PORE CHARACTERIZATION AND CLASSIFICATION IN CARBONATE RESERVOIRS AND THE INFLUENCE OF DIAGENESIS ON THE PORE SYSTEM. CASE STUDY: THROMBOLITE AND GRAINSTONE UNITS OF THE UPPER JURASSIC SMACKOVER FORMATION, GULF OF MEXICO

A Dissertation

by

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ABSTRACT

The grainstone and the thrombolite units of the Smackover Formation at Little Cedar Creek Field, in Alabama, USA, were analyzed to determine their reservoir characteristics. The Smackover Formation reservoirs in this field have only minor dolomitization, and most of the depositional texture of the reservoirs is preserved, making Little Cedar Creek Field a unique location to study facies distribution and diagenetic alteration of these reservoirs. Depositional facies define good quality reservoirs of Smackover Formation, but diagenesis plays an important role on enhancing or reducing their porosity and permeability. Thrombolite and ooid-oncoid-peloid grainstone are the most prolific reservoir facies of the Smackover Formation, whereas dolomitization and dissolution are the main diagenetic processes improving porosity and permeability.

A paragenetic sequence based on petrography, cathololuminescence, and minor and trace elements analysis was determined on both reservoirs types. Image analysis of scanned thin sections calculated the percentage of grains, pores and cements in the samples. Both reservoirs record distinct early diagenetic events, but similar late diagenetic evolution. The microbial thrombolite was exposed only to marine diagenesis, but the ooid-oncoid-peloid grainstone also was exposed to meteoric phreatic waters.

Samples of the dolomitized Smackover Formation thrombolite unit from Appleton and Vocation fields were analyzed and compared to Little Cedar Creek Field thrombolite samples. Porosity, permeability and capillary pressure analysis was completed on thrombolite samples with no dolomitization and samples with distinct degrees of dolomitization. The dolomitization, associated with dissolution of calcite,

created an intercrystalline pore network in the thrombolite, increasing porosity and pore connectivity (permeability), and usually reducing pore size. These processes also caused the high petrophysical heterogeneity of the thrombolite to decrease laterally and vertically, resulting in a more homogeneous pore system.

In this study a new pore characterization applied to carbonate rocks was developed. It encompasses pore geometry, pore connectivity and the influence of diagenesis in the pore system by generating a quantitative result in order to identify and map reservoir flow units and diagenetic trends. This new pore characterization is based on features observed in thin sections, being a fast and less expensive method to evaluate porosity characteristics.

DEDICATION

I dedicate my dissertation to my husband, Fabiano, and my kids, Lucas and Luiza, for the love and support during my PhD journey. I also dedicate my dissertation to Wayne M. Ahr, for being an outstanding professor and an inspiration to my study.

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I am grateful to: Petrobras (Petróleo Brasileiro S/A) for the financial support; Petrobras Research Center - Laboratory of petrophysics, Laboratory of Microprobe, Laboratory of thin-section preparation, and Laboratory of core analysis; Geological Survey of Alabama; Berg-Hughes Center; Geology and Geophysics Department, Texas A&M University; To Margaret Smoot for helping me with the image analysis data and development of the equations; To my sister Cise for helping me with the illustrations; To Dr. Michael C. Pope, a great professor and a dedicated advisor.

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CHAPTER I

DIAGENETIC EVOLUTION AND ITS INFLUENCE ON PETROPHYSICAL PROPERTIES OF THE JURASSIC SMACKOVER FORMATION THROMBOLITE AND GRAINSTONE UNITS OF LITTLE CEDAR CREEK FIELD, ALABAMA[1]

I.1 Synopsis

The ooid-oncoid-peloid grainstone and the microbial thrombolite reservoir facies of the Smackover Formation at Little Cedar Creek Field (LCCF), in Alabama, USA, have only a minor amount of dolomitization, and most of the depositional texture of these reservoir units is preserved, making LCCF a unique location to study facies distribution and diagenetic alteration of these reservoir facies. Depositional facies define good quality reservoirs in the Smackover Formation, but diagenesis plays an important role in enhancing or reducing their porosity and permeability.

