DEPOSITIONAL MODEL OF
LITTLE CEDAR CREEK FIELD AND BROOKLYN FIELD, ALABAMA:
A TOOL IN THE PURSUIT OF STRATIGRAPHIC SMACKOVER FIELDS

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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December 2019

Major Subject: Geology

ABSTRACT

The grainstone and the thrombolite reservoir units of the Smackover Formation at Little Cedar Creek Field, Brooklyn Field and Feagin Creek Field, Alabama, USA, were analyzed to determine their spatial and temporal relationships. The reservoir quality in the three fields is most closely linked with facies type; however, diagenesis plays a key role in enhancing or reducing porosity.

Core descriptions, thin sections, core analyses and wireline logs of the Smackover Formation were used to create lithologic facies logs. Geologic cross-sections were generated from the lithologic facies logs to map changes in facies deposition over and between the three fields. Sequence stratigraphy was applied to the cross-sections to produce a depositional model over time of the study area. Three 5th-order sequences comprise the study area. The grainstone reservoir of Little Cedar Creek Field was deposited during an earlier sequence than the grainstone reservoir of Brooklyn/Feagin Creek Fields.

Petrography and cathodoluminescence were analyzed to develop a paragenetic sequence of the Smackover Formation in the study area. Late stage diagenetic events are similar for all facies studied, but early diagenesis varies between the grainstone and thrombolite reservoir units. Dolomitization occurs in the southern thrombolite reservoirs, but does not serve to increase porosity, rather it may occlude it entirely.

DEDICATION

To two esteemed geoscientists, Dan A. Hughes Sr. and Wayne M. Ahr, who met a girl who loves rocks and turned her into a carbonate geologist. I will always admire the stones with which you built my path.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Pope, and my committee members, Dr. Laya, and Dr. Schechter, for their guidance, patience and support throughout the course of this research.

Thanks go to my colleagues and the department faculty and staff at Texas A&M University and the University of Alabama, for a great research experience at world class institutions.

Finally, thanks to my mother, brother and sister for their encouragement and to my husband, Craig, who will always be my champion.

CONTRIBUTORS AND FUNDING SOURCES

This work was supported by a committee consisting of Professor Michael Pope and Professor Juan Carlos Laya of the Department of Geology & Geophysics and Professor Schechter of the Department of Petroleum Engineering.

The data analyzed was provided by the State of Alabama Oil and Gas Board at the University of Alabama. Research trips to Alabama were sponsored by Dan A. Hughes.

All other work conducted for the thesis was completed by the student independently.

NOMENCLATURE

LCCF	Little Cedar Creek Field
BF	Brooklyn Field
FCF	Feagin Creek Field
BOPD	Barrels of Oil Per Day
Mbbls	Thousand Barrels
MMbls	Million Barrels
Bcf	Billion Cubic Feet
PL	Plane Light
CL	Cathodoluminescence
LAS	Log ASCII Standard
GR	Gamma Ray
Res	Resistivity
NPor	Neutron Porosity
DPor	Density Porosity

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INTRODUCTION

Among oil and gas exploration companies operating in the Gulf of Mexico region, the hunt is on for the next Little Cedar Creek (LCCF) and Brooklyn fields. Both fields produce oil from conventional wellbores drilled in highly porous and permeable carbonate rock. Little Cedar Creek Field is unique in Alabama due to its stratigraphic trap within the Smackover Formation, which cannot be easily identified through seismic interpretation (Mancini et al., 2008). These stratigraphic targets require an exploration strategy that utilizes detailed subsurface interpretation to locate a paleodepositional environment similar to the Smackover Formation in the LCCF area. In the study area, two units of the Smackover Formation are productive: a lower microbial thrombolite reservoir and an upper ooid-oncoid-peloid packstone-grainstone reservoir. Hydrocarbons are produced from both units in LCCF and neighboring Brooklyn Field (BF), whereas Feagin Creek Field (FCF) consists only of the packstone-grainstone reservoir.

The ooid-oncoid-peloid packstone-grainstone reservoir in BF is informally called the "Brooklyn oolite bar". It is not defined if the Brooklyn oolite bar is syndepositional with LCCF packstone-grainstone or if they result from earlier or later progradation of the LCCF carbonate ramp basinward. It is necessary, then, to update the LCCF depositional model to include data from BF and FCF.

Little Cedar Creek Field and Brooklyn Field History

The Upper Jurassic (Oxfordian) Smackover Formation is the most prolific hydrocarbon producing unit in Alabama. Since the discovery of Smackover Formation production in Toxey Field in 1967, over 100 Smackover fields were developed in the southwest region of Alabama (Alabama State Oil and Gas Board, 2010). The accepted method of identifying Smackover

Formation prospects is by detecting Paleozoic basement highs and salt features with seismic reflection, but was challenged with the discovery and development of Little Cedar Creek Field (Mancini et al., 2008).

In 1994, Hunt Oil Company drilled the discovery well 30-1 #1 Cedar Creek Land and Timber Company (permit #10560). This well was perforated at 11870-11883 ft. and tested 108 BOPD of 46°API oil (Heydari and Baria, 2006). In 2000 Midroc Operating Company purchased all leases from Hunt Oil and a second well was drilled. The second well tested 250 BOPD and in 2003, the third well was drilled and tested 365 BOPD (Mancini et al., 2008). As of September 2018, over 100 wells were drilled which have cumulatively produced 21 MMbls of oil and condensate and over 30 Bcf gas (Alabama State Oil & Gas Board, 2018). The field is undergoing secondary recovery efforts, including gas injection that began in 2007.

In 2007, Sklar Exploration Company drilled the Brooklyn Field discovery well Logan 5-7 #1 three miles south of existing Little Cedar Creek Field production. Brooklyn Field has produced 21 MMbls of oil and gas condensate and over 28 Bcf gas from over 75 wells (Alabama Oil & Gas Board, 2018).

Feagin Creek Field is a one well field between LCCF and BF (Figure 3), in the western edge of the study area. The Pruet U. L. JONES 28-7 #1 well produces from two sets of perforations in the packstone/grainstone reservoir, the lower of the two having a distinct pressure profile which distinguishes the well from adjacent LCCF and BF production. The well has produced 209,500 bbls of oil and 237,000 Mcf of gas as of September 2018 (Alabama Oil & Gas Board, 2018).

Previous Work

Previous studies have described and mapped the thrombolite and grainstone facies of Little Cedar Creek Field. The lithofacies in LCCF were described and their depositional environments interpreted (Baria and Heydari, 2005). Smackover Formation thrombolite buildups and their pore types were characterized (Mancini et al, 2006). A field study of LCCF focusing on the microbial thrombolite buildups and strategies for future Smackover Formation stratigraphic trap hydrocarbon exploration was conducted (Mancini et al, 2008). Seven facies were defined in LCCF and used to create a depositional model of the region (Ridgway, 2010). Geographic variations within the packstone-grainstone unit and a paragenetic history were described (Breeden, 2013). The updip limit of the grainstone unit, classified as an ooid-oncoid-peloid facies, was outlined, porosity was characterized, paragenetic sequences of the microbial thrombolite and grainstone were compared, porosity was characterized, and dolomitization was described (Tonietto and Pope, 2013).

GEOLOGIC BACKGROUND

Stratigraphic Framework

The stratigraphic framework across the Mississippi Interior Salt Basin and Conecuh and Manila subbasins is fairly complete throughout the Mesozoic and Cenozoic, however this paper covers only the Upper Jurassic (Figure 1).

Norphlet Formation

The Upper Jurassic (lower Oxfordian) Norphlet Formation is a siliciclastic deposit that stretches from central Mississippi, through southern Alabama, to the western portion of the Florida panhandle (Mancini et al., 1985). The depositional environment of the Norphlet Formation is interpreted as an arid eolian plain bordered to the north and east by the Appalachian Mountains and the south by a developing shallow sea (Mancini et al., 1985). The erosion of the southern Appalachian Mountains provided an influx of sediment to the subsiding basin to the west – the Mississippi Interior Salt Basin. Conglomeratic deposits which grade into red beds occurred at the base of the Appalachian Mountain as alluvial fans and braided streams. Further downdip, Norphlet Formation deposits transition into quartz-rich fluvial and eolian sandstone and become shallow marine deposits at the paleoshoreline (Mancini et al., 1985). The contact between the Norphlet and Smackover Formations typically is erosional but locally it is conformable (Mancini et al., 2008).

Smackover Formation

The Upper Jurassic (Oxfordian) Smackover Formation is a transgressive-regressive marine limestone that unconformably overlies the conglomeratic and arkosic beds of the Norphlet Formation or was deposited conformably on Norphlet Formation marine deposits

(Mancini, et al., 2006). The Smackover Formation occurs at depths of 5,000 to 20,000 ft. across the eastern coast of the Gulf of Mexico. Smackover Formation deposition in southwest Alabama occurred mainly in three interconnected basins, the Eastern Mississippi Interior Salt Basin, Manila embayment and Conecuh embayment (Kopaska-Merkel and Mann, 1991).

Reef buildups in Alabama and Florida (the eastern portion of Smackover Formation deposition) occurred at the base of the upper part of the Smackover Formation and are composed of Tubiphytes, digitate and branching blue-green algae (microbialites), and marine cements (Mancini and Parcell, 2001). Arkansas and Louisiana reefs formed in marine waters with improved salinity, better circulation and less turbidity which are reflected in the more diverse biota – corals, skeletal algae, sponges, bryozoans and hydrozoans (Mancini and Parcell, 2001). Outcrop study of similar microbialite buildups in Europe suggest three depositional settings for reef development: deep, quiet water below fair weather wave base, gently sloping ramps at fair weather wave base and margins of steeply rimmed wave-swept platforms (Mancini and Parcell, 2001). Thrombolitic and stromatolitic structures in the Smackover Formation occur within buildups at and below fair weather wave base (Mancini and Parcell, 2001).

Thrombolites in the lower part of the Smackover Formation provide good reservoir potential across the inner ramp deposits of this unit. A thrombolite is defined as an organic carbonate composed of micritic to peloidal crusts which have a clotted millimeter to centimeter scale fabric (Parcell, 2002). Thrombolites typically occur on hardgrounds or paleohigh features in shallow water (<30 ft. deep), in low energy environments with a relatively low background sedimentation rates (Mancini, et al., 2006). Along the northern rim of the Gulf of Mexico, thrombolites are composed of calcimicrobes, foraminifera, sponges, red algae, echinoids and bivalves (Mancini, et al., 2006).

The Little Cedar Creek, Feagin Creek, and Brooklyn fields formed near the updip limit of Smackover Formation deposition in the Conecuh sub-basin. In this region, the Smackover Formation is 70 to 110 feet thick at depths between 11,000 and 12,000 ft. below sea level (Mancini, et al., 2006). In the southern portion of Alabama, Smackover Formation beds can serve as a source, reservoir and seal. The role of the Smackover Formation in the petroleum system of a specific field depends on its facies. Smackover Formation facies in LCCF have little dolomitization and are primarily limestone. The six major facies of the Smackover Formation in LCCF as described by Mancini et al, (2008) from top to base are:

(1) Peritidal lime mudstone and dolomudstone to dolowackestone
(2) Shallow subtidal, nearshore ooid grainstone to wackestone
(3) Deeper water, subtidal lime mudstone
(4) Subtidal, microbially-influenced lime mudstone to lime packstone
(5) Subtidal thrombolite boundstone
(6) Transgressive subtidal lime mudstone and dolomudstone to dolowackestone

The Smackover Formation in LCCF is unique among Smackover Formation fields in southwestern Alabama as thrombolite boundstone facies here differs from regional buildups. The mounds did not form over Paleozoic basement paleotopography (Mancini et al., 2008). These thrombolite mounds developed further up depositional dip (within 3 miles of the paleoshoreline) in water depths less than ~33 ft. and are not associated with the crest of paleohighs (Mancini, et al., 2006).

LCCF is described as a “dual reservoir-seal system”: the lower reservoir is the subtidal thrombolite boundstone and the upper is the shallow subtidal nearshore ooid grainstone-wackestone (Heydari and Baria 2006). The deeper water, subtidal lime mudstone is a fine-grained unit deposited between the lower microbial reservoir and upper grainstone reservoir and it creates a vertical and lateral seal for the lower reservoir (Mancini, et al., 2006). The upper ooid grainstone-packstone reservoir also is sealed with fine-grained lime mudstone-wackstone and overlying evaporites (Mancini et al., 2008). Both reservoir facies are primarily limestone in LCCF and diagenesis is a crucial process in forming reservoir quality porosity in the field (Mancini, et al., 2006). The microbial reservoir in LCCF range from 0-36 feet in thickness in buildups located mostly in the southern portion of the field (Mancini et al., 2008). The porosity in the thrombolite buildups mainly is secondary vuggy pores formed by dissolution (Mancini, et al., 2006). The upper reservoir is a shallow subtidal nearshore peloid-ooid grainstone-packstone that ranges from 0-20 feet thick across the field area in a southwest to northeast lineament (Mancini et al., 2008). The thickest section of this reservoir occurs in the center of the field (Mancini, et al., 2006). This facies is primarily composed of ooids, oncoids, peloids and pellets cemented with lime mud (Tonietto and Pope, 2013). Porosity in this unit occurs where ooids were cemented and subsequently dissolved to produce moldic pores (Mancini, et al., 2006).

The Smackover Formation lime mudstone facies in LCCF have low TOC and are too thin to produce the volume of hydrocarbons in this field. The hydrocarbons that source these Smackover Formation reservoirs are postulated to have originated in the deeper parts of the Mississippi Interior Salt Basin, particularly in the Conecuh sub-basin, and migrated updip to the field. Basinward of LCCF, the lower part of the Smackover Formation is composed of thick subtidal algal laminated lime mudstone. The kerogen present is type IIS – algal (microbial) and amorphous organic material (Mancini et al., 2003). The Smackover Formation in the Conecuh Embayment is sub-divided into two systems tracts (Figure 3) separated by a maximum flooding surface (MFS): the base to middle Smackover Formation forms a transgressive systems tract

(TST) and the upper part of the Smackover Formation characterizes a highstand system tract (HST) (Tonietto, 2014).

Haynesville Formation

The Upper Jurassic (Lower Kimmeridgian) Haynesville Formation is a siliciclastic, carbonate and evaporitic unit which overlies Smackover Formation carbonate. The lower part of the Haynesville Formation is the Buckner Member, a massive anhydrite intercalcalated with crystalline dolomite (Markland, 1992; Tolson et al., 1983). In areas of Alabama, the Buckner Member is overlain by the Frisco City sandstone that consists of arkose and subarkose sandstone (Mann et al., 1989). The unnamed upper part of the Haynesville Formation consists of sandstone and shale interbedded with carbonate and dolostone (Tolson et al., 1983; Mancini et al., 1990; Markland, 1992). Red beds, thin-bedded shaly carbonate, and evaporite within the Haynesville Formation indicate deposition occurred in arid conditions. Previous studies on the northern Gulf of Mexico region identified the Smackover Formation and the Buckner Member of the Haynesville Formation as one genetically-related depositional sequence (Prather, 1992). The massive Buckner Member that directly overlays the Smackover Formation is absent in LCCF (Heydari and Baria, 2006, extended abstract).

Tectonic setting

Late Triassic to Jurassic rifting initiated the opening of the ancestral Gulf of Mexico. Seawater entered the Gulf of Mexico during the Callovian Stage, but initial widespread and prolonged marine incursion occurred during the Oxfordian Stage (Salvador, 1987). The inundation of this area is considered a third-order relative sea-level rise (Benson, 1988). Extensional fault systems in the Mississippi Interior Salt Basin formed during the early rifting stage of the Gulf of Mexico and formed the interior fracture portion of a margin sag basin (Mancini et al., 2003).

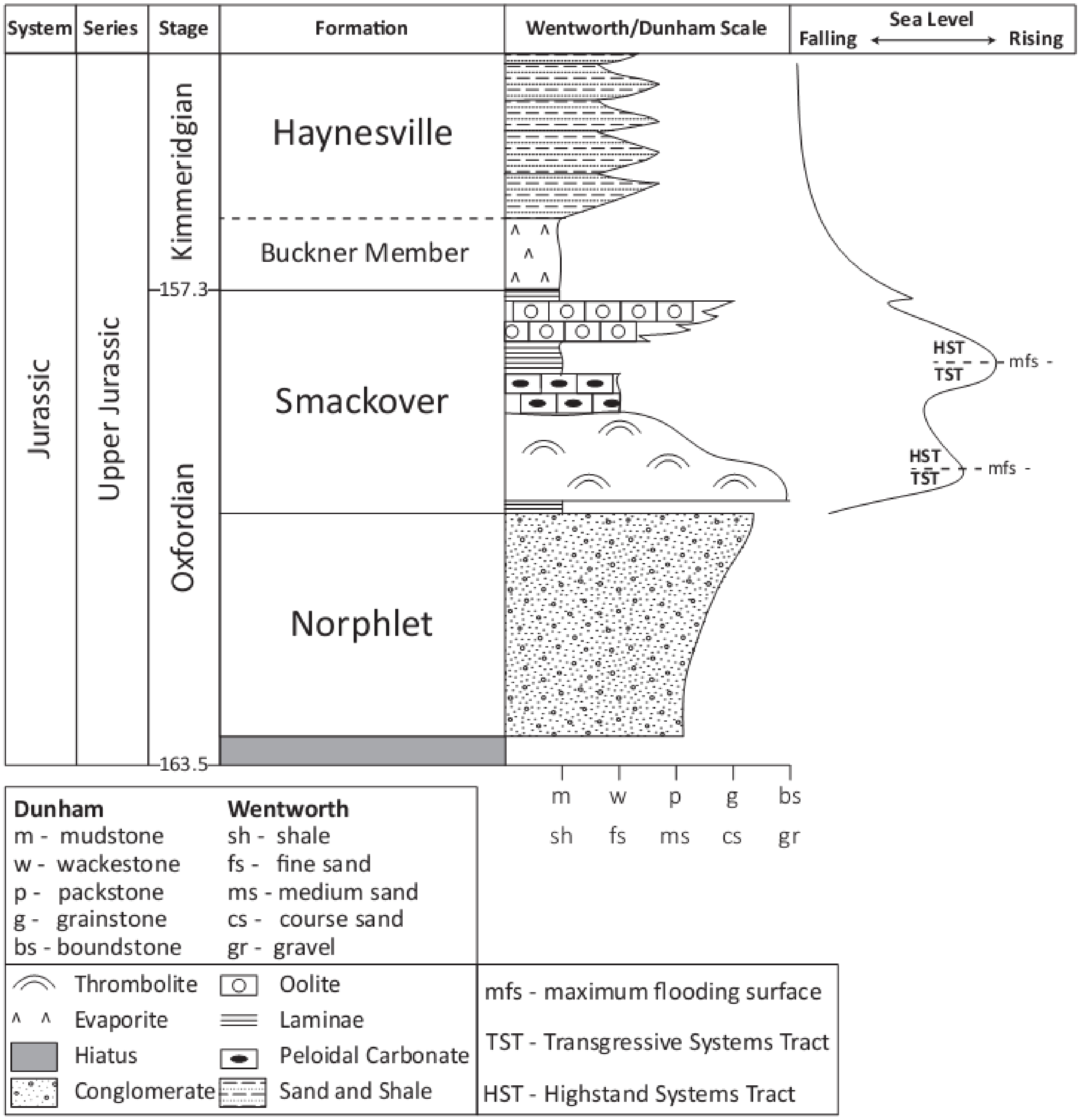


Figure 1. Stratigraphic column of the Upper Jurassic series of Little Cedar Creek Field (LCCF).

Structural style

The Smackover Formation was deposited on a carbonate ramp along the northern coast of the Gulf of Mexico (Ahr, 1973). Key characteristics of a carbonate ramp are concentric facies belts that follow bathymetric contours, no pronounced break in slope, pelagic mudstone deposited downdip grades up the ramp into grainstone and patch reefs, and the most landward facies on ramps are shallow lagoonal and/or tidal flat deposits (Ahr, 1973). Though the classification of carbonate ramp does characterize most of the Smackover Formation deposition along the rim of the Gulf of Mexico, deposition and ramp geometry is affected by positive relief features across the basin (Markland, 1992). Major structural features which affected Smackover Formation deposition in southwestern Alabama (Figure 2) were the Choctaw Ridge, Conecuh Ridge, Pensacola Ridge, Wiggins Arch, and salt features, including the regional peripheral fault system extending from central Mississippi through northwest Florida (Mancini and Benson, 1980; Markland, 1992).

DATA AND METHODS

Core Sampling and Description

Cores of 15 wells penetrated the Smackover Formation (Figure 3) totaling 1250 ft of rock were described using the Dunham (1962) classification of carbonate rocks and depositional texture. Of these cores, 10 wells with 708 ft are in Little Cedar Creek Field (LCCF), 4 wells totaling 454 ft are in Brooklyn Field (BF), and 1 well with 88 ft is in Feagin Creek Field (FCF).

Sedimentary structures, macrotexture, and visible porosity were also determined. Wells were chosen to span across the fields and include a range of productivity – from dry holes to wells that produced in excess of 500 Mbbls. Following the practice of the Alabama State Oil and Gas Board, wells are identified by their permit number. Samples of 18 core plugs were taken at depths corresponding with core analyses of porosity, permeability and oil saturation run by the wells' operators at the time of drilling. Smackover Formation facies are numbered one thru six, as encountered in a typical LCCF core, from the top of the section to the base.

Facies 1

Facies 1 is a light, medium or dark gray peloidal mudstone or wackestone with few bioclasts and occurs in nine wells. Features occurring in half of these wells are peloids, stylolites and intermittent laminations. Abundant healed fractures occur in permits 14114, 14309 and 16708. Pyrite crystals occur in well 16398 and in 16790 they increase in diameter up-section from 2 mm to 10 mm. Depositional environment is interpreted as peritidal.

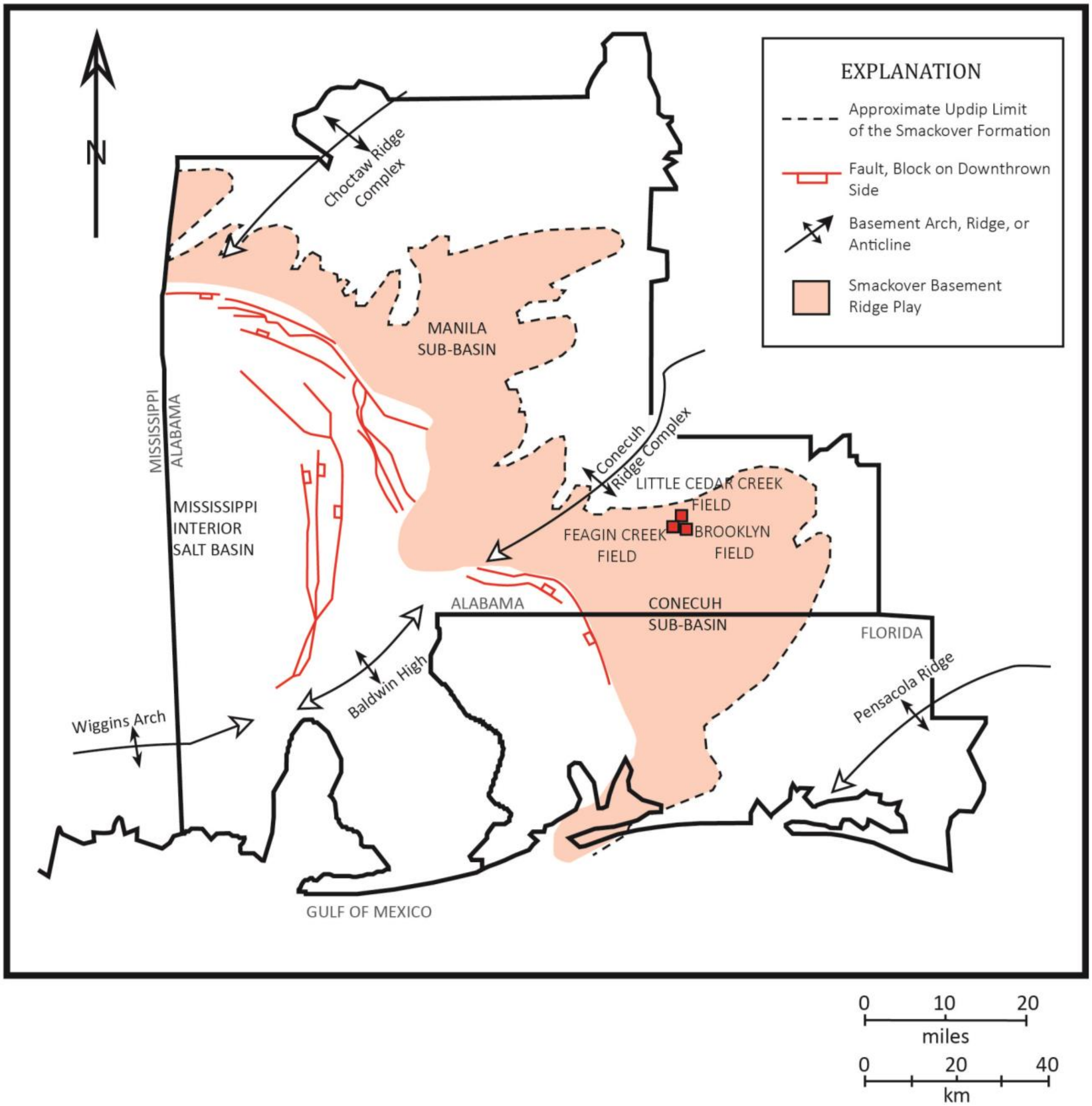


Figure 2. Location map showing major structural features and updip limit of the Smackover Formation in southwestern Alabama (Modified from Mancini et al., 2008).

