UPPER JURASSIC MICROBOLITE BUILDUPS IN THE LITTLE CEDAR CREEK AND BROOKLYN FIELDS IN SW ALABAMA

A Thesis by

Kyle Lee Day

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Earth, Environment and Physical Science with a major in Geology.

William Parcell, Committee Chair

Collette Burke, Committee Member

William Bischoff, Committee Member

Leland Russell, Committee Member

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ABSTRACT

This study investigates the stratal relationships of a pure microbolite within the Upper Jurassic strata at the Little Cedar Creek, and Brooklyn Fields, or complex, for the development of a refined exploration model of Smackover reefal buildups in the eastern Gulf Coast. During the Jurassic, southwestern Alabama was divided by Appalachian ridges into three sub-basins: the Conecuh Embayment, Manila Embayment, and the eastern extension of the Mississippi Interior Salt Basin. The complex is located in the Conecuh Embayment of southeastern Conecuh County, Alabama, and is the largest accumulation of hydrocarbons discovered in the state of Alabama. As of January of 2014 hydrocarbon production is currently over 31 million barrels of oil and over 34 billion cubic feet of gas. The microbolite buildups formed in an inner ramp setting of the Upper Jurassic (Oxfordian) Smackover Formation.

The Little Cedar Creek and Brooklyn Fields are anomalous discoveries compared to other oil and gas fields in the region. Previous studies observed that microbial nucleation occurred on Paleozoic crystalline basement highs where depositional fabrics were heavily modified by dolomitization. Instead, the complex's microbolite buildups developed on mudstones, have no apparent association with paleo-highs, and have retained a large percentage of original depositional fabrics. This study found thrombolitic reefs develop on paleotopographic highs that were indicated by a thinning of underlying transgressive lime mudstones.

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LIST OF ABBREVIATIONS

BBL	Barrels
MCF	Thousand Cubic Feet
PSI	Pounds per Square Inch
LCCF	Little Cedar Creek Field
BF	Brooklyn Field
GOM	Gulf of Mexico
MISB	Mississippi Interior Salt Basin
SOGBA	State Oil and Gas Board of Alabama
GSA	Geological Survey of Alabama

CHAPTER ONE

INTRODUCTION

This study examines the Upper Jurassic stratigraphy in the eastern Gulf Coast (Fig. 1) and characterizes the growth distribution of a pure reefal thrombolite. The Upper Jurassic (Oxfordian) Smackover Formation is a widespread carbonate unit that was deposited in a distally steepened ramp setting across the northern U.S. Gulf of Mexico from Texas to Florida (Ahr, 1973; Read, 1985). Within ramp settings reefal buildups dominate and affect surrounding deposition of carbonate sediments. Major global periods in the geologic past have been noted for widespread reef development include the: Early Proterozoic, Late Proterozoic, Late Ordovician to Devonian, Late Triassic, Late Jurassic, and Late Cenozoic (Parcell, 1999). Oxfordian aged reefs are dominated by coral, algae, and sponges (Parcell, 1999).

A thrombolite is an end member of the microbolite group. Microbolites are organic rich sediments that are created from the actions of bacteria, algae, fungi, and protozoans (Mancini et al., 2004). Microbolites contain three end members: (1) clotted peloidal thrombolite, (2) laminated stromatolites, and (3) microbial micrite or leiolites that contain no structure (Kennard and James, 1986). Thrombolites are the result of microbial activity and are recognized by their thrombolitic texture (contain microbial structures with clotted internal fabrics) (Aitken, 1967; Kennard and James, 1986). Thrombolites in the north east Gulf Coast differ in fabrics and growth forms (Parcell, 2002). Recognized thrombolite fabrics include layered, reticulate, dendritic, encrusting stromatolite, and oncoidal cortexes (Parcell, 2002).

Late Jurassic aged reefs and carbonate facies are significant because they are very productive hydrocarbon reservoirs and source rocks (Parcell, 1999). Production from Jurassic aged formations is found in the U.S. Gulf Coast, the Persian Gulf, Uzbekistan-, and Turkmenistan (Parcell, 1999). Outcroppings of remnant Upper Jurassic deposits have been recognized across Europe, North Africa, and the Middle East (Insalaco et al., 1997). European studied Oxfordian reefs are well studied, diverse, and widespread whereas Gulf Coast Oxfordian reefs are less studied, sparse and less diverse (Kopaska-Merkel, 1998). The reason for the lack of knowledge of Oxfordian Gulf Coast reefs is attributed to the fact that reefal buildups in Europe are exposed in outcroppings whereas Gulf Coast reefs are only found in the subsurface.

The Smackover Formation was first recognized in 1922 as a subsurface unit, when hydrocarbons were produced in Smackover, Arkansas (Bell, 1923; Bingham, 1937; Imlay, 1943; Schneider, 1925). The discovery of Smackover oil in Alabama is credited to the Toxey Field in 1967, Choctaw County (Mancini et al., 1991). The Smackover Formation is known to be a prolific oil producing carbonate reservoir across the Gulf Coast where shallow marine carbonates eventually onlap, thin and pinch-out northward (Mancini and Benson, 1980).

The Little Cedar Creek Field and Brooklyn Field are located in Conecuh County, Alabama. This complex is the largest field in Alabama, one of the largest in the gulf region, and produces hydrocarbons entirely from the Smackover Formation. As of January 2014 the complex has produced 31,587,681 Bbl (barrels) of oil, and 34,705,178 Mcf (thousand cubic feet) of gas (State Oil and Gas Board Alabama). Fields producing from the Smackover Formation are characterized to be in the Smackover play.

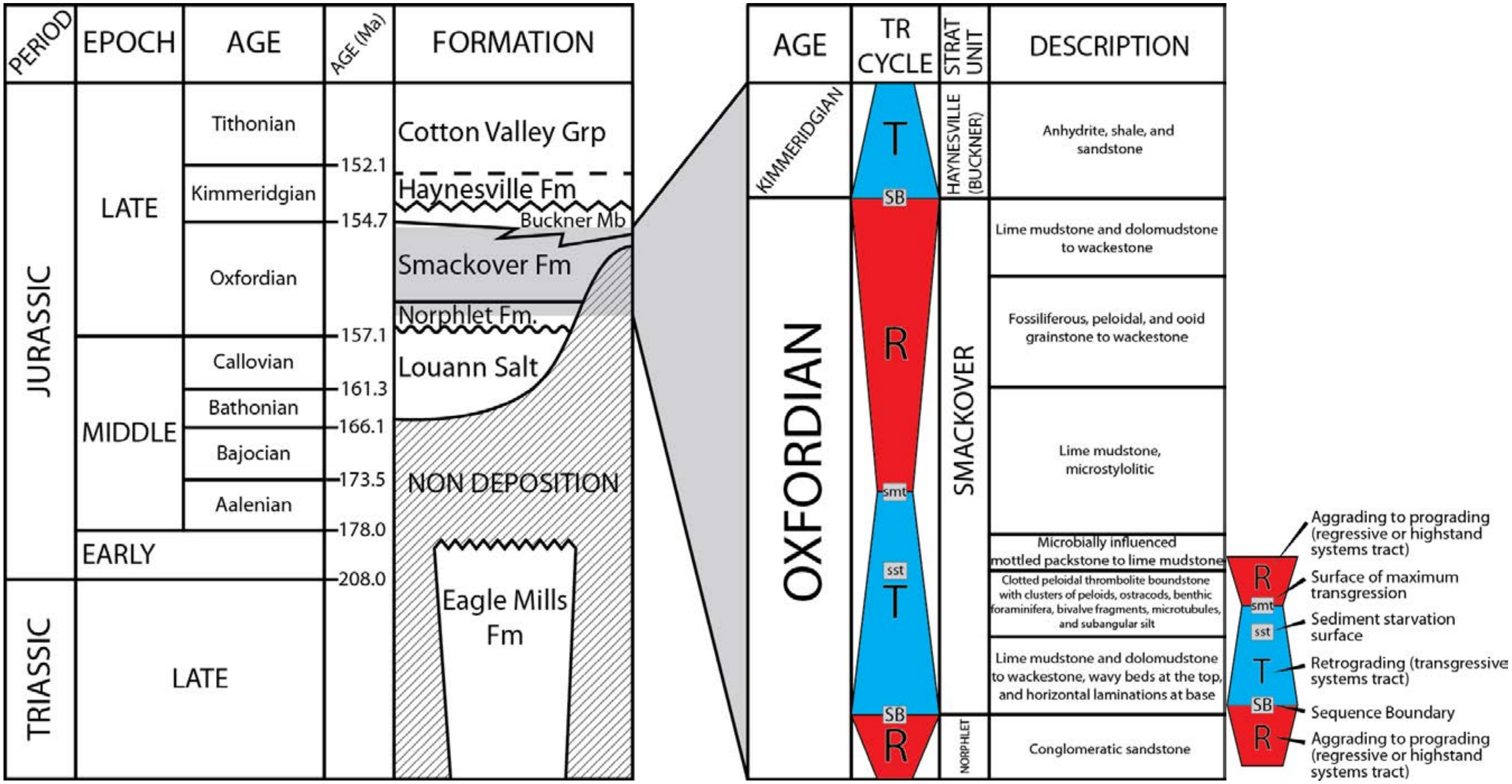


Figure 1: Gulf Coast stratigraphy with corresponding sequence stratigraphy for Smackover updip deposition (Modified from Mancini et al., 2008; Heydari and Baria, 2006)

CHAPTER 2

GEOLOGIC SETTING

2.1 Location

The Little Cedar Creek Field (LCCF) and Brooklyn Field (BF) complex is located in the Conecuh Embayment, south of the Conecuh ridge complex and north of the Pensacola Ridge (Fig. 2); in the southern portion of Conecuh County and Northern Portion of Escambia County, Alabama. The LCCF lies directly north of the BF (Fig. 3), they are considered separate from each other due to the reservoirs bearing different pressures. Depositional setting for the complex is defined as updip microbial nearshore environment (Mancini et al., 2006). Major Oxfordian depocenters in Alabama were controlled by paleotopography, halokinesis, and igneous activity (Kopaska-Merkel, 1998).

2.2 Tectonic History

Deposition in southwest Alabama was influenced by the breakup of supercontinent Pangea, and the formation of the Gulf of Mexico (GOM) Basin (Mancini et al., 1991; Salvador, 1991). Rifting and opening of the GOM occurred between the Middle Triassic to Late Jurassic (Salvador, 1991). Basement subsidence along with erosional and tectonic paleo-highs provided the basin setting for Jurassic deposition (Mancini et al., 1991; Wilson, 1975).

Four regional paleo-highs have been recognized as influencing deposition: the Choctaw Ridge, the Conecuh Ridge, the Wiggins Arch, and the Baldwin high (Fig. 2) (Mancini et al., 1991). The Choctaw and Conecuh Ridge Complexes are associated with Appalachian tectonic events, formed in the late Paleozoic, during the convergence of North America and African-South American continental plates (Mancini et al., 2003). The Wiggins Arch and Baldwin High might be remnant basement features of the rifting of the Gulf of Mexico in the Jurassic. These highs in southwest Alabama are separated by three sedimentary basins: Mississippi Interior Salt Basin (MISB), the Manila Embayment, and the Conecuh Embayment.

Many of these structural basins and positive features are considered a series of horsts and grabens that formed from crustal thinning and attenuation (Buffler and Sawyer, 1985; Wood and Walper, 1974). Attenuation persisted until Callovian to Early Oxfordian time, upon which oceanic spreading began to form the proto GOM basin (Klitgord et al., 1984; Pindell, 1985). Subsidence in the MISB resulted in thick accumulations of Jurassic sediments, and has been shown to have actively subsided through the Mesozoic and Early Cenozoic (Mancini et al., 1991).

Regional deposits consist of thick Jurassic salt sections (Louann and Haynesville), anhydrites (Werner, Pine Hill, and Buckner), red beds (Norphlet and Haynesville), limestones and dolostones (Smackover and Haynesville). These deposits suggest an arid climate prevalent from the Triassic to Jurassic (Mancini et al., 1991).

2.3 Petroleum Exploration

Production from the Smackover is derived from microbial dominated deposits, known as microbolites. Traditional petroleum exploration models for Gulf Coast exploration relied on a thorough understanding of Smackover deposition and seismic imaging of paleotopographic highs where microbial thrombolite buildups developed (Mancini et al., 2008). Vocation and Appleton oil fields (Fig. 2) are the most significant finds that exhibit microbial growth on paleotopographic highs (Llinas, 2004).

Thrombolites develop from microbial activity, are recognized by their textures, and belong to the microbolite group. Microbolite end members include peloidal thrombolites, laminated micritic stromatolites, and micritic leiolites that lack microstructure. Thrombolites in these areas nucleated on paleotopographic crystalline highs where low energy and sedimentation rates provided an ideal environment for microbial growth. Thrombolite growth was dependent on topography of basement features. Initial well locations were selected based on seismic imaging to pierce the flank of basement features, where microbial growth could occur (e.g. Vocation Field) (Fig. 2) (Parcell, 2002). Additionally, subsequent development in Appleton field (Fig. 2) proved that microbial growth could occur along the crest of basement features, if relief was minimal (Parcell, 2002).

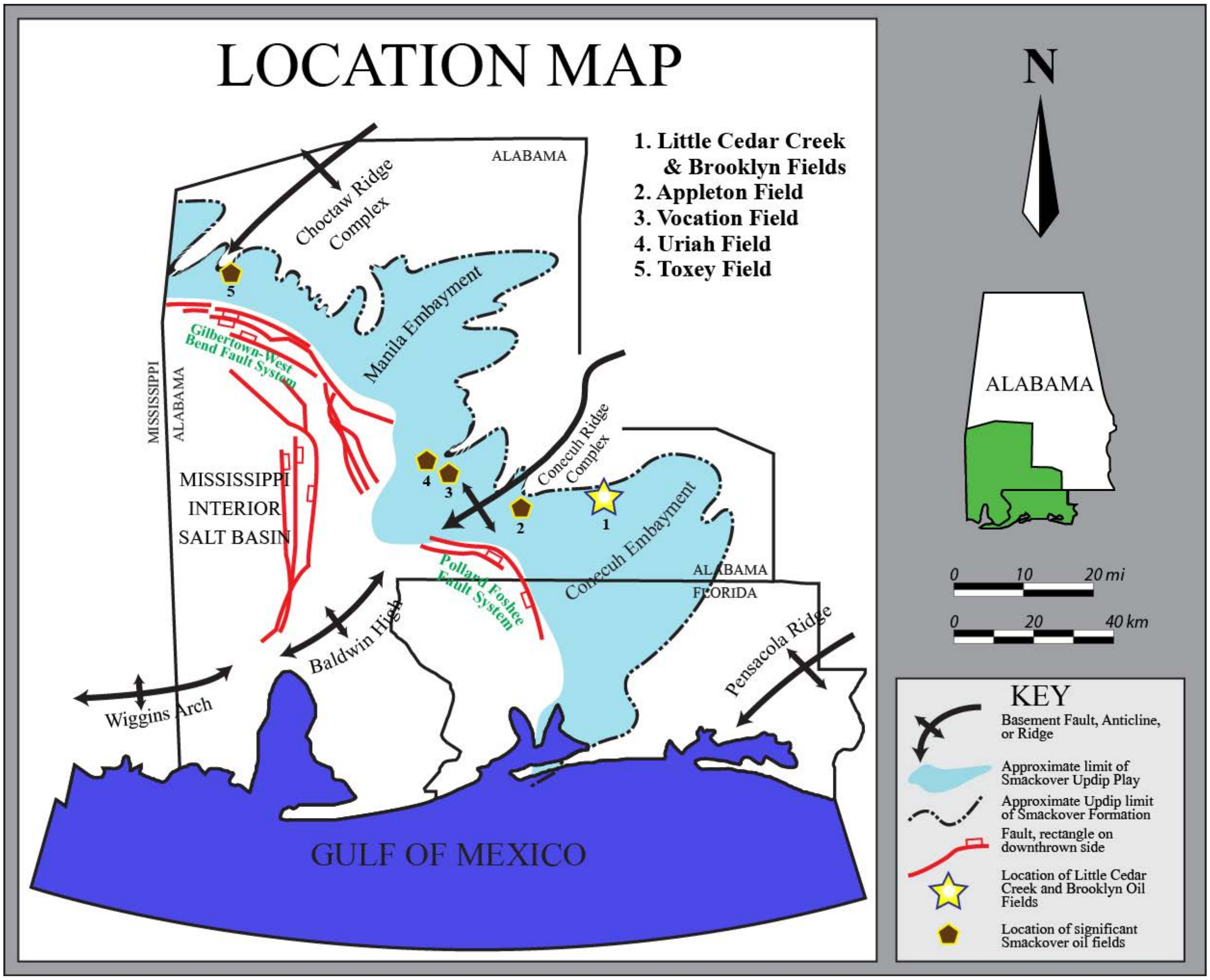


Figure 2: Location map showing structural features, updip Smackover limits, and Little Cedar Creek and Brooklyn Field location (Modified from Mancini et al., 2004; Mancini et al., 2008)

2.4 Field History

In 1994 Hunt Oil Company discovered the first well in the LCCF with the drilling and testing of the “Cedar Creek Land and Timber Company 30-1 #1” well. Initial production results were 108 barrels per day at 46° API gravity crude, 49,000 cubic feet of gas per day, and initial bottom hole pressure of 248 psi (pounds per square inch) from the Upper Jurassic Smackover Formation (Heydari and Baria, 2005). The field remained limited to one well until 2001 when Midroc Operating of Dallas expanded

LCCF limits. Subsequent drilling would be performed by Sklar Exploration Company, Columbia Petroleum, and Fairways Exploration and Production LLC. In 2007 Midroc initiated a gas injection project to stimulate production and preserve reservoir pressure in the western unitized portion of the LCCF. In 2011 Midroc contracted Pruet Production to operate and develop their remaining acreage and wells.

In 2007 Sklar Exploration drilled and produced the Logan 5-7 #1, which was roughly three miles south of the limits of the LCCF. The Logan 5-1 #1 well initially tested the Smackover Formation with 21 barrels a day and averaged out to eight barrels a day. The second well drilled, the Johnston-Steward 32-12 #1, followed the same trend as the LCCF but was still south of LCCF limits. Fletcher Petroleum drilled a third well, the Amos 36-3, which displayed significantly higher pressures than the LCCF; establishing the Brooklyn Field. Since pressures were significantly higher, it was evident that these new wells were exploiting a reservoir that was not in communication with LCCF wells. The Amos 36-3 initially tested 531 barrels of oil per day and 374,100 cubic feet of gas per day with initial bottom hole pressure of 950 psi. Sklar Exploration, Pruet Production, followed Fletcher Petroleum’s discovery, paralleling the same trend as the LCCF. Subsequent drilling established the BF in 2011 and the previous wells were incorporated to the BF.

