, show a more radioactive peak on gamma-ray curves. The gamma-ray logs (Plates 1-5 and Appendix D) show peaks which correspond to thin intervals of higher radioactivity, but there are no thick intervals of higher radioactivity readings which could indicate substantial shale layers. Comparisons of the cores to gamma-ray logs show that lithologies with higher levels of radiation contain more shale, which contains more decayed organic matter as well as a higher content of clay minerals. The gamma-ray log data coupled with core sample descriptions lead to the conclusion that the Bough zones within the study area are almost completely limestone with a small percentage of compacted shale layers and stylolites.

Cross-sections created for this study show that the Bough zone is structurally deeper on the eastern side of the study area (Figure 9). The Bough zone's depth increases by approximately 600 feet in the middle of the study area when moving east

Lithologic Units
 Pan Am "DL" State 1
 API # 30-025-22775

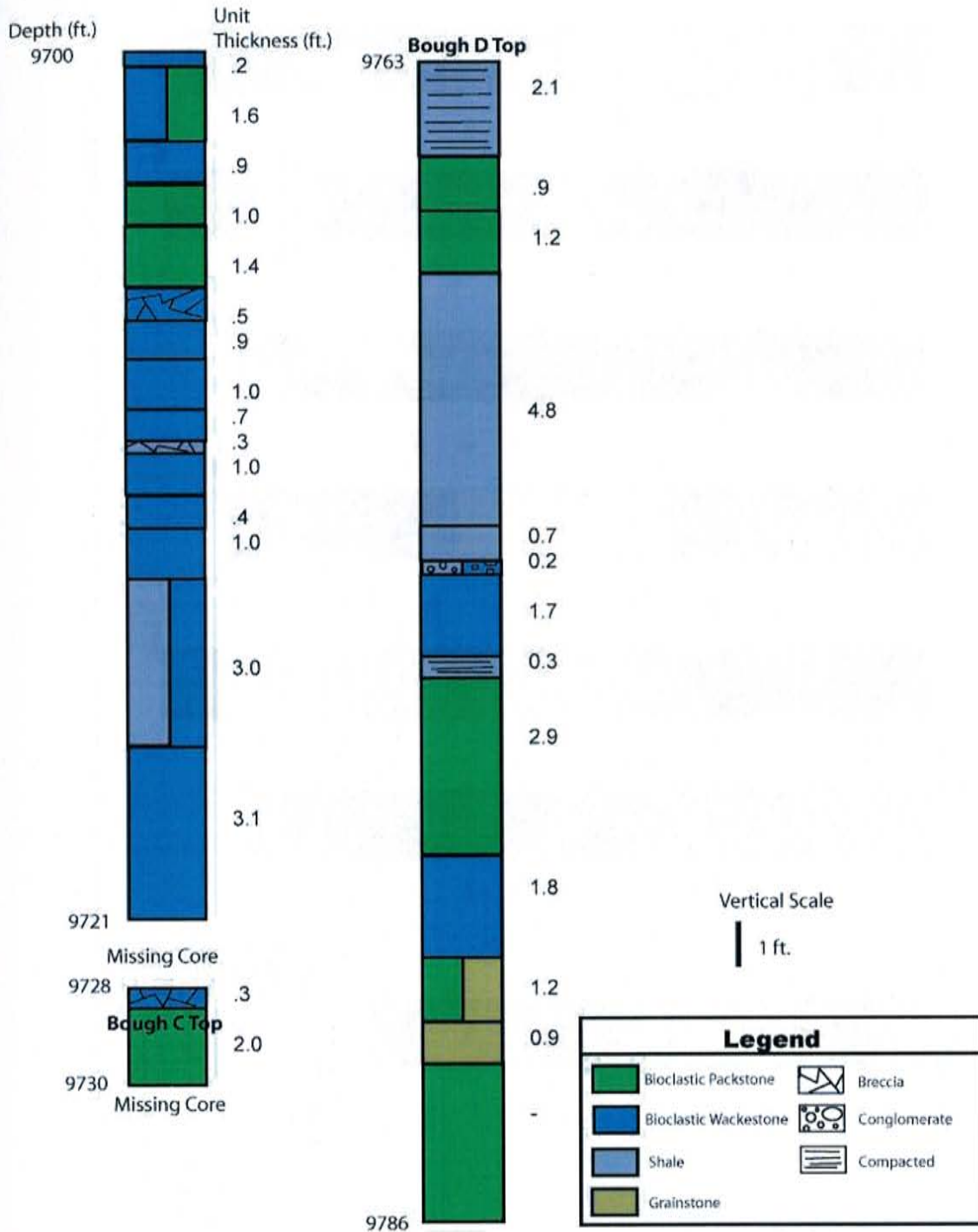


Figure 7 Stratigraphic column illustrating lithologies and unit thickness' of the core from Pan America Petroleum Corporation's "DL" state 1.

Willard Beatty 5
 API # 30-025-22010

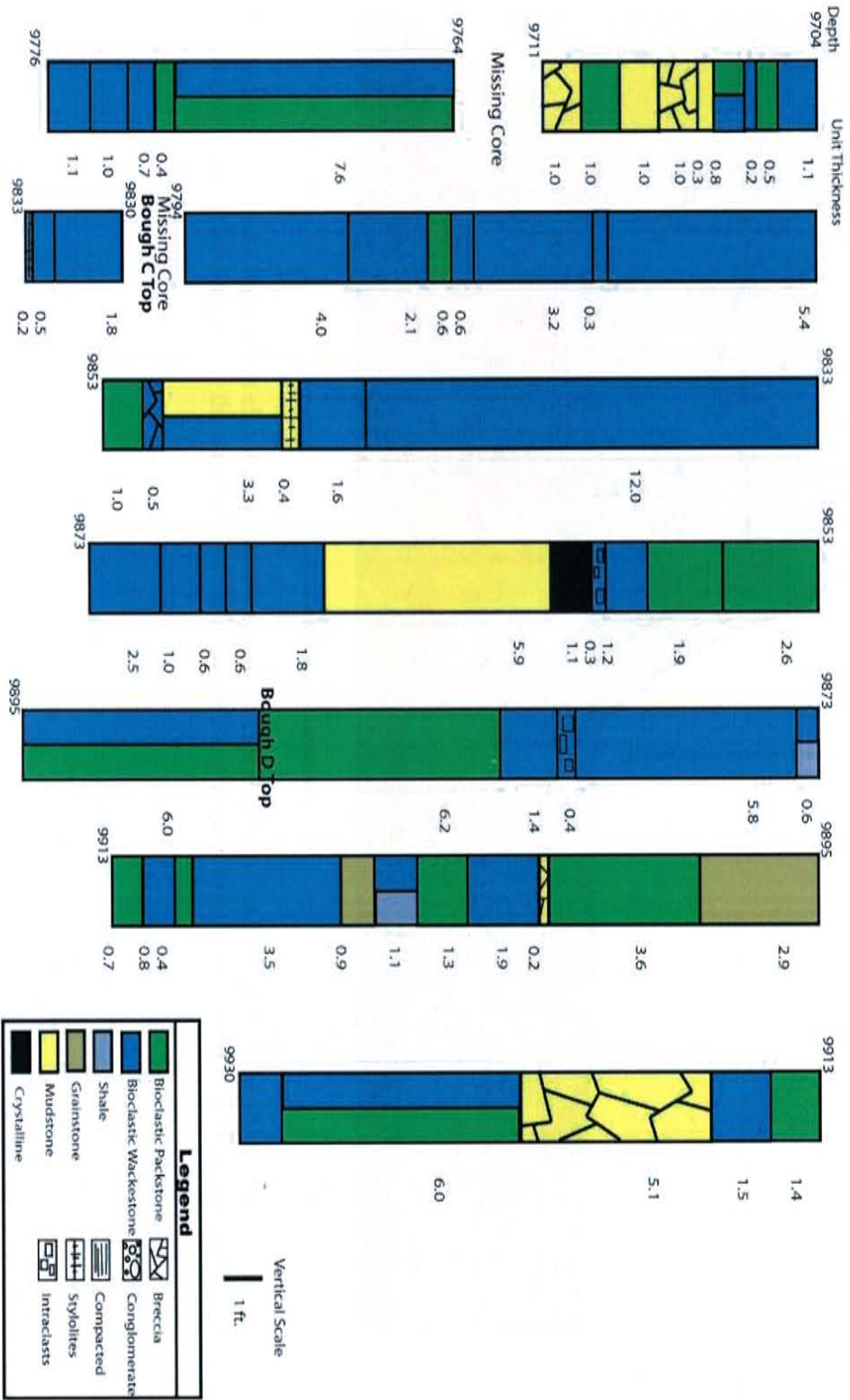


Figure 8 Stratigraphic section illustrating the lithologies and unit thickness of the core from Getty Oil Company's Willard Beatty 5.

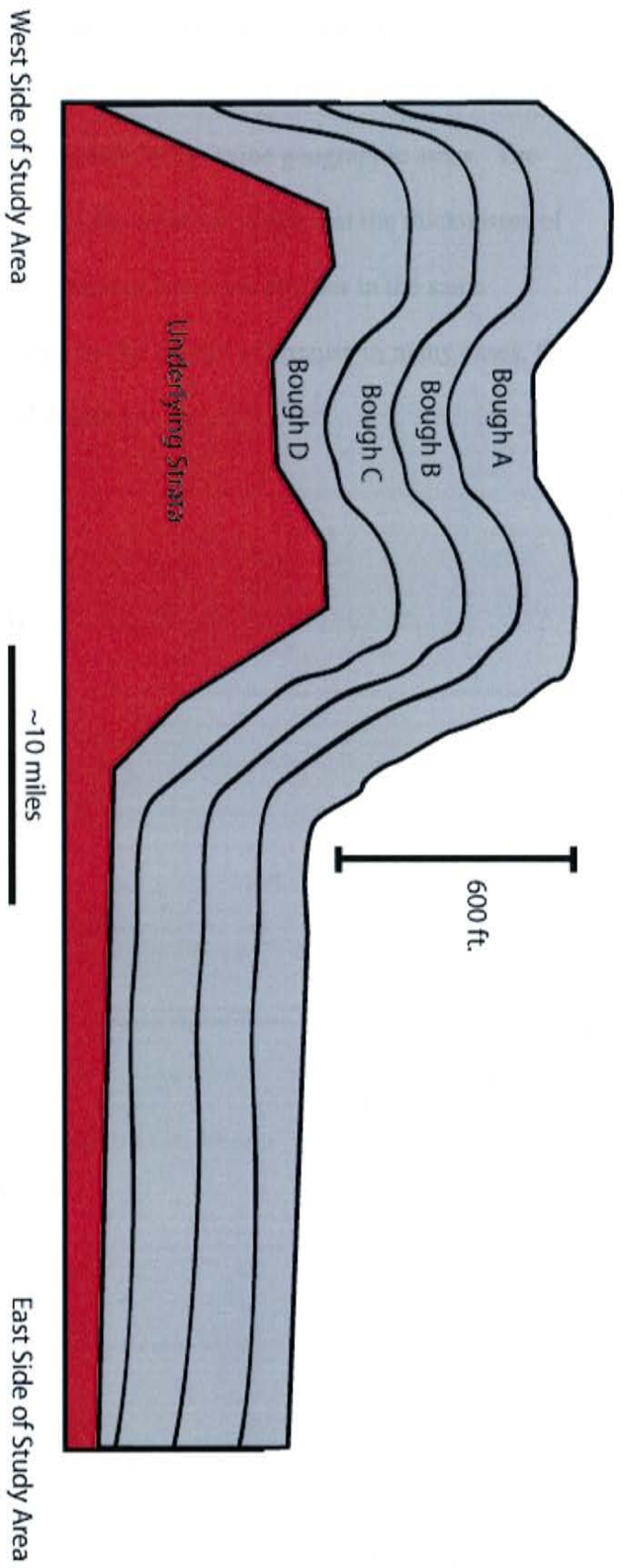


Figure 9 Illustration showing the drop in elevation of the Bough A, B, C and D from the west side of the study area to the east side in relation to ground level. Also notice how the structures of the separate Bough zones mimic each other and the underlying strata.

across the study area. The cross-sections also indicate the structures of the individual Bough zones (A, B, C, D) mimic each other. This is indicated by a lack of large scale change in depth between the individual deposits in the same geographic areas. The cross sections (Plates 1-5 and Appendix D) do, however, show that the thicknesses of the individual Bough zones can be very different from one another in the same geographic area. There is no isopach data on the Bough D because in many cases, the logs used for correlation did not record its base.

STRUCTURE AND PALEOSTRUCTURE

Inferred paleostructural axes of the study area are shown in Figure 10. This is an isopach map of the thickness between the top of the Mississippian and the top of the Abo Formation (Wolfcampian aged unit). The inferred pre-Mississippian paleostructural axes, representing structural highs, have been drawn onto the map. These axes are inferred from the thinning of the stratigraphic interval between the top of the Mississippian and the top of the Abo Formation, which indicates underlying structural highs (Broadhead, unpublished). The paleostructure map shows two prominent north-south trending structural axes, one on the west side of the study area and another in the center of the study area. Another prominent structural high can be seen on the boundary between townships 11 South Range 34 East and 12 South Range 34 East.

The structures of the individual Bough zones follow the same basic trends. Since this is true, the top of the Bough D (the lowest Bough unit) can be inferred to show the structure of the Bough zone (Figure 11). The structures of the Bough zones show a trend of increasing elevation towards the west side of the study area. A less prominent high, trending east-west, can also be seen in the middle of the east side of the study area.

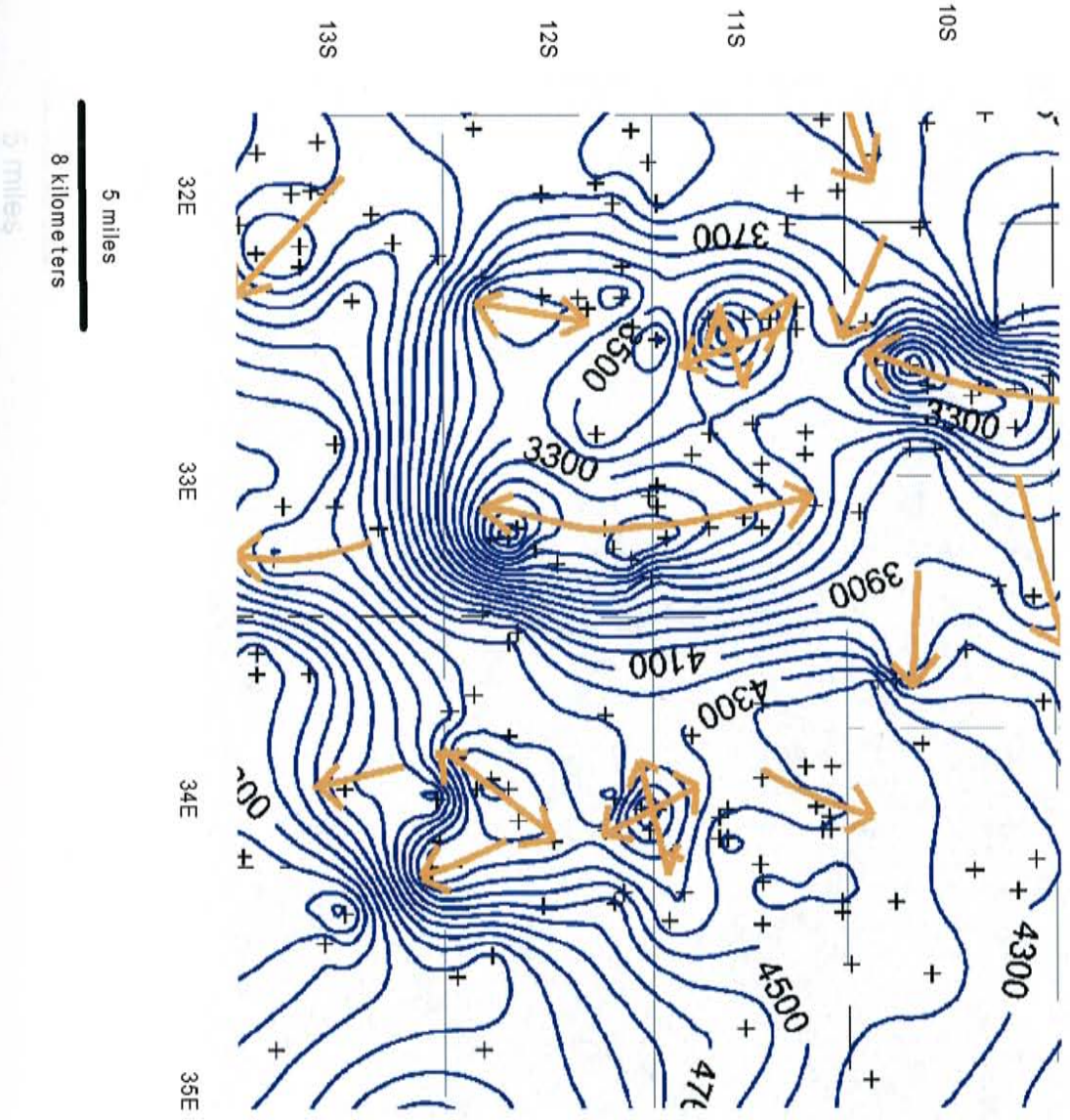
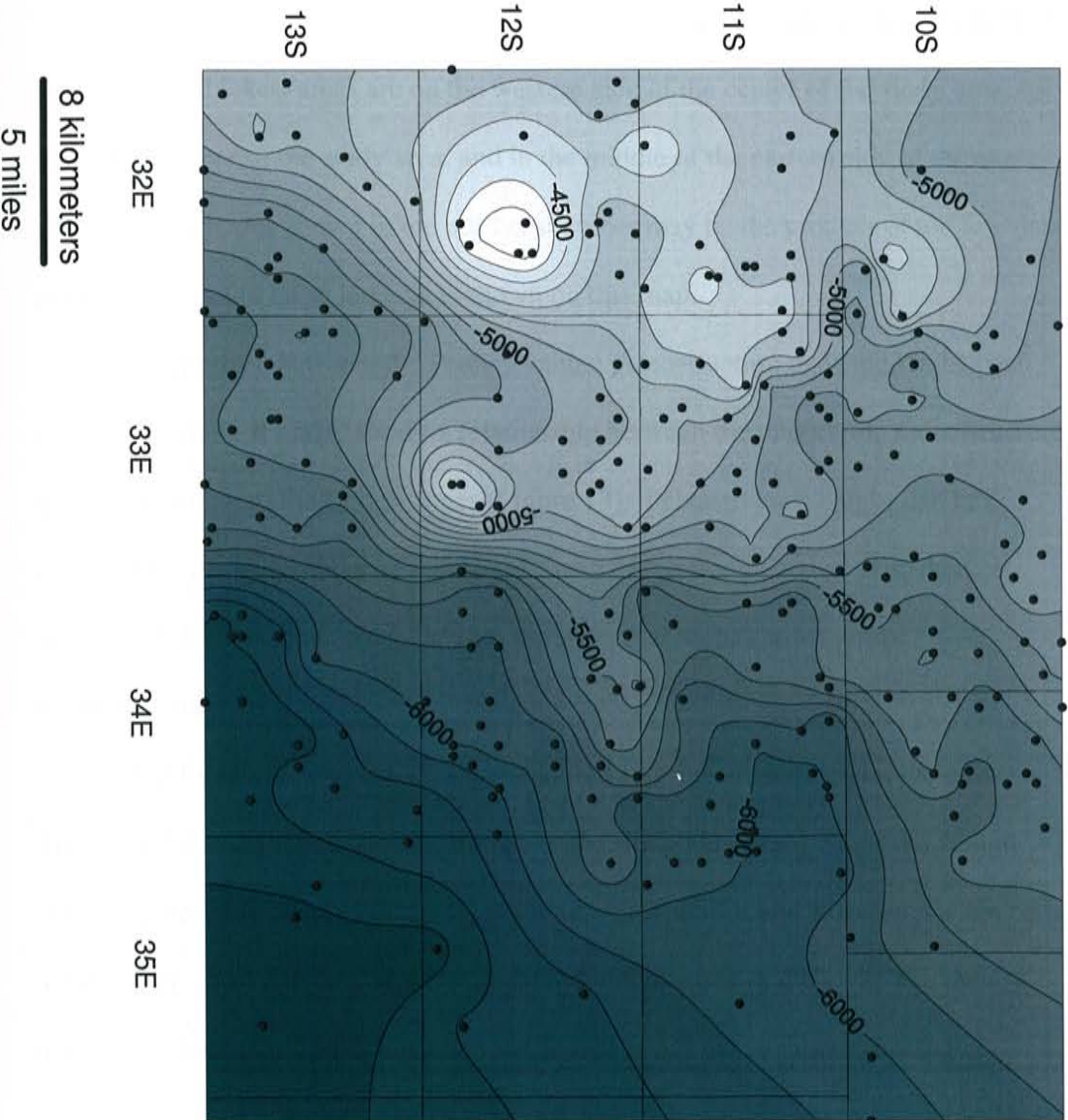


Figure 10 Inferred paleostructure map created by R. F. Broadhead (unpublished). Map shows the thickness between the top of the Mississippian and the top of the Abo Formation with paleostructural axes inferred from the areas of thinning. Contour interval is 100 ft. and the arrows represent paleostructural axes. Top of map is north.



Elevation
(Datum is SL)

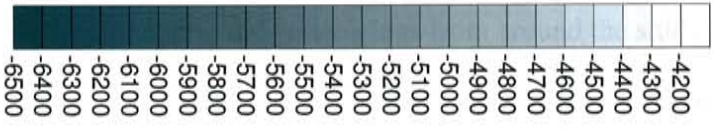
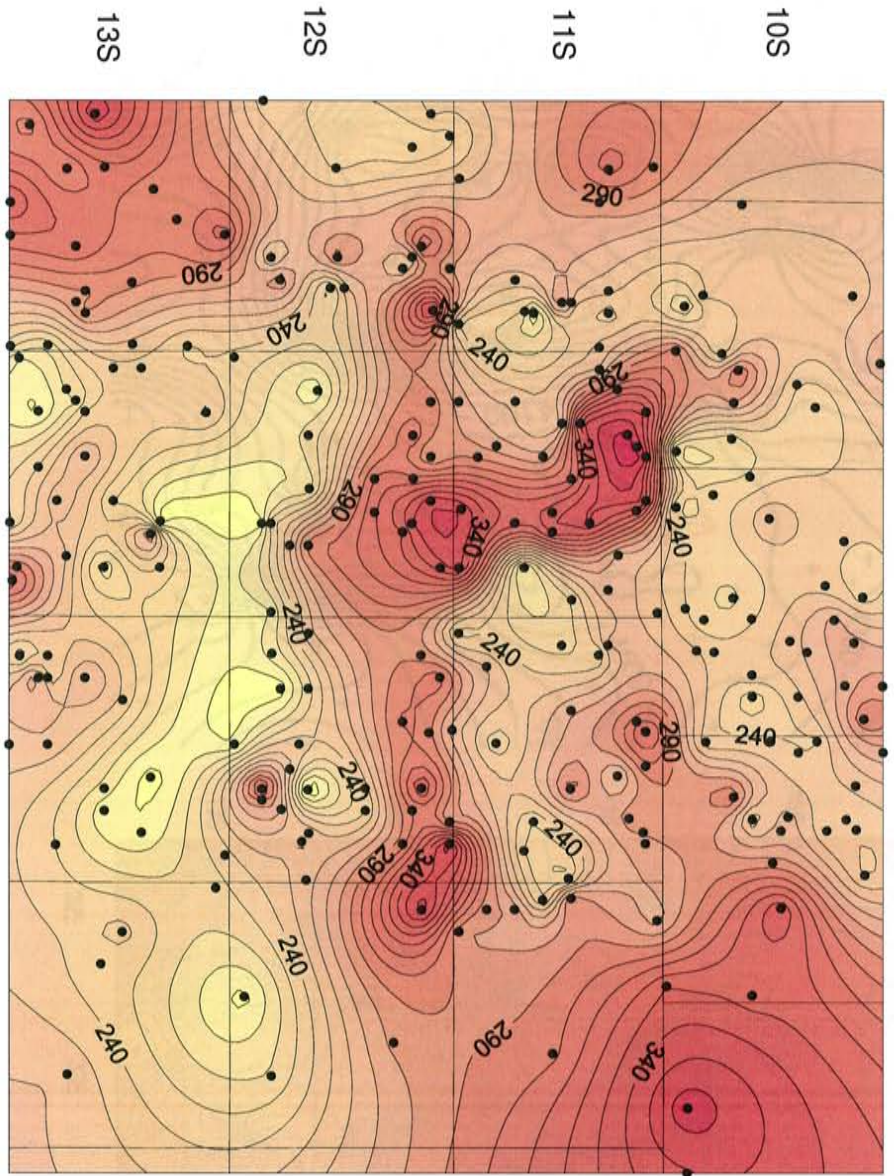


Figure 11 Structure contour map of the top of the Bough D within the study area. Top of map is north.