Facies 2

Facies 2 is a buff to tan peloid-ooid-oncoid packstone-grainstone (Figs. 4 A-D). All study wells contain stylolites in this section. Ooids, oncoids and peloids are visible though 10x hand lens in 80% of wells sampled.

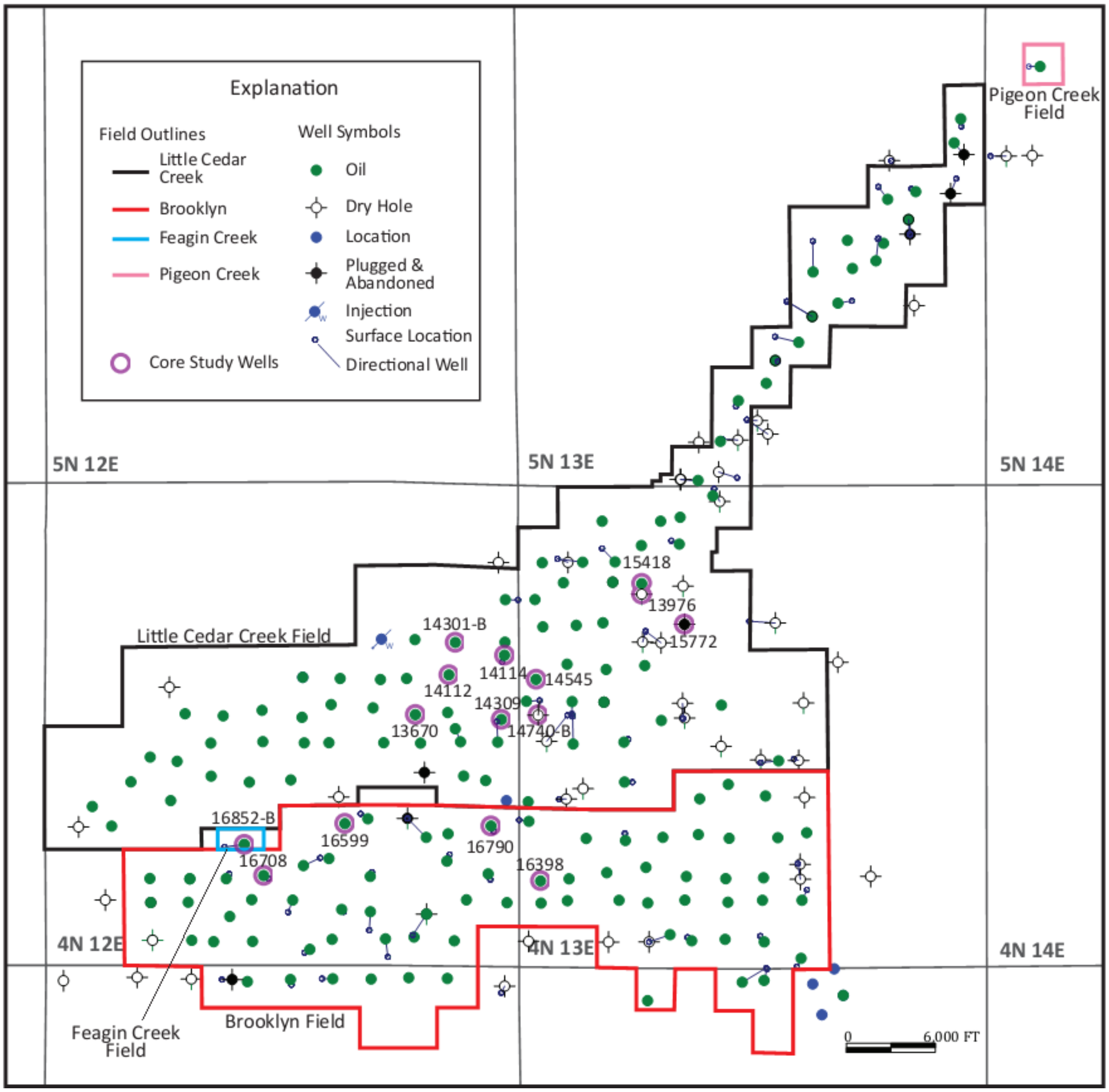


Figure 3. Field-scale map of study area wells.

Though ooids and peloids comprise the majority of grains in this facies, oncoids occur in bands within the ooid-peloid packstone-grainstone. Oncoids average 1-2 mm in diameter but can reach 10-25 mm in diameter, as seen in well 16398. Inverse followed by normal vertical grading of oncoids occurs in well 14112 from 11286-11287 ft. High-spired gastropods, milliolids and ostracodes are common, particularly at the contact between facies 1 and facies 2. Wells 14112 and 14301-B preserve calcite replacement of skeletal grains (Fig. 4 C). Wells 16398, 16708, 16779 and 16852-B have 10 mm grapestone molds or grains. Sixty percent of wells have visible (10-30%) oomoldic porosity (Fig. 4 A). Well 14301-B has visible moldic porosity (10-29%) in oil-stained peloidal packstone bands which alternates with non-stained gray peloidal packstone containing no visible (< 2%) moldic porosity (Fig. 4 C). Notably, skeletal molds ranging from 0.5-2 mm in length occur in well 16398. Half of the study wells contain vugs visible through 10x magnification. Facies 2 is interpreted as a nearshore ooid-oncolite shoal formed in high-energy conditions.

Facies 3

Facies 3 is a highly-stylolitized medium gray peloidal wackestone. The fine-grained deposit which forms a gradational contact at the base of facies 2 was described for nine of the fifteen study wells. Fractures occur in four of the core descriptions: permits 13670, 14309, 14545 and 16790. Facies 3 is interpreted to record a deep subtidal depositional environment.

Facies 4

Facies 4 is a dark brown to dark gray peloidal wackestone-packstone. Stylolites are common in all eleven cores with this facies. Skeletal fragments, including brachiopod shells, occur in permits 13670 and 14740-B. Permits 13670, 15418 and 16599 contain calcite-filled vugs visible to the unaided eye. Fractures occur in half of the wells that sample this facies. The depositional environment is interpreted as shallow subtidal.

Facies 5

Thirteen study cores penetrated peloidal boundstone in the lower part of the Smackover Formation. Microbialites form the bulk of this facies and range from Type I to Type IV (Parcell, 2002). Type I, II or III microbialites (thrombolites) occur in all thirteen cores and typify facies 5. The thrombolite boundstone of facies 5 is not a continuous unit throughout the study area. Stromatolites (Type IV microbialites) occur in six of the wells, in one to five foot beds with laminations of 1-15 mm thickness Two wells (16708 and 16852-B) contain peloidal wackestone/packstone in beds of 2 to twenty-six feet thick interbedded with microbialites. Within the boundstone, fragments of mollusks and gastropods occur in permits 13670, 13976, 14309 and 16599. Stylolites and fractures are common features throughout this unit; permit 13976 has horizontal calcite-filled fractures. Calcite-filled elongated vugs 2-18 mm in width occur in permits 13670, 13976, 14309 and 14545. Open vugs occur in these permits as well as permits 14112, 14114, 14740-B, 15418 and 16599. Facies 5 is interpreted as microbial mounds formed in a subtidal environment.

Facies 6

Facies 6 is the basal facies of the Smackover Formation in the study area and is a medium tan to brown limestone mudstone/wackestone. Eight of the study wells contain this unit, with some variations. The only well to contain skeletal fragments is permit 13976, with black brachiopod fossil fragments less than 0.5 mm in diameter. Pyrite crystals ranging from 5 to 20 mm in diameter developed in cores 14309 and 16599. Permits 14301-B, 16599 and 16790 have laminations averaging 0.2 mm thick. Stylolites occur in permits 13976,14309,14545,15772 and 16599. This facies is fractured in permit 14309. Facies 6 is interpreted to have formed in a shallow subtidal depositional environment.

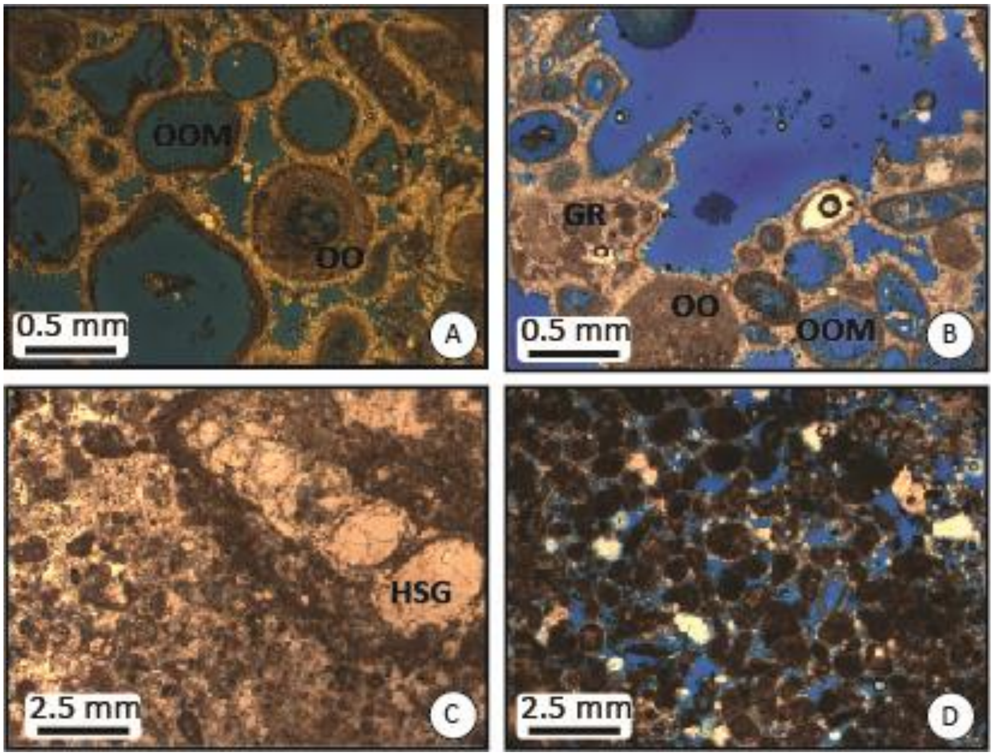


Figure 4. Photomicrographs display variance in depositional and diagenetic features in Facies 2. A - Partially dissolved ooids with oomoldic porosity. Permit 16398, depth: 11575.8 ft. B - Completely dissolved ooids, micritic rims and cement. Permit 16398, depth: 11578.8 ft. C - Calcite-filled bioclast surrounded by peloids and calcite cement, 3% porosity. Permit 16790, depth: 11534.85’. D- Peloidal grainstone with interparticle porosity (25%). Permit 16790, depth: 11575.35’. OO = ooid; OOM = oomoldic porosity; GR = grapestone; HSG = high spired gastropod.

Smackover/Norphlet Contact

The contact between the basal Smackover and Norphlet formations is sharp. The mudstone/wackestone of the basal Smackover Formation sharply overlays a fractured green/brown conglomerate at the top of the Norphlet Formation. The Norphlet Formation conglomerate contains 0.5 to 4 cm thick green, yellow and black sub-angular clasts of quartz, diorite, shale and siltstone in a gray or brown siltstone matrix.

Petrographic analysis

Thin sections were created from 18 core plugs by Applied Petrographic Services, Inc. Thin sections were impregnated with blue epoxy to discern porosity. Plane and polarized light petrography of the 18 thin sections was used to characterize diagenetic features, fabrics and porosity. The thin sections were classified according to Dunham (1962). Porosity was described using Ahr-Humboldt genetic pore classification (Humboldt and Ahr, 2008). Thin sections were stained with potassium ferricyanide and Alizarin Red-*S* applying the techniques presented by Dickson (1966) to distinguish depositional and diagenetic features.

Cathodoluminescence (CL) was performed on thin sections polished to a reflective finish to observe the relative Fe/Mn ratios of cements. CL data is available in Appendix I. The slides were placed in a vacuum chamber then the chamber was pumped down, and the vacuum was set at -0.05 torr and the cathode at 10-20 kV, which produced a gun current between 200 and 300 amperes. The Technosyn Cold Cathode Luminescence, Model 8200 MK II was used in conjunction with the Leitz Laborlux D microscope, which had the Coolsnap-Pro$_{cf}$ camera mounted above it to capture the CL images. The textural and porosity descriptions were correlated to the porosity and permeability derived from the core analyses available through the Alabama State Oil & Gas Board.

Porosity & Permeability

General porosity and permeability trends were studied through LCCF and BF. Cross-plots of porosity and permeability from core plugs were plotted with texture, genetic pore classification, and dolomite percentage of thin sections in order to analyze their relationships (Fig. 5). The facies cross-plot has the highest set of co-efficient of determination (R^2) values. Also included in the figure is a comparison of LCCF, BF and FCF, performed to assess variations in reservoir quality across fields.

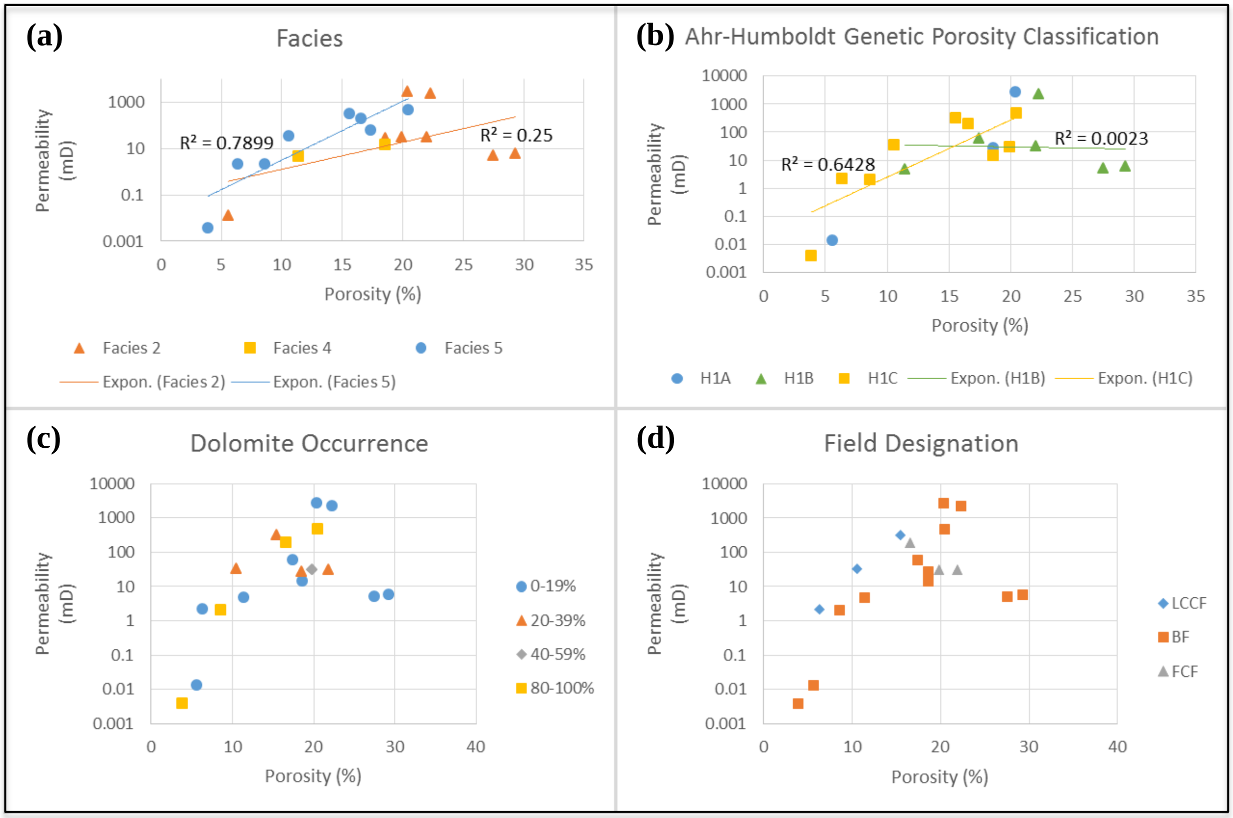


Figure 5. Cross-plots of porosity and permeability according to (a) facies classification, (b) genetic pore type, (c) percentage of dolomite, and (d) field designation.

Log Analysis

Electric logs from Smackover Formation in LCCF, BF and Feagin Creek were correlated with core analyses and thin section descriptions to create a composite log to illustrate relationships between fabrics, depositional and diagenetic textures, and electric log responses. If available, LAS files were used to create consistently scaled logs for lateral correlation. The gamma ray (GR), deep resistivity (Res), neutron porosity (NPor) and density porosity (DPor) curves were used to generate log displays. Sonic porosity is substituted for the NPor and DPor curves, if unavailable. Several wells were offset from vertical and are adjusted using their directional surveys to TVD (true vertical depth) in order to maintain a consistent datum. Refer to Appendix II for full composite logs. Permit 14309 was chosen as the type log (Fig. 6) as it contained core representative of the entire LCCF Smackover Formation. Log analysis of the gamma ray, photoelectric and density curves in wells in southeastern BF indicate shale occurs between facies 2 and 3. Two cores in this study contained siliciclastic units within the Smackover Formation, though not in thicknesses sufficient to produce an electric log response. Below is a description of the shale facies, based on literature review and core descriptions.

Shale Facies

Shale in the study area was first described by Baria (2008) as dark and silty mudstone with a high content of herbaceous organic material. The shale thickens in the middle of the Conecuh Embayment and pinches out up-dip. Plant fossils are abundant, but there is little bioturbation and few marine fossils (Baria, 2008). Shale "C" described by Niemeyer 2011 is consistent with the electric log signatures in southeastern BF, and is composed of lower light gray calcareous shale with minor burrowing and upper dark gray laminated fissile shale. Both layers contain abundant quartz and illite minerals, though primary mineralogy of the upper dark gray shale is quartz and the lower shale is calcite (Niemeyer, 2011). The TOC observed averages 0.32 wt.% and plotted as gas-prone terrestrial Type III kerogen (Niemeyer, 2011).

Though no shale is observed in the study cores, core descriptions of wells 16708 and 16852-B in this study note bands of dark gray fine-grained sandstone that is non-reactive with HCl acid. The core of BF well 16708 contains a three inch thick dark gray sandstone with pyrite crystals near the base of facies 2. Core from FCF well 16852-B contains three bands of the dark gray sandstone, less than four inches thick, in facies 2.

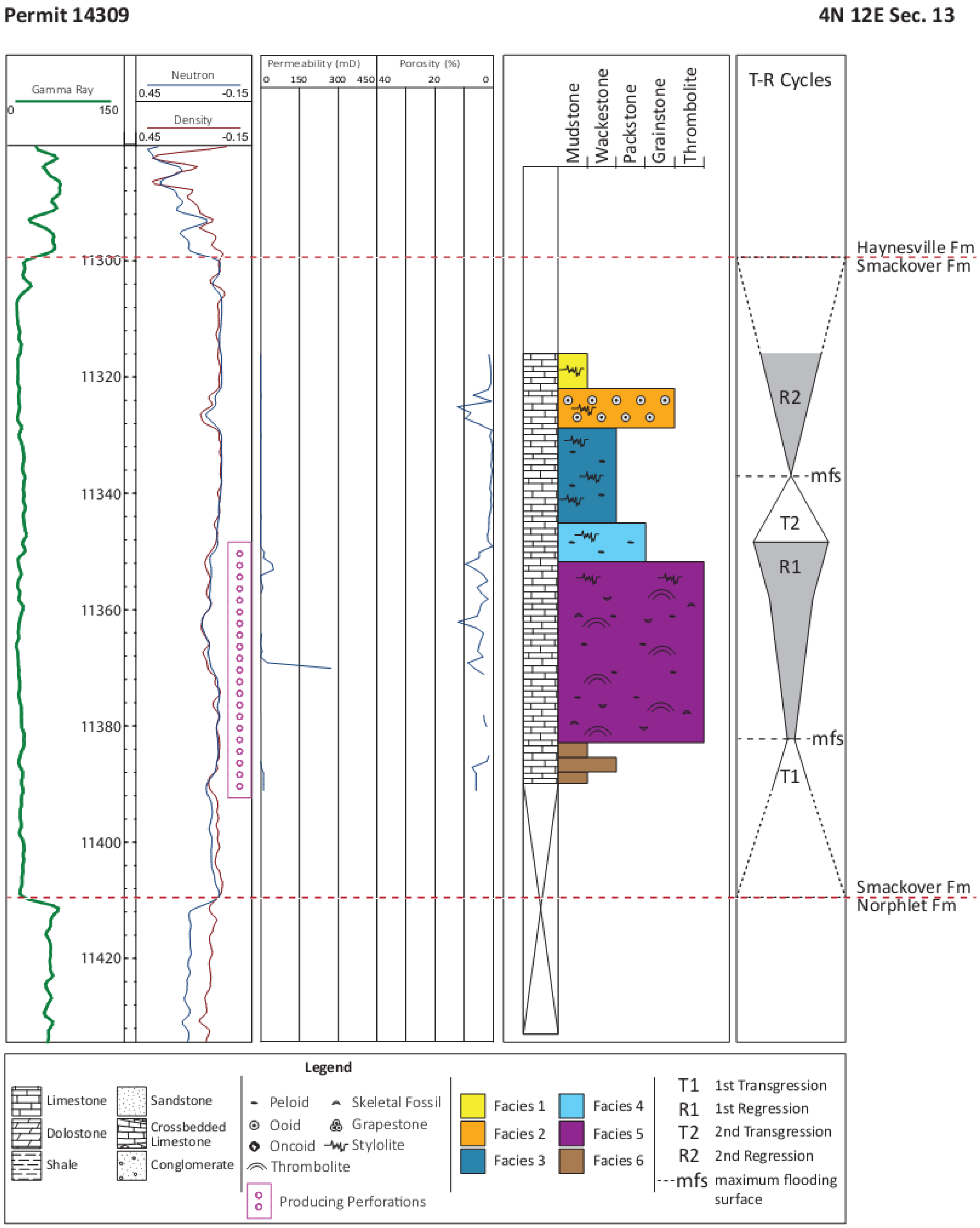


Figure 6. LCCF type log of upramp facies. Core porosity log is depth adjusted to correlate with porosity electric logs, providing a depth reference for the core facies track.

Geologic Cross-sections

Geologic cross-sections are built with electric logs along depositional strike (generally W-E) and dip (NW-SE) directions across the fields. The Smackover Formation and Norphlet Formation tops were tied to electric log data and interpreted over the entire study area.

The Smackover Formation ranges from 65 to 200 feet thick at a depth of -10,000 to -11,750 feet subsea in the wells studied. In LCCF, the Smackover Formation has a northwest-southeast strike and southwestern regional dip. The area of greatest thickness is in southeast BF, and the Smackover Formation is thinnest along the northwestern edge of LCCF. The thickness trend suggests that accommodation space increased from northwest to southeast during Smackover Formation deposition, placing the landward edge of the carbonate ramp along the northwest edge of the field. Depositional strike is inferred as SW to NE and depositional dip as NW to SE (Al Haddad and Mancini, 2013). All cross-sections are oriented to Smackover Formation depositional strike and dip

Regional patterns are illustrated through geologic cross-sections from electric logs overlain with facies derived from core descriptions. Perforations are provided at-depth. The cross-sections are presented stratigraphically to illustrate field-scale trends. Stratigraphic cross-sections reference the top of the Smackover Formation. Figure 7 is the base map of the five cross-sections compiled for this study.