As of August of 2013, the State Oil and Gas Board of Alabama (SOGBA) listed 80 producing wells in the LCCF, and 53 producing wells in the BF. Production for both fields exceeded initial expectations. As of January of 2014 the LCCF and BF produced over 31.5 million barrels of oil and 34.7 billion cubic feet of natural gas, driven by a natural gas drive reservoir. The complex alone produced enough natural resources to reverse the production curve in Alabama from a decline to an incline.

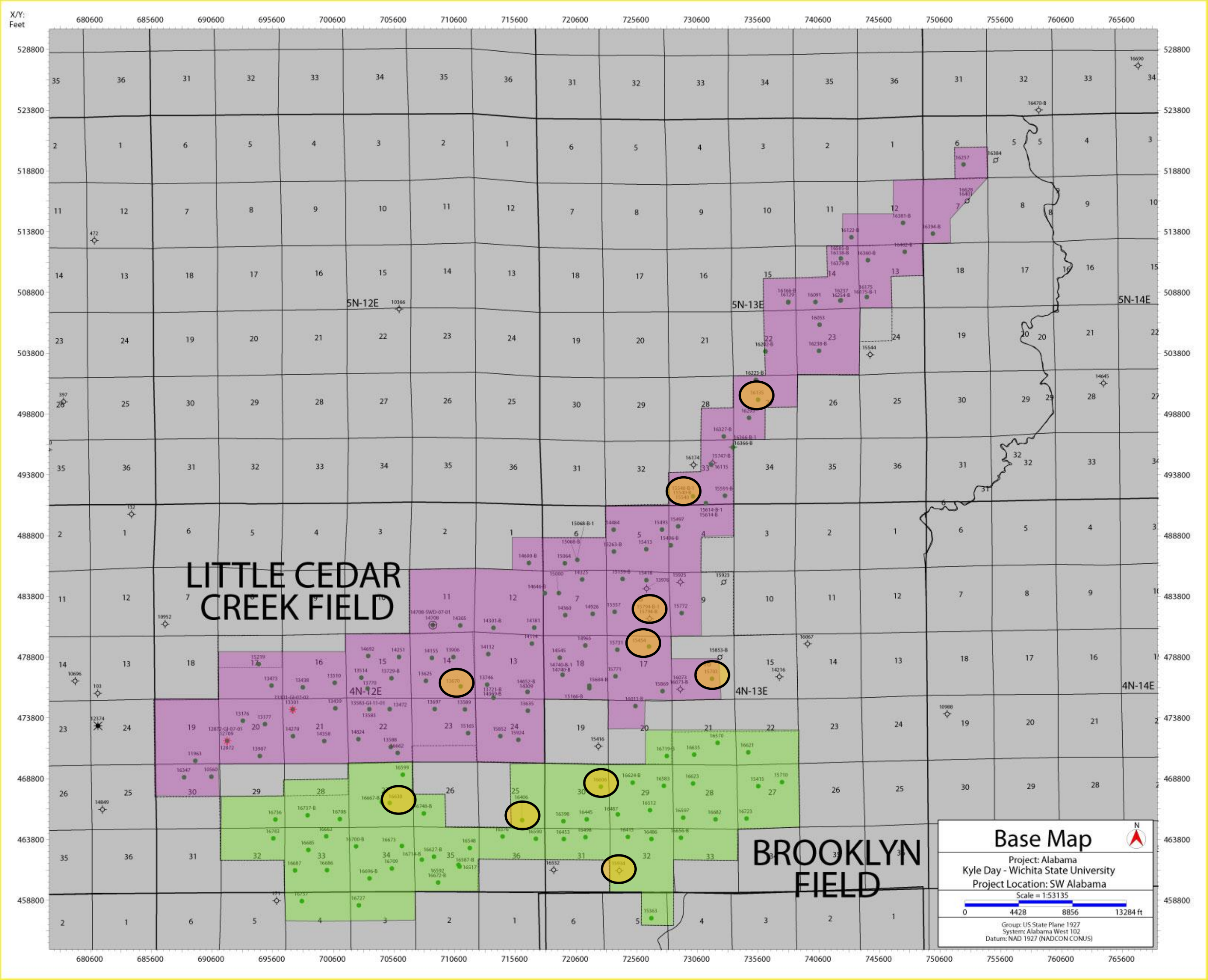


Figure 4: Base map showing location of Little Cedar Creek Field in relation to Brooklyn Field. Orange ovals indicate location of well core examined.

CHAPTER 3

METHODOLOGY

3.1 Data

Due to the anomalous and lucrative characteristics of the LCCF and BF, all or sections of the Smackover Formation were cored in nearly every well drilled in the complex. Once drilled, cores are stored in the core facility at the Geological Survey of Alabama (GSA), in Tuscaloosa, Alabama. This study utilized the core facility at the GSA to inspect 10 well cores (Fig. 4) that represented an entire Smackover interval.

In addition to well core, wireline logs are important forms of data because these tools give the interpreter the ability to determine porosity values, lithology changes, and the presence of hydrocarbons. Wireline log types used in this study include gamma ray, neutron density and porosity, electrical resistivity, and sonic porosity. All log types are instrumental for differentiating lithofacies within the Smackover Formation. For this study, depth registered raster logs were purchased from MJ Systems, and imported to the IHS Kingdom Suite software.

Thin sections were also obtained from core samples to inspect micro-facies data. Inspecting thin sections under microscope provide the interpreter with essential micro-facies data. Understanding micro-facies is important to studying microorganisms and micro-features within the carbonate lithologies. This study was provided 12 thin sections by the GSA.

This study utilized IHS Kingdom Suite Software to correlate Smackover facies using well log cross sections, structure and isopach maps. Kingdom Suite is a seismic and geologic modeling software that is capable of storing and utilizing well data, wireline logs, and geophysical data.

3.2 Methods

The initial step for this study was to set up a database in Kingdom Suite of well data, and wireline log data. Once completed, selection of available full core intervals at the Alabama Geological Survey was conducted by correlating well core intervals through the Smackover Formation in Kingdom Suite.

Ten cores were selected and examined for changes in lithofacies, fossil content, and microbial growth patterns. Description and classification of lithologies were based on the classic Dunham carbonate classification system. The Dunham classification system uses the ratio between grain and mud supported textures to differentiate carbonate rocks (Dunham, 1962).

To classify microbolites, this study used the classification system proposed by Parcell (2002) which modified the terminology of Kennard and James and the meso and macroscopic features from Schmid's (1996) classification. Kennard and James (1986) proposed three end members to classify microbolites: (1) clotted peloidal thrombolite, (2) laminated stromatolites, and (3) microbial micrite or leiolites that contain no structure. Schmid's (1996) European classification of Oxfordian aged microbolites includes six macroscopic growth forms: (1) bioherms, (2) patch reefs, (3) conical patch reefs, (4) biostromes, (5) isolated crusts, and (6) oncoids, along with eight mesoscopic growth forms: (1) massive, (2) conical, (3) dendritic, (4) encrusting, (5) platy, (6) reticulate, (7) hemispheroid, and (8) cryptic encrusters. Thrombolites are defined by their thrombolitic texture; which contain microbial structure with clotted internal fabrics (Aitken, 1967; Kennard and James, 1986).

Parcell tailored a classification system that could be utilized when dealing with subsurface data. Parcell first grouped Schmid's meso and macroscopic features into larger categories, due to the fact that large scale features are unrecognizable within a single well core, and also modified the implications of microbial growth forms to be dependent on the rate of sea level change (2002). These growth forms include five types: (Type I) layered thrombolite, (Type II) reticulate thrombolite, (Type III) dendritic thrombolite, (Type IV) encrusting stromatolites, and (Type V) oncoidal cortexes (Parcell, 2002).

Core descriptions of lithofacies were then correlated to wireline logs. Once correlation patterns were recognized, field-scale correlation was performed throughout the LCCF and BF. This procedure provided data to perform structural and thickness mapping of the lithofacies within the Smackover Formation.

CHAPTER 4

GULF COAST STRATIGRAPHY

4.1 Depositional History

Mesozoic Gulf Coast deposition is closely related to sea level fluctuations and subsidence related to proximity to a passive plate margin (Harris and Dodman, 1982; Pilger, 1980; Vail et al., 1977). Initial deposition of the Gulf Coast includes red beds of the Eagle Mills Formation and conglomeratic material from the Werner Formation that grade into the thick Louann Salt Formation (Harris and Dodman, 1982). During the Middle Jurassic a transgression reworked the top of the Louann, where a subsequent regression accommodated the deposition of sands and clays from the Norphlet Formation (Harris and Dodman, 1982). Differentially subsiding basins of the gulf provided a high angle, deep shelf environment for deposition of the brown dense limestone, or basal Smackover Formation (Harris and Dodman, 1982; Mancini et al., 1991). During Oxfordian time, a high sea level stand created a widespread distally-steepened ramp on which subtidal carbonates were deposited (Ahr, 1973; Harris and Dodman, 1982; Parcell, 1999). Subsequent regression deposited tidal flat facies of the Haynesville Formation that overlie the Smackover (Harris and Dodman, 1982; Mancini et al., 1991)

4.2 Smackover Formation

The Smackover Formation unconformably overlies the Norphlet Formation with gradational and abrupt contacts (Mancini et al., 1991). Imlay and Herman (1984) classified the Smackover Oxfordian in age based on ammonite fossils found in the lower Smackover in Texas and Louisiana, and Parcell (2000) further refined and supported the date range based on Strontium isotopes. Based on wireline logs, well core, and petrography, six lithofacies have been recognized within the Smackover Formation (Mancini et al., 2006); however, lithofacies within the Smackover are discontinuous and change dramatically between basement high, basin, and updip depositional settings.

Three lithofacies recognized on basement highs include the following: anhydritic dolowackestone to dolomudstone; ooid, oncoid, algal, and peloid dolograinstone and dolopackstone; microbial doloboundstone and peloidal dolomudstone to dolowackestone (Mancini et al., 2006). Four lithofacies are recognized in basin depositional settings include: lime mudstone with stromatolites and anhydrite; oncoid, peloid, and ooid grainstone to wackestone; microbial lime mudstone; intraclastic packstone and wackestone (Mancini et al., 2006). This study examined the six lithofacies that are recognized in updip depositional setting starting from the base of the Smackover Formation: (S-1) transgressive subtidal lime mudstone and dolomudstone to wackestone, wavy beds at top, horizontal laminated at base; (S-2) subtidal clotted peloidal thrombolite boundstone with clusters of peloids, ostracods, benthic foraminifera, bivalve fragments, microtubules, and subangular silt; (S-3) subtidal microbially influenced packstone to lime mudstone; (S-4) deeper water to subtidal lime mudstone, microstylolitic; (S-5) shallow subtidal nearshore fossiliferous, peloidal, and ooid grainstone to wackestone; (S-6) peritidal lime mudstone and dolomudstone to wackestone (Mancini et al., 2006; Mancini et al., 2008).

Updip nearshore Smackover facies occur in water depth less than ten feet and roughly three miles from paleo shoreline (Mancini et al., 2006). Reservoir rocks in the LCCF and BF are similar to other Smackover fields because they contain high-energy nearshore grainstone, packstone and microbial boundstones (Mancini et al., 2008) . However, LCCF and BF portray a dual reservoir system where reservoirs are separated and sealed by deeper water subtidal limestone facies (Mancini et al., 2004; Mancini et al., 2006; Mancini et al., 2008). The upper reservoir consists of a shallow subtidal high energy nearshore grainstone to wackestone, that includes ooids, peloids, pellets, lime mud, subangular silt, bivalve fragments, *Parafavreina* pellets, and benthic foraminifera, with thickness variations between zero and 20 feet (Mancini et al., 2006; Mancini et al., 2008). The lower reservoir consists of a subtidal peloidal thrombolite boundstone, that includes clotted peloidal boundstone (thrombolite) with fine, subangular silt, with thickness variations between zero and 36 feet (Mancini et al., 2006; Mancini et al., 2008).

Interactions between microbial communities and deposition of carbonate and siliciclastic regimes is very common (Riding and Awramik, 2000). Microbolites are organic rich sediments that are created from the actions of bacteria, algae, fungi, and protozoans which can produce microbial films that stabilize unconsolidated sediment, as well as activate the precipitation of calcareous crusts, which effectively defend against erosion (Mancini et al., 2004).Thrombolites have been recognized to require a hard substrate for nucleation, zero to low background sedimentation rate, and calm water energy to sustain and support growth (Leinfelder, 1993; Mancini et al., 2004; Parcell, 2003). The frequency of reef development has been recognize to increase dramatically after the transgression inflection point, or maximum rate of sea level rise and reefs begin to cease growth rate before water depths become deepest (Parcell, 2003). Mancini and Parcell also recognized reef growth occurred during sea level rise, on the surface of calcified crusts, or sediment starvation surfaces that facilitated the nucleation of microbial sediments which form thrombolitic reefs with continued growth (2004).

Bathymetry is another factor which determines thrombolite growth in the northeastern Gulf Coast (Mancini et al., 2008). Pure thrombolite bioherms studied in Western Europe have been noted to occur in depths greater than 230 ft., which suggests microbolite build ups are eurytopic (Leinfelder, 1993; Mancini et al., 2008). However, thrombolite build-ups in the Gulf Coast have been recognized to occur in shallow waters (Mancini et al., 2008).

Thrombolite growth forms vary regionally throughout the Smackover Formation. Localized growth patterns present at LCCF and BF include layered (Type I), and chaotic or reticulate (Type II) growth forms (Koralegedara and Parcell, 2008). Growth patterns are controlled by changes in water energy, substrate, and background sedimentation. Type I thrombolites are indicated by dark brown, horizontally oriented microbial layers (mm-cm thick) with interbedded gray mudstone layers, which indicate low to moderate energy settings with very low to zero background sedimentation rates (Parcell, 2002). Type II thrombolites are indicated by chaotic growth in the vertical and horizontal orientation, which are nearly equal in size, and contain coarse detrital material, and imply low to moderate energy settings with a slight increase in background sedimentation rate due to the strong vertical growth component (Parcell, 2002).

4.3 Haynesville Formation

The Haynesville Formation conformably overlies the Smackover Fm. Salvador (1987) classified the Haynesville to be Kimmeridgian in age. The Haynesville is broken into three units (Mancini et al., 1991). The lowest unit is recognized as the Bucker Anhydrite Member; which consists of massive anhydrite with intercalated dolomite (Mancini et al., 1991). When absent, anhydritic shale and sandstone, thin anhydrite, and salt stringers replace the Buckner (Mancini et al., 1991; Tolson et al., 1983). The Buckner is evaporite dominated, where anhydrite composes 75 to 95 percent of rock volume, and represents a shallowing upward sequence (Mann, 1988). The middle Haynesville includes interbedded sandstones, shales, and anhydrite layers (Mancini et al., 1991). The upper Haynesville includes interbedded carbonate mudstones, dolomitic limestones, sandstones, shales, and anhydrites (Mancini et al., 1991; Tolson et al., 1983).

Anhydrites predominately overlie Smackover grainstone and packstone reservoir facies in southwest Alabama. However, Buckner anhydrites do not directly overlie reservoir facies at the LCCF and BF; instead Buckner anhydrites are discontinuous and overlie lime mudstones of the Smackover (Heydari and Baria, 2006; Mancini et al., 2008).

CHAPTER 5

STRATIGRAPHY OF THE SMACKOVER FORMATION

5.1 Overview

The Upper Jurassic Smackover Formation is Oxfordian in age, consists of a marine transgressive microbial carbonates unit, which includes limestones and dolostones that unconformably overlies alluvial deposits of the Norphlet Formation. The Smackover is conformably overlain by interbedded anhydrites and shales by the Buckner Member of the Haynesville Formation (Fig. 1).

Six lithofacies are recognized, of which two are productive reservoirs. Starting at the base the lithofacies include: (S-1) transgressive subtidal lime mudstone and dolomudstone to wackestone; (S-2) subtidal clotted peloidal thrombolite boundstone; (S-3) subtidal microbially influenced packstone to lime mudstone; (S-4) deeper water to subtidal lime mudstone; (S-5) shallow subtidal nearshore fossiliferous, peloidal, and ooid grainstone to wackestone; (S-6) peritidal lime mudstone and dolomudstone to wackestone (Mancini et al., 2006; Mancini et al., 2008). One lithofacies from the Buckner Member, a tidal channel floatstone, was encountered, which formed at the same time as the Smackover.

5.2 S-1 Wavy Bedded Laminated Mudstone

Lithology

This unit is gray to light pink in color (Fig. 4), and is composed of lime mud, sub-angular silt and pressure dissolution stylolites. S-1 facies contain thin horizontal laminations near the base that grade into peloid rich microbial mat features with wavy bedding at the top.

Environment of Deposition

The laminated mudstone facies represent a unit deposited after an initial transgression in a subtidal setting. Due to the presence of mat material, this unit could have helped bind the alluvial fan material of the Norphlet Formation creating a more conducive substrate for nucleation (Heydari and Baria, 2006). The laminated character, fine grained material present and disconformable sharp contact suggest deposition occurred below wave base in the mid-ramp environment, in calm transgressive waters.