The isopach map of the Bough A, B and C (Figure 12) shows three main thick areas. These thickest areas are on the western side of the center of the study area, the southwest corner of the study area, and in the middle of the eastern side of the study area. The thick area shown in the northeast corner may be the product of too few data points and may not be as large as is shown on this map.

Comparison between the Pennsylvanian paleostructure map and the isopach map of Bough A, B and C shows a relationship between the underlying paleostructure and the thickness of the Bough zones (Figure 13). Paleostructural highs can be compared to the same areas on the isopach map of the Bough zones. The thickest areas of the Bough zones coincide with the structural highs shown on the paleostructure map.

The Bough zone strata are separated into four informal stratigraphic units. These are the Bough A, Bough B, Bough C and Bough D zones. Since the Bough zones are the same types of deposits, phylloid algal mounds and associated shale beds (observed in core analysis), separating the individual zones is difficult. For the purpose of this study I have separated the Bough zones using gamma-ray log correlation. Well completion cards often refer to the top of the Cisco Group as the top of the Bough C. In correlating the various logs from around the study area this assumption was followed and the top of the Bough C was treated as the boundary between Cisco Group and Wolfcampian limestone strata. Using the top of the Cisco Group as a stratigraphic datum, the 244 wells were correlated and the boundaries between the individual Bough zones were identified as recognizable gamma-ray log markers above and below the datum. These cross-sections were used to make the



Bough Zone Thickness (ft.)

Figure 12 Isopach map of the thickness of the Bough A, B and C zones showing the heterogeneity of Bough thickness above the Bough D. Top of map is north.

8 kilometers
5 miles

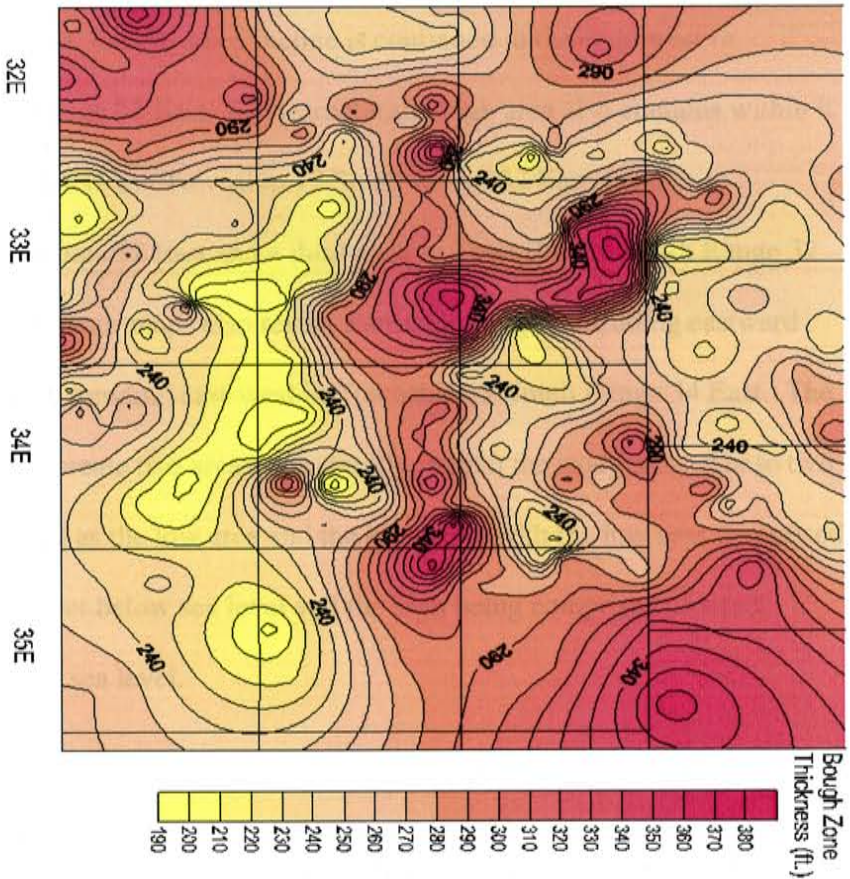
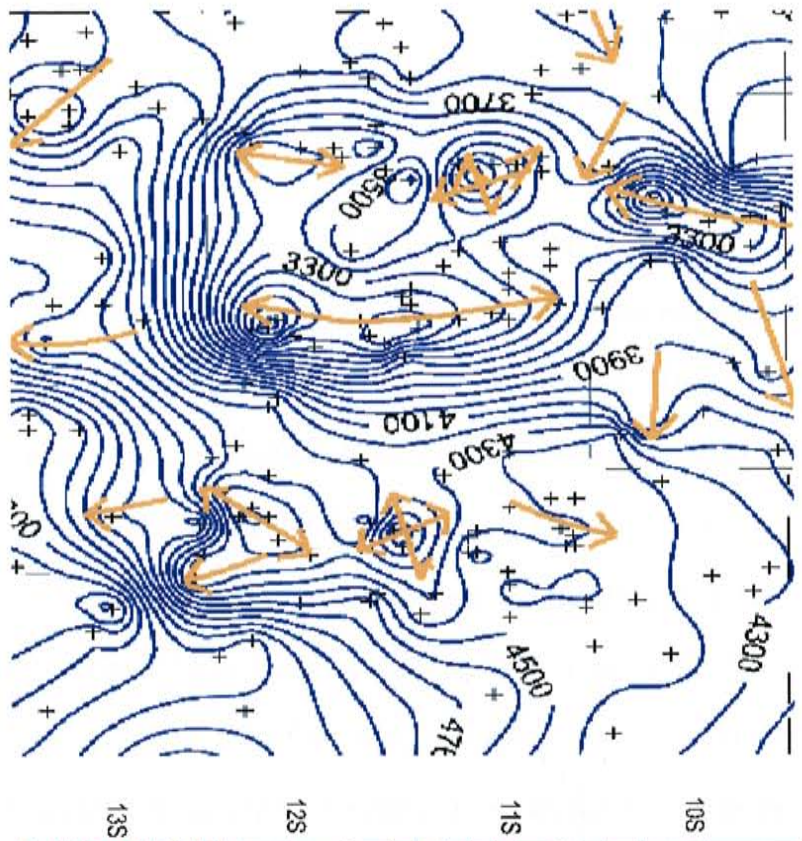
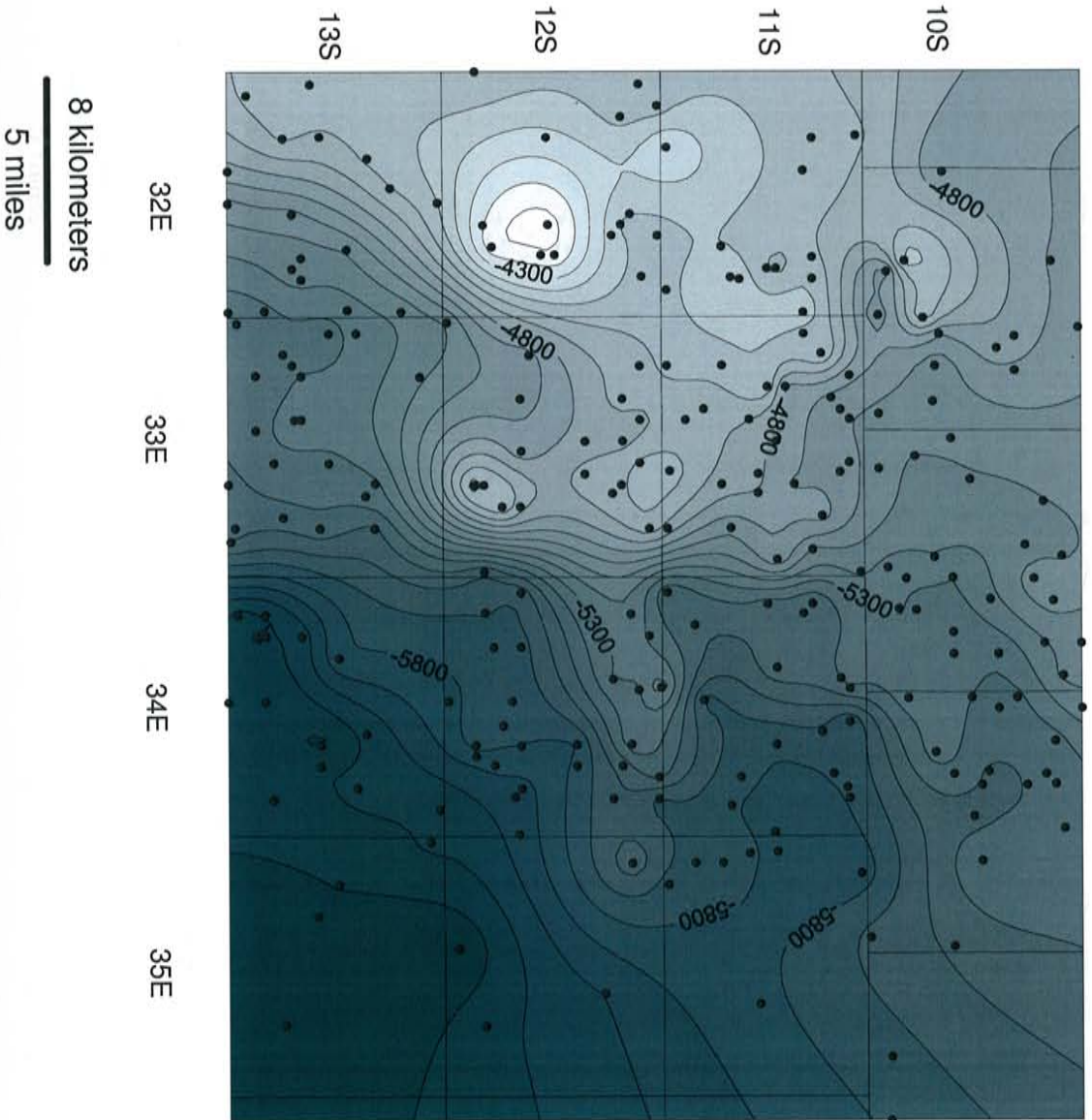


Figure 13 Inferred paleostructure map (left) versus the isopach map (right) of the same area. Notice the paleostructural axes generally correspond to thicker areas on the isopach map. Top of both maps is north.

structure and isopach maps of the Bough zones within the study area. Five examples of the cross-sections are available on Plates 1-5 and the other 13 are found in Appendix D.

The Bough A, B, C and D zones all exhibit the same structural trends (shown in Figs. 11, 14, 15 and 16), though not all trends are expressed to the same degree in each layer. The elevation of each zone increases in a westward direction. The elevation of the strata ranges from 6600 feet below sea level (east side of the study area) to 4000 feet below sea level (west side of the study area). The maps show that there is a steep structural rise running north-south in the center of the study area within Townships 11 South Range 33 East and 12 South Range 33 East. This structural rise is more defined in the center of the study area and the rise becomes less evident to the north and south of the center in Townships 13 South Range 33 East and 10 South Range 33 East, but the steep incline is continued to the southwest in Township 13 South Range 32 East. This structurally high area also contains within it three distinct peaks, one in the Township 12 South Range 33 East, another in Township 12 South Range 32 East and a third peak in Township 10 South Range 32 East. The structure contour maps also reveal a structural high protruding eastward from the larger plateau trending east-west in Township 12 South Range 34 East. The structural high acts to create two areas, structurally, within the study area. These two areas may be described as the low area and the high area, with the low area comprised of strata below 5500 feet below sea level and the high being comprised of strata above 5500 feet below sea level.



Elevation
(Datum is SL)

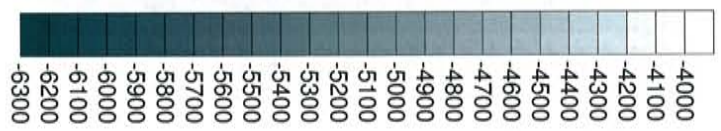


Figure 14 Structure contour map of the top of the Bough A showing the structural trends within this layer of the Bough zone. Top of the map is north.

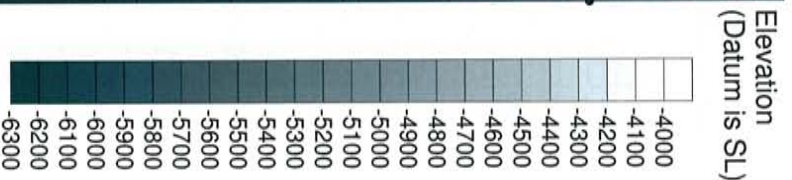
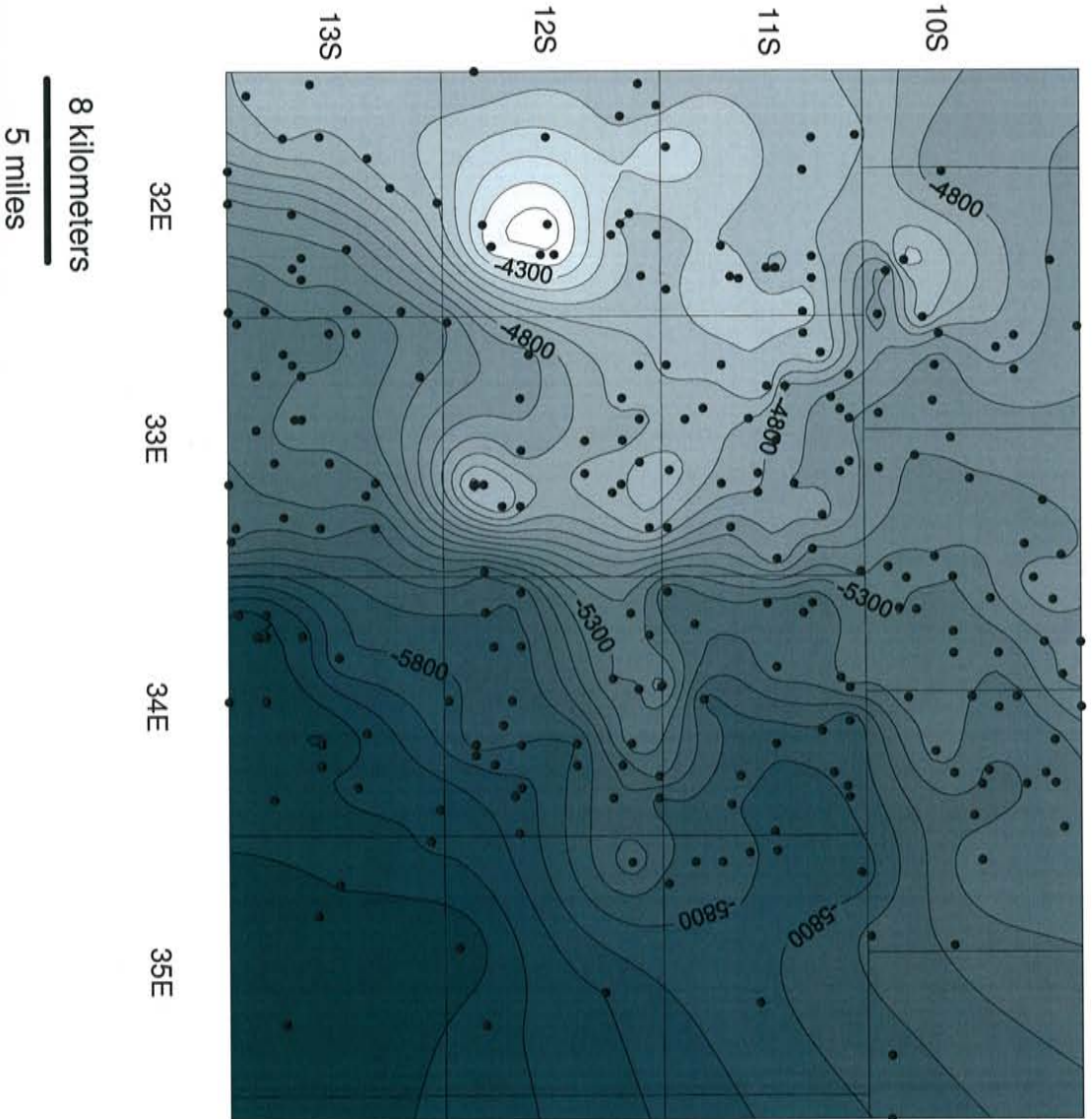


Figure 15 Structure contour map of the top of the Bough B showing the structural trends within this layer of the Bough zone. Top of the map is north.

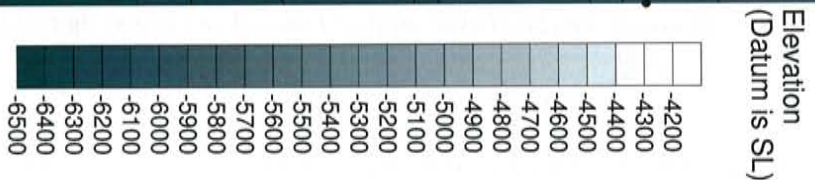
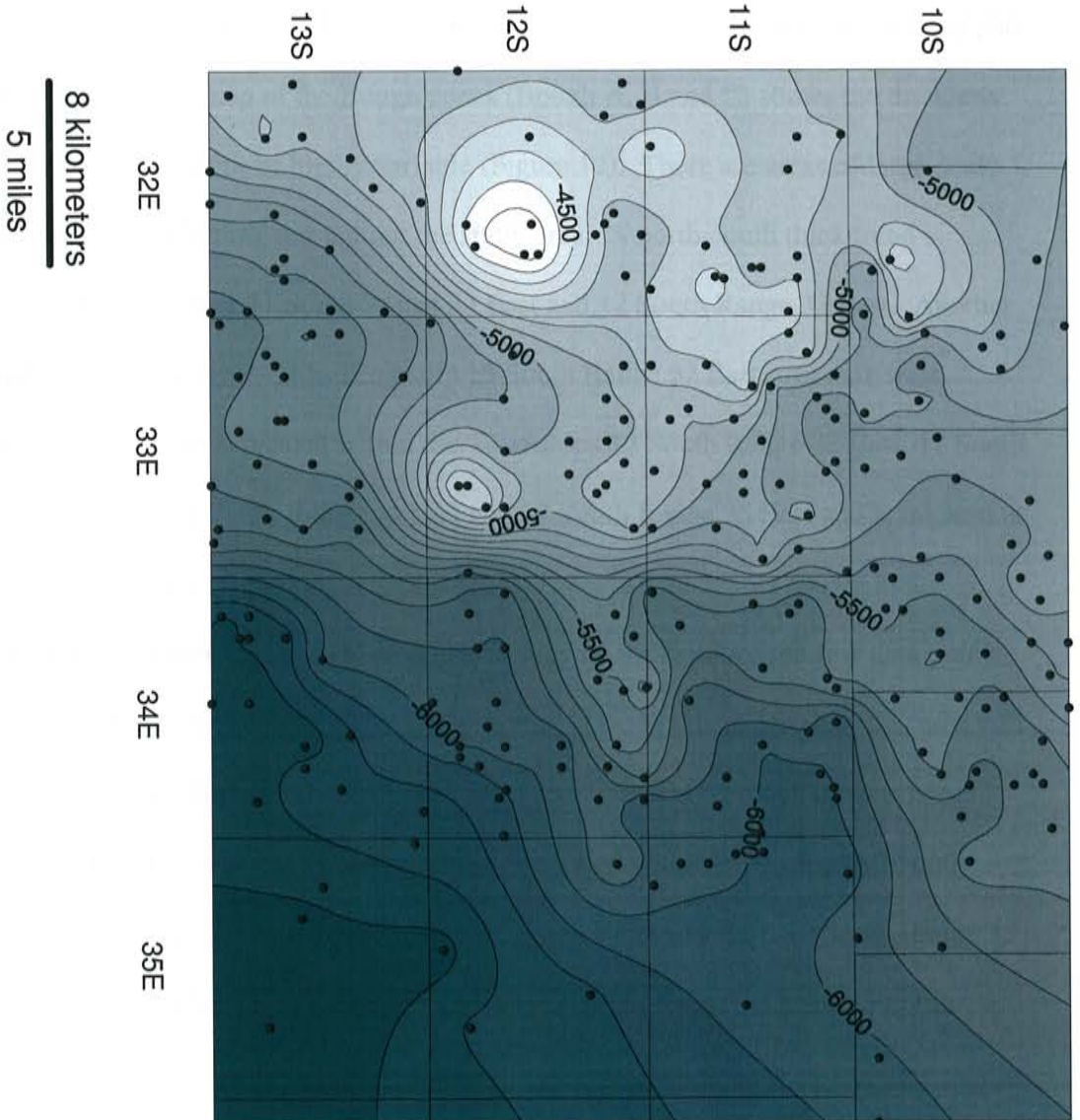


Figure 16 Structure contour map of the top of the Bough C showing the structural trends within this layer of the Bough zone. Top of the map is north.

The thickness of the Bough A, B and C zones range between 190 feet and 380 feet. The isopach map of the Bough zones (Bough A, B and C) shows the thickness of the Bough zones to be highly variable (Figure 12). There are areas of large-scale thinning and thickening throughout the study area. A north-south thick trend is present in Townships 11 South Range 33 East and 12 South Range 33 East. Another thicker area is present within Township 13 South Range 32 East. An east-west trending thick area is present within the Townships 12 South Range 32 East, 12 South Range 33 East, 12 South Range 34 East and 12 South Range 35 East and is thickest at its easternmost tip (approximately 360 feet). There is a thick area shown in the northeastern corner of the study area, which may be the result of too few data points and is probably smaller than the map represents. Due to this uncertainty this area will not be discussed further. These thicker areas are separated by much thinner zones, most notably the large east-west trending zone found within Townships 12 South Range 32 East, 12 South Range 33 East, 12 South Range 34 East, 12 South Range 35 East and Townships 13 South Range 32 East, 13 South Range 33 East, 13 South Range 34 East, 13 South Range 35 East.