Strike Cross-sections

As shown on Figure 8, the northern strike cross-section 1 begins in Feagin Creek Field and follows a string of wells northeast through BF and the bulk of LCCF. Facies 2 is greater than 100 feet thick in FCF and BF and thins generally to the northeast in LCCF. Facies 5 (microbialite) maintains a thickness of 40-70 feet along this cross-section. Core observations and log analysis did not record any shale through the Smackover Formation sections of wells in cross-section 1, although the corresponding dark gray sandstone was deposited in facies 2 of FCF well 16852-B but is too thin to be represented on the cross-section.

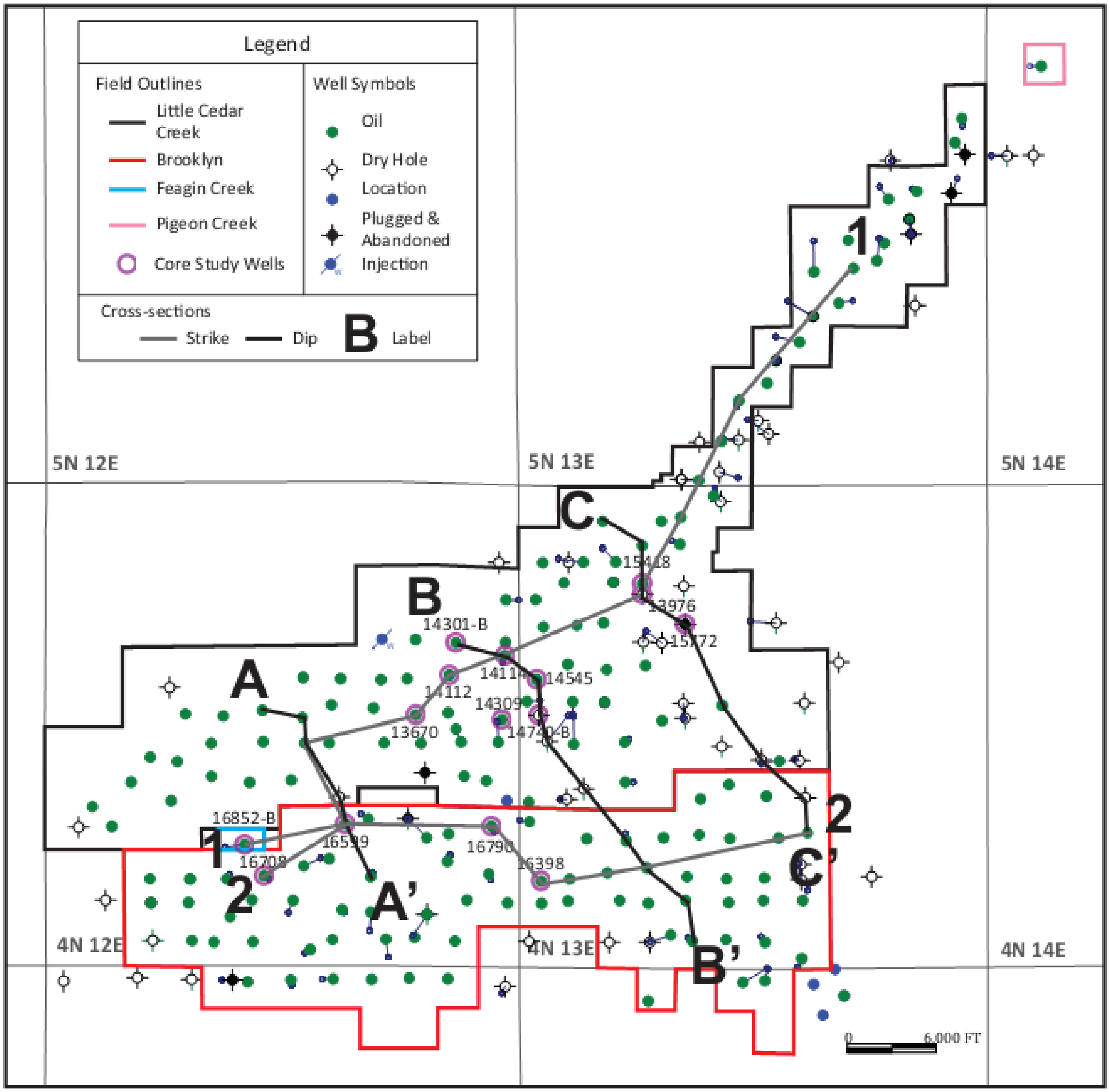


Figure 7. Base map of cross-sections. Two cross-sections (1 and 2) are oriented along the general direction of depositional strike. Three NW-SE dip-oriented cross-sections (A-A’, B-B’ and C-C’) run from LCCF to BF.

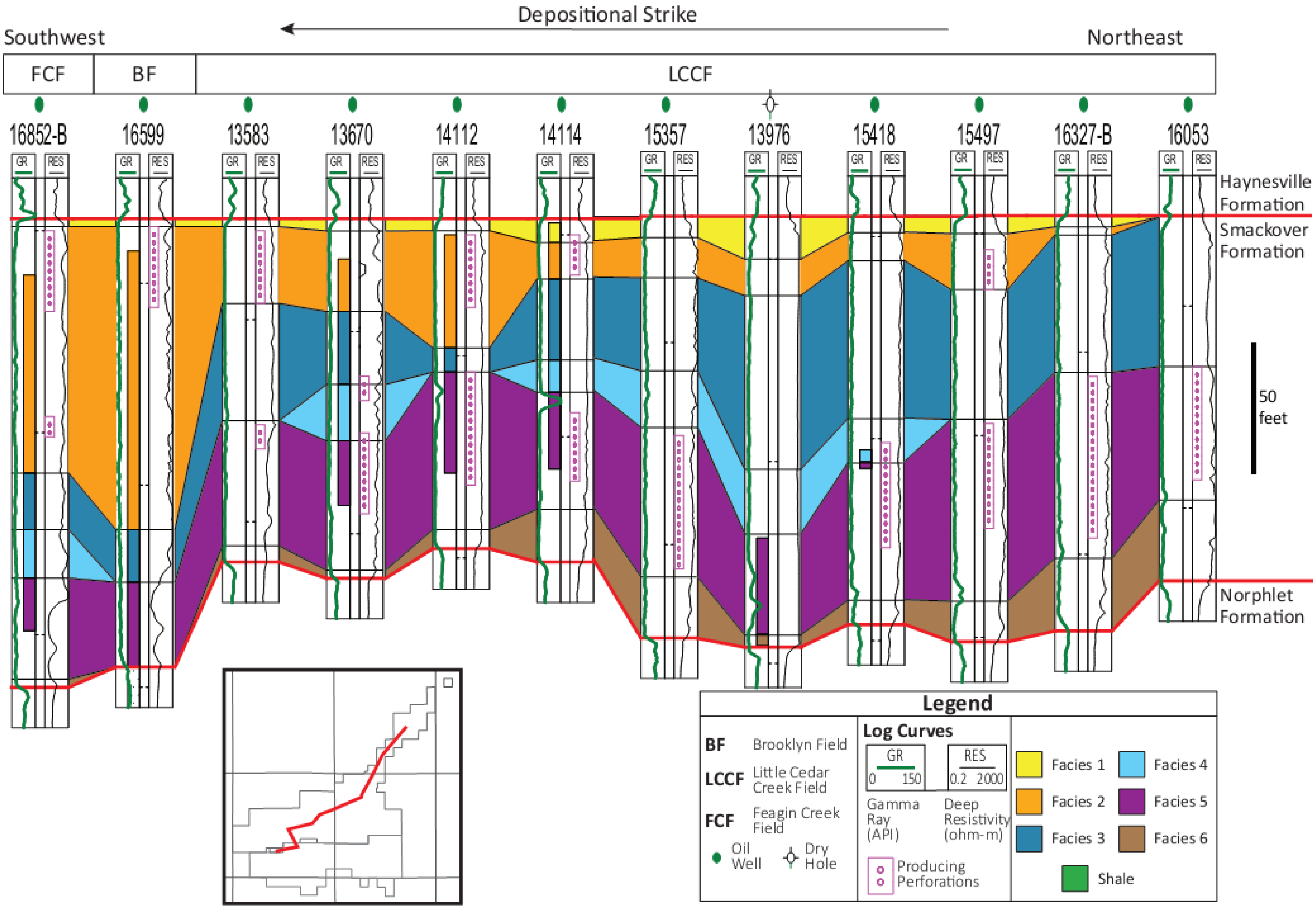


Figure 8. Cross-section 1: Southwest to northeast stratigraphic strike cross-section across FCF, BF and LCCF.

Figure 9 is the southern strike cross-section (cross-section 2) oriented west to east in Brooklyn Field. Facies 2 is thickest in the western half, and thins to the east. Well 16708 also contains the shale facies, but is too thin to be represented on the cross-section. Facies 5 is not productive in this cross-section, though the facies occurs in each well. Facies 6 is absent in core from the western half of the cross-section.

Dip Cross-sections

The western-most dip cross-section is A-A’, Figure 10, which begins in western LCCF and terminates in western BF. The northernmost two wells only produce from the lower microbialite reservoir. Along dip, facies 2 thickens near the LCCF and BF boundary. The southern-most well has a thin layer of shale developed between facies 2 and 3.

The longest dip cross-section, B-B’ (Figure 11) spans central LCCF to the center of BF and has over 400 feet of dip in the Smackover Formation section. In well 15416, the shale facies was deposited between facies 2 and 3. The shale layer thickens in the southeast to 75 ft. in well 16983-B. Facies 5 occurs from the western edge of the cross-section (well 14301-B) to well 16512 in southeastern BF. As the microbialite facies pinches out, facies 6 triples in thickness from an average of 20 to 60 feet.

The eastern-most depositional dip cross-section is C-C’ (Figure 12). Facies 2 occurs in the northwestern and southeastern ends of the cross-section, but is absent in the center. Facies 3 is continuous throughout the cross-section. The shale facies occurs in the southeastern third of the cross-section. Well 15772 produces oil from a microbialite reservoir (facies 5) that developed in the middle of the well, rather than the base. This mid-Smackover Formation thrombolite porosity is not developed in adjacent wells.

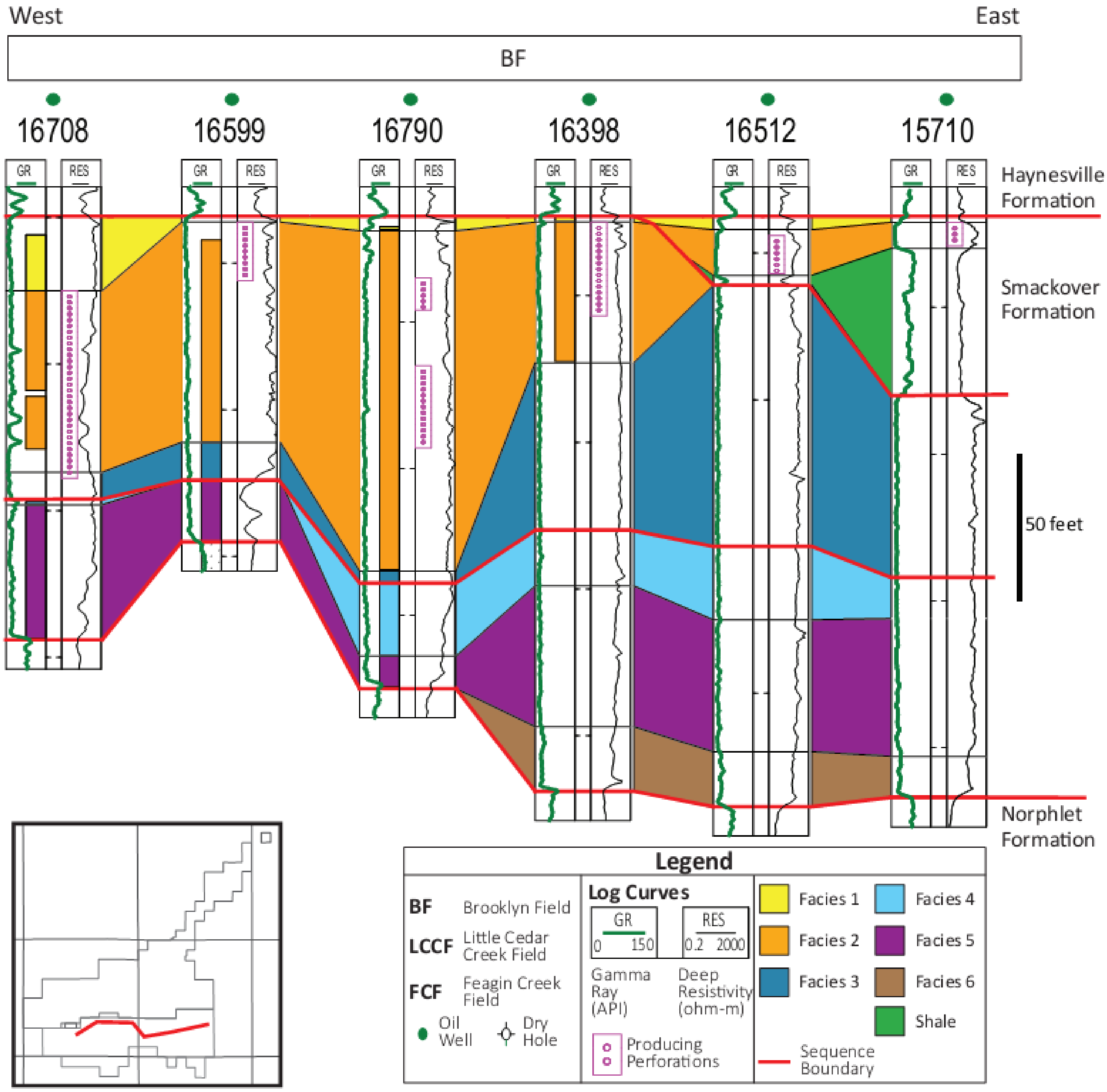


Figure 9. Cross-section 2: West to east stratigraphic oblique-strike cross-section in BF.

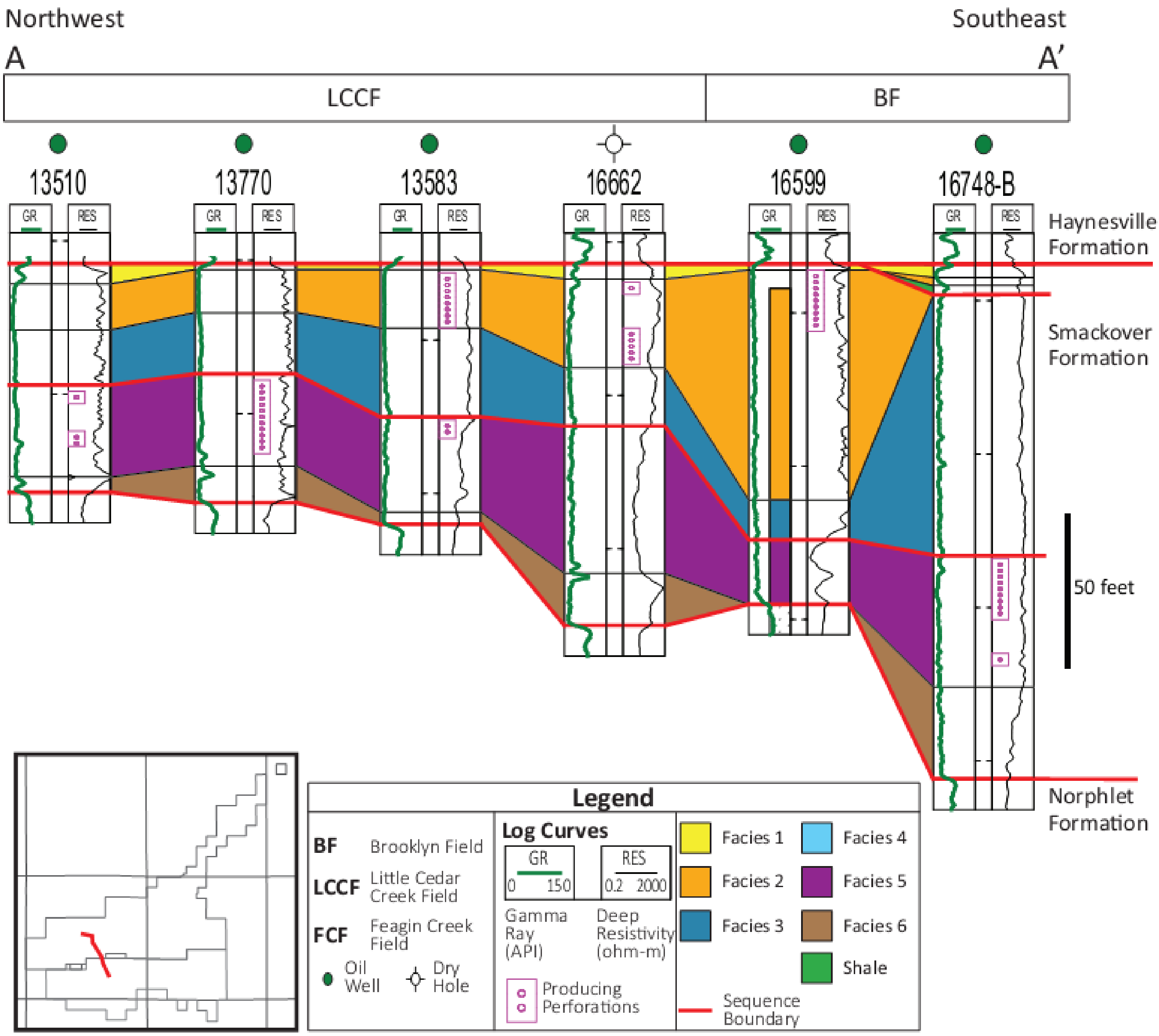


Figure 10. Northwest to southeast stratigraphic dip cross-section A-A’ in western LCCF and BF.

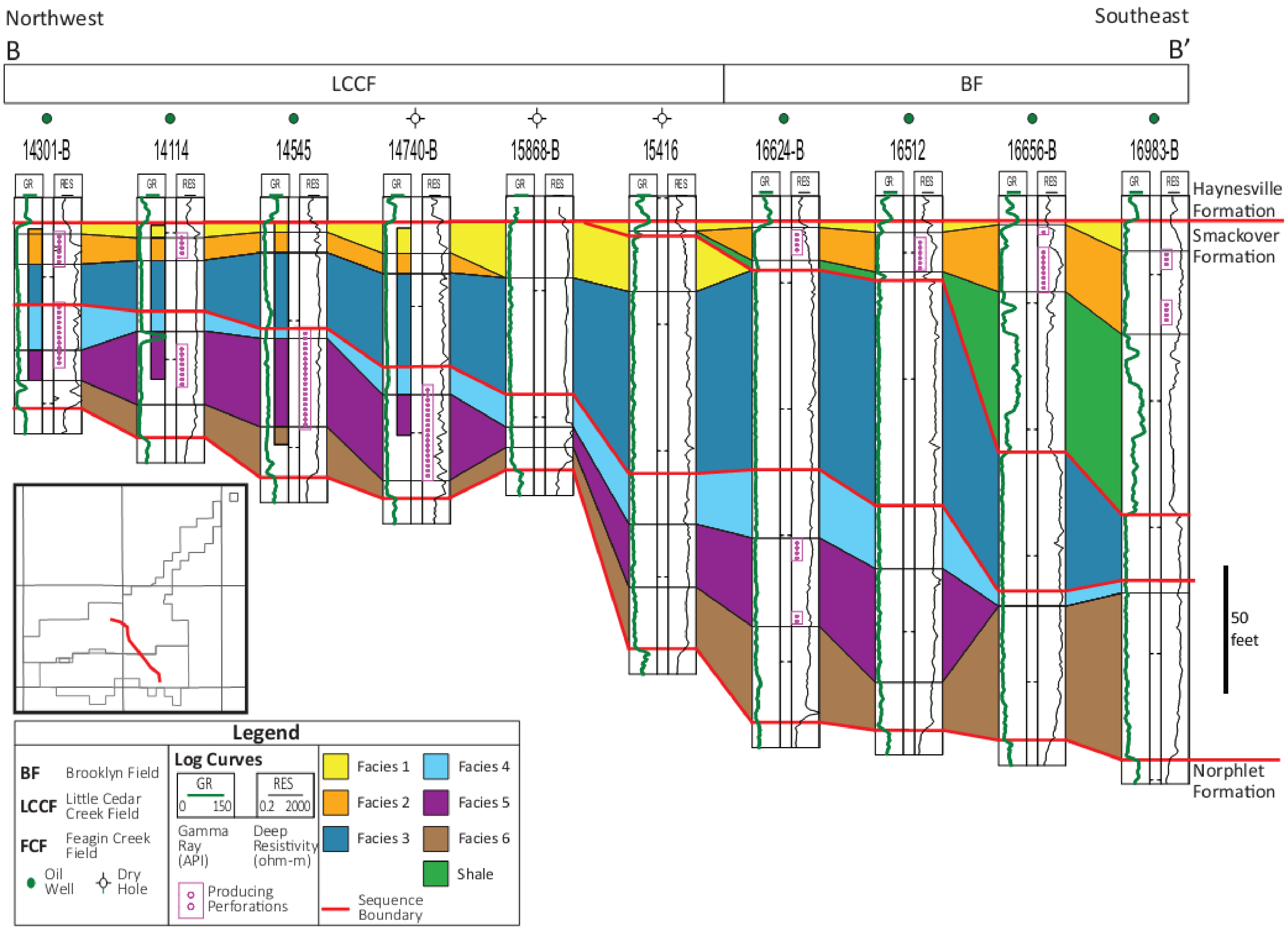


Figure 11. Northwest to southeast stratigraphic dip cross-section B-B’ in central LCCF and BF.

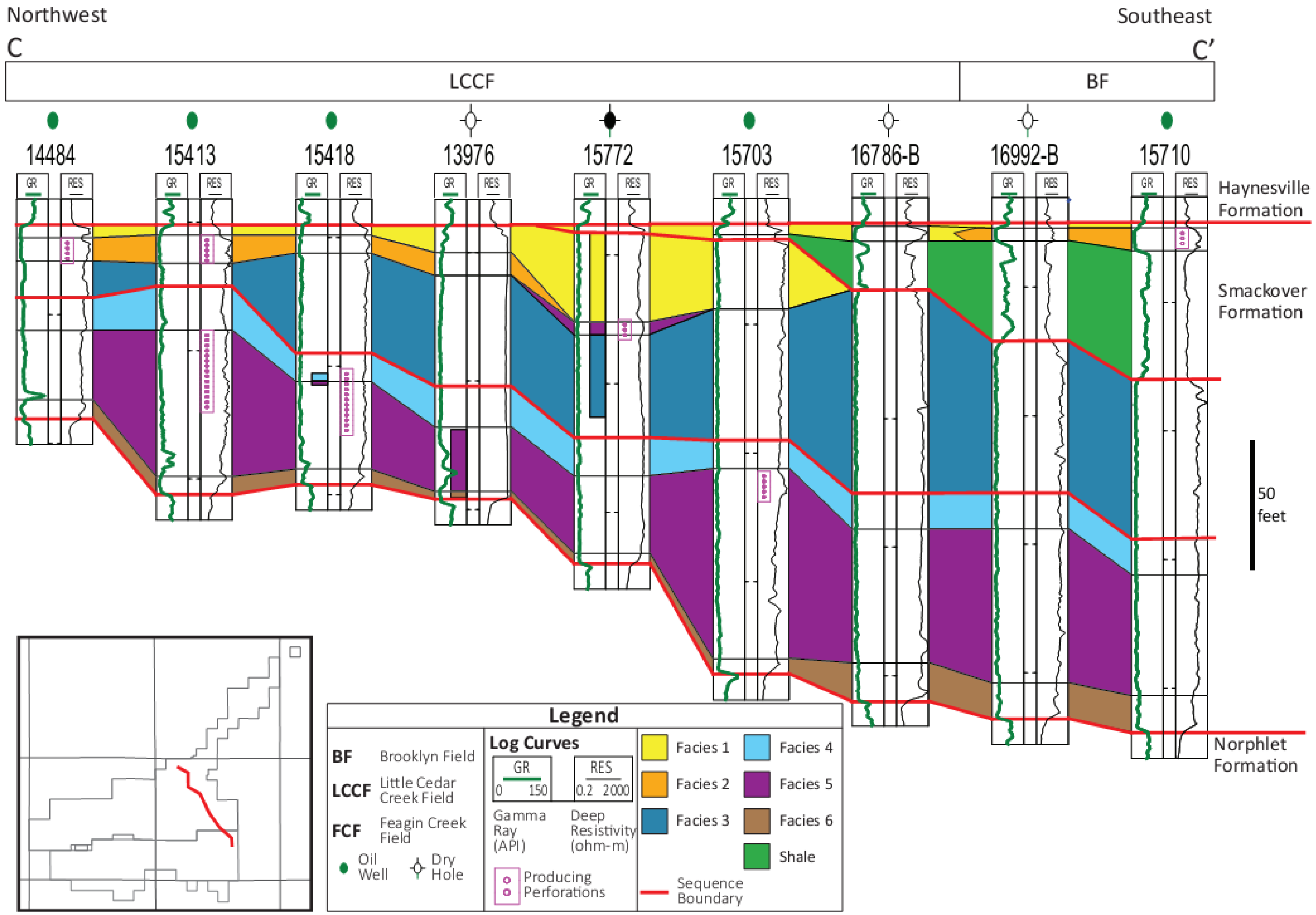


Figure 12. Northwest to southeast stratigraphic dip cross-section C-C’ in eastern LCCF and BF.