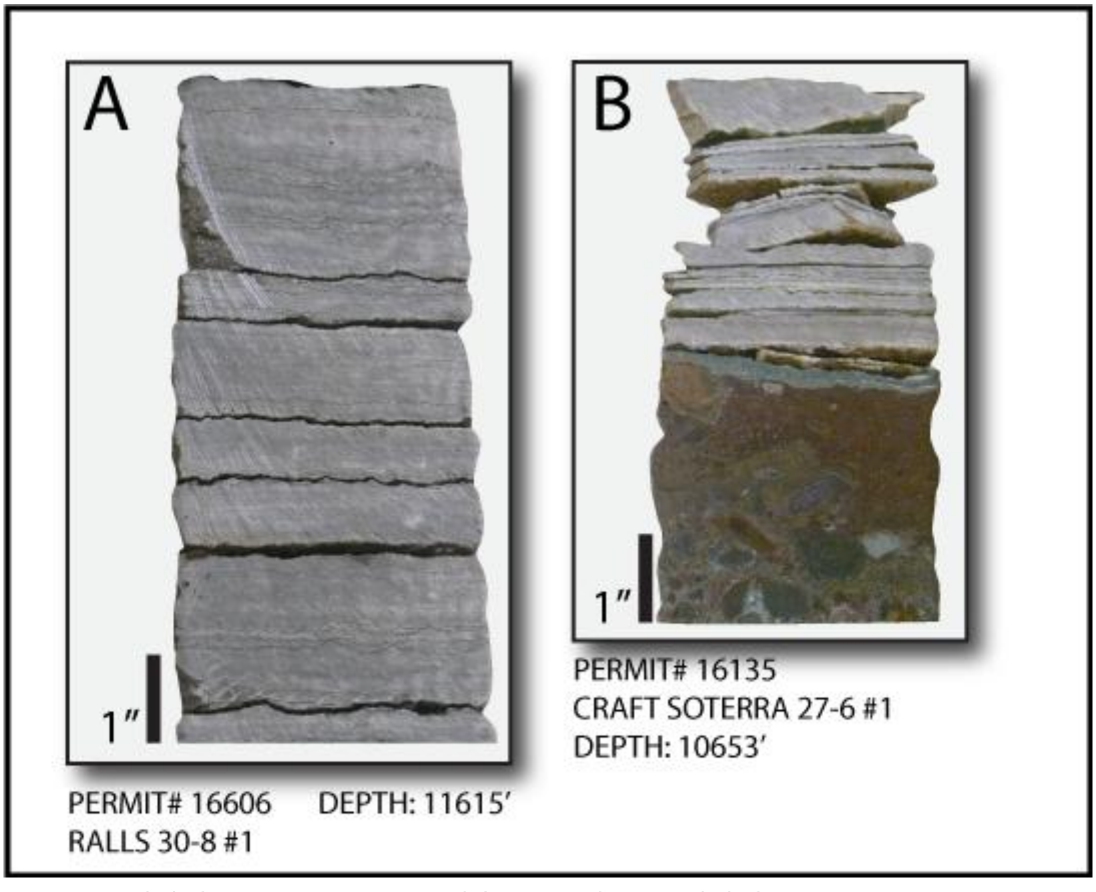


Figure 5: (A) Core photograph of S-1 lithofacies. (B) Core Photograph showing disconformable contact between S-1 and Norphlet Formation.

5.3 S-2 Thrombolite Boundstone

Lithology

This unit is a dolomitic limestone, dark to light gray to tan in color (Fig. 5); with a boundstone texture. The thrombolite facies contains clotted peloids, microbial filaments, ostracods fragments, subangular silt, *Favreina* sp. pellets, and miliolid foraminifers. Thrombolite facies exhibits extensive diagenetically modified fabrics, in the form of interparticle and vuggy porosity. However, micritic cements commonly bind allochems together and fibrous to bladed circumgranular dolomite cements can also occlude any effective porosity.

Environment of Deposition

Ahr (2011) classified microbial carbonates as “biogeochemical reefs”. Biofilms of cyanobacteria trap, bind, and cement grains together in the form of accretionary structures. Thrombolite boundstones formed in subtidal settings, with low energy waters.

Thrombolite growth forms vary regionally throughout the Smackover Formation. Localized growth patterns present at LCCF and BF include layered (Type I), and chaotic or reticulate (Type II) growth forms. The lack of coarse detrital material indicate Type I thrombolites to grow in low to moderate energy settings with very low to zero background sedimentation rates; where Type II thrombolites are recognized to grow in moderate energy settings with a slight increase in background sedimentation rate, due vertical growth patterns (Parcell, 2002).

Distribution

Isopach mapping of the thrombolite facies shows a series of three major buildups (Fig. 13). These buildups reside in the following areas (in legal description, Section-Township-Range): 20/21-4N-12E; 13/14/23-4N-12E; 22/23/27/28-5N-13E. All of these buildups are a major reservoir in the LCCF. In addition to the buildups in the LCCF, a smaller buildup occurs in the BF. The BF buildup occurs in 29/30/32-4N-13E. The largest buildup occurred in Section 23-Township 4N-Range 12E with 47’ (Fig. 13).

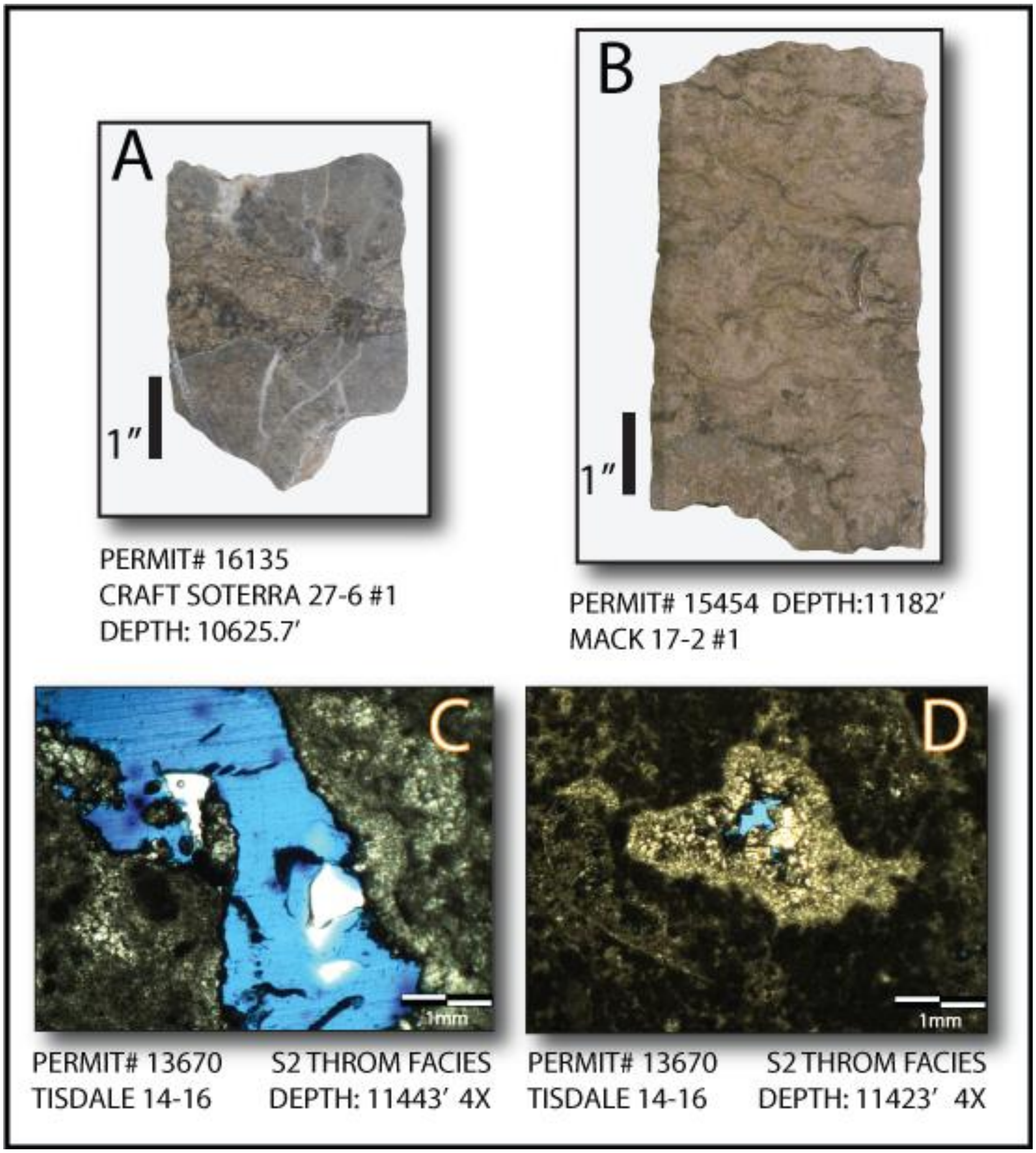


Figure 5: (A & B) Core photographs of S-2 Thrombolite facies. (C) Photomicrograph of S-2 Thrombolite facies. Note vuggy pore indicated by blue epoxy surrounded by dark microbial peloids. (D) Photomicrograph of S-2 Thrombolite facies. Note vuggy pore almost occluded by dolomitic cements.

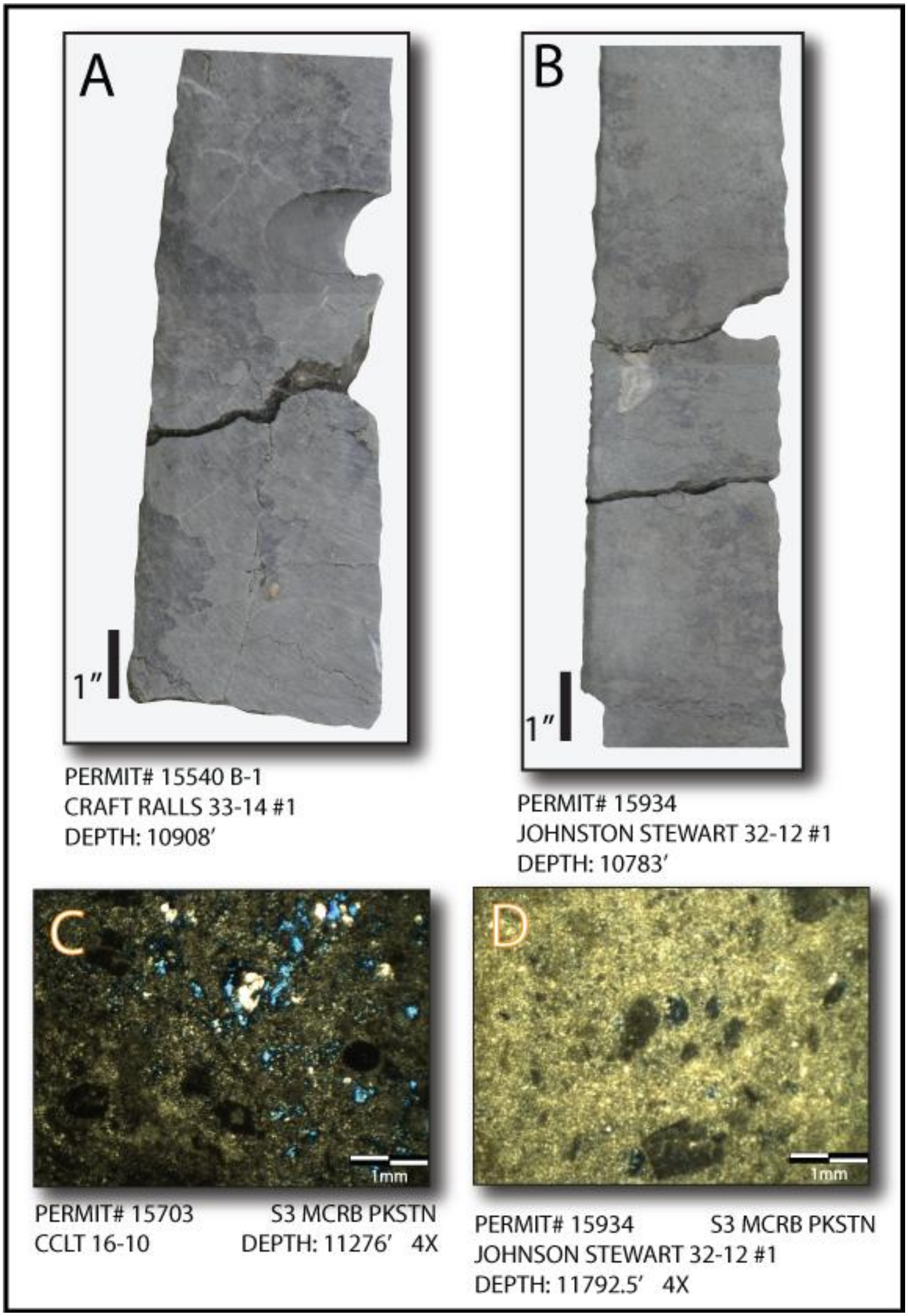
5.4 S-3 Microbially-Influenced Packstone

Lithology

This unit is defined as a microbially-influenced lime mudstone to packstone; gray to dark gray in color. S-3 facies contain peloids, algal filaments, micritized pellets, oncoids, and microstylolites. Porosity in this facies is minimal, but does contain minor intergranular type pores.

Environment of Deposition

This unit is formed in a subtidal marine environment. Due to the presence of microbial features (Fig. 6), but lack of widespread development, this facies may have developed in slightly deeper water than the thrombolite boundstone facies.



PERMIT# 15540 B-1
CRAFT RALLS 33-14 #1
DEPTH: 10908′

PERMIT# 15934
JOHNSTON STEWART 32-12 #1
DEPTH: 10783′

PERMIT# 15703 S3 MCRB PKSTN
CCLT 16-10 DEPTH: 11276′ 4X

PERMIT# 15934 S3 MCRB PKSTN
JOHNSON STEWART 32-12 #1
DEPTH: 11792.5′ 4X

Figure 6: (A & B) Photographs of S-3 facies exhibiting microbially influenced textures. Note vertical microbial features in both photos. (C & D) Photomicrograph of S-3 facies. Note *Parafavreina* pellets in rounded and elongate forms along with minimal porosity.

5.5 S-4 Lime Mudstone

Lithology

This unit is a lime mudstone, gray to dark gray in color, and contains textures ranging from mudstone to packstone to wackestone. Minimal algal features, bivalve fragments, oncoids, and microstylolites are present; along with very minimal intergranular porosity. This unit is horizontally and wavy laminated (Fig. 7) and serves as an effective vertical and lateral seal to the overlying S-5 ooid grainstone facies.

Environment of Deposition

Due to the lack of coarse material and the abundance of mud material, this unit developed in a deeper water sub-tidal marine setting near the base. However, due to the associated lithofacies this unit marks the transition from a transgressive system tract to a regressive system tract.

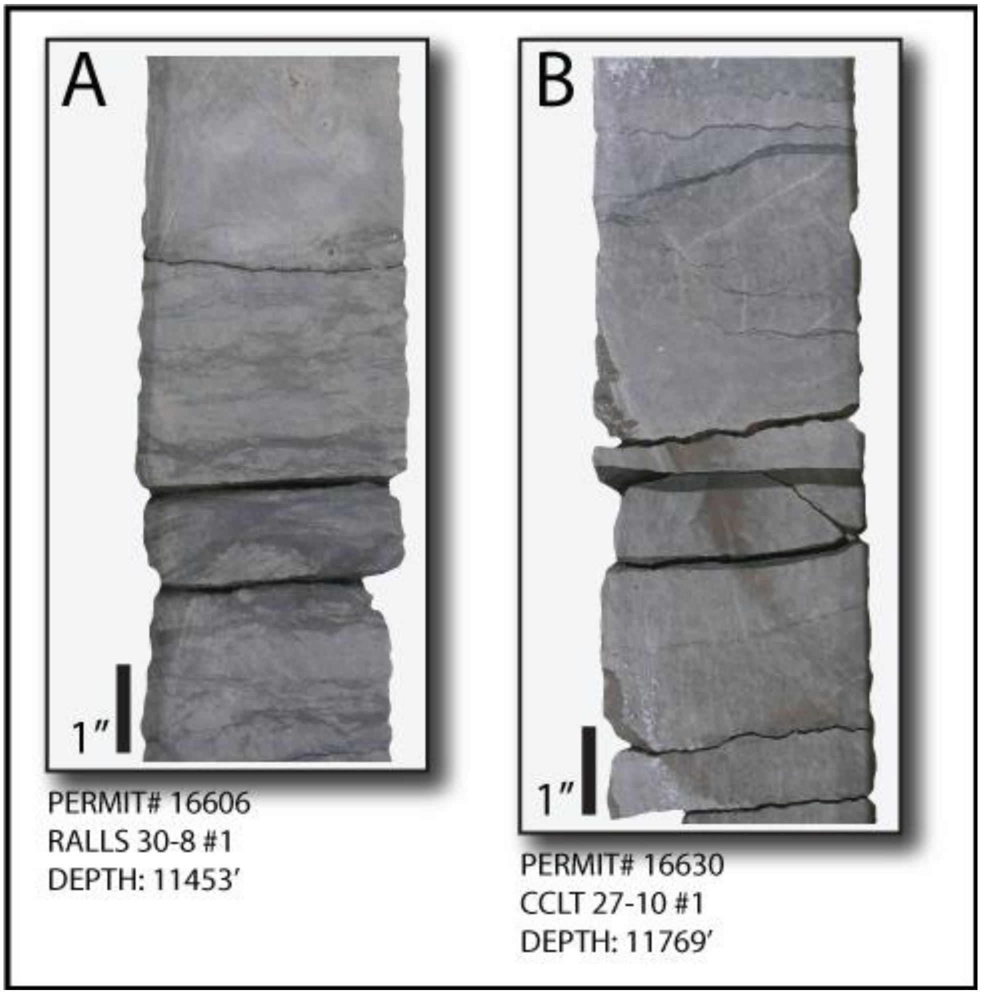


Figure 7: (A & B) Photographs of core samples from S-4 facies.