The microbial thrombolite experienced the following early paragenetic sequence: (1) marine fibrous calcite rim cement; (2) early burial bladed to drusy calcite fringing cement; (3) early burial mosaic calcite cement. The ooid-oncoid-peloid grainstone preserves a distinct early paragenetic sequence: (1) marine bladed calcite-rimming cement; (2) meteoric dissolution; (3) meteoric drusy calcite fringe cement; and (4) meteoric to early burial mosaic calcite cement. Both reservoir facies record similar late diagenetic evolution: (1) anhydrite cementation, (2) fracturing (closed or cemented), (3) chemical compaction (generating stylolites), (4) a second generation of fracturing (open

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microfractures), (5) burial dissolution, (6) local dolomitization, (7) late burial coarse mosaic to blocky calcite cement, (8) local quartz cementation and (9) pyrite nucleation.

The ooid-oncoid-peloid grainstone can be subdivided in two sub-units: oolitic grainstone and peloid-oncoid grainstone. The lateral distribution of these two sub-units shows that the ooid grainstone prograded over the peloid-oncoid grainstone to the southeast. Porosity values in the ooid-oncoid-peloid grainstone vary from 5 to 32%, and the areas where the ooid grainstone dominates have the greatest porosity values (16 to 26% in average). Permeability values are similar all over the ooid-oncoid-peloid grainstone reservoir, commonly between 1 and 10 md.

The largest pores of the thrombolite occur in areas where the microbial thrombolite is thicker, indicating that the dissolution process follows depositional features. Dolomitization occurs only in the south portion of the field. In the grainstone reservoir, dolomite occurs in a very small amount, usually less than 3%. In the thrombolite reservoir, dolomitization is more intense, locally affecting up to 30% of the rock. Dolomitization associated with dissolution significantly enhances permeability in this reservoir facies, from tens of millidarcys (usually 20 to 80 md) to hundreds of millidarcys (150 to 850 md). Blocky calcite cementation is more intense in the north portion of the reservoir, where dolomite is absent. Calcite cement can reach as much as 75% of the rock, significantly reducing porosity. As the reservoir dips southwest, this heterogeneous late burial calcite cement and dolomite distribution indicates that the deeper portion saw waters with a distinct chemistry, different than the shallower northeast portion of the reservoir.

I.2 Introduction

Depositional facies define good quality reservoirs of Smackover Formation, but diagenesis plays an important role on enhancing or reducing their porosity and permeability. Thrombolite and ooid-oncoid-peloid grainstone are the most prolific reservoir facies of the Smackover Formation (Benson and Mancini, 1999; Kopaska-Merkel and Mann, 1991; Mancini et al., 1991; Mancini et al., 2006), whereas dolomitization and dissolution are the main diagenetic processes improving porosity and permeability (Benson and Mancini, 1999; Benson, 1988; Kopaska-Merkel and Mann, 1991; Mancini et al., 1991; Moore and Druckman, 1981; Prather, 1992a).

The grainstone and thrombolite units of the Smackover Formation at Little Cedar Creek Field (LCCF), in Alabama, USA (Fig. I.1), have only a minor amount of dolomitization, and most of the depositional texture of the reservoirs is preserved, making LCCF a unique location among all the Smackover Formation reservoirs to study facies distribution and diagenetic alteration. Smackover Formation grainstone and thrombolitic reservoir facies in all other fields are intensely dolomitized (Barrett, 1986; Benson and Mancini, 1999; Mancini et al., 1991; Prather, 1992b) and most of the depositional characteristics of these rocks were obscured.