Sequence Stratigraphic Literature Review

Sequence stratigraphic analysis was performed according to the following workflow: identify tectonic setting, determine paleodepositional environment, and establish sequence stratigraphic framework (Cataneanu, et al., 2006). The tectonic setting was determined from literature review. The depositional environment and sequence stratigraphic framework are based on conventional core and wireline log analysis, geologic cross-sections, and literature review.

The Jurassic strata of the Mississippi Interior Salt Basin of Alabama are divided into three sequences of eustatic sea level change corresponding to six third-order eustatic sea level cycles of time equivalent Jurassic units from around the world: (1) pre-Norphlet Formation salt and anhydrites to Norphlet Formation clastics, (2) Smackover Formation to middle of the Haynesville Formation, and (3) the upper part of the Haynesville Formation (Mancini, et al., 1990). The Conecuh Embayment and southwest Alabama were determined to have an additional sequence comprised of the Buckner Member of the Haynesville Formation (Prather, 1992).

Calcareous shales are included in the Conecuh Embayment composite type log and a MFS assigned to the lower calcareous shale bed (Prather, 1992). Since then, three regionally-extensive shale beds within the Smackover Formation were characterized as siliciclastic-rich with abundant terrestrial organic material (Baria et al., 2008). These shale beds are inferred as sea levels falls with associated exposure surfaces during Smackover Formation deposition in Alabama (Baria et al., 2008).

In the North-Central U.S. Gulf Coast near the Louisiana and Arkansas border, three sequences are interpreted within the Smackover Formation from lower to higher stratigraphic position: Smackover “C”, Smackover “B” and Smackover “A” (Heydari and Baria, 2006). High-frequency seismic geomorphological and geometrical study performed on the same area suggests

Smackover Formation clinoform bodies prograde basinward over the 10.5 km extent of the 3D survey (Handford and Baria, 2007).

Sequence stratigraphic framework is established by identifying stratigraphic sequences. Stratigraphic sequences are bounded by the same type of sequence stratigraphic surface at the top and base (Catuneanu et al., 2009). The kind of stratigraphic sequence (depositional, genetic stratigraphic, or transgressive-regressive) depends on the sequence stratigraphic surface chosen as the cycle boundary (Catuneanu, 2017). The transgressive-regressive sequence model was chosen as it is useful in shallow-marine successions and in the absence of seismic data (Catuneanu, 2006). The maximum regressive surface is the bounding sequence stratigraphic surface for the transgressive-regressive sequence model. “Transgressive surface” is an alternative term for the maximum regressive surface and will be used to emphasize the onsets of transgression in the study area (Cataneanu, 2017). Once chosen, the sequence stratigraphic framework was established and applied to geologic cross-sections, sequence stratigraphic units identified and system tracts assigned to the strata. Integrating the depositional facies distribution, sequence stratigraphic framework, early diagenetic processes and geologic cross-sections, a depositional history is established.

DISCUSSION

Depositional Environment

The deposits of Smackover Formation in LCCF area are consistent with a ramp model (Heydari and Baria, 2006b). Table 1 compiles general characteristics and the interpreted depositional environment of each of the six facies. The depositional environment and distribution of facies along the ramp is illustrated in figure 13.

Though previous studies have not addressed the occurrence of microbialites in the study area above facies 4 of the Smackover Formation section, a microbialite occurs between facies 1 and facies 3 in permit 15772. The stratigraphic depth of this microbialite compared to wells 13976 and 15418 less than 1 mile (2 km) away suggests a microbial buildup formed adjacent to and downdip of the carbonate shoal deposition. This occurrence is not without analog, as adjacent shoaling and microbial mound growth is documented in outcrops of Middle Jurassic rocks near Amellago, Morocco with isolated mounds approximately 3 ft. (1 m) high and 6-9 ft. (2-3 m) wide alternating with ooid shoal deposits depending on water energy and depth; greater accommodation space providing conditions favorable for microbialite growth (Tomas et al., 2013). Near El Joyazo, Spain a Messinian bioherm consists of 12 ft. (4 m) wide and up to 4 ft. (1.5 m) high stromatolite and thrombolite domes surrounded by and interfingering with oolite (Riding, et al., 1991). Contemporaneous active oolitic sands and accreting microbial buildups occur present-day in Eleuthera Bank, Bahamas (Dravis, 1983).

Sequence Stratigraphy

As the sequence stratigraphic surfaces in the study area are determined from conventional core and wireline log analysis, the resulting sequence stratigraphic units will be higher frequency

(4th- and 5th- order) than work performed using seismic-scale or other lower resolution data. Table 2 identifies sequence stratigraphic surfaces within the Smackover Formation. These sequence stratigraphic surfaces are applied to the Smackover Formation in Figure 14 to build a depositional history.

Facies	Lithology	Sedimentary Features	Characteristics	Biota	Interpreted Depositional Environment
1	Peloidal mudstone-wackestone	Intermittent laminations	Gray limestone. Peloids, 2-10 mm pyrite cubes. Stylolites are common with abundant healed fractures.	Uncommon	Regressive peritidal
2	Peloid-ooid-oncoid packstone/grainstone	Cross-bedding	Buff to tan. Peloids, ooids, (1-25 mm) oncoids, 10 mm grapestone grains and molds. Visible vuggy and moldic porosity and oil-stains, stylolitized.	High-spired gastropod, bivalve, miliolid, ostracod	Regressive ooid-oncoid peloid nearshore shoal Shallow subtidal-intertidal
Shale	Lower calcareous shale, upper siliciclastic shale	Rare burrows in lower shale, laminated fissile upper shale	Light gray lower shale. Upper dark gray quartz sand/siltstone and fissile shale.	Abundant plant fossils	Terrestrial
3	Peloidal mudstone-wackestone	Horizontal laminations	Medium gray. Highly stylolitized and fractured.	Uncommon	Deep subtidal
4	Peloidal wackestone-packstone	Massive bedding	Dark brown to gray. Peloids, stylolites, calcite-filled vugs, and fractures.	Brachiopod, ostracod	Shallow subtidal
5	Peloidal microbialite boundstone	1-5 feet thick stromatolites with [1-15 mm thick] laminations, massive thrombolite interbedded with mud	Peloids and stylolites. Open vugs and fractures, calcite-filled fractures and vugs. Occasional [2-26 ft thick] sections of peloidal wackestone/packstone.	Ostracod, Serpulids, Tubyphites, miliolid, mollusks, forams	Transgressive subtidal microbial mounds
6	Mudstone	(2 mm thick) laminations, horizontal at base to wavy at top	Medium tan-brown. Fractures and stylolites. Few peloids, [5-20 mm] pyrite cubes.	Uncommon	Transgressive subtidal

Table 1. General characteristics and interpreted depositional environment of facies in the study area.

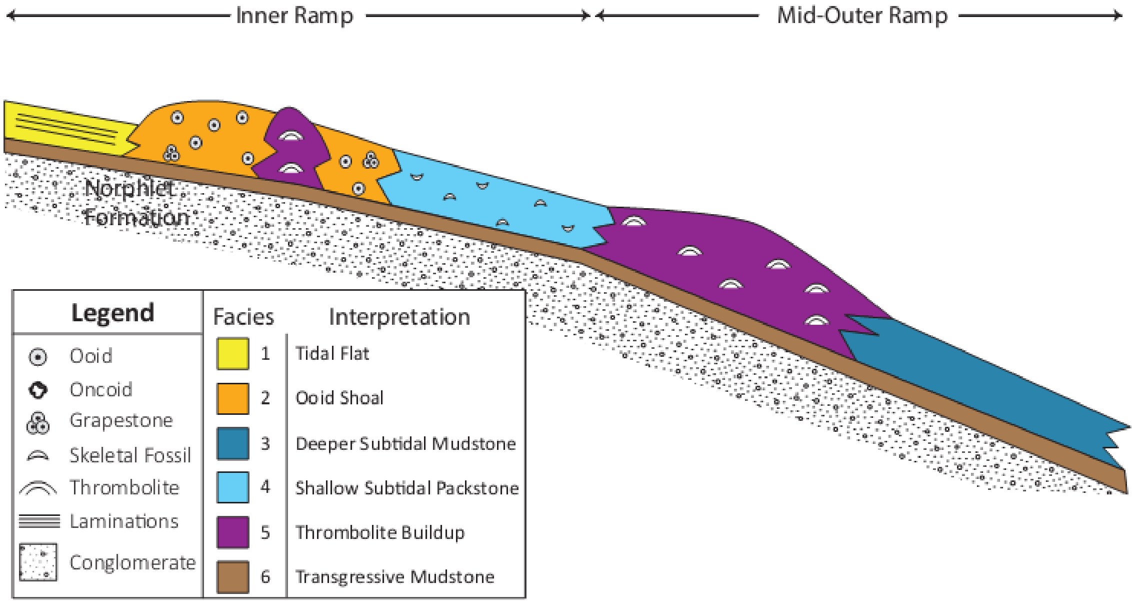


Figure 13. Depositional environment of Smackover Formation facies in study area. Though a rare incidence, thrombolite development occurs in permit 15772 at the stratigraphic position of oolitic grainstones in facies 2 of neighboring well 15418.

The T1 sequence stratigraphic unit at the base of the Smackover Formation begins with flooding. As the sea rose into the Conecuh Embayment over the Norphlet Formation siliciclastics it deposited a thin layer of lime mudstone (facies 6) across the seafloor. Microbialite colonies began to nucleate on the seafloor and developed into microbialite mounds (facies 5) during a highstand system tract of R1 unit. The appearance of fossil fragments, ooids and increased pellets in facies 4 and the top of facies 5, is consistent with shallow subtidal ramp deposits and indicates accommodation space decreased during the first Smackover Formation regressive system tract (R1) in the study area. Unit T2 begins with deeper subtidal fine-grained mudstone deposit (facies 3) and records the backstepping of the carbonate ramp landward. A MFS occurs within the laminated facies 3 deposit. During the second highstand systems tract (R2) extensive ooid shoals (facies 2) were deposited. Facies 1 tidal flat deposition moved southeast as accommodation space decreased during highstand regression as the ramp prograded basinward.

Location in Smackover Formation	Characteristics	Interpreted Sequence Stratigraphic Surface	Sequence Stratigraphic Unit
Top Smackover Shale	Marine deposits overlay siliclastic deposits.	Maximum regressive surface/Transgressive surface	T3
Base Smackover Shale	Underlying marine surface truncated by siliclastic shale.	Basal surface of forced regression	R2
Facies 3/4 contact	Fine-grained marine deposits of facies 3 overlie ooids at top facies 4 in permit 14301-B and 16852-B.	Maximum regressive surface/Transgressive surface	T2
Facies 5/6 contact	Increase in radioactivity shown on gamma ray logs.	Maximum flooding surface	R1
Top Norphlet Fm/base Smackover Fm	Sharp and erosional contact.	Subaerial unconformity	T1

Table 2. Sequence stratigraphic surfaces identified through conventional core and wireline log analysis, in order from higher to lower in the Smackover Formation section.

In BF and FCF wells, which lie basinward of the LCCF paleo-shoreline, the ooid shoals are separated from facies 3 by the shale facies deposited during the R2 cycle. The carbonaceous shale and its correlative sand deposits are interpreted as shallow water, terrestrial units deposited during a lowstand systems tract (Niemeyer, 2011). The forced regression left the LCCF shoreline subaerially exposed, as indicated by the dissolution of ooid and peloid grains which characterize the ooid-oncoid-peloid grainstone reservoir in LCCF. The seas transgressed once again (T3) and ooid shoals formed over the BF and FCF areas. An increase in thickness of the tidal flat facies occurs at the boundary between LCCF and BF, shown in Figure 14. The increased thickness is interpreted as tidal flats deposits of BF stacked on top of LCCF tidal flat deposits, separated by a transgressive surface seen in cores as a dark and thinly laminated mudstone between light gray mudstone. As the carbonate ramp experienced a final highstand normal regression (R3) and prograded basinward, tidal flat deposits capped the BF and FCF ooid shoal deposits. Like facies 2 at LCCF, the shoal deposits of BF and FCF experienced dissolution associated with subaerial exposure. Continued regression led to terrestrial Haynesville Formation deposits prograding over the Smackover Formation marine deposits.

Lateral Stratigraphic Variations

The fine-grained laminated mudstone-packstone of facies 6 is interpreted to be a transgressive unit over the Norphlet Formation (Mancini et al., 2008). Facies 6 is thickest in southeast BF, suggesting this area had greater accommodation space and was under deeper water conditions longer during the initial transgression. The occurrence of facies 5 is relatively constant throughout the study area, although the microbialite type that constitutes the facies changes from west to east. Facies 5 is further sub-divided into microbialite types I – IV (Fig. 14) whose distribution across FCF, BF and LCCF is shown in Figure 15. Toward the west, the microbialite facies is dominated by laminated stromatolite and layered thrombolite, and contains a section of peloidal packstone within facies 5 that does not occur in the eastern cores studied. The thickest microbialite sections are in the middle of the study area in LCCF and are primarily composed of reticulate thrombolite, except in well 13976, where layered thrombolite constitutes over 75% of the microbialite.

The skeletal wackestone-packstone of facies 4 occurs intermittently in the western third of the study area, has consistent thickness through the center, and disappears entirely northeast of well 15418. The thickness of facies 5 increases to the northeast as facies 4 pinches out, suggesting lower wave energy microbialite communities continued to grow there while increased wave energy continued to the southwest (Mancini et al., 2006). Facies associated with higher energy (facies 2 and 4) are much thinner in wells in the northeast of LCCF, indicating this area experienced less wave energy. As sea levels rose, the microbial mounds and shallow subtidal carbonate were flooded and deposition changed to a deep subtidal mudstone-wackestone

(Mancini et al., 2008). Facies 3 (deeper water mudstone-wackestone) occurs in all wells, although its thickness varies from ten to 80 feet. Wells which have a thick deposit of facies 2 contain a thinner than average deposit of facies 3, suggesting a reciprocal relationship between nearshore ooid/peloid shoals and subtidal mudstone-wackestone deposits. Facies 2 is thinnest in both eastern BF and eastern LCCF (averaging ten feet) and thickens to the west in excess of 75 feet in Feagin Creek and western Brooklyn fields. Facies 1 is interpreted as a tidal flat mudstone deposited as accommodation space decreased toward the end of Smackover Formation deposition. The thickness of facies 1 is inversely related to the thickness of facies 2; the thickest deposits of facies 1 occur where facies 2 is absent or markedly thinner than surrounding wells. The shale facies develops in eastern BF and the far southeast corner of LCCF, and thickens to the southeast.

Paragenetic Sequence

Diagenetic events of three facies from the Smackover Formation were determined from thin section analysis (Figure 16). Early isopachous and mosaic to equant cements in facies 2 are consistent with a marine environment (Longman, 1980). The upper Smackover Formation reservoir in LCCF is characterized by dissolution features, including leached ooids and pellets. Thin sections from facies 2 display partial to total destruction of original ooid and peloid internal grain structure, suggesting initial marine conditions gave way to meteoric dissolution associated with subaerial exposure (Longman, 1980).Equant calcite crystallization within the intergranular pore space in facies 2 is interpreted to form during the transition to and through early burial (Tonietto, 2014).

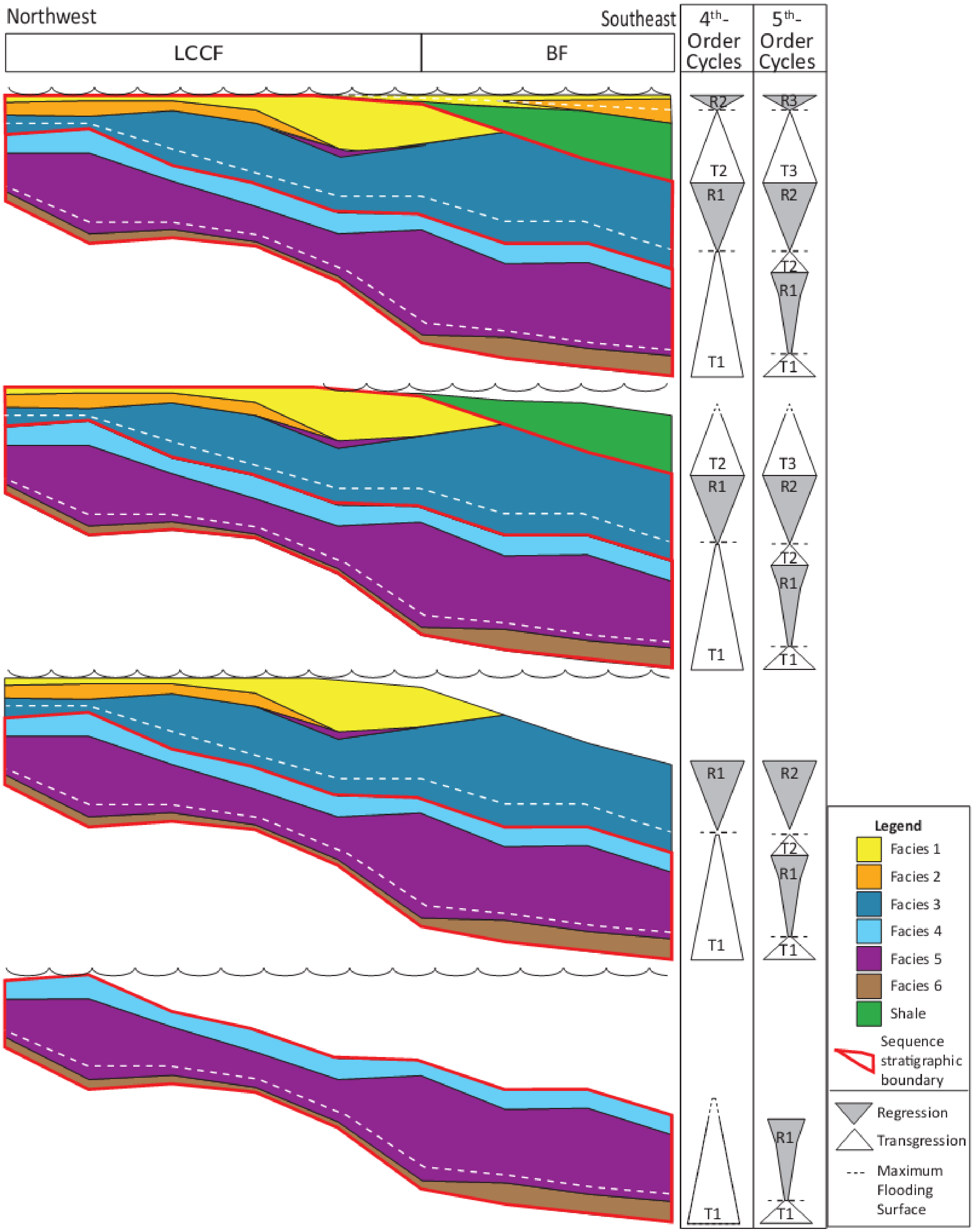
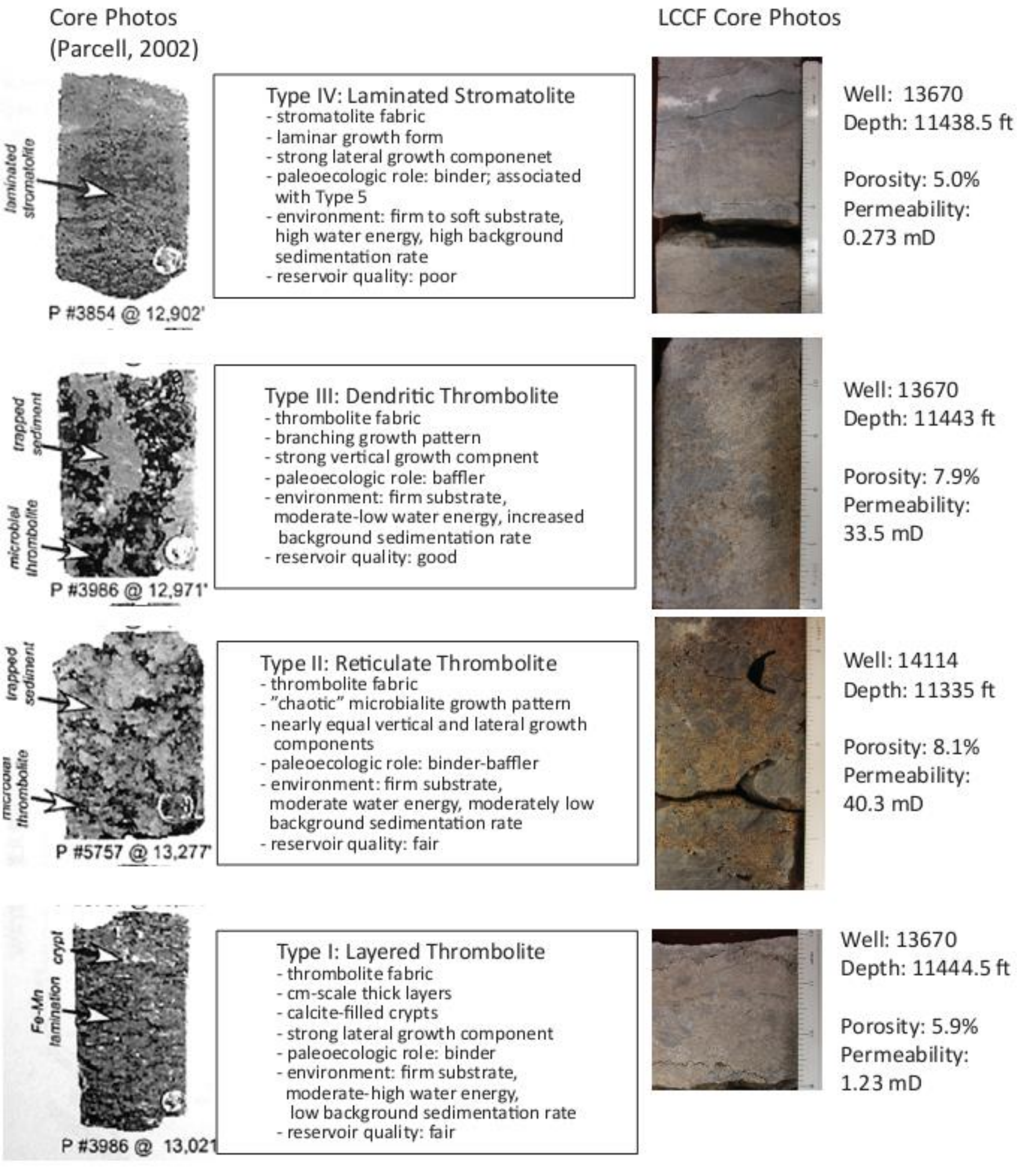


Figure 14. Depositional model of study area with transgressive-regressive sequence units based on 5th-order sea level fluctuations.