5.6 S-5 Ooid Grainstone

Lithology

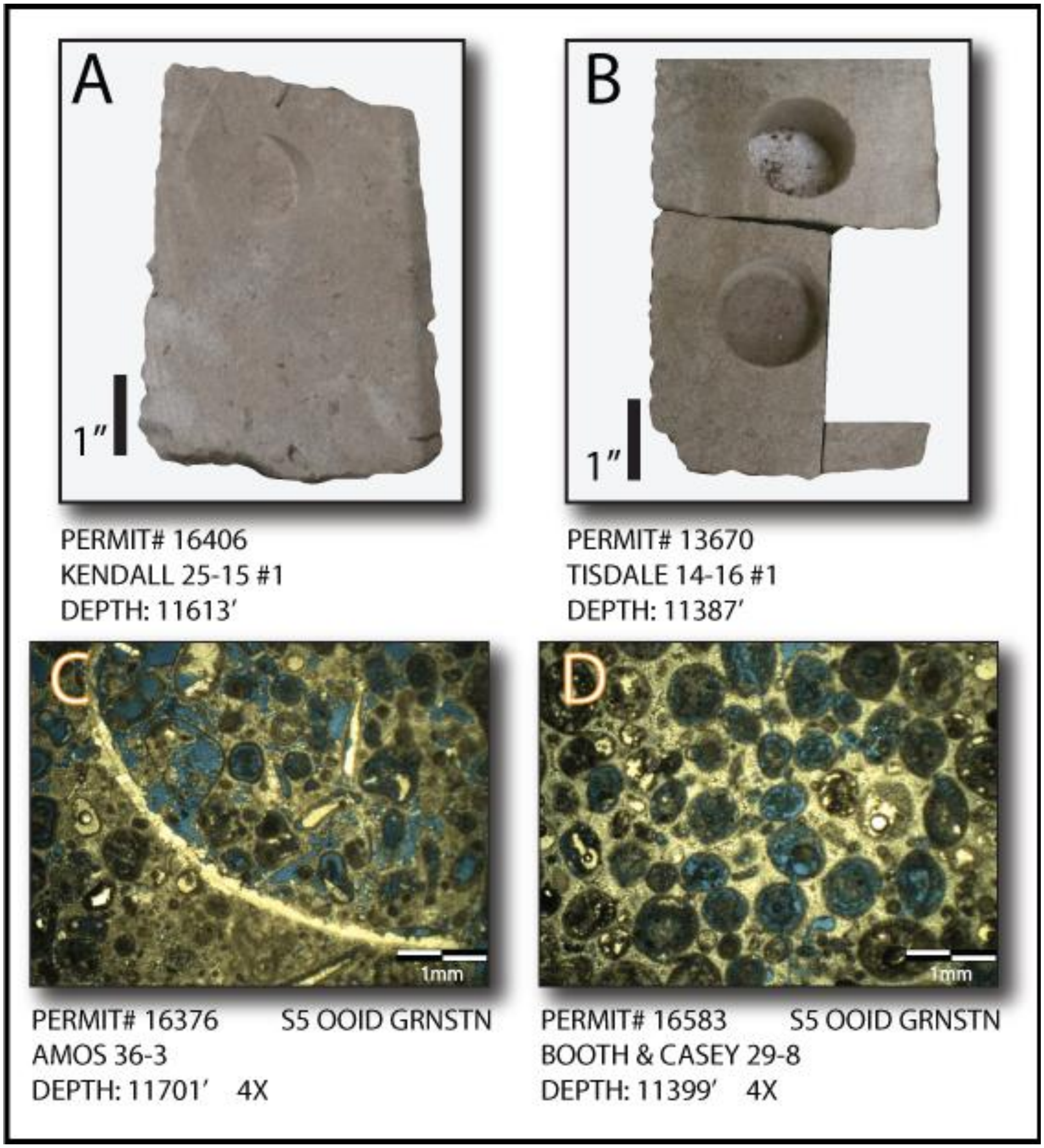
This unit is an ooid-peloid grainstone, light brown to gray in color, and contains cross laminated textures ranging from dominate grainstone to wackestone to packstone. Ooids, peloids, *Favreina* sp. pellets, skeletal fragments, oncoids, intraclasts, grapestones, bivalve fragments, and subangular silt are present in this facies (Fig. 8). This facies is the upper reservoir with porosity ranging from 0-35%, in the form of intergranular and leached secondary oomoldic to biomoldic porosity types. Sparry calcite and minor bladed calcite cements are present. Even though grainstone facies have high porosity, effective porosity is diminished due to the lack of interconnectedness of moldic pores (Fig. 8 C & D).

Environment of Deposition

This unit was deposited in a high energy near shore intertidal environment. Due to the abundance of intraclasts and cross laminations the ooid-peloid grainstone facies developed in a high energy near shore shallow water, (sub to intertidal) shoal setting.

Distribution

This facies is oriented in a southwest-northeast attitude, and attained maximum thickness in the LCCF in central part of the field (13/14/23-4N-12E), and thins dramatically in the northeast portion of the LCCF. However, the nearshore grainstone facies is the dominant reservoir in the BF, which is where true maximum thickness was attained of 37 feet (25/36-4N-12E; 29/30/31/32-4N-13E).



PERMIT# 16406
KENDALL 25-15 #1
DEPTH: 11613′

PERMIT# 13670
TISDALE 14-16 #1
DEPTH: 11387′

PERMIT# 16376 S5 OOID GRNSTN
AMOS 36-3
DEPTH: 11701′ 4X

PERMIT# 16583 S5 OOID GRNSTN
BOOTH & CASEY 29-8
DEPTH: 11399′ 4X

Figure 8: (A & B) Photographs of core samples from S-5 facies. Note intraclasts and ostracode fragments in lower portion of A. (C & D) Photomicrograph typical of S-5 facies. Note abundance of moldic and interparticle porosity exhibited by blue epoxy, and size comparison of ostracode fragment in (C) to smaller forams, ooids, and *Favreina* pellets. Also compare the amount of effective porosity between C and D; D exhibits invasively leached particles but lacks widespread interconnectedness.

5.7 Intermittent Tidal Channel Floatstone

Lithology

This unit is a light gray floatstone to conglomerate, which is defined as a limestone with more than ten percent of contained grains larger than two millimeters with a micritic matrix. Pebble sized grains are rounded to sub-rounded, and contain a mixture of granitic to volcanic clasts. Bedding is cross laminated to laminated with wavy bedding throughout.

Environment of Deposition

Due to the presence of pebbles and bedding characteristics, this unit is considered to develop in a tidal channel, fluvial to deltaic environment. When present, this unit replaces the S-5 ooid grainstone facies, and is associated within Buckner facies. Although not considered a facies within the Smackover Formation, this unit severely affected deposition of S-5 ooid grainstone shoal facies, and possibly affected S-2 thrombolite facies. Shoal development ceases when this unit is present, at this locality and north of the conglomerate (Fig. 15), and thrombolite thickness decreases in the same location (Fig. 13).

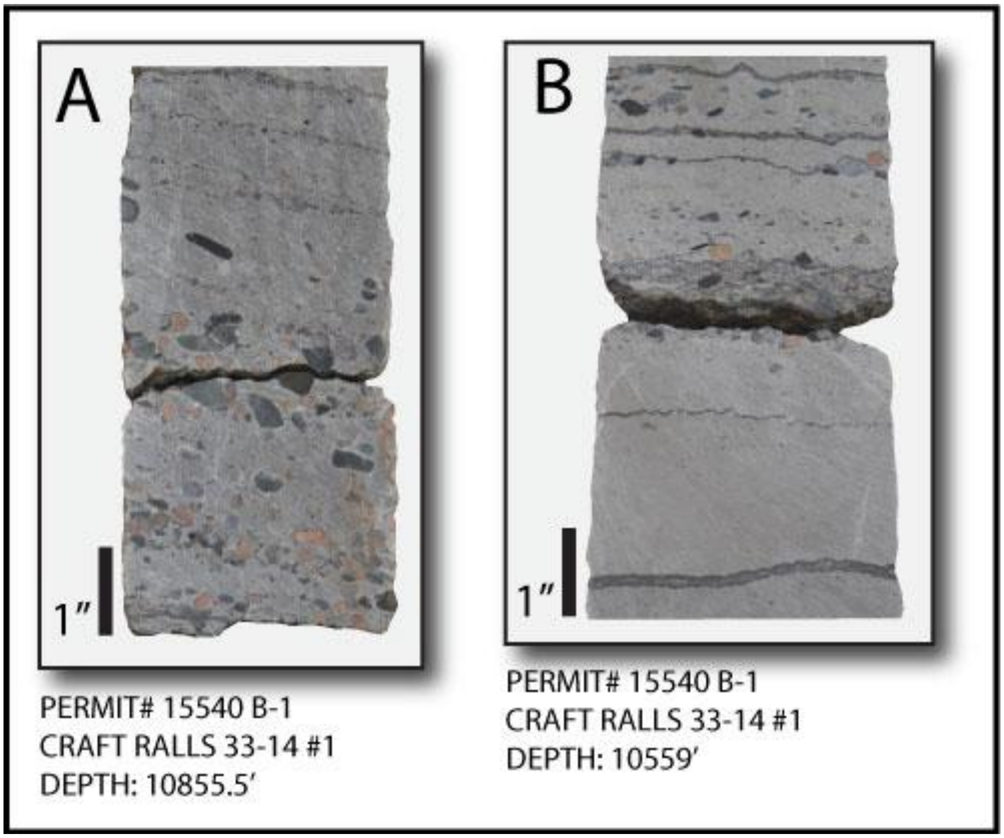


Figure 9: (A & B) Core photographs of tidal channel floatstone.

5.8 S-6 Peritidal Lime Mudstone-Dolostone

Lithology

This unit is a lime mudstone to dolomudstone (Fig. 10), gray to light gray in color, and contains peloids, ooids, subangular silt, and benthic foraminifera. Dolomitic to anhydritic shale laminae are present throughout the peritidal lime mudstone facies, along with dolomite, calcite, anhydrite, and gypsum cements.

Environment of Deposition

This unit was deposited in shallow water, low energy, lagoon setting due to the presence of evaporitic minerals. The contact between this facies and the overlying Buckner anhydrites and shales is easy to identify on well logs, but is gradational in well core samples. This facies acts as the upper seal, both vertically and laterally. However this facies thins dramatically in the northern portion of the LCCF (Sections 13/22/23/24/27-5N-13E).

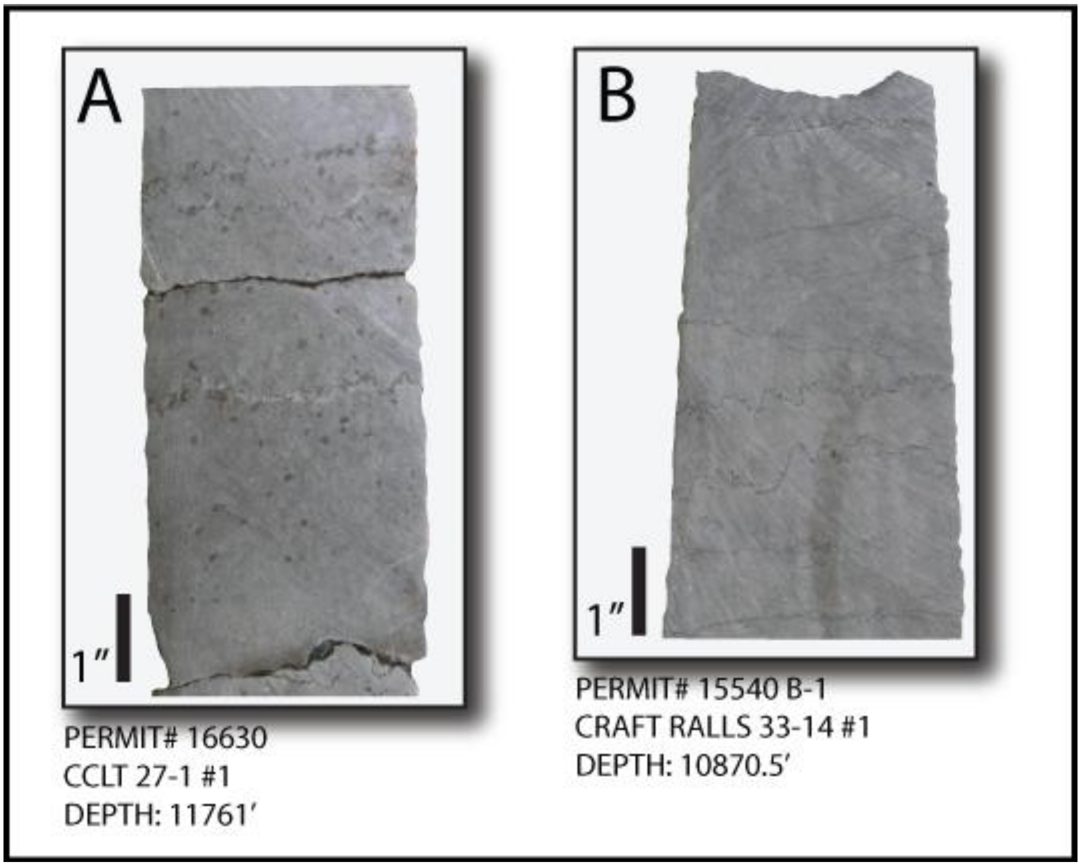


Figure 10: (A & B) Core photographs of typical S-6 facies. Note small anhydrite crystals in A, exhibiting the transition to an evaporitic environment.

CHAPTER 6

DICUSSION

Determining how and where thrombolite buildups develop in the Smackover Formation of the eastern Gulf Coast is not well understood (Mancini et al., 2004). Trends are hard to recognize between thrombolite buildups and adjacent strata within the Upper Jurassic Smackover Formation. Analysis of modern structural features between lithofacies within the Smackover Formation provides little useful information due to the variance in modern dip (Fig. 11; Fig. 12). However, trends between lithofacies thicknesses have been recognized. Thrombolite thickness appears to be directly related to S-1 thickness.

6.1 S-1 and S-2 Relationship

Unlike other known occurrences of microbolite buildups in Alabama, the thrombolites at LCCF and BF did not develop directly on basement rock or the surface of the Norphlet Formation. Initial transgression in the Conecuh sub-basin deposited S-1 laminated lime mudstone to dolostones. This highly laminated lime mudstone facilitated microbial nucleation in the LCCF and BF. During the deposition of S-1 facies, microbial activities produced microbial films that stabilized unconsolidated sediment, which initiated the precipitation of calcareous crusts, effectively protecting against erosion (Mancini et al., 2004). It is the occurrence of these calcified crusts or sediment starvation surfaces that facilitate in providing a suitable substrate for subsequent microbial reef nucleation, along with zero to low background sedimentation rates, and calm water energy that promote continued microbial growth (Mancini et al., 2004; Mancini et al., 2008). S-1 facies coincides stratigraphically with late transgressive systems tract, where sediment starvation surfaces form, and also where reef growth is initiated (Aurell and Bádenas, 1997; Mancini et al., 2004)

Bathymetry is another factor that has been debated on whether thrombolite growth is directly related to; Leinfelder (1993), Mancini (Mancini et al., 2004), and Parcell (2002) have documented the fact that microbolites have developed in a wide range of water depths. However, Mancini has noted microbolites in the northeast Gulf Coast developed in shallow waters due to the proximity where the Smackover Formation pinches out (2008).

The occurrence of well-developed S-3 facies in cores which have poorly-developed thrombolite facies is evident in core samples (e.g. permit 16630, Fig 6B). Wells that have well-developed thrombolite facies also have thin S-1 facies. Due to the conclusions that S-3 facies developed in deeper water, this could indicate that areas with minimal thrombolite growth, well developed S-3 facies, and thick S-1 facies represent deeper water settings, prohibiting extensive thrombolite growth.

Thickness mapping of the S-1 facies shows a clear correlation to maximum S-2 thrombolite thickness (Fig. 14). Maximum thrombolite thickness was attained in the LCCF (20/21-4N-12E; 13/23-4N-12E; 22/27/28-5N-13E) with additional complexes developing throughout the LCCF trend, and a smaller complex developing in the BF (Fig. 13) (29/30/32-4N-13E). Thrombolite facies terminates at the same location where S-1 facies dramatically thickens. This sudden thickening could represent the transition from a shelf to slope environment, an increase in water depth.

6.2 S-5 and S-4 Relationship

Ooid grainstone facies obtained maximum thickness in the Brooklyn field, along with a smaller complex developing in the LCCF (Fig. 15). This facies does not seem to be dependent on paleotopography due to the lack of correlation between S-4 and S-5 thicknesses (Fig. 16). Environment, tidal changes, and ocean currents play a large role in the development of shoal material.

Ooid shoal material nearly ceases in the LCCF after the introduction of the channel conglomerate (Fig. 15; black arrow). During deposition of the Smackover Formation, longshore currents originated from the west. Current direction along with introduction of tidal delta material leads to the conclusion that shoaling was halted with the introduction of new material.

6.3 Intermittent Channel Influence

A fluvial channel pebble floatstone can be recognized in core samples (33-5N-13E), which occurs at the same stratigraphic position as the ooid shoal grainstone facies (S-5). When present, this fluvial material replaces S-5 facies (Fig. 15) and reduces thrombolite thickness (Fig. 13). This channel may have affected deposition and diagenesis in the LCCF and BF complex.

Thrombolite growth thickened directly north of channel deposits. Microbial reefs have been recognized to develop during times transgression, and cease during maximum flooding (Parcell, 1999). Deposition during a transgressive system tract would cause any channel deposition to retrograde. Even though channel deposits were not encountered within the thrombolite facies, this channel could have provided fresh water, severely affecting diagenesis. Thin section investigation of the thrombolite (S-2) and microbial influenced facies (S-3) show a correlation between allochemical constituents. The diagnostic feature between the two facies is the occurrence of vuggy and growth framework porosity. Compare Figure 5 (C & D) to Figure 6 (C & D) and note similarity of constituents but the lack of porosity development in S-3 facies (Fig. 6 C & D). This fresh water source could have been active during thrombolite growth, facilitating porosity generation and severely affecting diagenesis.

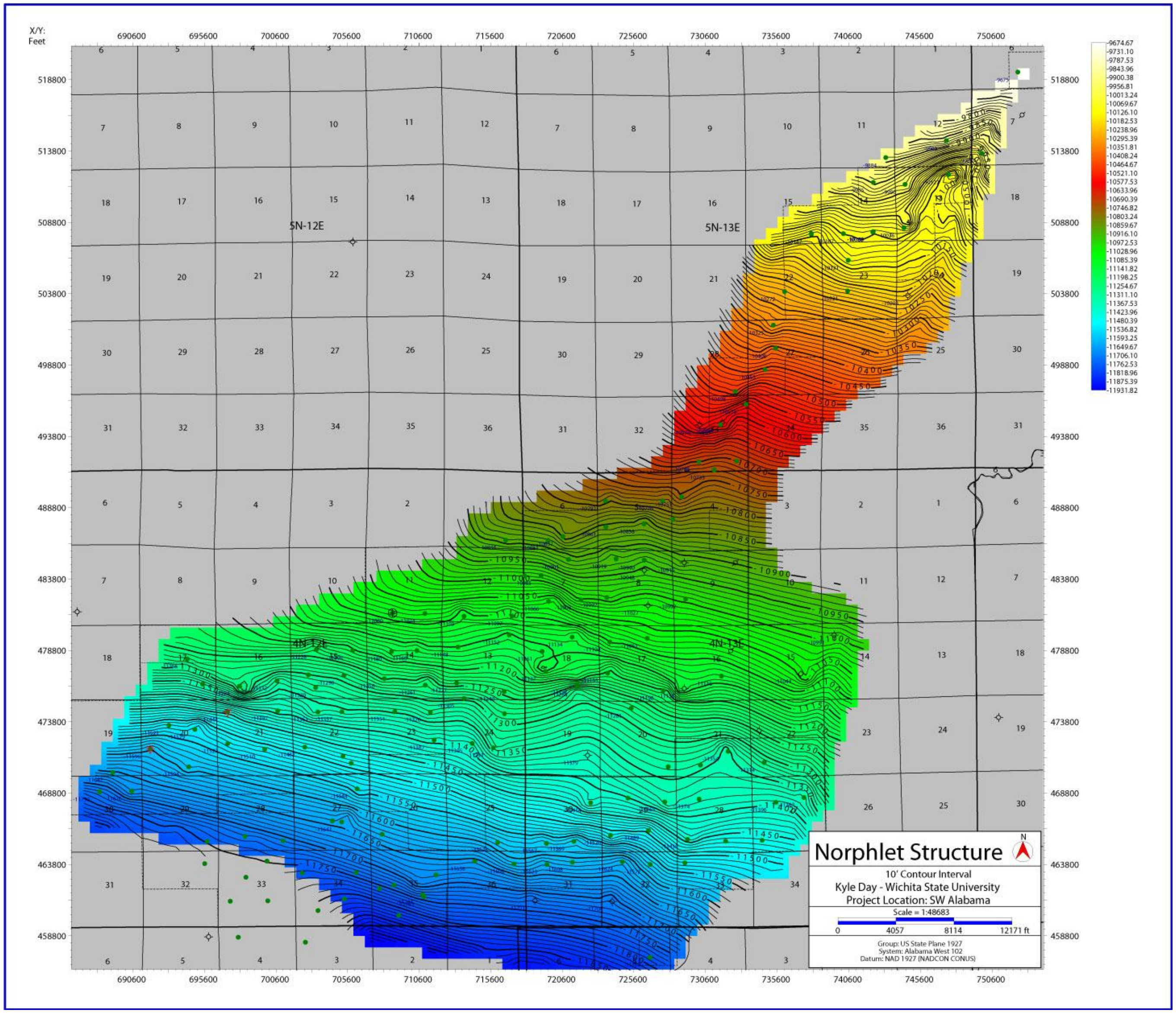


Figure 11: Structure contour map on top of the Norphlet Formation.