The individual Bough zones (A, B, and C) show very different trends in thickness among them. The three mapped zones show the same type of heterogeneous distribution of thicknesses that the overall Bough zone has, but they do not mimic each other. The Bough A (Figure 17) contains thicker areas in Townships 11 South Range 33 East and 12 South Range 33 East, as well as in Township 13 South Range 32 East. The Bough B (Figure 18) shows the same trend of having a thicker zone in the center of the study area and in the southwestern corner, but there

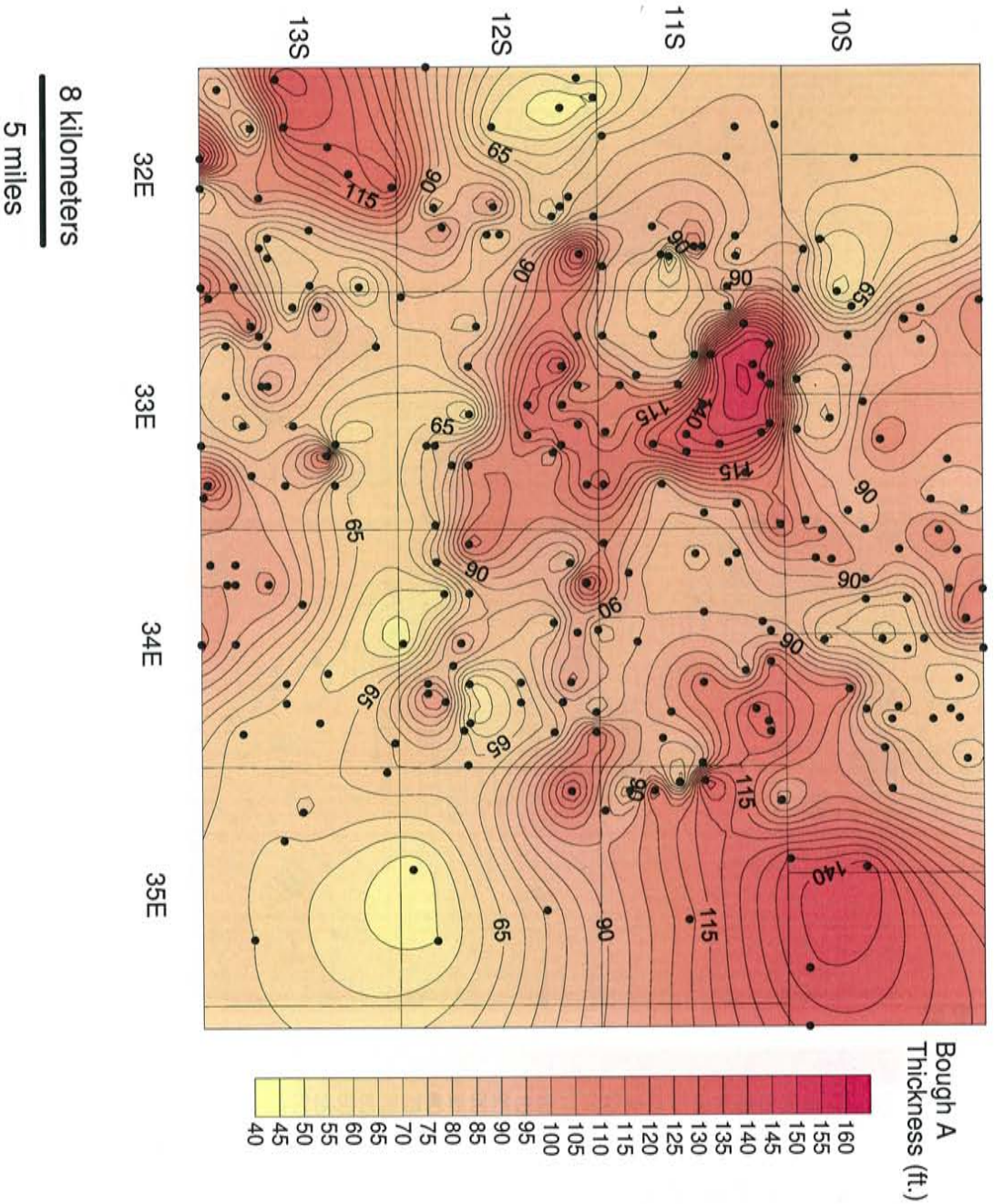
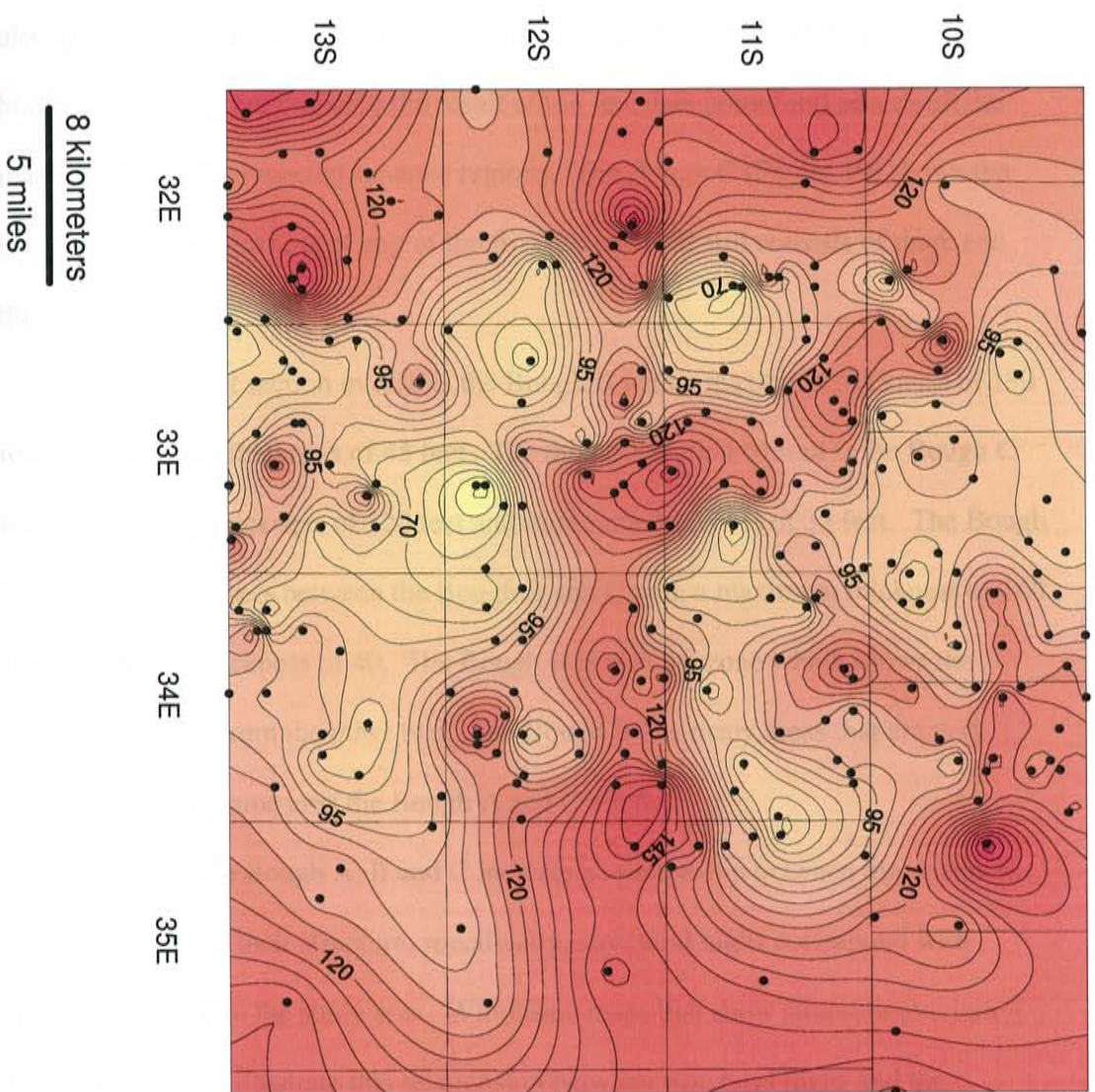


Figure 17 Isopach map of the Bough A showing thickness from the top of the Bough B to the top of the Bough A. Notice the heterogeneous thickness distribution over the study area. Top of the map is north.



Bough B
Thickness (ft.)

Figure 18 Isopach map of the Bough B showing thickness from the top of the Bough C to the top of the Bough B. Notice the heterogeneous thickness distribution over the study area. Top of the map is north.

also appears to be thickening on the east and west borders of the study area. These border thickenings are probably the result of too few data points and as a result the mapping program connected separate regions. The Bough C (Figure 19) shows the least variation in thickness of any of the Bough zones but still consists of thick and thin regions.

The thickest section overall is the Bough B with a maximum thickness of 180 feet and minimum thickness of 45 feet. The thinnest section overall is the Bough C with a maximum thickness of 120 feet and minimum thickness of 35 feet. The Bough A has thickness values between the Bough B and C with a maximum thickness of 160 and a minimum thickness of 40. The Bough B is also the zone which shows the largest difference from the other two. The Bough B has many areas that are very thick when in the same area the Bough A and C are thin.

Maps of the Bough A, B and C indicate a relationship between the thickness of the deposits and their structure, specifically, structural highs correspond with thicker zones within the study area. Wireframe maps that show structure overlain with isopach maps illustrate this relationship between structural highs and the thickness of the strata (Figs. 20-22). This relationship is evident in both individual Bough zone strata and is also seen in the map comprising the entire thickness of the Bough A, B and C (Figure 12).

Bough C
Thickness (ft.)

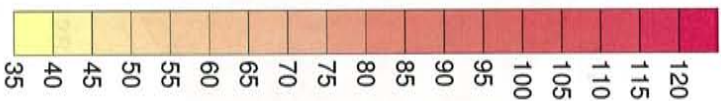
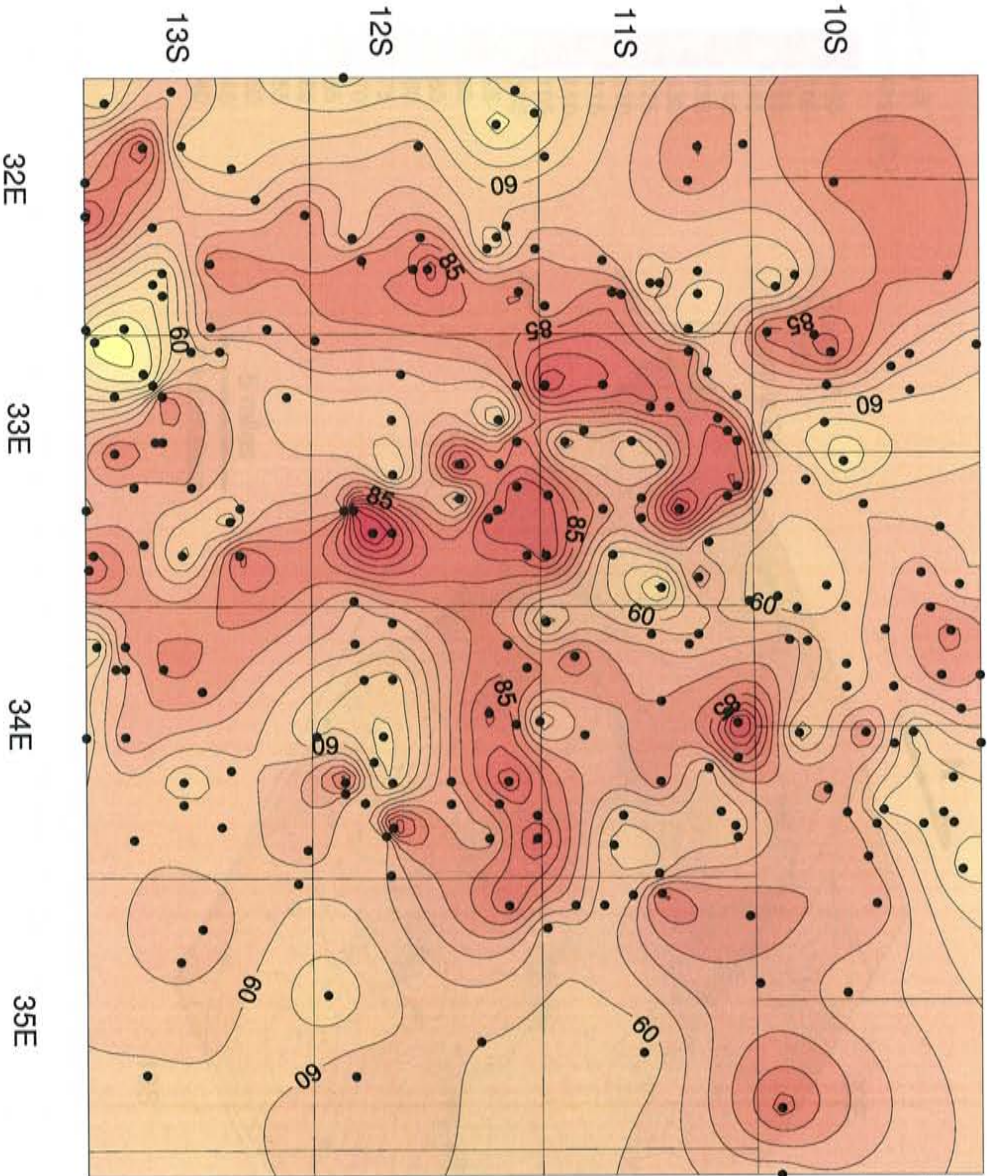


Figure 19 Isopach map of the Bough C showing thickness from the top of the Bough D to the top of the Bough C. Notice the heterogeneous thickness distribution over the study area. Top of the map is north.



8 kilometers
5 miles

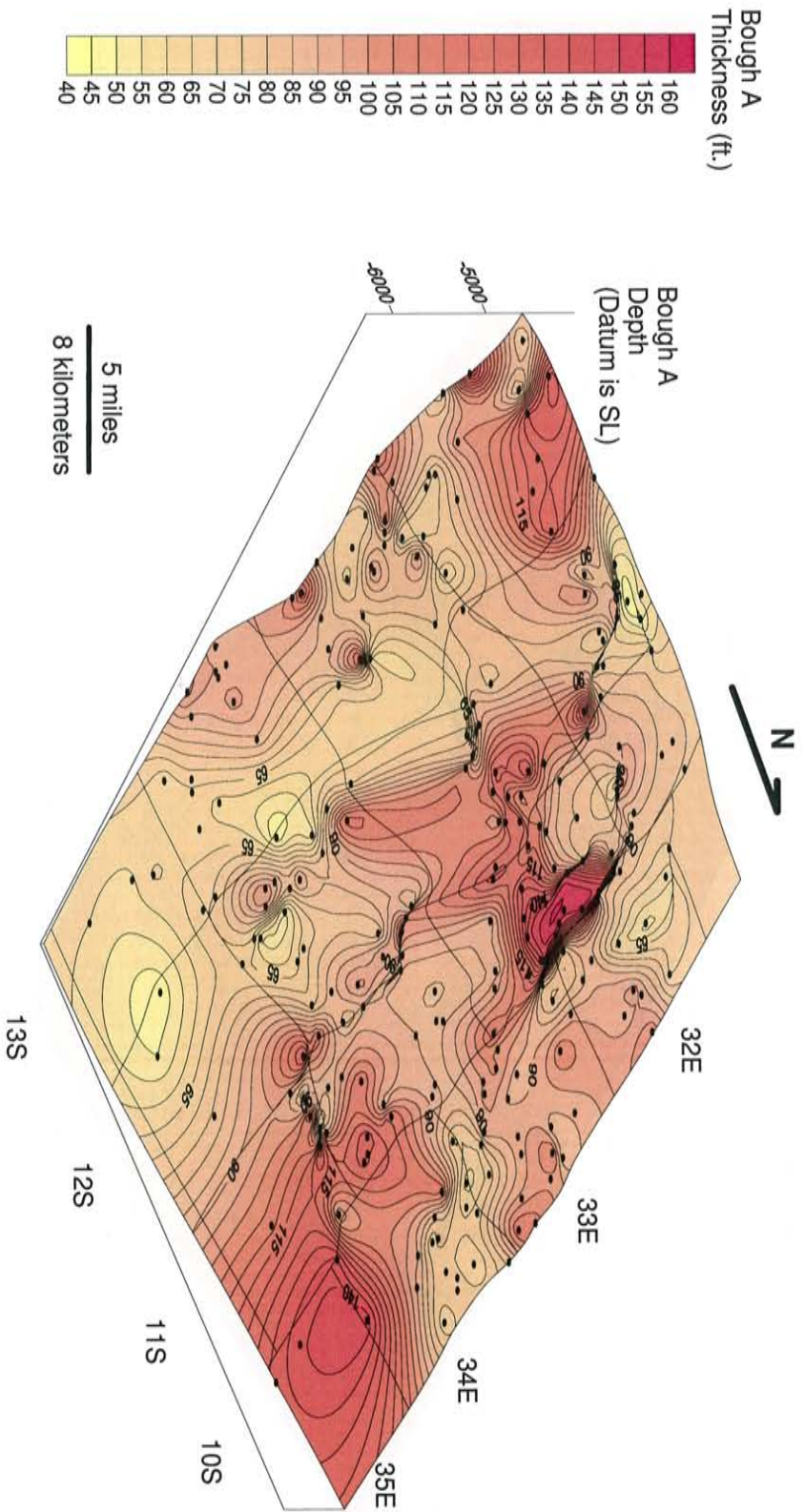


Figure 20 Map illustrating the relationship between structure and thickness of the Bough A. Contour isopach map of the thickness of the Bough A over a wireframe structure map of the top of the Bough B. Data points are shown.

Bough B
Thickness (ft.)

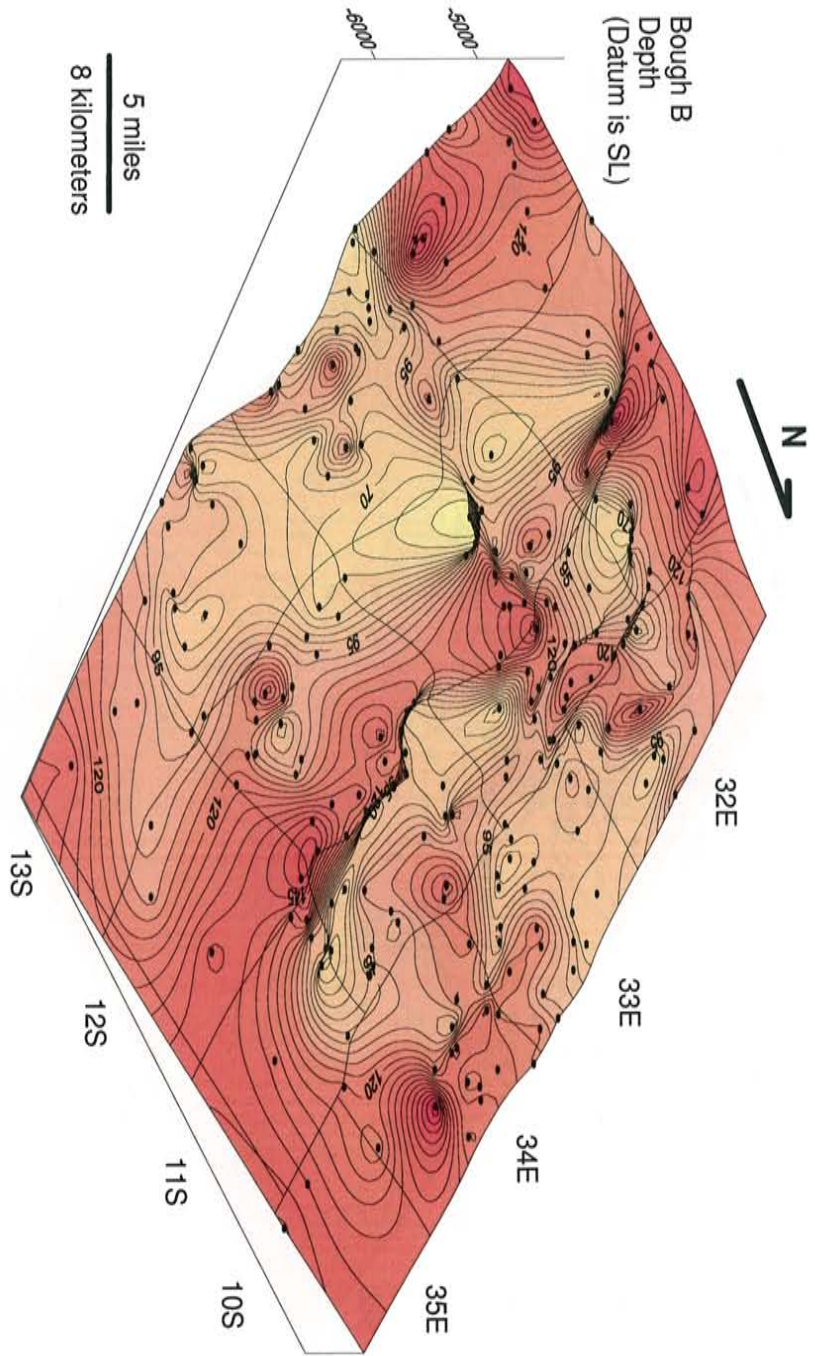
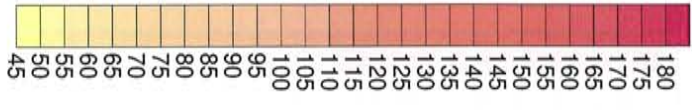


Figure 21 Map illustrating the relationship between structure and thickness of the Bough B. Contour isopach map of the thickness of the Bough B over a wireframe structure map of the top of the Bough C. Data points are shown.

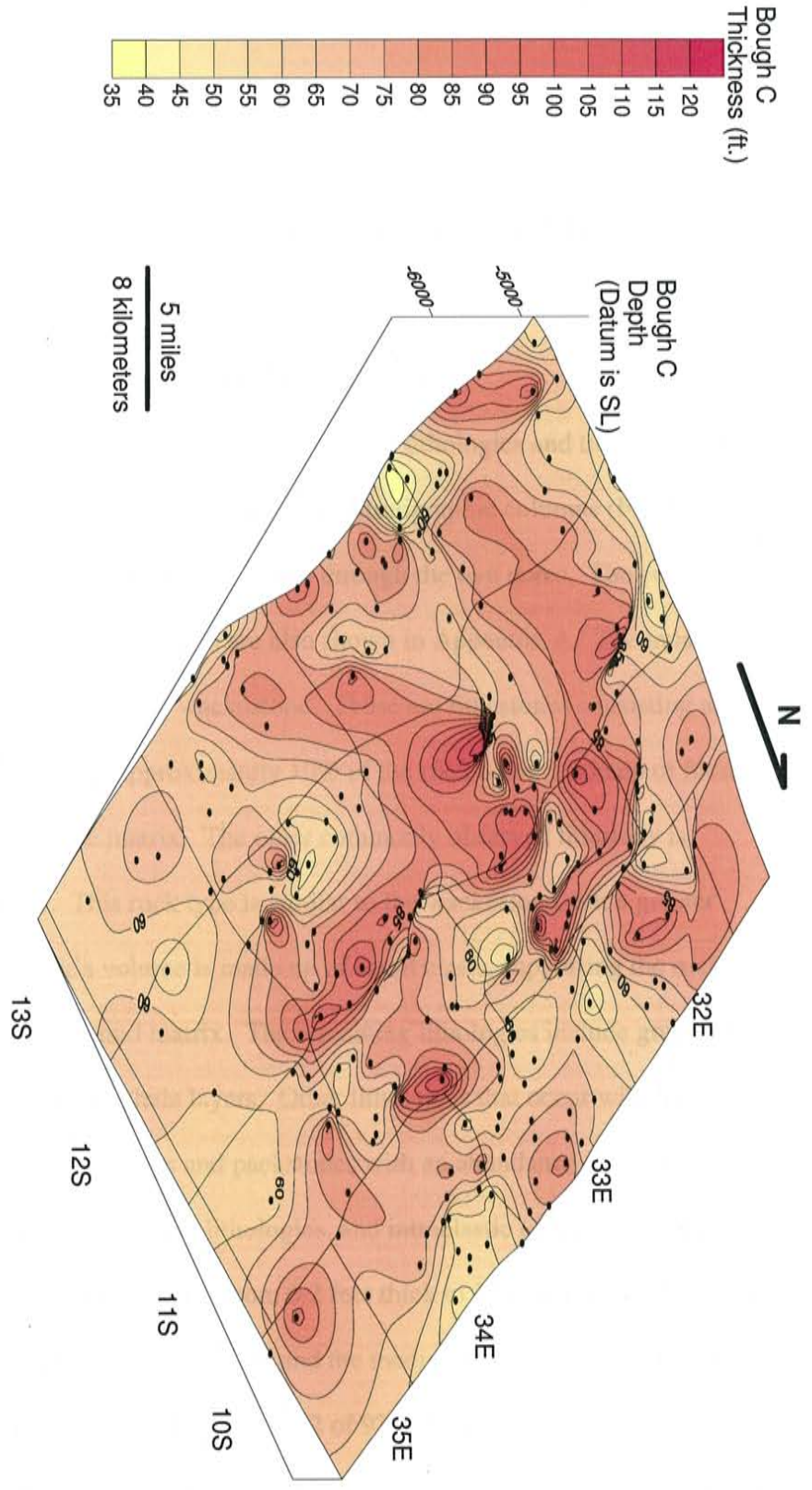


Figure 22 Map illustrating the relationship between structure and thickness of the Bough C. Contour isopach map of the thickness of the Bough C over a wireframe structure map of the top of the Bough D. Data points are shown.

LITHOLOGY OF THE BOUGH ZONES

CORE DESCRIPTIONS

Macroscopic core studies reveal three main lithologies and three other, less common, lithologies within the Bough zones. Stratigraphic columns (Figures 7 and 8) show the distribution of these lithologies through the two cores. The cores' units and descriptions of individual units are also shown in Appendix A. The most common lithology is bioclastic wackestone. These are limestones consisting almost entirely of lime mud with approximately 10% of the rock being made up of fossil clasts floating within the matrix. The other commonly observed lithology is bioclastic packstone. This rock type is similar to the wackestone, but a greater percentage of the rock's volume is made up of fossil clasts, supporting the rock's structure, within a lime mud matrix. The remaining lithologies include grainstones, crystalline limestones and shale layers. Other lithologies that occur with lesser frequency include wackestones and packstones with an abundance of one type of sedimentary structure, brecciated lithologies, and intraclastic (instead of bioclastic) limestones. Bed thicknesses range from 0.2 feet thick to 12.0 feet thick. The average unit thickness is approximately 1.0 foot and the median thickness is also 1.0 foot thick. The contacts between units are, in 82 of 93 total contacts, sharp. The boundaries between units are usually marked by a distinct color change. In the few

cases with gradational contacts between units, the distinction is made according to a change in the percentage of fossils present within the unit. There are a few cases in which the change in lithology is from a nonlaminated limestone unit to a brecciated unit, but in most cases the change is a more subtle change in lithology (i.e. wackestone to packstone or a change of color between similar lithologies).

Core description also provides insight into the porosity and sedimentary structures of the Bough zone. Most of the beds within the Bough zone lack any type of lamination. There are some shale layers which contain thin horizontal laminations, but none of the limestone layers are internally bedded. Beds are differentiated by the percentage of fossil clasts and slight color variations in the matrices. Sedimentary structures are limited almost entirely to stylolites and solution seams, which are observed in practically every limestone layer. Megascopic porosity types in the core samples range from highly visible moldic and vugular pore structures to no visible porosity at all. Moldic porosity stands out as the dominant porosity type observed in the core samples with many layers also containing vugular pores. Breccia pores occur in the brecciated layers, whereas a small number of layers contained a small degree of fracturing. The actual porosity percentages, using the Archie (1952) classification, range from ~2% in one bioclastic wackestone unit to 31% in one porous grainstone unit. The average porosity percentage falls into the 10-15% range for the limestone strata.

PETROGRAPHY

Petrographic analyses of 17 thin sections taken from two cores within the study area reveal three distinct rock types. These are: 1) dolomites, 2) biomicrites, and 3) altered biomicrites. In addition to multiple rock types, petrography has revealed varying degrees of porosity development and reduction. Brief descriptions of each of the seventeen thin sections are provided in Table 1 and more in depth descriptions are given in Appendix B.

