EFFECTS OF SEA LEVEL FLUCTUATIONS ON POROSITY AND PERMEABILITY OF THE LOWER COCHRANE MEMBER, CHIMNEYHILL SUBGROUP, HUNTON GROUP WEST CARNEY HUNTON FIELD LOGAN COUNTY, OK.

By

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Title of Study: EFFECTS OF SEA LEVEL FLUCTUATIONS ON POROSITY AND PERMEABILITY OF THE LOWER COCHRANE MEMBER, CHIMNEYHILL SUBGROUP, HUNTON GROUP WEST CARNEY HUNTON FIELD, LOGAN COUNTY, OK.

Major Field: GEOLOGY

Abstract: The West Carney Hunton Field is located in central Oklahoma in Lincoln and Logan Counties. The field is situated on the Oklahoma Platform just east of the Nemaha Ridge. The Hunton Group was deposited in a broad, shallow epicontinental sea. Sea level fluctuations occurred throughout the early Silurian that diagenetically affected porosity and permeability of the Lower Cochrane “member” of the Chimneyhill Subgroup. Petrography (Cathodoluminescence, and light microscopy), carbon and oxygen stable isotopes, and core analysis were used to document these diagenetic affects throughout the Lower Cochrane “member”.

Three distinct Cathodoluminescence (CL) zones are observed in the calcite cements of the Lower Cochrane. In order from oldest to youngest these three zones are: CL zone 1 (Z1), CL zone 2 (Z2), and CL zone 3 (Z3). CL zones 1 and 2 are both composed of non-CL calcite cements that occur as open space fillings in intergranular pores and as syntaxial overgrowths on crinoid grains. CL zones 1 and 2 are typically separated by a thin bright CL subzone. CL zone 3 (Z3) is a bright to dull CL multi-banded calcite cement which occurs as the last generation of calcite cement. The distribution of these cements varies with stratigraphic position. The Z1 and Z2 calcite cements display average values of $\delta^{18}O$ = -4.4‰ VPDB s.d.=1.0‰ and $\delta^{13}C$ = 0.2‰ VPDB s.d.=2.3‰. Z3 calcite cements display average values of $\delta^{18}O$ = -5.4‰ VPDB s.d.=1.9‰ and $\delta^{13}C$ = -0.2‰ VPDB s.d.=1.7‰. Brachiopods display average values of $\delta^{18}O$ = -4.2‰ VPDB s.d.= 0.4‰ and $\delta^{13}C$ = 0.8‰ VPDB s.d.= 0.8‰. CL Z1 and Z2 likely were precipitated in meteoric environments during lowstands in sea level related to glaciations during the early Silurian (early and latest Aeronian). CL Z3 calcite cements may have been precipitated in a later burial diagenetic environment.

Secondary porosity and permeability are enhanced up-dip closer to exposure surfaces. However, porosity and permeability may have been better preserved in the down dip wells because of less precipitation of CL Z1 and Z2 calcite cements. Final porosity and permeability may be facies as well as diagenetically controlled. The brachiopod packstone facies in this area preserved more shelter and vuggy porosity than other facies.

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CHAPTER I

INTRODUCTION

The West Carney Hunton Field (WCHF) (Fig. 1) is located in central Oklahoma in Lincoln and Logan Counties on the Oklahoma Platform (Cherokee Platform) just east of the Nemaha Ridge. The field consists of a shallow water carbonate reservoir comprised of roughly 30,000 acres and contains more than 250 producing wells. The WCHF primarily produces out of the Hunton Group which is a major producing horizon across much of Oklahoma (Derby et al., 2002a).

The Hunton Group is thought to have been deposited in a broad, shallow epicontinental sea, with the depositional slope trending southwestward into the more subsiding part of the basin, the Southern Oklahoma aulacogen (Derby et al., 2002a). The Chimneyhill Subgroup is the only stratigraphic unit of the Hunton present in the WCHF. From oldest to youngest depositional unit the Chimneyhill Subgroup is comprised of the Keel, Cochrane and Clarita Formations. The Keel Formation is absent in the study area.

Extensive biostratigraphic and lithostratigraphic studies have been conducted on the

Upper Cochrane A and B “members” by Braimoh (2010), Kelkar (2002), Bader et al (2007) and further by Bader (2007). However, extensive diagenetic studies of the Lower Cochrane “member” have not been conducted. The Lower Cochrane “member” does not outcrop in the study area, and therefore core analysis and petrology will be the primary tools for studying diagenesis of the Lower Cochrane “member” (Fig. 2).

Stratigraphic units of the Hunton Group represent episodic cycles of deposition and erosion resulting from repeated sea level change (Derby et al., 2002a). Throughout these sea level fluctuations diagenetic modifications likely occurred, that affected porosity and permeability. The purpose of this study is to determine the effects of sea level fluctuations, during and immediately after Hunton (Lower Cochrane) sedimentation, on porosity and permeability. Since this area was subjected to multiple sea level fluctuations (Derby et al., 2002a) during the early Silurian, there should be varying cementation patterns of calcite zoning throughout the Lower Cochrane that record these events. By understanding the origin and modifications of porosity and permeability networks, the Hunton reservoir will be better understood.

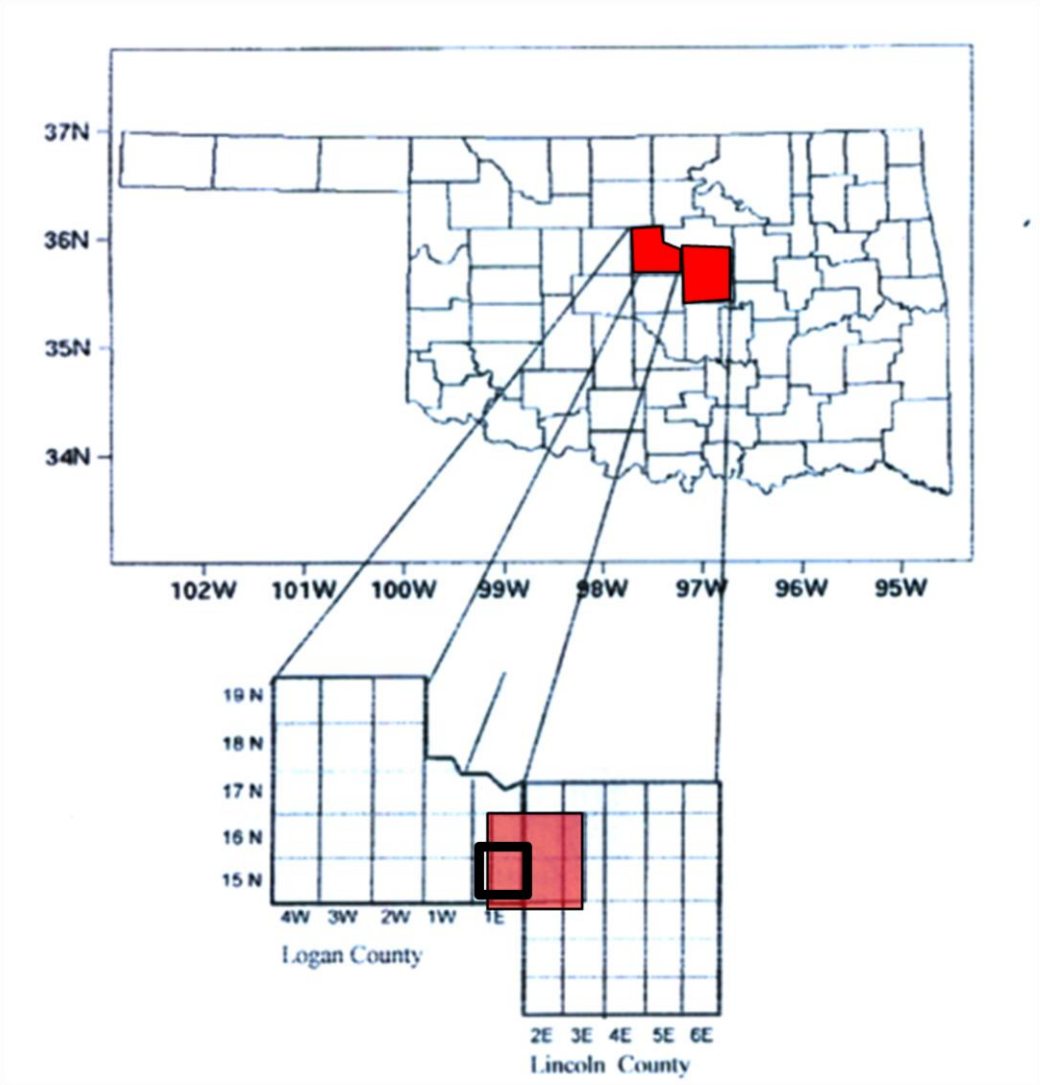


Figure 1. Map of the West Carney Hunton Field, Lincoln and Logan Counties, OK (T. 14-17N.,R 1-3E). Black box depicts the locations of the four cored wells included in the study.

CHAPTER II

GEOLOGIC SETTING

Regional Geology

The WCHF is located on the central Oklahoma platform (Cherokee Platform) which is bounded by the Nemaha Ridge to the west, Ozark Dome to the east, and the Arbuckle Uplift and Arkoma Basin to the south and east (Fig. 2). During deposition of the Hunton Group, the West Carney Hunton Field was located on the northeast flank of the Paleozoic Oklahoma basin, but was later separated from the deeper part of the basin by uplift of the Nemaha Ridge during Pennsylvanian time, after which it became part of the Central Oklahoma Platform (Derby et al., 2002a).

A southwestward depositional dip was established from the Late Cambrian through the Devonian. The southwestward dip was enhanced by the uplift of the Chautauqua Arch during the Late Devonian (pre-Woodford), which erosionally truncated all previously deposited units (Derby et al., 2002a). After deposition of Mississippian carbonates, in response to the Nemaha Uplift, the area was tilted east-southeastward resulting in the truncation of the Mississippian, Woodford and Hunton Group (Derby et al., 2002a). Continued eastward tilting of the WCHF occurred throughout the Paleozoic, but the region was later tilted back in a southwestward direction during the Mesozoic, which is the current dip direction today (Derby et al., 2002a).

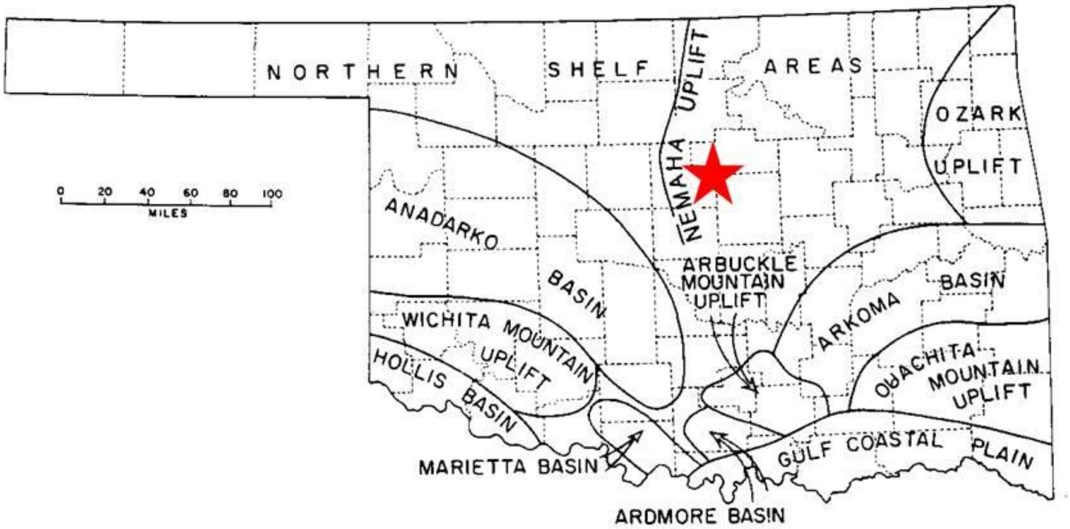


Figure 2. Map of major Oklahoma geological provinces. Red star marks the location of the WCHF. Modified from Derby et al. (2002a, Fig. 2)

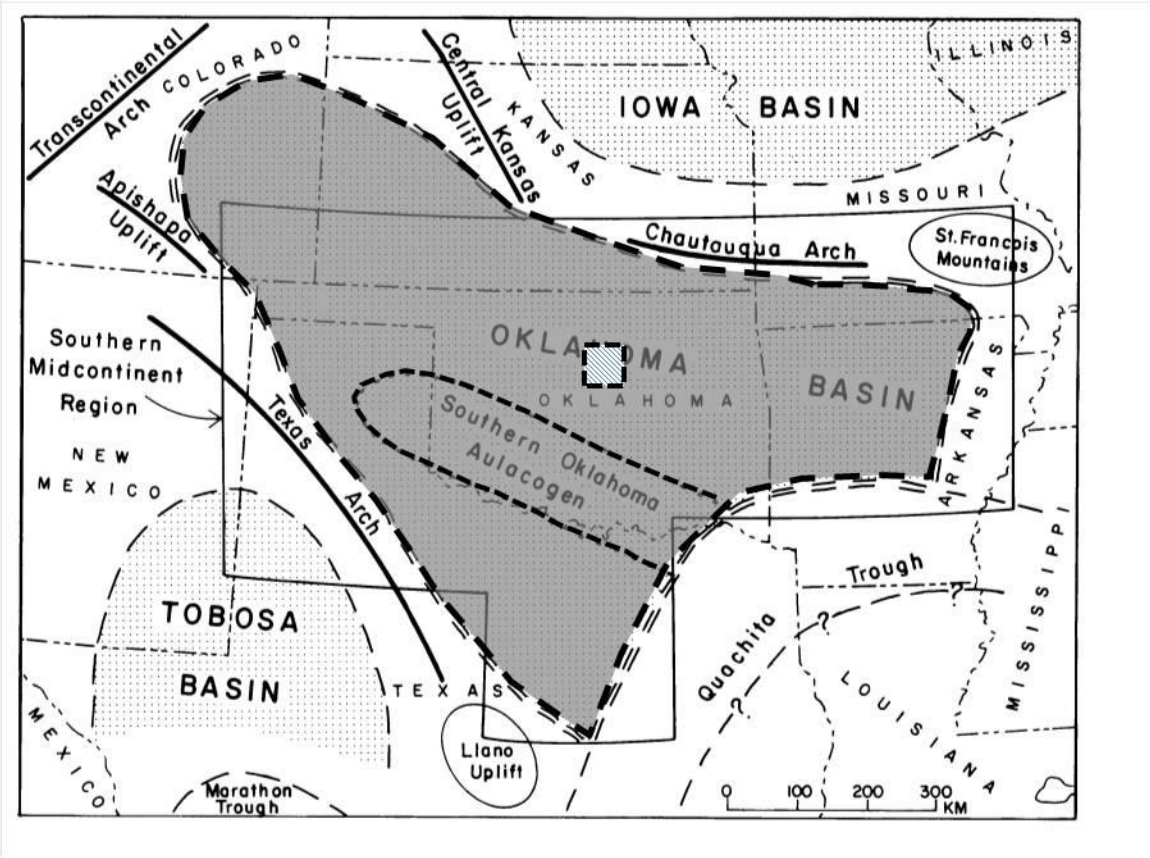


Figure 3. Map showing the location of WCHF with respect to the Paleo-Oklahoma Basin. Modified from Johnson (1988, Figure 3). Depositional slope would have been to the southwest into the basin whose axis overlies the Southern Oklahoma Aulacogen.

Stratigraphy

In the WCHF, the Hunton Group ranges in thickness from zero (eastern portion of the field) up to 39 meters in the western portion of the field (Fig. 4). This variance in thickness most likely represents an erosional surface (Braimoh, 2010). The Chimneyhill Subgroup is the only portion of the Hunton Group present in the WCHF. Pre-Woodford erosion removed most of the overlying stratigraphic section in the study area including the Henryhouse Formation, Bois d'arc Formation, and Frisco Formation (Braimoh, 2010) (Fig. 5).

Locally, within the WCHF, the Chimneyhill Subgroup is unconformably bounded above by the Upper Devonian-Lower Mississippian Woodford Shale and unconformably bounded below by the Upper Ordovician Sylvan Shale (Stanley, 2001). Locally, within the study area, there is a thin interval (~ 6 cm) of Misener Sandstone present at the contact between the Woodford Shale and the Hunton Group. The Chimneyhill Subgroup is comprised of three formations: Clarita, Cochrane and Keel in descending order. The Clarita was removed in the study area during a sea level lowstand (Braimoh, 2010). Chimneyhill sedimentation was initiated by the deposition of oolites, which represent shallow-water, high-energy conditions (Amsden, 1975). However, the oolitic section, the Keel Formation, was either not deposited or was eroded away in the WCHF.

The Cochrane Formation is primarily a limestone (with some dolomitization in some parts of the field) (Braimoh, 2010) and ranges in thickness from 46 meters in the western part of the field to just under 9 meters on the eastern part of the field. The sedimentology of the Cochrane Formation is complex and strata consist of bioherms dominated by coral and stromatoporoids, as well as pentamerid brachiopod bioherms that can reach up to 21 meters (Braimoh, 2010). In some areas the Cochrane is dominated by crinoidal grainstones (Kelkar, 2002). Previous conodont work breaks the Cochrane Formation into three informal “members”: Upper Cochrane B “member”, Upper Cochrane A “member” and the Lower Cochrane “member” (Bader et al., 2007). In the study area, both the informal Upper Cochrane A and B “members” are missing, and the Woodford shale unconformably overlies the informal Lower Cochrane “member”. The absence of these two members is most likely due to erosion during a sea level lowstand (Derby et al., 2002a).

The informal Lower Cochrane “member” is the focus of this study. The Lower Cochrane reaches thicknesses of up to 39 meters in the central and western portions of the Carney field, and is absent in the eastern/northeastern portions of the field. It consists primarily of crinoid-brachiopod grainstones, with few pentamerid brachiopod bioherms (Braimoh 2010) that were deposited as a lagoonal facies (Kelkar, 2002).

The development of karsts in the study area occurred during multiple sea level low stands during the Silurian and Devonian, when the WCHF area stood as a topographic high (Kelkar, 2002). During the sea level lowstands, the limestones and dolomites were exposed to subaerial weathering (Kelkar, 2002). Karst features such as breccias, interconnected vugs and solution-enhanced fractures occur throughout the Hunton and likely enhanced porosity and permeability (Derby et al., 2002b).

Upon deposition of the Cochrane Formation (Fig. 6-A), relative fall in sea level occurred preferentially eroding the fossiliferous limestone macrofacies of the Lower Cochrane (more resistive to erosion) and the flanking mudstones of the Upper Cochrane (less resistive to erosion) (Fig.6-B). The fossiliferous limestone macrofacies (Lower Cochrane) was left as a topographic high in the central portion of the field (Fig. 6-B). Relative sea level began to rise again which resulted in the deposition of the Clarita Formation, which is primarily a dolomitized limestone (Fig. 6-C). Subsequent decline in sea level resulted in the Clarita Formation being differentially eroded, leaving thicker sections on the west and east sides of the central limestone macrofacies (Fig. 6-D). Subsequent sea level rise resulted in the deposition of the sediments of the Woodford Shale, which unconformably overlies the Cochrane and Clarita Formations respectively, representing a hiatus of about 50 million years (Derby et al., 2002a).

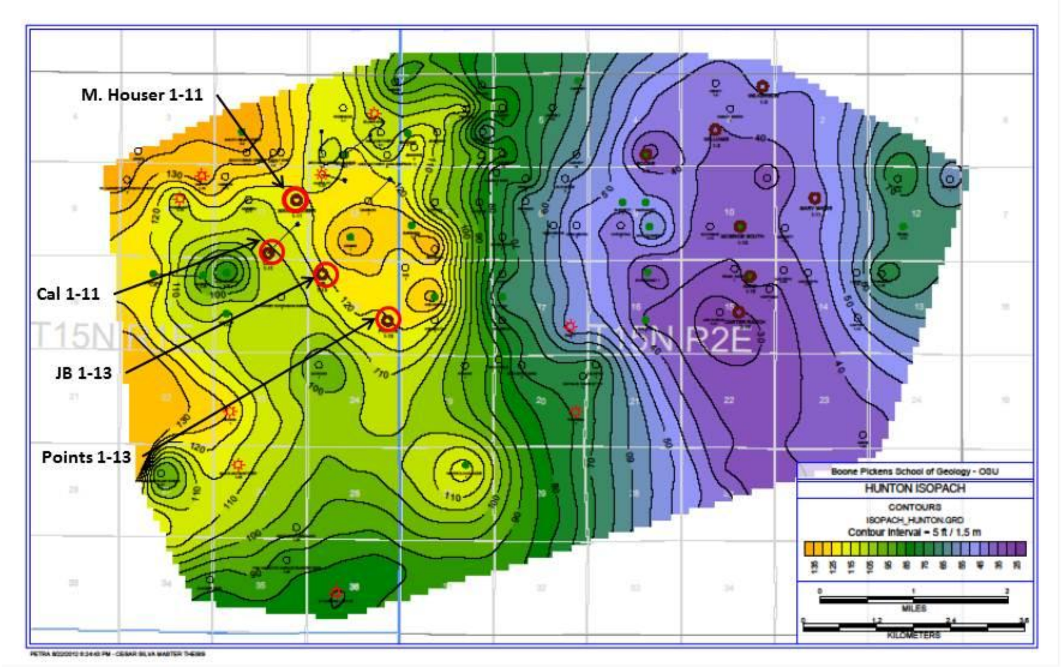


Figure 4. Isopach map of the Hunton Group in the area of study. Thicks are shown by lighter colors, thins are shown by darker colors to the east. There is an overall thickening to the west. Modified from Silva, 2012.

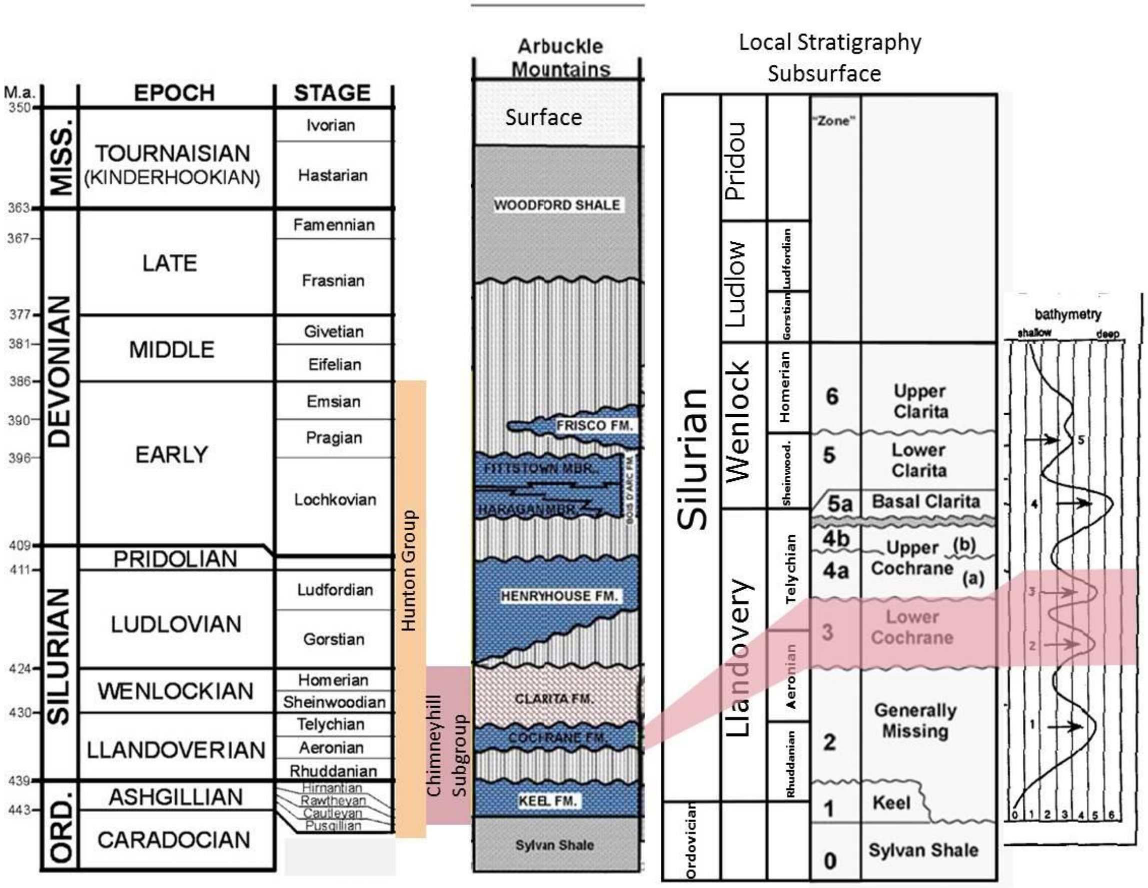
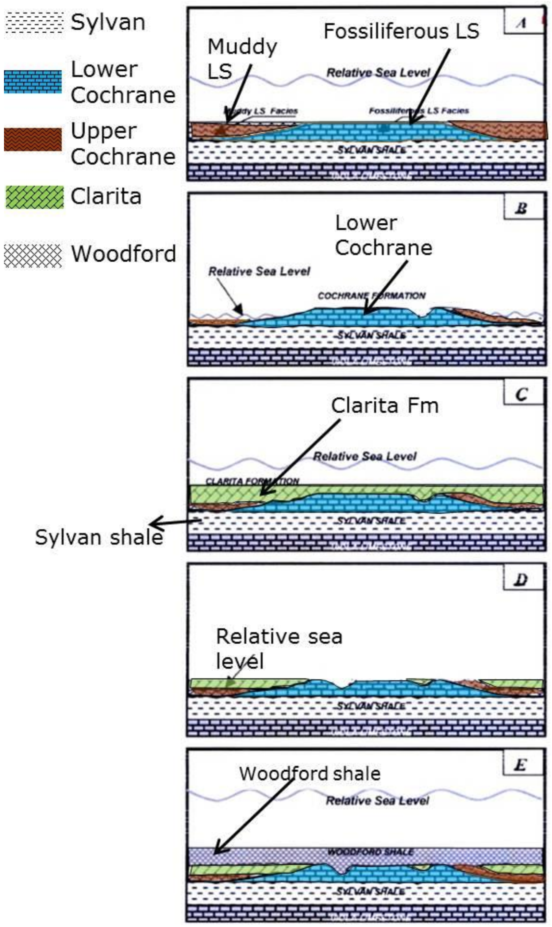


Figure 5. Stratigraphic nomenclature showing relationship between regional stratigraphy and local stratigraphy of the WCHF in conjunction with sea-level curve, Johnson (1996). Modified from Kelkar, (2002).



5-A: Lower Cochrane is unconformably deposited on top of the Sylvan shale. Sea-level falls, differentially eroding the Lower Cochrane, leaving a limestone macrofacies in the central portion of the field. Upper Cochrane is deposited.

5-B: Fall in relative sea-level erodes most of the Upper Cochrane. The Lower Cochrane was more resistive to erosion and is left as a topographic high.

5-C: Relative sea-level rises, resulting in the deposition of the Clarita Formation which is predominately a dolomite facies.

5-D: Relative sea-level falls leaving an erosional unconformity at the top of the Clarita Formation on the flanks of the field and on top of the central fossiliferous limestone facies of the Lower Cochrane. This unconformity represents around 43 million years of non-deposition or erosion.

5-E: Relative rise in sea-level results in the deposition of the Woodford Shale.

Figure 6. Proposed depositional history of the Chimneyhill Subgroup displaying a profile from west to east through the West Carney Hunton Field. Modified from Derby et al., 2002a.

CHAPTER III

SAMPLING AND METHODS

Core from four wells (Figure 7) were chosen from sections 11 and 13 of T. 15N., R. 1E. Logan County, Oklahoma (Appendix 1). The four wells are the Mark Houser 1-11(35.66 m of Hunton cored), Cal 1-11 (32.91 m of Hunton cored), JB 1-13 (46.93 m of Hunton cored) and the Points 1-13 (35.66 m of Hunton cored). The cores were provided by Dr. James Derby who acquired them from Marjo Operating Co., Inc. out of Tulsa, OK. The sample localities were chosen from the western part of the field in order to include thicker sections of the Lower Cochrane, as thickness decreases eastward in the field. An emphasis was placed on obtaining core from the limestone macrofacies, and areas with abundant calcite cements and less dolomitization.

Thin sections were prepared from 41 core samples. There also were a total of 10 oversized thin sections (6 from the Points 1-13, and 4 from the Mark Houser 1-11) available which were provided by Dr. James Derby and Marjo Operating Co., Inc.

Brachiopod shells were sampled every three meters from base to top in the Points 1-13 well for istotope analysis. Calcite cements and crinoids were also sampled for isotope analysis from the four wells; 9 samples were chosen from the Mark Houser 1-11, 4 samples were chosen from the Points 1-13 and 12 samples were chosen from the JB 1-13. An emphasis was placed on sampling inner and outer zones of calcite cements, determined from cathodoluminescence, throughout multiple stratigraphic locations from the four wells.

Laboratory Methods

Thin sections were examined using transmitted and reflected light microscopy. Cathodoluminescence petrography was conducted using a CITL CL 8200 MK5-1 Optical Cathodoluminescence System at Oklahoma State University, Stillwater, OK. Photomicrographs were obtained with a Q Imaging Micropublisher 5.0 RTV cooled camera mounted on an Olympus BX51 petrographic microscope. Cathodoluminescence is dependent upon the spatial distribution of the trace elements Fe^{2+} and Mn^{2+} (Scholle, Ulmer- Scholle 2003). Incorporation of Mn^{2+} into the crystal lattice will create CL and incorporation of Fe^{2+} will reduce or quench CL. Therefore variations in CL response in cements will record chemical variations in diagenetic fluids.

Core Analysis

Core analysis (Appendix 2) data was provided by Dr. James Derby, who acquired the data from Marjo Operating Company Co., Inc. Four two-inch diameter plugs were taken, sealed in core seal and sent to the University of Houston for further core analysis. Porosity values were determined using Boyle’s law helium expansion. Permeability values were measured in two horizontal directions and vertically while the core was confined in a Hassler-type rubber sleeve. Tests were performed at an ambient pressure of 400 psi, and select samples were sandblasted to remove coring induced skin damage.