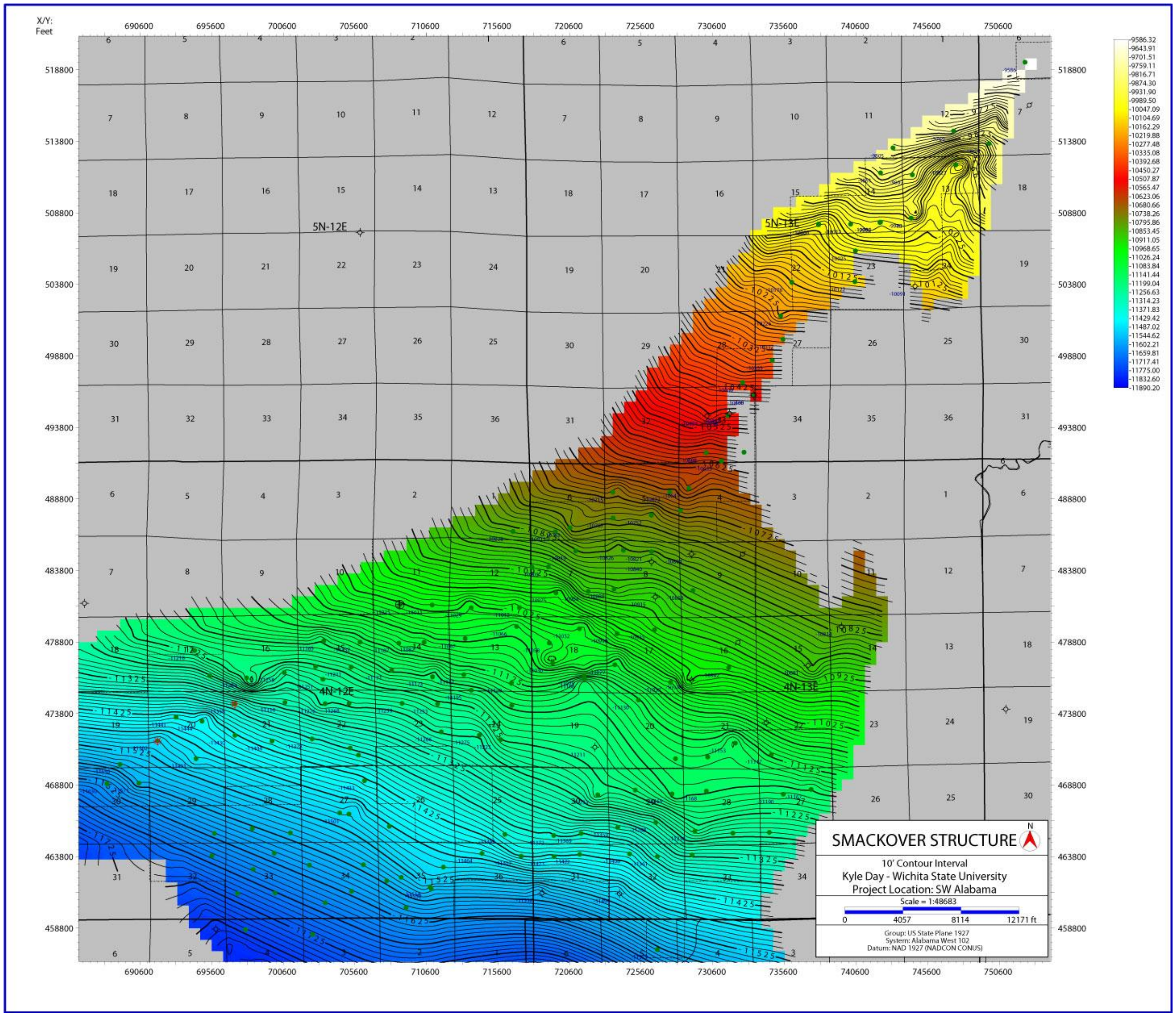


Figure 12: Structure contour map on top of the Smackover Formation.

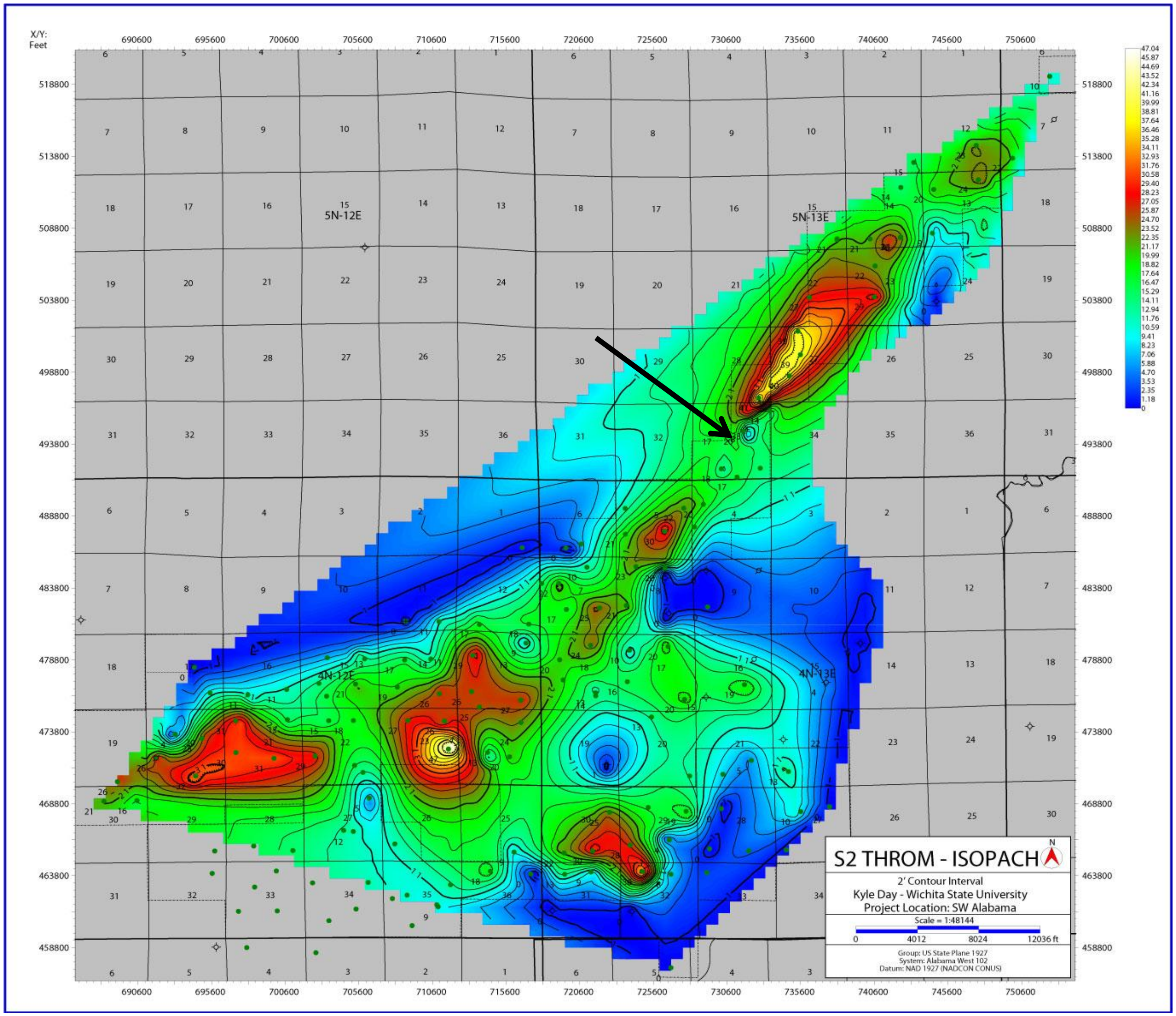


Figure 13: Isopach map of S-2 Thrombolite facies. Black arrow shows location of channel conglomerate.

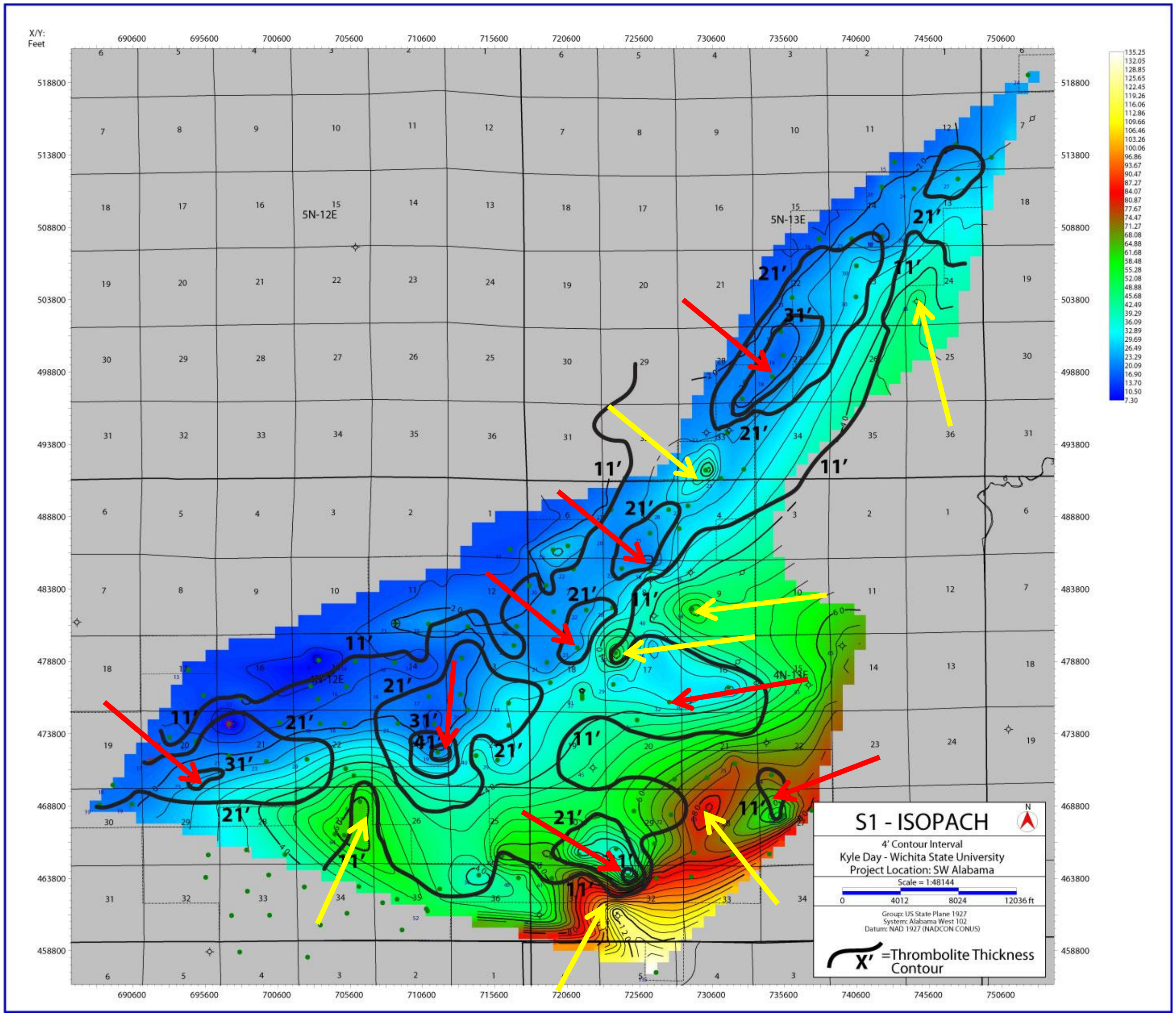


Figure 14: Isopach map of S-1 facies with S-2 Thrombolite contours overlain. Note S-2 thrombolite to thicken where S-1 thins. Red arrows indicate locations of thrombolite buildups; yellow arrows indicate where S-1 facies thickens with minimal thrombolite growth

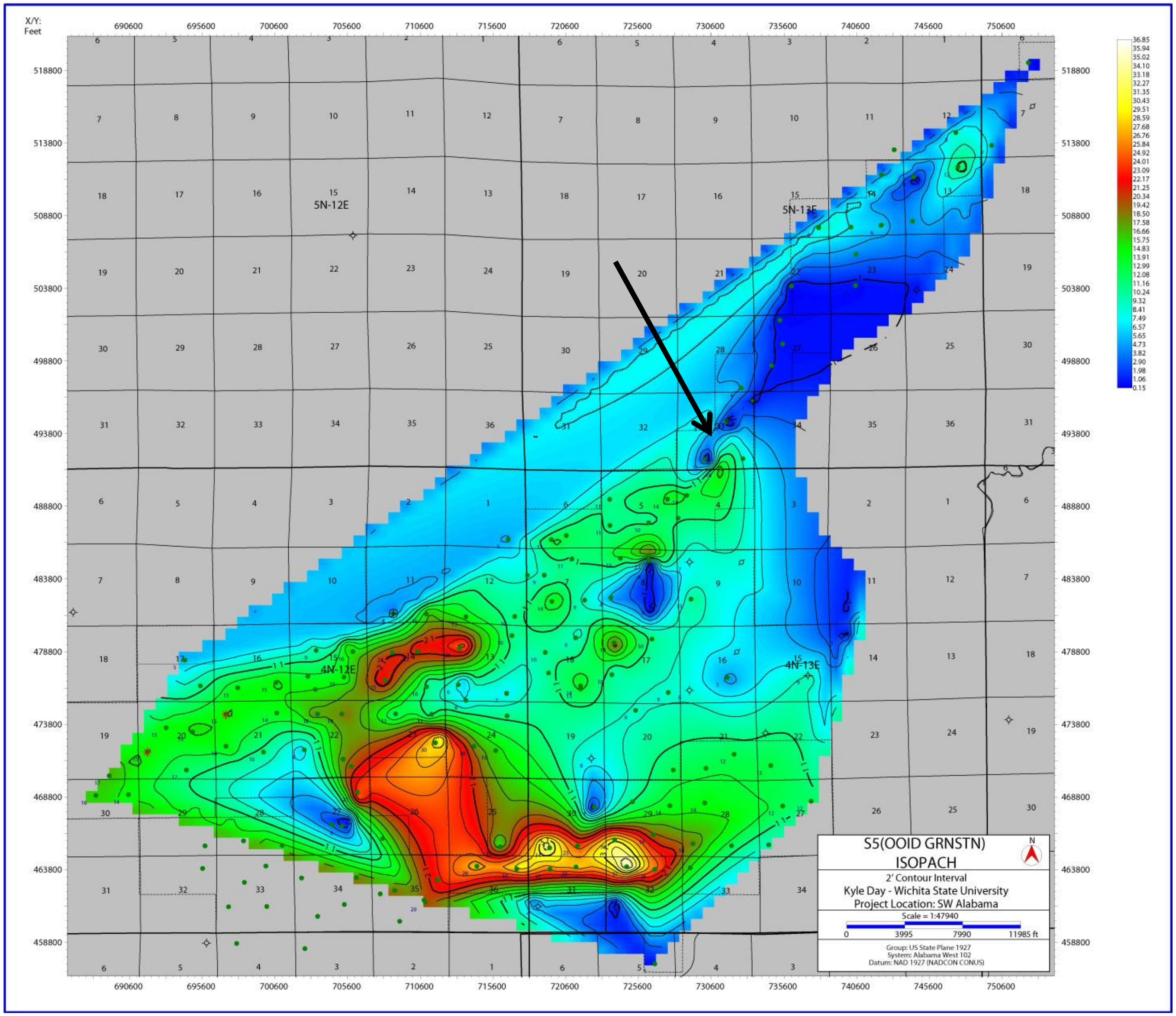


Figure 15: Isopach map of S-5 ooid grainstone facies. Note black arrow indicating location of channel conglomerate.