The biomicrites (Figure 23) are the main rock type observed in thin section, making up approximately 80% of the samples. The biomicrites contain an abundance of fossils including phylloid algae, echinoids, brachiopods, fusulinids, bivalve fragments and bryozoans. These fossils are found within a micritic matrix. Most are wackestones, but packstones are also present. In many cases the fossils have been dissolved, especially the more unstable fossil types, such as the phylloid algae. A large degree of micritization of fossil allochems can also be observed in the biomicrites. Pores are dominantly moldic with some solution enlarged vugs as well as a small amount of fracture and channel porosity. The amount of unfilled pore space varies greatly within the biomicrites, ranging from 0 to 37% depending on the degree of occlusion caused by calcite crystals.

The altered biomicrites (Figure 24) also contain an abundance of the fossil types mentioned above, but much of the micrite matrix has been replaced by pseudospar. The porosity within the altered biomicrites is much lower than that found in the micrites due to occlusion of porosity by calcite cement. The altered biomicrites are similar to the micrites as far as observed porosity types. Porosity

Table 1 Classification and percent porosity of thin sections.

Lease Name	Sample Depth (Ft.)	Folk Classification	Dunham Classification	Percent Porosity
Willard Beaty 5	9775	Packed Biomicrite	Packstone	2
Willard Beaty 5	9887	Packed Biomicrite	Fossiliferous Packstone	15
Willard Beaty 5	9850	Sparse Biomicrite	Fossiliferous Wackestone	10
Willard Beaty 5	9856	Phylloid Algal Packed Biomicrite	Fossiliferous Packstone	35
Willard Beaty 5	9864	Dolomitized Sparse Sorted Biomicrite	Cementstone	20
Willard Beaty 5	9869	Altered Unsorted Biomicrite	Fossiliferous Packstone	20
Willard Beaty 5	9879	Packed Biomicrite	Fossiliferous Packstone	37
Willard Beaty 5	9892	Packed Biomicrite	Fossiliferous Packstone	30
Willard Beaty 5	9901	Packed Biomicrite/ Altered Unsorted Biomicrite	Fossiliferous Packstone	30/70
Willard Beaty 5	9935	Packed Biomicrite	Fossiliferous Packstone	40
Willard Beaty 5	9972	Unsorted/ Packed Biomicrite	Fossiliferous Packstone/Wackestone	25
DL State 1	9710	Packed Biomicrite	Fossiliferous Packstone	20
DL State 1	9721	Packed Biomicrite/ Altered Poorly Washed Biomicrite	Fossiliferous Wackestone	15/30
DL State 1	9772	Dolomitized Micrite	Cementstone	0
DL State 1	9780	Phylloid Algal Packed Biomicrite	Fossiliferous Wackestone	30
DL State 1	9805	Altered Porous Phylloid Algal Biomicrite	Fossiliferous Packstone	50
DL State 1	9814	Porous Phylloid Algal Biomicrite	Fossiliferous Wackestone	30



Figure 23
Photomicrograph of a biomicrorite. Sample shown has had some pore space occluded by calcite crystals. A large recrystallized phylloid algal blade is present in the center of the thin-section. The dark material in the thin-section is mostly micrite with a few fossil fragments. The blue indicates porosity.

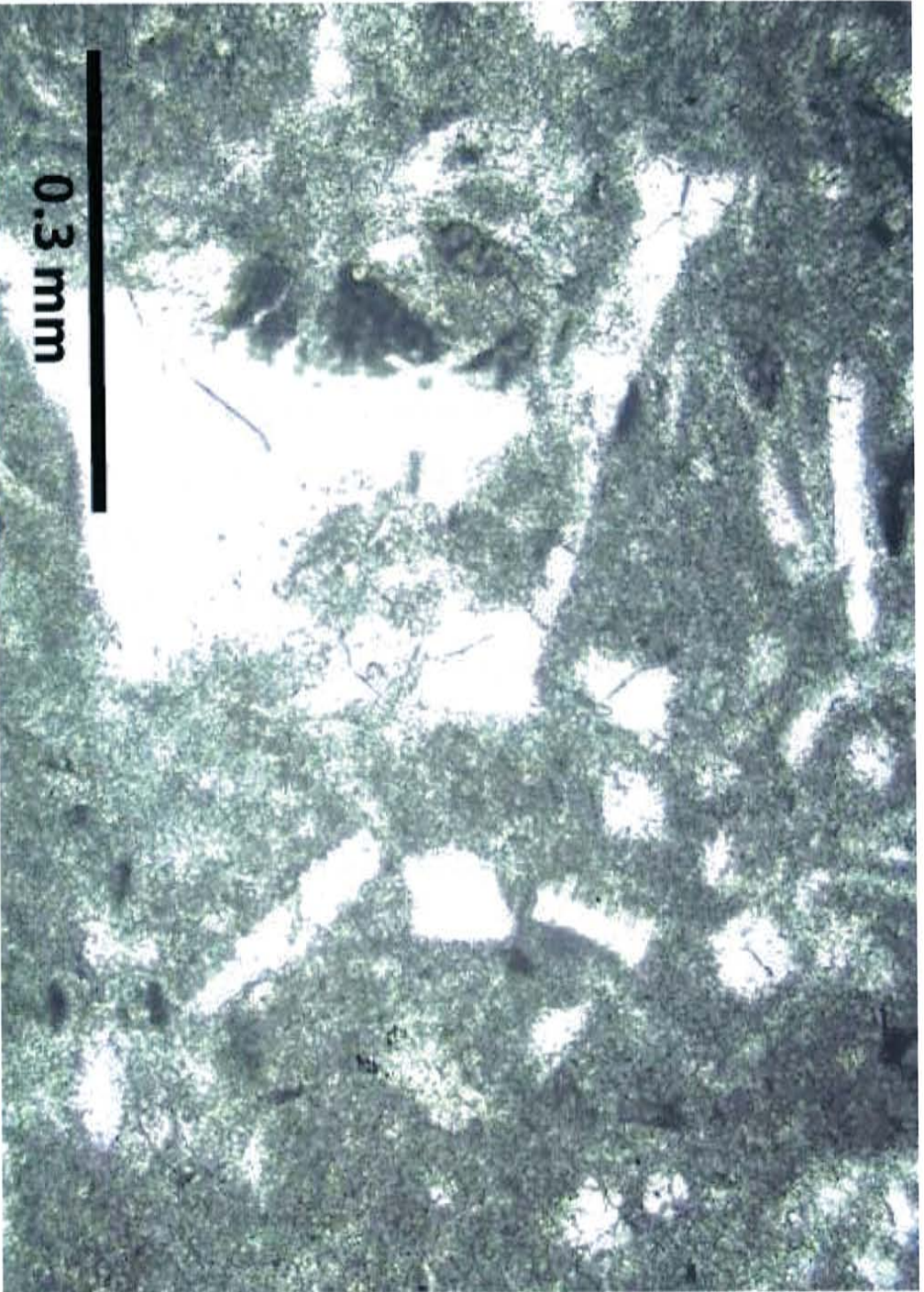


Figure 24
Photomicrograph of an altered biomicrite. Sample shown has had all porosity occluded by calcite crystals and calcite cement. A phylloid algal blade with a distinctive flared end is visible in the center of the thin-section. In this slide pseudospar has replaced an originally micritic matrix.

within the altered biomicrites is dominantly moldic with some vugular porosity, but almost all of the porosity observed has been completely infilled by calcite crystals.

The dolomites (Figure 25) are not as common as either the biomicrites or the altered biomicrites. The dolomitized facies are lacking in recognizable fossils and are mostly made up of a non-facies selective fabric destructive dolomite matrix consisting of small subhedral crystals with few larger spherical crystals which may be recrystallized ooids or relict burrows. Small amounts of calcite crystals can be seen within the dolomite zones using a carbonate stain. Porosity within the dolomitized zone is intracrystalline and reaches a maximum value of about 20%.

There is also evidence of deep burial observed in the cores. This includes the presence of stylolites, solution seams, plasticly deformed grains and baroque dolomite. It is evident that the pores were created, and in many cases filled, prior to significant burial, because a number of the filled pore spaces are cut by stylolites. There were also other allochems (e.g. sponge spicules, bryozoans) compacted around the pore spaces filled with calcite cement.

The detailed description of the cores with 17 thin sections and 66 acetate peels allowed for direct comparison between the defined rock types and gamma-ray log curves. The purpose of this comparison was to create a set of gamma-ray log values for the different rock types. This comparison yielded little due to the similarities between the gamma-ray log curves representing the different rock types and in the end no distinct gamma-ray log values could be determined for individual rock types.

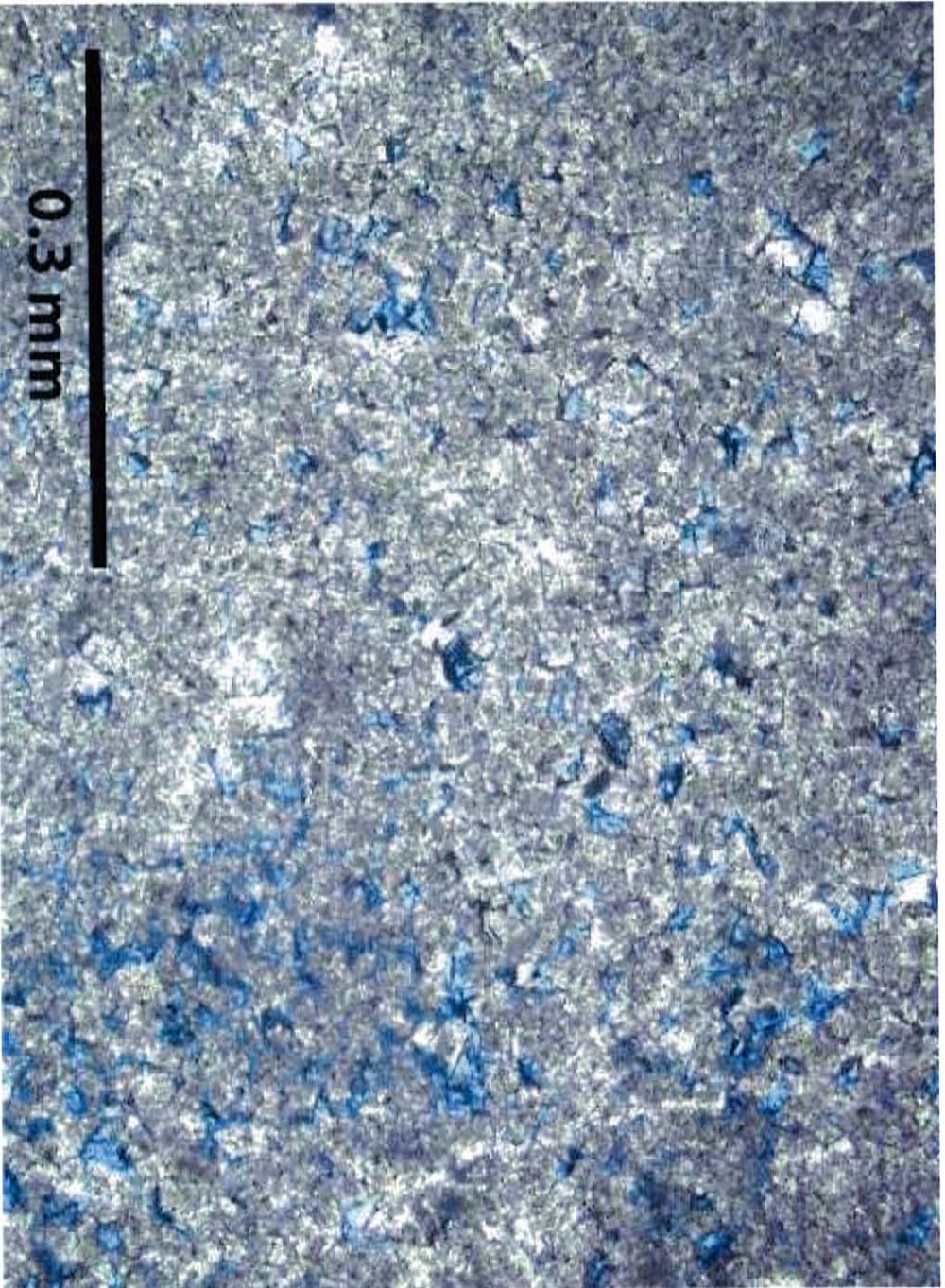


Figure 25
Photomicrograph of a dolomite with intercrystalline porosity highlighted by blue epoxy. Rhombohedral crystal faces are visible as relict micrite within the dolomite crystals.

OIL PRODUCTION

The distribution of oil production from the Upper Pennsylvanian and Lower Permian strata is heterogeneous within the study area. Out of the 242 wells used in the creation of structure and isopach maps, 63 are productive from the Bough zones (Figure 26). A productive well is defined as any well for which cumulative oil production was reported in the 2003 Southeast Annual Report (BL Resources, 2003). The productive wells have an uneven geographic distribution, with clusters of productive wells in the northern and southern parts of the study area, as well as scattered productive wells in the center. There is a complete lack of productive wells in the extreme eastern and western portions of the study area.

Oil production within the Bough zones is also stratigraphically heterogeneous. The oil produced comes from one of four of the individual Bough zones. There were ten wells producing from the Bough A (Figure 27), fourteen from the Bough B (Figure 28), forty-three from the Bough C (Figure 29), and twenty-three from the Bough D (Figure 30). These numbers don't add up to the sixty-three wells mentioned in the previous paragraph, because several wells produce from more than one Bough zone. These data are summarized in Table 2. Productive wells are listed along with the stratum they are producing from in the table in Appendix C.

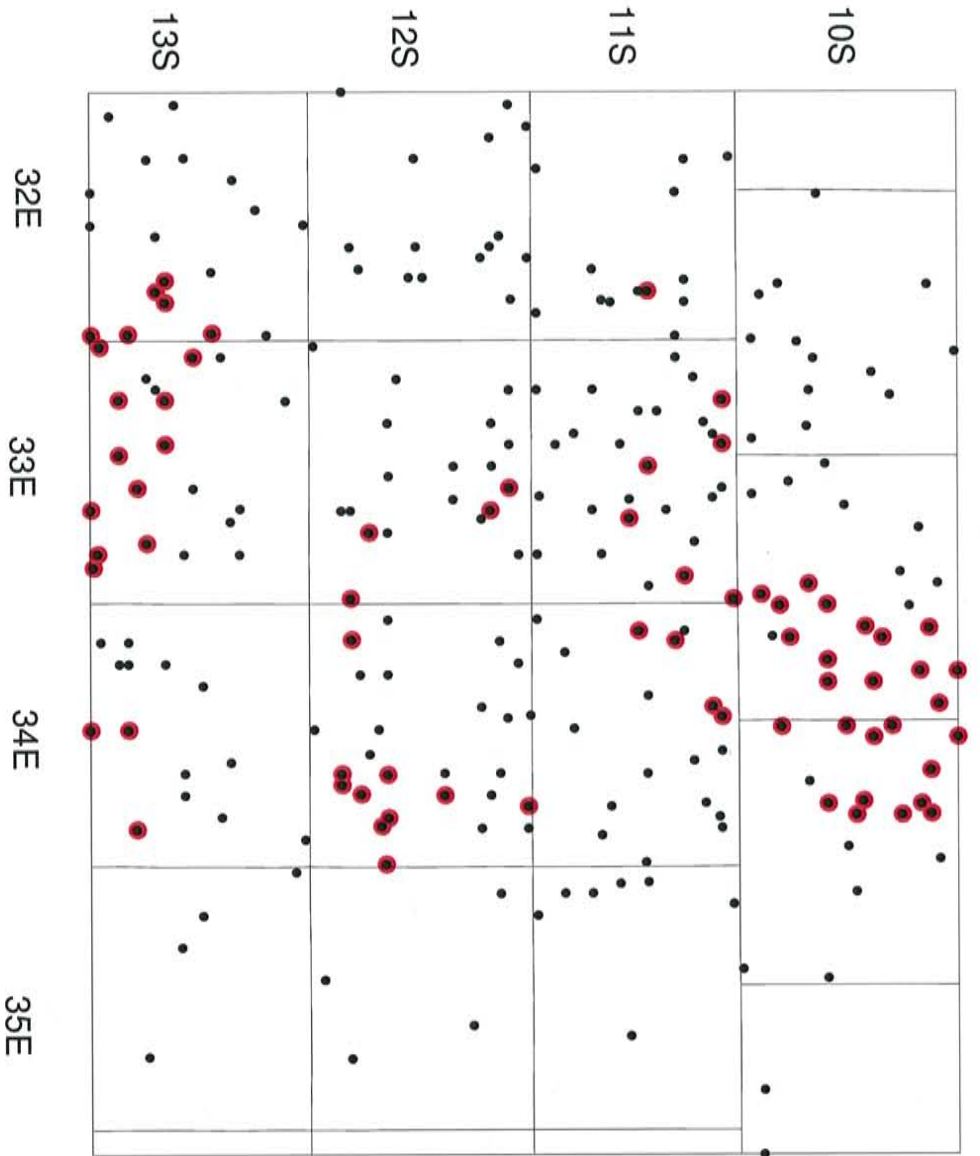


Figure 26 Map showing the distribution of productive wells and nonproductive wells used in this study. Productive wells are marked by red dots and nonproductive wells are black dots. The productive wells shown are productive from the Bough A, B, C and D zones. Top of map is north.

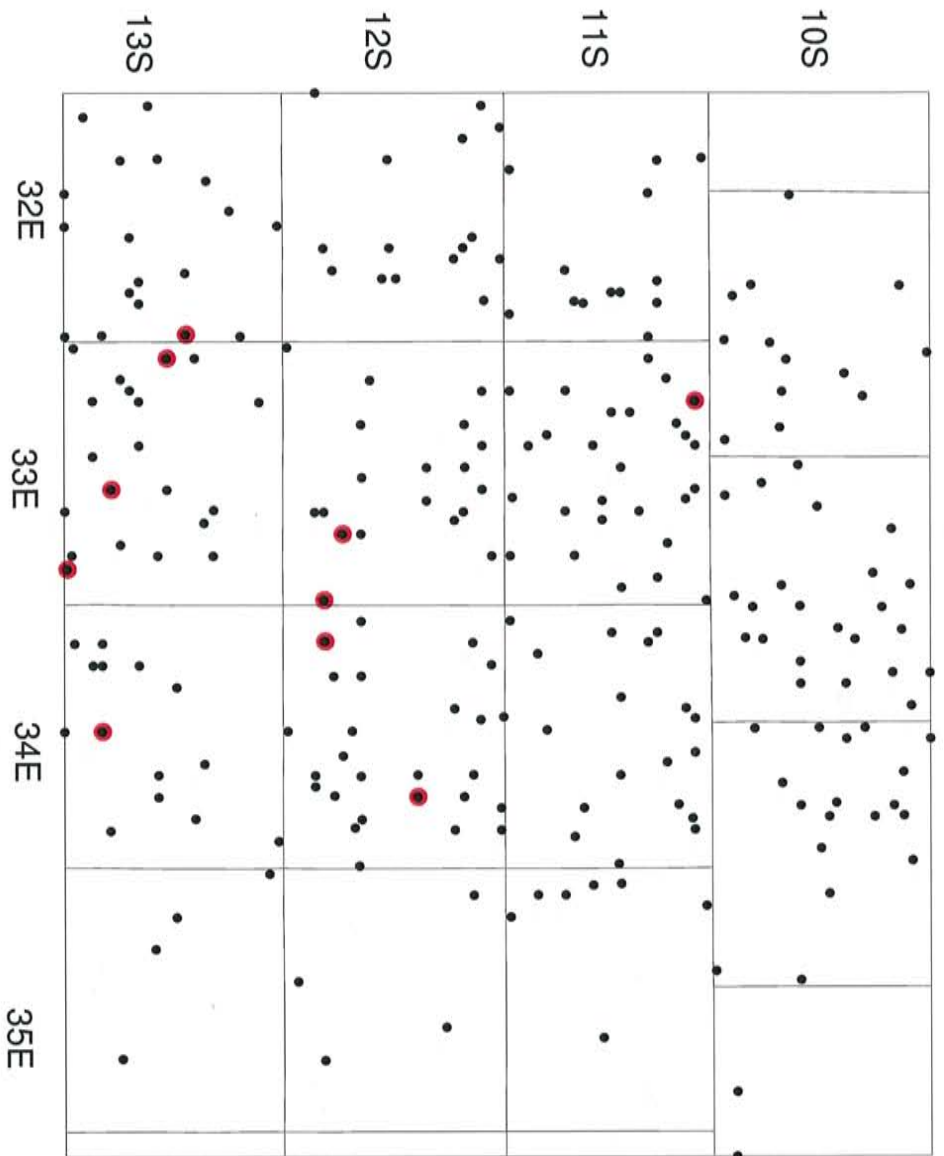


Figure 27 The distribution of wells used in the study with wells productive from the Bough A highlighted. Productive wells are marked by red dots and nonproductive wells are black dots. Top of map is north.

8 kilometers
5 miles

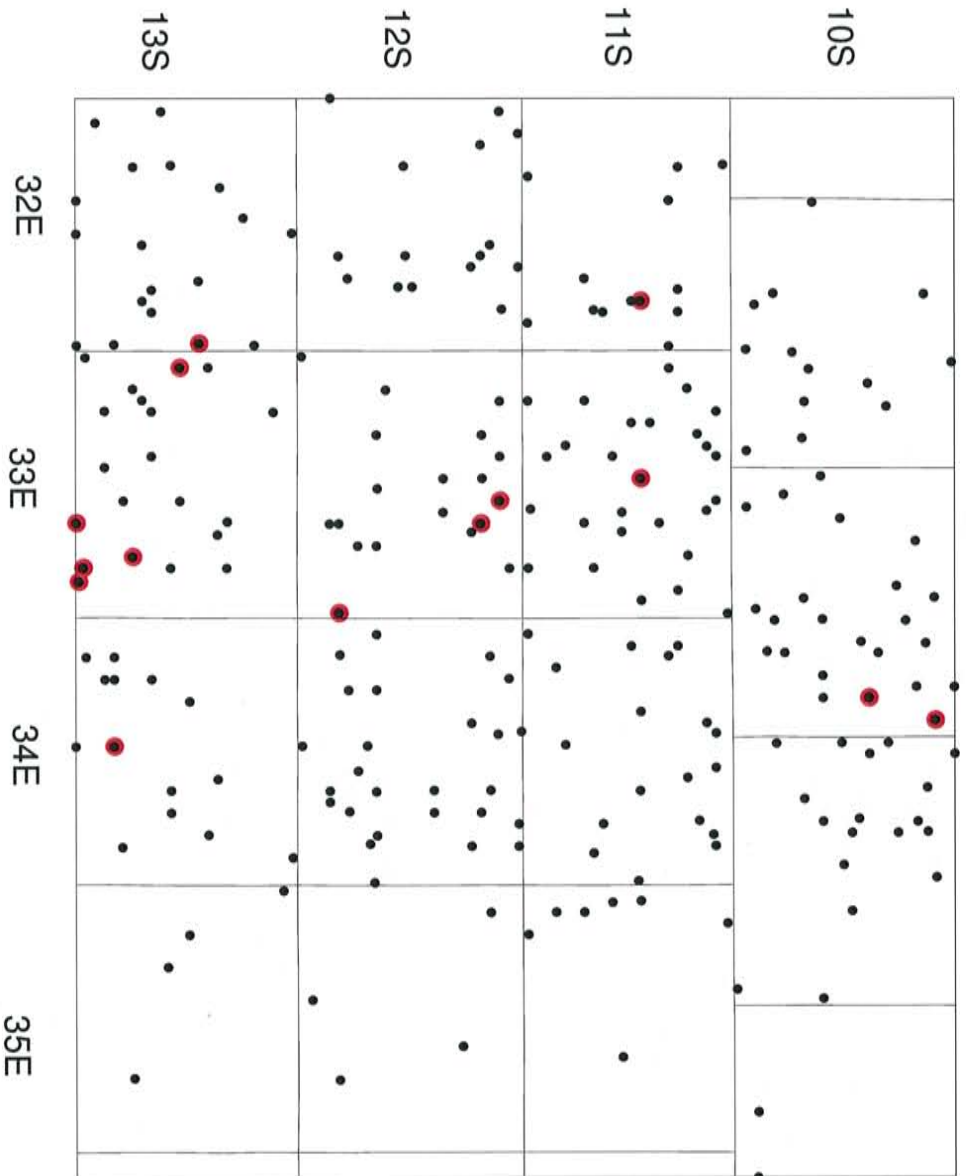


Figure 28 The distribution of wells used in the study with wells productive from the Bough B highlighted. Productive wells are marked by red dots and nonproductive wells are black dots. Top of map is north.