Type IV: Laminated Stromatolite
- stromatolite fabric
- laminar growth form
- strong lateral growth componenet
- paleoecologic role: binder; associated with Type 5
- environment: firm to soft substrate, high water energy, high background sedimentation rate
- reservoir quality: poor

Well: 13670
Depth: 11438.5 ft

Porosity: 5.0%
Permeability: 0.273 mD

Type III: Dendritic Thrombolite
- thrombolite fabric
- branching growth pattern
- strong vertical growth compnent
- paleoecologic role: baffler
- environment: firm substrate, moderate-low water energy, increased background sedimentation rate
- reservoir quality: good

Well: 13670
Depth: 11443 ft

Porosity: 7.9%
Permeability: 33.5 mD

Type II: Reticulate Thrombolite
- thrombolite fabric
- "chaotic" microbialite growth pattern
- nearly equal vertical and lateral growth components
- paleoecologic role: binder-baffler
- environment: firm substrate, moderate water energy, moderately low background sedimentation rate
- reservoir quality: fair

Well: 14114
Depth: 11335 ft

Porosity: 8.1%
Permeability: 40.3 mD

Type I: Layered Thrombolite
- thrombolite fabric
- cm-scale thick layers
- calcite-filled crypts
- strong lateral growth component
- paleoecologic role: binder
- environment: firm substrate, moderate-high water energy, low background sedimentation rate
- reservoir quality: fair

Well: 13670
Depth: 11444.5 ft

Porosity: 5.9%
Permeability: 1.23 mD

Figure 15. General characteristics of the four microbialite types (I-IV) described in the study area. Porosity and permeability values are from conventional core analyses at nearest core plug depths (Modified from Parcell, 2002).

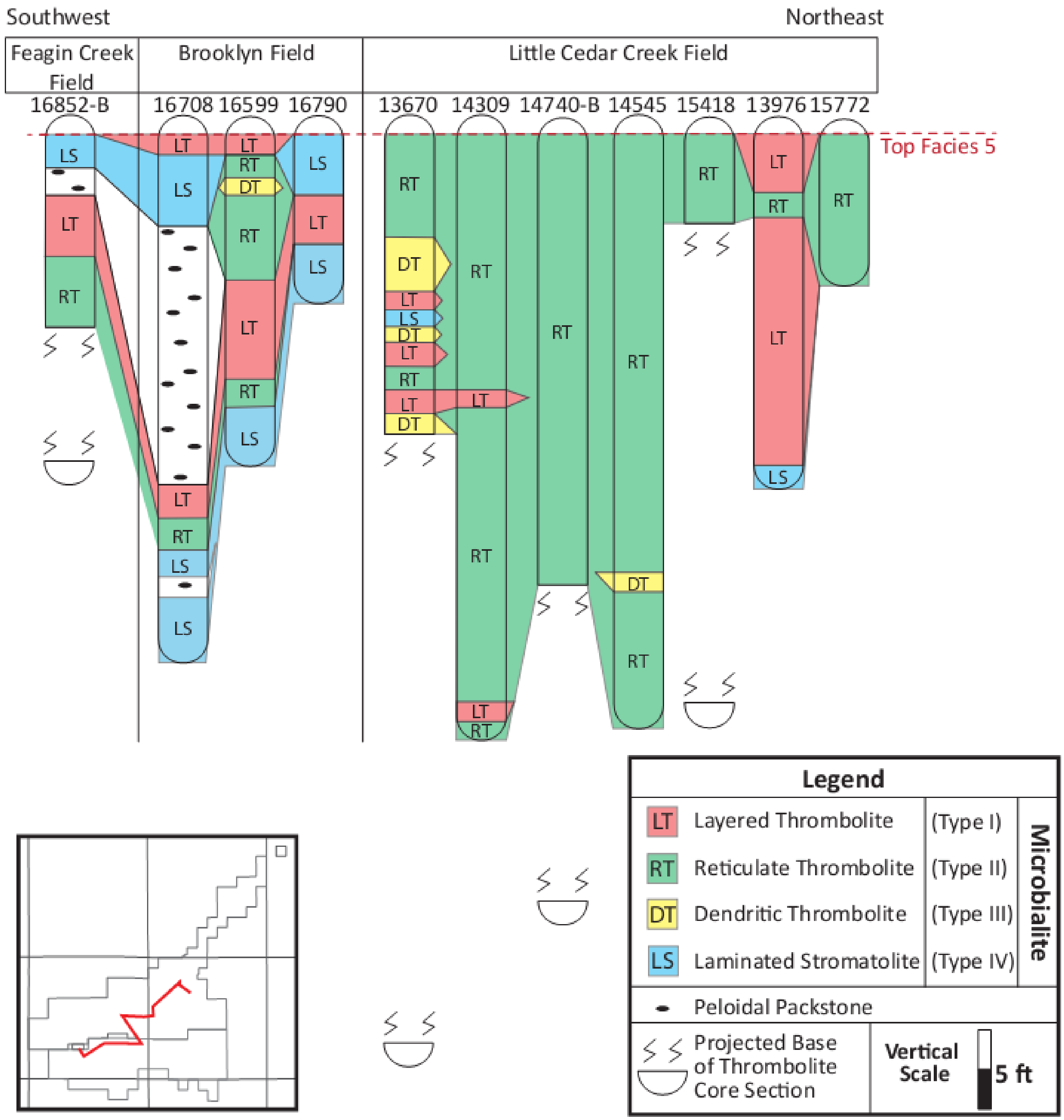


Figure 16. Southwest to northeast stratigraphic cross-section of microbialite type from FCF to LCCF through BF. The projected base of the microbialite sections are based on wireline correlations.

Facies 5 contains an initial marine cement of fibrous calcite rim cement and drusy calcite fringe cement not seen in facies 4. Facies 4 and 5 share similar early burial events of granular calcite crystallization and fracturing.

Deep burial events are similar for all facies and include from earliest to latest: stylolites formed during chemical and mechanical compaction, blocky calcite crystallization and syntaxial overgrowth, open fracture, burial dissolution, dolomite precipitation, blocky calcite crystallization, syntaxial overgrowth and closed fractures. Calcite replacement of dolomite crystals occurs in thin sections of facies 5 from wells 14309, 16708, 16852-B.

Porosity and Permeability

No single attribute determines the porosity and permeability in facies 2, 4 or 5 of the Smackover Formation in the study area (Figure 5). The data from the facies and porosity classification cross-plots occur in clusters; the highest porosity values occur in facies 2 and H1B samples. The percent of dolomite shows no correlation with the porosity or permeability of the wells sampled (Fig. 5C). The field designation cross-plot indicates LCCF has higher permeability values associated with similar porosity values in BF, likely due to the inclusion of the higher-permeability thrombolite reservoir of LCCF wells.

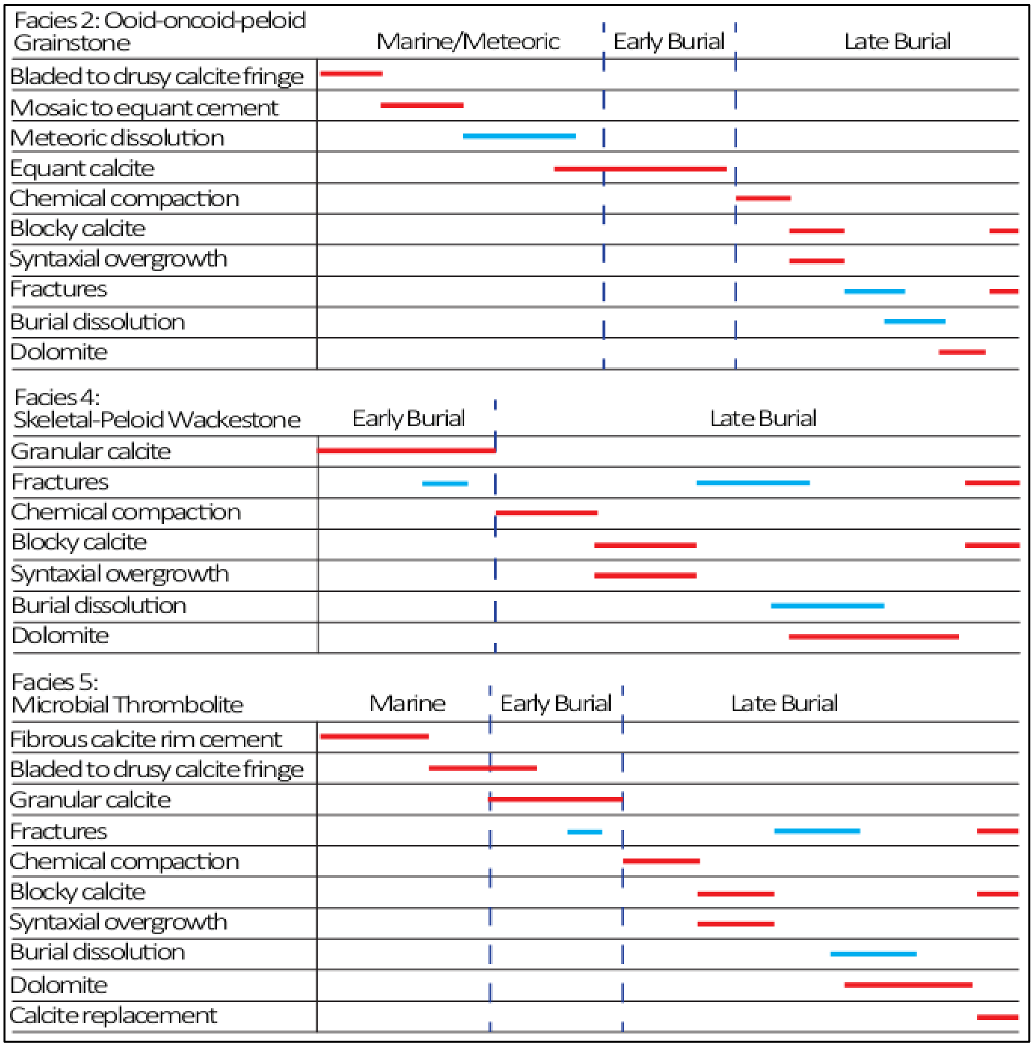


Figure 17. Paragenetic sequences of facies 2, 4 and 5. Red horizontal lines are porosity occluding processes, and blue horizontal lines are porosity enhancing.

CONCLUSIONS

Little Cedar Creek Field records two 5th-order transgressive-regressive cycles (T1-R1 and T2-R2) followed by downdip deposition of a siliciclastic shale during a forced regression. Brooklyn Field and Feagin Creek Field subsequently record an additional 5th-order cycle (T3-R3) that deposited a shoal facies temporally isolated from the shoal facies that are LCCF's upper reservoir. Thin sand layers in facies 2 of FCF and BF wells are correlative to terrestrial shale described in southern Brooklyn Field.

Porosity and permeability in the Smackover Formation reservoirs cannot be predicted by a single attribute, and was dependent on diagenetic controls on depositional facies to produce reservoir quality rock. The facies attribute has the highest correlation coefficient relating porosity and permeability; however, dry hole wells containing reservoir facies likely may never have experienced key diagenetic processes to create reservoir-quality rock. Subaerial exposure was a crucial component to forming, maintaining and enhancing porosity in the ooid-oncoid-peloid packstone-grainstone unit. Thrombolite buildups interbedded with peloidal mud formed extensive reservoirs in mid-outer ramp settings and locally developed within inner ramp among ooid shoal deposition. Where the thrombolite units were not leached from the microbialite, the unusually high permeability present within the thrombolite reservoir of producing wells is absent, resulting in an uneconomic well. Although dolomite often enhances porosity and permeability, the increased (20-100%) dolomite present in southern LCCF/BF thrombolite facies does not correlate to increased porosity or permeability.

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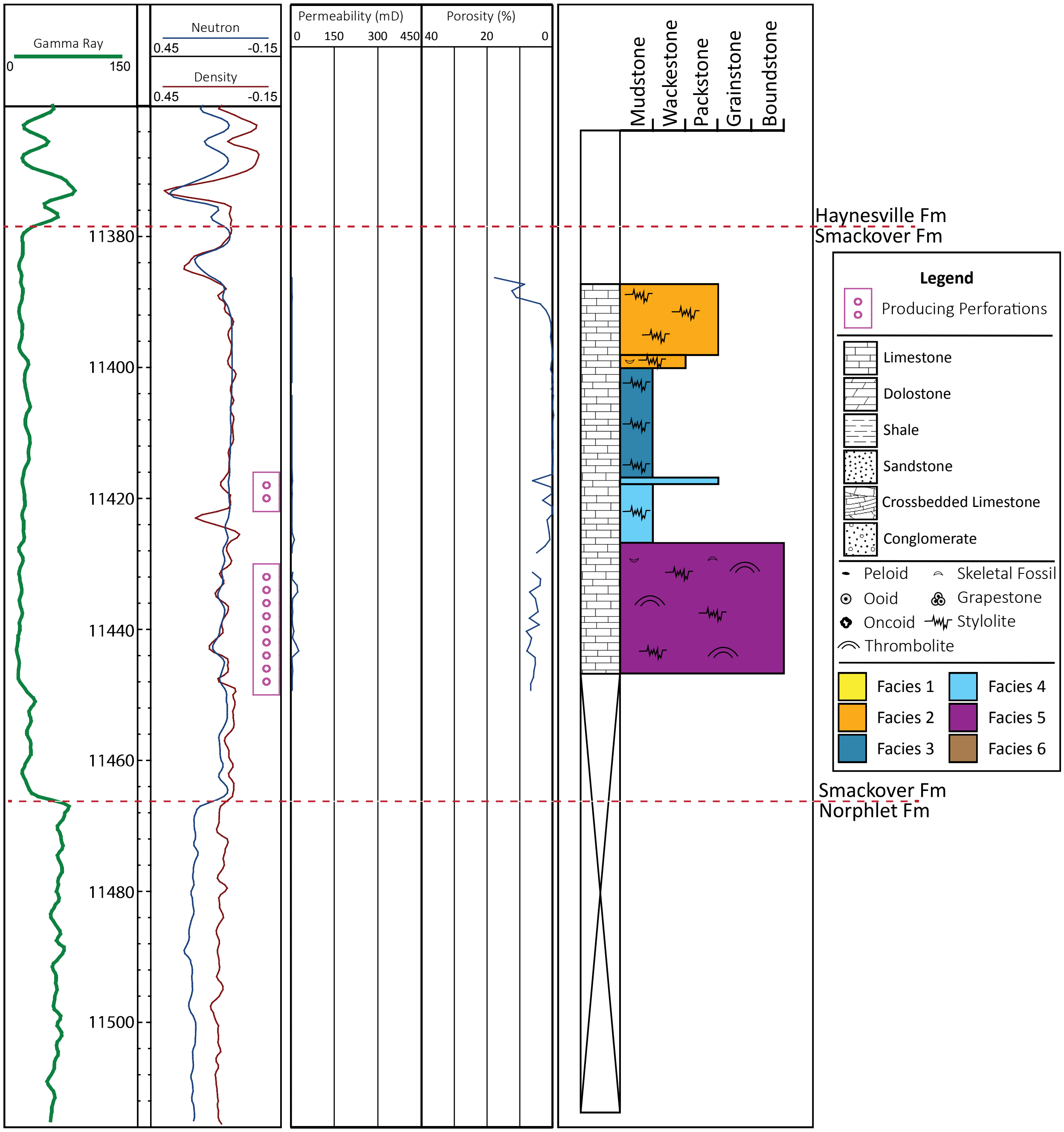
APPENDIX A

Composite Logs of Lithologic Core Description, Core Analysis, Electric Porosity Logs

Permit 13670 LCCF 4N12E Sec. 14



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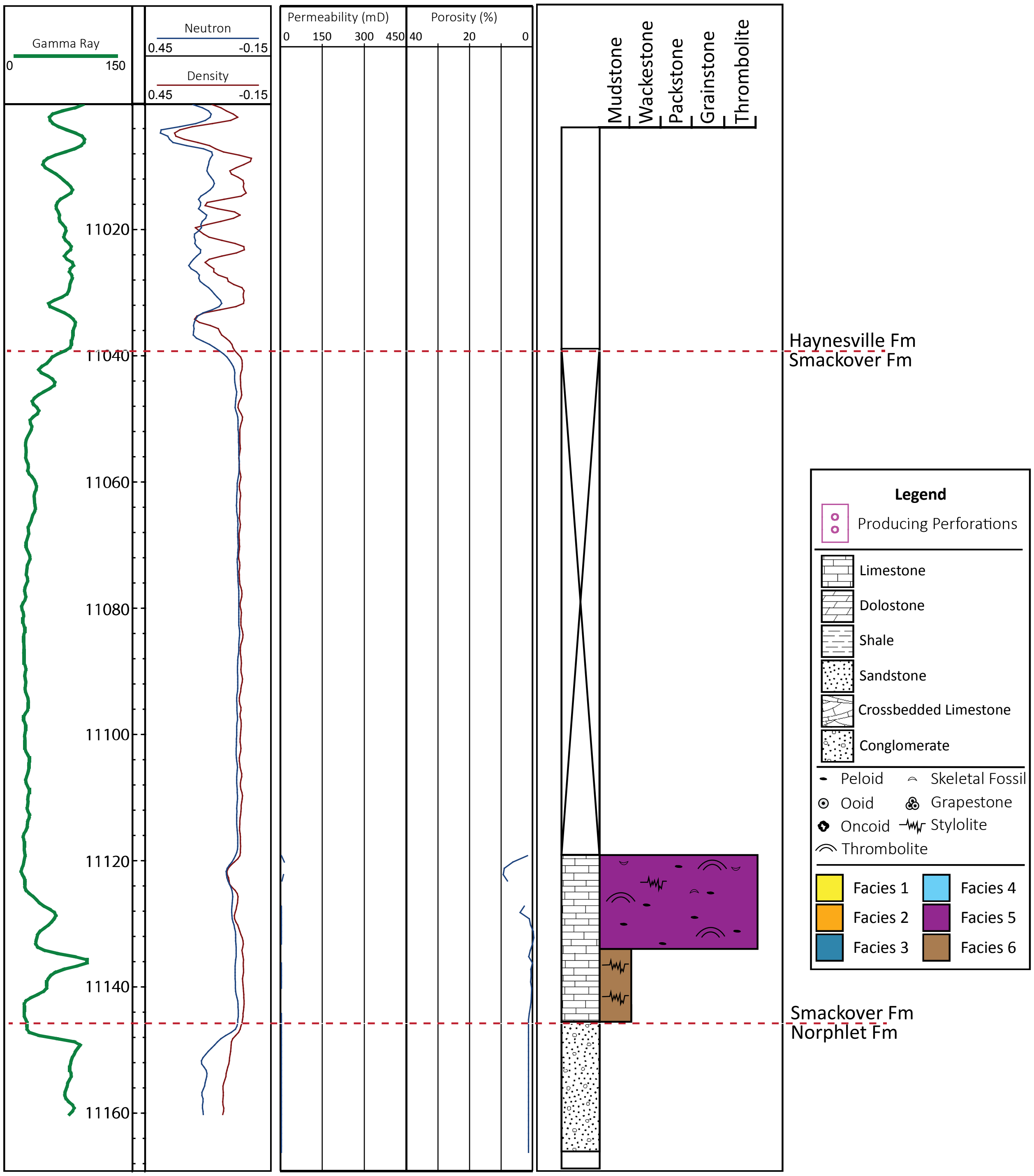

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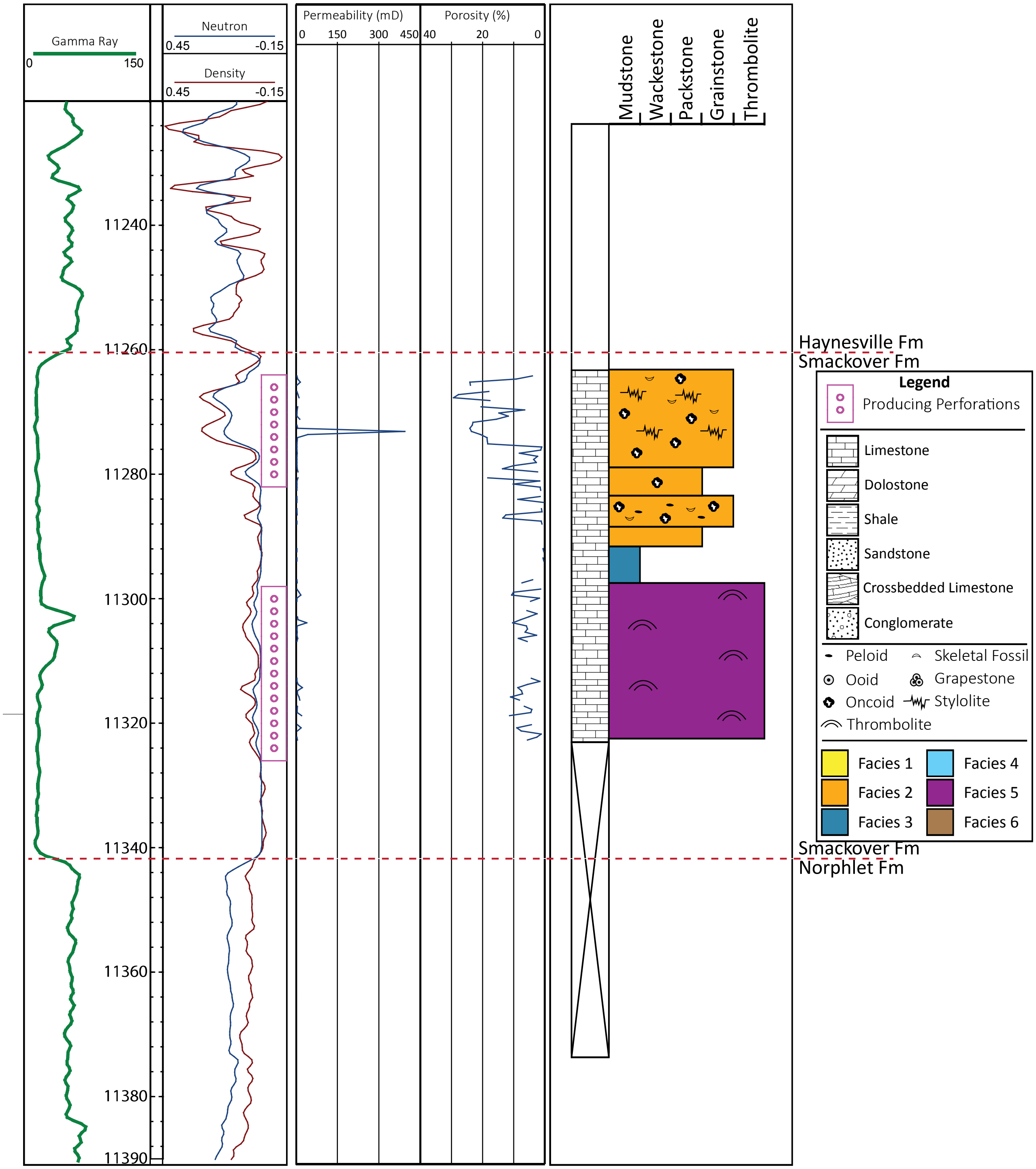