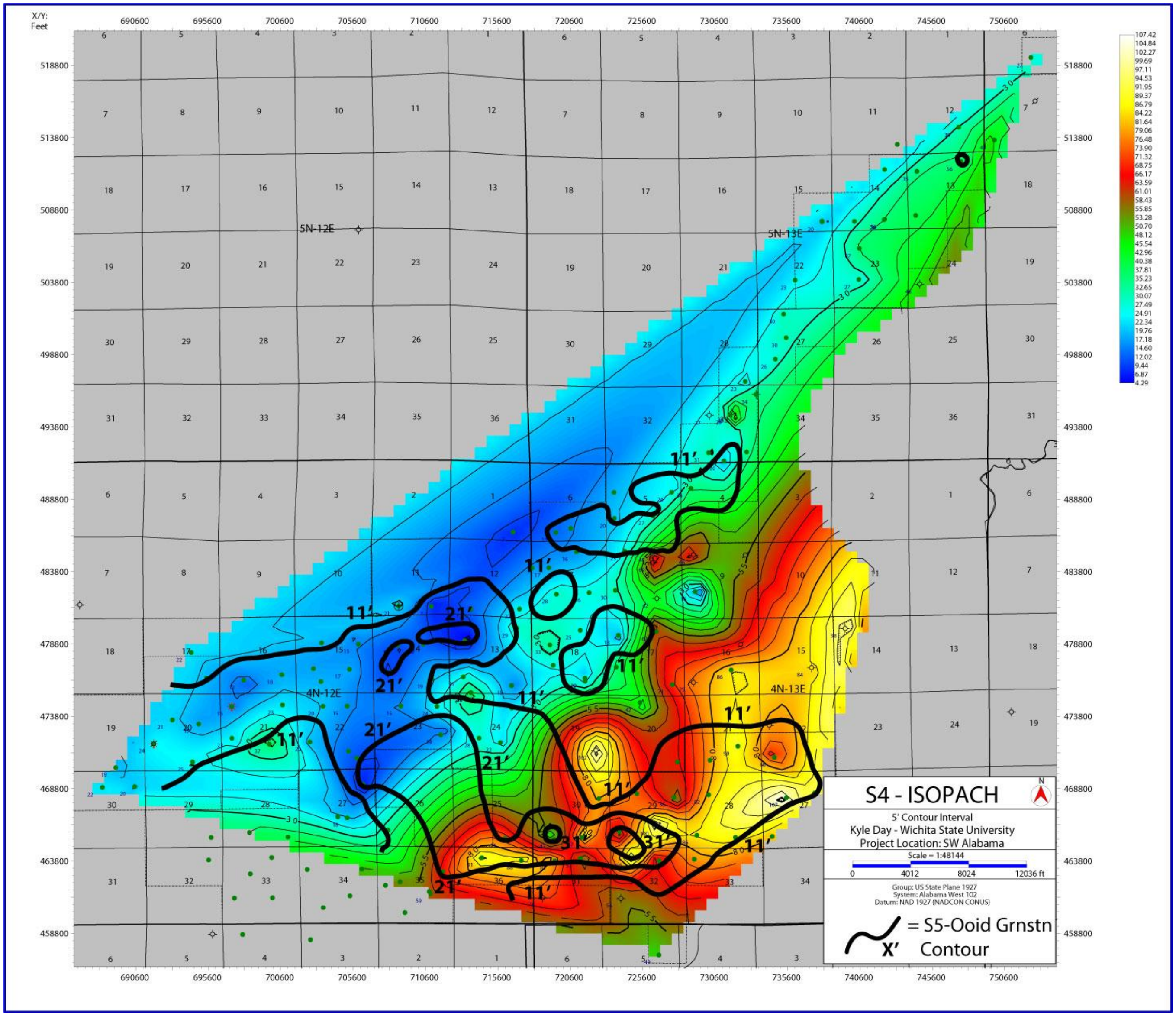


Figure 16: Isopach map of S-4 facies with S-5 ooid grainstone facies overlain. Note the lack of similarity between S-4 thickness and S-5 thickness.

6.4 DEPOSITIONAL MODEL

The depositional model for the LCCF and BF is dominated by ooid shoals and microbial reefs, which developed in high to low/moderate energy, respectively; along with low energy subtidal inner shelf sediments. However, both reservoirs portray significant differences with regard to development.

The clearest relationship was discovered upon comparing S-2 thickness to S-1 thickness. Thrombolitic reefs developed where S-1 facies thinned (Fig. 14). Also, reef thickness became minimal to non-existent when S-1 facies thickened, within the LCCF and BF and when S-1 thickened basinward. Additionally, there is no correlation between the occurrence of mat features, or microbial overprints, because these are common in wells with minimal thrombolite growth. This suggests that the combinations of bathymetry, water energy, and paleotopography are the main factors that controlled reef development.

Where similar microbial reefs in the Gulf Coast utilized direct nucleation on basement hard grounds, this study suggests a model where faulted pre-Norphlet basement rocks created the necessary paleotopography for subsequent deposition of the Norphlet and S-1 facies to facilitate microbial nucleation (Fig. 17). S-1 facies are critical for reef development at LCCF and BF because thrombolites required firm calcified crusts, or sediment starvation surfaces, along with zero to low background sedimentation rate and low to moderate water energy to promote microbial growth. This model should be considered hypothetical due to the lack of wells drilled to the basement and available seismic data.

Moreover, ooid shoal development does not seem to have a correlation between paleotopography, which is understandable since shoals are heavily dependent on environmental conditions (Mancini et al., 2008). This is proven by overlaying shoal thickness to S-4 thickness (Fig. 16).

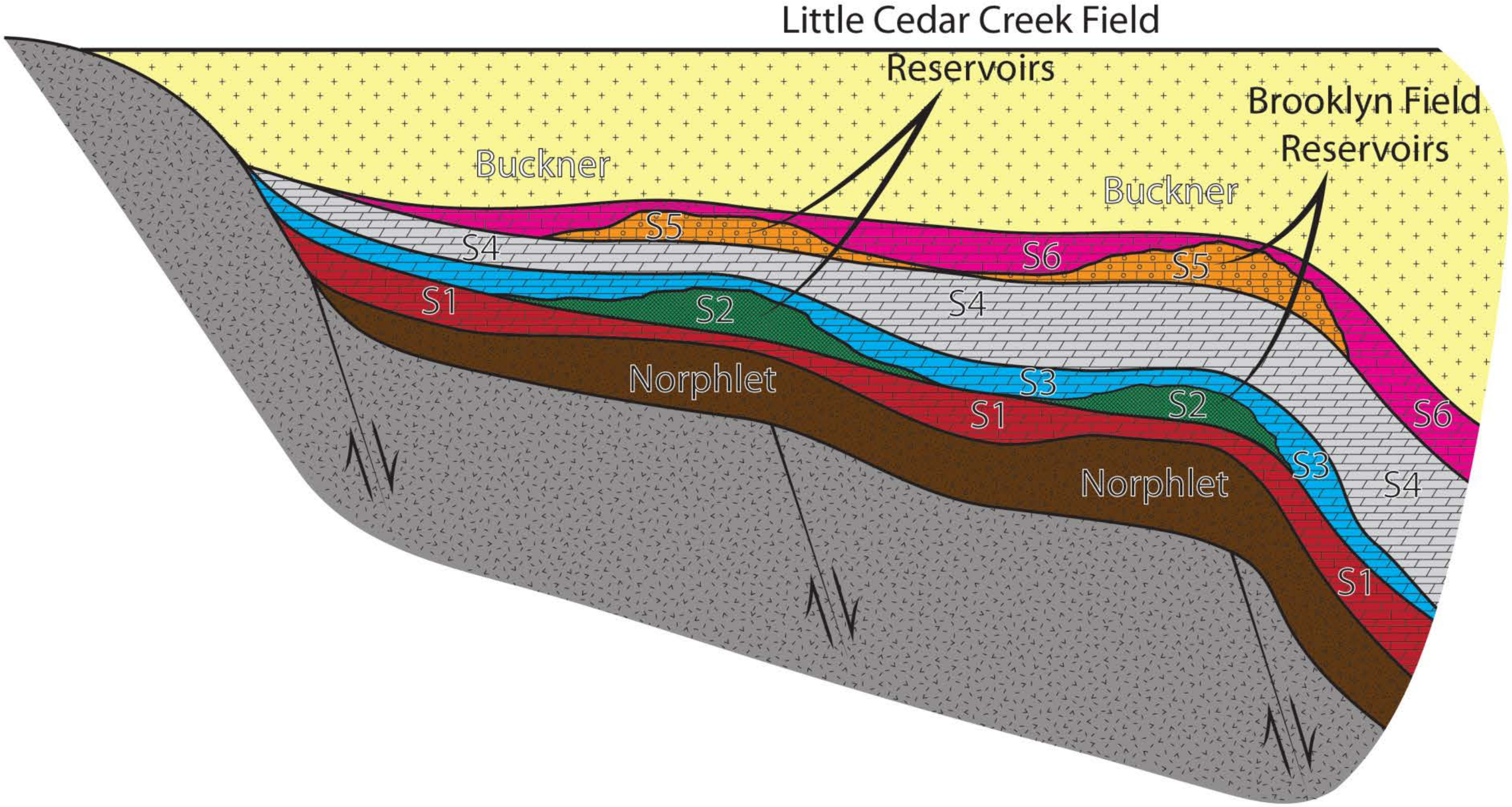


Figure 17: Schematic depositional model where basement faulting produces 1topographic highs for subsequent deposition to drape over paleotopographic crystalline topographic highs.

CHAPTER 7

CONCLUSION

1. The Little Cedar Creek and Brooklyn Fields produce hydrocarbons from a dual reservoir system, comprised of ooid grainstones and thrombolitic limestones with interbedded low energy subtidal inner shelf sediments.

2. This study utilized core, wireline logs, thin section micrographs, and geologic computer modeling software to characterize a pure reefal thrombolite in the north east Gulf Coast in southwest Alabama.

3. Six Smackover lithofacies and one Buckner Member lithofacies characterize the Little Cedar Creek and Brooklyn Fields; which include (from the base of the Smackover Formation): (S-1) transgressive subtidal lime mudstone and dolomudstone to wackestone; (S-2) subtidal clotted peloidal thrombolite boundstone; (S-3) subtidal microbially influenced packstone to lime mudstone; (S-4) deeper water to subtidal lime mudstone; (S-5) shallow subtidal nearshore fossiliferous, peloidal, and ooid grainstone to wackestone; (S-6) peritidal lime mudstone and dolomudstone to wackestone, and a tidal channel floatstone from the Buckner Member.

4. The lower reservoir (S-2) is comprised of a subtidal peloidal thrombolite boundstone that includes clotted peloidal boundstone (thrombolite) with fine, subangular silt, and thickness variations between zero and 47 feet. The upper reservoir (S-5) is comprised of a shallow subtidal nearshore fossiliferous, peloidal, and ooid grainstone, with thickness variations between zero and 37 feet.

5. S-2 thrombolite boundstone development was affected by bathymetry, water energy, and background sedimentation rate. Thrombolite buildups were found to be

thickest when underlying S-1 mudstone facies were thin, which is attributed to paleotopography. Locations with thicker S-1 facies are considered deeper water settings, which prohibited thrombolite development. S-5 reservoir development was affected by environmental conditions, and was not affected by underlying strata.

6. Modern day structural analysis provides little useful information; whereas isopach thickness mapping provides correlative relationships between Smackover lithofacies.

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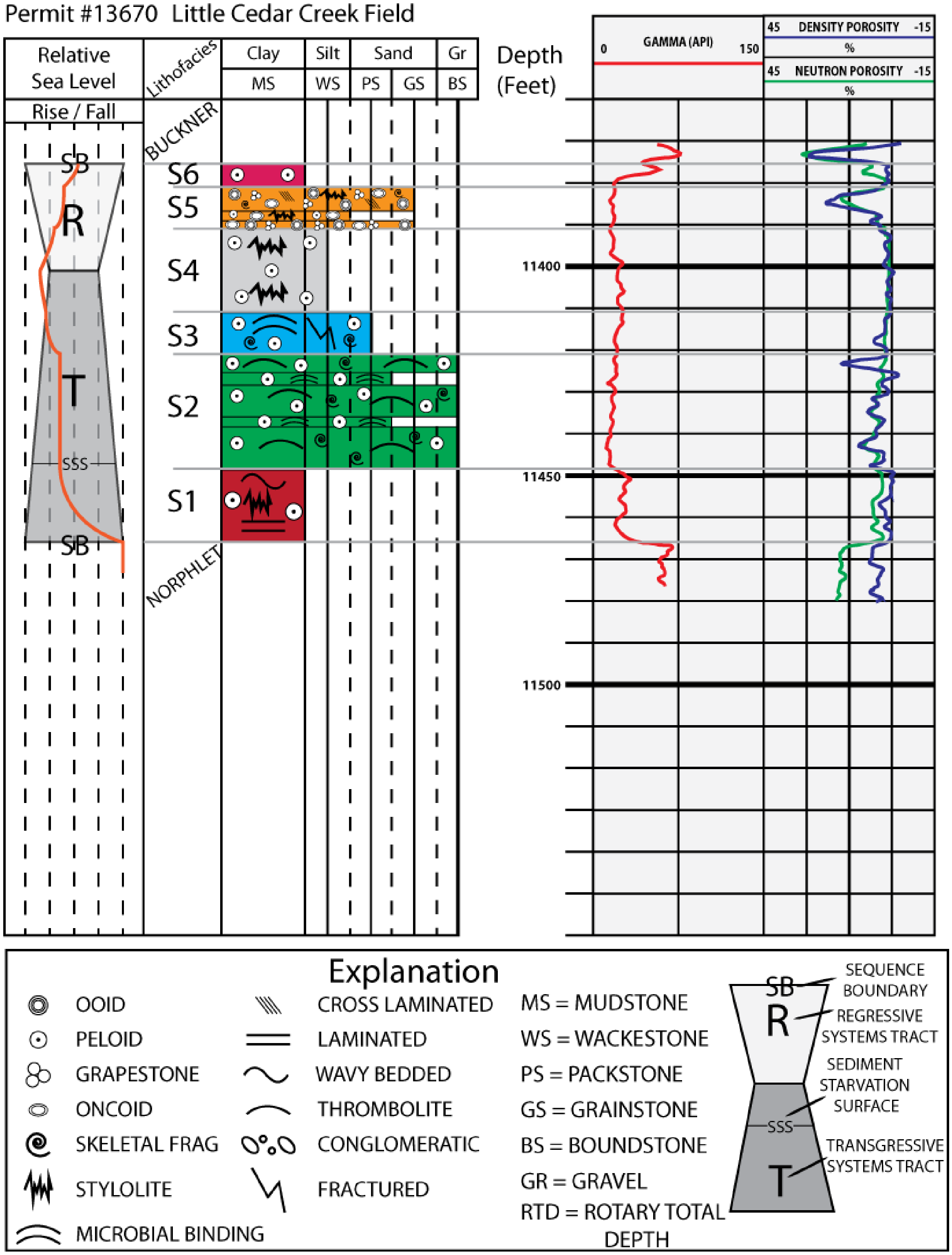
APPENDICES