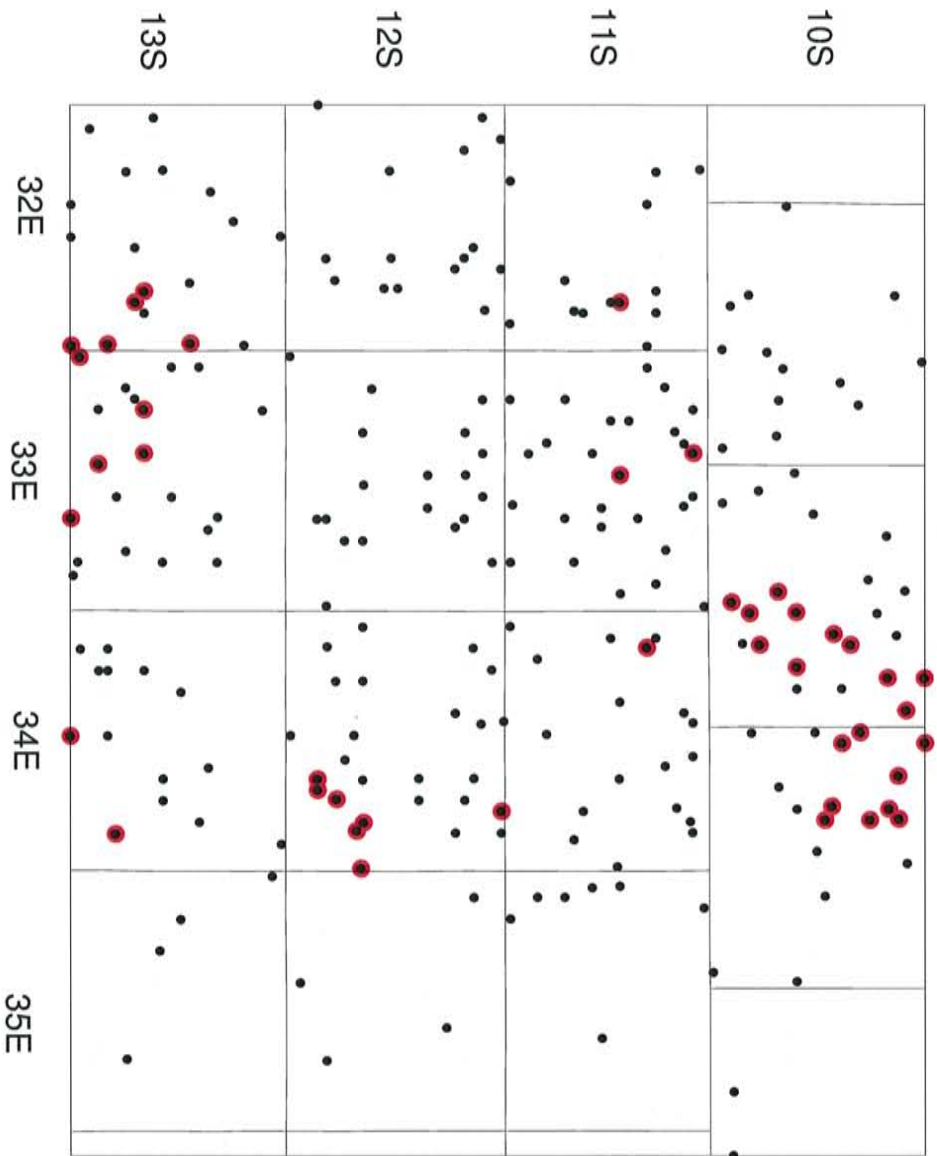


Figure 29 The distribution of wells used in the study with wells productive from the Bough C highlighted. Productive wells are marked by red dots and nonproductive wells are black dots. Top of map is north.

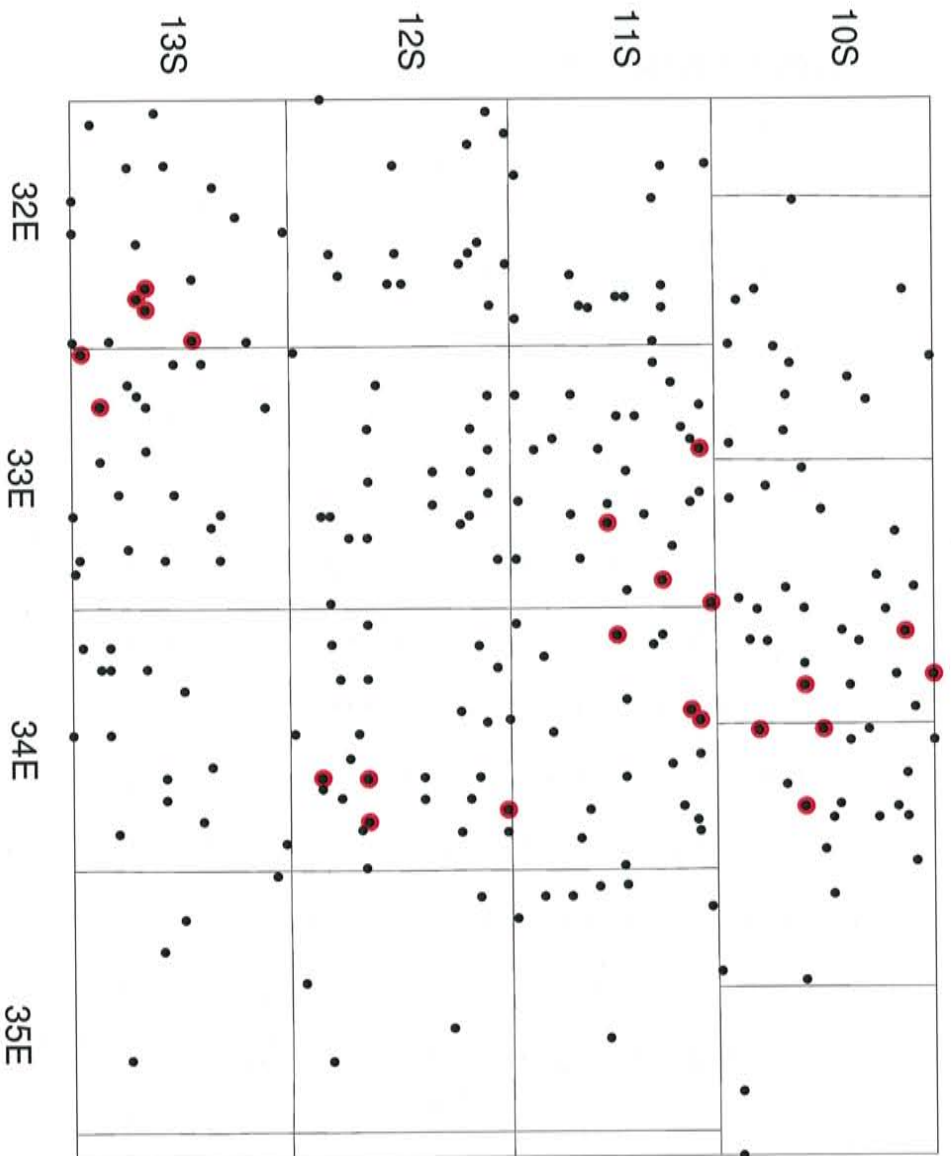


Figure 30 The distribution of wells used in the study with wells productive from the Bough D highlighted. Productive wells are marked by red dots and nonproductive wells are black dots. Top of map is north.

Table 2 The number of productive wells producing from the Bough A, B C and D.

	Number of productive wells
Bough A	10
Bough B	14
Bough C	43
Bough D	23

Cumulative production from all four Bough zones compared with the isopach map data show that larger volumes of oil have generally been produced from areas on the margins of where the Bough zones are thicker (Figure 31). Individually, productive wells are found in areas both thick and thin over the entire thickness of the Bough A, B and C (Figure 32). In the Bough A and B, if one compares productive wells to the individual zones they are producing from, in most cases the productive wells are found on the border of thicker zones within the stratum. This can be seen on isopach maps for the individual Bough zones with the productive wells superimposed on them (Figures 33 and 34).

The Bough C does not seem to share this relationship between thickness and oil production. Oil wells producing from the Bough C are found in areas where the Bough C thickens as well as thins (Figure 35). This implies there is some other factor controlling the reservoir quality of the Bough C.

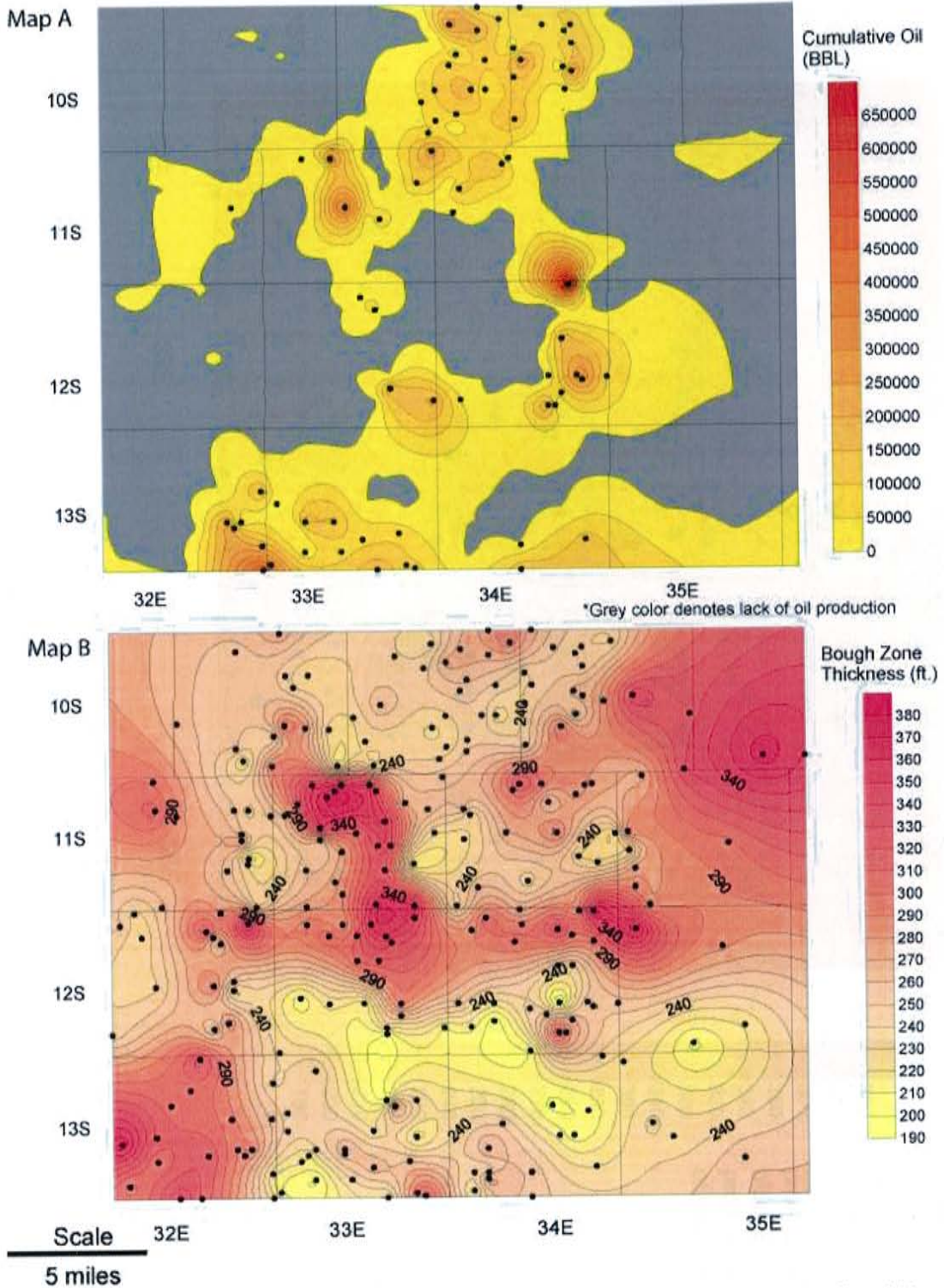
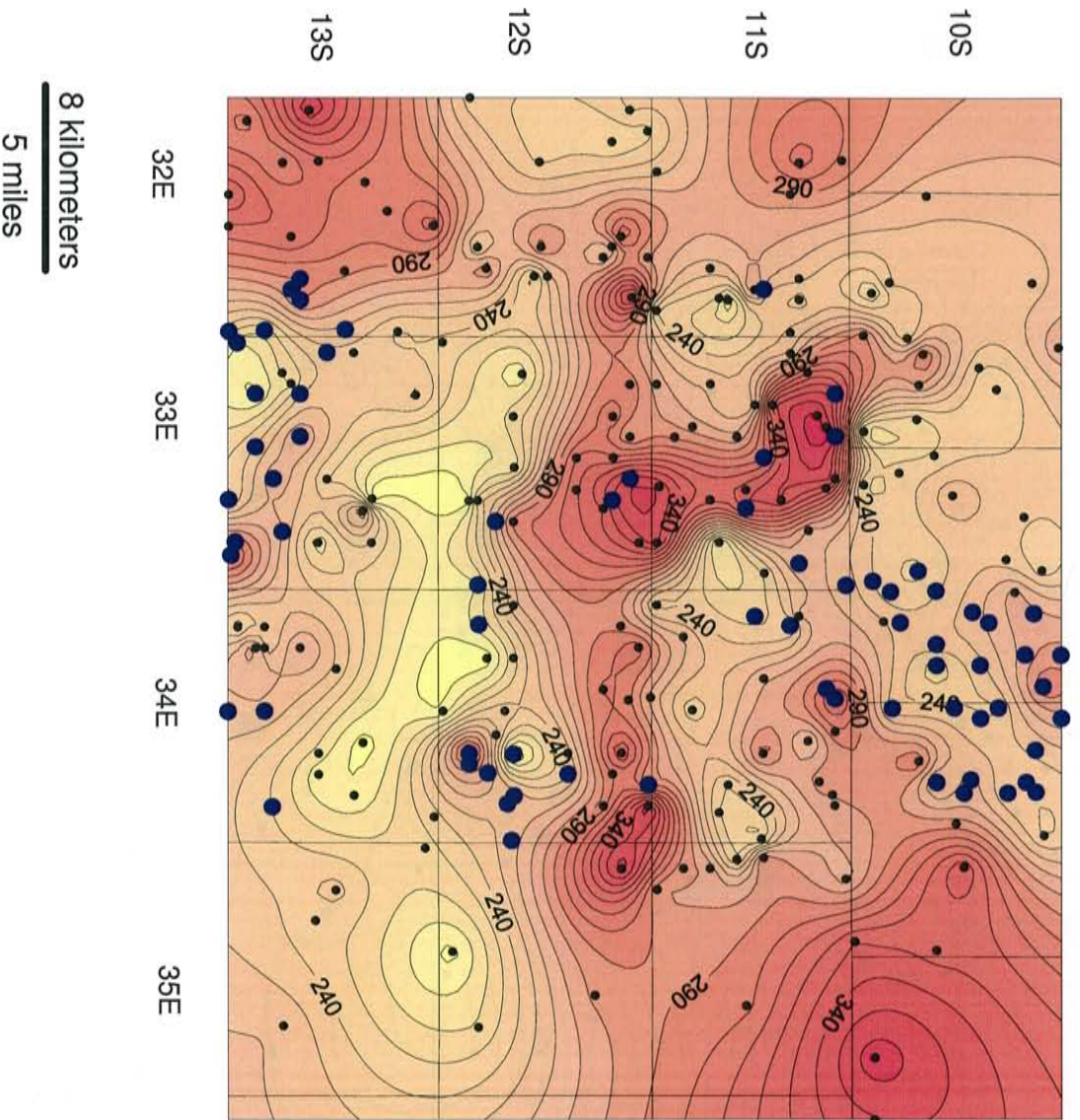
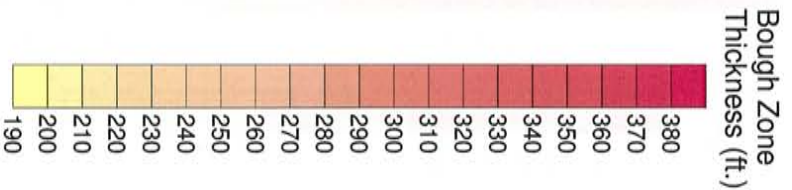


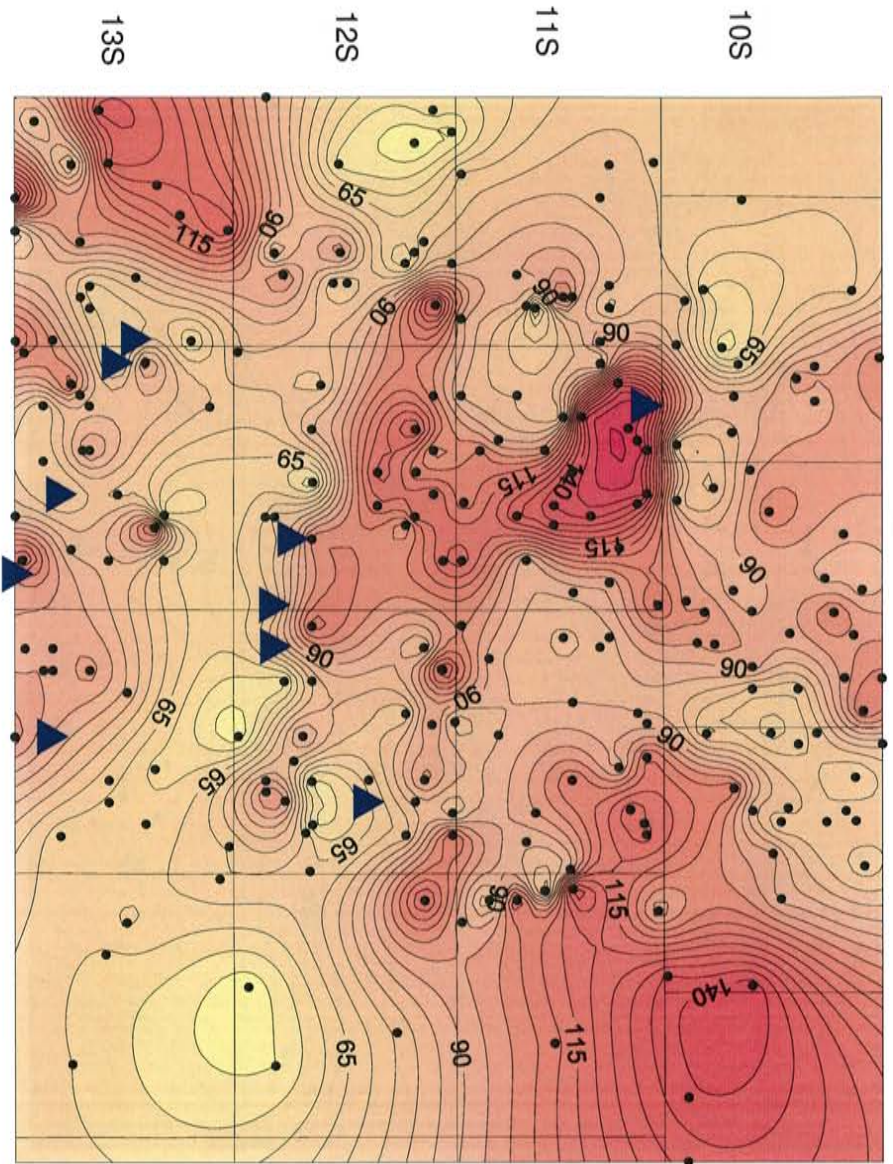
Figure 31 Maps comparing cumulative oil production from the Bough A, B, C and D (map A) with isopach data from the Bough A, B and C (map B). Note that (excluding oil production in northern townships) the higher production values correlate to the margins of where the Bough zone thickens. Top of map is north.



8 kilometers
5 miles

Figure 32 Map showing the thickness of the Bough A, B and C with all data points. The blue dots indicate productive wells while black dots indicate non-productive wells. Top of map is north.





Bough A
Thickness (ft.)

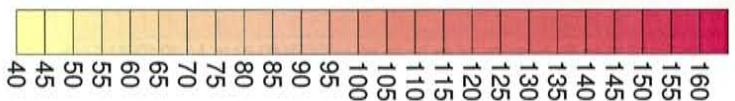
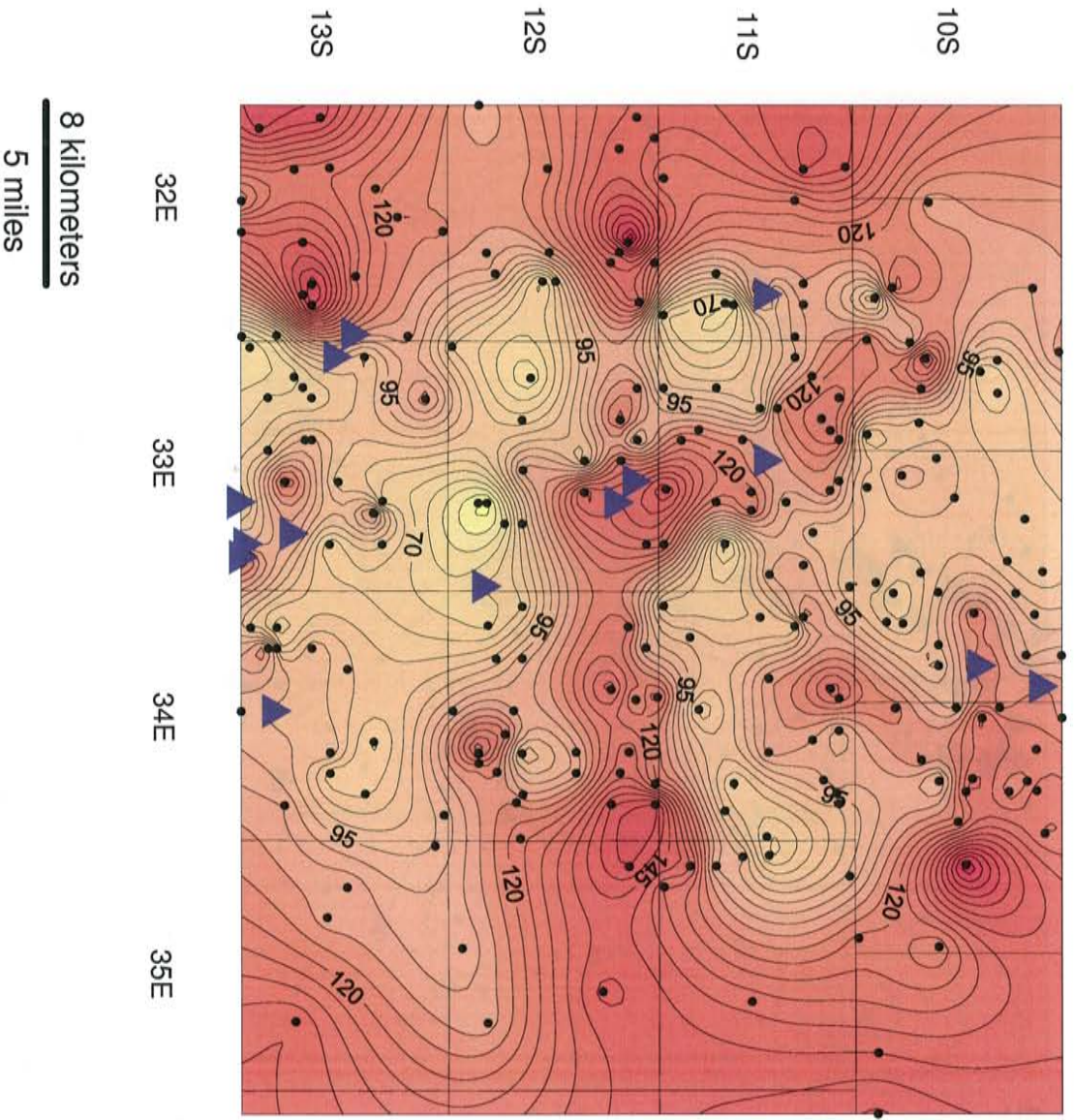


Figure 33 Isopach map of the Bough A with the location of oil wells producing from the Bough A shown as blue triangles. Note that productive wells are most often located on the margins of thicker areas within the Bough A. Top of map is north.

8 kilometers
5 miles



Bough B
Thickness (ft.)