CHAPTER IV

RESULTS

Well Core Descriptions

CAL 1-11

The Cal 1-11 core (Marjo Operating Co., Inc.) (Fig. 7) is located in Sec. 11, T15N, R1E, Logan County, Oklahoma. The cored interval is 34 meters thick at a depth of 1534-1568 m (Appendix 1). No Woodford Shale was cored, and 3 meters of Sylvan cored at the base. The dominant lithologies in this core are limestone (Fig. 8) and some partially dolomitized limestones with sparse interbedded chert nodules. The contact between the Hunton and Woodford Shale is sharp, as is the contact between the Lower Cochrane and the Sylvan shale (Fig. 9)

Dunham's classification was used in describing the texture of the rock (Dunham, 1962). The core consists primarily of skeletal packstones and grainstones with vugular, intraparticle, interparticle and fracture porosity throughout. There is a thick mudstone interval from 1559-1563 m. Fractures are typically horizontal and vertical and can be healed with calcite cement. Thin intervals (15 cm) of chert nodules are found towards the base of the core from 1564.7-1564.85 m. There is a diverse fauna throughout including brachiopods (*Stricklandia* and *Pentamerus*) (Derby et al., 2002b), crinoids, tabulate corals, bryozoa, ostracodes and sparse trilobites. From 1564-1568 m the lithology becomes dolomitic.

JB 1-13

The JB 1-13 core (Marjo Operating Co., Inc.) is located in Sec. 13, T15N, R1E, Logan County, Oklahoma. The cored interval is 27 meters thick at a depth of 1515-1541 m (Appendix 1). There is 27 cm of Woodford Shale at the top of this core, and 6 cm of Misener Sandstone. No Sylvan Shale was cored.

The dominant lithology in this core is limestone. The core consists primarily of skeletal packstones and grainstones with thin intervals of wackestones. The primary fauna include brachiopods (*Stricklandia* and *Pentamerus*), tabulate corals (*Favosites, Halysites*) (Derby et al., 2002b), crinoids, and sparse stromatoporids and rugose corals. Dips of 20-30° were observed in grainstones, as well as several intervals of reef-flank debris with dips of 25-35° towards the top 9 meters of the section. Karst features observed include thin mosaic breccias, solution enlarged fractures filled with dark silt, and large vugs primarily in interior of brachiopods. Pore types include shelter porosity within brachiopods, fracture porosity, interparticle, and large vugs.

MARK HOUSER 1-11

The Mark Houser 1-11core (Marjo Operating Co., Inc.) is located in Sec. 11, T15N, R1E, Logan County, Oklahoma. The cored interval is 36 meters thick at a depth of 1512-1547.5 m (Appendix 1). There is no Woodford or Sylvan Shale present in the core and 3 meters of Lower Cochrane was not cored.

The dominant lithology in this core is limestone with partly dolomitized limestone towards the base of the core. The core consists primarily of skeletal packstones and grainstones with sparse thin intervals (1-2m) of wackestones. There is a diverse fauna including brachiopods (*Stricklandia* and *Pentamerus*), crinoids, and tabulate corals (*Favosites*, and *Halysites*). The top of the core contains a large (1-7 cm wide) solution-enlarged fracture which is filled with dark black silt and clay as well as fine quartz sand. Pore types include interparticle, vuggy, shelter porosity within brachiopods, and fractures throughout.

There is a large (3 meters) cavern within the core from 1542.6- 1545.9 m which has been completely filled with bioclasts and intraclasts as well as mud from the Lower Cochrane. This filling can be described as a fine to coarse cave fill matrix supported breccia, which is partly dolomitic at the base. This is post-Hunton karst infill and there are no cave dripstones or flowstones present. There is more karst sediment fill present in this core in the upper portion, than the other three cores. This may be due to its stratigraphic position being closer to the exposure surface.

POINTS 1-13

The Points 1-13 core (Marjo Operating Co., Inc.) is located in Sec. 13, T15N, R1E, Logan County, Oklahoma. The cored interval is 37 meters thick at a depth of 1520-1556.6 m (Appendix 1). There is 1 meter of Woodford cored, 6 cm of Misener cored, and no Sylvan cored. The contact between the Lower Cochrane and Misener is sharp (Figure 10).

The dominant lithology of this cored section is limestone that becomes partly dolomitized towards the base of the core. The core consists primarily of skeletal packstones and grainstones with intervals (1-3 m) of wackestones throughout. The primary fauna include brachiopods (*Stricklandia* and *Pentamerus*), crinoids with sparse tabulate corals (*Favosites*), rugose corals, bryozoa and Stromatoporoids. The interval from 1520.6-1541 m consists of a coarse *Stricklandia* brachiopod packstone with vuggy and shelter porosity throughout. Pore types include vuggy, moldic, interparticle, shelter porosity within brachiopods and fracture porosity throughout. The base of the core is a dolomitic, burrow-mottled fine skeletal wackestone.

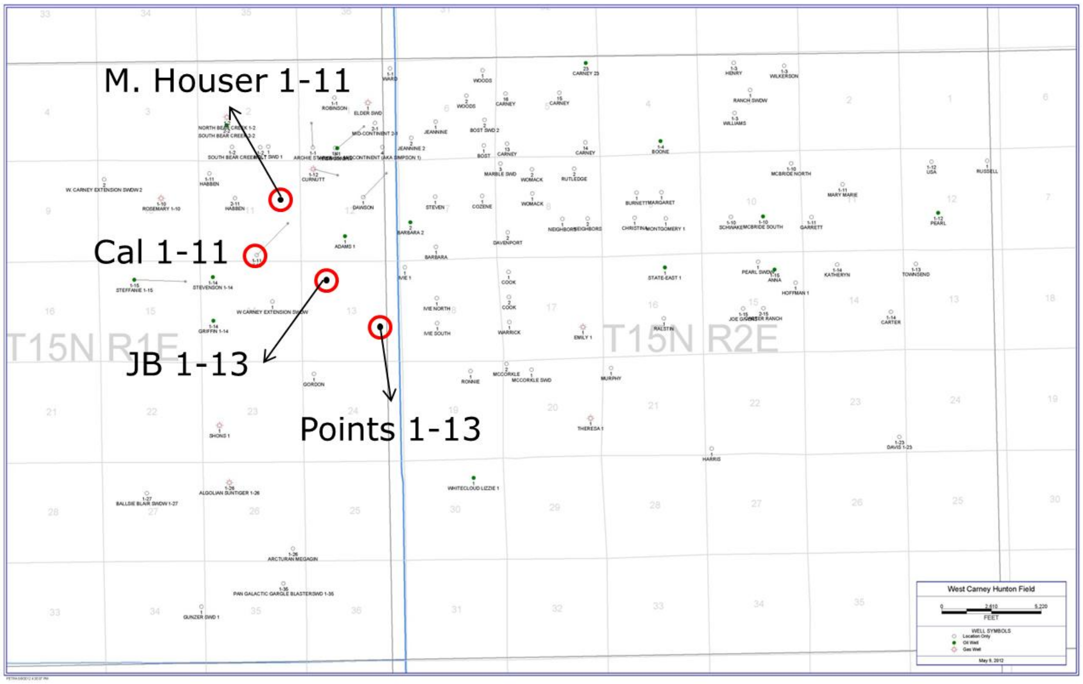
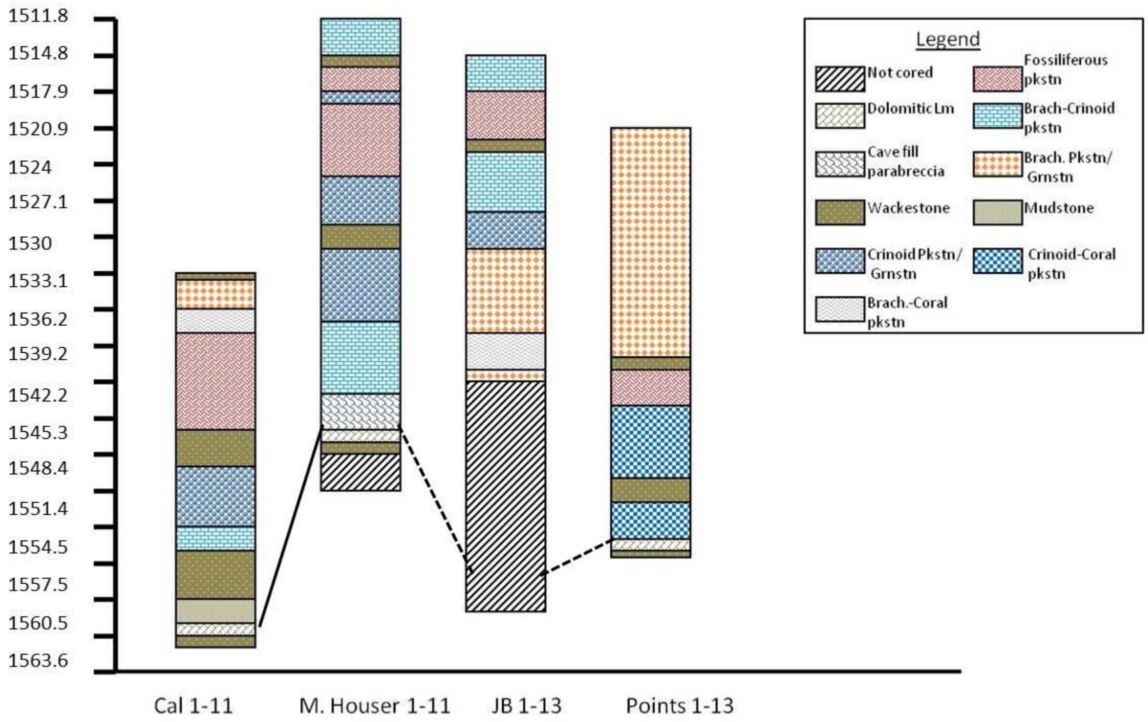


Figure 7. Locations of the four cored wells included in the study noted by the red circles. Other well spots within the area are also depicted. Cores were provided by Dr. James Derby through Marjo Operating Co., Inc. (Mark Houser 1-11, Cal 1-11, JB 1-13, Points 1-13)



* Wells are ~ ¾ mile apart from eachother

Figure 8. Lithofacies of four cored wells (scale in meters). Black lines correlate dolomitized mudstone at the base of the section. JB 1-13 core is missing bottom half of Lower Cochrane, dashed line indicates assumed correlation. More detailed core descriptions can be found in Appendix 1. Cored wells are approximately ¾ of a mile (1609.3 meters) apart from each other.

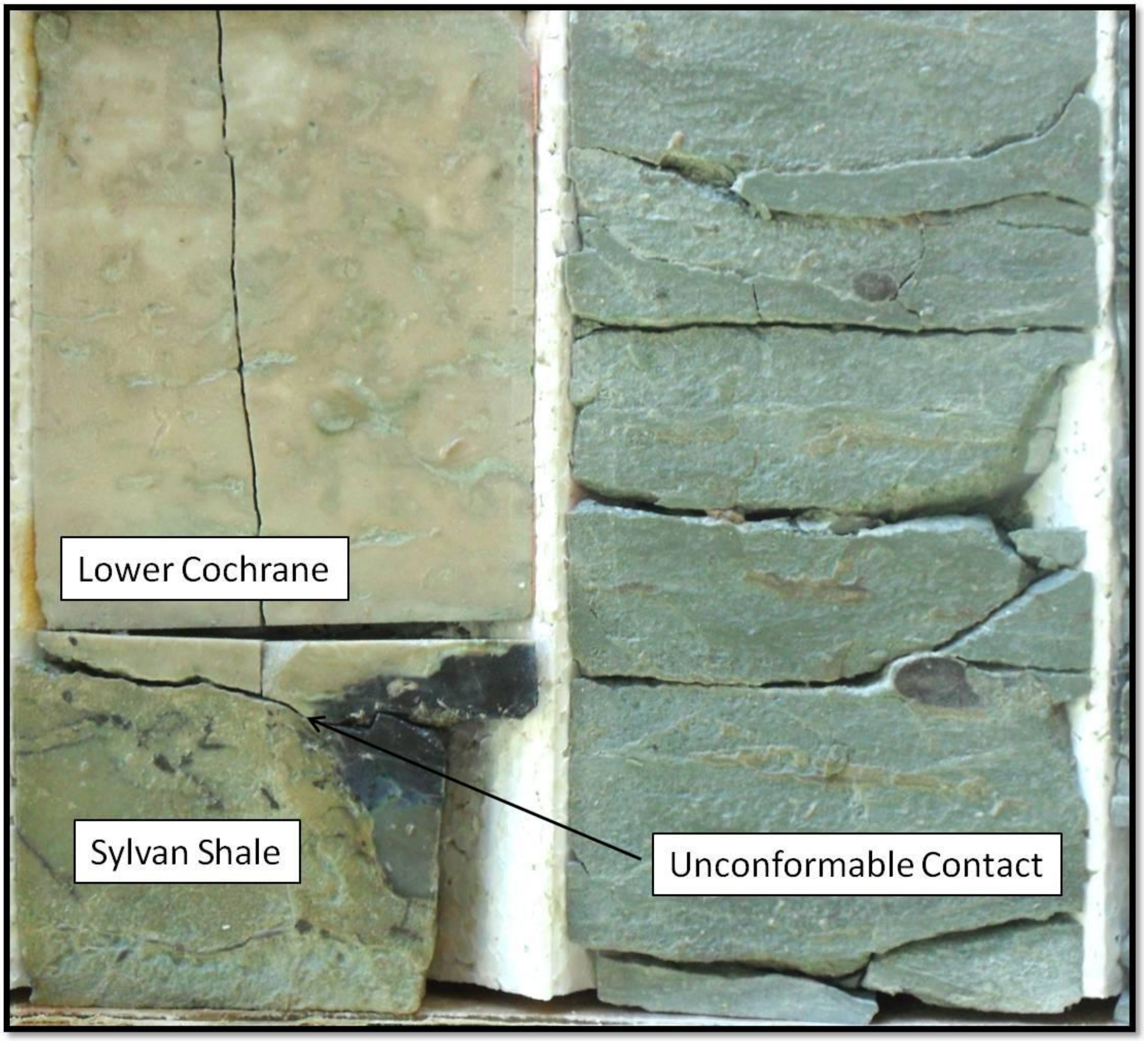


Fig. 9. Cal 1-11; Contact between Lower Cochrane and Sylvan Shale at 1565.2 m. There is a chert nodule at the contact.

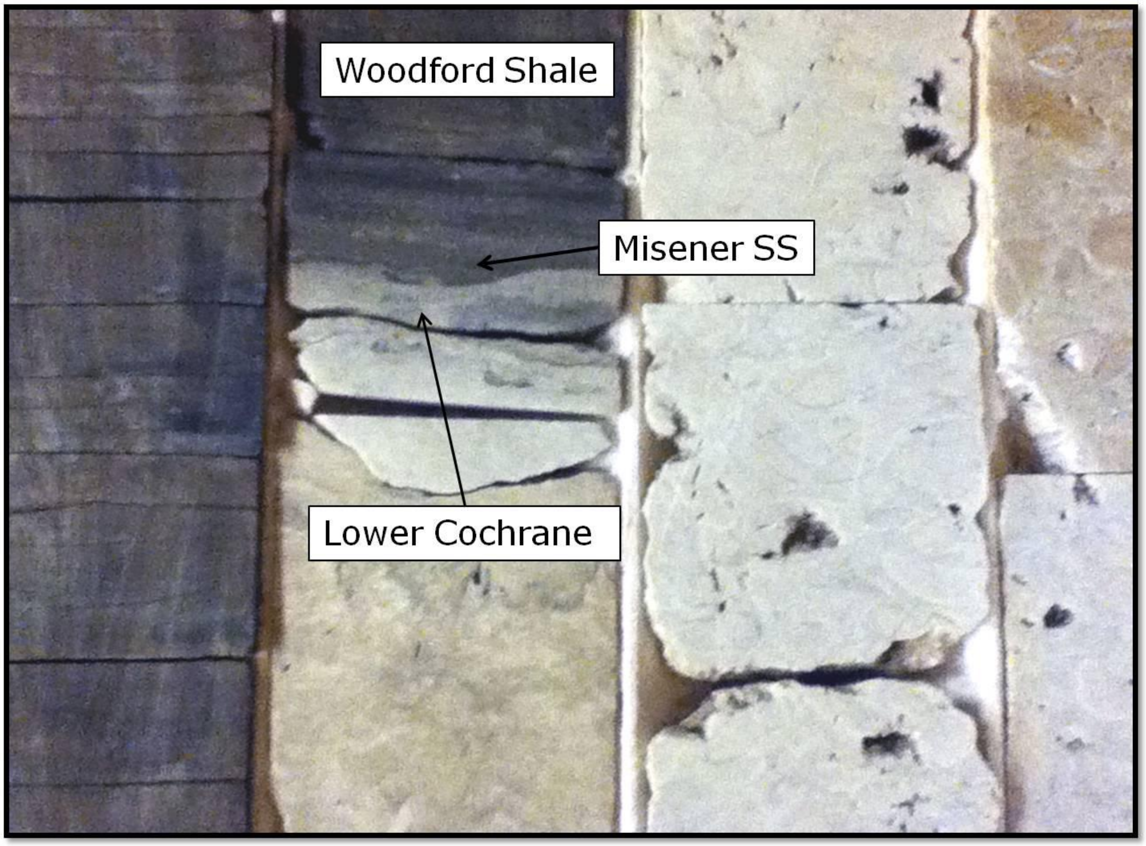


Figure 10. Points 1-13; Contact between the Woodford Shale and the Hunton Group at 1520.8 m. The Woodford shale and Misener sandstone are both Upper Devonian.

Petrography

Observed lithologies of the four cored wells (Cal 1-11, Mark Houser 1-11, JB 1-13, Points 1-13) include coarse brachiopod-crinoid packstones and grainstones with intermixed wackestones (Appendix 3). Sparse fossils throughout include tabulate corals, bryozoa, trilobites (rare) and ostracodes. Facies are not correlatable from well to well. Grain contacts throughout each of the cored wells typically are sutured. Microstylolites and higher amplitude stylolites (1-2 mm) are commonly found.

Porosity types throughout the cored wells include shelter porosity (Fig. 11), vuggy porosity, intergranular, intragranular, fracture, partial dissolution porosity, and sparse growth framework porosity occurring in tabulate corals and bryozoa. Vugs are commonly filled with karst sediment and sparse fine quartz grains from the overlying sediments. Fractures range in size from 0.2 mm to 1.5 mm, and vugs range in size from 1-4 mm, and can be filled with fine quartz grains and silt towards the top of sections. Porosity values determined by point counting ranged from 1-8% throughout the four cored wells. Most porosity is occluded by blocky calcite cement and syntaxial overgrowths on crinoid grains, and the majority of thin sections have porosity values of 1%. Higher porosity values are found in partly dolomitized intervals where pores are better connected (base of M. Houser 1-11), where karst dissolution occurs (Cal 1-11 1534.6 and 1558.7 m), and facies which contain an abundant amount of brachiopod's (Points 1-13 1520.6-1541.1 m). The lower part of the unit becomes muddier and more dolomitic in each of the cores.

Calcite cementation of the four cored wells occurs in intergranular space, fractures, vugs and as syntaxial overgrowths on crinoid grains (Fig. 12). Calcite cement in fractures and intergranular space is composed of medium to coarse (0.5 mm to 3.0 mm) blocky calcite spar cement. The blocky calcite cements commonly exhibit calcite twinning. Boundaries between cement crystals commonly have sharp edges. Brachiopods typically exhibit prismatic layers of radial fibrous cement growing into adjacent porosity. Syntaxial overgrowths on crinoid grains are always followed by blocky calcite cement. Potassium ferricyanide staining was attempted (Friedman, 1959) but none of the calcite cements observed have iron contents high enough to yield a positive stain.

Silica cement occurs in the base of the Cal 1-11 as a later generation of cement. Silica cement occurs as open space filling cement, filling intergranular space. Silica cement is sparse to not absent throughout the other three cores.

Cathodoluminescence (CL) Petrography

The methodology for CL petrography used in this study followed those developed by Meyers (1974). The luminescent character and distribution were recorded using a zone numeric method. Three distinct cathodoluminescence (CL) zones were observed in calcite cements throughout the four cored wells. Their distributions, however, vary from core to core and with stratigraphic position (Fig. 13). The three zones from earliest to latest cement (based off of law of superposition) are: CL Zone 1 (Z1), a non-CL cement, CL Zone 2 (Z2), which includes a thin band of bright-CL followed by a thin non-CL cement, and CL Zone 3 (Z3), multi-banded cement consisting of alternating bright and dull CL bands. Z3 typically is the last generation of cement and occludes the majority of pore space. Samples from the JB 1-13, Points 1-13, and Mark Houser 1-11 exhibit similar cement stratigraphies with the Mark Houser 1-11 being slightly different. This difference will be discussed below. The Cal 1-11 cored well exhibits a different cement stratigraphy than the rest of the cored well with less zoning of cements seen.

Samples from the JB 1-13 and Points 1-13 cores exhibit similar cement zones throughout the whole Lower Cochrane member (Fig. 14). CL Z1 occurs as syntaxial overgrowths on crinoid grains as well as the first generation of open space filling cement where crinoids are not present. CL Z1 is always followed by CL Z2 which primarily occurs only as open space filling cement and not on crinoid substrates. These two zones are followed lastly by Z3 which occludes primary porosity. This same cement stratigraphy is found throughout, from the base to the top of the JB 1-13 and Points 1-13 cores.

In samples from the Mark Houser 1-11 core a mixed cement stratigraphy (Fig. 15) throughout the whole section was observed. The base of the Mark Houser 1-11 exhibits a succession of cement zones similar to that of the JB 1-13 core and Points 1-13 core. CL Z1 and CL Z2 are present as both open space filling cements where pores are not bordered by crinoids, and as syntaxial overgrowths on crinoid grains. Moving up section, however, Z1 and Z2 only occur as syntaxial overgrowths where crinoid grains border pores or other open space, and the bright to dully luminescent mulit-banded CL Z3 becomes dominant.

The Cal 1-11 core exhibits a cement stratigraphy (Fig. 16) similar to that of the upper portion of the Mark Houser 1-11 core. CL Z1 and CL Z2, cements occur only as syntaxial overgrowths in pores that are bordered by crinoid grains. In this core CL Z3 is more abundant as the open space filling and porosity occluding cement from the base of the section to the top.

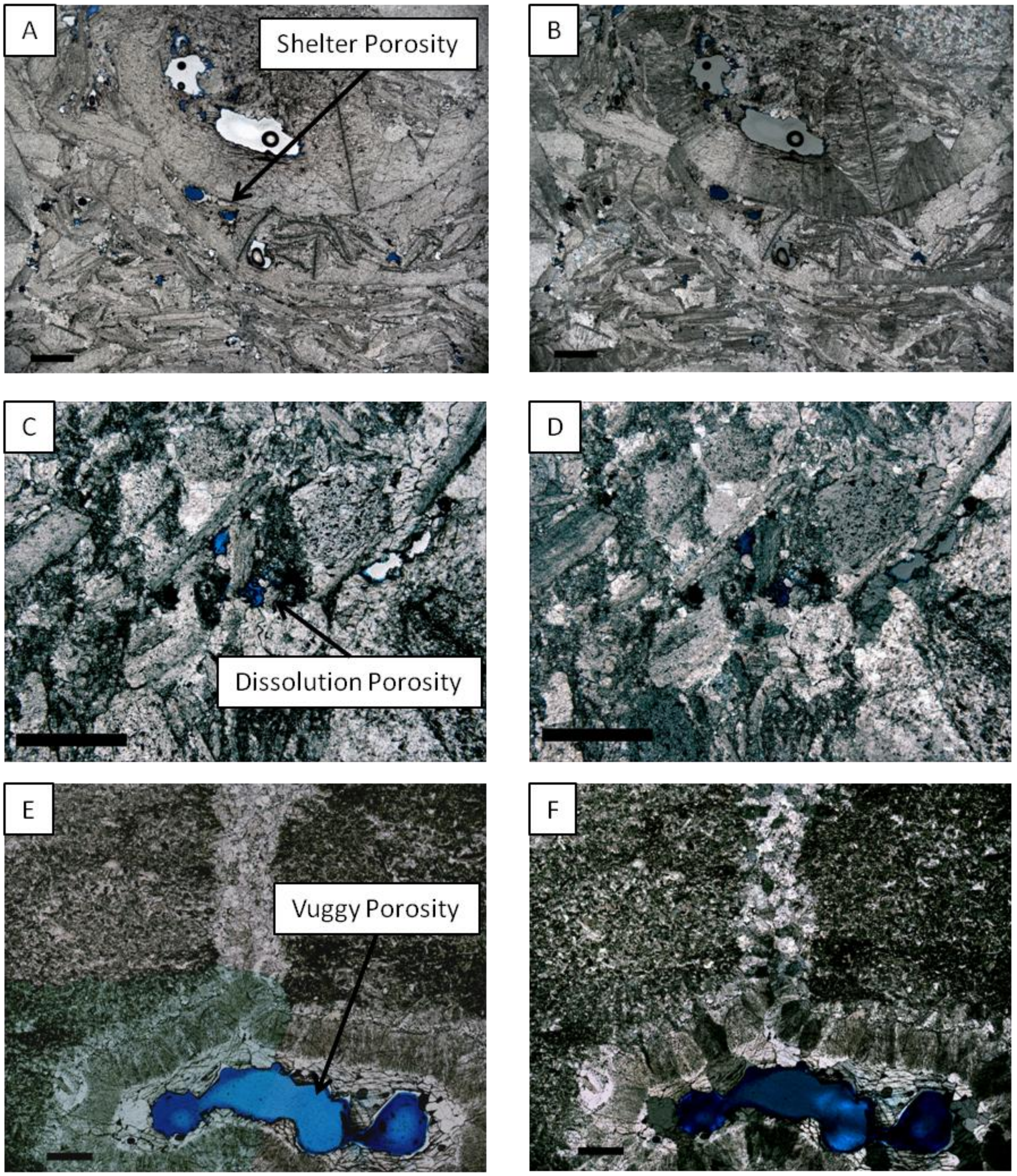


Figure 11. A) Shelter porosity; Cal 1534 plane light (ppl) 2x (scale bar 1mm) B) Cal 1534 2x cross-polarized light (cpl). C) Dissolution porosity; JB 1525 (ppl) 4x (0.5 mm) D) JB 1525(cpl). E) Vuggy porosity; Mark Houser 1546 (ppl) 2x (1mm) F) Mark Houser 1546 (cpl)

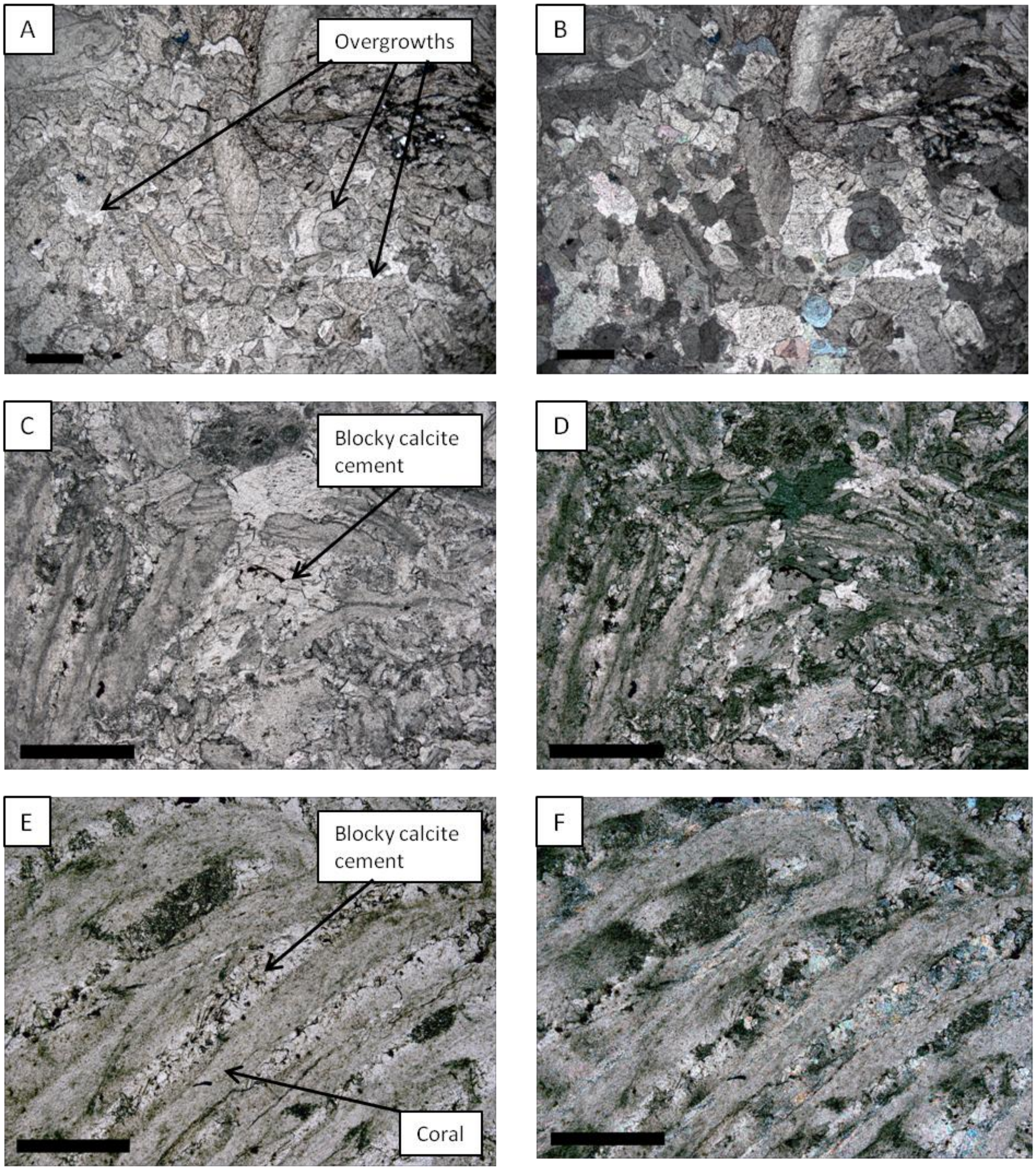


Figure 12. A) Syntaxial overgrowths on crinoid grains; Cal 1541 2x ppl (scale is 1 mm). B) Cal 1541 2x cpl. C) Blocky calcite cement; Cal 1547 4x ppl (scale is 0.5mm), D) Cal 1547 4x cpl. E) Blocky calcite cement filling tabulae of coral; M. Houser 1547.5 2x ppl (1mm), F) M. Houser 1547.5 2x cpl.