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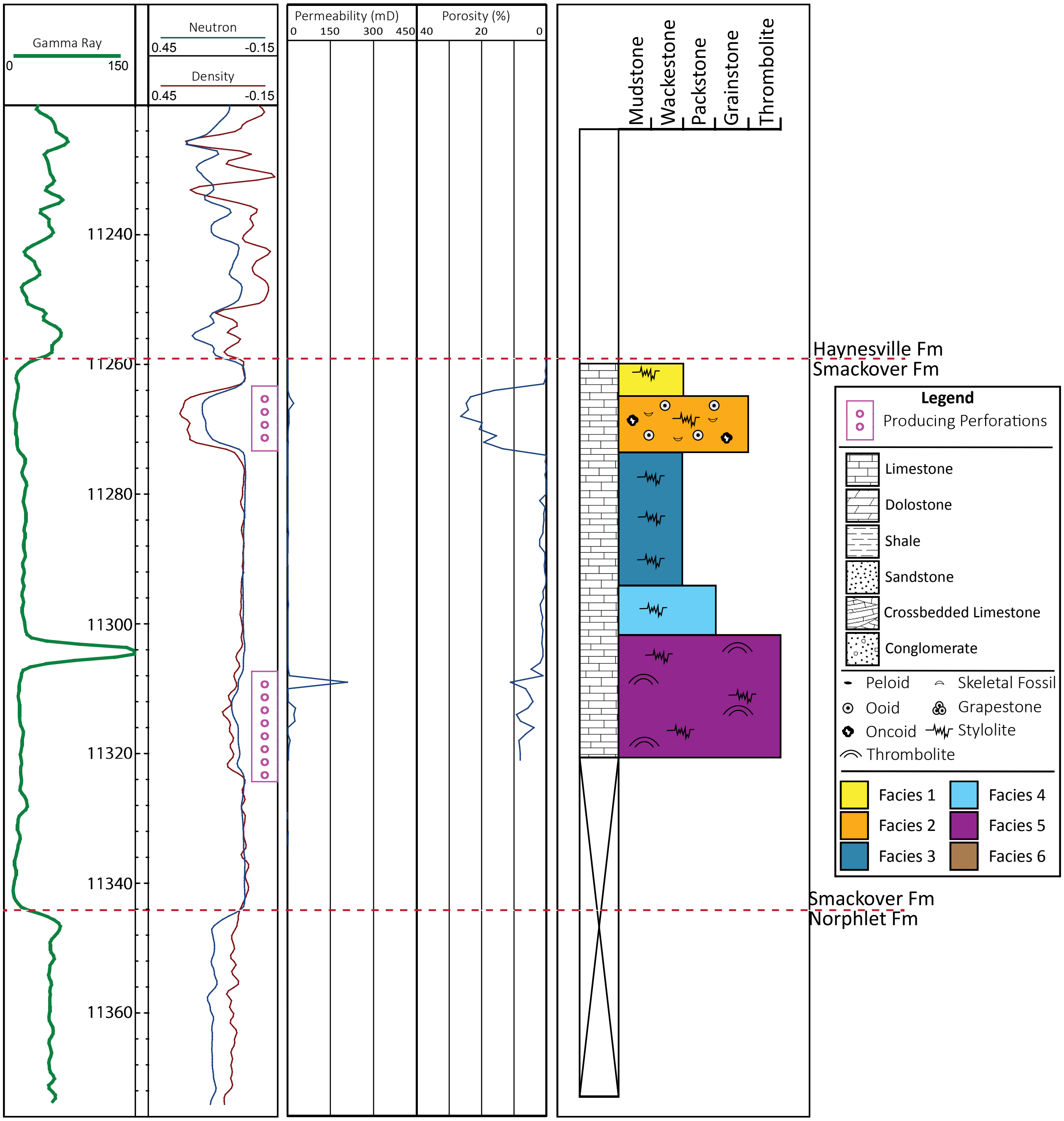

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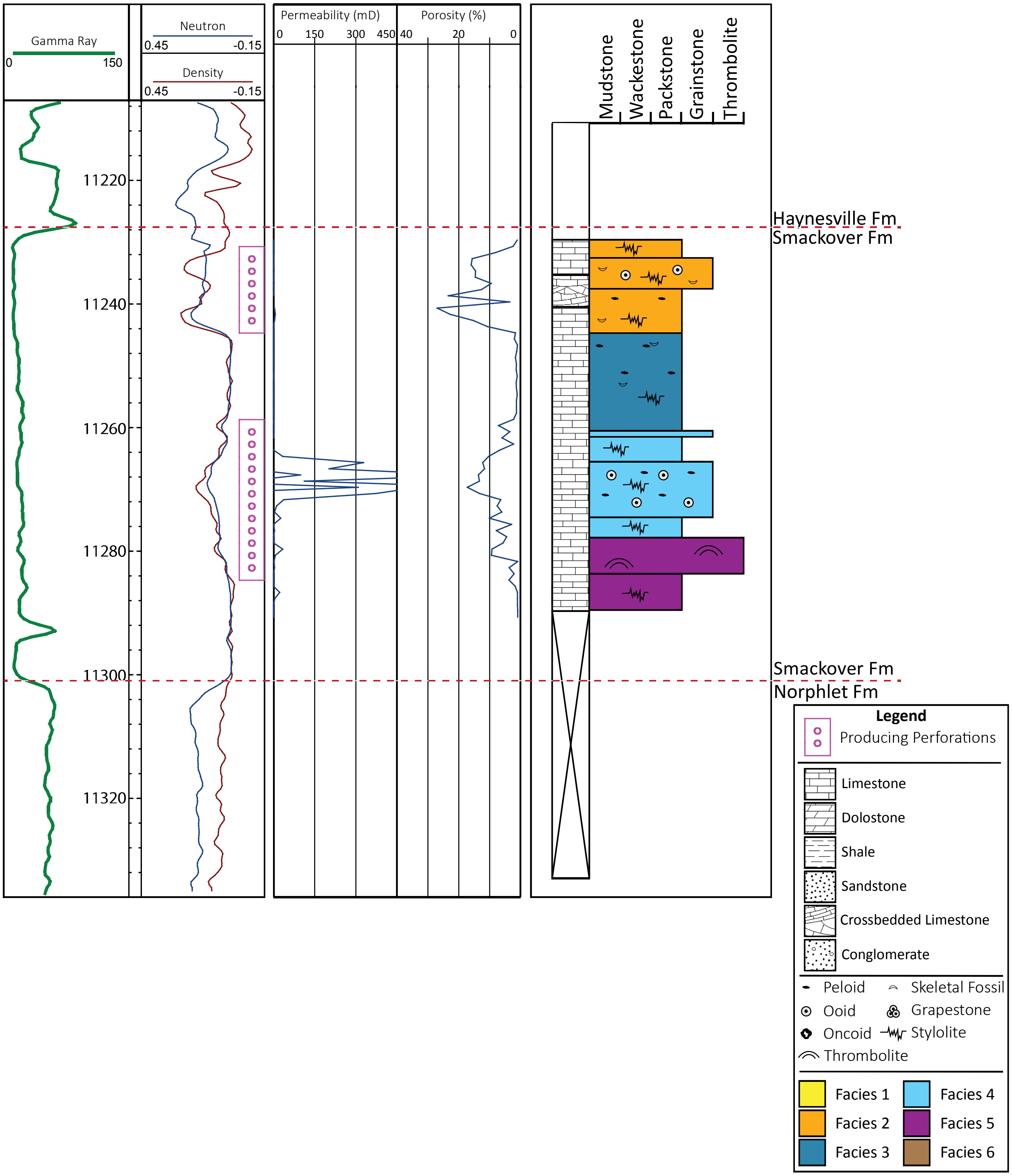

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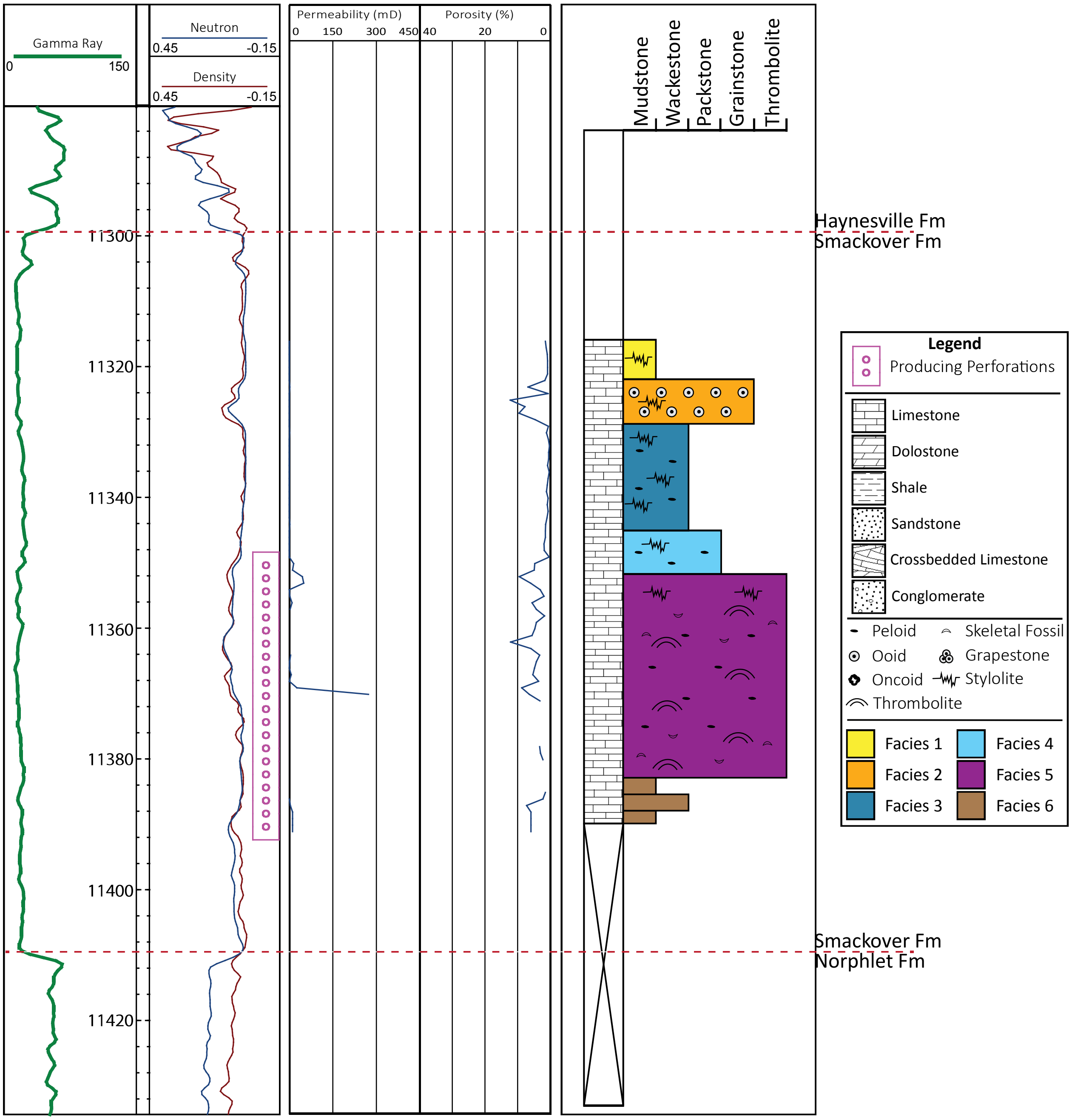

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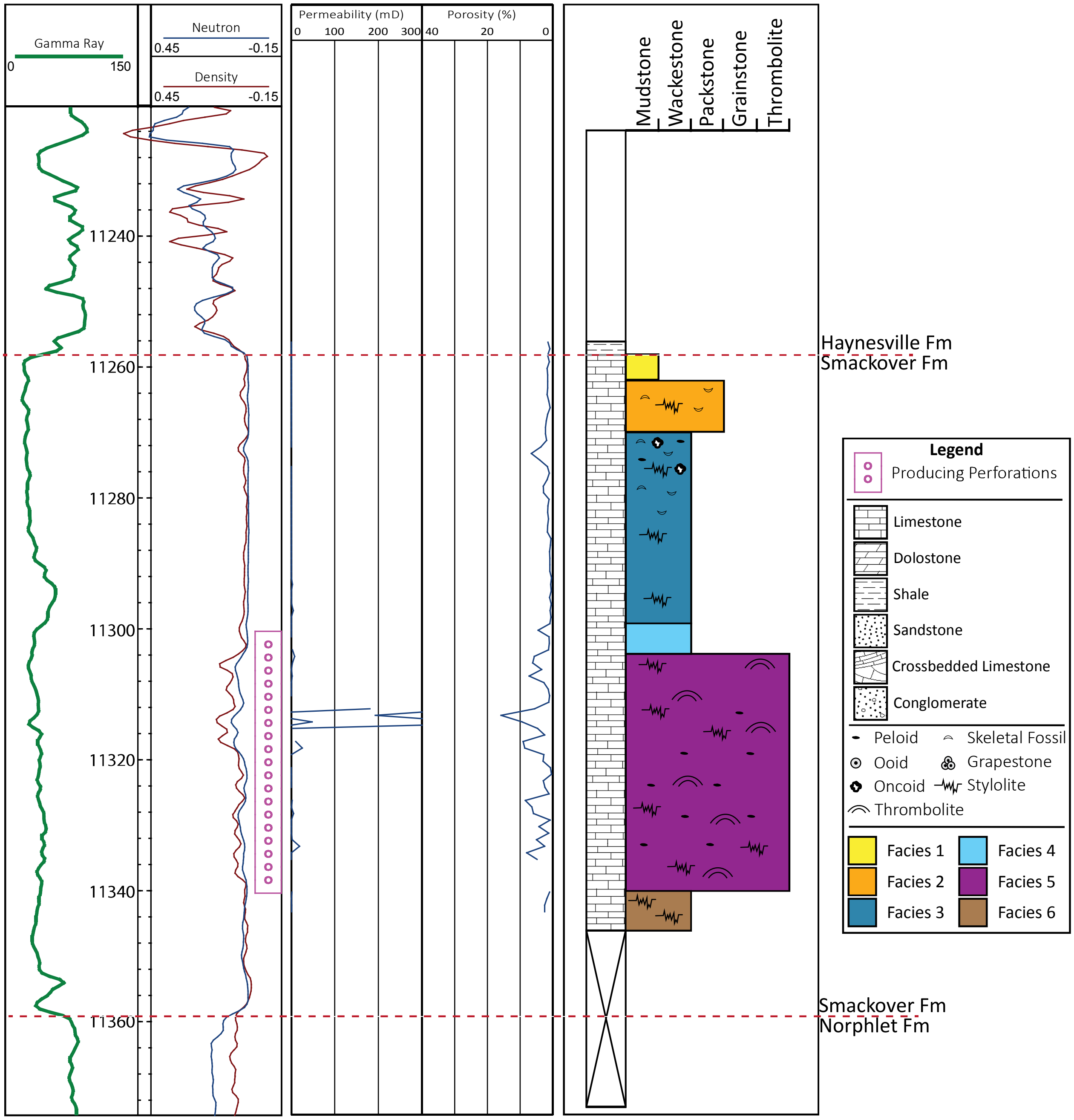

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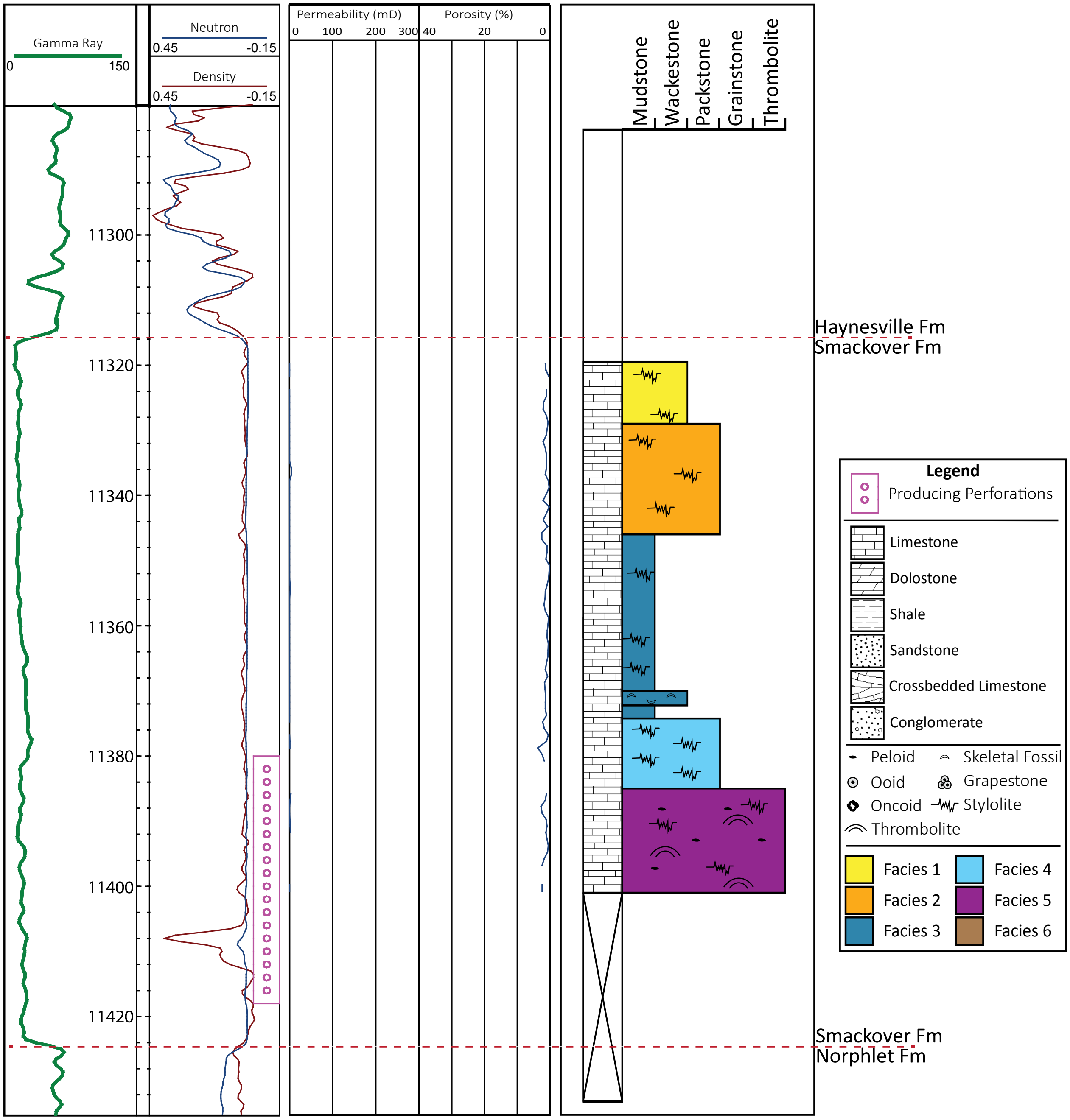

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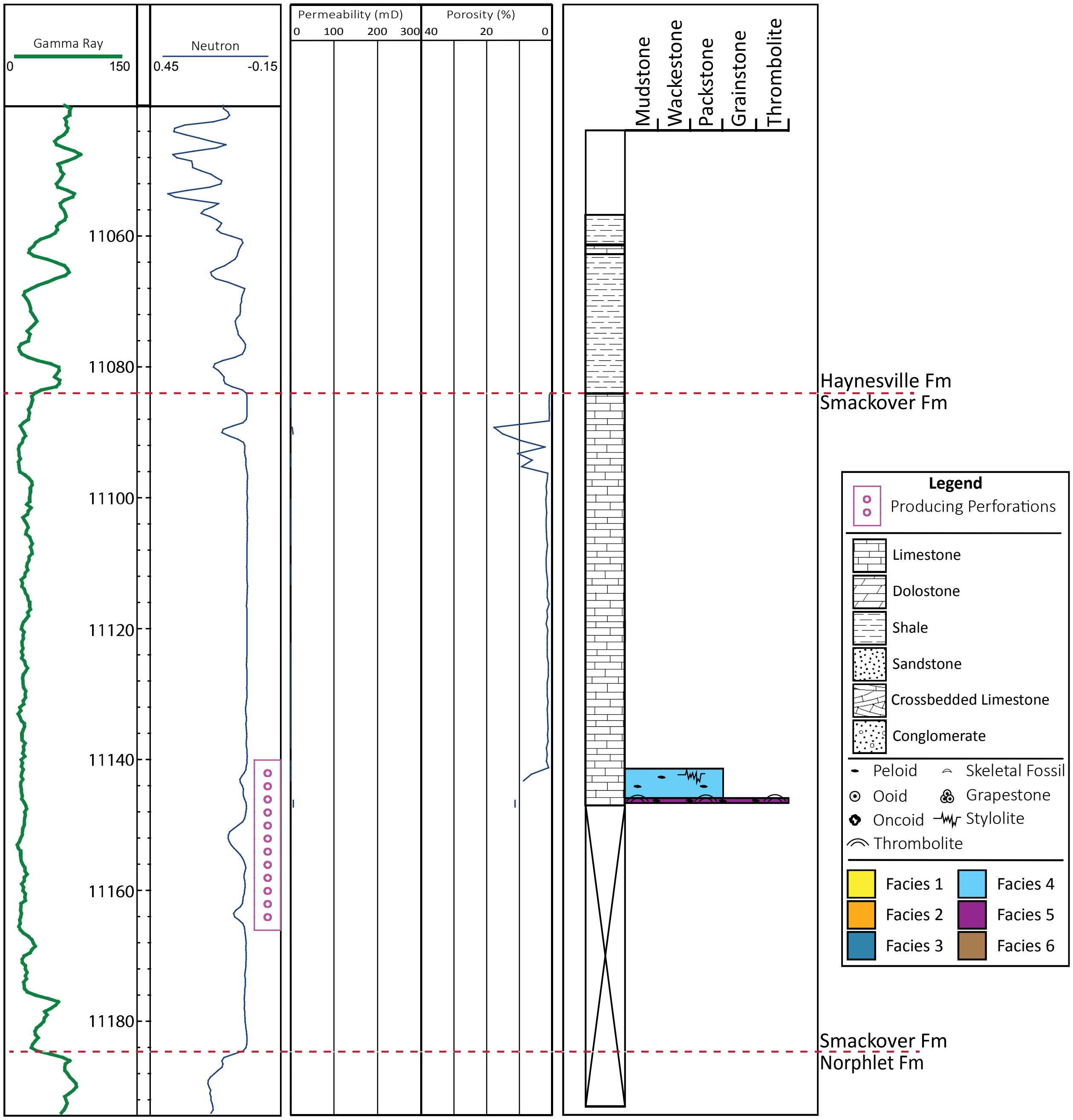

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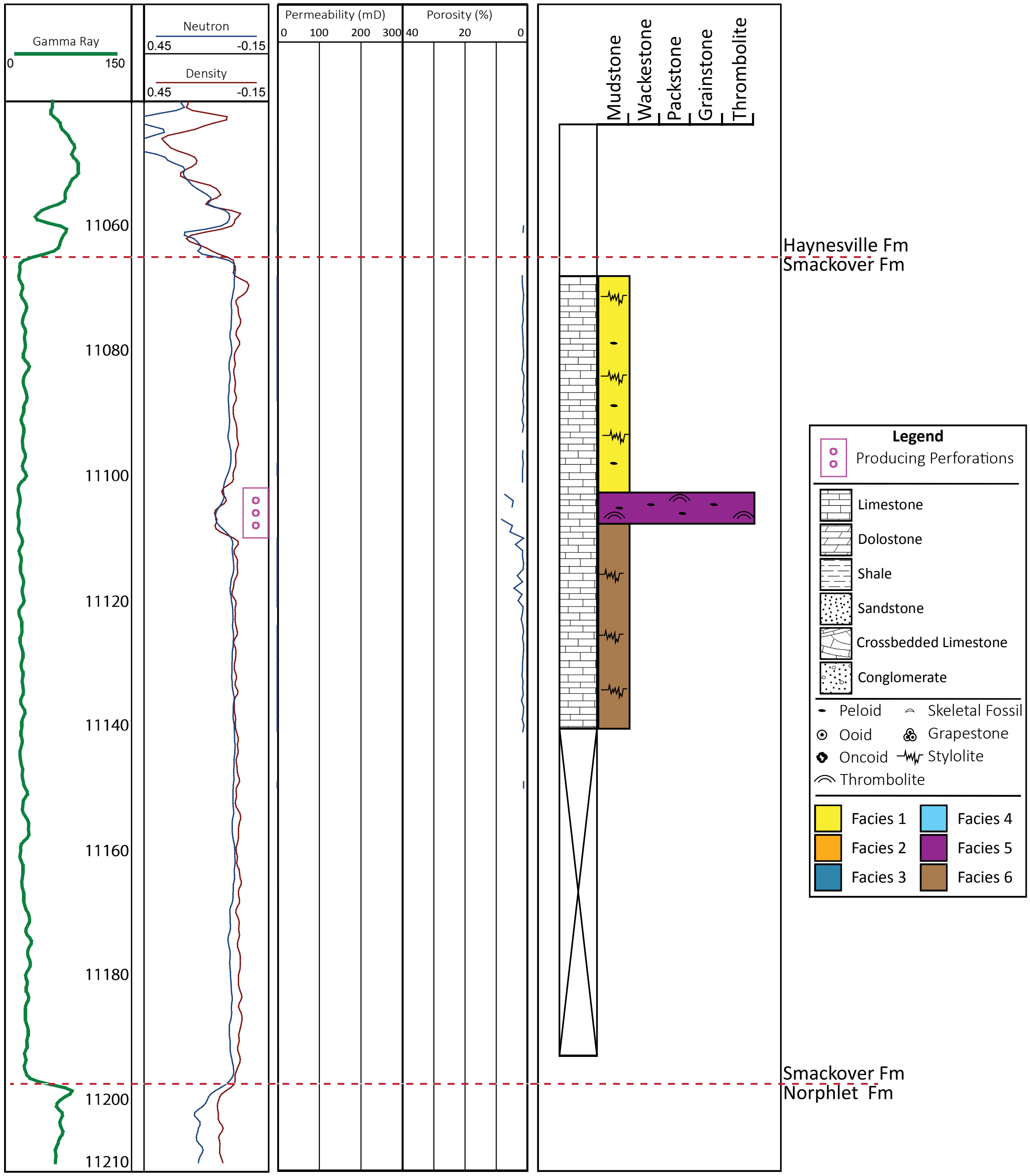