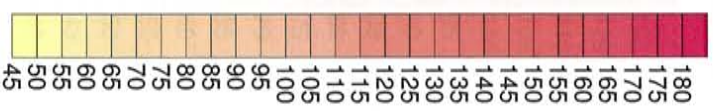
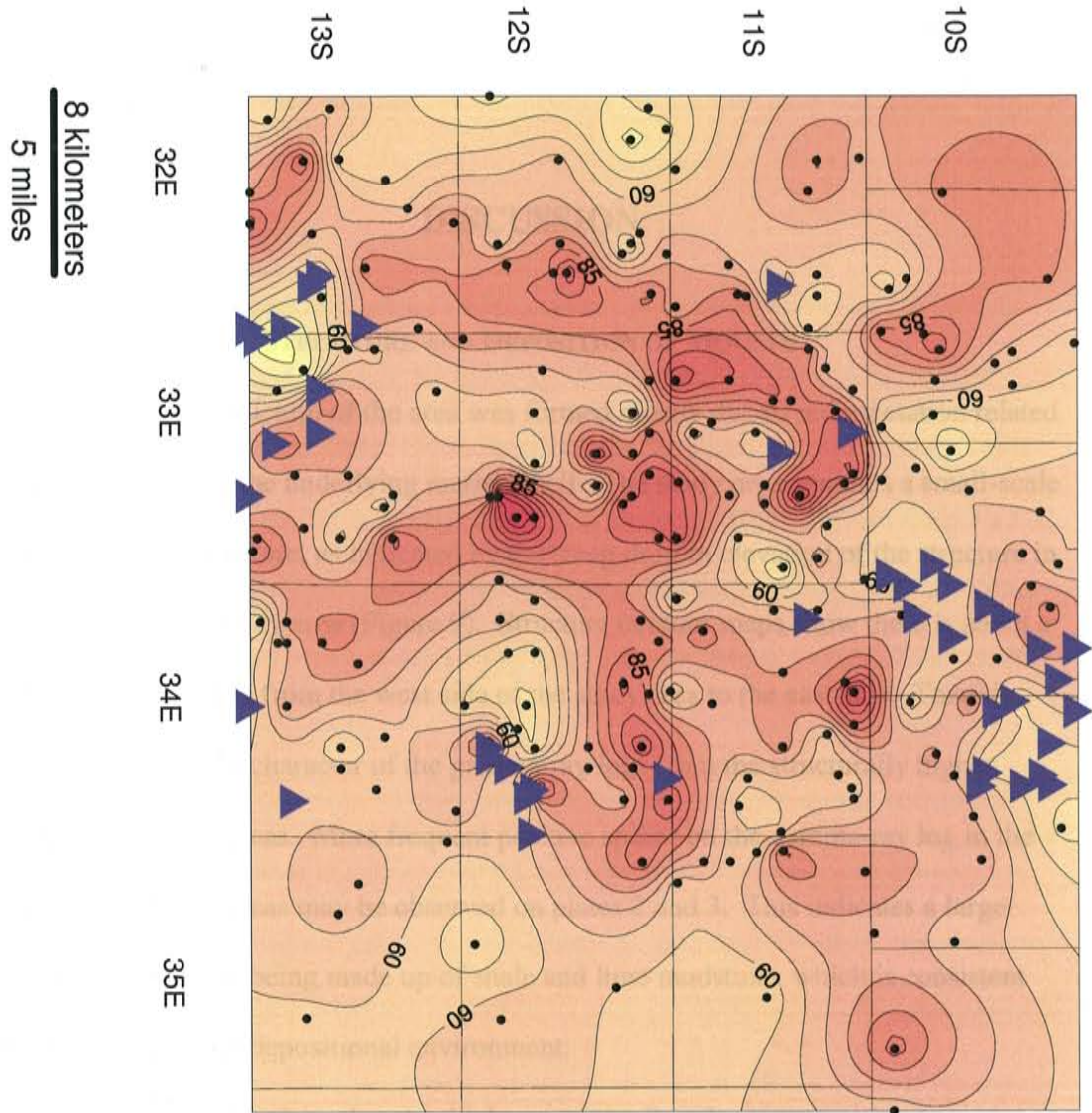


Figure 34 Isopach map of the Bough B with the location of oil wells producing from the Bough B shown as blue triangles. Note that productive wells are most often located on the margin of thicker areas within the Bough B. Top of map is north.



Bough C Thickness (ft.)

Figure 35 Isopach map of the Bough C with the location of oil wells producing from the Bough C shown as blue triangles. Note the presence of productive wells around thick areas as well as thinner areas within the Bough C. Top of map is north.

DISCUSSION

STRUCTURE AND DEPOSITION OF MOUNDS

The paleostructure of the area was formed mostly due to sedimentation related to the formation of the underlying marine shelf. The study area contains a small-scale shelf and basin structure, as indicated by the steep drop in elevation of the structure in the middle of the study area (Figure 9). Structure contour maps show there is about a 600 foot, steep, drop from the west side of the study area to the east side. There is also a change in the character of the gamma-ray logs from the structurally higher areas to the lower areas. More frequent positive spikes on the gamma-ray log in the structurally lower areas may be observed on plates 2 and 3. This indicates a larger portion of the strata being made up of shale and lime mudstone, which is consistent with a more basinal depositional environment.

Isopach maps show that the thickness of the Bough zone strata increases in isolated spots within the study area. These zones of increased thickness are related to the same zones shown to have structural highs by the structure contour maps. The fact that these zones of increased thickness correspond to structural highs shows there is a relationship between the underlying structure and the growth of the phylloid algal mounds which are the main type of deposit within the Bough zone. The phylloid algae grew and accumulated along the shelf edge and structural highs. After the algae

began to grow on these highs the elevated bathymetry was perpetuated by the continued growth of the algal grove.

DIAGENESIS

The most common products of diagenetic alteration observed in the Bough zones' cores are moldic and vugular porosity. These types of pores were created through the dissolution of fossil clasts found within the limestones. The main types of fossil clasts dissolved were phylloid algal blades, as evidenced by the shape of the moldic pores. The shapes of many of the observed moldic pores are elongate with a tapering thickness and in some cases have relict wall structures (tubules filled with micrite on the grain margins).

The algal mounds would have been exposed to meteoric waters when the mound structures were located above the local sea level. This situation could occur through changes in eustatic sea level, which were common in the late Pennsylvanian (Goldstein, 1988) and would have exposed the mounds to the meteoric waters capable of dissolving the aragonitic phylloid algal blades (Kirkland, 1991). Soreghan and others (2000) showed that the presence of non-facies selective fabric destructive dolomite is evidence of an increase in sea level and sea water moving through the rock during transgression. This means the dolomite observed in thin section formed as sea water moved through the exposed algal mound while sea level rose. This is further evidence that the mounds were exposed to a subaerial diagenetic environment.

OIL FORMATION AND MIGRATION

The phylloid algal mounds of southeastern New Mexico make good targets for oil production (Mazzullo, 1998). This is because the geologic characteristics of the mounds makes good reservoir rocks and the mounds formed around lithologies that make good source rocks. These source rocks include organic rich basinal shales (Broadhead et al., 2004). It is also likely the lime muds incorporated into the mound complexes were also source rocks.

The shales and lime muds were good source rocks because of their high organic content. The evidence of high organic content of the shale and lime mudstone, qualitatively, is their dark color and, quantitatively, gamma-ray logs with peaks that correspond to the thin shale layers and higher gamma-ray readings displayed by limestones with large lime mud contents. The organic matter found within these marine deposits may mature into oil. After maturation of the oil, migration begins, the oil migrates to higher points in the reservoir rock until it can move no further. In the case of the study area, the porous phylloid algal mounds are where the oil ended up. The domed shapes of the mounds along with the heterogeneous porosity distribution made stratigraphic traps.

Comparing the isopach and structure contour maps to oil production in the study area indicates that higher amounts of oil production correspond to areas where the Bough zone thickens (i.e. margins of thick zones). This is probably because the thicker parts of the Bough zone have a larger amount of the porous limestone which makes good reservoir rocks and the stacking of the mound structures creates more

trapping structures. This relationship does not seem to apply to the most productive stratigraphic unit, the Bough C.

The thicker areas of the Bough zone also correspond to structural highs and because these spots were bathymetrically higher a lowering of sea level would expose them to a subaerial environment for longer periods than the topographically lower areas. A longer exposure to the subaerial environment leads to a longer period of dissolution caused by meteoric waters and results in a more porous rock. These topographically higher areas would also have had porosity preserved, unlike the lower areas. This is because of the gravitational flow of meteoric water saturated with respect to the carbonate minerals dissolved out of the mounds. As the water (saturated with calcium carbonate) flows through the topographically lower portions of the exposed mound, the carbonates would precipitate out of the water and form cements that occluded the porosity. The stacking of the mounds formed complex reservoirs. As new phylloid algae grew on top of preexisting mounds the outer, more porous areas, would cause the outer margins of the mound to be more porous and permeable than the middle of the mounds (Figure 36). This explains why production in the Bough A and B is concentrated on the margins of the thicker areas of these strata.

The filling of pores in the topographically lower areas of the mound complexes would act as a seal for oil that eventually migrates into the thick, porous sections of the Bough zone. The heterogeneity of porosity within the time equivalent units could create stratigraphic traps for oil. The geographic position of the mounds, in relation to organic rich shales and lime muds, made them targets for oil

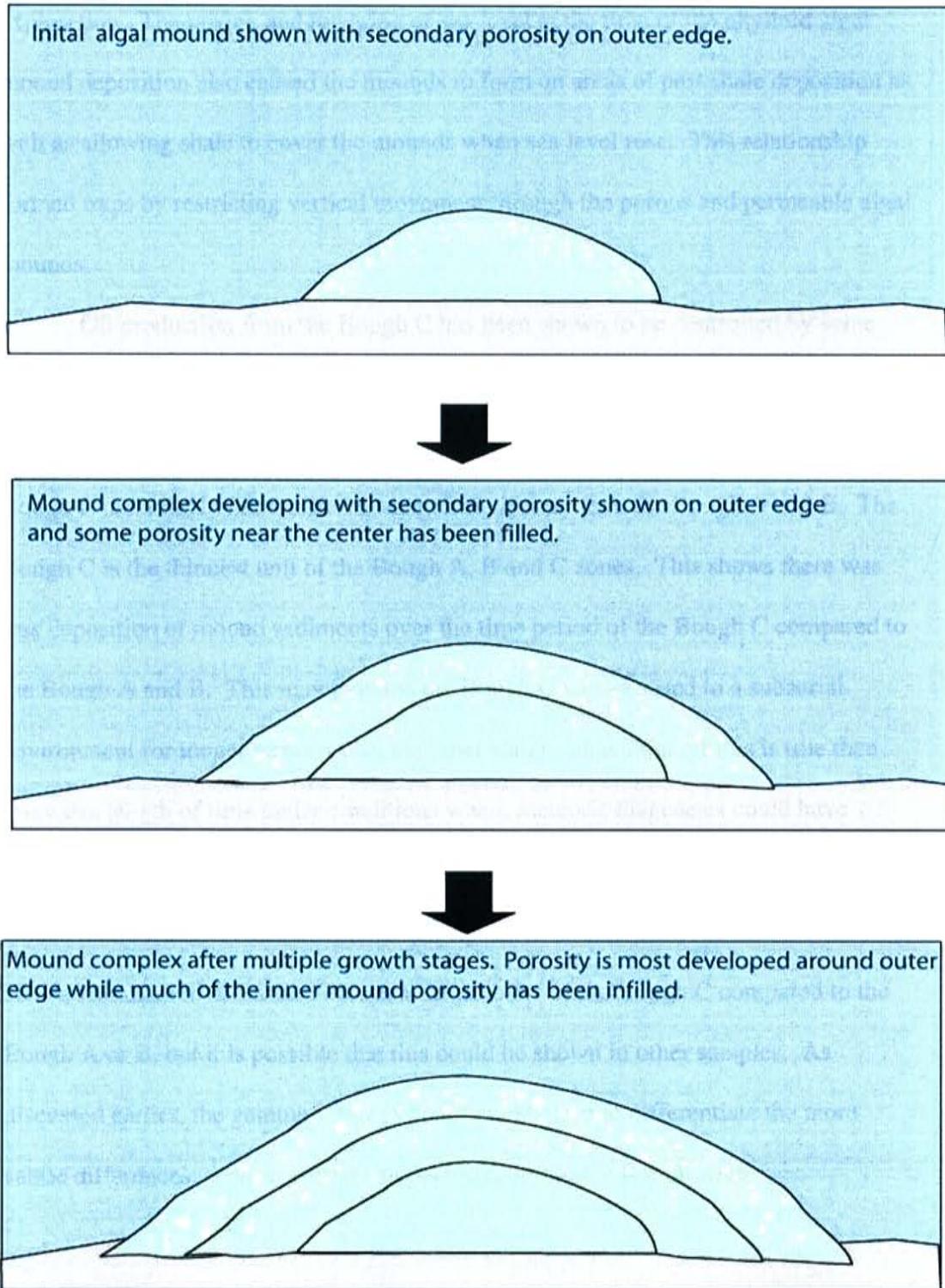


Figure 36 Illustration of the formation of a mound complex. Notice the secondary porosity is more developed on the outer margin of the complex. Mounds are tens of meters thick.

exploration. The raising and lowering of sea level at the time of the phylloid algal mound deposition also caused the mounds to form on areas of past shale deposition as well as allowing shale to cover the mounds when sea level rose. This relationship formed traps by restricting vertical movement through the porous and permeable algal mounds.

Oil production from the Bough C has been shown to be controlled by some factor other than the thickness of the unit. This observation is illustrated by the location of productive wells in areas of the Bough C that are thin and thick. The Bough C most likely has a different diagenetic history than the Bough A and B. The Bough C is the thinnest unit of the Bough A, B and C zones. This shows there was less deposition of mound sediments over the time period of the Bough C compared to the Bough A and B. This may indicate the Bough C was exposed to a subaerial environment for longer periods than the other stratigraphic units. If this is true then this extra length of time under conditions where meteoric diagenesis could have occurred could have created more secondary porosity and permeability in the Bough C than in the Bough A and B. Unfortunately the two cores analyzed for this study showed no marked difference between the porosity of the Bough C compared to the Bough A or B, but it is possible that this could be shown in other samples. As discussed earlier, the gamma-ray logs could not be used to differentiate the more subtle differences, such as changes in porosity, within the Bough zone.

CONCLUSIONS

1. Cores from within the study area are made up of rock types consistent with those found in phylloid algal mound complexes and contain an abundance of phylloid algal fossils. Studies of cores coupled with background research indicate the Bough zones consist of interbedded phylloid algal mound deposits and shales.

2. Cross-sections and structure contour maps show a distinct lowering of the elevation of the Bough zone when moving eastward across the study area. This indicates the presence of a shelf-to-basin environment of deposition. The Bough A, B and C are thicker on the shelf edge indicating the phylloid algal mounds grew preferentially on the shelf edge.

3. Comparison between the paleostructure, structure and isopach maps indicated that the mounds preferred to grow on paleostructural highs and also caused the continuation of these bathymetric highs through their own growth. This is shown by the thicker sections of the Bough A, B, and C being located on the regions shown to have preexisting paleostructural axes.

4. Phylloid algal mounds within the Bough zones were deposited in close proximity to organic rich rock types, (i.e., shales and lime mudstones) and were also frequently

altered. Petrographic analyses indicate these mounds were exposed to a multitude of diagenetic environments including the subaerial, deep burial, and marine, which resulted in diagenetic alteration, most notably the creation of moldic and vugular porosity. Diagenesis of the mounds also included compaction, dolomitization, occlusion of pore space by calcite cements and recrystallization of original unstable minerals. The results of diagenesis coupled with the areas of deposition made these types of algal mounds good targets for oil exploration.

5. Oil production from the Bough A and B zones was shown to be higher on the margins of regions of thicker mound deposition. This is because diagenesis of these thicker areas resulted in more porous and permeable rocks on the edges of mound complexes that created stratigraphic traps for oil. This relationship was not shared by the Bough C, which had oil production from thicker and thinner areas. Oil production from the Bough C was dependant on factors other than the thickness of the stratum, although the relative thinness of the Bough C compared to the Bough A and B may indicate less time for deposition and more time for diagenesis and the creation of secondary porosity.

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APPENDIX A

DESCRIPTION OF UNITS IN CORE SAMPLES

Core 1

Company: Pan Am Lease: "DL" State 1

API # 30-025-22775

Location: T. 13S R. 32E Sec. 13 Footage: 1980' FSL & 660' FEL

Unit 1

Upper Boundary Type: NA

Bag Depth (ft.): 9700.1-9700.7

Thickness of Unit (ft.): >0.2

Dunham Classification: Bioclastic Wackestone

Color: Med. Dark Grey (N4) – Brownish Grey (5 YR 4/1)

Archie Porosity: I – XF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Solution seams present. Fine sand sized white fossil fragments throughout. Few dark elongate fossils. Very few (2) spheroidal light fossils observed.

Unit 2

Upper Boundary Type: Sharp

Bag Depth (ft.): 9700.1-9700.7

Thickness of Unit (ft.): 1.6

Dunham Classification: Bioclastic Wackestone/Packstone

Color: Pale Yellowish Brown (10 YR 6/2), Yellowish Grey (5 Y 6/1) and Light Olive Grey (5 Y 6/1)

Archie Porosity: I – XF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Mottled color pattern. Large (5cm) sections of big dark fossils. Large shell fragments and elongate fossils. Smaller fossil fragments in lighter areas. Calcite mineralization of some shell fragments. Porosity occluded by crystals (likely calcite). Few thin stylolites also present.

Unit 3

Upper Boundary Type: Sharp

Bag Depth (ft.): 9702.7-9703.2

Thickness of Unit (ft.): 0.9

Dunham Classification: Bioclastic Wackestone

Color: Yellowish Grey (5 Y 8/1) and Light Olive Grey (5 Y 6/1)

Archie Porosity: III - F ~6% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Solution seams present. Fine sand sized white fossil fragments throughout. Few dark elongate fossils.

Unit 4

Upper Boundary Type: Sharp

Bag Depth (ft.): 9704.2-9705.0

Thickness of Unit (ft.): 1.0

Dunham Classification: Bioclastic Packstone

Color: Pale Yellowish Brown (10 YR 6/2)

Archie Porosity: III - F ~6% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Over 50% shell fossil allochems. No phylloid algae observed in hand sample. Some moldic pores filled with calcite crystals. Stylolites throughout section. Large (>5cm) bivalve fossils observed. Grains are finer lower in section.

Unit 5

Upper Boundary Type: Sharp

Bag Depth (ft.): 9705.6-9706.2

Thickness of Unit (ft.): 1.4

Dunham Classification: Bioclastic Packstone

Color: Med. Light Grey (N6) and Yellowish Grey (5 Y 8/1)

Archie Porosity: III - F ~6% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Composed of fine grained fossil material. Mottled color pattern. Fractures filled w/ white crystals (likely calcite). Fossil material looks compacted.

Unit 6

Upper Boundary Type: Sharp

Bag Depth (ft.): 9707.4-9708.2

Thickness of Unit (ft.): 0.5

Dunham Classification: Brecciated Bioclastic Wackestone

Color: Medium Grey (N5) and Olive Grey (5 Y 6/1)

Archie Porosity: I - VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Highly fractured appearance. Made up of large (>5 cm) intraclasts separated by shale filled fractures. Intraclasts composed of very fine fossil debris with white fracture lines.

Unit 7

Upper Boundary Type: Sharp

Bag Depth (ft.): 9708.2-9709.0

Thickness of Unit (ft.): 0.9

Dunham Classification: Bioclastic Wackestone

Color: Olive Grey (5 Y 4/1) and Light Olive Grey (5 Y 6/1)

Archie Porosity: I – VF-C₈ ~11% porosity

Choquette and Pray Porosity: Moldic porosity

Observations:

Mottled color pattern. Fossil material concentrated in darker colored zones. Most fossil debris white with few dark grey fossils. Some fractures/pores filled with calcite crystals.

Unit 8

Upper Boundary Type: Sharp

Bag Depth (ft.): 9709.6-9710.1

Thickness of Unit (ft.): 1.0

Dunham Classification: Bioclastic Wackestone

Color: Olive Grey (5 Y 4/1) and Light Olive Grey (5 Y 6/1)

Archie Porosity: I – VF-C₈ ~11% porosity

Choquette and Pray Porosity: Moldic porosity

Observations:

Similar to Unit 7 but top of unit has 2 inch stylolites and fossils are more intact and more pores are filled with calcite crystals.

Unit 9

Upper Boundary Type: Sharp

Bag Depth (ft.): 9710.1-9710.7

Thickness of Unit (ft.): 0.7

Dunham Classification: Bioclastic Wackestone

Color: Light Olive Grey (5 Y 6/1) and Light Grey (N7)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

1 cm sized white shell debris throughout unit. Some large zones which appear to be plasticly deformed. Stylolites throughout unit. Many white fracture lines near bottom of unit.

Unit 10

Upper Boundary Type: Sharp

Bag Depth (ft.): 9711.8-9712.4

Thickness of Unit (ft.): 0.3

Dunham Classification: Brecciated Mudstone

Color: Light Grey (N7)

Archie Porosity: I – XF – C₂₀ ~23% porosity

Choquette and Pray Porosity: Breccia porosity

Observations:

Highly fractured mudstone with very few fossils. Shale filling fractures. Evidence of compaction (brittle deformation) seen on single elongate fossil. Fractures have appearance of solution seams.

Unit 11

Upper Boundary Type: Sharp

Bag Depth (ft.): 9711.8-9712.4

Thickness of Unit (ft.): 1.7

Dunham Classification: Bioclastic Wackestone

Color: Light Olive Grey (5 Y 6/1)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

White fracture lines throughout unit. Fossil debris in slight abundance throughout. Solution seams also observed.

Unit 12

Upper Boundary Type: Sharp

Bag Depth (ft.): 9713.9-9714.4

Thickness of Unit (ft.): 0.4

Dunham Classification: Bioclastic Wackestone/Packstone

Color: Medium Grey (N5)

Archie Porosity: III – F ~6% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Fine grained. Almost all grains dark grey fossil debris. Solution seams present. Few larger white fossils. Fossils become much more abundant near bottom of unit (packstone area).

Unit 13

Upper Boundary Type: Gradational

Bag Depth (ft.): 9714.4-9715.2

Thickness of Unit (ft.): 1.0

Dunham Classification: Bioclastic Wackestone

Color: Light Brownish Grey (5 YR 6/1) and Yellowish Grey (5 Y 8/1)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Mottled color pattern. Dark elongate fossils throughout unit. Stylolites throughout unit. Some stylolites appear to run vertically through unit. Solution seams also present.

Unit 14

Upper Boundary Type: Gradational

Bag Depth (ft.): 9715.9-9716.4

Thickness of Unit (ft.): 3.0

Dunham Classification: Shaley Bioclastic Wackestone

Color: Light Olive Grey (5 Y 6/1)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Uniform matrix. Few fine dark grey fossils throughout unit. Many solution seams.

Thick (1") section of red solution seams near top of unit.

Unit 15

Upper Boundary Type: Sharp

Bag Depth (ft.): 9718.9-9719.6

Thickness of Unit (ft.): 3.1

Dunham Classification: Bioclastic Wackestone

Color: Medium Grey (N5)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Very fine dark grey fossil debris throughout unit. Few thin solution seams observed.

Unit 16

Upper Boundary Type: Sharp

Bag Depth (ft.): 9728.9-9729.5

Thickness of Unit (ft.): 0.3

Dunham Classification: Brecciated Bioclastic Wackestone

Color: Blackish Red (5 R 2/2) and Yellowish Grey (5 Y 8/1)

Archie Porosity: III – VF ~7% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Consists of large intraclasts from underlying unit with some dark red speckled with black semi-layered intraclasts. Thick solution seams and stylolites separate clasts.

Calcified elongate fossils observed in lighter colored clasts.

Unit 17

Upper Boundary Type: Sharp

Bag Depth (ft.): 9728.9-9729.5

Thickness of Unit (ft.): 2.0

Dunham Classification: Bioclastic Packstone

Color: Med. Light Grey (N6) and Yellowish Grey (5 Y 8/1)

Archie Porosity: III – VF ~7% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Large amounts of disarticulated white fossil fragments. Few dark elongate fossils throughout unit. Marbled coloring of units with zones of (N6) or (5 Y 8/1). Thin stylolites and solution seams throughout unit.

Unit 18

Upper Boundary Type: Missing

Bag Depth (ft.): 9763.1-9763.6

Thickness of Unit (ft.): 2.1

Dunham Classification: Compacted Mudstone

Color: Brownish Grey (5 YR 4/1), Light Bluish Grey (5 B 7/1) and Light Brownish Grey (5 YR 6/1)

Archie Porosity: III – XF ~7% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Many solution seams deformed around large intraclasts of packstones. Some fractures and cavities filled with bluish (chertlike) material. Muddy grains plastically deformed from spheroidal to a more elliptical shape.

Unit 19

Upper Boundary Type: Sharp

Bag Depth (ft.): 9765.7-9766.6

Thickness of Unit (ft.): 0.9

Dunham Classification: Bioclastic Packstone

Color: Medium Grey (N5) and Medium Brownish Grey (5 YR 5/1)

Archie Porosity: III – VF – B₅ ~12% porosity

Choquette and Pray Porosity: Moldic Porosity

Observations:

Consists of fossils ranging in size from fine to extremely fine. Fossils are mainly dark elongate fossils with white coatings. Shell fragments also observed along with white spheroidal fossils.

Unit 20

Upper Boundary Type: Sharp

Bag Depth (ft.): 9767.2-9767.9

Thickness of Unit (ft.): 1.2

Dunham Classification: Bioclastic Packstone

Color: Med. Dark Grey (N 4) to Olive Grey (5 Y 4/1)

Archie Porosity: III – VF – B₅ ~12% porosity

Choquette and Pray Porosity: Moldic Porosity

Observations:

Fossils are almost all dark elongate fossils with few spheroidal fossils. Separated from Unit 19 by a solution seam/compacted shale layer. Very Fine white fossils within matrix.

Unit 21

Upper Boundary Type: Sharp

Bag Depth (ft.): 9768.6-9769.2

Thickness of Unit (ft.): 4.8

Dunham Classification: Marine Shale

Color: Grayish Black (N2)

Archie Porosity: Shale

Choquette and Pray Porosity: No Visible Porosity

Observations:

Almost solid coloring. Laminated with few elongate fossils and shell fragments throughout unit.