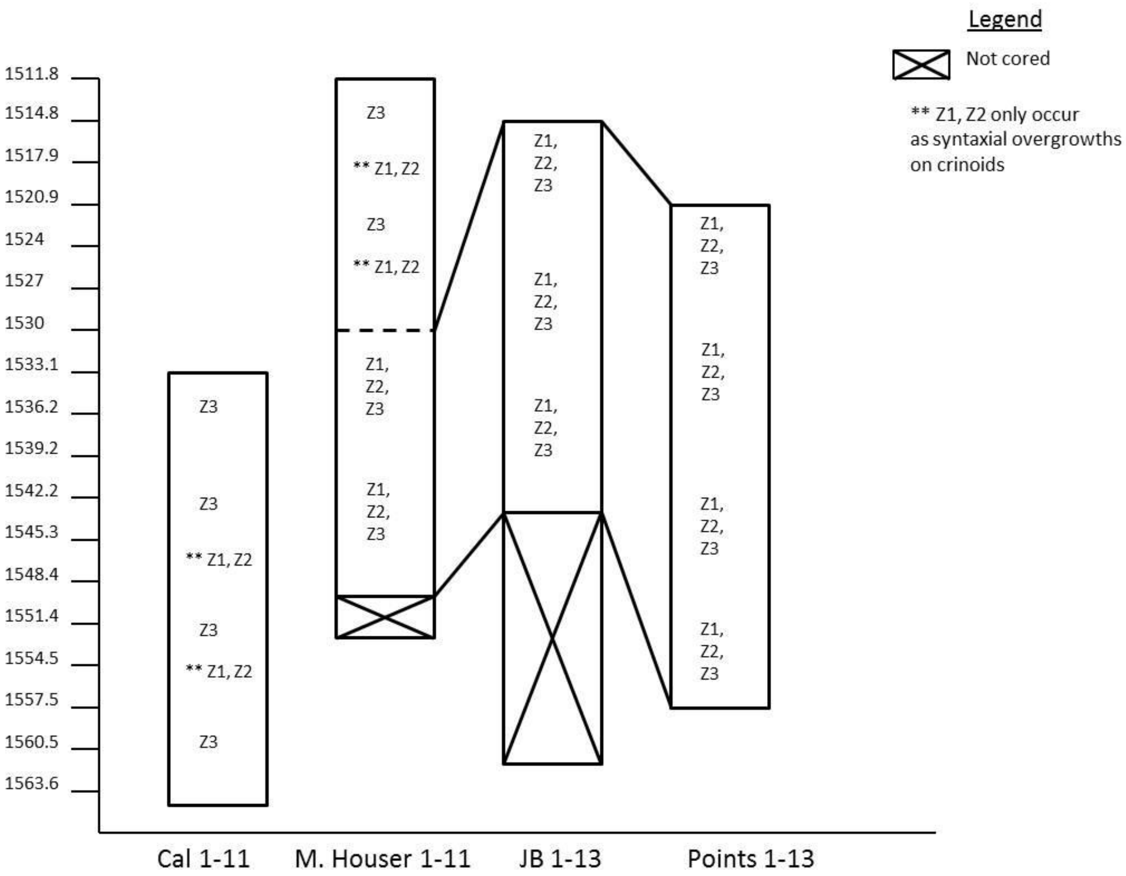


Figure 13. Distribution of CL Zones 1-3 throughout the four cored wells in the study (scale in meters). CL Z1 and Z2 only occur as syntaxial overgrowths on crinoid grains in the Cal 1-11 cored well, and upper portions of Mark Houser 1-11.

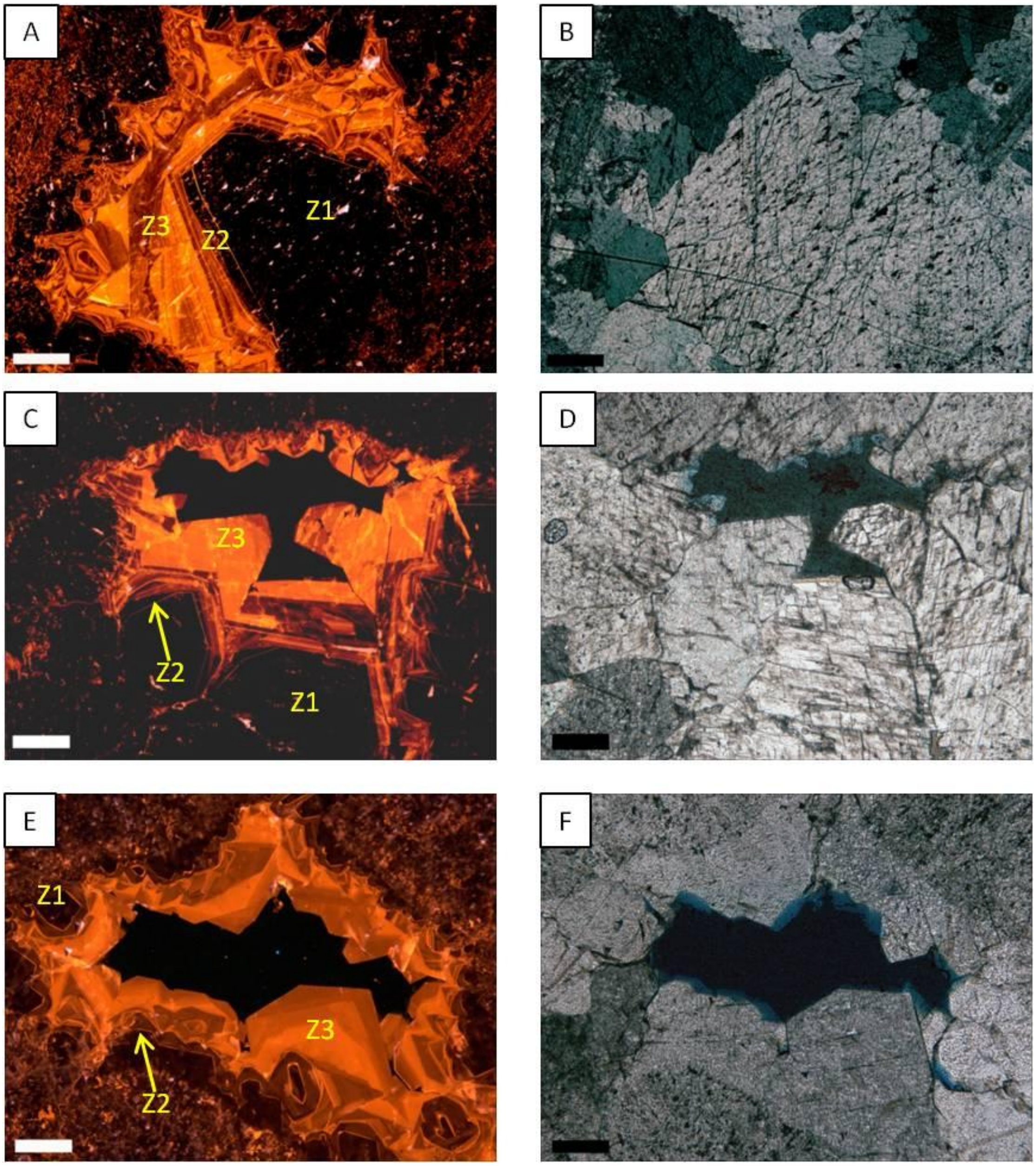


Figure 14. A) Z1-Z3 filling vug; JB 1517 4x CL (scale bar 0.5mm) B) JB 1517 4x cpl C) Z1-Z3 filling vug; JB 1520 10x (bar is 0.2mm) D) JB 1520 4x cpl. E) Z1-Z3 filling vug; Points 1554 10x (bar is 0.2mm) F) Points 1554 10x cpl.

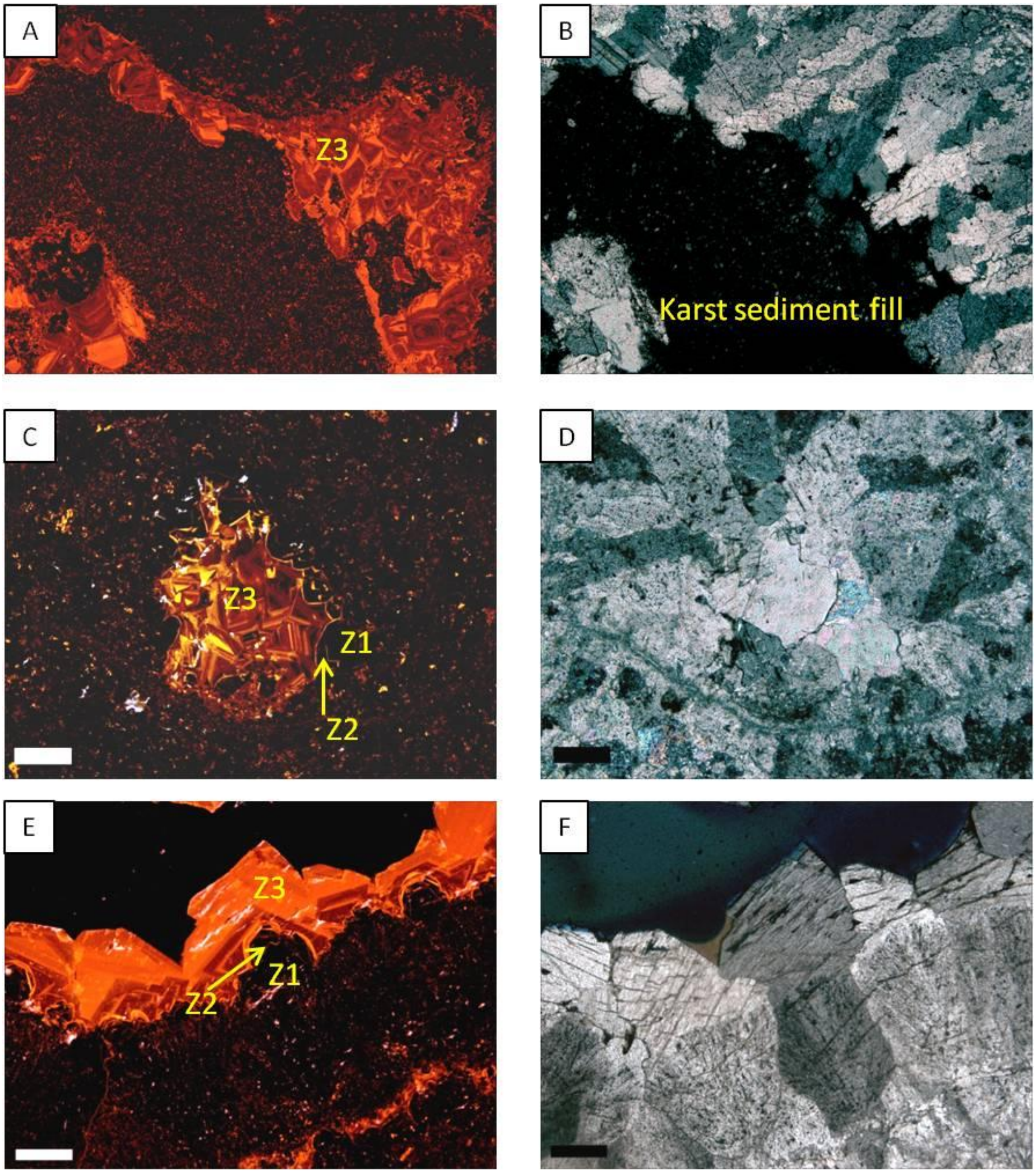


Figure 15. A) Z3 is only open space filling cement, Z1 and Z2 are not present towards top of section; M. Houser 1-11 1512 4x CL (scale is 0.5 mm) B) M. Houser 1512 cpl C) Middle of section Z1, Z2 are now present; M. Houser 1-11 1537 10x CL (scale is 0.2 mm) D) M. Houser 1-11 1537 cpl E) Base of section, Z1 and Z2 are present filling vug porosity; M. Houser 1-11 1546 4x CL F) M. Houser 1-11 1546 cpl.

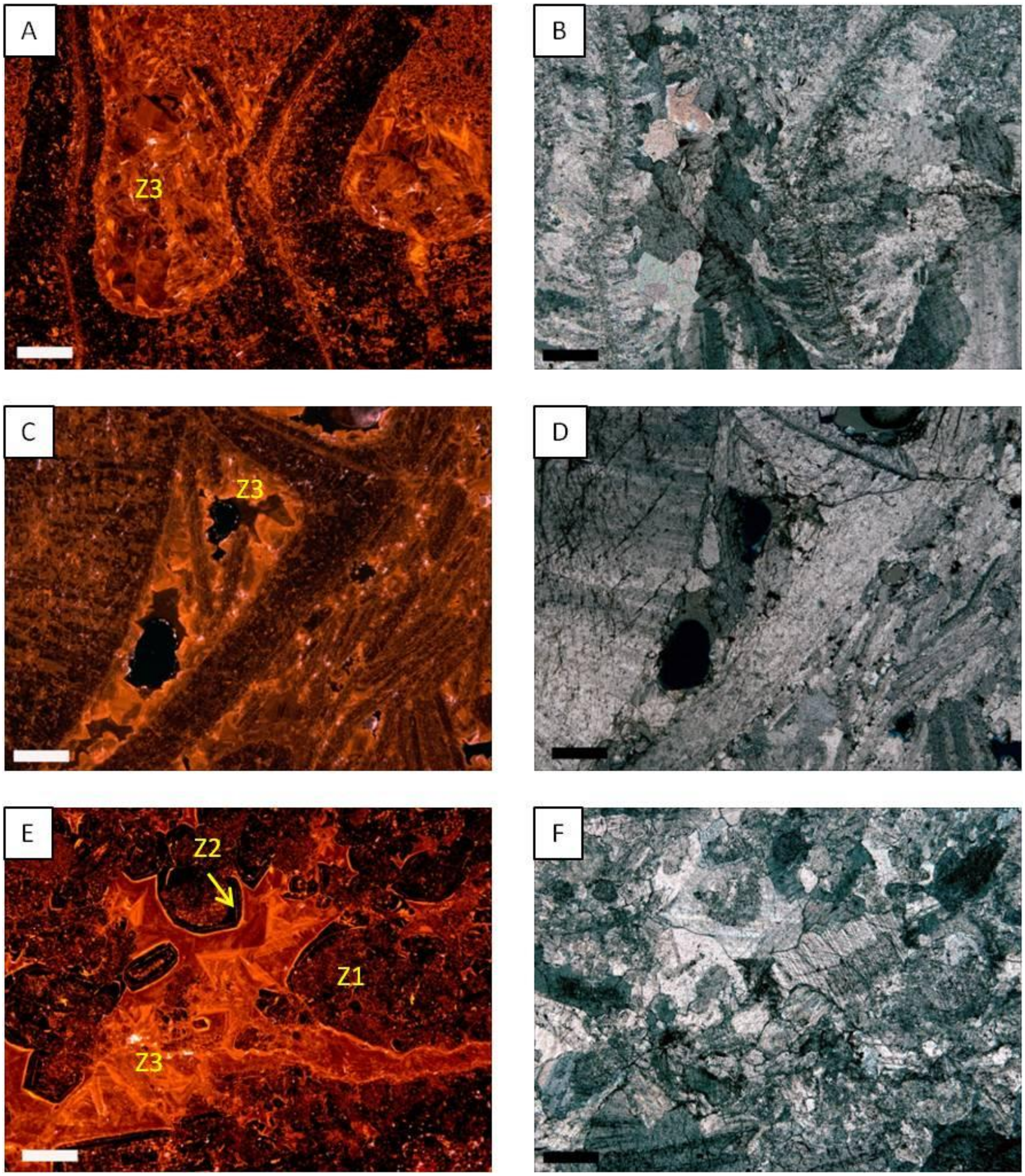


Figure 16. A) Z3 is present filling shelter porosity beneath brachiopod shell, Z1 and Z2 are not present; Cal 1534 4x (scale is 0.5mm) B) Cal 1534 4x cpl. C) Z3 is present filling shelter porosity ; Cal 1534.6 4x (scale is 0.5mm) D) Cal 1534.6 4x cpl. E) Z1 and Z2 are present as overgrowths on crinoids, Z3 as filling open space ;Cal 1552 4x CL (0.5mm scale) F) Cal 1552 4x cpl.

Carbon and Oxygen Isotopes

Ten brachiopods were sampled for carbon and oxygen isotope analysis in order to establish an isotopic value for Silurian seawater. Samples were taken every three meters from top to base of the Points 1-13 core. Prior to sampling, brachiopods were observed using CL to assure that they were not diagenetically altered. Brachiopod samples display $\delta^{13}C$ values of -0.8‰ to 1.9‰ VPDB and $\delta^{18}O$ values of -5.2‰ to -3.6‰ VPDB (Fig. 17). The average $\delta^{13}C$ for the brachiopod samples is 0.8‰ VPDB s.d. (standard deviation) = 0.8‰, and the average $\delta^{18}O$ value is -4.2‰ VPDB s.d.= 0.4‰ (Table 1).

Samples of calcite cement for C and O isotope analysis were selected using CL images in conjunction with the billets from which the thin sections were cut and then were drilled out by hand. An attempt was made to separate early (inner) and later (outer) calcite cements zones during drilling. Inner zone calcite cements (Z1, Z2) were sampled from the Mark Houser 1-11, JB 1-13, and Points 1-13 cored wells (Fig. 14). Outer zones of calcite cements (Z3), the more brightly luminescent cements, were sampled from the Mark Houser 1-11, JB 1-13, Cal 1-11, and the Points 1-13 cored wells. The inner zoned calcite cements display $\delta^{13}C$ values of -4.7‰ to 1.8‰ VPDB and $\delta^{18}O$ values of -5.8‰ to -2.8‰ VPDB. The average $\delta^{13}C$ value for the inner zoned calcite cements is 0.2‰ VPDB s.d.= 2.3‰, and the average $\delta^{18}O$ value is -4.4‰ VPDB s.d.= 1.0‰ (Table 2). The outer zones of calcite cements display $\delta^{13}C$ values of -2.3‰ to 2.1‰ VPDB and $\delta^{18}O$ values of -7.8‰ to -2.4‰ VPDB. The average $\delta^{13}C$ value for these calcite cements is -0.3‰ VPDB s.d.=1.7‰, and the average $\delta^{18}O$ value is -5.4‰ VPDB s.d=1.9‰.

Crinoid fragments were sampled from the JB 1-13 and the Points 1-13 cored wells. The crinoid grains display $\delta^{13}C$ values of 0.9‰ to 3.5‰ VPDB and $\delta^{18}O$ values of -4.6‰ to -2.8‰ VPDB. The average $\delta^{13}C$ value for the crinoid grains is 1.7‰ VPDB s.d.= 0.7‰, and the average $\delta^{18}O$ value is -3.9‰ VPDB s.d.= 0.6‰. Crinoid grains are typically composed of high-Mg calcite which is more susceptible to diagenetic alterations, therefore should reflect early diagenetic environments.

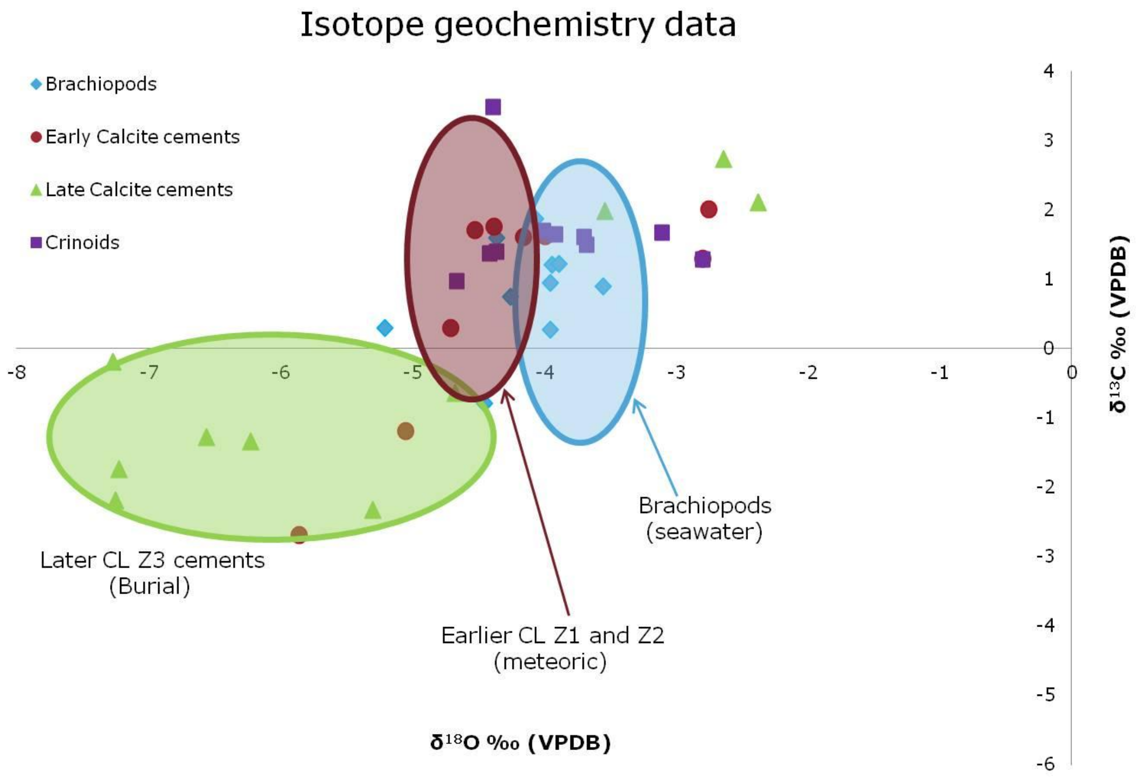
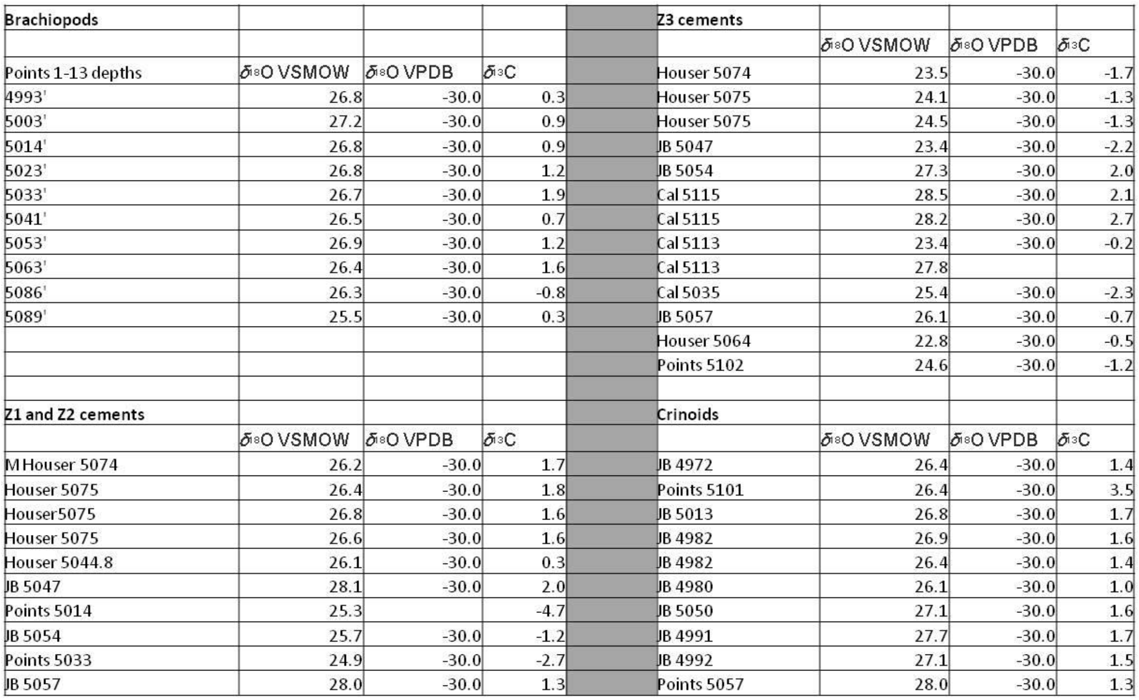
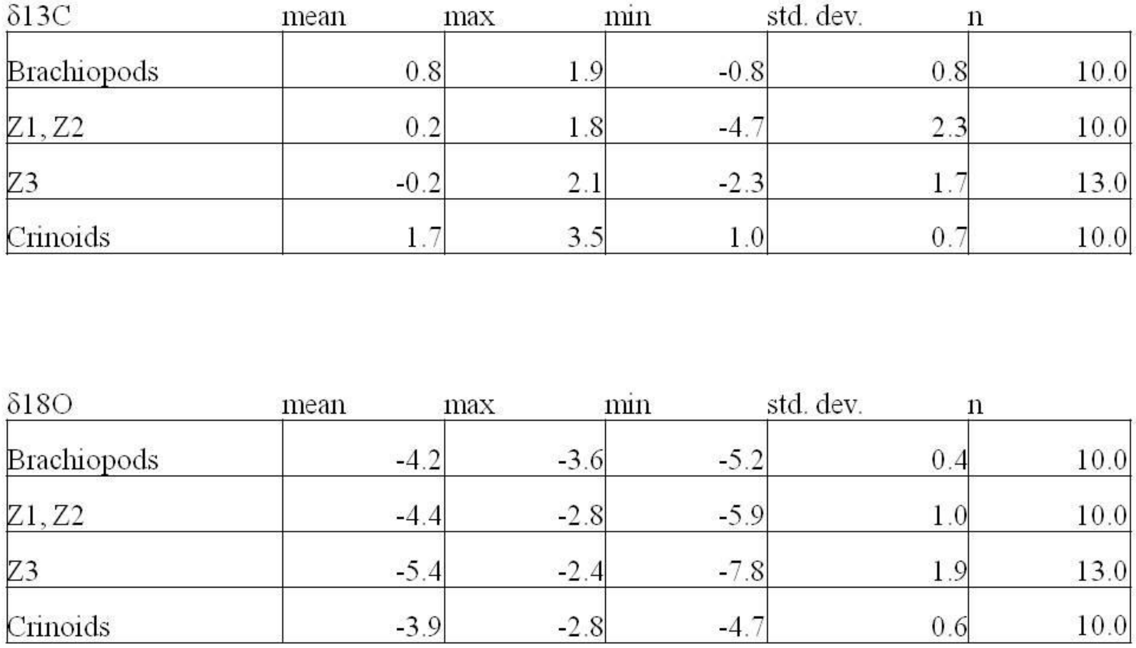


Figure 17. δ^{13}C versus δ^{18}O for the brachiopod, zoned calcite cements, and crinoid grains. Late calcite cements (Z3) overall trend is depleted in both δ^{13}C and δ^{18}O with respect to the brachiopod samples. Early calcite cements (Z1, Z2) have an overall trend that plots slightly depleted in δ^{18}O values compared to the brachiopods. The two values from the late calcite cements and one from the earlier calcite cements that plot heavier in δ^{18}O and δ^{13}C may have been precipitated in evaporitic environments. However, no evidence of evaporites were found in thin section.



Brachiopods					**Z3 cements**			
						δ^{18}O VSMOW	δ^{18}O VPDB	δ^{13}C
Points 1-13 depths	δ^{18}O VSMOW	δ^{18}O VPDB	δ^{13}C		Houser 5074	23.5	-30.0	-1.7
4993'	26.8	-30.0	0.3		Houser 5075	24.1	-30.0	-1.3
5003'	27.2	-30.0	0.9		Houser 5075	24.5	-30.0	-1.3
5014'	26.8	-30.0	0.9		JB 5047	23.4	-30.0	-2.2
5023'	26.8	-30.0	1.2		JB 5054	27.3	-30.0	2.0
5033'	26.7	-30.0	1.9		Cal 5115	28.5	-30.0	2.1
5041'	26.5	-30.0	0.7		Cal 5115	28.2	-30.0	2.7
5053'	26.9	-30.0	1.2		Cal 5113	23.4	-30.0	-0.2
5063'	26.4	-30.0	1.6		Cal 5113	27.8		
5086'	26.3	-30.0	-0.8		Cal 5035	25.4	-30.0	-2.3
5089'	25.5	-30.0	0.3		JB 5057	26.1	-30.0	-0.7
					Houser 5064	22.8	-30.0	-0.5
					Points 5102	24.6	-30.0	-1.2
Z1 and Z2 cements					**Crinoids**			
	δ^{18}O VSMOW	δ^{18}O VPDB	δ^{13}C			δ^{18}O VSMOW	δ^{18}O VPDB	δ^{13}C
M Houser 5074	26.2	-30.0	1.7		JB 4972	26.4	-30.0	1.4
Houser 5075	26.4	-30.0	1.8		Points 5101	26.4	-30.0	3.5
Houser5075	26.8	-30.0	1.6		JB 5013	26.8	-30.0	1.7
Houser 5075	26.6	-30.0	1.6		JB 4982	26.9	-30.0	1.6
Houser 5044.8	26.1	-30.0	0.3		JB 4982	26.4	-30.0	1.4
JB 5047	28.1	-30.0	2.0		JB 4980	26.1	-30.0	1.0
Points 5014	25.3		-4.7		JB 5050	27.1	-30.0	1.6
JB 5054	25.7	-30.0	-1.2		JB 4991	27.7	-30.0	1.7
Points 5033	24.9	-30.0	-2.7		JB 4992	27.1	-30.0	1.5
JB 5057	28.0	-30.0	1.3		Points 5057	28.0	-30.0	1.3

Table 1. Stable isotopic values by depth. δ^{18}O VSMOW (Vienna Standard Mean Ocean Water) is a water standard defining the isotopic composition of fresh water. δ^{18}O VPDB is another standard based on a fossil Belemnite shell from the Peedee Formation (Upper Cretaceous). These are the references against which all δ^{13}C measurements and carbonate-δ^{18}O are reported.