The LCCF initiated its production of oil (42-46 API gravity) in 1994 and oil and gas in 1995, presenting in 2013 a cumulative production of 20 million bbl of oil and condensate, and 19 million mcf of gas. Since 2005 LCCF is the top oil-producing field in Alabama. A gas-injection secondary recovery project within the grainstone reservoir facies began and production from wells surrounding the two injection sites has increased since the project was initiated. A similar recovery project is currently being considered for the thrombolite reservoir unit.

Comparing depositional textures, diagenetic events, including percentage of cement and dissolution, and petrophysical properties across both reservoirs, provides better understanding of heterogeneities in the reservoir facies and may influence future exploration and exploitation decisions. This paper discusses the relationship between the original depositional texture and the subsequent diagenetic alteration in both Smackover Formation reservoirs at LCCF, as well as lateral and vertical variation of facies, diagenesis and petrophysical properties of the reservoirs.

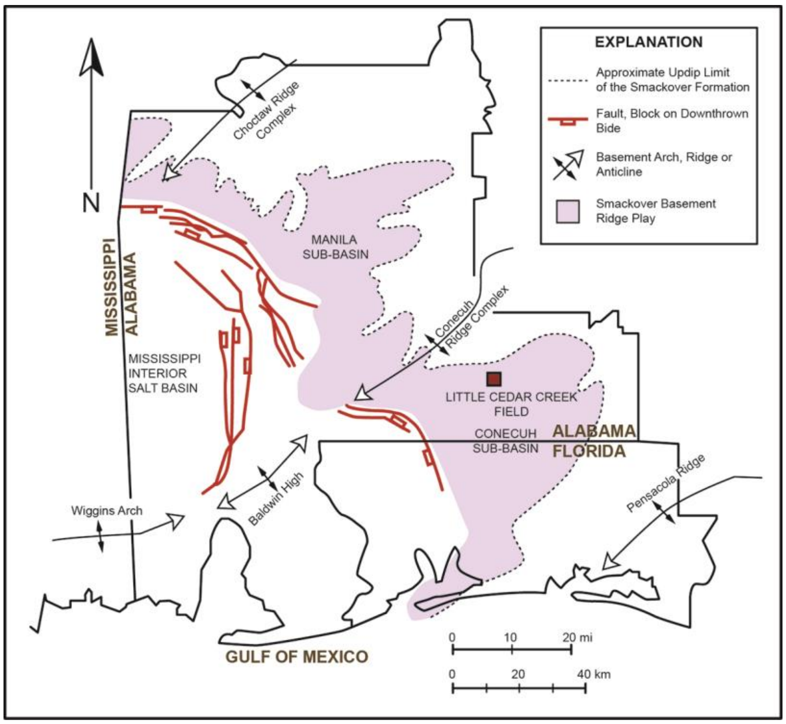


Figure I.1. Location map of Conecuh sub-basin and LCCF, Southwestern Alabama, USA (modified from Mancini et al. 2008).

I.3 Geologic Setting

The Gulf of Mexico is a passive margin consisting of a thick section of Mesozoic and Cenozoic sedimentary strata whose basic structural and stratigraphic framework was established during the Late Triassic and Jurassic (Salvador, 1987). Lithospheric extension occurred during the Early to Middle Jurassic as North America rifted from Africa followed by a long period of thermal subsidence (Driskill et al., 1988). The Upper Jurassic (Oxfordian) Smackover Formation was deposited during a major transgression during the formation of oceanic crust in the Gulf of Mexico and its thermal subsidence is due to cooling of the oceanic crust (Mancini et al., 1999; Nunn et al., 1984).

Seawater first inundated the Gulf of Mexico during the late Bathonian or the Callovian (Middle Jurassic) and was followed by a widespread and prolonged marine invasion during the Oxfordian. The shallow restricted hypersaline waters from which the Callovian salt precipitated were replaced during the Oxfordian by an increasingly larger and deeper water mass with unrestricted circulation and normal salinity (Salvador, 1987). The Upper Jurassic (Oxfordian) Smackover Formation records carbonate deposition on a carbonate ramp (Ahr, 1973). Local variations in topography on the ramp occurred due to pre-Jurassic salient or were produced by salt tectonics (Ahr, 1973; Driskill et al., 1988).