Unit 22

Upper Boundary Type: Sharp

Bag Depth (ft.): 9773.4-9774.1

Thickness of Unit (ft.): 0.7

Dunham Classification: Mudstone

Color: Dark Grey (N3)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Few pressure fractures. Some small grayish black clasts. No other notable features.

Unit 23

Upper Boundary Type: Sharp

Bag Depth (ft.): 9774.1-9774.7

Thickness of Unit (ft.): 0.2

Dunham Classification: Shaley Wackestone Conglomerate

Color: Olive Black (5 Y 2/1) and Brownish Black (5 YR 2/1)

Archie Porosity: NA

Choquette and Pray Porosity: No visible porosity

Observations:

Mostly shale with a few intraclasts of light grey bioclastic wackestones most likely from Unit 24.

Unit 24

Upper Boundary Type: Sharp

Bag Depth (ft.): 9774.1-9774.7

Thickness of Unit (ft.): 1.7

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6) and Pale Yellowish Brown (10 YR 6/2)

Archie Porosity: III – F – B₃ ~11% porosity

Choquette and Pray Porosity: Moldic Porosity

Observations:

Moldic porosity in grey zones. Solution seams present. Yellowish brown zones appear to be plastically deformed with more fossils coming into contact. Few recrystallized fossils. Small stylolites throughout unit.

Unit 25

Upper Boundary Type: Sharp

Bag Depth (ft.): 9775.9-9776.7

Thickness of Unit (ft.): 0.3

Dunham Classification: Compacted Shale

Color: Greyish Black (N2) and Grayish Orange (10 YR 7/4)

Archie Porosity: Shale

Choquette and Pray Porosity: No visible porosity

Observations:

Obvious plastic deformation of orange layers. Laminations in black layers.

Conchoidal fracture. No noticeable fossils in orange or black zones. Very sharp contact with units 24 and 26.

Unit 26

Upper Boundary Type: Sharp

Bag Depth (ft.): 9775.9-9776.7

Thickness of Unit (ft.): 2.9

Dunham Classification: Bioclastic Packstone

Color: Pale Yellowish Brown (10 YR 6/2)

Archie Porosity: II – BC₁₀ ~25% porosity

Choquette and Pray Porosity: Moldic Porosity

Observations:

Bioclasts are mainly dissociated elongate fossils. Few spheroidal fossils also present.

Most fossils appear to have dissolved out and are filled with calcite crystals.

Stylolites and solution seams near bottom of unit.

Unit 27

Upper Boundary Type: Sharp

Bag Depth (ft.): 9780.1-9780.7

Thickness of Unit (ft.): 1.8

Dunham Classification: Bioclastic Wackestone

Color: Olive Grey (5 Y 4/1) and Brownish Grey (5 YR 4/1)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Dark solution seams near top and bottom of unit. Seams associated with fusulinids.

Small dark grey and white fossil fragments throughout. White fracture lines throughout. Some elongate fossil fragments observed.

Unit 28

Upper Boundary Type: Sharp

Bag Depth (ft.): 9782.0-9782.8

Thickness of Unit (ft.): 1.2

Dunham Classification: Bioclastic Packstone

Color: Moderate Brown (5 YR 3/4) and Med. Light Grey (N6)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Much fossil debris. Most fossils elongate dark grey and shell fragments with few fusulinids.

Unit 29

Upper Boundary Type: Sharp

Bag Depth (ft.): 9784.0-9784.6

Thickness of Unit (ft.): 0.9

Dunham Classification: Fusulinid Grainstone

Color: Moderate Brown (5 YR 3/4) and Med. Light Grey (N6)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Small grouping of stylolites near top of unit. Solution seams associated with fusulinids. Stress fractures throughout. Lower fusulinids show plastic deformation. Percentage of fusulinids increase lower in unit.

Unit 30

Upper Boundary Type: Sharp

Bag Depth (ft.): 9785.2-9785.9

Thickness of Unit (ft.): NA

Dunham Classification: Bioclastic Packstone

Color: Moderate Brown (5 YR 3/4) and Dark Yellowish Brown (10 YR 4/2)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Dissociated dark elongate fossils and fusulinids throughout unit. Few stylolites. Stress fractures throughout. Some spots of recrystallization.

Core 2

Company: Getty Oil Lease: Willard Beaty # 5

API # 30-025-22010

Location: T. 13S R. 33E Sec. 35 Footage: 1650' FSL & 660' FEL

Unit 1

Upper Boundary Type: NA

Box Depth (ft.): 9704-9707

Unit Thickness (ft.): >1.1

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6) to Medium Grey (N5)

Archie Porosity: I – XF – A ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Marbled color pattern with solution seams and stylolites present. Fossils are spheroidal and lighter colored (very light grey N8).

Unit 2

Upper Boundary Type: Sharp

Box Depth (ft.): 9704-9707

Unit Thickness (ft.): 0.5

Dunham Classification: Bioclastic Packstone

Color: Med. Light Grey (N6) and Greyish Orange Pink (5 YR 7/2)

Archie Porosity: I – XF – A ~3% porosity

Choquette and Pray Porosity: Filled fracture porosity

Observations:

Fractures filled with silt/mud present. Fossil are very light Grey (N8). Fossils range in size from coarse sand – very fine sand and are spheroidal in shape with some flattened fossils.

Unit 3

Upper Boundary Type: Sharp

Box Depth (ft.): 9704-9707

Unit Thickness (ft.): 0.2

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7) with patches of Greyish Pink (5 R 8/2)

Archie Porosity: I – XF – C₁₀ ~13% porosity

Choquette and Pray Porosity: Visible Fracture Porosity

Observations:

Highly fractured. Elongate fossils seem continuous through fractures. Pink color patchily distributed. Some fractures filled with darker sediment.

Unit 4

Upper Boundary Type: Sharp

Box Depth (ft.): 9704-9707

Unit Thickness (ft.): 0.8

Dunham Classification: Bioclastic Wackestone-Packstone

Color: Light Grey (N7)

Archie Porosity: I – XF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Spheroidal fossils become more densely packed lower in unit. Spheroidal fossils have lighter color with pink hue. Darker elongate fossils also present. Few sediment filled fractures. Possible soft grain deformation.

Unit 5

Upper Boundary Type: Sharp

Box Depth (ft.): 9704-9707

Unit Thickness (ft.): 0.3

Dunham Classification: Mudstone

Color: Light Grey (N7) and patches of Greyish Pink (5 R 8/2)

Archie Porosity: I – XF – C₈ ~11% porosity

Choquette and Pray Porosity: Visible fracture porosity

Observations:

Fractured appearance. Fractures filled with dark sediment. Some dark elongate fossils present (~3%)

Unit 6

Upper Boundary Type: Missing

Box Depth (ft.): 9707-9710

Unit Thickness (ft.): >1.0

Dunham Classification: Brecciated Mudstone

Color: Med. Light Grey (N6) and Dusky Red (5 R 3/4)

Archie Porosity: I – XF – C₂₀ ~23% porosity

Choquette and Pray Porosity: Breccia porosity

Observations:

Highly fractured. Fractures filled with Dusky red sediment (XF). Cluster of spheroidal fossils present (possible intraclast)

Unit 7

Upper Boundary Type: Sharp

Box Depth (ft.): 9707-9710

Unit Thickness (ft.): 1.0

Dunham Classification: Mudstone

Color: Med. Light Grey (N6) to Medium Grey (N5)

Archie Porosity: I – XF – C₁₀ ~13% porosity

Choquette and Pray Porosity: Visible Fracture porosity

Observations:

Abundant light (white) and dark grey fractures present. Few dark grey elongate-circular fossils.

Unit 8

Upper Boundary Type: Sharp

Box Depth (ft.): 9710-9713

Unit Thickness (ft.): 1.0

Dunham Classification: Bioclastic Packstone

Color: Light Grey (N7) to Very Light Grey (N8)

Archie Porosity: I – XF – B₁C₁₀ ~13% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Matrix color mottled between N7/N8. Elongate bent dark grey-white fossils.

Porosity concentrated in lighter matrix. Some stylolites present.

Unit 9

Upper Boundary Type: Sharp

Box Depth (ft.): 9710-9713

Unit Thickness (ft.): 1.0

Dunham Classification: Brecciated Mudstone

Color: Med. Light Grey (N6) and Dusky Red (5 R 3/4)

Archie Porosity: I – XF – C₂₀ ~23% porosity

Choquette and Pray Porosity: Breccia Porosity

Observations:

Highly fractured. Fractures filled with dusky red sediment. Some spheroidal fossils present.

Unit 10

Upper Boundary Type: Missing

Box Depth (ft.): 9764-9767

Unit Thickness (ft.): >7.6

Dunham Classification: Bioclastic Wackestone/Packstone

Color: Light Grey (N7) to Very Light Grey (N8)

Archie Porosity: I – XF – B₁C₆ ~9% porosity

Choquette and Pray Porosity: Zones of Vugular Porosity

Observations:

Mottled color, elongate bent dark-grey-white fossils. Light (very light grey) spheroidal fossils also present. Stylolites present. Porosity concentrated in lighter colored matrix. Porosity not uniform.

Unit 11

Upper Boundary Type: Sharp

Box Depth (ft.): 9770-9773

Unit Thickness (ft.): 0.4

Dunham Classification: Bioclastic Packstone

Color: Light Grey (N7) and Pinkish Grey (5 YR 8/1)

Archie Porosity: I – XF – CD₁₅ ~18% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Medium Grey elongate fossils abundant. Mostly light grey with patches of pinkish grey. Fossils and vugs throughout sample.

Unit 12

Upper Boundary Type: Sharp

Box Depth (ft.): 9773-9776

Unit Thickness (ft.): 0.7

Dunham Classification: Bioclastic Wackestone

Color: Yellowish Grey (5 Y 8/1) and Light Grey (N7)

Archie Porosity: I – XF – BCD₂₀ ~23% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Abundance of vugular pores. Vugs concentrated in Yellowish Grey matrix. Well defined stylolites present at top and bottom of unit. Some elongate fossils present.

Unit 13

Upper Boundary Type: Sharp

Box Depth (ft.): 9773-9776

Unit Thickness (ft.): 1.0

Dunham Classification: Bioclastic Wackestone

Color: Yellowish Grey (5 Y 8/1) and Light Grey (N7)

Archie Porosity: I – XF BCD₂₅ ~ 28% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Abundant vugular pores. Concentrated in Yellowish Grey matrix. Large pores concentrated in middle of unit and abundance of pores (in general) increases lower in unit.

Unit 14

Upper Boundary Type: Sharp

Box Depth (ft.): 9773-9776

Unit Thickness (ft.): 1.1

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1) and Very Light Grey (N8)

Archie Porosity: I – XF – BC₁₅ ~18% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Marbled color pattern. Vugular porosity seen mainly in yellowish grey patches. Dark elongate fossils throughout sample.

Unit 15

Upper Boundary Type: Gradational

Box Depth (ft.): 9776-9779

Unit Thickness (ft.): 5.4

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)

Archie Porosity: I – XF – BCD₂₀ ~23% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Vugular porosity concentrated in yellow grey matrix. Large amount of large (>2mm) pores. Elongate dark fossils throughout sample. Few well defined stylolites. Marbled appearance.

Unit 16

Upper Boundary Type: Sharp

Box Depth (ft.): 9782-9785

Unit Thickness (ft.): 0.3

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)

Archie Porosity: I – XF – BC₅ ~8% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Marbled color pattern. Elongate fossils (dark grey) throughout unit. White fractures throughout. Porosity concentrated in yellow grey matrix. Stylolites also observed.

Unit 17

Upper Boundary Type: Sharp

Box Depth (ft.): 9782-9785

Unit Thickness (ft.): 3.2

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)

Archie Porosity: I – XF – BCD₁₀ ~13% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Marble color pattern. Porosity concentrated in yellow grey matrix. White color around pores and throughout yellow grey patches. Darker grey elongate fossils throughout unit stylolites present.

Unit 18

Upper Boundary Type: Gradational

Box Depth (ft.): 9785-9788

Unit Thickness (ft.): 0.6

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)

Archie Porosity: I – XF – BC₅ ~8% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Marble color pattern. Elongate dark grey fossils throughout. Vugs concentrated in yellow grey zones. White fracture lines abundant throughout sample. Some discontinuous stylolites observed.

Unit 19

Upper Boundary Type: Sharp

Box Depth (ft.): 9785-9788

Unit Thickness (ft.): 0.6

Dunham Classification: Bioclastic Packstone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)

Archie Porosity: I – XF – CD₁₅ ~18% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Marbled appearance. Large vugs concentrated in yellow grey. Abundance of dark grey fossils throughout unit. White color observed around pores. Small discontinuous stylolites observed.

Unit 20

Upper Boundary Type: Sharp

Box Depth (ft.): 9785-9788

Unit Thickness (ft.): 2.1

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6) and Very Light Grey (N8)

Archie Porosity: I – XF – BC₅ ~8% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Marbled appearance. Elongate dark grey fossils throughout sample. Vugs only observed in very light grey matrix. Some white discoloration around pores. White fracture lines observed.

Unit 21

Upper Boundary Type: Gradational

Box Depth (ft.): 9788-9791

Unit Thickness (ft.): >4.0

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7) and Very Light Grey (N8)

Archie Porosity: I – XF – BC₃ ~6% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Marbled appearance. Elongate grey fossils throughout unit. Small patches of vugs throughout unit. Abundance of white fracture lines throughout unit. Small stylolites.

Unit 22

Upper Boundary Type: Missing

Box Depth (ft.): 9830-9833

Unit Thickness (ft.): >1.8

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6) and Pinkish Grey (5 YR 8/1)

Archie Porosity: I – F/VF ~2% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Mottled color. Mainly pinkish grey. Small elongate dark grey fossils. Some light spheroidal fossils. Few patches of Med. Dark Grey present. Grainy appearance.

Unit 23

Upper Boundary Type: Sharp

Box Depth (ft.): 9830-9833

Unit Thickness (ft.): 0.5

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6) and Yellowish Grey (5 Y 8/1)

Archie Porosity: I – XF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Slightly mottled appearance. Elongate fossils present. Few small patches of Med. Dark Grey. Fine dark circles also present. Small stylolites observed.

Unit 24

Upper Boundary Type: Sharp

Box Depth (ft.): 9830-9833

Unit Thickness (ft.): 0.2

Dunham Classification: Bioclastic Stylolitic Wackestone

Color: Brownish Grey (5 YR 4/1) and Med. Light Grey (N6)

Archie Porosity: I – XF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Abundant stylolites. Elongate fossils concentrated in Med. Light Grey zones.

Unit 25

Upper Boundary Type: Sharp

Box Depth (ft.): 9833-9836

Unit Thickness (ft.): 12.0

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)

Archie Porosity: I – XF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Marbled appearance. Many dark grey stylolites. Small elongate fossils throughout but mainly found in light grey zones. White fracture lines throughout unit. In some cases small fractures seem to outline yellowish grey colorations.

Unit 26

Upper Boundary Type: Sharp

Box Depth (ft.): 9845-9848

Unit Thickness (ft.): 1.6

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6) and Pinkish Grey (5 YR 8/1)

Archie Porosity: I – XF –BCD₁₅ ~18% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Almost linear marbling with Med. Light Grey the dominant color with streaks of Pinkish Grey. Highly vugular. Mostly C sized vugs (0.125-2.0 mm). Elongate fossils and spheroidal fossils present throughout. Small stylolites observed.

Unit 27

Upper Boundary Type: Sharp

Box Depth (ft.): 9845-9848

Unit Thickness (ft.): 0.4

Dunham Classification: Stylolitic Mudstone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)

Archie Porosity: I – XF ~3% porosity
Choquette and Pray Porosity: No visible porosity

Observations:

Abundance of well defined stylolites. Many white fracture lines. Fractures crosscut stylolites. Somewhat marbled coloring.

Unit 28

Upper Boundary Type: Sharp

Box Depth (ft.): 9845-9848

Unit Thickness (ft.): 3.3

Dunham Classification: Mudstone/Wackestone

Color: Light Grey (N7) and Light Brownish Grey (5 YR 6/1)

Archie Porosity: I – XF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Mottled coloring. Sections of stylolites present. Very few elongate fossils and spheroidal fossils observed. Slightly lighter fracture lines throughout unit.

Abundance of fossils increases towards bottom of unit.

Unit 29

Upper Boundary Type: Sharp

Box Depth (ft.): 9851-9854

Unit Thickness (ft.): 0.5

Dunham Classification: Brecciated Wackestone

Color: Medium Grey (N5)

Archie Porosity: I – XF – CD₁₅ ~18% porosity

Choquette and Pray Porosity: Breccia Porosity

Observations:

Highly fractured. Dark grey sediment fills fractures. Large white clasts present (fossils/intraclasts). Absence of smaller fossils within brecciated clasts.

Unit 30

Upper Boundary Type: Sharp

Box Depth (ft.): 9851-9854

Unit Thickness (ft.): 1.0

Dunham Classification: Bioclastic Packstone

Color: Light Grey (N7)

Archie Porosity: III – VF – B₅ ~13% porosity

Choquette and Pray Porosity: Moldic/Vugular Porosity

Observations:

Very fine grainy appearance due to abundance of bioclasts. Few larger bioclasts observed (elongate and spheroidal). Very small moldic/vugular pores also present.

Unit 31

Upper Boundary Type: Gradational

Box Depth (ft.): 9851-9854

Unit Thickness (ft.): 2.6

Dunham Classification: Bioclastic Packstone

Color: Med. Light Grey (N6) and Light Grey (N7)

Archie Porosity: III – F – BCD₂₀ ~26% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Large vugs. Abundance of dark grey elongate fossils. Some vugs contain large crystals (calcite?). White grains (fine) present (filled vugs?). Vugs more apparent in areas with higher concentrations of macroscopic fossils. Small light stylolites also observed.

Unit 32

Upper Boundary Type: Sharp

Box Depth (ft.): 9854-9857

Unit Thickness (ft.): 1.9

Dunham Classification: Bioclastic Packstone

Color: Light Grey (N7) and Pinkish Grey (5 YR 8/1)

Archie Porosity: I – VF – BC₁₀ ~13% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Marbled coloring. Abundance of very fine Dark Grey elongate fossils (possibly dissociated). Small scale vugular porosity throughout unit with pores getting larger in middle of unit with lighter matrix. Stylolites present near top of unit.

Unit 33

Upper Boundary Type: Sharp

Box Depth (ft.): 9857-9860

Unit Thickness (ft.): 1.2

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6) and Medium Grey (N5)

Archie Porosity: I – VF – D₁₀ ~13% porosity

Choquette and Pray Porosity: Fracture Porosity

Observations:

Interbedded with thin shale beds (possibly solution seams). Slight fossil variations between lime mud beds (fusulinid to elongate fossils). Some lighter colored fracture lines.

Unit 34

Upper Boundary Type: Sharp

Box Depth (ft.): 9857-9860

Unit Thickness (ft.): 0.3

Dunham Classification: Bioclastic/Intraclastic Wackestone

Color: Yellowish Grey (5 YR 8/1)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Large zones of Med. Light Grey intraclasts (probably rip-ups). Fossils give this unit a grainy appearance. Small stylolites throughout.

Unit 35

Upper Boundary Type: Sharp

Box Depth (ft.): 9857-9860

Unit Thickness (ft.): 1.1

Dunham Classification: Crystalline

Color: Pinkish Grey (5 YR 8/1) with zones of Moderate Yellowish Brown (10 YR 5/4)

Archie Porosity: I – XF ~4% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Highly fractured. Fractures filled by crystals. Large fractures run vertically. Few large clasts of darker more grainy appearance present. Fractures possibly filled by internal sediment(?).

Unit 36

Upper Boundary Type: Sharp

Box Depth (ft.): 9860-9863

Unit Thickness (ft.): 5.9

Dunham Classification: Mudstone

Color: Grayish Yellowish Orange (10 YR 7/2)

Archie Porosity: II – SL ~15% porosity

Choquette and Pray Porosity: No visible porosity (few cracks)

Observations:

Fractured. Fractures filled by crystals. Some small light stylolites present. Few sand sized black particles observed. Small zones of very light grey. Few crystal filled vugs observed. 0.3 ft. thick zone of light grey bioclastic packstone in middle of unit (mostly dark grey elongate fossils).

Unit 37

Upper Boundary Type: Sharp

Box Depth (ft.): 9866-9869

Unit Thickness (ft.): 1.8

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6)

Archie Porosity: I – VF – B₈ ~11% porosity

Choquette and Pray Porosity: Moldic/Vugular Porosity

Observations:

Abundant white fracture lines. XF disarticulated dark grey elongate fossils are clasts. Small zones of silt/shale with fusulinid fossils present. Stylolites observed. Fine moldic/vugular porosity throughout.

Unit 38

Upper Boundary Type: Sharp

Box Depth (ft.): 9866-9869

Unit Thickness (ft.): 0.6

Dunham Classification: Bioclastic Wackestone

Color: Very Light Grey (N8) and Medium Grey (N5)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Thin shale bed at top of unit. Highly fractured (filled with shale) at top of unit. Dark grey elongate fossils present. Small (5-15 mm) Medium Grey zones. Could be internal sediment filling fractures. White fracture lines common.

Unit 39

Upper Boundary Type: Sharp

Box Depth (ft.): 9866-9869

Unit Thickness (ft.): 0.6

Dunham Classification: Bioclastic Wackestone

Color: Med. Dark Grey (N4)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Thin interbeds of shale throughout unit. Elongate fossils throughout mud sections. White fracture lines common.

Unit 40

Upper Boundary Type: Sharp

Box Depth (ft.): 9869-9872

Unit Thickness (ft.): 1.0

Dunham Classification: Bioclastic Wackestone

Color: Medium Grey (N5)

Archie Porosity: I – VF –B10 ~13% porosity

Choquette and Pray Porosity: Moldic/Vugular Porosity

Observations:

Highly interbedded with thin shale layers. Abundance of white fracture lines. Elongate dark fossils in limestone. White spheroidal (fusulinids?) fossils in shale. Very fine vugular/moldic pores in LS layers.

Unit 41

Upper Boundary Type: Sharp

Box Depth (ft.): 9869-9872

Unit Thickness (ft.): 2.5

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6)

Archie Porosity: I – VF –BC₁₅ ~18% porosity

Choquette and Pray Porosity: Moldic/Vugular Porosity

Observations:

Elongate dark fossils and dark spheroidal fossils present. White fracture lines common near bottom of unit. Some small fractures filled with olive grey shale. Very fine moldic/vugular pores throughout unit. Thin shale interbeds near bottom of section.

Unit 42

Upper Boundary Type: Sharp

Box Depth (ft.): 9872-9875

Unit Thickness (ft.): 0.6

Dunham Classification: Shaley Bioclastic Wackestone

Color: Light Grey (N7) and Med. Light Grey (N6)

Archie Porosity: Light Grey Zone: III – VF ~6% porosity

Med. Light Grey Zone: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Abundant thin shale seams. White spheroidal fossils present amidst shale. Dark disarticulated elongate fossils within Light Grey zones. Med. Light Grey zones are possibly intraclasts and contain elongate fossils.

Unit 43

Upper Boundary Type: Sharp

Box Depth (ft.): 9872-9875

Unit Thickness (ft.): 5.8

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7)

Archie Porosity: III – VF – B₅ ~11% porosity

Choquette and Pray Porosity: Moldic/Vugular Porosity

Observations:

Few well defined stylolites. Abundant white fracture lines in middle of unit (along with most concentrated stylolite zone). Dark Grey elongate fossils throughout unit.

Unit 44

Upper Boundary Type: Sharp

Box Depth (ft.): 9878-9881

Unit Thickness (ft.): 0.4

Dunham Classification: Intraclastic Wackestone

Color: Very Light Grey (N8) and Med. Light Grey (N6)

Archie Porosity: Matrix: I – VF ~3% porosity

Intraclasts: III – F ~6% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Abundant shale seams at top of unit as well as small/thin stylolites. Very Light Grey matrix with zones of Med. Light Grey intraclasts. Intraclasts are filled with sand sized light grey grains. Unit has bedded appearance.

Unit 45

Upper Boundary Type: Sharp

Box Depth (ft.): 9878-9881

Unit Thickness (ft.): 1.4

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Abundant shale seams and stylolites in middle of unit. Primarily spheroidal white fossils found throughout unit.

Unit 46

Upper Boundary Type: Sharp

Box Depth (ft.): 9881-9884

Unit Thickness (ft.): 6.2

Dunham Classification: Bioclastic Packstone

Color: Very Pale Orange (10 YR 8/2) and Light Grey (N7)

Archie Porosity: III – VF – BCD₂₀ ~26% porosity

Choquette and Pray Porosity: Moldic/Vugular Porosity

Observations:

Inch thick breccia zone at top of unit. Abundant vugs throughout as well as dark grey elongate fossils. Vugs resemble fossils in some cases. Thin stylolites throughout unit. Some white coloring around vugs and speckled throughout unit. Mottled color pattern.