δ13C	mean	max	min	std. dev.	n
Brachiopods	0.8	1.9	-0.8	0.8	10.0
Z1, Z2	0.2	1.8	-4.7	2.3	10.0
Z3	-0.2	2.1	-2.3	1.7	13.0
Crinoids	1.7	3.5	1.0	0.7	10.0

δ18O	mean	max	min	std. dev.	n
Brachiopods	-4.2	-3.6	-5.2	0.4	10.0
Z1, Z2	-4.4	-2.8	-5.9	1.0	10.0
Z3	-5.4	-2.4	-7.8	1.9	13.0
Crinoids	-3.9	-2.8	-4.7	0.6	10.0

Table 2. Summary of stable-isotope analysis of brachiopods, zoned calcite cements, and crinoid grains.

Core Analysis

The average porosity and permeability values (Appendix 3) for the four cored wells are: Points 1-11 core has an average porosity of 3.2% and permeability average of 96.5 k90 md, the JB 1-13 core has an average porosity of 1.8% and permeability average of 0.47 k90 md, the Mark Houser 1-13 core has an average porosity of 1.3% and an average permeability of 0.32 k90 md, and the Cal 1-11 core has an average porosity of 1.2% and average permeability of 96.72 kmax md. The Points 1-11 core displays excellent porosity values (4-9%) from 1520-1540 m which comprised primarily of a brachiopod packstone, and may have been a brachiopod bioherm.

CHAPTER V

DISCUSSION

Sedimentation

The informal Lower Cochrane member, of the Chimneyhill Subgroup, was deposited in a warm, subtidal, shallow epicontinental sea based off of benthic assemblages (Derby et al., 2002b). Brachiopod and crinoid packstones and grainstones are the most common lithology found in the Lower Cochrane. Brachiopod assemblages are typically deposited in 60-90 m water depth, whereas crinoids are deposited in 10-30 m of water (Johnson, 1987). Facies distribution between the four cored wells is relatively heterogeneous. This could be because of stratigraphic position during deposition, and or preferential erosion post Lower Cochrane deposition. The only facies correlatable throughout the area is a basal dolomitized wackestone (Fig. 9).

Cathodoluminescence

Cathodoluminescence (CL) petrography can be used for local and regional mapping, as well as the interpretation of the timing of different cement zones relative to unconformities (Meyers, 1991). CL has been used to develop calcite and dolomite cement stratigrahies with relative success in understanding paragenetic sequences and timing of diagenetic events. Zoning of carbonate cements is caused by variations in concentrations of trace elements, and abundance of inclusions (Meyers, and Lohman 1985). It is inferred that calcite zones are time representative and calcite closer to the substrate would be interpreted as being older than those which come after (Meyers, 1991).

A common order of calcite cement events observed in the Mississippian Lake Valley Formation, New Mexico (Meyers, 1991) includes older banded cement, represented by non-CL zones separated by a thin CL zone, which is then overgrown by a dull to brightly CL sequence which may be broadly zoned or unzoned. The older non-CL sequence is primarily low in Fe where the younger CL zones are enriched in Fe (Meyers, 1991). The CL stratigraphy observed in the Lower Cochrane in interpreted here as following this pattern. CL zone 1 and zone 2 correspond to the older banded cement (non-CL) followed by a thin CL interval, that is subsequently followed a broadly zoned CL sequence CL zone 3. The transition from the older non-CL banded cements to the younger CL cements reflects a change in diagenetic environments, typically from near-surface to a deeper burial environment as suggested by (Meyers, 1991) for the Mississippi Lake Valley Formation.

Calcite cementation

No meniscus cements or microstalactitic cements are observed in any of the wells examined in this study to indicate exposure to a vadose environment. Therefore the four cored wells were either subjected only to meteoric phreatic or marine phreatic environments, which typically produce blocky calcite cement. All of the calcite cement observed is blocky calcite cement, and no evidence for early marine calcite cementation is observed.

Brachiopod $\delta^{18}O$ values range from -5.2‰ to -3.5‰ VPDB and $\delta^{13}C$ values range from -0.8‰ to 1.9‰ VPDB, with average values of $\delta^{18}O$ = -4.2‰ VPDB s.d.=0.4‰, and $\delta^{13}C$= 0.8‰ VPDB s.d.=0.8‰. These values may have been affected by glaciation taking place during early- middle Llandovery and latest Aeronian (middle Llandovery). Higher $\delta^{18}O$ values are assigned to colder temperatures, and lower $\delta^{18}O$ values are assigned to warmer temperatures (Azmy et al., 1998). Brachiopods are originally composed of low-Mg calcite, which is typically the most diagenetically stable form of calcium carbonate (Bathurst, 1975). Therefore it is inferred that brachiopods will be the least altered by later diagenetic effects and will reflect the isotopic compositions of the sea water from which they precipitated (Rush et al, 1990). Comparing the isotopic values of various calcite cement zones to the brachiopod samples collected from the same unit allows a determination of the isotopic variation of diagenetic fluids from seawater. The isotopic values of CL zones 1 and 2 indicate precipitation by meteoric or mixed meteoric and sea water, where CL zone 3 likely indicates precipitation by deeper burial fluids.

There are two samples from the later calcite cements (Z3) and one sample from the earlier calcite cements (Z1, Z2) that plot heavier in both $\delta^{18}O$ and $\delta^{13}C$ compared to the brachiopods isotopic signature. These samples may have been by local evaporitic environments in which ^{18}O would be more concentrated. However, no evidence of evaporites were found in thin section and samples are not stratigraphically or depositionally related.

CL Z1 and Z2 calcite cement interpretation

Based on isotopic data and petrology CL Z1 and Z2 cements likely were precipitated in a meteroic phreatic (saturated) environment. The $\delta^{18}O$ values for Z1 and Z2 cements range from -5.9‰ to -2.8‰ and have an average of -4.4‰ s.d.=1.0‰, (Table 2) which is slightly depleted compared to the average -4.2‰ VPDB s.d.=0.4‰ of the brachiopods (Fig. 17). The $\delta^{13}C$ values of Z1 and Z2 cements range from -4.7‰ to 1.8‰ and have an average of 0.2‰ VPDB s.d.=2.3‰, which is slightly depleted compared to 0.8‰ of the brachiopods. These zones are more in abundance in the Points 1-13, JB 1-13 and upper portions of the Mark Houser 1-11 cored wells as compared to the Cal 1-11 cored well. Stratigraphically the Cal 1-11 well (Fig. 18) is down-dip from these wells and may not have been exposed to the meteoric waters for as long of a period. As sea level falls, there typically is greater dissolution of marine carbonates and subsequently more precipitation of meteoric carbonate cements up dip due to longer exposure to meteoric waters (Carlson et al., 2003).

CL Z1 and Z2 are non-CL, and lack the “blotchy” CL that is typical of ancient marine cements as noted by Kaufman et al., 1988. Brachiopod’s from the four cored wells displayed a “blotchy” CL, evidence of a marine origin and unaltered. Reduced manganese and iron contents would quench CL, further evidence for more oxidizing conditions, typical of a meteoric phreatic environment (Kaufman et al., 1988). These non-CL zones possibly represent small scale lenses of meteoric water, which were established post deposition, beneath subaerial exposure horizons. Glaciation effects may have caused the meteoric lens to drop as well causing the precipitation of these non-CL zones. The thin CL interval between CL Z1 and Z2 may represent the reduced downflow recharge meteoric waters, in which Mn^{2+} is more abundant (Meyers, 1991). These fluctuations in the meteoric lens ultimately add cement to older zones moving up in section, which in return destroys primary porosity.

The Mark Houser 1-11 cored well displays decreasing Z1 and Z2 calcite cements moving up section. This could be explained by the observed abundance of karst sediment which filled fractures and vugs, making the limestone more argillaceous. This likely resulted in more reducing conditions, and greater abundance of the bright CL cements. This decrease in non-CL zones moving up in sections was also observed in the Burlington-Keokuk Formation by Kaufman et al., 1988. CL Z1, Z2 and Z3 are present in the rocks that are found in the cave fill from 1542.6-1546 m providing evidence for karsting having occurred prior to cementation. Cements present within the cave fill display the concentric zoning found within the rest of the formation, therefore karsting and cave fill may have come prior to cementation.

CL Z3 calcite cement interpretation

CL Z3 is present in all of the four cored wells in the study area, and is the last generation of calcite cement. The $\delta^{18}O$ values for Z3 cements range in value from -7.8‰ to -2.4‰ and have an average of -5.4‰ VPDB s.d.=1.9‰, which is depleted compared to the -4.2‰ VPDB ±0.4‰ of the brachiopods and the average $\delta^{18}O$ values for Z1 and Z2 cements. The $\delta^{13}C$ values for Z3 cements range in value from -2.3‰ to 2.1‰ and have an average of -0.3‰ VPDB s.d.=1.7‰, which also is depleted compared to 0.8‰ VPDB ±0.8‰ of the brachiopods.

For the $\delta^{13}C$ value to be depleted the rocks may have been buried deeper than the zone of bacterial sulfate reduction (> 60° C). The WCHF, during Hunton deposition, was on the northeast flank of the Paleozoic Oklahoma basin (Derby et al., 2002a), and was later uplifted during the Pennsylvanian. Prior to that uplift the area may have been subjected to moderate burial temperatures between 60° and 100°C.

Assuming a value of -3.5‰ SMOW for warmer Silurian seawater and a value of -2.5‰ SMOW (Azmy et al., 1998) for cooler temperatures during Silurian glacial episodes, and using Friedman and O'Neill's (1977) equations CL Z3 cements may have been precipitated from 42° C to 66°C. The higher temperature (66°C) may be the more realistic temperature from which the CL Z3 cements precipitated, and a burial environment could be assumed. These calculations are based off of +0‰ and +4‰ VSMOW respectively assuming they were precipitated in a burial environment, which would be needed to have the -5‰ to -7‰ VPDB values displayed by these cements. If these cements were precipitated in a burial environment, the assumption that they have the same isotopic composition of Early Silurian seawater would be wrong. Without fluid inclusion data for CL Z3 cements, there is some uncertainty to these values. CL Z3 is present throughout all of the four cored wells from the base of the cores to the top of the cores meaning they may have all been subjected to the same type of diagenetic environment. A burial environment interpretation for these cements would seem reasonable given that a burial environment would subject the same diagenetic alterations to all of the cores at relatively the same time.

Porosity and Permeability

Secondary porosity, primarily vuggy porosity, is observed from the base of the Lower Cochrane to top in both the JB 1-13, and Points 1-13 wells, and is found throughout the lower half of the Mark Houser 1-11 well. Karst features such as vugs, as well as fractures will enhance porosity and permeability however; calcite precipitation will occlude primary porosity (Rechlin, 2005). More early meteoric calcite cementation is present up-dip closer to exposure surfaces; therefore more primary porosity is likely to be occluded in up-dip settings (Carlson et al, 2003).

There is more interparticle porosity within the Cal 1-11 well (Appendix 1), than the other three. The JB 1-13, Points 1-13 and Mark Houser 1-11 cored wells are located structurally up-dip from the Cal 1-11, and would have been proximal to the exposure surface where carbonate minerals would be more readily dissolved by meteoric waters. Therefore, the Cal 1-11 may not have as much enhanced secondary porosity, but preserves more primary porosity than the other cored wells due to its less abundance of concentrically zoned calcite cements (CL Z1 and Z2). Comparing observations made by Carlson et al. 2003 in the Carboniferous Lisburne Group of Alaska, the Cal 1-11 would have had a decreased time of exposure, being more down-dip, therefore less meteoric calcite cements precipitated in its pores and more primary porosity is preserved.

Lithological controls on porosity and permeability are important in porosity development within the WCHF. The Points 1-13 cored well displays the highest porosity values (Appendix 3) from the interval 1521-1541 m (4-9%). This whole interval's lithology includes a brachiopod packstone, and may have been a brachiopod bioherm. Shelter porosity is created beneath brachiopod shells, vugs are more abundant and fractures connect these pores to create better permeability (Fig. 19). Intervals in which crinoid grains are more prevalent tend to have depleted porosity values (1-2%) due to syntaxial cement overgrowths.

At least two major glaciations periods occurred during the deposition of the Lower Cochrane. These glaciations periods occurred during the early Aeronian and late Aeronian respectively (Azmy et al., 1998) and caused sea level falls, which in turn likely caused the meteoric and sea water contact to drop as well. The lowering of the meteoric lenses would create a mixing zone lower in section and the precipitation of more meteoric calcite cements. Glacial episodes may affect porosity and permeability by the apparent precipitation of more meteoric calcite cements.

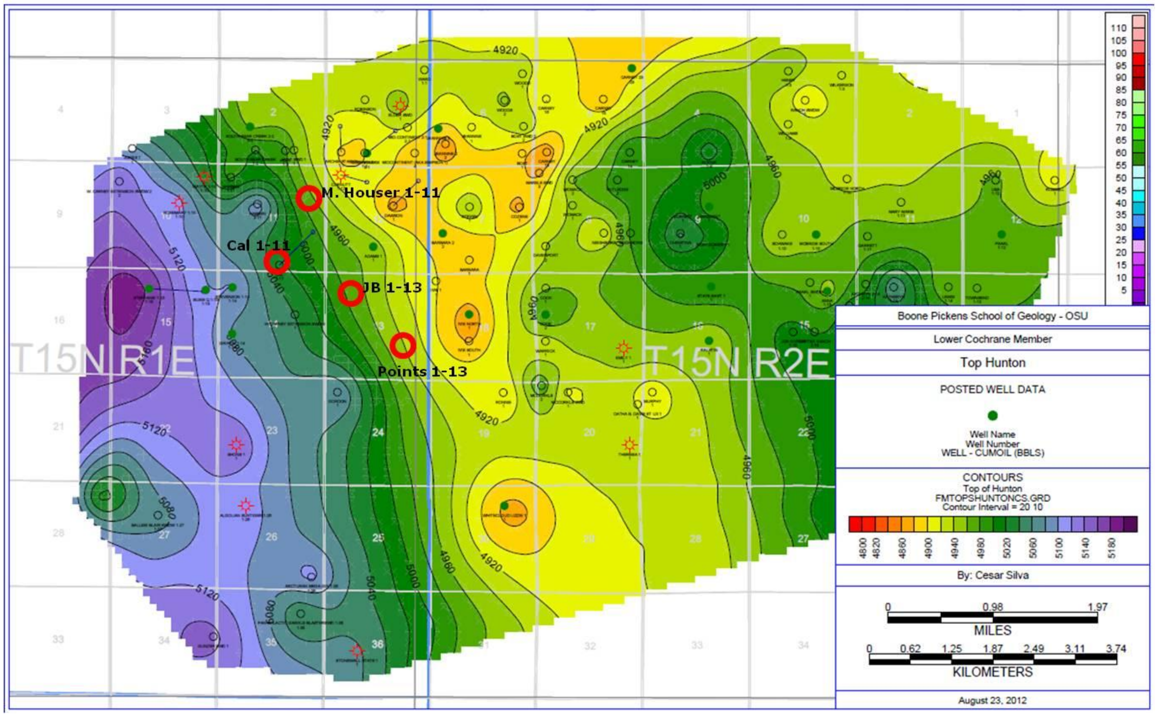


Figure 18. Structure map of Lower Cochrane “member”. Lighter colors represent stratigraphically higher areas, and darker colors to the west represent stratigraphically lower areas (Cal 1-11). Location of four cored wells indicated by red circles. Modified from Silva, 2012.

Figure 19. Brachiopod packstone (bioherm) with well developed shelter & vuggy porosity. Lower Cochrane limestone, Marjo Operating Co., Points 1-13 well. Depth from 1563-1564.8 m.

CHAPTER VI

CONCLUSIONS

Based upon the research conducted by using core descriptions, petrography, and core analysis the following conclusions are proposed. There is also a recommendation for future work.

1. JB 1-13, Points 1-13, and Mark Houser 1-11 are structurally up-dip from the Cal 1-11 and display more concentric zones of calcite cement (non-cathodoluminescent intervals). CL Zones Z1 and Z2 exhibit δ^{18}O and δ^{13}C values that are slightly depleted compared to seawater. CL Z1 and Z2 are interpreted to represent small scale meteoric lenses which were established post deposition beneath subaerial exposures. The sequence of non-CL calcite cements may have resulted from the superposition of these meteoric lenses moving up in the section, adding cement to older zones.
2. CL Z3, a brightly banded cathodoluminescent zone occurs in all four of the cored wells as open space filling cement. These cements display δ^{18}O and δ^{13}C values that are significantly depleted compared to seawater. These cements likely precipitated deeper than the zone of bacterial sulfate reduction (> 60° C) as indicated by their depleted δ^{18}O and δ^{13}C values.

3. Secondary porosity and permeability are enhanced up-dip closer to exposure surfaces. However, primary porosity is better preserved down-dip from exposure surfaces due to less concentric zones of calcite cement. Therefore, it is not always best to drill carbonate reservoirs in locations interpreted as being closer to exposure surfaces, and the diagenetic history needs to be taken into consideration.
4. Final porosity and permeability is more lithologically controlled than diagenetically controlled in the WCHF, and facies that contain more brachiopod fragments may represent better reservoir rock.
5. Recommendations for future work include obtaining fluid inclusion data from the calcite cements in order to understand the isotopic signatures of the fluids which precipitated them. By obtaining this data, one could better calculate the temperatures at which the calcite cement zones were precipitated.

REFERENCES

AMIEUX, P., Bernier, P., Dalongeville, R., and Medwecki, V., 1989, Cathodoluminescence of carbonate-cemented Holocene beachrock from the Togo coastline (West Africa): an approach to early diagenesis, *Sedimentary Geology*, 65, p. 261-272.

AMSDEN, T.W., 1975, Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Anadarko Basin of Oklahoma: *Oklahoma Geological Survey Bulletin* 121, 214 p., 15 pl.

AZMY, K., Veizer, J., Bassett, M.G., and Copper, P., 1998, Oxygen and carbon isotopic composition of Silurian brachiopods: Implications for coeval seawater and glaciations: GSA Bulletin, v. 110, n. 11, p. 1499-1512.

BADER, J.D., 2007, Telchian (Llandovery, Silurian) Conodonts from the Chimneyhill Subgroup, West Carney Hunton Field, North Central Oklahoma, Master's Thesis, Texas Tech University, Lubbock, Texas, 92 p.

BATHURST, R.G.C., 1975, Carbonate Sediments and their Diagenesis. Amsterdam, Elsevier Scientific Publishing Co., 658 p.

BRAIMOH, K.A., 2010, Deepwater, Shoalwater, and Lagoonal Facies in the Silurian Upper Cochrane Member, Hunton Group, Chimneyhill Subgroup, West Carney Hunton Field, Oklahoma, Master's thesis, University of Tulsa, Tulsa, Oklahoma, 150 p.

CALNER, M. 2008, Silurian global events- at the tipping point of climate change. In: Ashraf M.T. Elesa (ed.): Mass Extinctions, pp. 21-58, Springer-Verlag. Berlin and Heidelberg.

CARLSON, R.C., Goldstein, R.H., and Enos, P., 2003, Effects of subaerial Exposure on Porosity Evolution in the Carboniferous Lisburne Group, Northeastern Brooks Range, Alaska, U.S.A, SEPM Special Publications n. 78 and AAPG Memoir 83.

CRAMER, B.D, and Saltzman, M.R., 2007, Fluctuations in epeiric sea carbonate production during Silurian positive carbon isotope excursions: A review of proposed palaeoceanogaphic models, *Palaeogeography, Palaeoclimatology, Palaeoecology* 245, p. 37-45.

DERBY, J.R., Podpechan, J.F., Andrews, J., and Ramakrishna, S., 2002, U.S. DOE-Sponsored Study of West Carney Hunton Field, Lincoln and Logan Counties, Oklahoma: A Preliminary Report (Part II, Conclusion), *Shale Shaker* v. 53, n. 2, September-October 2002.

DUNHAM, R.J., 1962, "Classification of carbonate rocks according to depositional texture".

FRANK, T.D., Lohmann, K.C., and Meyers, W.J., 1995, Chronostratigraphic significance of cathodoluminescence zoning in syntaxial cement: Mississippian Lake Valley Formation, New Mexico, *Sedimentary Geology* 105, p. 29-50.

FRIEDMAN, I., and O'Neil, J.R., 1977, Compilation of stable isotope fractionation factors of geochemical interest, Data of Geochemistry, U.S. Geological Survey, Prof. Pap., 440-KK, 6th ed.

FRITZ, R.D., and Medlock, P.L., 1994, Sequence Stratigraphy of the Hunton Group as Defined by Core, Outcrop, and Log Data, *Bulletin Houston Geological Society*, February 1994.

GREGG, J.M., and Sibley, D.F., 1984, Epigenetic dolomitization and the origin of xenotopic dolomite texture, *Journal of Sedimentary Research*, 54, n. 3, p. 908-931

GROVER, JR. G, and J.F. Read, 1983, Paleoaquifer and Deep Burial Related Cements defined by Regional Cathodoluminescent Patterns, Middle Ordovician Carbonates, Virginia, *AAPG Bulletin* v. 67, n. 8, p. 1275-1303.

JOHNSON, K.S., and others, 1988, Southern MidContinent region, in Sloss, L.L. (ed.), Sedimentary cover-North American craton, U.S., The Geology of North America, Geological Society of North America, Boulder, v. D-2, p. 307-359.

JOHNSON, M.E., 1987, Extent and bathymetry of North American platform seas in the Early Silurian: *Paleoceanography*, v. 2, n. 2, p. 184-211.

JOHNSON, M.E., 1996, Stable cratonic sequences and a standard for Silurian eustasy. in Paleozoic sequence stratigraphy: views from the North American craton (eds B. J. Witzke, G. A Ludvigson and J. Day), p. 203-211. *Geological Society of America* Special Paper no. 306.

KAUFMAN, J., Cander, H.S., Daniels, L.D., and Meyers, W.J., 1988, Calcite Cement Stratigraphy and Cementation History of the Burlington-Keokuk Formation (Mississippian), Illinois and Missouri, *Journal of Sedimentary Petrology*, v. 58, n.2, p. 312-326.

KELKAR, M., 2002, Exploitation and optimization of reservoir performance in Hunton Formation, Oklahoma: U.S. DOE, Tulsa, OK, Final Report, Budget Period 1 on work performed under contract No. DF-FC26-00BC15125, prepared for the National Energy Technology Laboratory, National Petroleum Technology Office, 305 p.

KRISHNAMURTHY, R.V., Atekwana, E.A., and Guha H., 1997, A simple, inexpensive carbonate – phosphoric acid reaction method for the analysis of carbon and oxygen isotopes of carbonates. *Anal. Chem*., 69 (20): 4256-4258; doi: 10,1021/ac9702047.

LAVOIE, D., 1993, Early Devonian marine isotopic signatures: brachiopods from the Upper Gaspé Limestones, Gaspé Peninsula, Québec, Canada, *Journal of Sedimentary Petrology*, v. 63, n. 4, p. 620-627.

LOYDELL, D.K., 1998, Early Silurian Sea-Level Changes, Geologic Magazine, 135 (4), p. 447-471, Cambridge University Press.

MACHEL, H.G., 1985, Cathodoluminescence in calcite and dolomite and its chemical interpretation, *Geoscience Canada* v. 12, n. 4, p. 139-179.

MATTHEWS, F.D., 1994, Paleokarstic features and reservoir characteristics of the Hunton Group in the Anadarko Basin, Oklahoma, *Shale Shaker Digest* XIII, V. XXXX-XXXXXIV (1989-1994), p. 143-150.

MELIM, L.A., Swart, P.K., and G.P. Eberli, 2004, Mixing zone diagenesis in the subsurface of Florida and the Bahamas, *Journal of Sedimentary Research*, v. 74, no. 6, p. 904-913.

MEYERS, W.J., and Lohmann, K.C., 1985, Isotope geochemistry of regionally extensive calcite cement zones and marine components in Mississippian limestones, New Mexico, SEPM, Carbonate Cements (SP36), p. 223-237.

MEYERS, W.J., 1991, Calcite Cement Stratigraphy: An Overview, SEPM Luminescence Microscopy and Spectroscopy: Qualitative and Quantitative Applications (SC25), 1991.

MUNNECKE, A., Claner, M., Harper, D.A., and Servais, T., 2010, Ordovician and Silurian sea-water chemistry, sea level, and climate: A synopsis, *Palaeogeography, Palaeoclimatology, Palaeoecology* 296, p. 389-413

MYLROIE, J.E., and James, L.C., 1995, Karst development on carbonate islands. Unconformites in Carbonate Strata – Their Recognition and the Significance of Associated Porosity, AAPG Memoir 63, p. 55-76.

RECHLIN, K. J., 2005, Reservoir quality of the Frisco Formation, Hunton Group, Seminole County, Oklahoma, (Part 2, Conclusion), Shale Shaker, v. 56, n. 1, p. 15-24.

RUSH, P.F., and Chafetz, H.S., 1990, Fabric-retentive, non-luminescent brachiopods as indicators of original δ^{13}C and δ^{18}O Composition: A test, *Journal of Sedimentary Petrology*, v. 60, n. 6, p. 968-981.

SALLER, A.H., Budd, D.A., and Harris, P.M., 1994, Unconformities and porosity development in carbonate strata: Ideas from a Hedberg Conference, *AAPG Bulletin*, v. 78, n. 6, p. 857-872.

SCHOLLE, P.A., and Scholle, D.S., 2003, A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis. Published by AAPG, Tulsa, Oklahoma, 473 p.

SEARL, A., 1988, The limitations of "cement statigraphy" as revealed in some Lower Carboniferous oolites from South Wales, *Sedimentary Geology*, 57, p. 171-183.

SILVA, C., 2012, Reservoir and diagenetic characterization of the Lower Cochrane member, Hunton Group – Lincoln and Logan Counties, Oklahoma, Master's thesis, Oklahoma State University, Stillwater, Oklahoma, 83 p.

STANLEY, T.M., 2001, Stratigraphy and facies relationship of the Hunton Group, northern Arbuckle Mountains and Lawrence Uplift, Oklahoma: Oklahoma Geological Survey Guidebook 33, 73 p.

TUCKER, M.E., and Wright, V.P., 1990, Carbonate Sedimentology, Oxford, UK, Blackwell Publishing, 482 p.

WENZEL, B., and Joachimski, M.M., 1996, Carbon and oxygen iostopic composition of Silurian brachiopods (Gotland/Sweden): Palaeoceanographic implications, *Palaeogeography, Palaeoclimatology, Palaeoecology* v. 122, p. 143-166.

WENZEL, B., Lécuyer, and Joachimski, M. M., 2000, Comparing oxygen isotope records of Silurian calcite and phosphate - δ^{18}O compositions of brachiopods and conodonts, *Geochimica et Cosmochimica Acta*, v. 64, n. 11, p. 1859-1872.

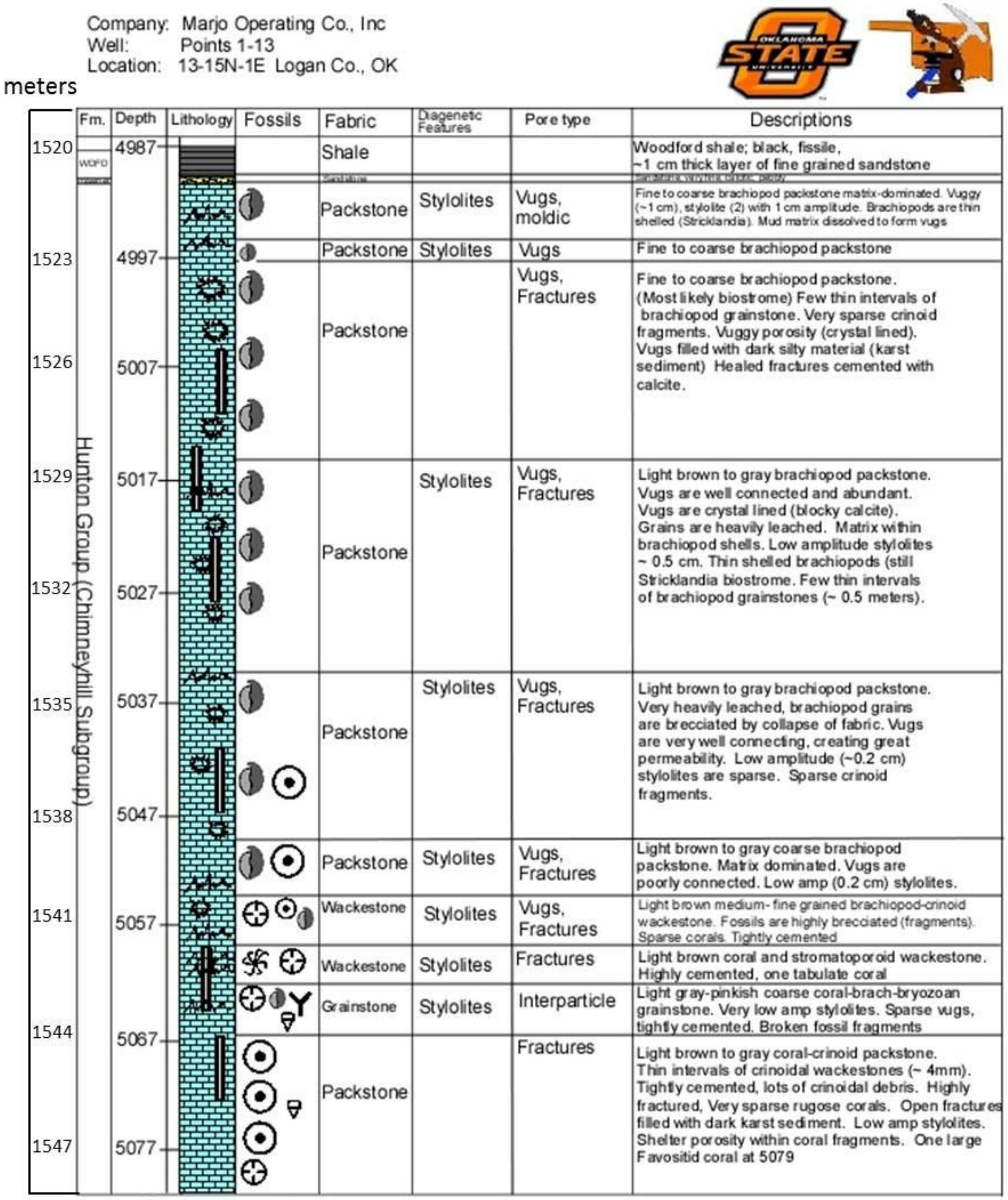
WHITICAR, J.M., and Faber, E., 1988, Carbon, hydrogen, and oxygen isotope distribution in the interstitial fluids of ODP Let 104, Holes 642B, 642D, 643A, and 644A, Voring Plateau, Norwegian Sea, *Proceedings of the Ocean Drilling Program*,

WORONICK, R.E., and Land, L.S., 1985, Late burial diagenesis, Lower Cretaceous Pearsall and Lower Glen Rose Formations, South Texas: The Society of Economic Paleontologists and Mineralogists, Carbonate Cements (SP36).
Scientific Results, V. 104.