I.3.1 Conecuh Sub-basin

Paleozoic ridges and Mesozoic horst blocks produced a number of paleohighs in the eastern Gulf of Mexico that separated southwest Alabama into a series of sub-basins or embayments (Benson, 1988; Mancini and Benson, 1980; Prather, 1992a). The Conecuh Ridge separates the Manila Sub-basin from the Conecuh Sub-basin, which is bordered to the southeast by the Pensacola Ridge (Fig. I.1). The Wiggins Arch, an east-west trending basement high, borders the Mississippi Interior Salt Basin to the south and significantly influenced Smackover Formation deposition throughout much of southwest Alabama (Benson, 1988).

The Conecuh Sub-basin is located updip from the major rift-related fault trend (Fig. I.1). The Smackover Formation in the Conecuh Sub-basin (as well as in the Manila Sub-basin) overlies continental crust extended by 25%, whereas the crust under the Smackover Formation updip, outside the embayments, corresponds to ~ 45% extension (Driskill et al. 1988). Landward from the peripheral fault zones, the magnitude of tectonic subsidence gradually increased from north to south. Basinward from the peripheral fault zones, magnitudes of the tectonic subsidence during the Jurassic and Cretaceous were nearly equal, but higher than in the landward direction from the peripheral fault zones (Driskill et al., 1988).

I.3.2 Sequence Stratigraphy

Late Jurassic to Early Cretaceous transgressive-regressive (T-R) sequences recognized in the Gulf of Mexico coastal plain record the post-rift tectonic and depositional history of this period. The Oxfordian was characterized by a widespread sea level rise that progressively affected larger parts of the Gulf of Mexico Basin and surrounding areas (Salvador, 1987). Four Upper Jurassic (Oxfordian) to Lower Cretaceous (Valanginian) T-R sequences occur across the Gulf Coast and the offshore northeastern Gulf of Mexico region (Mancini et al., 2008). The Smackover Formation sequence is sub-divided into two systems tracts. The lower and middle Smackover Formation compose a transgressive systems tract (TST). Microbial reefs developed in the TST, and their growth ended before the maximum flooding zone (MFZ) that is characterized by a marine condensed section composed of relatively deep subtidal carbonate mudstone. The upper Smackover Formation (oncoid, peloid and ooid grainstone to wackestone) and the Buckner Anhydrite Member of the Haynesville Formation represent a subsequent highstand systems tract (HST) (Mancini et al., 1990).

I.3.3 Smackover Formation Reefs

Reef growth was primarily described from the inner ramp areas, north of the Wiggins Arch (Parcell, 1999). Smackover Formation reefs occur from Arkansas to Florida as elongate features, 10 to 141 ft (3 to 43 m) thick, and several square kilometers in plan view. The reefs consist of cyanobacteria (microbial buildups) or a more diverse coral-algal assemblage. Smackover Formation reef diversity is higher in southern Arkansas and northern Louisiana than in Alabama and Florida, where its depositional environment was more restricted (Baria et al., 1982). The reefs developed seaward of oolite shoals on three types of paleostructures that created subtle topographic highs: (1) basement ridges, (2) faulted basement highs, and (3) upthrown salt-cored fault blocks (Baria et al., 1982). However, LCCF microbial buildups developed in paleogeographic settings including nearshore, shallow subtidal paleoenvironments along the updip margin of the Smackover Formation rather than on Paleozoic basement paleohighs (Mancini et al., 2008).