APPENDIX A: Log to Core Correlations

Permit #13670 Little Cedar Creek Field



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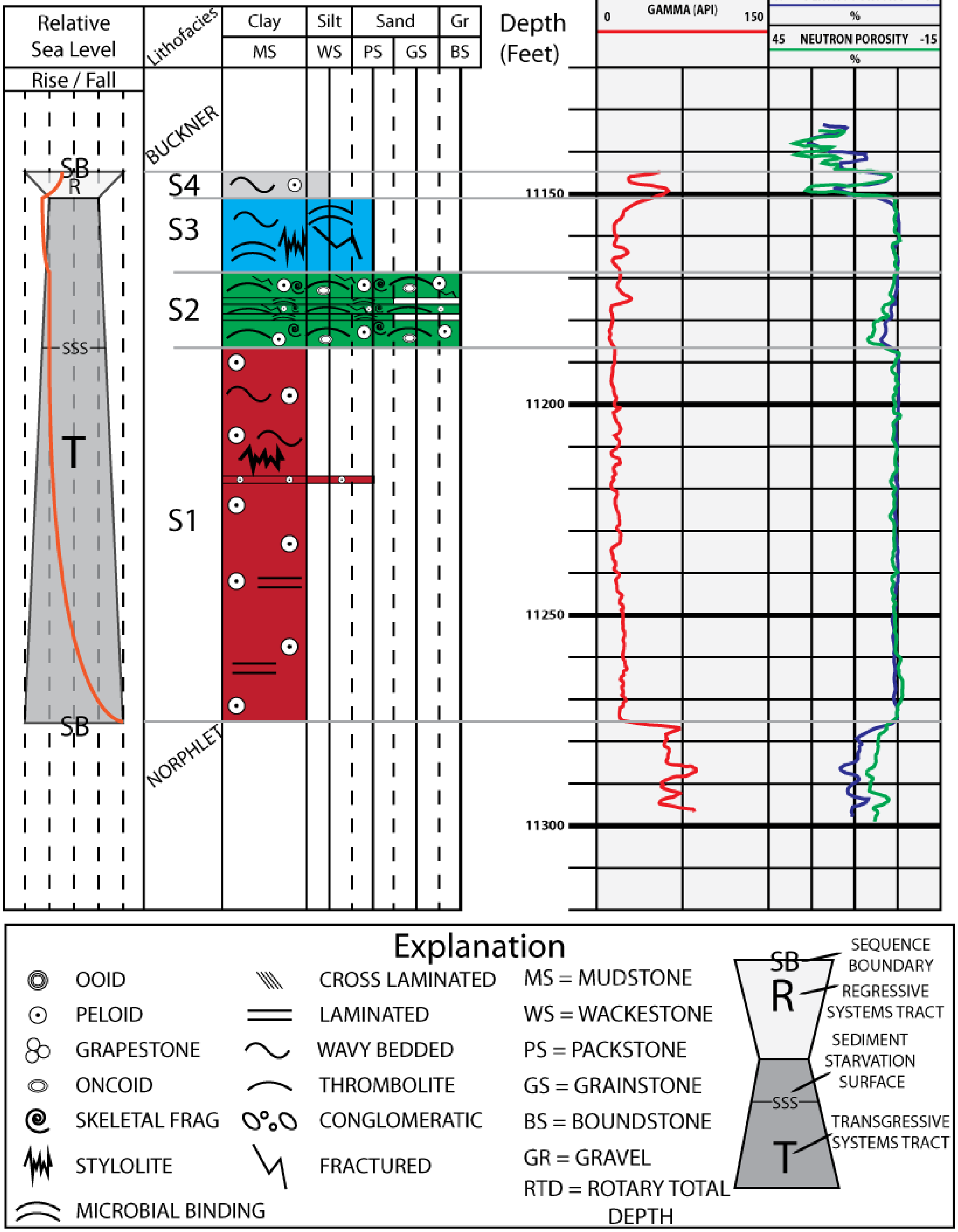
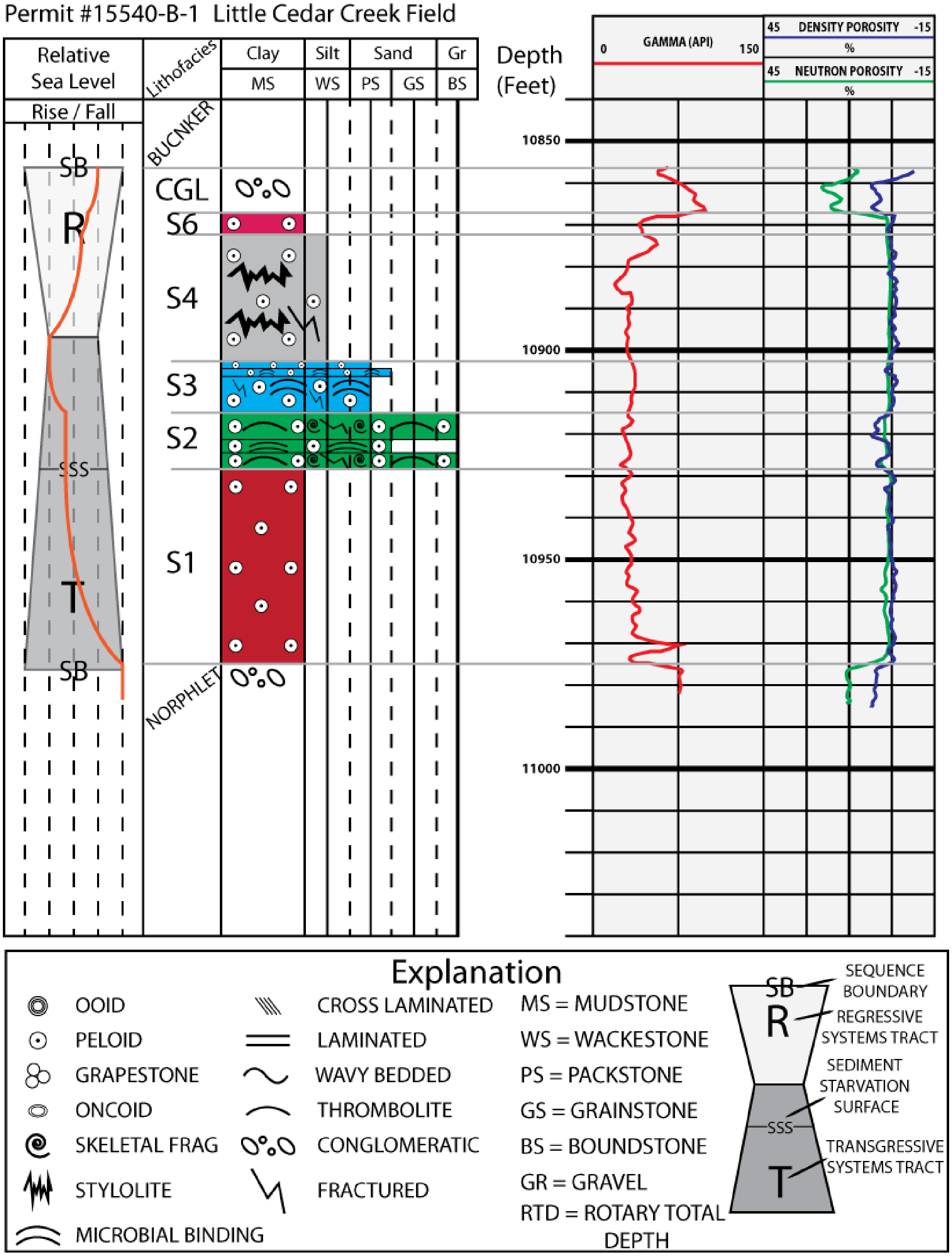
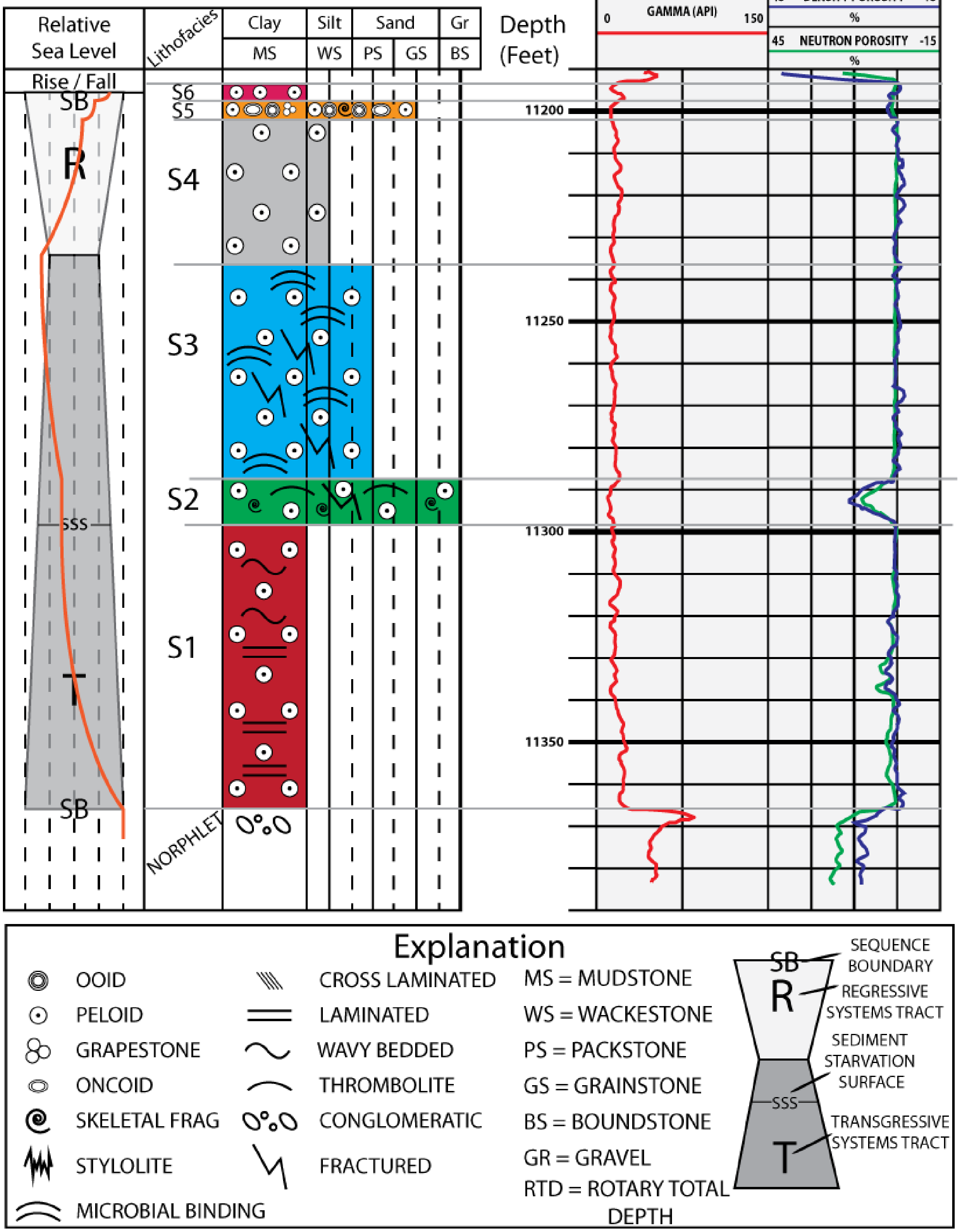


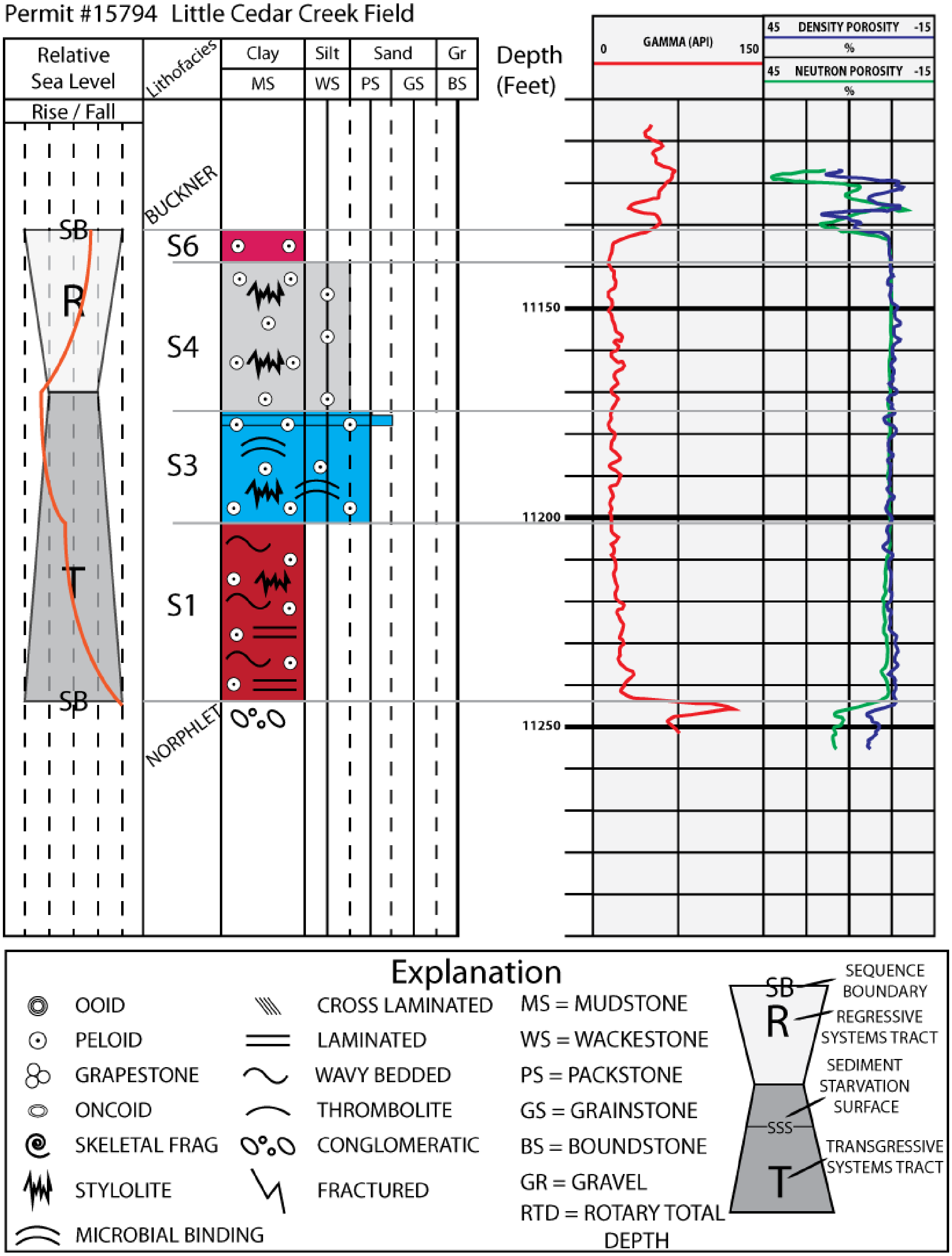
Permit #15540-B-1 Little Cedar Creek Field