APPENDICES

Appendix 1 – Core Logs

Core Logs of the four cored wells in the study which include the Marjo Operating Co., Inc. Points 1-13, JB 1-13, Mark Houser 1-11, and the Cal 1-11.



Company: Marjo Operating Co., Inc
Well: Points 1-13
Location: 13-15N-1E Logan Co., OK

Fabric	Diagenetic Features	Pore type	Descriptions
Shale			Woodford shale; black, fissile, ~1 cm thick layer of fine grained sandstone
Sandstone			[illegible]
Packstone	Stylolites	Vugs, moldic	Fine to coarse brachiopod packstone matrix-dominated. Vuggy (~1 cm), stylolite (2) with 1 cm amplitude. Brachiopods are thin shelled (Stricklandia). Mud matrix dissolved to form vugs
Packstone	Stylolites	Vugs	Fine to coarse brachiopod packstone
Packstone		Vugs, Fractures	Fine to coarse brachiopod packstone. (Most likely biostrome) Few thin intervals of brachiopod grainstone. Very sparse crinoid fragments. Vuggy porosity (crystal lined). Vugs filled with dark silty material (karst sediment) Healed fractures cemented with calcite.
Packstone	Stylolites	Vugs, Fractures	Light brown to gray brachiopod packstone. Vugs are well connected and abundant. Vugs are crystal lined (blocky calcite). Grains are heavily leached. Matrix within brachiopod shells. Low amplitude stylolites ~ 0.5 cm. Thin shelled brachiopods (still Stricklandia biostrome. Few thin intervals of brachiopod grainstones (~ 0.5 meters).
Packstone	Stylolites	Vugs, Fractures	Light brown to gray brachiopod packstone. Very heavily leached, brachiopod grains are brecciated by collapse of fabric. Vugs are very well connecting, creating great permeability. Low amplitude (~0.2 cm) stylolites are sparse. Sparse crinoid fragments.
Packstone	Stylolites	Vugs, Fractures	Light brown to gray coarse brachiopod packstone. Matrix dominated. Vugs are poorly connected. Low amp (0.2 cm) stylolites.
Wackestone	Stylolites	Vugs, Fractures	Light brown medium- fine grained brachiopod-crinoid wackestone. Fossils are highly brecciated (fragments). Sparse corals. Tightly cemented
Wackestone	Stylolites	Fractures	Light brown coral and stromatoporoid wackestone. Highly cemented, one tabulate coral
Grainstone	Stylolites	Interparticle	Light gray-pinkish coarse coral-brach-bryozoan grainstone. Very low amp stylolites. Sparse vugs, tighfly cemented. Broken fossil fragments
Packstone		Fractures	Light brown to gray coral-crinoid packstone. Thin intervals of crinoidal wackestones (~ 4mm). Tighfly cemented, lots of crinoidal debris. Highly fractured, Very sparse rugose corals. Open fractures filled with dark karst sediment. Low amp stylolites. Shelter porosity within coral fragments. One large Favositid coral at 5079

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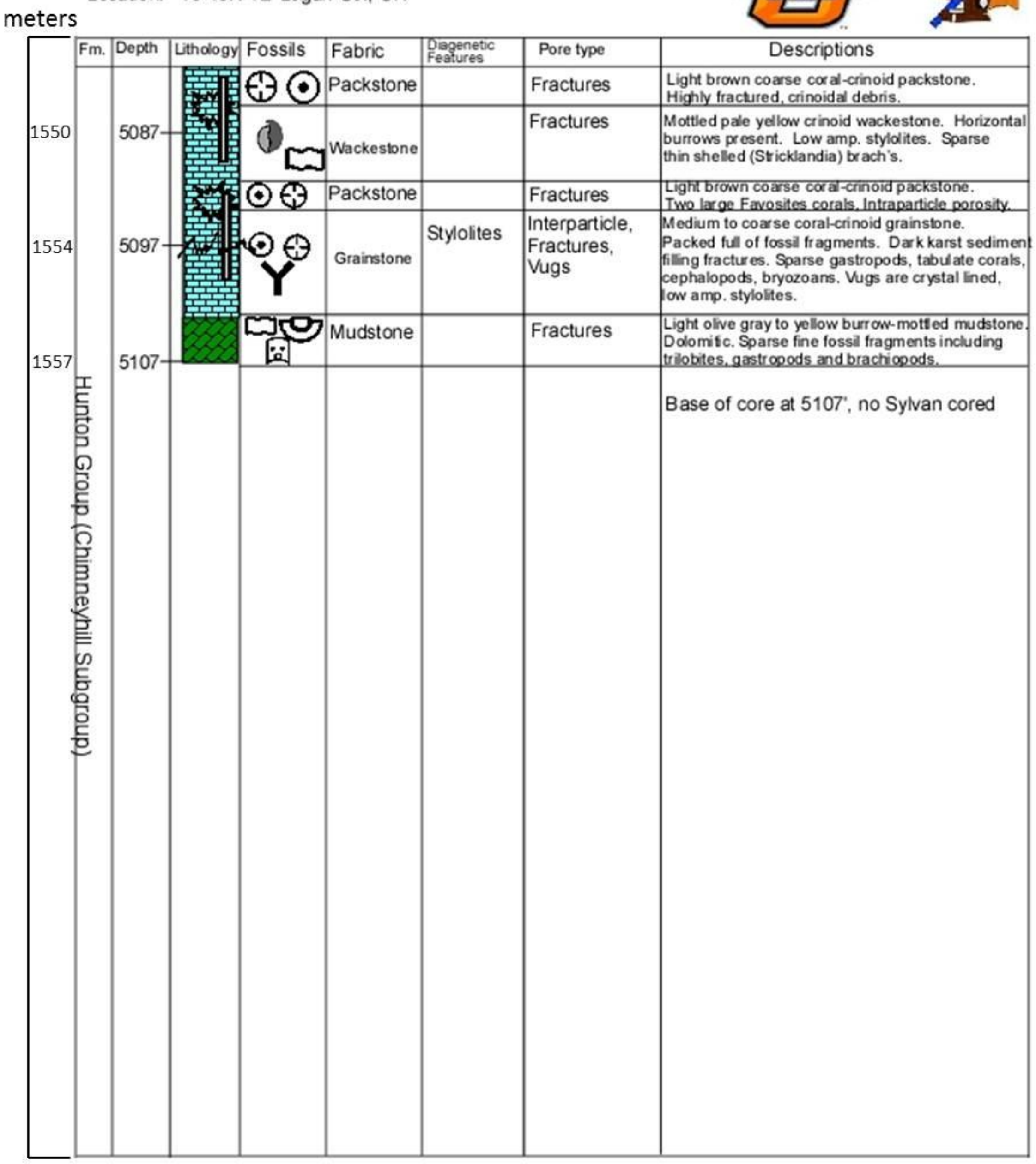
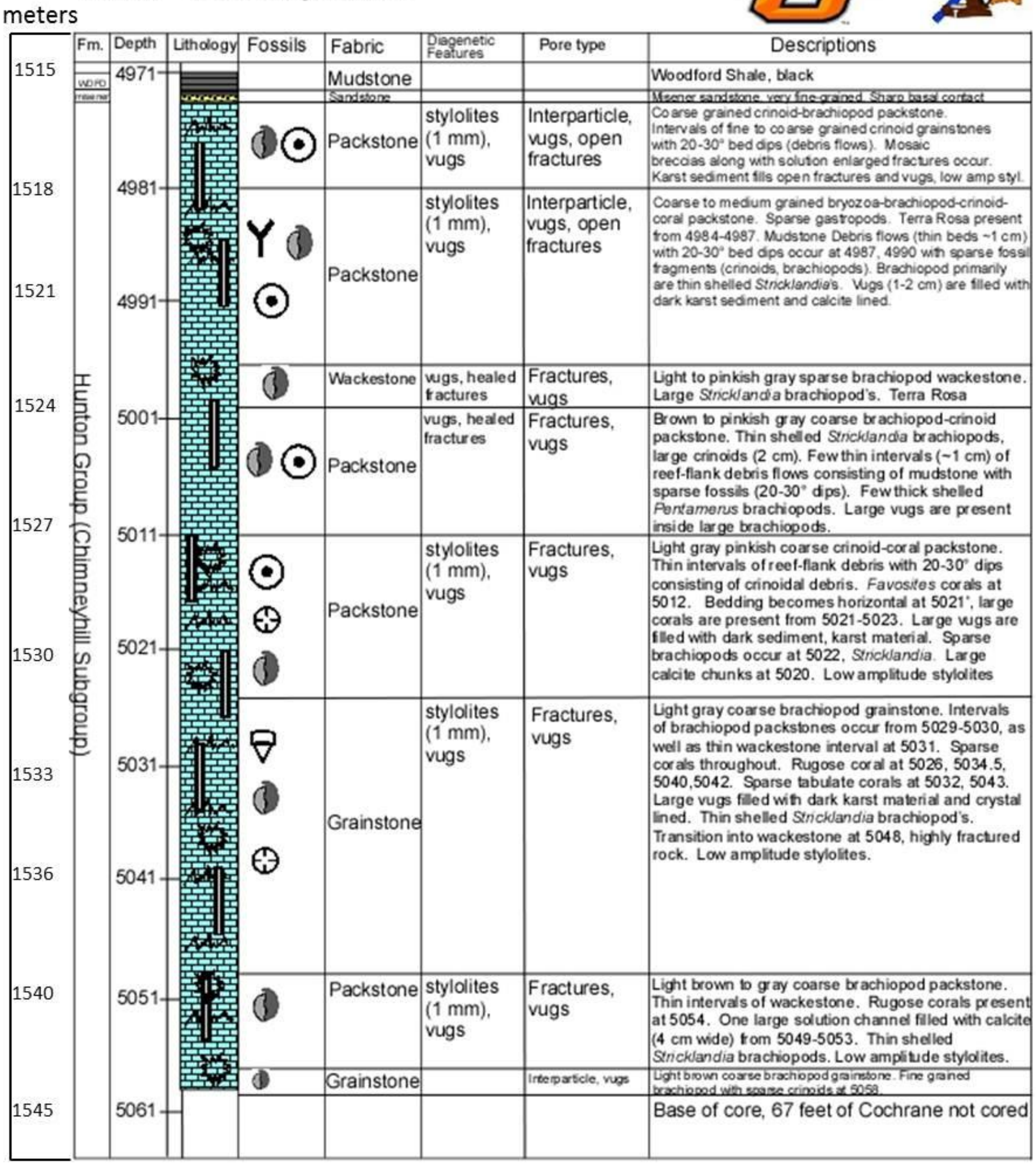
Company: Marjo Operating Co., Inc
Well: Points 1-13
Location: 13-15N-1E Logan Co., OK

Continued from previous



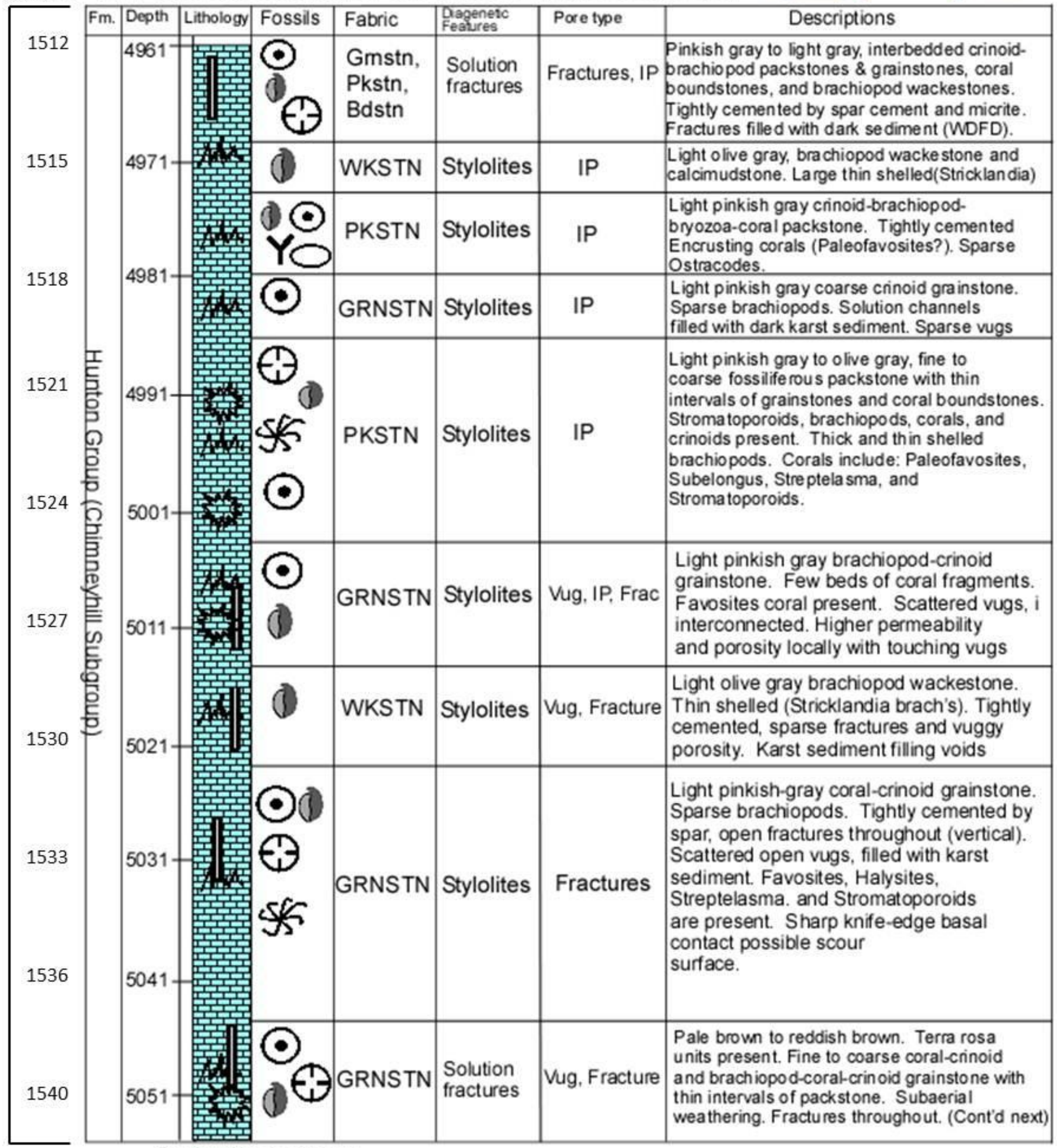
meters	Fm.	Depth	Lithology	Fossils	Fabric	Diagenetic Features	Pore type	Descriptions
	Hunton Group (Chimneyhill Subgroup)				Packstone		Fractures	Light brown coarse coral-crinoid packstone. Highly fractured, crinoidal debris.
1550		5087			Wackestone		Fractures	Mottled pale yellow crinoid wackestone. Horizontal burrows present. Low amp. stylolites. Sparse thin shelled (Stricklandia) brach's.
					Packstone		Fractures	Light brown coarse coral-crinoid packstone. Two large Favosites corals. Intraparticle porosity.
1554		5097			Grainstone	Stylolites	Interparticle, Fractures, Vugs	Medium to coarse coral-crinoid grainstone. Packed full of fossil fragments. Dark karst sediment filling fractures. Sparse gastropods, tabulate corals, cephalopods, bryozoans. Vugs are crystal lined, low amp. stylolites.
1557		5107			Mudstone		Fractures	Light olive gray to yellow burrow-mottled mudstone. Dolomitic. Sparse fine fossil fragments including trilobites, gastropods and brachiopods.
								Base of core at 5107', no Sylvan cored

Company: Marjo Operating Co., Inc
Well: JB 1-13
Location: 13-15N-1E Logan Co., OK



Fm.	Fabric	Diagenetic Features	Pore type	Descriptions
WDFD	Mudstone			Woodford Shale, black
misener	Sandstone			Misener sandstone, very fine-grained. Sharp basal contact
Hunton Group (Chimneyhill Subgroup)	Packstone	stylolites (1 mm), vugs	Interparticle, vugs, open fractures	Coarse grained crinoid-brachiopod packstone. Intervals of fine to coarse grained crinoid grainstones with 20-30° bed dips (debris flows). Mosaic breccias along with solution enlarged fractures occur. Karst sediment fills open fractures and vugs, low amp styl.
	Packstone	stylolites (1 mm), vugs	Interparticle, vugs, open fractures	Coarse to medium grained bryozoa-brachiopod-crinoid-coral packstone. Sparse gastropods. Terra Rosa present from 4984-4987. Mudstone Debris flows (thin beds ~1 cm) with 20-30° bed dips occur at 4987, 4990 with sparse fossil fragments (crinoids, brachiopods). Brachiopod primarily are thin shelled *Stricklandia's*. Vugs (1-2 cm) are filled with dark karst sediment and calcite lined.
	Wackestone	vugs, healed fractures	Fractures, vugs	Light to pinkish gray sparse brachiopod wackestone. Large *Stricklandia* brachiopod's. Terra Rosa
	Packstone	vugs, healed fractures	Fractures, vugs	Brown to pinkish gray coarse brachiopod-crinoid packstone. Thin shelled *Stricklandia* brachiopods, large crinoids (2 cm). Few thin intervals (~1 cm) of reef-flank debris flows consisting of mudstone with sparse fossils (20-30° dips). Few thick shelled *Pentamerus* brachiopods. Large vugs are present inside large brachiopods.
	Packstone	stylolites (1 mm), vugs	Fractures, vugs	Light gray pinkish coarse crinoid-coral packstone. Thin intervals of reef-flank debris with 20-30° dips consisting of crinoidal debris. *Favosites* corals at 5012. Bedding becomes horizontal at 5021', large corals are present from 5021-5023. Large vugs are filled with dark sediment, karst material. Sparse brachiopods occur at 5022, *Stricklandia*. Large calcite chunks at 5020. Low amplitude stylolites
	Grainstone	stylolites (1 mm), vugs	Fractures, vugs	Light gray coarse brachiopod grainstone. Intervals of brachiopod packstones occur from 5029-5030, as well as thin wackestone interval at 5031. Sparse corals throughout. Rugose coral at 5026, 5034.5, 5040,5042. Sparse tabulate corals at 5032, 5043. Large vugs filled with dark karst material and crystal lined. Thin shelled *Stricklandia* brachiopod's. Transition into wackestone at 5048, highly fractured rock. Low amplitude stylolites.
	Packstone	stylolites (1 mm), vugs	Fractures, vugs	Light brown to gray coarse brachiopod packstone. Thin intervals of wackestone. Rugose corals present at 5054. One large solution channel filled with calcite (4 cm wide) from 5049-5053. Thin shelled *Stricklandia* brachiopods. Low amplitude stylolites.
	Grainstone		Interparticle, vugs	Light brown coarse brachiopod grainstone. Fine grained brachiopod with sparse crinoids at 5058.
				Base of core, 67 feet of Cochrane not cored

Company: Marjo Operating Co., Inc
Well: Mark Houser 1-11
Location: 11-15N-1E Logan Co., OK
Core: 0 feet of Woodford Cored, 4961' top of Core (Hunton Group 116.6')



Fm.	Fabric	Diagenetic Features	Pore type	Descriptions
Hunton Group (Chimneyhill Subgroup)	Gmstn, Pkstn, Bdstn	Solution fractures	Fractures, IP	Pinkish gray to light gray, interbedded crinoid-brachiopod packstones & grainstones, coral boundstones, and brachiopod wackestones. Tightly cemented by spar cement and micrite. Fractures filled with dark sediment (WDFD).
	WKSTN	Stylolites	IP	Light olive gray, brachiopod wackestone and calcimudstone. Large thin shelled(Stricklandia)
	PKSTN	Stylolites	IP	Light pinkish gray crinoid-brachiopod-bryozoa-coral packstone. Tightly cemented Encrusting corals (Paleofavosites?). Sparse Ostracodes.
	GRNSTN	Stylolites	IP	Light pinkish gray coarse crinoid grainstone. Sparse brachiopods. Solution channels filled with dark karst sediment. Sparse vugs
	PKSTN	Stylolites	IP	Light pinkish gray to olive gray, fine to coarse fossiliferous packstone with thin intervals of grainstones and coral boundstones. Stromatoporoids, brachiopods, corals, and crinoids present. Thick and thin shelled brachiopods. Corals include: Paleofavosites, Subelongus, Streptelasma, and Stromatoporoids.
	GRNSTN	Stylolites	Vug, IP, Frac	Light pinkish gray brachiopod-crinoid grainstone. Few beds of coral fragments. Favosites coral present. Scattered vugs, i interconnected. Higher permeability and porosity locally with touching vugs
	WKSTN	Stylolites	Vug, Fracture	Light olive gray brachiopod wackestone. Thin shelled (Stricklandia brach's). Tightly cemented, sparse fractures and vuggy porosity. Karst sediment filling voids
	GRNSTN	Stylolites	Fractures	Light pinkish-gray coral-crinoid grainstone. Sparse brachiopods. Tightly cemented by spar, open fractures throughout (vertical). Scattered open vugs, filled with karst sediment. Favosites, Halysites, Streptelasma. and Stromatoporoids are present. Sharp knife-edge basal contact possible scour surface.
	GRNSTN	Solution fractures	Vug, Fracture	Pale brown to reddish brown. Terra rosa units present. Fine to coarse coral-crinoid and brachiopod-coral-crinoid grainstone with thin intervals of packstone. Subaerial weathering. Fractures throughout. (Cont'd next)

Continued on next page

Company: Marjo Operating Co., Inc
Well: M. Houser 1-11
Location: 11-15N-1E Logan Co., OK
Core: 9.4 feet of Hunton not cored, 0 feet of Sylvan cored

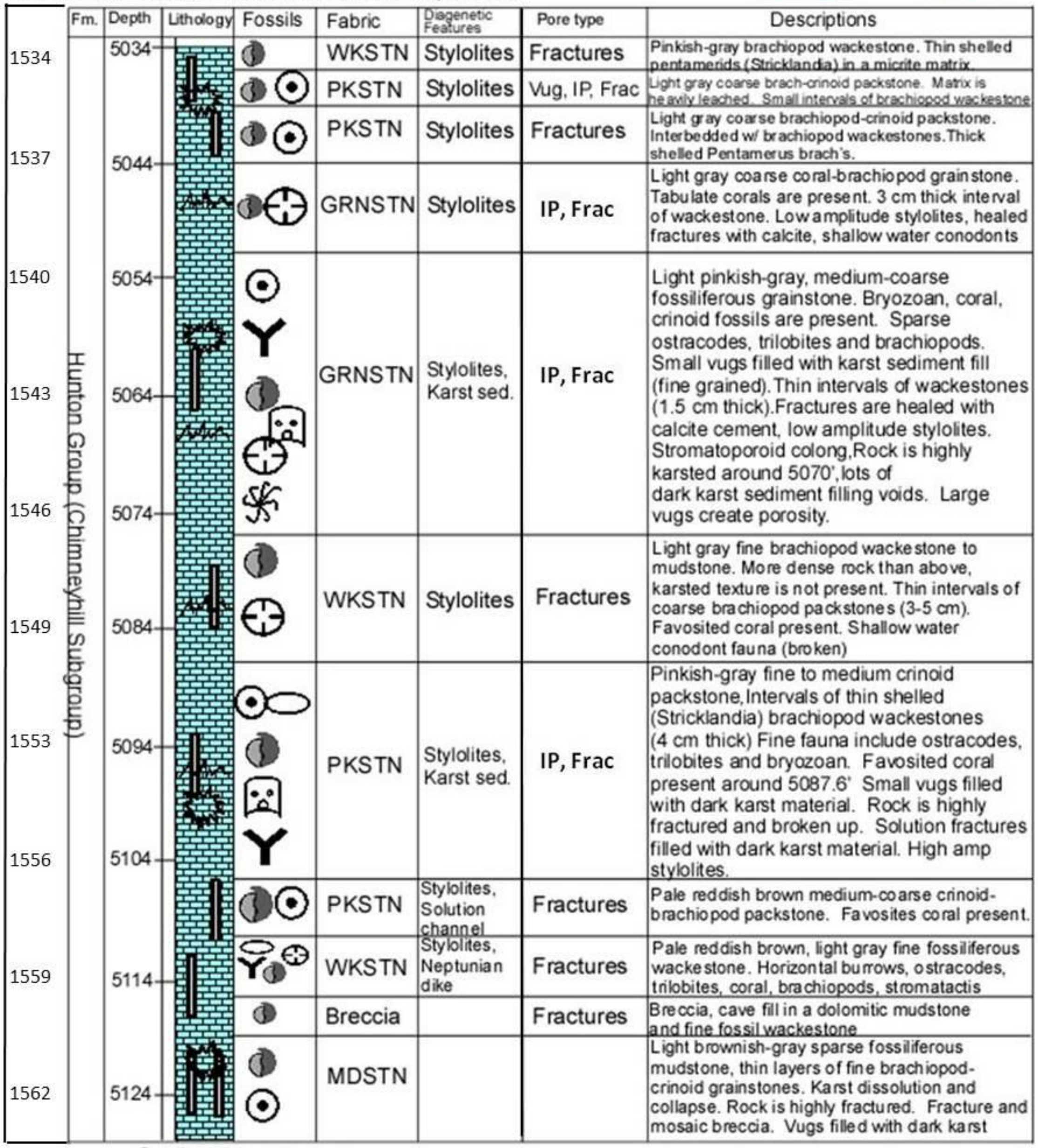
Continued from previous

meters
1543
1546
1549

Depth
5061
5071
5081

Fm.	Depth	Lithology	Fossils	Fabric	Diagenetic Features	Pore type	Descriptions
			◐ ⊙ ⊕	GRNSTN	Solution fractures	Vug, Fracture	Large dissolution cavities filled with dark karst sediment. Sharp basal contact.
	5061			PKSTN	Cave, karst sediment	Vug, Fracture	Fine to coarse cave fill parabreccia-matrix supported breccia. 11.4 foot high cavern filled with bioclasts and intraclasts. Secondary karst cavity at 5066.5-5067 filled with karst mud overlain by laminated silt and very fine sand (WDFD and MSNR). Dolomitic at base
	5071		⊕ ⊙	WKSTN	Stylolites	Fracture	Light gray-pale orange fine coral-crinoid wackestone. Partly dolomitized in top foot. Top contact is scalloped. Large druze-lined vug at 5075.5'
	5081						

Company: Marjo Operating Co., Inc
Well: Cal 1-11
Location: 11-15N-1E Logan Co., OK
Core: 0 feet of Woodford Cored, 5034' top of Core



Fabric	Diagenetic Features	Pore type	Descriptions
WKSTN	Stylolites	Fractures	Pinkish-gray brachiopod wackestone. Thin shelled pentamerids (Stricklandia) in a micrite matrix.
PKSTN	Stylolites	Vug, IP, Frac	Light gray coarse brach-crinoid packstone. Matrix is heavily leached. Small intervals of brachiopod wackestone
PKSTN	Stylolites	Fractures	Light gray coarse brachiopod-crinoid packstone. Interbedded w/ brachiopod wackestones. Thick shelled Pentamerus brach's.
GRNSTN	Stylolites	IP, Frac	Light gray coarse coral-brachiopod grainstone. Tabulate corals are present. 3 cm thick interval of wackestone. Low amplitude stylolites, healed fractures with calcite, shallow water conodonts
GRNSTN	Stylolites, Karst sed.	IP, Frac	Light pinkish-gray, medium-coarse fossiliferous grainstone. Bryozoan, coral, crinoid fossils are present. Sparse ostracodes, trilobites and brachiopods. Small vugs filled with karst sediment fill (fine grained). Thin intervals of wackestones (1.5 cm thick). Fractures are healed with calcite cement, low amplitude stylolites. Stromatoporoid colong, Rock is highly karsted around 5070', lots of dark karst sediment filling voids. Large vugs create porosity.
WKSTN	Stylolites	Fractures	Light gray fine brachiopod wackestone to mudstone. More dense rock than above, karsted texture is not present. Thin intervals of coarse brachiopod packstones (3-5 cm). Favosited coral present. Shallow water conodont fauna (broken)
PKSTN	Stylolites, Karst sed.	IP, Frac	Pinkish-gray fine to medium crinoid packstone, Intervals of thin shelled (Stricklandia) brachiopod wackestones (4 cm thick) Fine fauna include ostracodes, trilobites and bryozoan. Favosited coral present around 5087.6' Small vugs filled with dark karst material. Rock is highly fractured and broken up. Solution fractures filled with dark karst material. High amp stylolites.
PKSTN	Stylolites, Solution channel	Fractures	Pale reddish brown medium-coarse crinoid-brachiopod packstone. Favosites coral present.
WKSTN	Stylolites, Neptunian dike	Fractures	Pale reddish brown, light gray fine fossiliferous wackestone. Horizontal burrows, ostracodes, trilobites, coral, brachiopods, stromatactis
Breccia		Fractures	Breccia, cave fill in a dolomitic mudstone and fine fossil wackestone
MDSTN			Light brownish-gray sparse fossiliferous mudstone, thin layers of fine brachiopod-crinoid grainstones. Karst dissolution and collapse. Rock is highly fractured. Fracture and mosaic breccia. Vugs filled with dark karst