Nearly all the microbial buildups in the eastern part of the trend (Alabama and Florida) formed at the base of the upper Smackover Formation, regardless of the structural setting of the reefs. However, in Alabama, reefs formed at the base of the lower Smackover Formation and also within the upper Smackover Formation, whereas in Arkansas and Louisiana, the reefs are stratigraphically higher, occurring only within the upper Smackover Formation. Microbial buildups generally form higher in the stratigraphic section in the downdip direction (Baria et al., 1982).

I.3.4 Smackover Formation Ooid-oncoid-peloid Grainstone to Packstone

Ooid-oncoid-peloid grainstone to packstone was deposited in the upper Smackover Formation during aggradation and progradation of shallow water shoal and tidal-flat complexes during a prolonged sea level highstand. The bulk of the upper Smackover interval consists of cyclic, coarsening upward sequences of peloidal, oncoidal, and oolitic packstone and grainstone. The uppermost cycles contain considerably more micrite than the lower cycles and fine rather than coarsen upward. In the Conecuh Embayment, peloidal and oncoidal grainstone and packstone interbedded with peloidal and skeletal packstone and wackestone predominate in the upper Smackover Formation. Oolitic grainstone is less common in this upper unit. Fauna is somewhat restricted and includes abundant algal particles along with lesser numbers of foraminifera, ostracods, gastropods, and bivalves (Benson, 1988).

The grainstone facies in Alabama commonly consists of one or more upward shoaling cycles ranging from 15 to 50 feet (4.5 to 15 m) in thickness. These are 4th- or 5th-order cycles within the 3rd-order upper Norphlet to lower Haynesville depositional sequence (Kopaska-Merkel and Mann, 1993).

I.4 Methods

Cores of 32 wells, consisting of 2610 ft (795 m) of rock, from Little Cedar Creek field (LCCF) were described using the Dunham (1962) classification of carbonate textures.

Structures and macrotextures, porous intervals, and pore size were also documented. Samples include 192 plugs from cores (1 inch diameter) taken of a variety of textures and porosity features of the reservoirs. The wells analyzed occur across most of the field, and include both poor and highly productive wells. Log analysis, cross sections and isopach maps were constructed with PETRA® software using the data of 77 wells (Tables A.1 and A.2 in the Appendix A; Fig. I.2 A).

Standard petrographic analysis of 192 thin sections, 41 of which were stained with Alizarin Red-S and ferricyanide (Dickson 1966) were used to characterize microfabrics, diagenetic features and porosity. Image analysis was performed on scanned thin section images (176 thin sections), and percentages of grains and porosity were quantified by IMAGO® software, resulting in a numerical estimative of cement in the microbial thrombolite reservoir (Table A.1 in the Appendix A). Ten analyses were performed on each thin section to reduce analytical errors. Standard deviation from 0.9 to 8.1 was observed in the cement percentage values. Percentage of cement and grains were not calculated in the ooid-oncoid-peloid reservoir because of the poor contrast between them, so only their porosity was calculated.

Cathodoluminescence (CL) analysis was performed on all 192 thin sections, using a Technosyn cold cathode luminescence equipment, model 8200 MK II. Operating conditions for the analysis were 10 KeV accelerating voltage and 300 μA current. The luminescence characteristics of the carbonate minerals are controlled primarily by the relative abundances of Mn, rare-earth elements (REEs), and Fe. The Mn^{2+} ion and trivalent REE ions (particularly Sm^{3+}, Dy^{3+}, Tb^{3+}) appear to be the most important activator ions, whereas Fe^{2+} is the principal quencher (Marshall, 1988; Machel, 2000;