Unit 47

Upper Boundary Type: Gradational

Box Depth (ft.): 9888-9891

Unit Thickness (ft.): 6.0

Dunham Classification: Bioclastic Wackestone/Packstone

Color: Light Grey (N7) and Pinkish Grey (5 YR 8/1)

Archie Porosity: I – VF ~3% porosity

Middle Porous Zone: I – VF – BC₁₅ ~18% porosity

Choquette and Pray Porosity: No visible porosity in matrix

Middle Porous Zone: Vugular Porosity

Observations:

Dark Grey elongate fossils throughout, but are more concentrated in Light Grey zones. Mottled coloring. Light Grey layer in middle of unit with high volume of fossils. Another zone of higher porosity in middle of unit. Stylolites separate tendencies.

Unit 48

Upper Boundary Type: Gradational

Box Depth (ft.): 9894-9897

Unit Thickness (ft.): 2.9

Dunham Classification: Porous Grainstone
Color: Yellowish Grey (5 Y 8/1)
Archie Porosity: III – F – BC₂₅ ~31% porosity
Choquette and Pray Porosity: Vugular Porosity
Observations:

Abundant fine vugs. Few dark grey elongate fossils noticed. Vugs possibly dissolved disarticulated fossils. Very grainy appearance.

Unit 49

Upper Boundary Type: Gradational
Box Depth (ft.): 9897-9900
Unit Thickness (ft.): 3.6
Dunham Classification: Bioclastic Packstone
Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)
Archie Porosity: I – VF ~3% porosity
Choquette and Pray Porosity: No visible porosity
Observations:

Mottled coloring. White sand sized fossils throughout. Spheroidal and dark elongate fossils also observed throughout unit. Well developed stylolites.

Unit 50

Upper Boundary Type: Sharp
Box Depth (ft.): 9900-9903
Unit Thickness (ft.): 0.2
Dunham Classification: Brecciated Mudstone
Color: Light Grey (N7) and Med. Light Grey (N6)
Archie Porosity: I – VF ~3% porosity
Choquette and Pray Porosity: No visible porosity
Observations:

Intraclasts separated by stylolites. Clasts are ~0.5-2.0 inches in size and are either light grey or med. Light grey. Fracture lines also present.

Unit 51

Upper Boundary Type: Sharp
Box Depth (ft.): 9900-9903
Unit Thickness (ft.): 1.9
Dunham Classification: Bioclastic Wackestone
Color: Light Grey (N7)
Archie Porosity: III – VF ~6% porosity
Choquette and Pray Porosity: No visible porosity
Observations:

Grainy texture. Few sand sized white fossils. Disarticulated dark grey elongate fossils (mm's). Sand sized dark grey grains (fossils?) present throughout unit.

Unit 52

Upper Boundary Type: Sharp

Box Depth (ft.): 9903-9906

Unit Thickness (ft.): 1.3

Dunham Classification: Bioclastic Packstone

Color: Light Grey (N7)

Archie Porosity: III – VF ~6% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Many coarse sand-sized white fossils. Top of unit characterized by abundant solution seams and concentrated aforementioned fossils. Lower in unit fossils spread out and many disarticulated elongate (dark) fossils are observed.

Unit 53

Upper Boundary Type: Sharp

Box Depth (ft.): 9906-9909

Unit Thickness (ft.): 1.1

Dunham Classification: Shaley Bioclastic Wackestone

Color: Light Grey (N7) and Olive Black (5 Y 2/1)

Archie Porosity: I – VF –B₅ ~8% porosity

Choquette and Pray Porosity: Fracture Porosity

Observations:

Coarse grain sized white spheroidal fossils concentrated near top of unit. 0.5 inch thick shale seams throughout unit. Middle of unit consists of 3 inch thick shale bed. Fractures and fracture lines throughout unit.

Unit 54

Upper Boundary Type: Sharp

Box Depth (ft.): 9906-9909

Unit Thickness (ft.): 0.9

Dunham Classification: Bioclastic Grainstone

Color: Light Grey (N7) and Med. Light Grey (N6)

Archie Porosity: III – F ~4% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Grains consist of fine sand sized dark grey disarticulated elongate fossils. Coarse sand sized white spheroidal and block shaped fossils as well as sand sized white fossil material. Some elongate fossils intact. Massive texture.

Unit 55

Upper Boundary Type: Sharp

Box Depth (ft.): 9906-9909

Unit Thickness (ft.): 3.5

Dunham Classification: Bioclastic Wackestone

Color: Medium Grey (N5)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Interbedded with shale seams (cm thick). Few white spheroidal fossils and dark grey elongate fossils. Fracture lines around shale seams.

Unit 56

Upper Boundary Type: Gradational

Box Depth (ft.): 9909-9912

Unit Thickness (ft.): 0.4

Dunham Classification: Bioclastic Packstone

Color: Light Grey (N7)

Archie Porosity: III – VF – B₅ ~11% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Grains are oval shaped very light grey mm-cm's in length and are more concentrated near bottom of unit. Some dark grey elongate fossils present. VF vugular porosity.

Unit 57

Upper Boundary Type: Sharp

Box Depth (ft.): 9909-9912

Unit Thickness (ft.): 0.8

Dunham Classification: Bioclastic Wackestone

Color: Med. Light Grey (N6)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Thin stylolites and solution seams throughout unit as well as fracture lines. Dark grey elongate fossils present intact and disarticulated.

Unit 58

Upper Boundary Type: Sharp

Box Depth (ft.): 9912-9915

Unit Thickness (ft.): 0.7

Dunham Classification: Bioclastic Packstone

Color: Light Grey (N7) and Yellowish Grey (5 Y 8/1)

Archie Porosity: III – F – BC₁₅ ~21% porosity

Choquette and Pray Porosity: Vugular Porosity

Observations:

Grainy appearance. Many oval shaped light fossils. Fossils very condensed near bottom of unit. Small vugs throughout.

Unit 59

Upper Boundary Type: Sharp

Box Depth (ft.): 9912-9915

Unit Thickness (ft.): 1.4

Dunham Classification: Bioclastic Packstone
Color: Very Light Grey (N8) and Yellowish Grey (5 Y 8/1)
Archie Porosity: I – VF – BC₁₀ ~13% porosity
Choquette and Pray Porosity: Vugular Porosity

Observations:

Mottled coloring. Vugular porosity in Yellowish Grey zones. Elongate fossils throughout –light and dark colored. Light colored may be bivalves. Porosity more condensed at boundaries of colored zones.

Unit 60

Upper Boundary Type: Sharp

Box Depth (ft.): 9912-9915

Unit Thickness (ft.): 1.5

Dunham Classification: Bioclastic Wackestone

Color: Very Light Grey (N8) and Med. Light Grey (N6)

Archie Porosity: I – F ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Primarily N8 with 5 cm N6 spots throughout unit. Few elongate dark fossils almost exclusively in N6 zones. Few small stylolites.

Unit 61

Upper Boundary Type: Sharp

Box Depth (ft.): 9915-9918

Unit Thickness (ft.): 5.1

Dunham Classification: Brecciated Mudstone

Color: Light Grey (N7) and Light Olive Grey (5 Y 6/1)

Archie Porosity: I – VF –BCD₁₀ ~13% porosity

Choquette and Pray Porosity: Breccia Porosity

Observations:

Highly fractured. Silt fills fractures. Some recrystallized dark grains (probable fossils) in clasts. Hard to tell if fractures were filled or if they are solution seams.

Unit 62

Upper Boundary Type: Sharp

Box Depth (ft.): 9921-9924

Unit Thickness (ft.): 6.0

Dunham Classification: Bioclastic Wackestone/Packstone

Color: Very Light Grey (N8) and Light Grey (N7)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Predominantly Very Light Grey with zones of Light Grey. Stylolites throughout unit. Dark elongate fossils concentrated in N7 zones with few fossils in N8 colored zones. N7 zones are possibly intraclasts.

Unit 63

Upper Boundary Type: Gradational

Box Depth (ft.): 9927-9930

Unit Thickness (ft.): >1.1

Dunham Classification: Bioclastic Wackestone

Color: Light Grey (N7)

Archie Porosity: I – VF ~3% porosity

Choquette and Pray Porosity: No visible porosity

Observations:

Few fine dark elongate fossils. Abundant solution seams/shale intrabeds. Few coarse white square/rectangular fossils. Few white fracture lines also observed.

APPENDIX B

THIN SECTION DESCRIPTIONS

Sample 1

Sampled Core: BMI 1841

Sample Depth: 9775'

Folk Classification: packed biomicrite

Dunham Classification: packstone

Porosity: 2% cement-reduced secondary eogenetic moldic/vuggy porosity

Visual Description:

Recrystallized phylloid algal blades observed, few fractures also filled with calcite cement. Matrix almost completely micrite. Abundant foram, echinoid and bivalve fossils throughout matrix. Most small pore spaces filled with calcite cement. Observed calcite is euhedral with clear fracture planes.

Sample 2

Sampled Core: BMI 1841

Sample Depth: 9887'

Folk Classification: packed biomicrite

Dunham Classification: fossiliferous packstone

Porosity: 15% cement-filled secondary eogenetic moldic/vugular porosity

Visual Description:

All pore space filled with anhedral calcite grains. Grains are bivalve, foram, phylloid algae and echinoderms. Stylolites cut through porosity, this leads to conclusion that porosity and filling of porosity by calcite cement was prior to deep burial. Some phylloid algal blades have fairly well preserved wall structure.

Sample 3

Sampled Core: BMI 1841

Sample Depth: 9850'

Folk Classification: sparse biomicrite

Dunham Classification: fossiliferous wackestone

Porosity: 10% cement-filled secondary eogenetic moldic porosity with small amount of cement filled fracture porosity

Visual Description:

Abundance of phylloid algal blades with forams, bivalve fragments and echinoderm fragments. All porosity completely filled with sub-anhedral calcite crystals. Few recrystallized ooids also observed with cores but lacking discernible concentric structure.

Sample 4

Sampled Core: BMI 1841

Sample Depth: 9856'

Folk Classification: phylloid algal packed biomicrite

Dunham Classification: fossiliferous packstone

Porosity: 35% cement filled secondary eogenetic moldic porosity with small amount of cement filled channel porosity

Visual Description:

Slide dominated by large phylloid algal blades. All blades completely recrystallized by calcite with very little observable internal structure. Few blades show micritization around wall structure. Other observed fossils include mainly forams and bivalve fragments. Few echinoderm fragments and bryozoan fragments also observed. Porosity completely filled by subhedral calcite crystals. Channel porosity seems to connect moldic porosity of recrystallized algal blades.

Sample 5

Sampled Core: BMI 1841

Sample Depth: 9864'

Folk Classification: dolomitized sparse sorted sparite

Dunham Classification: cementstone

Porosity: 20% mesogenetic intercrystalline porosity

Visual Description:

Circular structures thought to be relict burrows which have been filled by coarse baroque dolomite crystals. Matrix consists mainly of Planar-e dolomite cement. Fractures also filled with coarse baroque dolomite crystals. Staining shows some relict calcite (<5%) within matrix as well as very little ferroan calcite. Circular structures surrounded by darker matrix, which is thought to be part of burrow walls.

Sample 6

Sampled Core: BMI 1841

Sample Depth: 9869'

Folk Classification: unsorted altered biomicrite

Dunham Classification: fossiliferous packstone

Porosity: 20% cement-filled secondary eogenetic porosity

Visual Description:

Matrix consists of mainly sparite with two large clasts of dolomitized muds. Recognized fossils include biserial foraminifer, fusulinid foraminifer, bryozoan fragments, recrystallized brachiopod and mollusk fragments.

Sample 7

Sampled Core: BMI 1841

Sample Depth: 9879'

Folk Classification: packed biomicrite

Dunham Classification: fossiliferous packstone

Porosity: 30% cement-filled secondary eogenetic moldic porosity with ~7% cement filled channel/fracture porosity

Visual Description:

Porosity completely occluded by coarse subhedral calcite crystals. Observed a wide range of fossil allochems, including bryozoans, forams, burrows, bivalves, echinoderm fragments. Fracture and channel porosity also completely filled by calcite crystals.

Sample 8

Sampled Core: BMI 1841

Sample Depth: 9892'

Folk Classification: packed biomicrite

Dunham Classification: fossiliferous packstone

Porosity: 30% cement-reduced moldic porosity

Visual Description:

Similar to sample 7 with more preserved open porosity (~40% total porosity). Bryozoans and forams present as well as possible burrows and sponge spicules. More extensively burrowed than sample 7 and micrite is more tightly packed with less occluded pore space within matrix. Hard to tell if porosity is re-emerging through dissolution or is being filled due to cementation. Lack of fracturing leads to conclusion of re-emerging porosity because porosity would be closed during burial if no cement were present.

Sample 9

Sampled Core: BMI 1841

Sample Depth: 9901'

Folk Classification: packed biomicrite and unsorted altered biomicrite

Dunham Classification: fossiliferous packstone

Porosity: biomicrite - 25% cement-filled moldic with <5% interparticle porosity
altered biomicrite - 65% cement filled moldic with <5% interparticle porosity

Visual Description:

biomicrite: Filled with phylloid algal blades which have been completely recrystallized. Almost completely made up of compacted recrystallized fossils mostly recognized by micritic outlines. Other observed fossils include bryozoans, miliolid forams, fusulinid forams, echinoderms, sponges and biserial forams.
altered biomicrite: Sponge spicules throughout, micrite is not thoroughly compacted. Forams and bivalve fossils observed as well as a few large echinoderm fragments, miliolid forams and brachiopod fragments.

Sample 10

Sampled Core: BMI 1841

Sample Depth: 9935'

Folk Classification: packed biomicrite

Dunham Classification: fossiliferous packstone

Porosity: 40% cement-filled moldic and interparticle porosity

Visual Description:

This could be termed a fusulinid foram biomicrite, since 60% of the fossils are said forams. Space between fossils lead to the conclusion that cementation occurred prior to burial. Along with forams, phylloid algal blades makes up large quantity of fossils. Also observed few echinoid fragments and sponge spicules. One large fracture cuts through slide in SE quadrant, section of slide cut off by fracture looks slightly more compacted than the rest of the slide.

Sample 11

Sampled Core: BMI 1841

Sample Depth: 9972'

Folk Classification: unsorted/packed biomicrite

Dunham Classification: fossiliferous packstone/wackestone

Porosity: 25% cement filled moldic porosity

Visual Description:

Many large echinoid fragments and brachiopod fossils. Observed few phylloid algal blades but they have well preserved wall structures and are very large. Few forams observed, micrite matrix appears to be well compacted with little open pore space within matrix.

Sample 12

Sampled Core: BMI 1851

Sample Depth: 9710'

Folk Classification: packed biomicrite

Dunham Classification: fossiliferous packstone

Porosity: 20% cement filled moldic porosity

Visual Description:

Abundant sponge spicules, bryozoan, fusulinid, echinoid fossils. Few phylloid algal blades observed. Multiple stylolites cut through thin-section. Micritization around many of the moldic pore's rims.

Sample 13

Sampled Core: BMI 1851

Sample Depth: 9721'

Folk Classification: packed biomicrite and poorly washed altered biomicrite

Dunham Classification: fossiliferous wackestone

Porosity: biomicrite -15% cement filled moldic porosity

altered biomicrite – 30% cement filled moldic/vugular porosity

Visual Description:

Most of the thin-section (80%) is packed biomicrite with the middle of the thin-section containing a zone of poorly washed altered biomicrite, much higher volume of moldic pores within the altered biomicrite. Sponge spicules and small phylloid algal blades with micritized wall structures. Large echinoderm and fusulinid fossils also observed.

Sample 14

Sampled Core: BMI 1851

Sample Depth: 9772'

Folk Classification: dolomitized micrite

Dunham Classification: cementstone

Porosity: No porosity observed

Visual Description:

2% of thin-section's volume is intercrystalline hydrocarbon residue. Few indistinct relict fossils observed. Thin-section's volume is 50% dolomite and 50% micrite with dolomitization appearing to have occurred through channels. Micrite and dolomite throughout thin-section with few large zones of either.

Sample 15

Sampled Core: BMI 1851

Sample Depth: 9780'

Folk Classification: phylloid algal packed biomicrite

Dunham Classification: fossiliferous wackestone

Porosity: 30% cement filled moldic porosity

Visual Description:

The largest observed pores are all phylloid algal blade molds filled with coarse subhedral calcite cement. Dissociated fossils also observed within the micrite matrix include sponge spicules, fusulinids, bivalves and bryozoans.

Sample 16

Sampled Core: BMI 1823

Sample Depth: 9805'

Folk Classification: porous phylloid algal altered biomicrite

Dunham Classification: fossiliferous packstone

Porosity: 50% cement reduced moldic and solution enlarged vugular porosity

Visual Description:

Majority of pore spaces are phylloid algal blade molds filled or reduced by coarse subhedral calcite crystals. Evidence suggests pores are being infilled with cement since all pore spaces are enclosed by a rimming boundary of sparry calcite cement.

Sample 17

Sampled Core: BMI 1823

Sample Depth: 9814'

Folk Classification: porous phylloid algal biomicrite

Dunham Classification: fossiliferous wackestone

Porosity: 30% cement reduced moldic porosity

Visual Description:

Almost all fossils observed in thin-section are phylloid algal blades with very few sponge spicules also observed. Saddle dolomite reduces the majority of pore spaces with some pores containing subhedral calcite cement. More than 50% of the pore spaces remain open. The matrix within this thin-section contains much less spar than all other thin-section samples.

Appendix C

Indicates which Bought zone each productive well produced from along with lease information and location. Productive zones are inferred from the depths of perforations in each well.

Operator	Lease	Well #	Section	Placement	In Section	Bought A Production	Bought B Production	Bought C Production	Bought D Production
Phillips Petr. Co.	Ranger Lake Unit TR 2	2	25-12S-34E	330 FNL	330 FWL			X	
Gordon M. Cone	State 24	2	24-12S-34E	330 FSL	330 FEL			X	
Sunray DX Oil Co.	State of NIM AO	1	16-10S-34E	660 FSL	660 FWL			X	
Atlantic Richfield Co.	State BJ	1	9-10S-34E	1980 FNL	660 FWL			X	
Amoco Production	NMI State	1	11-10S-33E	660 FNL	660 FEL			X	
Charles B. Read	Continue ntal State	2	7-10S-34E	660 FSL	660 FWL			X	
Champlin Petr. Co.	State "8"	1	8-10S-34E	660 FNL	660 FEL			X	
Amerada Petr. Corp.	Caudle	6	3-12S-33E	1980 FSL	1980 FWL		X		
Amerada Petr. Corp.	JT Caudle	3	10-12S-33E	660 FNL	660 FEL		X		
Gulf Oil Company	Lea State AN	1	27-13S-33E	1980 FSL	1980 FWL	X			
Charles B. Read	State "D"	1	28-10S-33E	660 FNL	510 FEL			X	
Humble Oil & Refg. Co.	"CC" State	2	27-10S-33E	554 FSL	2086 FWL			X	

Humble Oil & Refig. Co.	NM State "BQ"	1	26-10S-33E	1980 FSL	660 FWL			X	
Monsanto Company	Lane-State	1-Y	30-10S-34E	660 FSL	760 FWL				X
Sun Oil Company	NM "Q" State	2	9-11S-34E	660 FNL	1980 FWL				X
Amerada Petr. Corp.	State BTB	2	26-12S-33E	1980 FNL	1980 FWL	X			
Shell Oil Company	State HT	1	25-12S-33E	660 FSL	660 FEL	X	X		
Harper Oil Company	Seay	1	30-12S-34E	660 FSL	660 FEL	X			
Phillips Petr. Co.	West Ranger Lake Unit	16	26-12S-34E	1980 FSL	1980 FWL			X	
Robert B. Holt	Aztec State	2	26-13S-32E	660 FNL	660 FEL			X	X
Sun Oil Company DX Division	NM State "JJ"	1	23-13S-32E	660 FSL	1980 FEL			X	X
Pan American Petr. Corp.	State "DL"	1	13-13S-32E	1980 FSL	660 FEL	X	X	X	X
Coastal States Gas Producing Co.	Federal "20"	2	20-13S-33E	660 FSL	1980 FWL			X	
Texaco Inc.	DM State NCT-1	1	21-13S-33E	660 FSL	1980 FWL			X	
OXY USA	Elkan "A"	1	25-13S-34E	1650 FSL	990 FWL			X	
Robert B. Holt	Aztec State	4	25-13S-32E	554 FSL	554 FEL			X	

Texas Crude Oil Co.	State "26"	1	26-13S-33E	1980 FNL	1980 FEL		X		
Jack McClellan	Dye	1	28-13S-34E	660 FSL	660 FEL	X	X		
Aztec Oil and Gas & Delhi-Taylor Oil	State LW	2	2-10S-33E	660 FNL	660 FEL			X	X
BTA Oil Producers	Lane "A" 674 Ltd.	1	1-10S-33E	1980 FSL	1980 FEL		X	X	
Superior Oil Company	State "L" Com	1	33-13S-34E	510 FSL	660 FEL			X	
Yates Petroleum	Pyro "ABK" State	1	33-13S-33E	660 FNL	1980 FEL			X	
Trice Production Company	Lazy "J" B	1	34-13S-33E	660 FSL	660 FEL		X	X	
Texaco Inc.	State of NM "BV" NCT-2	3	36-13S-33E	990 FSL	990 FWL	X	X		
Getty / (Skelly)	Willard Beaty	5	35-13S-33E	1650 FSL	660 FEL		X		
Coastal States Gas Producing Co.	State 31	1	31-13S-33E	1881 FSL	759 FWL			X	X
Coastal States Gas Producing Co.	State 32 Com	2	32-13S-33E	660 FNL	1980 FWL				X
BTA Oil Producers	674 LTD Lane "C"	4	6-10S-34E	660 FNL	1980 FWL			X	

BTA Oil Producers	679 LTD MAR	2	5-10S-34E	660 FSL	660 FWL				X	
Tom Brown Drilling Co. Inc.	Holt State	1	4-10S-34E	766 FSL	554 FWL				X	
Charles B. Read	Aztec	1	15-10S-33E	2130 FSL	660 FEL				X	
Midwest Oil Corp.	State of NM "A"	1	14-10S-33E	660 FNL	660 FWL				X	
Union Oil Co. of California	State "13"	1	13-10S-33E	1980 FNL	660 FWL			X		
Charles B. Read	Apache	1	3-10S-33E	660 FSL	510 FEL					X
Apache Oil Corp.	Midwest State	1	23-10S-33E	1980 FSL	1980 FEL				X	
Sun Oil Company	NM "M" State	1	19-10S-34E	660 FNL	660 FWL					X
Sunray DX	NM State "AWA"	1	20-10S-34E	1980 FSL	660 FEL					X
Charles B. Read	Continental State	1	18-10S-34E	1977 FNL	1970 FWL				X	
Sunray DX Oil Co.	NM State "AP"	1	17-10S-34E	1650 FSL	990 FEL				X	
Mesa Petroleum Company	Humble CC State	7	34-10S-33E	2086 FNL	766 FWL				X	

MGF Production	Nine Ranch Inc State	3	22-10S-33E	1980 FSL	1980 FWL			X	
Cayman Corp.	Murphy State "A"	3	24-10S-33E	1980 FSL	660 FWL			X	
J.C. Barnes Oil Company	Southern Natural	1	1-11S-33E	740 FNL	570 FEL			X	
Southland Royalty Co.	JD Guye	5	12-11S-33E	660 FSL	2030 FWL			X	
A.F. Roberts, Jr.	Gulf State	1	18-11S-34E	660 FNL	660 FEL			X	
SW Natural Gas	TP State "4"	1	4-11S-34E	660 FSL	2100 FEL			X	
Amerada Petr. Corp.	CW Robinson A	1	14-11S-32E	660 FSL	660 FEL		X	X	
Pan American Petr. Corp.	DC	1	16-11S-33E	660 FSL	660 FEL		X	X	
American Oil	Candy Com	1	5-11S-33E	660 FSL	1980 FWL	X			
Stoltz & Company	Lulu State "L"	1	4-11S-33E	656 FSL 1970 FNL	1985 FWL		X	X	
Cabot Corporation	State "L"	1	23-11S-33E	1970 FNL	330 FWL			X	
Paul Declava	Shell State	1	19-11S-34E	660 FNL	1830 FEL			X	

Phillips Petroleum Company	South Four Lakes Unit	1	2-12S-34E	660 FNL	1980 FEL			X	X
Amerada Petr. Corp.	State WR "A"	1	35-12S-34E	660 FNL	660 FWL			X	
Amoco	State AZ	1	34-12S-34E	660 FNL	660 FEL			X	X
Texas Pacific Oil Co.	State AH	1	14-12S-34E	1980 FNL	1980 FWL	X			
American Trading Prod.	State 22	1	22-12S-34E	555 FSL	555 FEL				X
Phillips Petr. Co.	West Ranger Unit	1	23-12S-34E	660 FSL	660 FEL			X	X
Sabine Corporation	Paris State	1	36-13S-32E	660 FSL	660 FEL			X	
Union Texas Petroleum Corp.	State "24"	1	24-13S-32E	660 FSL	660 FWL				X
Par American Petr. Corp.	State "DN"	1	19-13S-33E	660 FNL	1980 FWL	X			X