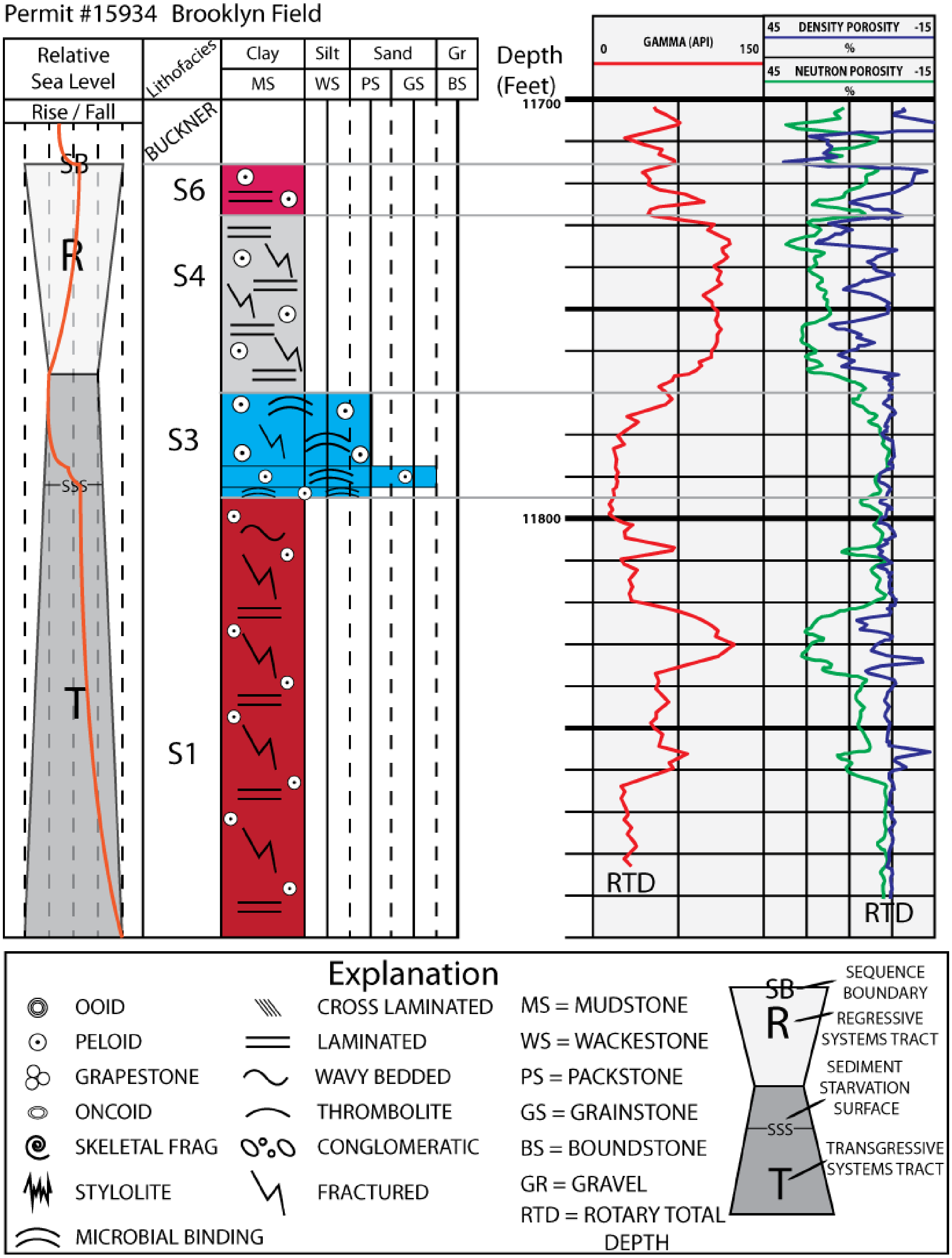
Permit #15703 Little Cedar Creek Field



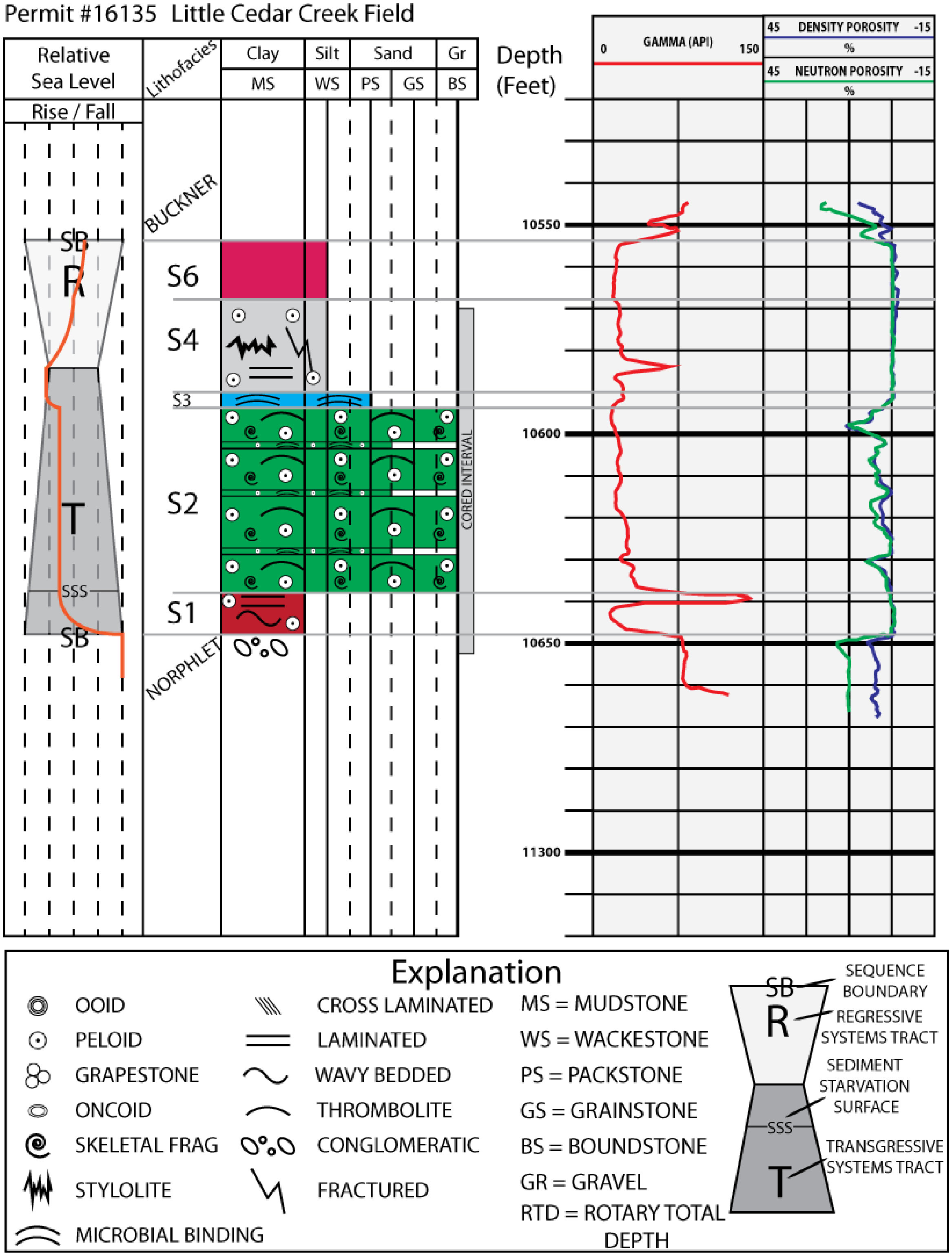
Permit #15794 Little Cedar Creek Field



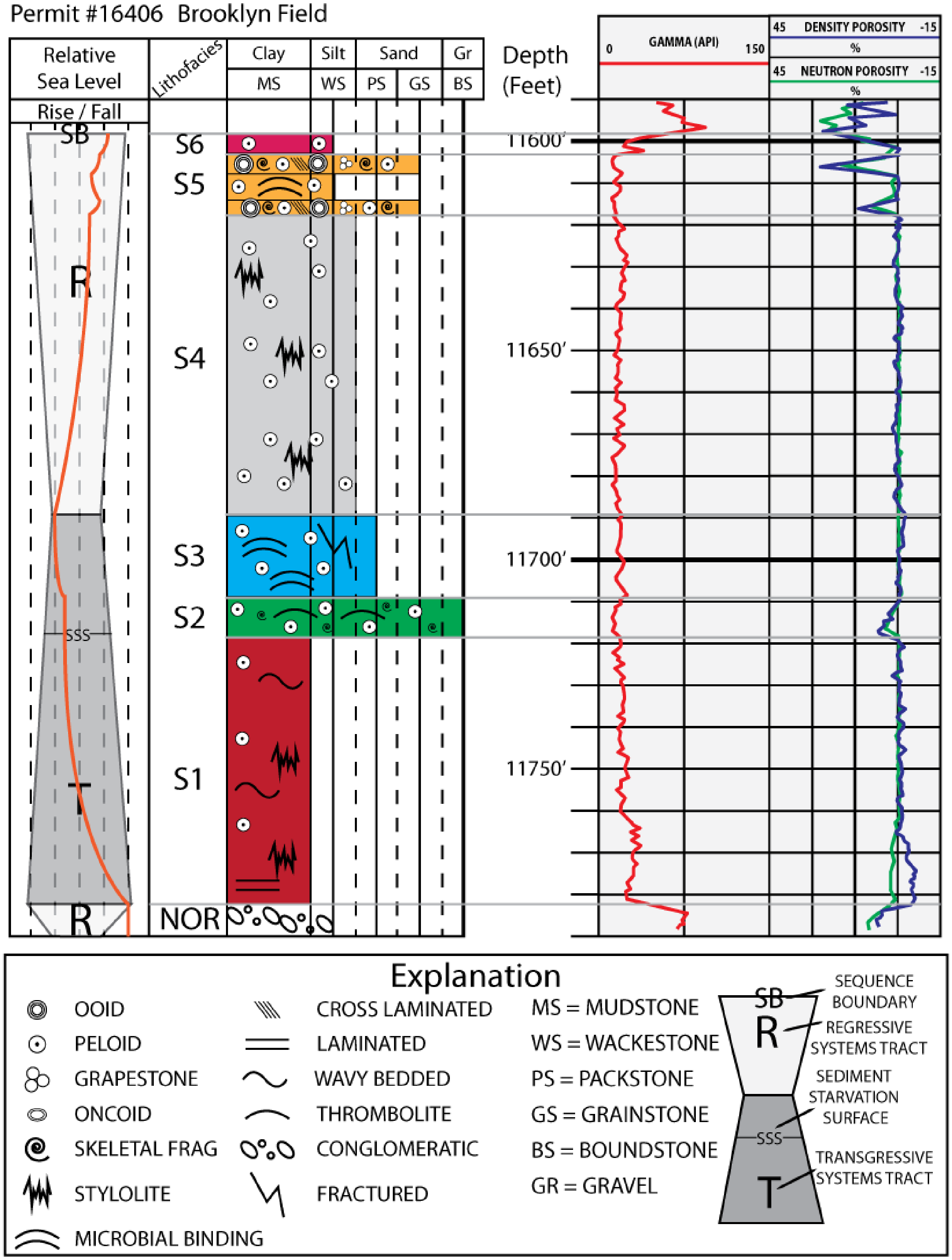
Permit #15934 Brooklyn Field

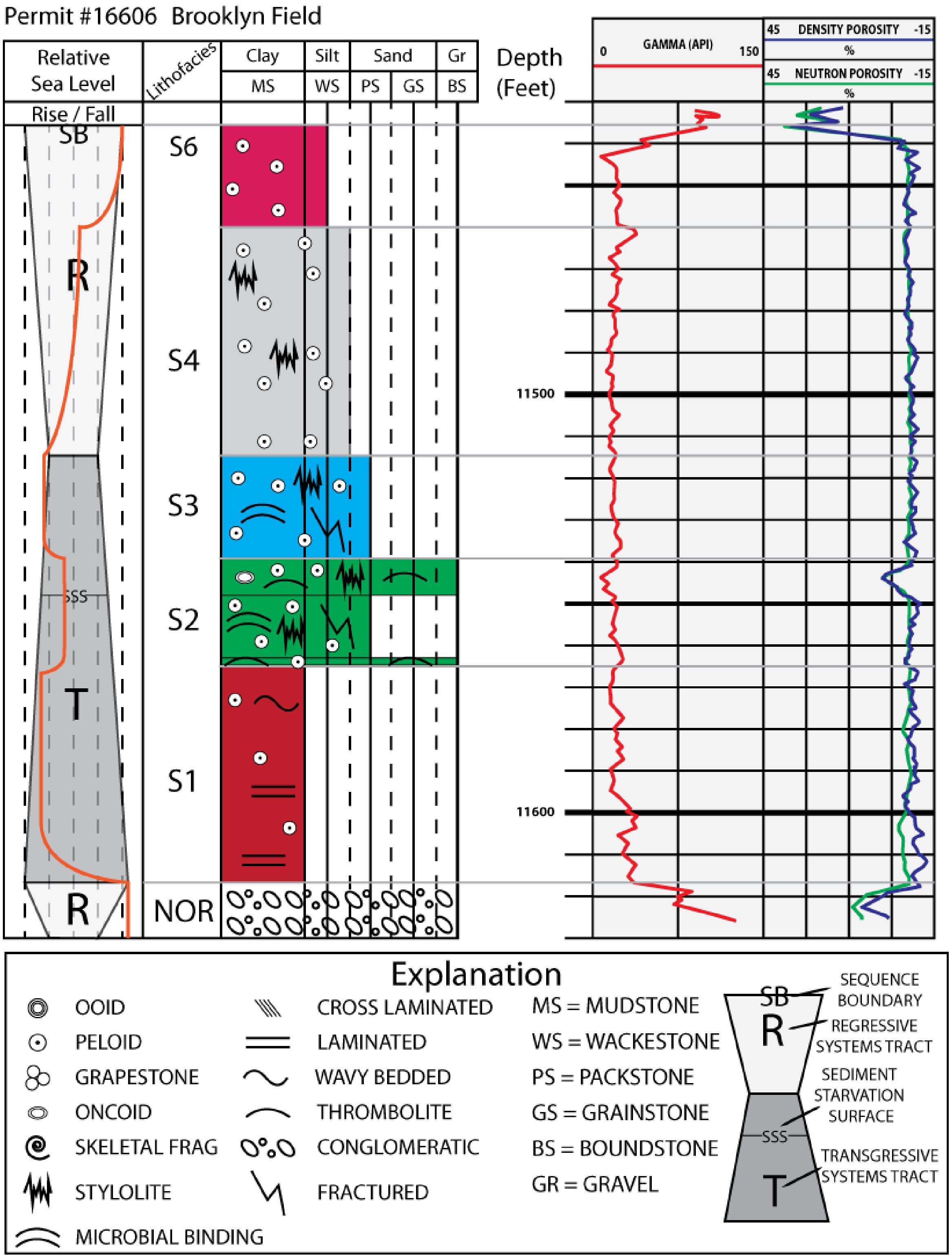


Permit #16135 Little Cedar Creek Field

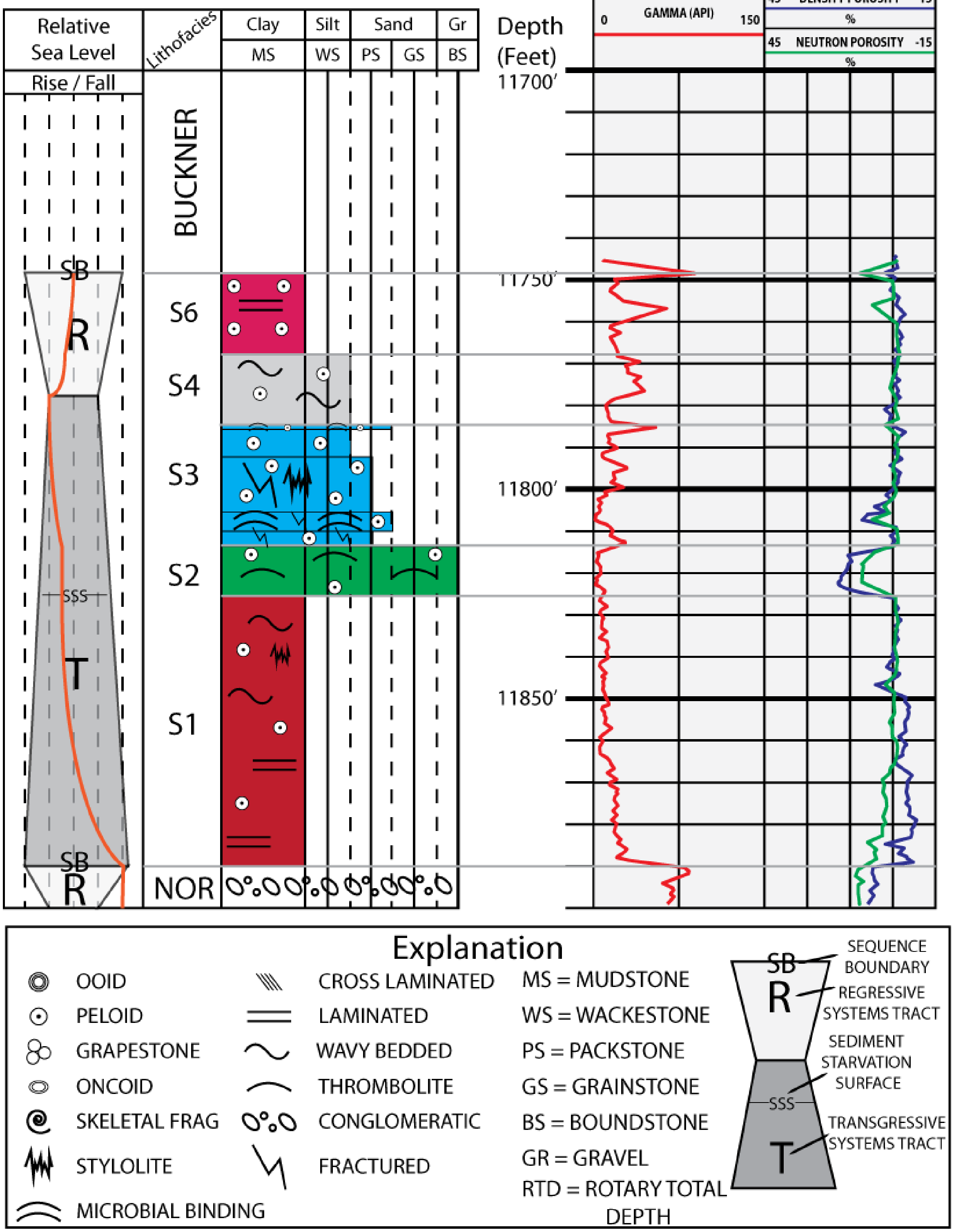


Permit #16406 Brooklyn Field




Permit #16606 Brooklyn Field
Relative Sea Level
Rise / Fall
Lithofacies
Clay
Silt
Sand
Gr
MS
WS
PS
GS
BS
Depth (Feet)
GAMMA (API)
0
150
45 DENSITY POROSITY -15
%
45 NEUTRON POROSITY -15
%
SB
R
SSS
T
R
S6
S4
S3
S2
S1
NOR
11500
11600
Explanation
OOID
PELOID
GRAPESTONE
ONCOID
SKELETAL FRAG
STYLOLITE
MICROBIAL BINDING
CROSS LAMINATED
LAMINATED
WAVY BEDDED
THROMBOLITE
CONGLOMERATIC
FRACTURED
MS = MUDSTONE
WS = WACKESTONE
PS = PACKSTONE
GS = GRAINSTONE
BS = BOUNDSTONE
GR = GRAVEL
SB
R
SSS
T
SEQUENCE BOUNDARY
REGRESSIVE SYSTEMS TRACT
SEDIMENT STARVATION SURFACE
TRANSGRESSIVE SYSTEMS TRACT

Permit #16630 Brooklyn Field



APPENDIX B: Thin Section Descriptions

WELL PERMIT #13670 Little Cedar Creek Field S5 (Ooid Grainstone Facies)
Depth: 11387’
Name/Lithology: Unsorted Bio-Pelsparite
Minerals: Calcite, Dolomite, Anhydrite
Texture: Wack-Packstone
Allochemical Constituents: Favreina (sp?) pellets (rounded and elongate forms), Peloids, Ostracode Fragments
Biogenic Structures: Oncoids, Microbial Masses
Cements: Calcite rinds, Euhedral Dolomite
Porosity: 0-15%; Intraparticle, Interparticle, small vuggy pores
Remarks: Wackstone layer within Ooid Grainstone facies

WELL PERMIT #13670 Little Cedar Creek Field S2 (Thrombolite Facies)
Depth: 11443’
Name/Lithology: Sorted pelsparite, pelletal boundstone
Minerals: Calcite, Dolomite
Textures: Boundstone
Allochemical Constituents: Favreina (sp?) pellets, peloids
Biogenic Structures: Microbial/Algal Filaments
Cements: Thick Sparry rinds calcite, prismatic spar overgrowth to drusy mosaic of equant spar
Porosity: 0-20%, Vuggy Porosity

WELL PERMIT #13670 Little Cedar Creek Field S2 (Thrombolite Facies)
Depth: 11423’
Name/Lithology: Pelsparite, Pelletal Grainstone-Packstone
Minerals: Calcite, Dolomite
Textures: Packstone to Grainstone
Allochemical Constituents: Favreina (sp?) pellets, Miliolid Foraminifera, Peloid clusters
Biogenic Structures: Microbial/Algal Filaments
Cements: Equant Calcite, Dolomite
Porosity: Most Vuggy pores have been occluded by dolomite and calcite

WELL PERMIT #13670 Little Cedar Creek Field S3 (Microb. Influenced Pkstn)
Depth: 11416’
Name/Lithology: Sorted Pel-Biosparite
Minerals: Calclite, Dolomite
Texture: Wack-Packstone
Allochemical Constituents: Peloids, Favreina (sp?) pellets, Miliolid Foraminifera
Biogenic Structures: Algal/Microbial Encrusting Filaments
Cements: Calcite rinds
Porosity: 0-10%; Small vuggy to interparticle pores

WELL PERMIT #15703 Little Cedar Creek Field S4 (Lime Mudstone)
Depth: 11276’
Name/Lithology: Pel-Bio Micrite
Minerals: Calcite, Dolomite, Anhydrite
Textures: Poorly washed pel-bio sparite, mudstone to wackestone
Allochemical Constituents: Peloids, Favreina (sp?) pellets
Cements: Pore filling dolomite, anhydrite
Porosity: 0-5%; interparticle to small vugs

WELL PERMIT #15934 Brooklyn Field S3 (Microbially Influenced Packstone)
Depth: 11789’
Name/Lithology: Packed Bio-Pel Micrite
Minerals: Calcite, Dolomite, Anhydrite
Texture: Mudstone/Wackstone
Allochemical Constituents: Favreina (sp?) pellets, Peloids
Biogenic Structures: Algal/Microbial Mats
Sedimentary Structures: Microstylolites
Cement: Calcite
Porosity: <5%; Very minimal interparticle to intraparticle

WELL PERMIT #15934 Brooklyn Field S3 (Microbially Influenced Packstone)
Depth: 11792.5’
Name/Lithology: Pel-micrite
Minerals: Calcite, Anhydrite, Dolomite
Texture: Mudstone
Allochemical Constituents: Favreina (sp?) pellets, Peloids
Biogenic Structures: Algal/Microbial Mats
Cement: Calcite
Porosity: <5%; Minimal interparticle

WELL PERMIT #16135 Little Cedar Creek Field S2 (Thrombolite Facies)
Depth: 10627’
Name/Lithology: Bio-Pel Boundstone
Minerals: Calcite, Dolomite
Textures: Boundstone
Allochemical Constituents: Peloids, Favreina (sp?) Pellets, Miliolid Foraminifera
Biogenic Structures: Algal/Microbial Filaments
Cements: Sparry Calcite rinds coating grains
Porosity: 0-25%; vuggy (growth framework?) to interparticle
Remarks: Cements grade from equant to bladed

WELL PERMIT #16135 Little Cedar Creek Field S2 (Thrombolite Facies)
Depth: 10634’
Name: Pel-Boundstone
Minerals: Calcite, Dolomite
Textures: Boundstone
Allochemical Constituents: Favreina (sp?) pellets, Peloids
Biogenic Structures: Algal/Microbial Filaments
Cements: Sparry Calcite rinds coating grains
Porosity: 20-40%; vuggy to interparticle to growth framework

WELL PERMIT #16376 Brooklyn Field S5 (Ooid Grainstone Facies)
Depth: 11701’
Name/Lithology: Bio-Pel-Ooid Grainstone
Minerals: Calcite, minor Dolomite
Textures: Grainstone-Packstone
Allochemical Constituents: Favreina (sp?) pellets, Ooids, Ostracode, Peloids, Gastropods, Intraclasts, Grapestones
Biogenic Structures: Burrows
Cements: Sparry Calcite cement rinds, minor bladed calcite
Porosity: 20%-30%; Interparticle, with secondary leached moldic pores
Remarks: Favreina (sp?) pellets present in tubular, elongate, and circular forms

WELL PERMIT #16583 Brooklyn Field S5 (Ooid Grainstone Facies)
Depth: 11399’
Name/Lithology: Oosparite, Ooid Grainstone
Minerals: Calcite, minimal dolomite
Texture: Sorted Oosparite grainstone
Allochemical Constituents: Ooids, Peloids, Favreina (sp?) pellets (rounded & elongate), gastropods, foraminifera
Cements: Sparry Calcite
Porosity: 10-15%; intergranular, leached secondary moldic porosity
Remarks: Some ooids look to be compacted, fracture porosity-generation not discernable, oil staining in pores

WELL PERMIT #16597 Brooklyn Field S5 (Ooid Grainstone Facies)
Depth: 11425’
Name/Lithology: Peloid-Ooid Grainstone
Minerals: Calcite, with minor Dolomite
Textures: Grainstone-Packstone
Allochemical Constituents: Peloids, Ooids, Favreina (sp?) pellets, intraclasts, Grapestones, Foraminifera
Biogenic Structures:
Cements: Minimal Sparry Calcite cement
Porosity: Interparticle, with secondary leached moldic ooids, peloids, forams