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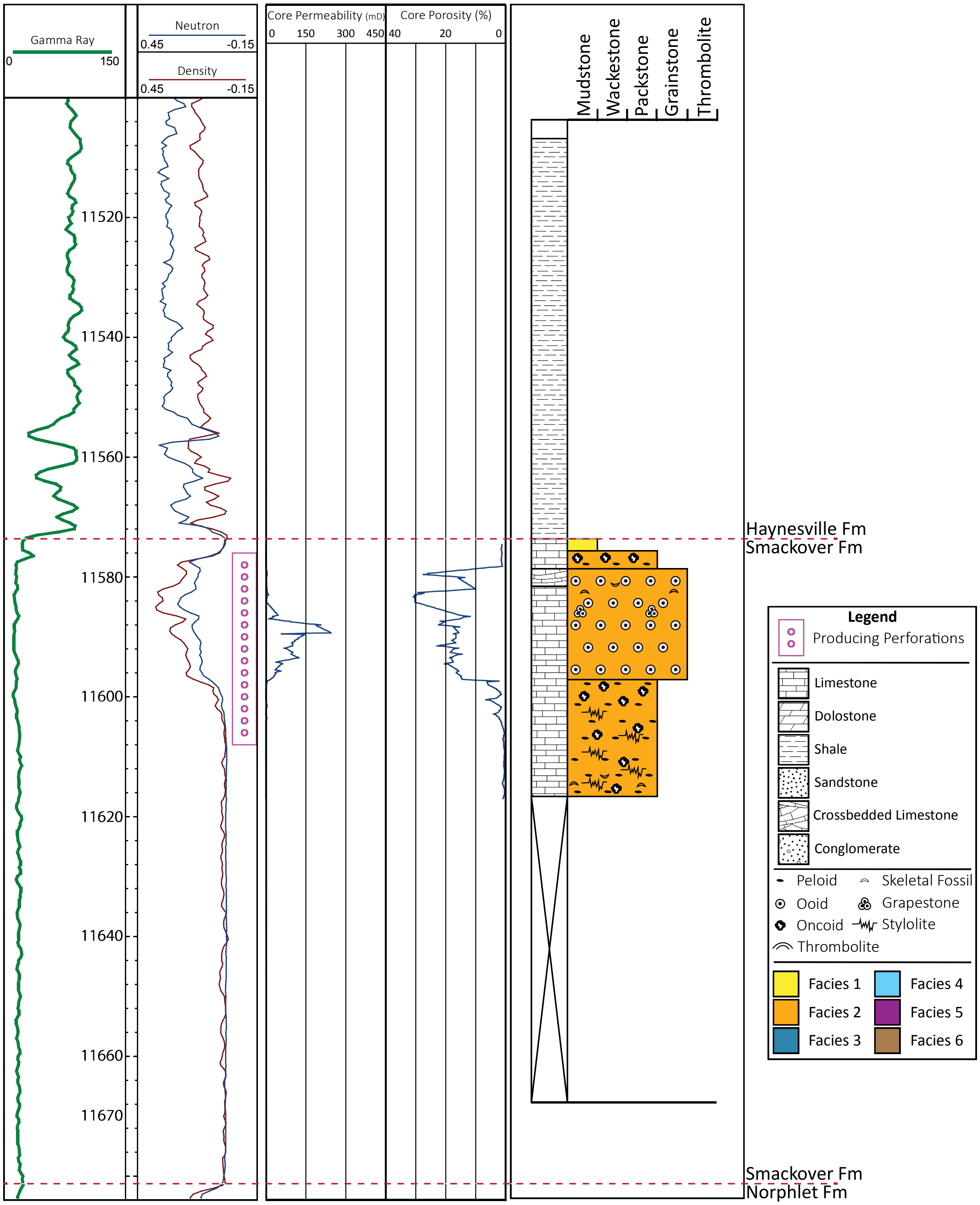

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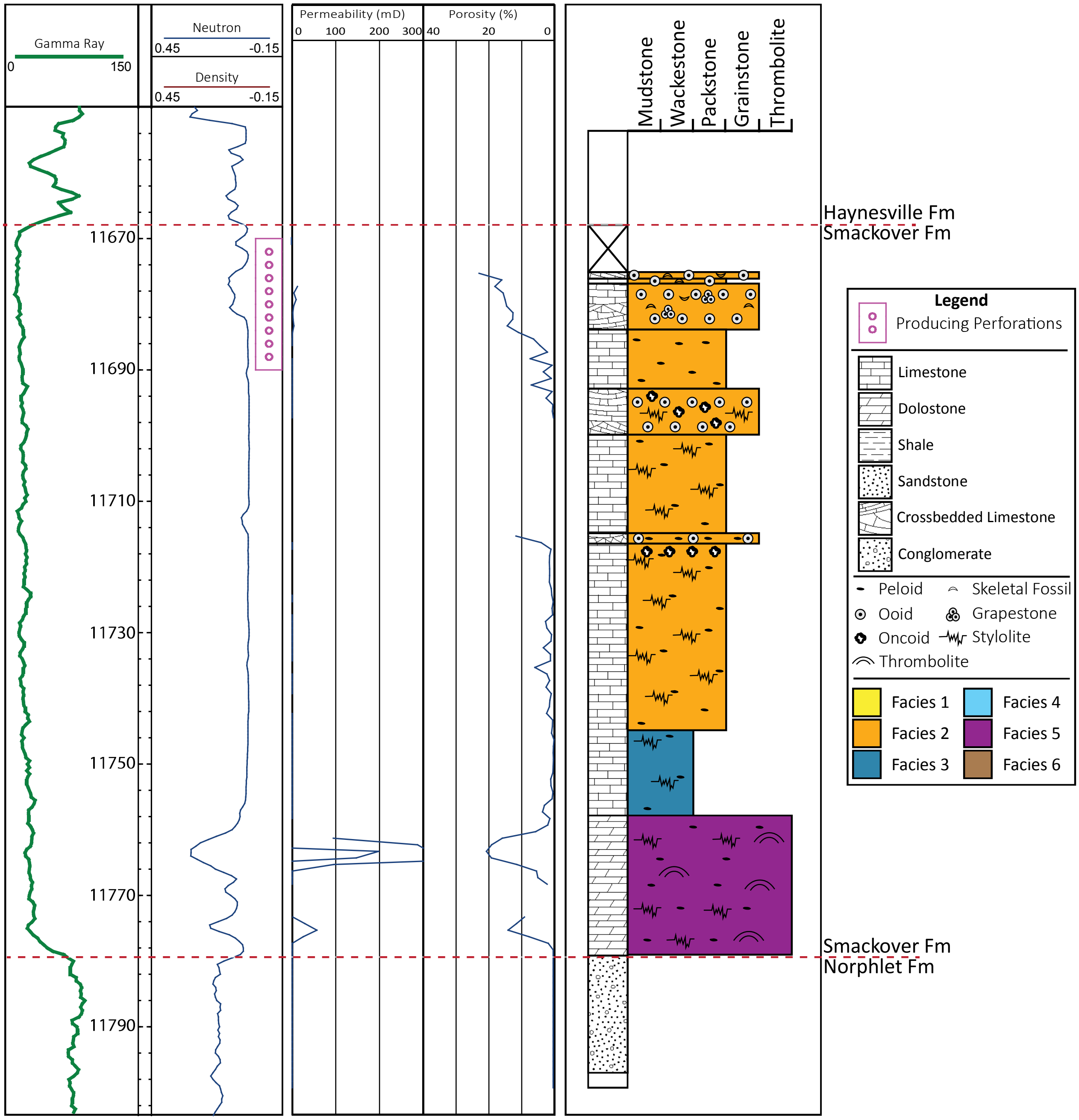

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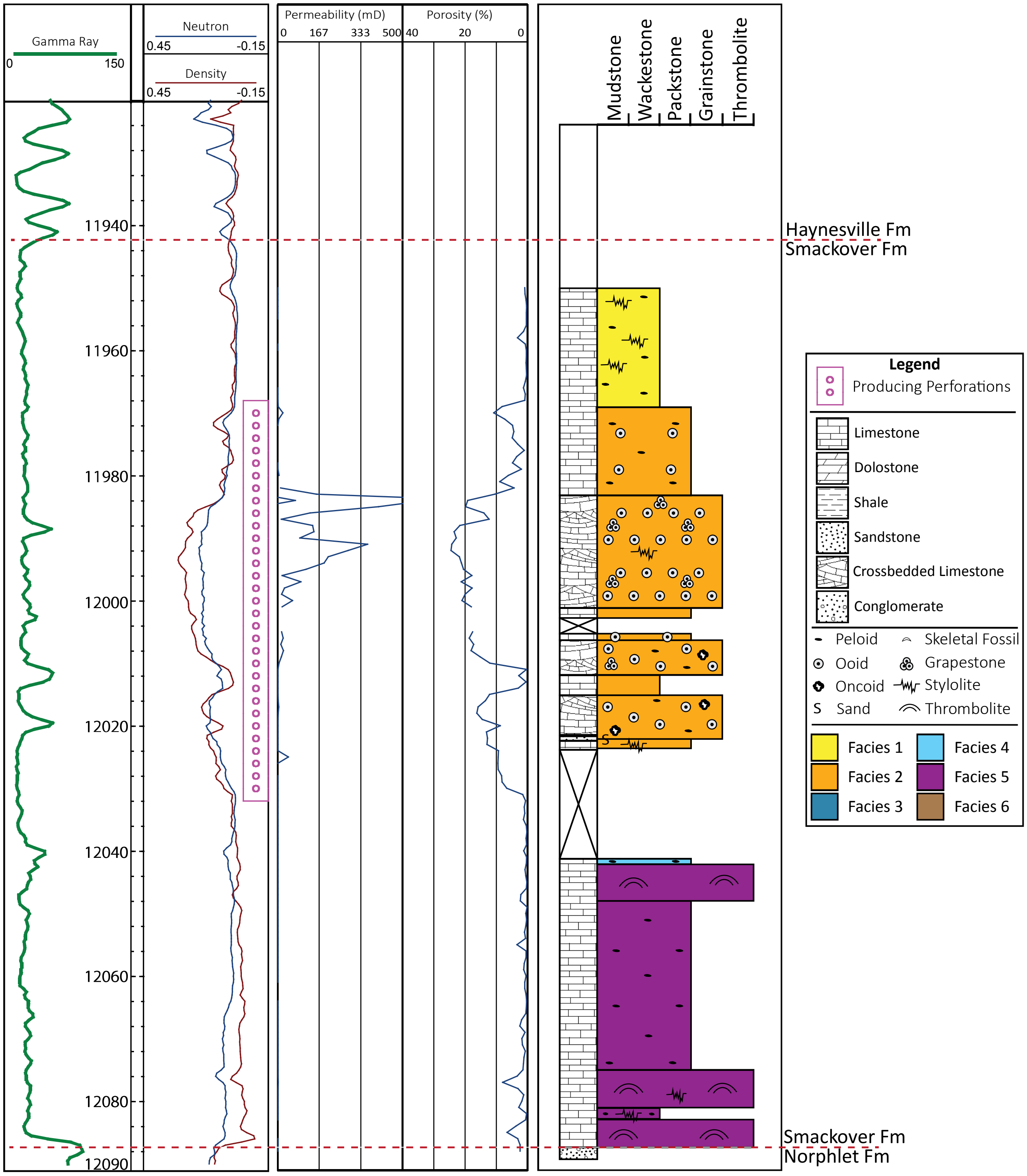

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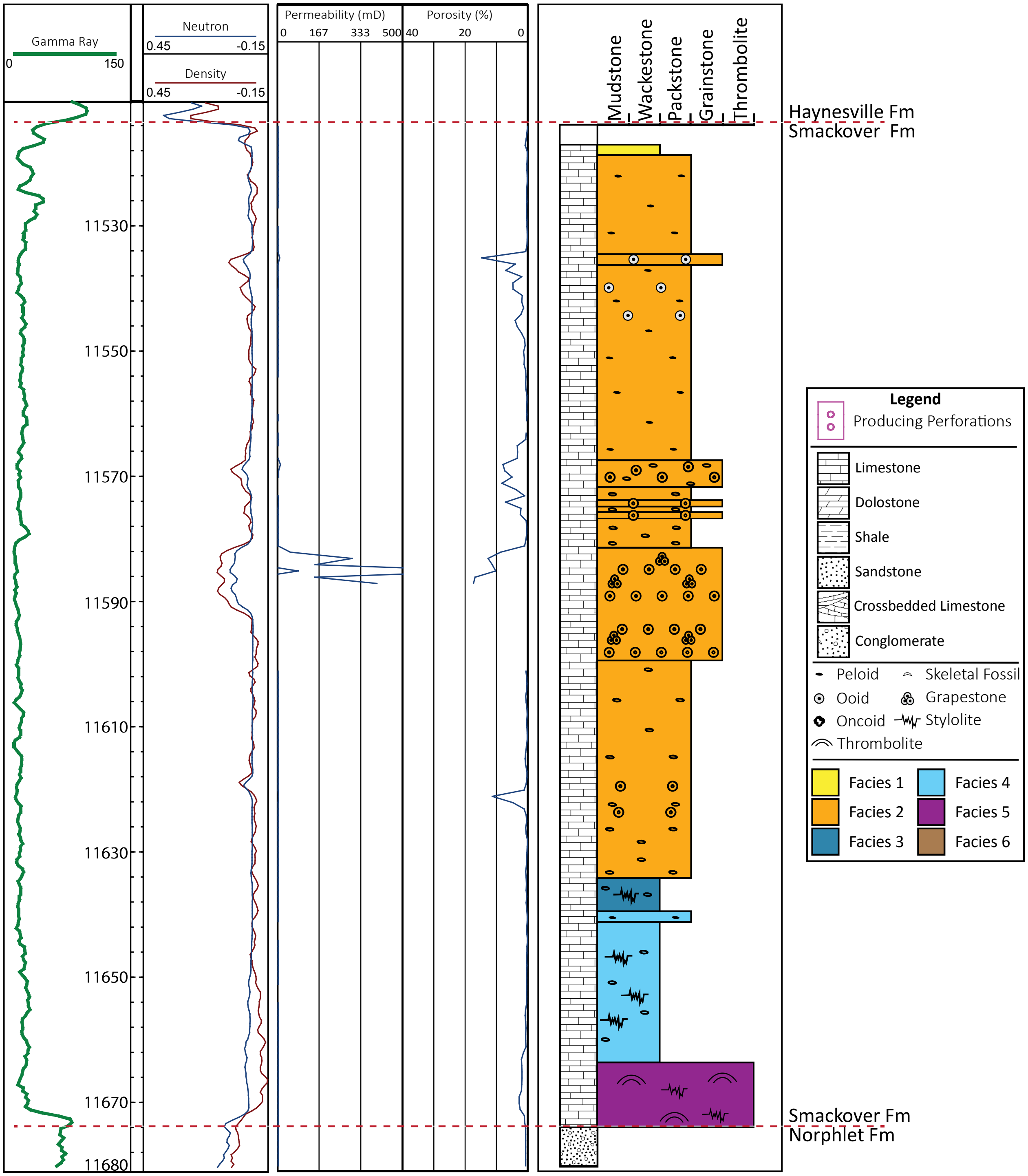

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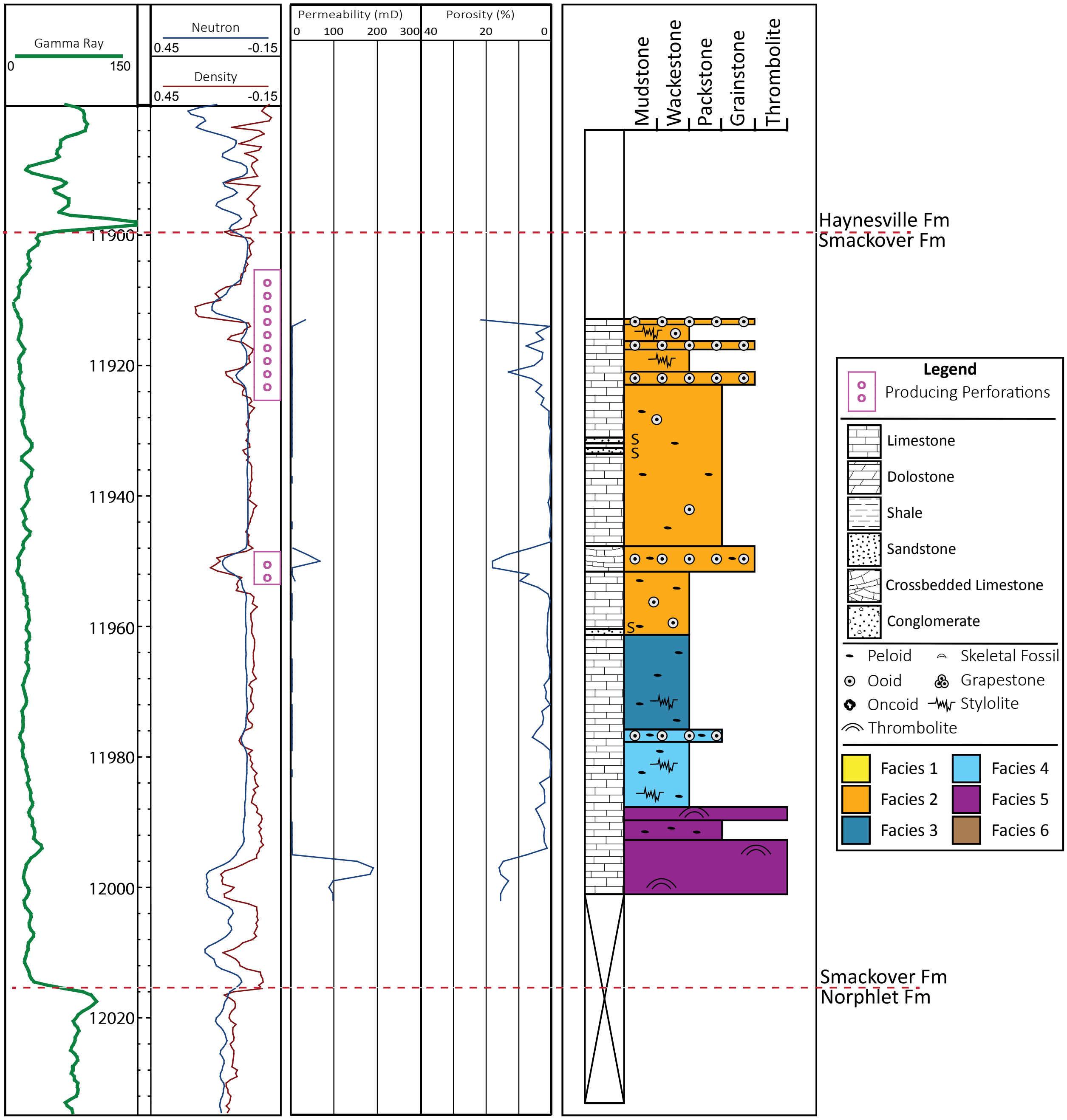


APPENDIX B

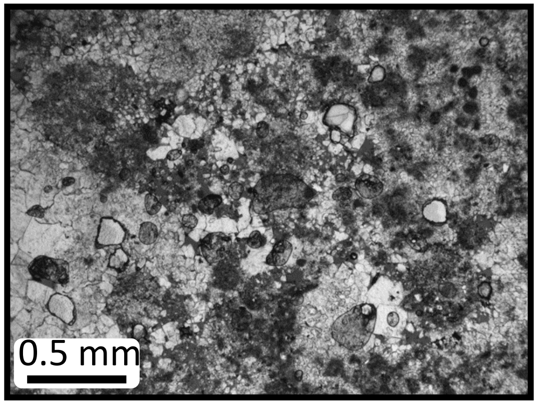
Petrography

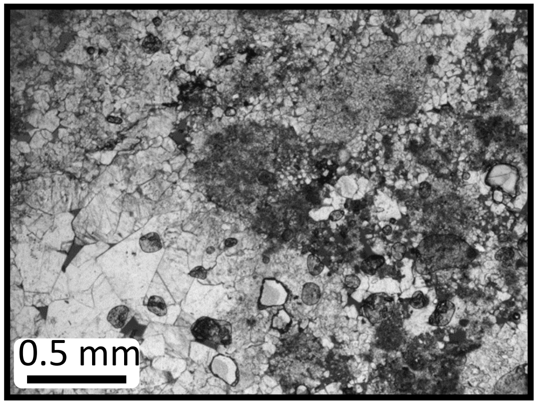
Permit: 13976

Depth: 11127.65’

Peloidal Boundstone, H1-C

Plane Light (PL)





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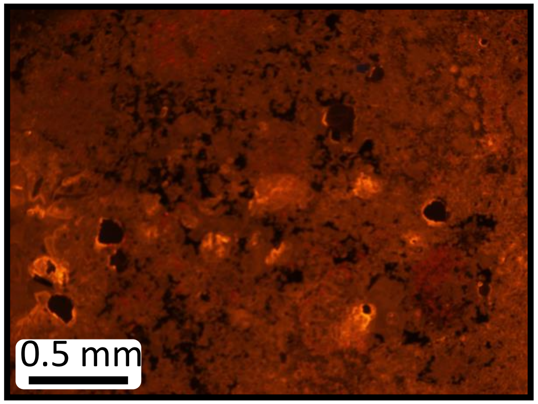
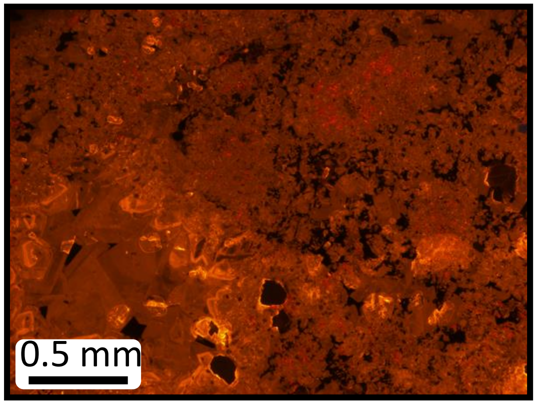


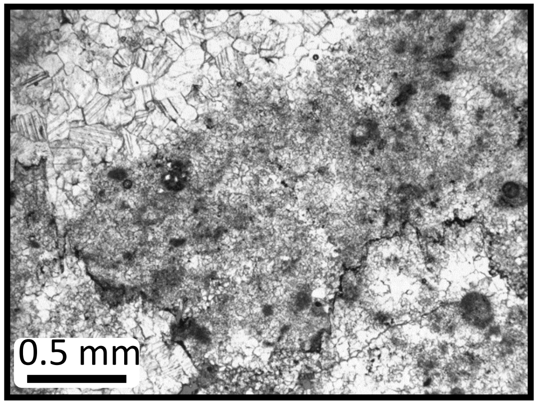


Permit: 14309

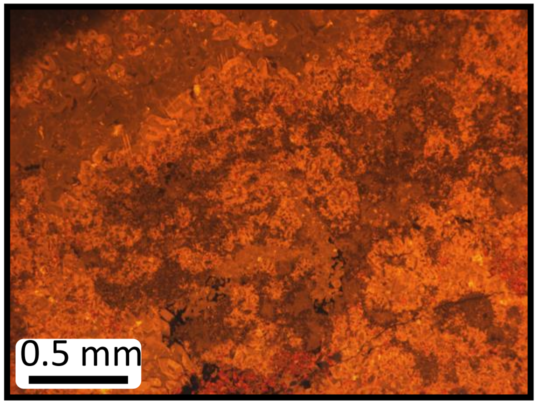
Depth: 11361.8’