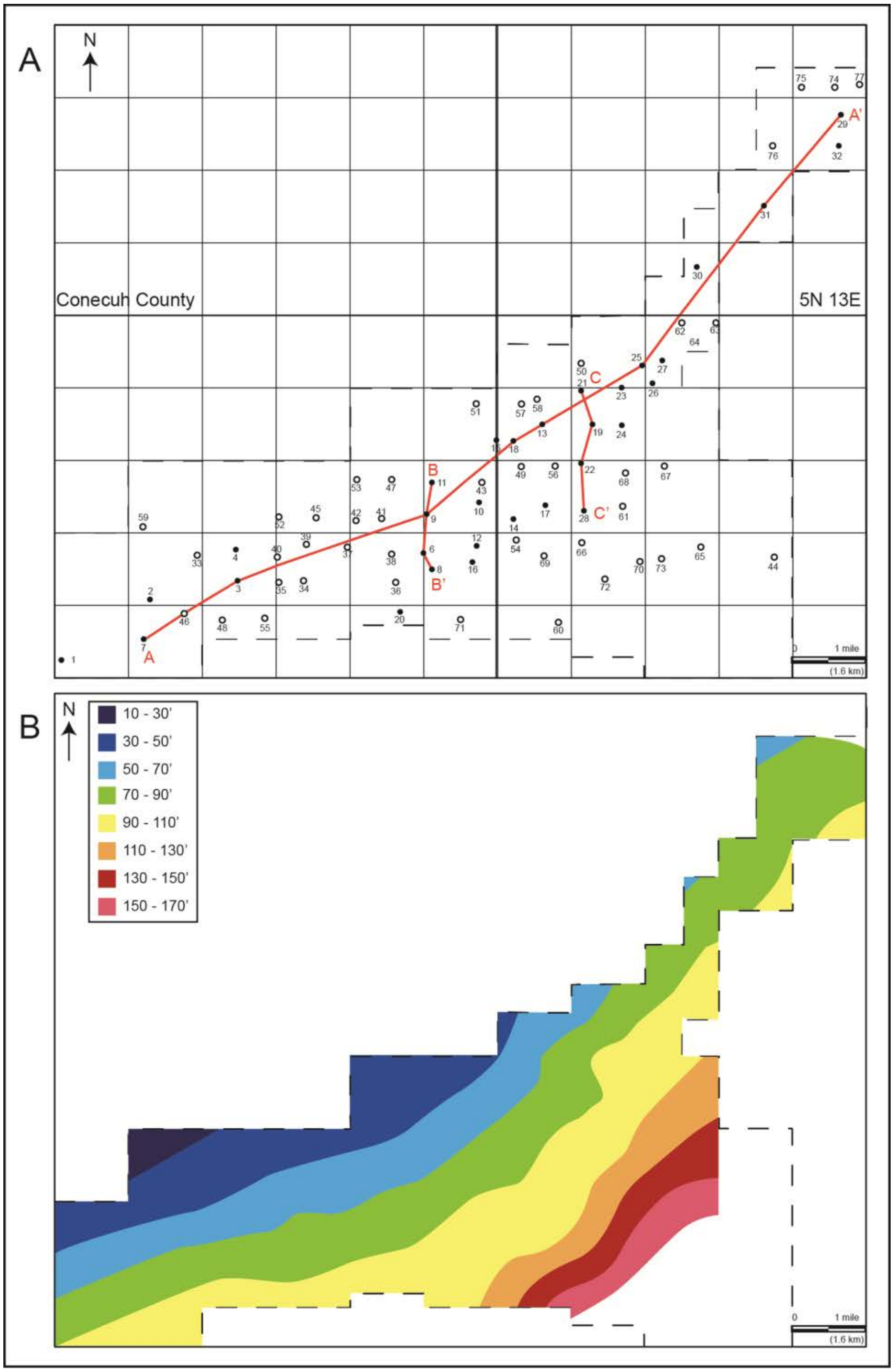


Figure I.2. Little Cedar Creek Field map and Smackover Formation isopach map. A - Map of LCCF area with wells and cross section lines. See Figure I.1 for regional location of the field. Wells depicted by black balls have logs, core description and samples. Unfilled circles represent wells with logs, but without core description and samples. B - Smackover Formation isopach map in Little Cedar Creek field area showing thickening toward the southeast.

Richter et al., 2003). Distinct luminescent zones based on the CL images were analyzed by microprobe to quantify Mn and Fe.