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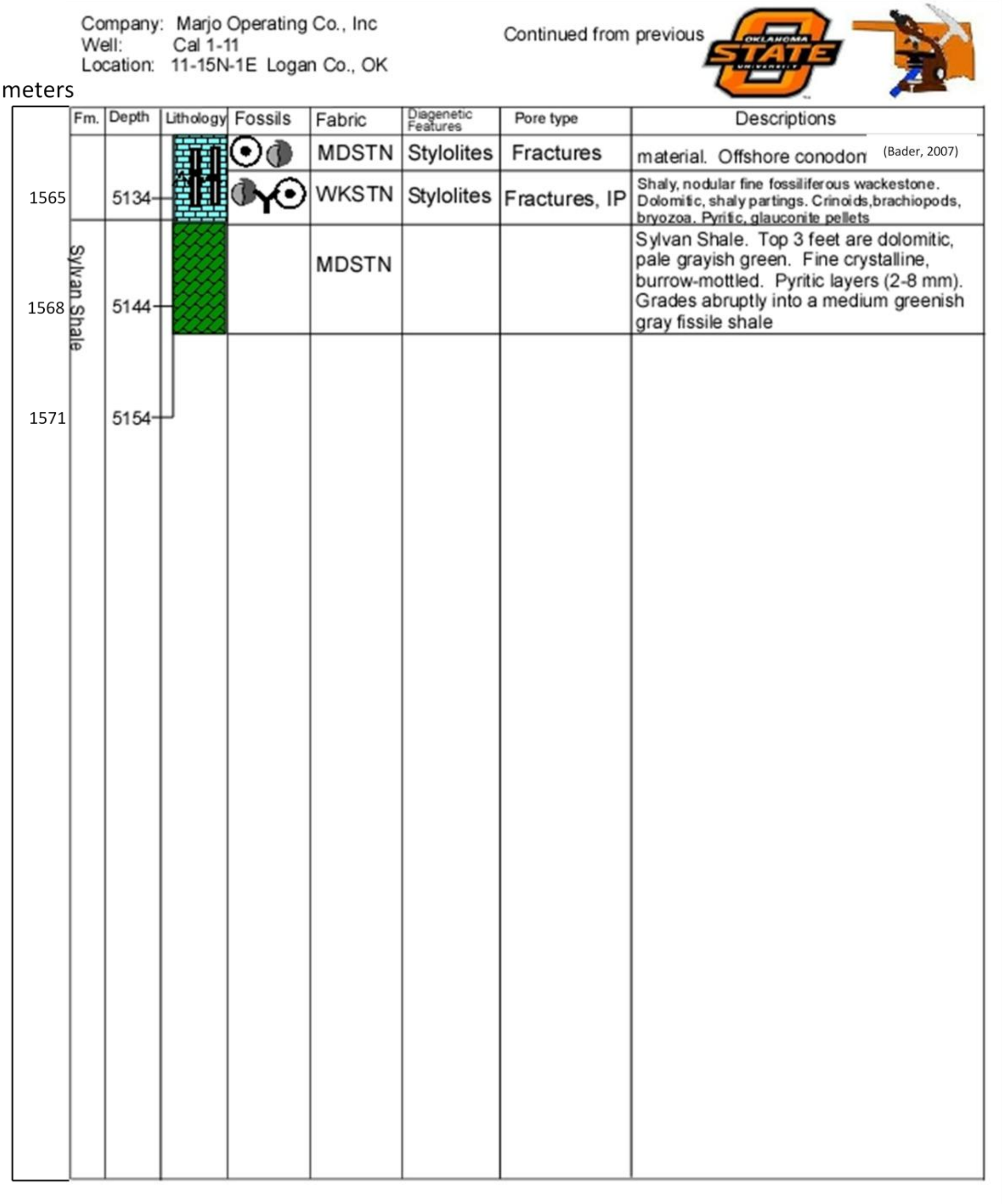
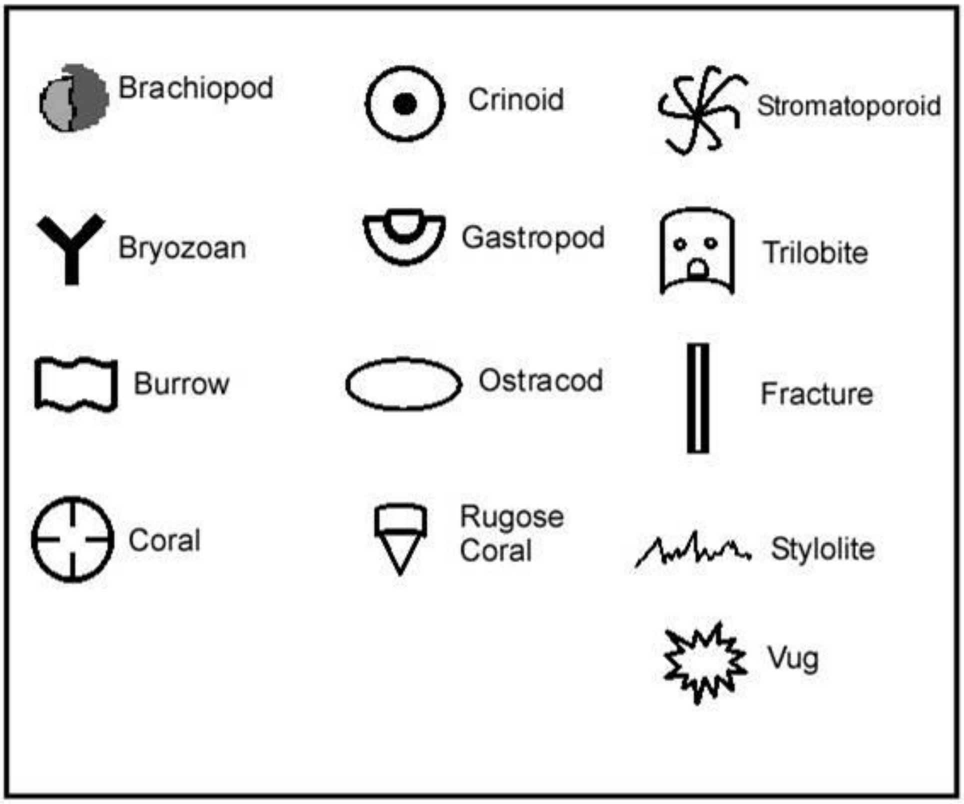


Company: Marjo Operating Co., Inc
Well: Cal 1-11
Location: 11-15N-1E Logan Co., OK

Continued from previous

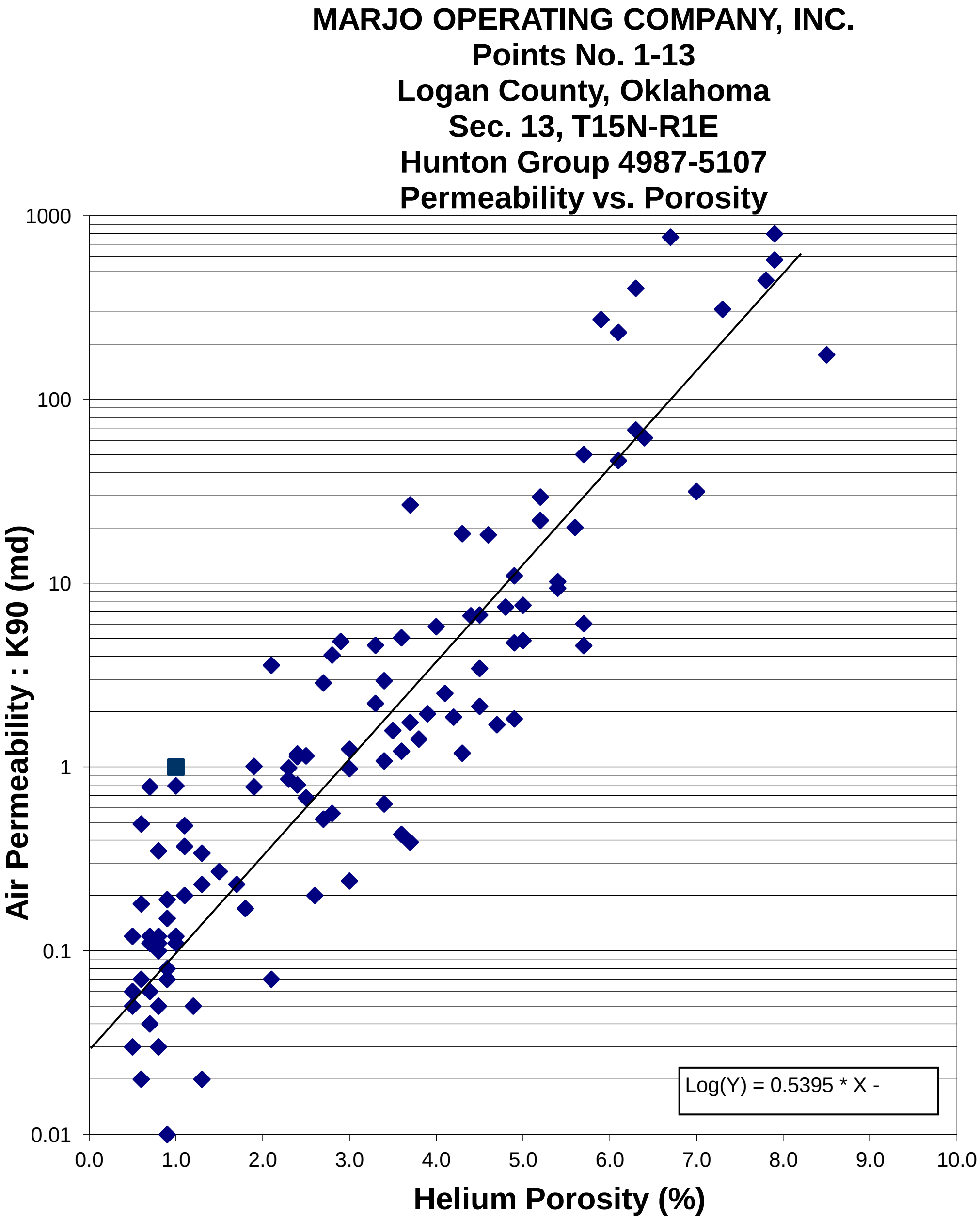
meters	Fm.	Depth	Lithology	Fossils	Fabric	Diagenetic Features	Pore type	Descriptions
					MDSTN	Stylolites	Fractures	material. Offshore conodon (Bader, 2007)
1565		5134			WKSTN	Stylolites	Fractures, IP	Shaly, nodular fine fossiliferous wackestone. Dolomitic, shaly partings. Crinoids, brachiopods, bryozoa. Pyritic, glauconite pellets
1568	Sylvan Shale	5144			MDSTN			Sylvan Shale. Top 3 feet are dolomitic, pale grayish green. Fine crystalline, burrow-mottled. Pyritic layers (2-8 mm). Grades abruptly into a medium greenish gray fissile shale
1571		5154						

Core Log Legend

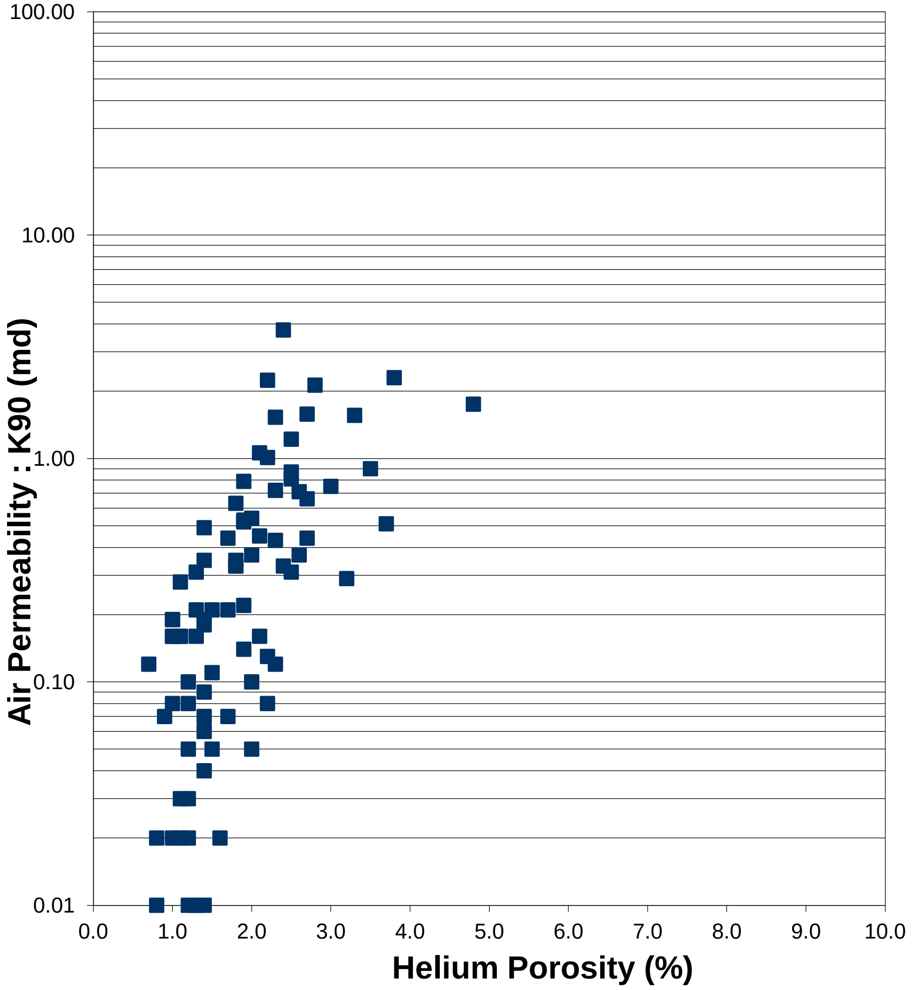


Appendix 2 – Core Analysis

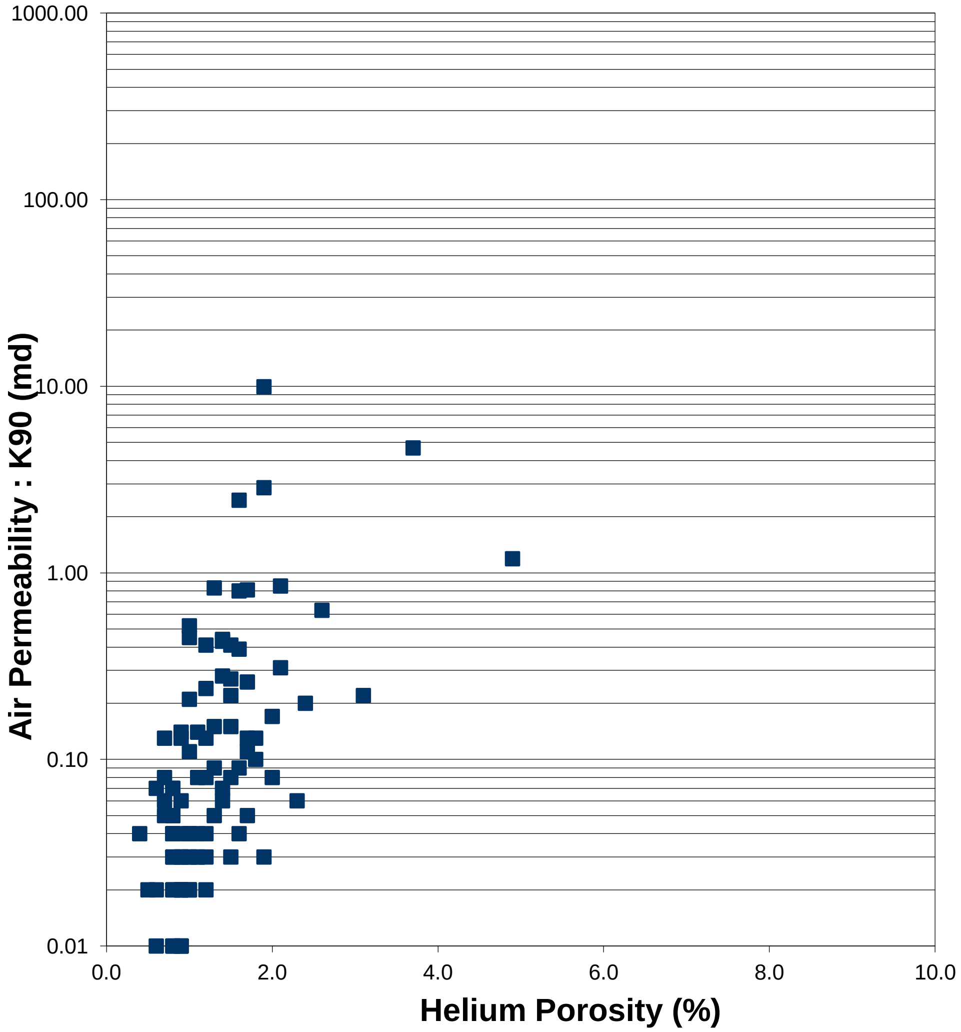
Core Analysis was provided by Dr. James Derby through Marjo Operating Co., Inc. Core Analysis plots are listed first, followed by raw data values.



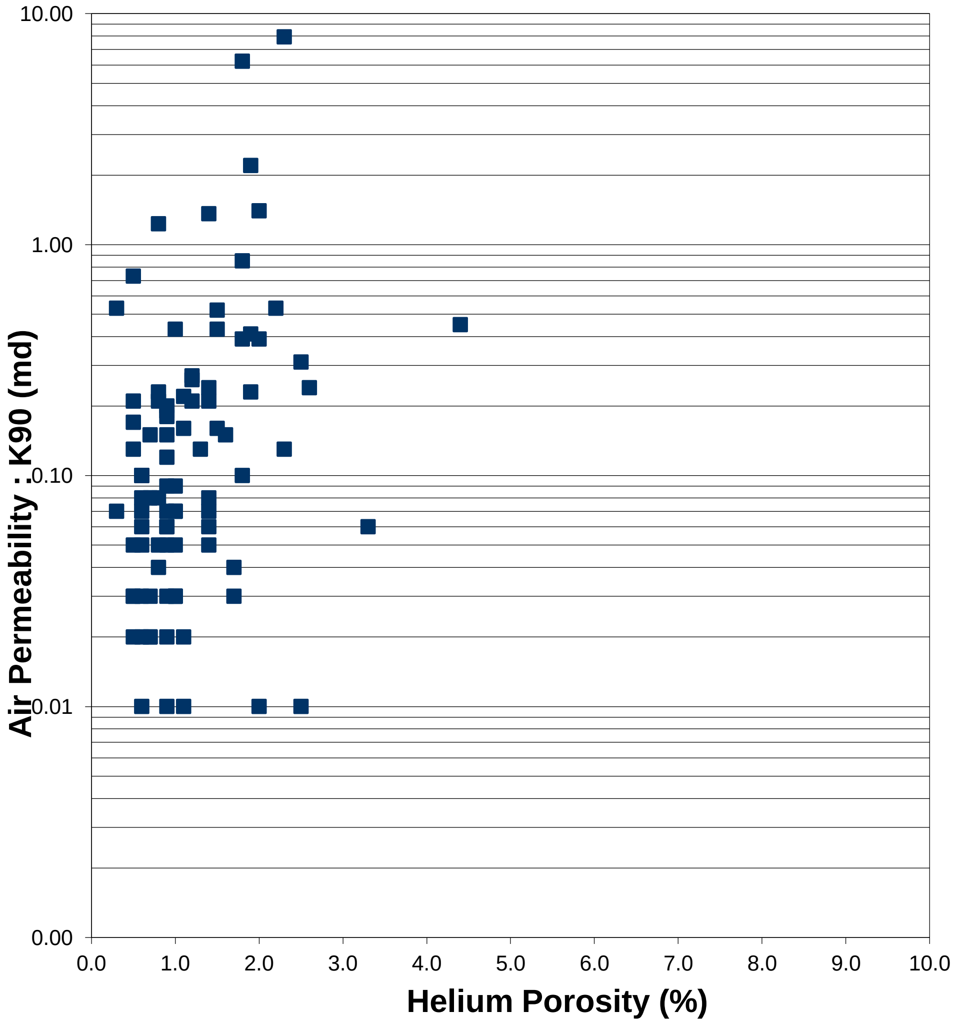
Marjo Operating Company, Inc.
JB No. 1-13
Logan County, Oklahoma
Hunton Group (4971 to 5058.5 feet)
Permeability vs. Porosity



Marjo Operating Company, Inc.
Mark Houser No. 1-11
Logan County, Oklahoma
Hunton Group (4961 to 5078 feet)
Permeability vs. Porosity



Marjo Operating Company, Inc.
Cal No. 1-11
Logan County, Oklahoma
Hunton Group (5034 to 5136 feet)
Permeability vs. Porosity



Company: MARJO OPERATING COMPANY, INC.

Well: POINTS NO. 1-13

Location: LOGAN COUNTY, OKLAHOMA
SEC. 13, T15N-R1E

Date: 7/31/2001

Files: SL 6143 and CL 57181-18341

ROUTINE CORE ANALYSIS

Sample	Depth			Helium	Air Permeability			Grain	Lithology
I.D.	Top feet		Bottom feet	Porosity %	Kmax md	K90 md	Kvert md	Density g/cm	
1	4987.0	to	88.0						Sh, slty, no show
2	4988.0	to	89.0						Sh, slty, no show
3	4989.6	to	90.0	1.8	0.18	0.17	0.03	2.71	Lm, foss, 5% yel flu
4	4990.0	to	90.4	4.2	490	1.87	0.07	2.71	Lm, foss, 5% yel flu
5	4991.0	to	91.5	5.7	5.80	4.58	4.94	2.72	Lm, foss, sl vug, 15% yel flu
6	4992.1	to	92.6	3.8	2.27	1.42	2.06	2.71	Lm, foss, sl vug, 25% yel flu
7	4993.0	to	93.7	4.7	4.38	1.70	1.71	2.71	Lm, foss, sl vug, 25% yel flu
8	4994.2	to	94.6	3.7	61.2	26.7	8.76	2.71	Lm, foss, sl vug, 30% yel flu
9	4995.1	to	95.5	2.5	42.8	0.68	0.19	2.71	Lm, foss, sl vug, 20% yel flu
10	4996.5	to	96.8	7.8	1517	445	421	2.74	Lm, foss, sl vug, 25% yel flu
11	4997.1	to	97.5	5.0	1163	4.88	10.5	2.72	Lm, foss, sl vug, 55% yel flu
12	4998.0	to	98.8	3.6	14.1	0.43	0.25	2.72	Lm, foss, sl vug, 30% yel flu
13	4999.1	to	99.8	4.9	4.43	1.83	0.47	2.72	Lm, foss, sl vug, 40% yel flu
14	5000.5	to	1.0	3.9	2.09	1.95	0.59	2.71	Lm, foss, sl vug, 30% yel flu
15	5001.3	to	1.8	4.3	1.42	1.19	1.11	2.70	Lm, foss, 40% yel flu
16	5002.0	to	2.8	3.7	0.43	0.39	0.19	2.71	Lm, foss, sl vug, 10% yel flu
17	5003.3	to	4.0	3.4	2.45	1.08	1.22	2.71	Lm, foss, sl vug, 10% yel flu
18	5004.4	to	5.0	3.0	1.24	0.98	0.26	2.71	Lm, foss, sl vug, 20% yel flu
19	5005.0	to	5.8	2.5	1.72	1.15	0.45	2.71	Lm, foss, 15% yel flu
20	5006.6	to	7.0	4.5	17.3	3.44	8.16	2.71	Lm, foss, sl vug, 50% yel flu
21	5007.0	to	7.8	4.0	6.60	5.81	0.89	2.71	Lm, foss, sl vug, 30% yel flu
22	5008.0	to	8.5	3.6	6.12	5.06	1.64	2.71	Lm, foss, sl vug, 50% yel flu
23	5009.0	to	9.5	2.8	111	4.07	4.62	2.71	Lm, foss, sl vug, 25% yel flu
24	5010.0	to	10.7	2.4	0.89	0.80	0.23	2.71	Lm, foss, 25% yel flu
25	5011.0	to	11.6	3.6	20.7	1.22	0.61	2.71	Lm, foss, sl vug, 45% yel flu
26	5012.6	to	13.0	2.7	4.22	2.87	14.0	2.71	Lm, foss, sl vug, 60% yel flu
27	5013.5	to	13.8	1.5	0.31	0.27	0.74	2.71	Lm, foss, sl vug, 60% yel flu
28	5014.0	to	14.7	4.1	6.39	2.52	2.87	2.71	Lm, foss, sl vug, 20% yel flu
29	5015.3	to	15.9	4.5	3.13	2.14	2.19	2.71	Lm, foss, sl vug, 60% yel flu
30	5016.2	to	17.0	4.9	26.8	11.0	9.30	2.71	Lm, foss, sl vug, 35% yel flu
31	5017.4	to	18.0	5.4	27.0	10.2	14.5	2.72	Lm, foss, sl vug, 60% yel flu
32	5018.0	to	18.5	5.2	112	22.0	10.1	2.72	Lm, foss, sl vug, 45% yel flu
33	5019.0	to	19.5	3.5	1.86	1.58	1.72	2.71	Lm, foss, sl vug, 15% yel flu
34	5020.0	to	20.5	4.9	7.40	4.75	4.27	2.71	Lm, foss, sl vug, 40% yel flu
35	5021.0	to	21.6	6.4	67.5	62.0	183	2.71	Lm, foss, sl vug, 70% yel flu
36	5022.0	to	22.3	3.3	4.89	4.6	3.58	2.71	Lm, foss, sl vug, 30% yel flu
37	5023.3	to	23.5	4.8	14.1	7.43	4.15	2.71	Lm, foss, sl vug, 30% yel flu
38	5024.0	to	24.5	5.7	13.9	6.03	7.08	2.70	Lm, foss, sl vug, 25% yel flu
39	5025.0	to	25.5	5.0	14.3	7.60	5.45	2.71	Lm, foss, sl vug, 45% yel flu
40	5026.8			3.7	*	1.75	*	2.71	Lm, foss, sl vug, 20% yel flu
41	5027.0	to	27.5	6.1	572	232	452	2.73	Lm, foss, sl vug, 40% yel flu
42	5028.0	to	28.2	2.4	1.79	1.18	1.00	2.71	Lm, foss, sl vug, 30% yel flu
43	5029.0	to	29.5	7.3	404	310.1	244	2.73	Lm, foss, sl vug, 25% yel flu
44	5030.0	to	30.5	4.5	9.65	6.72	6.50	2.71	Lm, foss, sl vug, 30% yel flu
45	5031.0	to	31.5	5.4	13.3	9.41	16.7	2.72	Lm, foss, sl vug, 45% yel flu
46	5032.0	to	32.6	7.0	145	31.6	321	2.72	Lm, foss, sl vug, 30% yel flu
47	5033.0	to	33.5	5.6	21.82	20.1	20.9	2.72	Lm, foss, sl vug, 25% yel flu
48	5034.0	to	34.4	4.4	7.10	6.66	5.76	2.71	Lm, foss, sl vug, 30% yel flu
49	5035.0	to	35.4	8.5	372	175	113	2.71	Lm, foss, sl vug, 50% yel flu
50	5036.1	to	36.4	5.2	134	29.5	54.2	2.72	Lm, foss, sl vug, 40% yel flu
51	5037.4	to	37.9	7.9	585	575	159	2.72	Lm, foss, sl vug, 30% yel flu
52	5038.3	to	38.8	4.6	21.9	18.4	7.29	2.71	Lm, foss, sl vug, 30% yel flu
53	5039.3			9.1	*	2147	*	2.70	Lm, foss, sl vug, 15% yel flu
54	5040.0	to	40.7	6.3	909	403	88.5	2.73	Lm, foss, sl vug, 20% yel flu
55	5041.5	to	41.8	7.6	2059	1122	29.2	2.74	Lm, foss, sl vug, 40% yel flu
56	5042.0	to	42.6	6.1	113	46.6	31.0	2.71	Lm, foss, sl vug, 40% yel flu
57	5043.0	to	43.6	7.9	2017	798	601	2.71	Lm, foss, sl vug, 40% yel flu
58	5044.0	to	44.5	6.3	1331	1245	376	2.73	Lm, foss, sl vug, 45% yel flu
59	5045.6	to	46.0	6.7	2190	765	998	2.72	Lm, foss, sl vug, 45% yel flu
60	5046.7			5.9	*	273	*	2.70	Lm, foss, sl vug, 10% yel flu