Peloidal Boundstone, H1-C

PL



CL

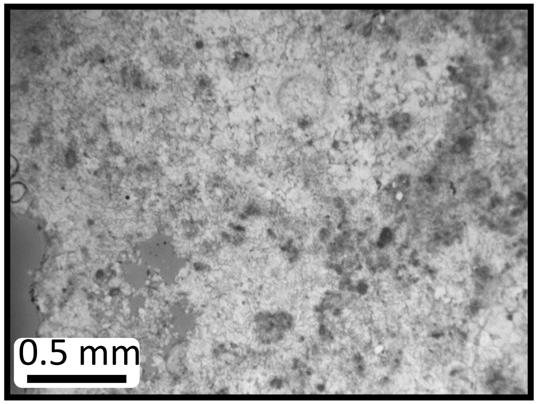


Permit: 14309

Depth: 11368.85’

Peloidal Boundstone, H1-C

PL



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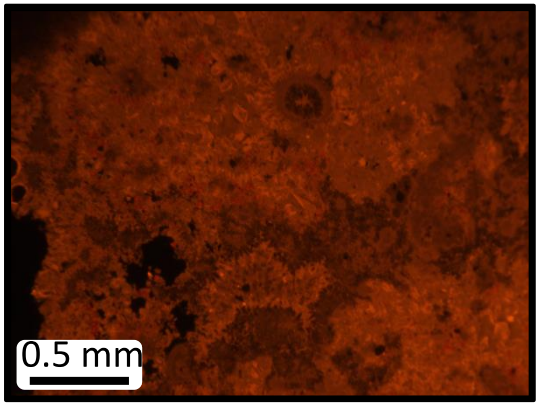
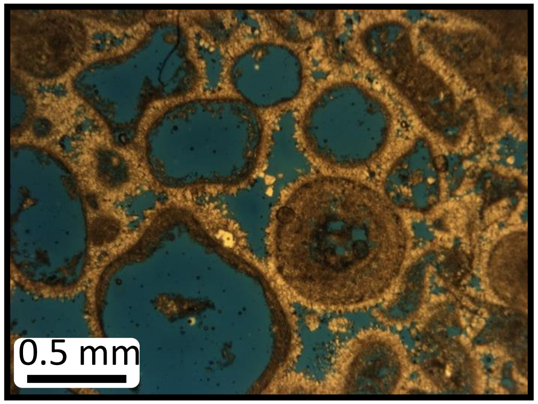


Permit: 16398

Depth: 11575.8’

Oolitic Grainstone, H1-B

PL



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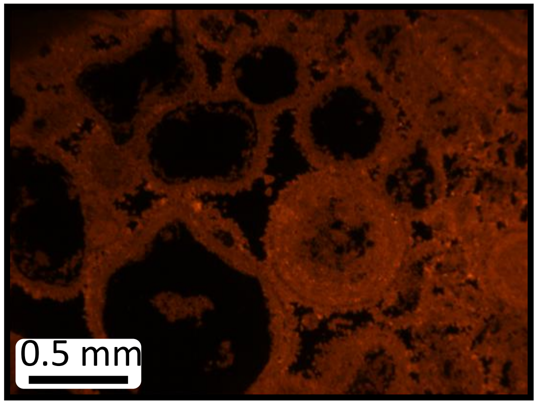
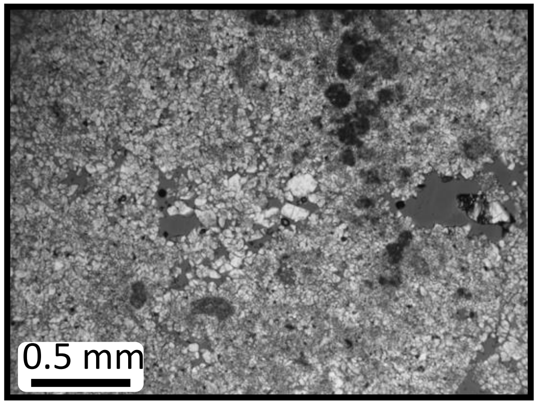


Permit: 16398 Depth: 11585.7’

Peloidal Grainstone, H1-B

PL



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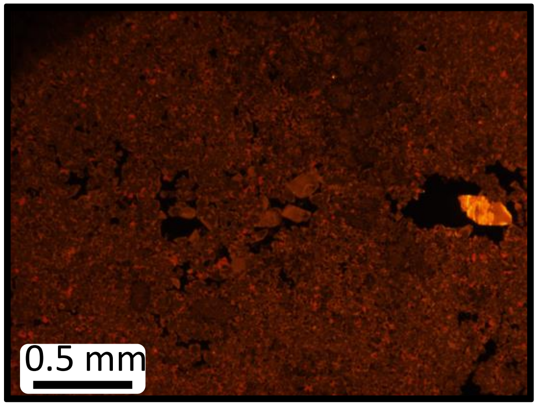
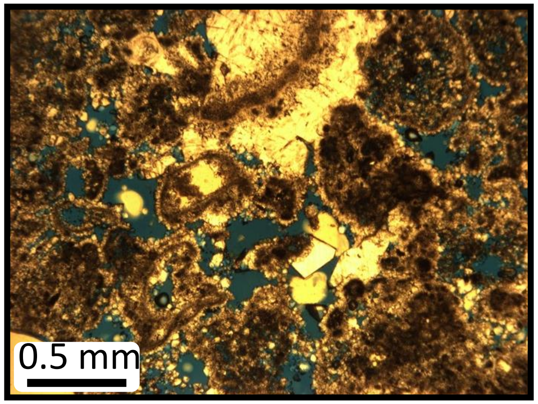


Permit: 16708 Depth: 11984.8’

Peloidal Grainstone, H1-B

PL



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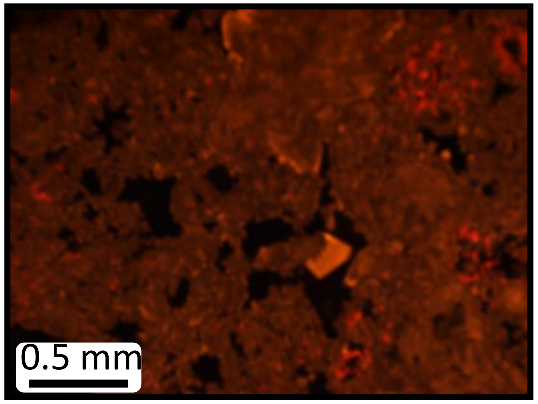
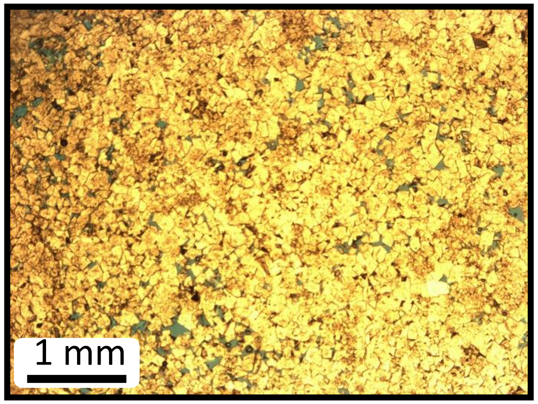


Permit: 16708

Depth: 12077.45’

Peloidal Boundstone, H1-C

PL



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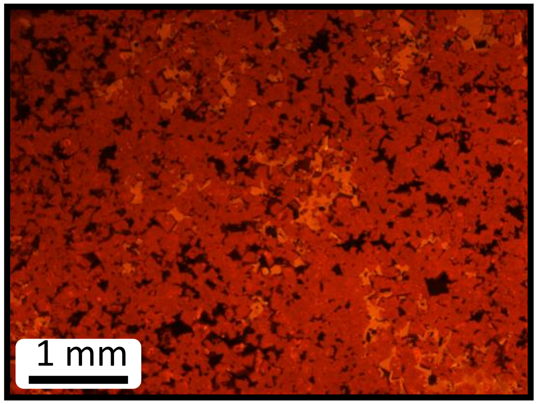


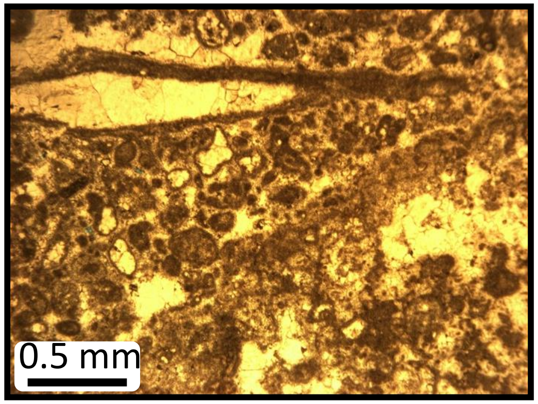
Permit: 16790

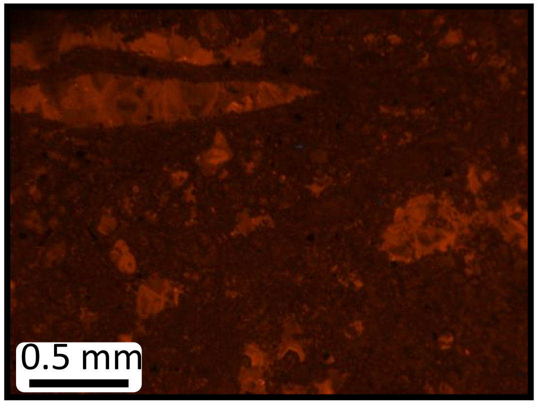
Depth: 11534.85’

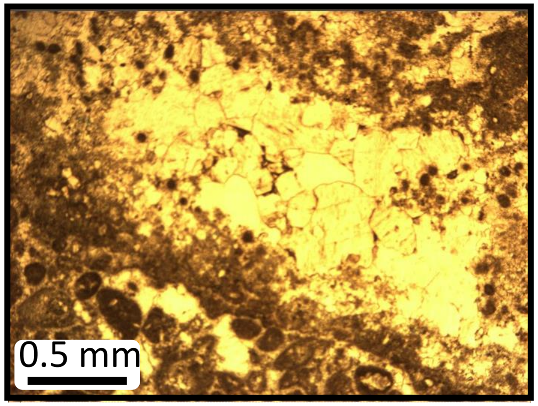
Skeletal-Peloidal Packstone, H1-A

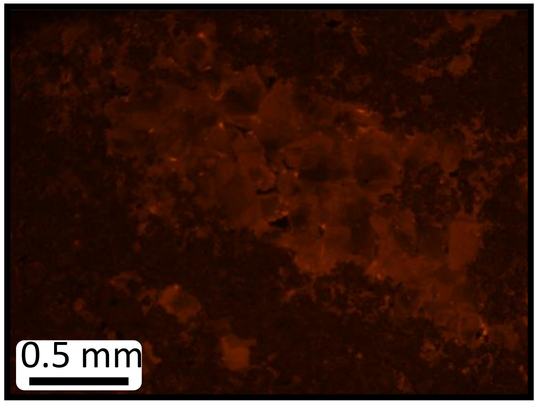
PL

CL







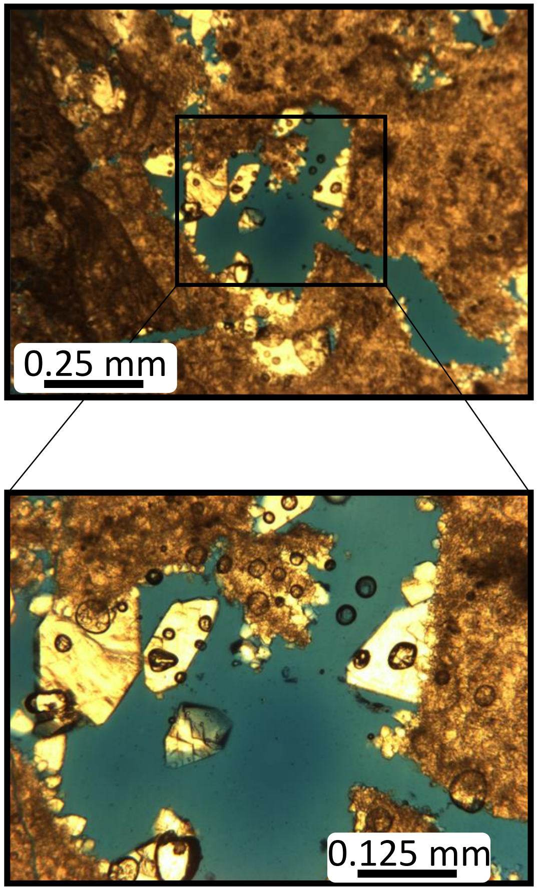


Permit: 16790

Depth: 11575.35’

Peloidal Grainstone, H1-A

PL



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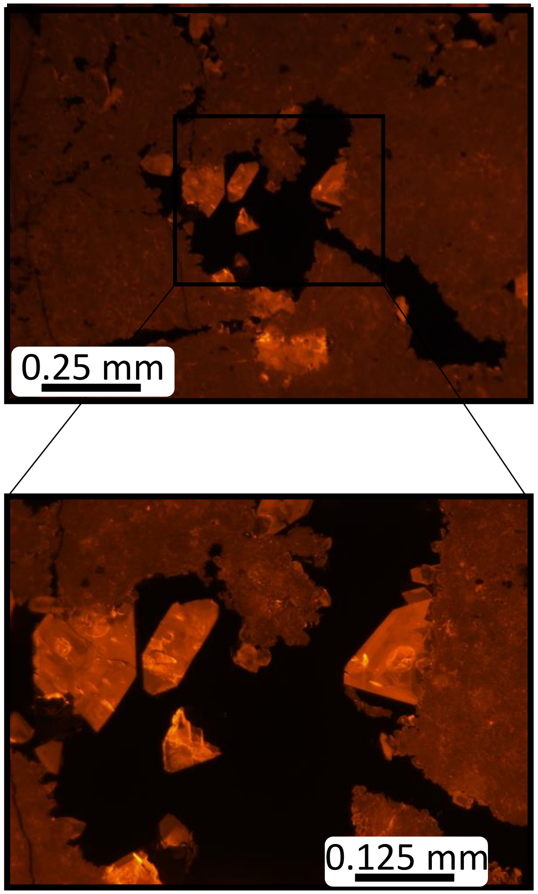


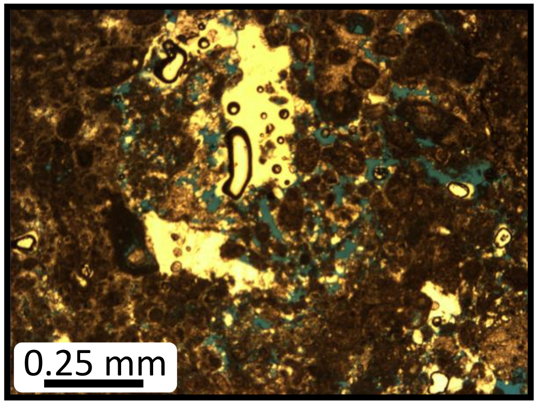
50% Zoom

Permit: 16790

Depth: 11575.35’

Peloidal Grainstone, H1-A

PL



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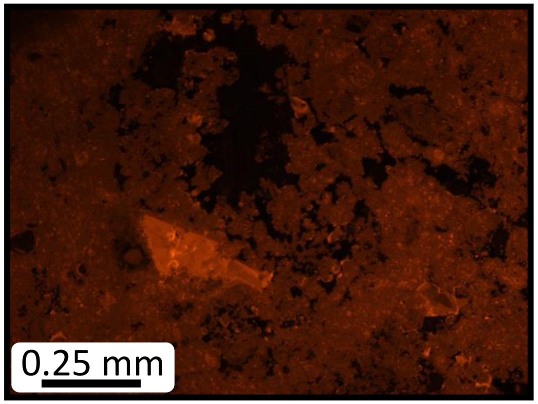
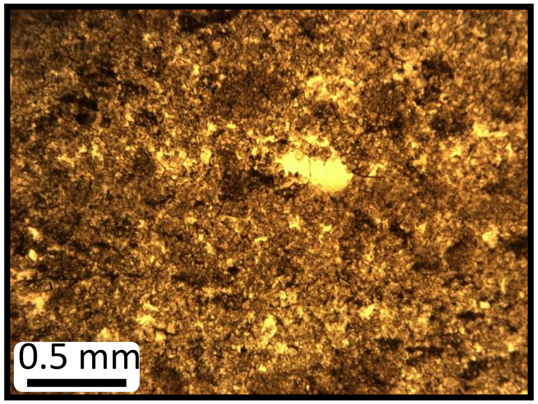


Permit: 16790

Depth: 11658.9’

Peloidal Boundstone, H1-C

PL



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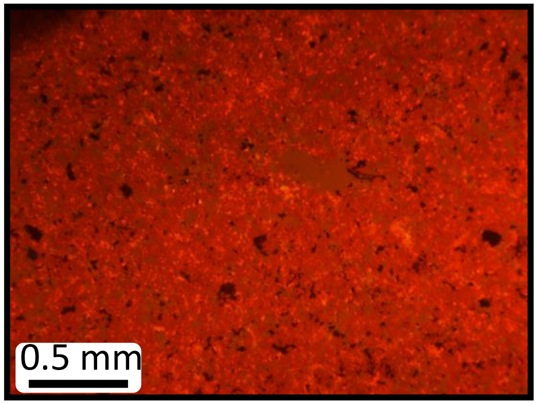
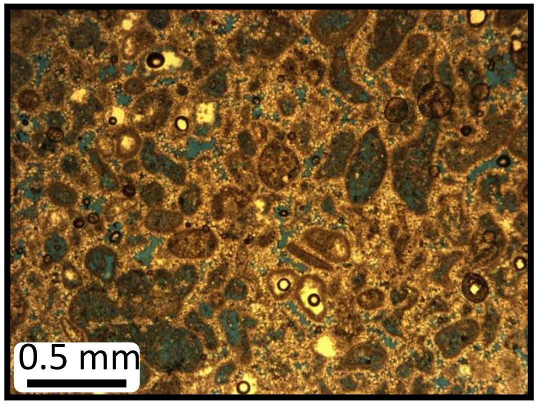


Permit: 16852-B

Depth: 12111.35’

Oolitic Grainstone, H1-B

PL



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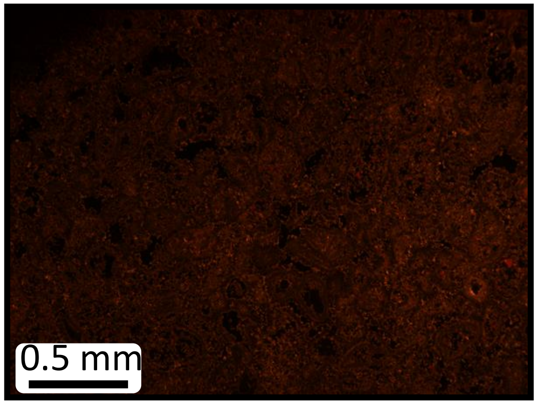

Permit: 16852-B

Depth: 12148.6’

Peloidal Grainstone, H1-B

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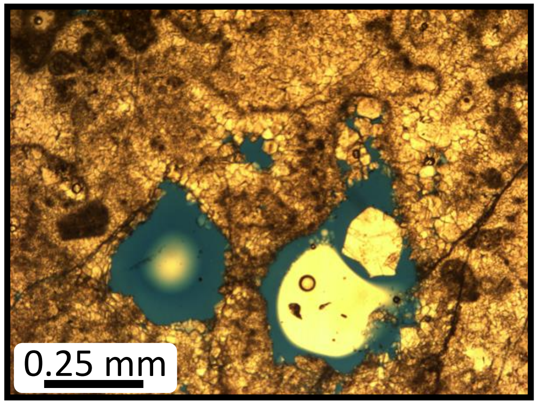

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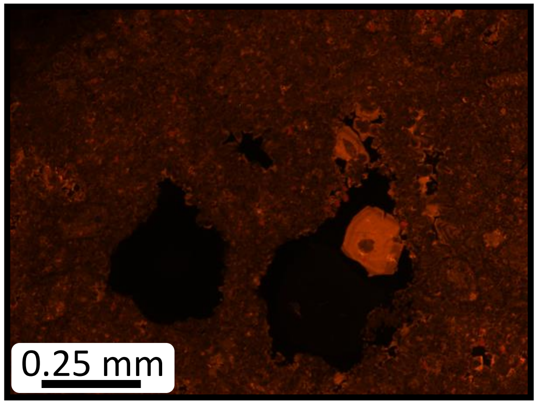

Permit: 16852-B

Depth: 12195.45’

Peloidal Boundstone, H1-C

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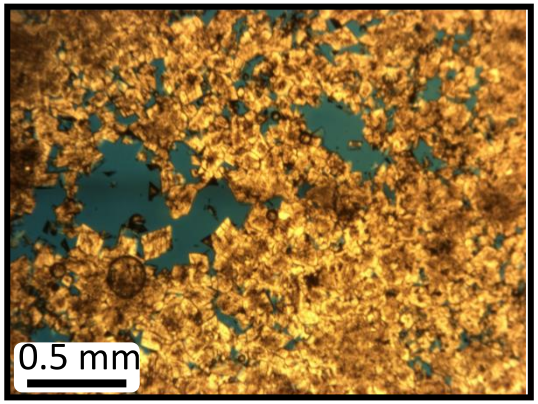

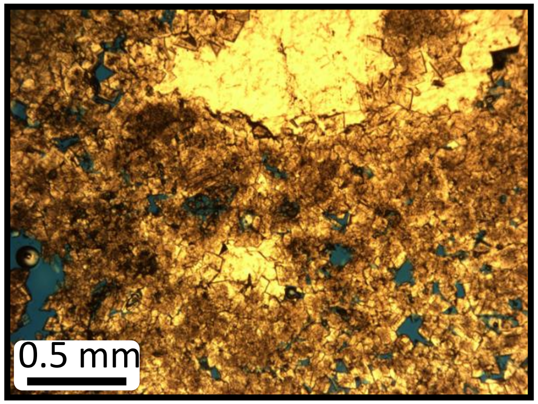

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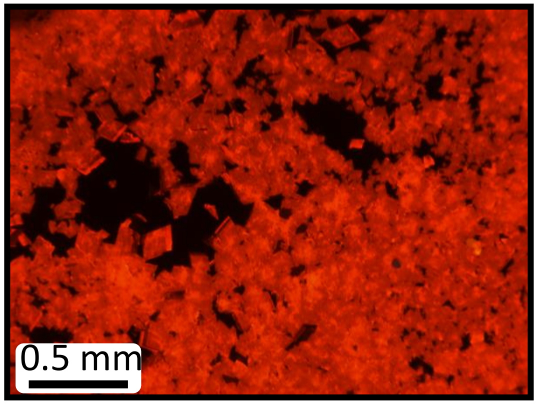
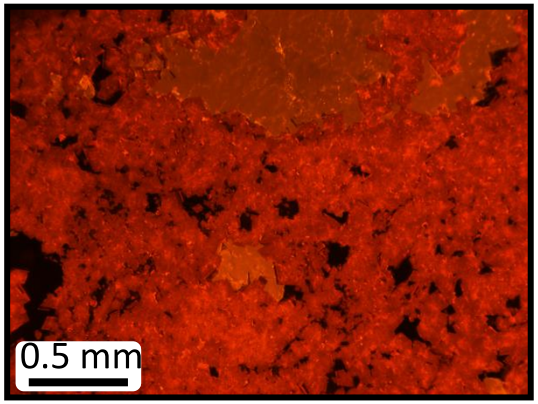


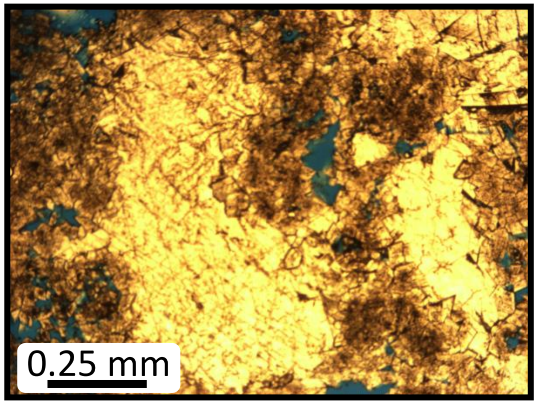


Permit: 16852-B

Depth: 12195.45’

Peloidal Boundstone, H1-C

PL



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