Trace-elements analyses of 187 data points in 12 selected thin sections were obtained using a four spectrometer Cameca SX50 Microprobe (Tables A.3 and A.4 in the Appendix A). Operating conditions for the microprobe were 15 KeV accelerating voltage, 50 nA beam current, and 10 μm spot size. Lower limit of detection (LLD) for each element in this condition are (ppm): Mn (130), Fe (150), Sr (290), S (60), Mg (60), and Na (80). The LLD is statistical, and is not necessarily a practical lower limit of determination. The error at the statistical LLD is infinite, thus the practical lower limit of determination is usually taken to be at least twice the statistical LLD (i.e., a concentration equivalent to at least six standard deviations of the background count [Williams, 1987]). In the present work only the values above twice the LLD (ppm) were used to calculate the average of each element (i.e,. Mn [260], Fe [300], Sr [580], S [120], Mg [120], and Na [160]). Below these values the element was considered not detected or not present.

I.5 Results

The Smackover Formation is 30 to 160 ft (9 to 49 m) thick in LCCF (Fig. I.2 B). The Smackover Formation in LCCF has five units with distinct lithofacies and petrophysical characteristics (Figs. I.3 and I.4). From base to top, those units are: (1) microbial mats, (2) microbial thrombolite, (3) mudstone to peloid-oncoid packstone, (4) ooid-oncoid-peloid grainstone to packstone and (5) peloidal mudstone to wackestone, locally with very abundant siliciclastic grains. In the southwest portion of LCCF a microbial thrombolite also locally occurs above unit 4 (present on well 20). The thicknesses of the five facies are different in each well, and some wells do not contain all facies. In LCCF only the microbial thrombolite and ooid-oncoid-peloid grainstone to packstone units are reservoirs, and they were described and analyzed in detail.

I.5.1 Microbial Thrombolite (unit 2) and Ooid-Oncoid-Peloid Grainstone to Packstone (unit 4) Reservoirs

The microbial thrombolite reservoir facies in LCCF is approximately 26 mi (42 km) long, 3 to 7 mi (5 to 11 km) wide and from 30 to 70 ft (9 to 21 m) thick, and is elongated NE-SW orientation (Fig. I.5 A). It developed in a shallow subtidal environment not influenced by underlying basement topography (Koralegadara and Parcell, 2008; Mancini et al., 2006; Mancini et al., 2008). The microbial thrombolite has a clotted, mottled and nodular texture, with rare domal and branching structures. The thrombolite includes abundant peloids, with minor amounts of skeletal fragments of ostracods, benthic foraminifera and green algae (Fig. I.6).

The ooid-oncoid-peloid grainstone to packstone reservoir in LCCF is approximately 18 mi (29 km) long, 5 to 7 mi (8 to 11 km) wide and from 4 to 20 ft (1.2 to 6 m) thick (Fig. I.5 B). This facies is elongated in a NE-SW direction, mostly overlapping the microbial thrombolite unit. In the north portion of the field the ooid-oncoid-peloid grainstone to packstone unit is absent, replaced by a fine sandstone. The grainstone unit can be sub-divided into two subunits: ooid grainstone and peloid-oncoid grainstone to packstone (Fig. I.7). Only the grainstone facies were described, because porosity and permeability in the packstone intervals are very low or absent. The ooid grainstone is composed by fine to medium sand-sized ooids (0.125 to 0.5 mm diameter) and a minor amount of coarse-sand to granule sized grapestones, bioclasts (mollusk, echinoid,