61	5047.3	to	47.7	8.1	2594	1959	1079	2.72	Lim, foss, sl vug, 20% yel flu
62	5048.3	to	49.0	3.3	3.09	2.22	1.64	2.72	Lim, foss, sl vug, 30% yel flu
63	5049.4	to	50.0	6.3	192	68.3	1088	2.72	Lim, foss, sl vug, 65% yel flu
64	5050.5	to	51.0	4.3	19.8	18.6	7.33	2.71	Lim, foss, sl vug, 20% yel flu
65	5051.5	to	52.0	2.3	2.50	0.86	2.58	2.71	Lim, foss, tr% yel flu in frac
66	5052.7	to	53.0	5.7	97.5	50.3	20.7	2.71	Lim, foss, sl vug, 1% yel flu
67	5053.0	to	53.5	3.4	7.34	2.95	1.09	2.72	Lim, foss, sl vug, tr% yel flu
68	5054.0	to	54.8	2.4	1.77	1.14	3.38	2.71	Lim, foss, sl vug, tr% yel flu
69	5055.3	to	55.8	2.3	1.58	0.99	0.95	2.71	Lim, foss, sl vug, tr% yel flu
70	5056.1	to	56.8	2.1	6.58	3.58	1.17	2.72	Lim, foss, 1% yel flu
71	5057.3	to	58.0	1.0	0.25	0.12	0.71	2.71	Lim, foss, 1% yel flu
72	5058.0	to	58.4	0.9	0.26	0.07	0.43	2.71	Lim, foss, 5% yel flu
73	5059.0	to	59.8	0.8	0.10	0.10	0.04	2.71	Lim, foss, 5% yel flu
74	5060.2	to	61.0	1.1	0.38	0.20	0.30	2.71	Lim, foss, tr% yel flu
75	5061.0	to	61.5	1.3	0.36	0.34	0.40	2.71	Lim, foss, 10% yel flu
76	5062.2	to	63.0	0.8	5.34	0.05	0.49	2.71	Lim, foss, 1% yel flu
77	5063.3	to	63.7	0.8	0.35	0.35	1.63	2.71	Lim, foss, 5% yel flu
78	5064.0	to	64.7	0.9	0.25	0.07	2.93	2.71	Lim, foss, 0% flu
79	5065.3	to	65.6	0.7	0.09	0.06	0.11	2.71	Lim, foss, 0% flu
80	5066.1			0.7	*	<0.01	*	2.70	Lim, foss, 0% flu
81	5067.0	to	67.8	1.0	1.31	0.79	3.81	2.71	Lim, foss, 0% flu
82	5068.0	to	68.4	0.7	0.21	0.12	1.07	2.70	Lim, foss, 0% flu
83	5069.1	to	69.7	0.8	0.21	0.03	0.09	2.71	Lim, foss, 0% flu
84	5070.4	to	70.8	0.6	15.4	0.49	1.40	2.70	Lim, foss, 0% flu
85	5071.0	to	71.5	0.5	0.22	0.06	0.58	2.71	Lim, foss, 0% flu
86	5072.2	to	72.7	0.5	0.67	0.05	1.15	2.71	Lim, foss, 0% flu
87	5073.0	to	73.6	0.6	0.42	0.18	0.03	2.71	Lim, foss, 0% flu
88	5074.0	to	74.7	0.7	0.07	0.04	0.03	2.71	Lim, foss, 0% flu
89	5075.0	to	75.8	0.7	1.65	0.78	1.20	2.71	Lim, foss, 0% flu
90	5076.5	to	77.0	1.2	0.69	0.05	0.57	2.71	Lim, foss, tr% yel flu
91	5077.3	to	78.0	0.9	1.09	0.08	2.74	2.71	Lim, foss, tr% yel flu
92	5078.0	to	78.3	0.9	0.35	0.19	0.84	2.71	Lim, foss, tr% yel flu
93	5079.3	to	80.0	0.8	0.41	0.11	0.55	2.71	Lim, foss, tr% yel flu
94	5080.3			0.9	*	0.01	*	2.70	Lim, foss, 0% flu
95	5081.0	to	81.8	1.1	0.60	0.37	0.48	2.71	Lim, foss, 0% flu
96	5082.1	to	82.8	0.6	0.03	0.02	6.46	2.71	Lim, foss, 0% flu
97	5083.3			0.6	*	<0.01	*	2.70	Lim, foss, 0% flu
98	5084.0	to	84.8	1.1	0.50	0.48	1.62	2.71	Lim, foss, 0% flu
99	5085.4	to	85.9	0.5	0.08	0.03	0.02	2.71	Lim, foss, 0% flu
100	5086.4	to	86.9	0.7	0.66	0.11	0.08	2.71	Lim, foss, tr% yel flu
101	5087.0	to	87.5	0.6	0.42	0.07	0.08	2.71	Lim, foss, 0% flu
102	5088.0	to	88.8	0.5	0.12	0.12	0.03	2.70	Lim, foss, 0% flu
103	5089.5	to	90.0	1.3	0.35	0.23	0.22	2.71	Lim, foss, 0% flu
104	5090.0	to	90.7	1.7	15.1	0.23	1.16	2.71	Lim, foss, sl vug, 0% flu
105	5091.3			1.7	*	<0.01	*	2.70	Lim, foss, tr% yel flu
106	5092.3	to	92.9	1.0	226	0.11	244	2.70	Lim, foss, tr% yel flu
107	5093.0	to	93.8	0.8	2.26	0.12	0.35	2.70	Lim, foss, tr% yel flu
108	5094.4	to	94.8	0.9	0.36	0.15	0.02	2.70	Lim, foss, tr% yel flu
109	5095.3	to	96.0	1.9	1.08	0.78	0.40	2.70	Lim, foss, sl vug, 0% flu
110	5096.0	to	96.5	1.9	2.47	1.01	50.4	2.70	Lim, foss, sl vug, 0% flu
111	5097.4			1.1	*	<0.01	*	2.70	Lim, foss, sl vug, 0% flu
112	5098.5	to	99.0	2.9	212	4.83	0.49	2.71	Lim, foss, sl vug, 0% flu
113	5099.0	to	99.5	3.0	0.86	0.24	0.85	2.71	Lim, foss, sl vug, 0% flu
114	5100.5	to	1.0	2.8	0.57	0.56	0.40	2.71	Lim, foss, sl vug, 0% flu
115	5101.0	to	1.8	2.6	0.46	0.20	0.67	2.70	Lim, foss, 0% flu
116	5102.6	to	3.0	2.7	0.70	0.52	0.62	2.70	Lim, sl frac, foss, 0% flu
117	5103.0	to	3.8	3.0	1.27	1.25	2.74	2.70	Lim, sl frac, foss, 0% flu
118	5104.6	to	5.0	3.4	0.76	0.63	0.70	2.70	Lim, sl frac, foss, 0% flu
119	5105.2			2.1	*	0.07	*	2.68	Lim, sl frac, foss, 0% flu
120	5106.7	to	7.0	1.3	0.10	0.02	0.31	2.77	Lim, v/dol, sl frac, 0% flu

* Indicates plug analysis.

Company: MARJO OPERATING COMPANY, INC.
Well: JB No. 1-13

Location: LOGAN COUNTY, OKLAHOMA
SEC. 13, T15N-R1E

Date: 6/12/2001
Files: SL 6112 and CL 57181-18317

ROUTINE CORE ANALYSIS

Sample	Depth			Helium	Air Permeability			Grain	Lithology
I.D.	Top feet		Bottom feet	Porosity %	Kmax md	K90 md	Kvert md	Density g/cm	
1	4971.5								Too Broken For Analysis: Sh, slty, sl pyr, 35% yel flu
2	4972.7	to	73.0	2.2	1.86	0.13	0.09	2.73	Ls, sli/frac, vug, styl, 30% yel flu
3	4973.3	to	73.9	2.4	0.46	0.33	0.68	2.71	Ls, sli/frac, vug, styl, 35% yel flu
4	4974.4	to	75.0	2.1	0.20	0.16	0.12	2.71	Ls, vug, 40% yel flu
5	4975.0	to	75.4	1.9	0.54	0.53	0.26	2.71	Ls, vug, 40% yel flu
6	4976.1	to	76.6	2.0	8.11	0.37	1011	2.70	Ls, vert/frac, vug, 40% yel flu
7	4977.4	to	78.0	2.3	2.06	1.53	0.85	2.70	Ls, vug, 85% yel flu
8	4978.0	to	78.6	3.3	2.43	1.56	0.17	2.71	Ls, sli/frac, vug, styl, 80% yel flu
9	4979.6	to	80.0	2.2	4.57	2.24	10.1	2.70	Ls, frac, vug, 80% yel flu
10	4980.4	to	81.0	1.7	0.65	0.21	3.24	2.70	Ls, vert/frac, vug, 75% yel flu
11	4981.0	to	81.3	3.2	1.11	0.29	709	2.70	Ls, vug, foss, 90% yel flu
12	4982.1	to	82.8	3.0	3.40	0.75	0.80	2.72	Ls, sli/frac, vug, foss, styl, 70% yel flu
13	4983.9			2.1	*	1.06	*	2.71	Ls, frac, vug, styl, 40% yel flu
14	4984.7			1.1	*	0.02	*	2.70	Ls, frac, foss, 30% yel flu
15	4985.7			2.0	*	0.05	*	2.70	Ls, frac, 65% yel flu
16	4986.4	to	87.0	4.8	6.52	1.75	20.6	2.72	Ls, vug, foss, 70% yel flu
17	4987.0	to	87.4	2.2	859	1.01	145	2.70	Ls, vert/frac, sli/vug, 80% yel flu
18	4988.4	to	89.0	3.8	2.60	2.30	0.48	2.72	Ls, vug, 90% yel flu
19	4989.3	to	89.9	2.5	1.23	0.87	0.32	2.71	Ls, vug, 70% yel flu
20	4990.0	to	90.4	2.3	3.31	0.72	0.85	2.75	Ls, vug, 80% yel flu
21	4991.4	to	92.0	2.6	0.41	0.37	0.46	2.70	Ls, vug, 80% yel flu
22	4992.4	to	93.0	2.7	0.53	0.44	0.24	2.71	Ls, vug, 75% yel flu
23	4993.0	to	93.4	1.4	0.04	0.04	0.30	2.71	Ls, vug, 65% yel flu
24	4994.8			0.8	*	0.02	*	2.71	Ls, frac, 30% yel flu
25	4995.7			1.2	*	0.02	*	2.71	Ls, frac, 40% yel flu
26	4996.1	to	96.5	3.7	4.74	0.51	7.39	2.72	Ls, frac, vug, 65% yel flu
27	4997.0	to	97.4	1.2	0.09	0.05	0.04	2.71	Ls, vug, styl, 60% yel flu
28	4998.7	to	99.0	1.4	0.38	0.18	0.22	2.71	Ls, frac, vug, 90% yel flu
29	4999.0	to	99.3	2.0	3.39	0.54	9.89	2.70	Ls, frac, sli/vug, 95% yel flu
30	5000.1	to	0.7	2.3	0.22	0.12	0.10	2.72	Ls, sli/vug, 85% yel flu
31	5001.2			1.3	*	0.01	*	2.70	Ls, frac, vug, 10% yel flu
32	5002.5	to	3.0	2.6	3.42	0.71	0.29	2.72	Ls, vert/frac, vug, 35% yel flu
33	5003.8			1.2	*	0.01	*	2.71	Ls, frac, vug, 20% yel flu
34	5004.0	to	4.8	2.5	0.55	0.31	0.56	2.71	Ls, vug, 65% yel flu
35	5005.0	to	5.4	1.9	0.75	0.22	1.13	2.71	Ls, vug, 70% yel flu
36	5006.4	to	7.0	2.5	1.01	0.81	0.33	2.73	Ls, vug, 40% yel flu
37	5007.3			1.4	*	0.01	*	2.72	Ls, frac, 45% yel flu
38	5008.4	to	9.0	2.8	2.92	2.13	0.22	2.72	Ls, 75% yel flu
39	5009.3	to	9.9	1.8	0.33	0.33	0.28	2.72	Ls, vug, 30% yel flu
40	5010.0	to	10.6	1.1	0.18	0.16	0.11	2.71	Ls, vug, 60% yel flu
41	5011.4	to	12.0	1.0	2.05	0.19	0.30	2.71	Ls, sli/frac, styl, 80% yel flu
42	5012.0	to	12.4	1.5	13.6	0.11	0.28	2.70	Ls, sli/vug, styl, 70% yel flu
43	5013.0	to	13.6	1.2	0.18	0.08	0.98	2.70	Ls, sli/vug, 60% yel flu
44	5014.0	to	14.6	1.7	0.45	0.44	0.30	2.71	Ls, vug, foss, styl, 55% yel flu

45	5015.8			1.0	*	0.16	*	2.70	Ls, frac, tr% flu
46	5016.0	to	16.5	1.9	61.4	0.14	48.2	2.71	Ls, vert/frac, vug, styl, 10% yel flu
47	5017.4	to	18.0	1.4	0.08	0.06	0.04	2.73	Ls, vert/frac, pp, foss, 5% yel flu
48	5018.8			1.2	*	<0.01	*	2.73	Ls, frac, 5% yel flu
49	5019.5	to	19.9	1.4	991	0.35	360	2.72	Ls, vert/frac, styl, 45% yel flu
50	5020.6	to	21.0	2.4	6.00	3.76	1.45	2.72	Ls, frac, vug, styl, 40% yel flu
51	5021.8	to	22.0	1.6	0.17	0.02	0.09	2.76	Ls, sli/frac, vug, 45% yel flu
52	5022.4	to	23.0	1.8	1.08	0.63	1.99	2.72	Ls, vert/frac, vug, styl, 45% yel flu
53	5023.5	to	24.0	1.8	0.35	0.33	0.26	2.73	Ls, vert/frac, sli/vug, 45% yel flu
54	5024.4	to	25.0	1.4	0.37	0.19	0.27	2.72	Ls, vert/frac, sli/vug, foss, 55% yel flu
55	5025.3	to	25.8	1.8	0.85	0.35	0.59	2.71	Ls, sli/vug, foss, styl, 65% yel flu
56	5026.0	to	26.6	0.9	0.15	0.07	0.09	2.71	Ls, sli/vug, 50% yel flu
57	5027.0	to	27.4	0.8	0.03	0.01	0.01	2.72	Ls, 70% yel flu
58	5028.2	to	29.0	1.3	*	<0.01	*	2.71	Ls, frac, vug, foss, 15% yel flu
59	5029.0	to	30.0	1.4	72.9	0.09	43.5	2.70	Ls, vert/frac, vug, 80% yel flu
60	5030.0	to	31.0	1.5	0.51	0.21	0.30	2.70	Ls, sli/frac, sli/vug, foss, 80% yel flu
61	5031.2	to	31.6	1.3	0.32	0.31	0.38	2.71	Ls, frac, vug, 80% yel flu
62	5032.5	to	32.9	1.3	0.36	0.21	0.45	2.71	Ls, frac, sli/vug, 60% yel flu
63	5033.0	to	33.6	1.0	1.27	0.19	0.51	2.71	Ls, vert/frac, sli/vug, 65% yel flu
64	5034.6	to	35.0	1.1	0.37	0.16	3.41	2.71	Ls, frac, styl, 75% yel flu
65	5035.0	to	36.6	1.4	0.81	0.49	0.59	2.71	Ls, vug, 80% yel flu
66	5036.2	to	36.6	1.3	0.26	0.16	0.09	2.70	Ls, sli/frac, vug, 60% yel flu
67	5037.2			1.1	*	0.03	*	2.70	Ls, frac, vug, 55% yel flu
68	5038.0	to	38.3	1.9	1.18	0.79	1.56	2.70	Ls, vug, styl, 85% yel flu
69	5039.0	to	39.6	2.5	2.93	1.22	0.37	2.70	Ls, vug, 85% yel flu
70	5040.0	to	40.6	3.5	1.42	0.90	0.34	2.71	Ls, vug, 85% yel flu
71	5041.0	to	41.6	1.9	0.53	0.52	0.49	2.70	Ls, vert/frac, vug, 90% yel flu
72	5042.6	to	43.0	2.3	0.43	0.43	0.21	2.70	Ls, vug, 90% yel flu
73	5043.0	to	43.4	2.7	1.74	1.58	0.43	2.71	Ls, vug, 95% yel flu
74	5044.2			2.2	*	0.08	*	2.71	Ls, frac, vug, 80% yel flu
75	5045.9			1.1	*	<0.01	*	2.71	Ls, frac, vug, 70% yel flu
76	5046.6	to	47.0	2.0	0.11	0.10	0.03	2.71	Ls, vug, styl, 70% yel flu
77	5047.0	to	47.6	2.7	1.38	0.66	0.75	2.71	Ls, vug, 80% yel flu
78	5048.0	to	48.3	2.1	1751	0.45	1526	2.71	Ls, vert/frac, vug, 70% yel flu
79	5049.0	to	49.6	0.7	0.51	0.12	0.50	2.71	Ls, sli/frac, sli/vug, 35% yel flu
80	5050.0	to	50.4	1.0	0.21	0.16	0.55	2.71	Ls, vug, 30% yel flu
81	5051.0	to	51.4	1.7	0.09	0.07	0.04	2.71	Ls, vug, 45% yel flu
82	5052.6	to	53.0	1.2	0.07	0.03	0.06	2.71	Ls, vug, styl, 60% yel flu
83	5053.0	to	53.3	1.5	0.07	0.05	0.03	2.71	Ls, vert/frac, sli/vug, 40% yel flu
84	5054.6	to	55.0	1.1	0.35	0.28	0.83	2.71	Ls, vug, 20% yel flu
85	5055.6	to	56.0	1.2	0.33	0.10	0.40	2.71	Ls, sli/vug, 15% yel flu
86	5056.6	to	57.0	1.0	0.06	0.02	0.08	2.71	Ls, sli/vug, 10% yel flu
87	5057.0	to	57.6	1.4	0.25	0.07	0.13	2.71	Ls, vug, 10% yel flu
88	5058.0	to	58.5	1.0	0.29	0.08	0.06	2.71	Ls, vug, foss, 5% yel flu
* indicates plug analysis				1.8					

Company: MARJO OPERATING COMPANY, INC.
Well: MARK HOUSER No. 1-11
Location: LOGAN COUNTY, OKLAHOMA
SEC. 11, T15N-R1E

Date: 5/30/2001
Files: SL6100 and CL57181-18313

ROUTINE CORE ANALYSIS

	Depth			Helium	Air Permeability			Grain	
Sample I.D.	Top feet		Bottom feet	Porosity %	Kmax md	K90 md	Kvert md	Density g/cm	Lithology
1	4961.1	to	61.7	1.9	0.04	0.03	0.01	2.70	Ls, tr% yel flu
2	4962.3	to	63.0	0.9	0.04	0.03	0.04	2.71	Ls, styl, 5% yel flu
3	4963.0	to	63.7	0.9	0.42	0.06	0.04	2.71	Ls, styl, 5% yel flu
4	4964.2	to	65.0	2.3	2.47	0.06	0.23	2.70	Ls, sh lam, styl, 5% yel flu
5	4965.5	to	66.0	1.0	0.04	0.03	0.03	2.70	Ls, sh lam, tr% yel flu in frac
6	4966.5	to	67.0	1.1	0.05	0.04	0.05	2.70	Ls, sh lam, 10% org flu
7	4967.4	to	68.0	0.8	0.03	0.03	0.02	2.70	Ls, styl, 10% org flu
8	4968.0	to	68.4	0.8	0.03	0.01	0.02	2.70	Ls, styl, 0% flu
9	4969.0	to	69.7	1.4	0.15	0.06	0.12	2.73	Ls, styl, tr% yel flu
10	4970.4	to	71.0	0.9	0.20	0.13	0.07	2.71	Ls, styl, tr% yel flu
11	4971.0	to	71.8	0.8	0.07	0.05	0.05	2.71	Ls, styl, tr% yel flu
12	4972.5	to	73.0	0.4	0.08	0.04	0.03	2.71	Ls, sli/frac, foss, styl, tr% yel flu
13	4973.5	to	74.0	0.7	0.08	0.08	<.01	2.71	Ls, styl, 5% yel flu
14	4974.0	to	74.7	0.8	0.11	0.07	0.04	2.71	Ls, styl, 10% yel flu
15	4975.0	to	75.8	0.8	0.05	0.04	0.03	2.71	Ls, sli/frac, styl, 10% yel flu
16	4976.1	to	76.8	0.8	0.02	0.02	0.01	2.71	Ls, styl, 5% yel flu
17	4977.0	to	77.8	1.0	0.49	0.11	<.01	2.71	Ls, styl, 5% yel flu
18	4978.5	to	79.0	1.6	0.13	0.09	0.02	2.72	Ls, styl, tr% yel flu
19	4979.5	to	80.0	1.3	0.06	0.05	0.03	2.70	Ls, 20% yel flu
20	4980.0	to	80.6	1.3	0.09	0.09	0.05	2.71	Ls, 20% yel flu
21	4981.0	to	81.8	2.1	0.85	0.31	0.15	2.70	Ls, pp, styl, 40% yel flu
22	4982.5	to	83.0	2.4	3.52	0.20	0.03	2.70	Ls, styl, 10% yel flu
23	4983.0	to	83.6	1.5	1.62	0.08	0.86	2.70	Ls, styl, 5% yel flu
24	4984.2	to	85.0	1.5	0.23	0.15	0.41	2.71	Ls, tr% yel flu
25	4985.2	to	86.0	1.0	0.06	0.04	0.15	2.71	Ls, styl, 5% yel flu
26	4986.2	to	87.0	0.9	0.02	0.02	0.03	2.72	Ls, 5% yel flu
27	4987.0	to	87.5	1.0	0.02	0.02	<.01	2.72	Ls, 5% yel flu
28	4988.2	to	89.0	0.9	0.02	0.02	0.03	2.71	Ls, 5% yel flu
29	4989.0	to	89.8	0.9	0.03	0.03	0.02	2.71	Ls, tr% yel flu
30	4990.0	to	90.7	0.9	0.02	0.02	<.01	2.71	Ls, tr% yel flu
31	4991.0	to	91.8	0.8	0.02	0.02	0.02	2.71	Ls, styl, tr% yel flu
32	4992.0	to	92.6	0.9	0.02	0.00	<.01	2.72	Ls, styl, 5% yel flu
33	4993.0	to	93.8	0.8	0.04	0.04	0.02	2.71	Ls, styl, 5% yel flu
34	4994.5	to	95.0	0.5	0.02	0.02	<.01	2.71	Ls, 5% yel flu
35	4995.0	to	95.7	0.8	0.04	0.04	0.01	2.71	Ls, 10% yel flu
36	4996.2	to	97.0	0.9	0.04	0.03	0.02	2.71	Ls, 5% yel flu
37	4997.4	to	98.0	1.0	0.06	0.04	0.03	2.71	Ls, styl, tr% yel flu
38	4998.5	to	99.0	0.6	0.02	0.02	<.01	2.71	Ls, 5% yel flu
39	4999.3	to	99.8	0.9	0.07	0.04	0.02	2.71	Ls, styl, 5% yel flu
40	5000.2	to	1.0	1.0	0.06	0.03	0.02	2.71	Ls, styl, 5% yel flu
41	5001.0	to	1.5	0.8	0.16	0.05	0.02	2.71	Ls, 10% brt-yel flu
42	5002.2	to	3.0	0.8	0.04	0.03	0.05	2.71	Ls, styl, 5% brt-yel flu
43	5003.0	to	3.6	0.9	0.04	0.02	0.02	2.71	Ls, styl, tr% yel flu
44	5004.2	to	5.0	1.2	1.85	0.08	0.46	2.71	Ls, styl, 15% brt-yel flu
45	5005.0	to	5.5	1.7	0.12	0.11	0.04	2.71	Ls, 30% brt-yel flu
46	5006.1	to	6.4	2.0	0.16	0.08	0.29	2.70	Ls, styl, 30% brt-yel flu
47	5007.8	to	8.0	0.8	0.30	0.01	47.1	2.70	Ls, 26% dull gold flu
48	5008.4	to	9.0	1.2	1.64	0.04	0.03	2.71	Ls, vert/frac, 10% dull gold flu
49	5009.3	to	9.8	1.3	3.21	0.83	0.52	2.71	Ls, sli/frac, sli/vug, 10% dull gold flu
50	5010.3	to	10.7	1.5	33.4	0.41	10.1	2.70	Ls, sli/frac, pp, 5% dull gold flu
51	5011.5	to	12.0	1.8	1.04	0.13	<.01	2.70	Ls, sli/vug, 40% dull gold flu
52	5012.2	to	13.0	3.7	6.80	4.67	1.66	2.71	Ls, sli/frac, pp, 15% dull gold flu
53	5013.7	to	14.0	1.8	0.38	0.10	1.67	2.71	Ls, sli/frac, sli/vug, 5% dull gold flu
54	5014.4	to	15.0	1.6	0.18	0.04	708	2.72	Ls, sli/frac, 5% dull gold flu
55	5015.4	to	15.9	1.1	4.16	0.03	0.04	2.71	Ls, frac, tr% yel flu
56	5016.0	to	16.2	0.9	0.17	0.14	0.17	2.70	Ls, frac, tr% yel flu
57	5017.0	to	17.7	0.7	0.17	0.06	0.23	2.71	Ls, frac, styl, tr% yel flu
58	5018.0	to	18.7	0.6	0.10	0.07	0.10	2.71	Ls, frac, styl, tr% yel flu
59	5019.6			0.4	*	<.01	*	2.71	Ls, frac, tr% yel flu
60	5020.6			0.6	*	0.01	*	2.71	Ls, frac, tr% yel flu

61	5021.5			1.0	*	0.02	*	2.70	Ls, frac, 0% flu
62	5022.3	to	23	0.7	0.31	0.13	0.32	2.72	Ls, vert/frac, styl, tr% yel flu
63	5023.0	to	23.7	1.4	0.61	0.44	298	2.71	Ls, vert/frac, tr% yel flu in frac
64	5024.3	to	25	1.9	10.2	9.94	7.55	2.71	Ls, vert/frac, sli/vug, tr% yel flu in frac
65	5025.0	to	25.7	1.7	1.08	0.26	2.28	2.70	Ls, vert/frac, sli/vug, tr% yel flu in frac
66	5026.6			1.0	*	0.02	*	2.71	Ls, vert/frac, sli/vug, tr% yel flu
67	5027.5	to	28	1.7	0.05	0.05	0.04	2.71	Ls, sli/vug, 5% yel flu
68	5028.0	to	28.3	2.6	4.11	0.63	0.35	2.71	Ls, sli/vug, styl, 5% yel flu
69	5029.0	to	29.7	2.0	0.22	0.17	0.22	2.71	Ls, sli/vug, tr% yel flu in frac
70	5030.3			0.6	*	<.01	*	2.71	Ls, frac, 0% flu
71	5031.3	to	31.9	1.0	1.11	0.45	0.37	2.71	Ls, frac, 0% flu
72	5032.5			0.8	*	0.00	*	2.71	Ls, frac, 0% flu
73	5033.3			1.2	*	0.13	*	2.70	Ls, frac, 0% flu
74	5034.3			0.9	*	0.01	*	2.71	Ls, frac, 0% flu
75	5035.0	to	35.7	1.9	3.43	2.86	0.47	2.71	Ls, frac, tr% yel flu
76	5036.1			1.2	*	0.03	*	2.71	Ls, frac, tr% yel flu
77	5037.6			0.9	*	0.01	*	2.71	Ls, frac, tr% yel flu
78	5038.2			1.1	*	<.01	*	2.70	Ls, frac, 0% flu
79	5039.1			0.9	*	0.01	*	2.71	Ls, frac, 0% flu
80	5040.3	to	41	1.6	1.16	0.80	5.28	2.70	Ls, frac, tr% yel flu
81	5041.1			1.1	*	0.14	*	2.70	Ls, frac, 0% flu
82	5042.0	to	42.7	1.7	0.14	0.13	3.68	2.71	Ls, frac, tr% yel flu
83	5043.5	to	44	2.1	1.22	0.85	1.77	2.72	Ls, frac, pp, 5% yel flu
84	5044.0	to	44.6	1.2	0.47	0.24	0.79	2.71	Ls, frac, styl, 5% yel flu
85	5045.0	to	45.4	0.7	0.08	0.05	0.18	2.71	Ls, sli/frac, styl, 0% flu
86	5046.4	to	46.7	0.8	0.09	0.07	0.03	2.70	Ls, sli/frac, tr% yel flu in frac
87	5047.0	to	47.7	1.2	0.70	0.41	0.65	2.71	Ls, vert/frac, styl, 0% flu
88	5048.6	to	49	1.6	10.8	2.45	27.3	2.69	Ls, frac, styl, 5% yel flu
89	5049.7	to	50	1.3	0.16	0.15	0.06	2.69	Ls, frac, styl, 5% yel flu
90	5050.3	to	51	1.6	1.59	0.39	0.33	2.71	Ls, styl, 5% yel flu
91	5051.0	to	51.6	1.5	0.78	0.22	0.12	2.70	Ls, vert/frac, styl, 5% yel flu
92	5052.3	to	53	1.5	0.60	0.27	0.19	2.70	Ls, styl, 5% yel flu
93	5053.0	to	53.7	1.0	0.25	0.52	0.06	2.71	Ls, sli/frac, 5% yel flu
94	5054.3	to	55	1.4	0.30	0.28	0.13	2.70	Ls, 5% yel flu
95	5055.0	to	53.4	1.4	0.75	0.43	0.21	2.71	Ls, frac, 5% yel flu
96	5056.0	to	56.7	1.7	1.10	0.81	0.27	2.71	Ls, frac, vug, tr% yel flu
97	5057.4	to	58	1.0	0.22	0.21	0.11	2.71	Ls, styl, tr% yel flu
98	5058.3	to	59	1.1	0.08	0.08	0.08	2.71	Ls, 0% flu
99	5059.4	to	60	0.9	<.01	<.01	0.02	2.71	Ls, 0% flu
100	5060.0	to	60.7	0.9	0.02	0.02	0.01	2.71	Ls, 0% flu
101	5061.5	to	61.9	1.2	0.03	0.02	0.02	2.71	Ls, tr% yel flu
102	5062.3	to	63	1.4	0.08	0.07	0.19	2.71	Ls, styl, 5% yel flu
103	5063.5	to	64	3.1	0.25	0.22	0.65	2.71	Ls, vug, foss, 5% yel flu
104	5064.0	to	64.5	4.9	529	1.19	849	2.73	Ls, vug, foss, tr% yel flu
105	5065.0	to	65.6	1.1	0.09	0.03	0.09	2.72	Ls, styl, tr% yel flu
106	5066.3	to	67	1.5	0.12	0.03	0.03	2.72	Ls, styl, 5% yel flu
107	5067.0	to	67.6	1.2	0.44	0.19	0.02	2.71	Ls, styl, 5% yel flu
108	5068.3	to	69	0.9	0.08	0.07	0.03	2.72	Ls, styl, 5% yel flu
109	5069.4			2.5	*	0.04	*	2.72	Ls, frac, tr% yel flu
110	5070.3	to	70.8	3.8	1.30	0.15	1.08	2.78	Ls, sli/dol, vug, 5% yel flu
111	5071.1			2.7	*	<.01	*	2.74	Ls, frac, vug, tr% yel flu
112	5072.0	to	72.7	2.1	0.18	0.07	1.35	2.74	Ls, sli/vug, tr% yel flu
113	5073.0	to	73.7	0.8	0.03	<.01	1.08	2.72	Ls, styl, tr% yel flu
114	5074.1			0.5	*	<.01	*	2.71	Ls, frac, 0% flu
115	5075.5			0.9	*	0.02	*	2.70	Ls, frac, sli/vug, 15% yel flu
116	5076.2			0.7	*	<.01	*	2.71	Ls, frac, tr% yel flu
117	5077.5			1.2	*	0.01	*	2.71	Ls, frac, 0% flu

* Indicates plug analysis.

Company: MARJO OPERATING COMPANY, INC.
Well: CAL No. 1-11

Location: LOGAN COUNTY, OKLAHOMA
SEC. 11, T15N-R1E

Date: 5/30/2001
Files: SL 6088 and CL 57181-18302

ROUTINE CORE ANALYSIS

Sample I.D.	Depth Top feet		Depth Bottom feet	Helium Porosity %	Air Permeability Kmax md	Air Permeability K90 md	Air Permeability Kvert md	Grain Density g/cm	Lithology
1	5034.1	to	34.7	1.0	0.05	0.03	0.01	2.70	Ls, styl, 0% flu
2	5035.4	to	35.3	4.4	0.88	0.45	0.12	2.72	Ls, sli/vug, foss, 40% yel flu
3	5036.4	to	37.0	0.7	0.02	0.02	0.03	2.71	Ls, styl, tr% yel flu
4	5037.2	to	37.8	0.7	0.05	0.03	0.04	2.71	Ls, styl, 0% flu
5	5038.0	to	38.6	0.7	0.09	0.08	0.08	2.71	Ls, sli/frac, styl, 0% flu
6	5039.4	to	40.0	0.6	0.26	0.10	0.17	2.71	Ls, sli/frac, styl, 0% flu
7	5040.4	to	41.0	0.6	2512	0.07	159	2.71	Ls, vert/frac, styl, 0% flu
8	5041.0	to	41.4	0.5	0.08	0.05	0.03	2.71	Ls, styl, tr% yel flu
9	5042.1	to	42.6	0.5	0.33	0.13	0.03	2.71	Ls, frac, foss, styl, 5% yel flu
10	5043.4	to	44.0	0.7	0.19	<0.01	5.15	2.71	Ls, sli/frac, styl, 0% flu
11	5044.5	to	44.9	0.6	1908	0.08	220	2.70	Ls, vert/frac, styl, 0% flu
12	5045.7	to	45.9	0.5	0.41	0.21	0.22	2.71	Ls, styl, tr% yel flu
13	5046.2	to	46.8	1.4	0.18	0.08	0.08	2.71	Ls, sli/vug, tr% yel flu
14	5047.1	to	47.5	0.7	0.11	0.08	0.08	2.71	Ls, vert/frac, 0% flu
15	5048.0	to	48.6	0.7	228	0.15	0.04	2.71	Ls, vert/frac, styl, 5% yel flu
16	5049.0	to	49.6	0.8	0.13	0.04	0.03	2.71	Ls, styl, 5% yel flu
17	5050.0	to	50.6	1.0	0.09	0.07	0.01	2.71	Ls, 5% yel flu
18	5051.0	to	51.7	1.0	0.10	0.09	0.04	2.71	Ls, styl, 5% yel flu
19	5052.3	to	53.0	0.9	0.12	0.09	<0.01	2.70	Ls, styl, 0% flu
20	5053.6	to	54.0	0.9	0.07	0.07	0.02	2.70	Ls, styl, tr% yel flu
21	5054.0	to	54.6	1.0	0.09	0.07	<0.01	2.71	Ls, styl, 0% flu
22	5055.1	to	55.6	1.4	0.06	0.05	0.02	2.70	Ls, sli/vug, styl, tr% yel flu in frac
23	5056.4	to	57.0	1.0	0.17	<0.01	0.30	2.70	Ls, styl, 5% yel flu
24	5057.4	to	58.0	1.2	0.35	0.21	0.07	2.70	Ls, styl, 10% yel flu
25	5058.1	to	58.5	0.6	0.10	0.10	0.02	2.70	Ls, styl, tr% yel flu
26	5059.4	to	60.0	0.9	339	0.12	57.8	2.70	Ls, vert/frac, styl, 5% yel flu
27	5060.4	to	60.9	0.6	2.54	<0.01	0.56	2.70	Ls, styl, tr% yel flu in frac
28	5061.3	to	62.0	0.8	2.27	1.23	0.08	2.71	Ls, styl, tr% yel flu in frac
29	5062.4	to	63.0	1.9	5.44	2.20	3.26	2.71	Ls, vug, 20% yel flu
30	5063.0	to	63.5	2.3	35.1	7.93	16.5	2.70	Ls, vug, 20% yel flu
31	5064.0	to	64.7	2.0	3.43	1.40	0.89	2.71	Ls, vug, styl, 20% yel flu
32	5065.1	to	65.3	1.2	1.22	0.26	0.73	2.70	Ls, sli/frac, sli/vug, 10% yel flu
33	5066.2	to	66.6	0.8	1.08	0.08	0.26	2.70	Ls, sli/frac, tr% yel flu in frac
34	5067.0	to	67.6	1.6	0.16	0.15	0.06	2.71	Ls, vug, tr% yel flu
35	5068.0	to	68.5	1.7	5.90	0.03	3.99	2.70	Ls, styl, tr% yel flu in frac
36	5069.3	to	69.9	1.8	3.88	0.10	0.43	2.71	Ls, sli/vug, styl, 5% yel flu
37	5070.4	to	71.0	2.6	15.8	0.24	17.5	2.70	Ls, vert/frac, sli/vug, styl, tr% yel flu
38	5071.3	to	72.0	1.5	0.60	0.43	0.36	2.71	Ls, styl, tr% yel flu
39	5072.3	to	73.0	2.5	0.50	0.31	0.18	2.71	Ls, sli/vug, styl, tr% yel flu in frac
40	5073.0	to	73.4	1.7	1.71	0.04	1.29	2.70	Ls, sli/vug, styl, tr% yel flu
41	5074.1	to	74.6	1.1	1.87	0.01	2.01	2.70	Ls, styl, tr% yel flu
42	5075.0	to	75.5	0.9	0.48	0.20	0.10	2.70	Ls, styl, 0% flu
43	5076.4	to	76.9	1.1	<0.01	<0.01	<0.01	2.71	Ls, pp, styl, 5% yel flu
44	5077.3	to	78.0	1.1	0.23	0.02	0.46	2.71	Ls, vert/frac, pp, styl, 5% yel flu
45	5078.0	to	78.6	0.9	<0.01	<0.01	0.02	2.71	Ls, styl, 0% flu
46	5079.3	to	80.0	0.6	0.07	0.06	0.04	2.71	Ls, styl, 0% flu
47	5080.3	to	81.0	0.8	0.14	0.05	0.04	2.71	Ls, styl, 0% flu
48	5081.0	to	81.5	0.5	0.03	0.03	0.00	2.70	Ls, styl, tr% yel flu
49	5082.0	to	82.6	0.7	0.10	<0.01	0.05	2.71	Ls, vert/frac, styl, tr% yel flu
50	5083.0	to	83.6	0.6	0.01	<0.01	0.01	2.71	Ls, styl, tr% yel flu
51	5084.1	to	84.7	0.6	0.03	0.03	<0.01	2.71	Ls, styl, 0% flu

52	5085.3	to	86.0	0.6	0.02	0.02	<0.01	2.71	Ls, styl, 0% flu
53	5086.3	to	87.0	0.5	0.09	0.02	<0.01	2.71	Ls, styl, tr% yel flu
54	5087.0	to	87.5	0.6	0.03	0.01	0.03	2.72	Ls, styl, 5% yel flu
55	5088.0	to	88.6	1.4	0.33	0.06	0.50	2.71	Ls, sli/frac, styl, 5% yel flu
56	5089.1	to	89.3	1.5	0.69	0.52	41.7	2.70	Ls, vert/frac, styl, tr% yel flu
57	5090.1	to		0.9	*	0.02	*	2.71	Ls, frac, 0% flu
58	5091.6	to	92.0	0.9	0.23	0.15	1.80	2.70	Ls, frac, tr% yel flu in frac
59	5092.6	to		1.9	*	0.41	*	2.70	Ls, frac, pp, 0% flu
60	5093.1	to		1.0	*	0.03	*	2.70	Ls, frac, pp, 0% flu
61	5094.1	to	94.8	1.8	1.22	0.85	0.16	2.71	Ls, sli/vug, styl, 0% flu
62	5095.3	to	96.0	1.4	0.17	0.07	0.08	2.71	Ls, vug, foss, 0% flu
63	5096.4	to	97.0	1.2	0.34	0.27	0.14	2.71	Ls, pp, styl, 0% flu
64	5097.3	to	98.0	1.4	0.28	0.24	0.21	2.71	Ls, pp, sli/frac, styl, 0% flu
65	5098.0	to	98.4	1.9	4041	0.23	986	2.71	Ls, vert/frac, tr% yel flu
66	5099.2	to	99.7	2.0	1.46	0.39	0.25	2.70	Ls, vug, styl, tr% yel flu
67	5100.0	to	0.7	2.3	14.0	0.13	5.15	2.70	Ls, frac, 0% flu
68	5101.0	to	1.5	1.4	1.07	0.21	0.12	2.69	Ls, frac, styl, 0% flu
69	5102.4	to	2.8	2.2	2.00	0.53	0.58	2.70	Ls, pp, foss, styl, 0% flu
70	5103.0	to	3.4	1.8	0.96	0.39	0.95	2.70	Ls, styl, tr% yel flu
71	5104.0	to	4.6	1.8	10.4	6.22	2.22	2.71	Ls, vert/frac, 5% yel flu
72	5105.0	to	5.5	1.4	5.35	1.36	2.00	2.70	Ls, vert/frac, styl, 5% yel flu
73	5106.5	to		0.9	*	0.03	*	2.70	Ls, frac, 0% flu
74	5107.5	to	8.0	0.6	0.20	0.10	0.03	2.70	Ls, sli/frac, styl, tr% yel flu
75	5108.6	to	9.0	0.5	4.66	0.73	0.16	2.69	Ls, frac, 5% yel flu
76	5109.5	to	10.0	0.9	0.33	0.18	0.09	2.70	Ls, styl, 5% yel flu
77	5110.0	to	10.7	1.1	0.91	0.16	0.14	2.71	Ls, styl, tr% yel flu
78	5111.5	to	12.0	0.8	0.23	0.23	0.06	2.70	Ls, styl, 5% yel flu
79	5112.3	to	12.6	1.0	0.57	0.43	0.03	2.70	Ls, frac, pp, styl, 5% yel flu
80	5113.0	to	13.6	1.3	0.20	0.13	<0.01	2.74	Ls, sli/frac, tr% yel flu
81	5114.3	to	14.7	0.6	0.18	0.10	<0.01	2.71	Ls, 10% yel flu
82	5115.4	to	16.0	1.0	0.07	0.03	0.25	2.75	Ls, styl, 5% yel flu
83	5116.3	to	17.0	0.9	0.01	0.01	0.01	2.73	Ls, styl, 5% yel flu
84	5117.4	to	18.0	0.7	0.04	0.02	<0.01	2.72	Ls, styl, 5% yel flu
85	5118.5	to	19.0	0.3	0.19	0.07	<0.01	2.71	Ls, styl, tr% yel flu
86	5119.0	to	19.7	0.5	0.44	0.17	<0.01	2.68	Ls, sli/frac, styl, 0% flu
87	5120.1	to	20.6	0.3	1.39	0.53	<0.01	2.70	Ls, styl, 5% yel flu
88	5121.2	to	21.8	1.1	0.24	0.22	<0.01	2.72	Ls, sli/frac, styl, 5% yel flu
89	5122.2	to	22.6	0.5	0.09	0.03	0.09	2.70	Ls, sli/frac, styl, 5% yel flu
90	5123.0	to	23.6	0.9	0.55	0.19	0.04	2.73	Ls, sli/frac, 5% yel flu
91	5124.1	to	24.4	0.9	0.06	0.06	<0.01	2.71	Ls, sli/frac, 5% yel flu
92	5125.3	to	26.0	0.9	0.06	0.06	<0.01	2.72	Ls, sli/frac, styl, 0% flu
93	5126.3	to	27.0	0.8	0.27	0.21	0.10	2.72	Ls, sli/frac, styl, 0% flu
94	5127.4	to	28.0	0.6	1.59	0.05	0.07	2.72	Ls, sli/frac, styl, 0% flu
95	5128.3	to	29.0	0.9	0.79	0.05	0.36	2.72	Ls, sli/frac, tr% yel flu
96	5129.0	to	29.6	1.0	5.96	0.05	0.36	2.71	Ls, sli/frac, styl, 0% flu
97	5130.0	to	30.5	1.8	0.01	<0.01	<0.01	2.77	Ls, sli/pyr, sh lam, 0% flu
98	5131.4	to	32.0	2.0	0.03	0.01	0.01	2.76	Ls, sli/pyr, sh lam, 0% flu
99	5132.5	to	33.0	2.5	15.5	0.01	2.48	2.74	Ls, sli/pyr, sli/cht, sh lam, 0% flu
100	5133.0	to	33.4	3.3	0.26	0.06	<0.01	2.78	Ls, cht, sli/pyr, sh lam, 0% flu
101	5134.0	to	34.6	1.5	0.25	0.16	1.09	2.73	Ls, cht, sl pyr, tr% yel flu
102	5135.4	to	35.8	1.2	<0.01	<0.01	0.17	2.78	Ls, dol, cht, sl pyr, 5% yel flu

* Indicates plug analysis.

Appendix 3 – Thin section descriptions for the four cored wells.

PAGE	1	OF	1	**WEST CARNEY HUNTON FIELD: PETROGRAPHIC THIN SECTION DESCRIPTIONS**
FORMATION	**Hunton: Lower Cochrane**	AGE	**Silurian**	WELL NAME **Cal 1-11 (11-15N-1E Logan County, Oklahoma) - Marjo Operating Co., Inc**

SAMPLE NO. AND/OR DEPTH		CLASS (DUNHAM'S)			WHOLE ROCK 100%														CARBONATE GRAIN TYPES 100%					AVG. SIZE G = GRNS. X = XTALS.			MINERALOGY 100%					PORE TYPES (TOTAL = 90 ϕ, NOT 100%)									
		MUD SUP.		GRN. SUP.				GRAINS						KARST																											
														INFILL																											
NO.	DEPTH	MUDSTONE	WACKESTONE	PACKSTONE	GRAINSTONE	BOUNDSTONE	CRYST. - CARB.	NON-CARB	CARBONATE	MATRIX (<20 m)	CEMENT	RECRYST.	PORES	SAND	SILT	CLAY	CLASTS	CARB. CMT.	SKELETAL	PELLETS	OOLITES	INTRACLASTS		< 2.0 mm	2.0 - 0.25 mm	0.25 - 0.02 mm	CALCITE	DOLOMITE	QUARTZ	ANHYDRITE	CLAY	INTERPARTICLE	INTERCRYST.	INTRAPART.	MOLDIC	VUG - SEPARATE	VUG - TOUCHING	FRACTURE		AVG. PORE THROAT SIZE	COMMENTS
1	5034'		■						■	■	■							■	■							■	■				■					■		■			Coarse brachiopod wackestone. Tight rock, microfractures. Blocky calcite cement filling vugs.
2	5035'				■				■		■		■					■	■					■			■				■			■		■					Coarse brachiopod grainstone. Vugs (1-2mm), partial leaching of grains. Intraparticle porosity w/ in brachiopods. Blocky calcite cement
3	5036'			■					■	■	■							■	■					■			■				■							■			Coarse brachiopod packstone. Tight rock, microfractures present. Blocky calcite cement
4	5036.1'			■					■	■	■							■	■					■			■											■			Coarse brachiopod packstone. Tight rock, microfractures present. Blocky calcite cement
5	5045.3'			■		■			■		■							■	■					■			■				■										Tabulate coral (Favosites?) boundstone in contact with a crinoid-brachiopod packstone above. Very tight rock, no pores. Blocky calcite cement filling voids.
6	5046'				■				■		■							■	■					■			■				■		■	■		■		■			Coarse brachiopod-crinoid grainstone. Partial dissolution (Vuggy) of calcite. Microfractures, intercrystallin porosity. Blocky calcite cement
7	5057'				■				■		■							■	■					■			■				■		■			■		■			Coarse crinoid brachiopod grainstone. Syntaxial overgrowths throughout, stylolites are present
8	5078'				■				■		■							■	■					■			■				■						■				Coarse brachiopod crinoid grainstone. Vugs created by partial dissolution of crystals/grains. Overgrowths, blocky calcite cement filling shelter porosity
9	5083'		■						■	■									■					■		■	■				■										Brachiopod crinoid wackestone. Very tight rock, no porosity.
10	5085'		■						■	■									■					■		■	■				■										Brachiopod crinoid wackestone. Very tight rock, no porosity.
11	5094'			■					■		■							■	■					■			■				■			■		■					Coarse crinoid packstone. Partial dissolution of grains, stylolites forming porosity. Syntaxial overgrowths, blocky calcite cement filling voids.
12	5114'		■						■	■									■					■		■	■	■						■				■			Dolomitized fossiliferous wackestone. Dolomites are planar-e (0.2-0.6 mm). Occur around fractures. Moderately to almost completely leached grains.
13	5115'		■						■	■									■					■		■	■	■													Dolomitized crinoid brachiopod wackestone. Dolomites are planar-e (0.6 - 1 mm). Dolomites follow dissolution seams and fractures. Tight rock
14	5121'			■					■		■							■	■					■			■	■			■							■			Partly dolomitized brachiopod-crinoid packstone. Very tight rock, Dolomites are planar-e and planar-s (0.6 - 1 mm). Blocky caclite filling fractures, overgrowths.
15	5128'			■					■		■							■	■					■			■	■			■							■			Partly dolomitized brachiopod-crinoid packstone. Very tight rock, Dolomites are planar-e and planar-s (0.6 - 1 mm). Blocky caclite filling fractures, overgrowths.

Thin section descriptions of the Points 1-13 (Marjo Operating Co., Inc. T, 15N- R. 1E- S.13)

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WEST CARNEY HUNTON FIELD: PETROGRAPHIC THIN SECTION DESCRIPTIONS

FORMATION **Hunton: Lower Cochrane** AGE **Silurian** WELL NAME **Points 1-13 (13-15N-1E Logan County, Oklahoma) - Marjo Operating Co., Inc**

SAMPLE NO. AND/OR DEPTH		CLASS (DUNHAM'S)			WHOLE ROCK 100%														CARBONATE GRAIN TYPES 100%					AVG. SIZE G = GRNS. X = XTALS.			MINERALOGY 100%					PORE TYPES (TOTAL = 90 ϕ, NOT 100%)									
		MUD SUP.		GRN. SUP.				GRAINS						KARST INFILL																											
NO.	DEPTH	MUDSTONE	WACKESTONE	PACKSTONE	GRAINSTONE	BOUNDSTONE	CRYST. - CARB.	NON-CARB.	CARBONATE	MATRIX (<20 m)	CEMENT	RECRYST.	PORES	SAND	SILT	CLAY	CLASTS	CARB. CMT.	SKELETAL	PELLETS	OOLITES	INTRACLASTS		< 2.0 mm	2.0 - 0.25 mm	0.25 - 0.02 mm	CALCITE	DOLOMITE	QUARTZ	ANHYDRITE	CLAY	INTERPARTICLE	INTERCRYST.	INTRAPART.	MOLDIC	VUG - SEPARATE	VUG - TOUCHING	FRACTURE		AVG. PORE THROAT SIZE	COMMENTS
1	4993'			■					■	■	■		■						■						■		■		■					■			■	■			Brachiopod's very abundant, brachiopod biostrome? Sparse bryozoa & Ostracodes. Well developed porosity
2	5014.2'			■					■	■	■		■					■	■					■			■		■					■		■	■	■			Ghost remnants of ostracodes, stylolites present. Sparse crinoids, blocky calcite cement. Well developed porosity
3	5041.6'			■					■	■	■		■		■			■	■					■			■					■		■	■			■			Blocky calcite cement, karst sediment w/ in fractures. Well developed porosity
4	5072'			■					■	■			■					■	■					■			■		■		■							■			Coarse brachiopod-crinoid packstone. Fracture porosity (0.3 mm), stylolites are present.
5	5080'		■						■	■														■		■	■				■							■			Fossiliferous wackestone. Ostracodes, gastropods, crinoids, bryozoa. Fracture filled with blocky calcite cement
6	5082'			■					■	■								■	■					■			■				■										Coral-brachiopod-crinoid packstone. Tabulate coral growth framework porosity filled with blocky calcite cement. Sparse bryozoa. Micrite
7	5082.4'			■					■	■	■		■		■			■	■					■			■							■				■			Coarse brachiopod-crinoid packstone, crionoids more abundant. Very tight
8	5101'				■				■		■							■	■					■			■				■			■							Crinoid bryozoa grainstone. Partial dissolution of crinoid fragments and bryozoa. Tight rock, overgrowths on crinoids occluding porosity.
9	5102'				■				■		■							■	■					■			■				■			■		■					Coarse crinoid bryozoa grainstone. Partial dissolution of grains. Brecciation creating vugs. Vugs filled with blocky calcite cement. Majority of rock is syntaxial overgrowths.
10	5104.6'				■				■		■				■				■					■			■									■		■			Coarse crinoid-coral-brachiopod grainstone. Tight rock, well cemented. Karst sediment filling fractures. Blocky calcite cement
11	5106.8'	■							■	■									■							■	■	■										■			Partly dolomitized mudstone. Sparse fossils (brachiopods, gastropods, crinoids, triolobites).

** Indicates Oversized thin sections

Thin section descriptions for the JB 1-13 (Marjo Operating Co., Inc. T. 15N- R. 1E- S. 13)

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WEST CARNEY HUNTON FIELD: PETROGRAPHIC THIN SECTION DESCRIPTIONS

FORMATION **Hunton: Lower Cochrane** AGE **Silurian** WELL NAME **JB 1-13 (13-15N-1E Logan County, Oklahoma) - Marjo Operating Co., Inc**

SAMPLE NO. AND/OR DEPTH		CLASS (DUNHAM'S)			WHOLE ROCK 100%														CARBONATE GRAIN TYPES 100%					AVG. SIZE G = GRNS. X = XTALS.			MINERALOGY 100%					PORE TYPES (TOTAL = 90 ϕ, NOT 100%)									
														KARST																											
		MUD SUP.		GRN. SUP.				GRAINS						INFILL																											
NO.	DEPTH	MUDSTONE	WACKESTONE	PACKSTONE	GRAINSTONE	BOUNDSTONE	CRYST. - CARB.	NON-CARB.	CARBONATE	MATRIX (<20 m)	CEMENT	RECRYST.	PORES	SAND	SILT	CLAY	CLASTS	CARB. CMT.	SKELETAL	PELLETS	OOLITES	INTRACLASTS		< 2.0 mm	2.0 - 0.25 mm	0.25 - 0.02 mm	CALCITE	DOLOMITE	QUARTZ	ANHYDRITE	CLAY	INTERPARTICLE	INTERCRYST.	INTRAPART.	MOLDIC	VUG - SEPARATE	VUG - TOUCHING	FRACTURE		AVG. PORE THROAT SIZE	COMMENTS
1	4972'				■				■		■		■					■	■					■			■							■							Coarse crinoid grainstone. Sparse coral fragments. Very tight rock, overgrowths on crinoids occluding porosity. Shelter porosity
2	4978'				■				■		■		■					■	■					■			■				■							■			Brachiopod-crinoid grainstone. Tight rock, crinoid abundance. Blocky calcite cement, fractures (0.1-0.05 mm)
3	4989'				■				■		■		■					■	■					■			■		■		■					■		■			Brachiopod grainstone. Blocky calcite cement, sparse crinoid fragments.
4	4991'			■					■	■	■							■	■					■			■		■									■			Brachiopod-crinoid packstone. Microfractures, tight rock. Blocky calcite cement, syntaxial overgrowths on crinoids
5	5000'			■					■	■	■							■	■					■			■	■	■									■			Brachiopod-crinoid packstone. Very sparse dolomite crystals. Fracture porosity, (1-2 mm). Blocky calcite cement
6	5004'			■					■	■	■							■	■					■										■							Brachiopod-crinoid-bryozoan packstone. Partially leached grains, coarse blocky calcite cement. Overgrowths on crinoids occlude porosity
7	5013'				■				■		■							■	■					■			■				■										Crinoid grainstone. Very tight rick, no porosity. Sparse brachiopods, trilobites, ostracodes. Abundant syntaxial overgrowths
8	5022'		■						■	■	■							■	■					■			■	■													Tabulate coral boundstone in contact w/ a dolomitized brachiopod wackestone. Blocky calcite cement filling fractures. Micrite filling growth framework of coral
9	5026'				■				■		■							■	■					■			■														Coral-brachiopod-crinoid grainstone. Very tight rock, coarsely crystalline rock. Blocky calcite cement
10	5030'			■					■	■	■				■			■	■					■			■				■					■					Coarse brachiopod-bryozoan grainstone. Vugs filled with blocky calcite cement. Shelter porosity of brachiopods filled with dark karst sediment
11	5031'			■					■	■	■		■					■	■					■			■				■					■		■			Brachiopod-crinoid packstone. Blocky calcite cement, overgrowths. Vugg porosity (4-5 mm), fractures (1 mm)
12	5043'			■					■	■	■				■			■	■					■			■		■									■			Brachiopod packstone, microfractures, sparse crinoids. Blocky calcite cement, shelter porosity filled with karst sediment
13	5053'			■					■	■	■		■		■			■	■					■			■		■			■		■		■					Coarse brachiopod-coral-bryozoan packstone. One rugose coral w/ growth framework porosity. Sparse interparticle porosity, tight rock. Blocky calcite cement
14	5057'			■					■	■	■		■		■			■	■					■			■		■					■							Coarse brachiopod-crinoid packstone. Shelter porosity filled with dark karst sediment. Partial leaching of crinoid grains, brecciated brach fragment. Blocky calcite cement

Thin section descriptions for the Mark Houser 1-11 (Marjo Operating Co., Inc. T. 15N- R. 1E- S. 11)

PAGE 1	OF 1	***WEST CARNEY HUNTON FIELD: PETROGRAPHIC THIN SECTION DESCRIPTIONS***		
FORMATION	**Hunton: Lower Cochrane**	AGE	**Silurian**	WELL NAME **Mark Houser 1-11 (11-15N-1E Logan County, Oklahoma) - Marjo Operating Co., Inc**

SAMPLE NO. AND/OR DEPTH		CLASS (DUNHAM'S)				WHOLE ROCK 100%												
		MUD SUP.		GRN. SUP.				GRAINS						KARST INFILL				
NO.	DEPTH	MUDSTONE	WACKESTONE	PACKSTONE	GRAINSTONE	BOUNDSTONE	CRYST. - CARB	NON-CARB	CARBONATE	MATRIX (<20 m)	CEMENT	RECRYST.	PORES	SAND	SILT	CLAY	CLASTS	CARB. CMT.
1	4962'		■						■	■					■			
2	5012.4 **				■				■		■		■		■			■
3	5018.2'		■						■	■					■			
4	5028.2' **				■				■		■		■		■			■
5	5044.8'				■				■		■		■		■			■
6	5064'			■					■	■	■		■					
7	5070.8'				■				■						■			
8	5072.2' **		■						■	■								
9	5074'		■						■	■					■			
10	5075.2'			■					■		■							

SAMPLE NO. AND/OR DEPTH		CARBONATE GRAIN TYPES 100%					AVG. SIZE G = GRNS. X = XTALS.			MINERALOGY 100%				
NO.	DEPTH	SKELETAL	PELLETS	OOLITES	INTRACLASTS		< 2.0 mm	2.0 - 0.25 mm	0.25 - 0.02 mm	CALCITE	DOLOMITE	QUARTZ	ANHYDRITE	CLAY
1	4962'	■					■		■	■		■		■
2	5012.4 **	■					■							
3	5018.2'	■					■		■	■		■		■
4	5028.2' **	■					■							
5	5044.8'	■					■			■				
6	5064'	■					■							
7	5070.8'							■		■	■			■
8	5072.2' **	■						■		■	■			
9	5074'	■					■		■	■				■
10	5075.2'	■					■							

SAMPLE NO. AND/OR DEPTH		PORE TYPES (TOTAL = 90 ϕ, NOT 100%)									
NO.	DEPTH	INTERPARTICLE	INTERCRYST.	INTRAPART.	MOLDIC	VUG - SEPARATE	VUG - TOUCHING	FRACTURE		AVG. PORE THROAT SIZE	COMMENTS
1	4962'										Brachiopod-crinoid wackestone. Very tight rock, stylolites present (1mm amp). Karst sediment infilling voids w/in brachiopods. Blocky calcite cement
2	5012.4 **			■		■		■			Coarse brachiopod-bryozoan-grainstone. Breccia porosity, blocky calcite cement, dark karst sediment filling fractures and vugs
3	5018.2'							■			Coarse brachiopod wackestone. Tight rock, microporosity w/in stylolites. Partial leaching of brachiopod grains.
4	5028.2' **			■		■		■			Coarse brachiopod-bryozoa-crinoid grainstone. Fracture filled with dark karst sediment and fine quartz grains (Misener?), low amp styololites
5	5044.8'							■			Tabulate coral grainstone (Favosites?) Fracture porosity (0.5 mm), tight rock. Corralites are filled with block calcite cement. Some karst sediment filling corralites.
6	5064'			■		■					Coarse coral-brachiopod-packstone. Tabulate coral has intraparticle porosity. Blocky calcite cement
7	5070.8'		■								Dolomitized grainstone. Replaced wackestone texture, dissolution of matrix. Dolomite crystalls overgrown w/ calcite. Karst sediment fill. Good porosity
8	5072.2' **			■							Coarse brachiopod wackestone, partly dolomitized (planar-e and planar-s, dolomite grains are 0.5 - 1 mm). Dissolution of matrix
9	5074'					■					Crinoid-coral wackestone. Vugs filled with blocky calcite cement, not connected. Some karst sediment fill
10	5075.2'					■					Crinoid packstone. Tight rock, overgrowths on crinoid grains is abundant.

** Indicates Oversized thin sections

VITA

Brian Joseph Smith

Candidate for the Degree of

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