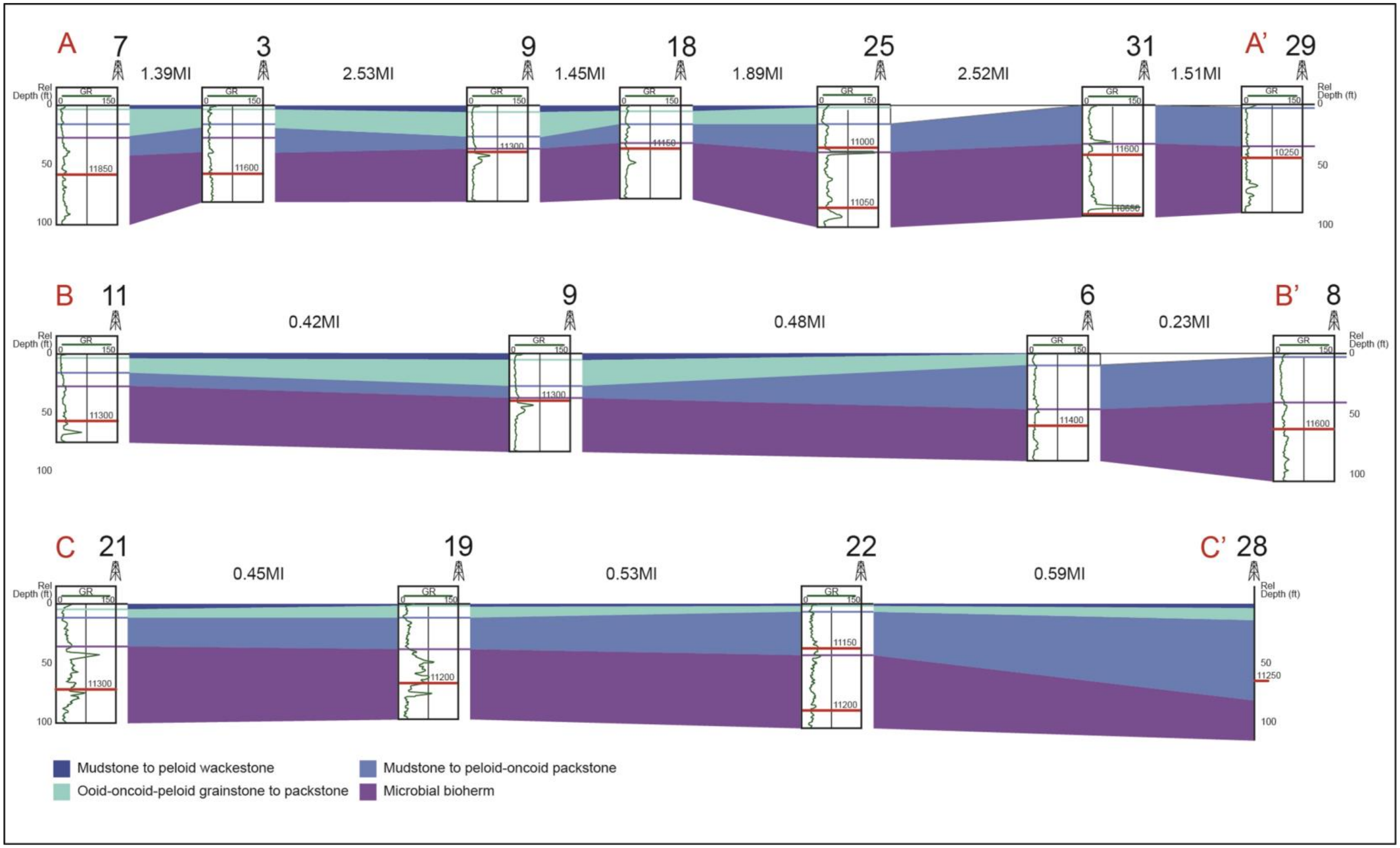


Figure I.3. Stratigraphic cross sections of the Smackover Formation showing fieldwide extent of depositional facies. A - Strike cross section A-A' oriented southwest to northeast. B and C - Dip cross sections B-B' and C-C' oriented northwest to southeast. See Figure I.2A for location of cross sections. Datum is top of Smackover Formation.

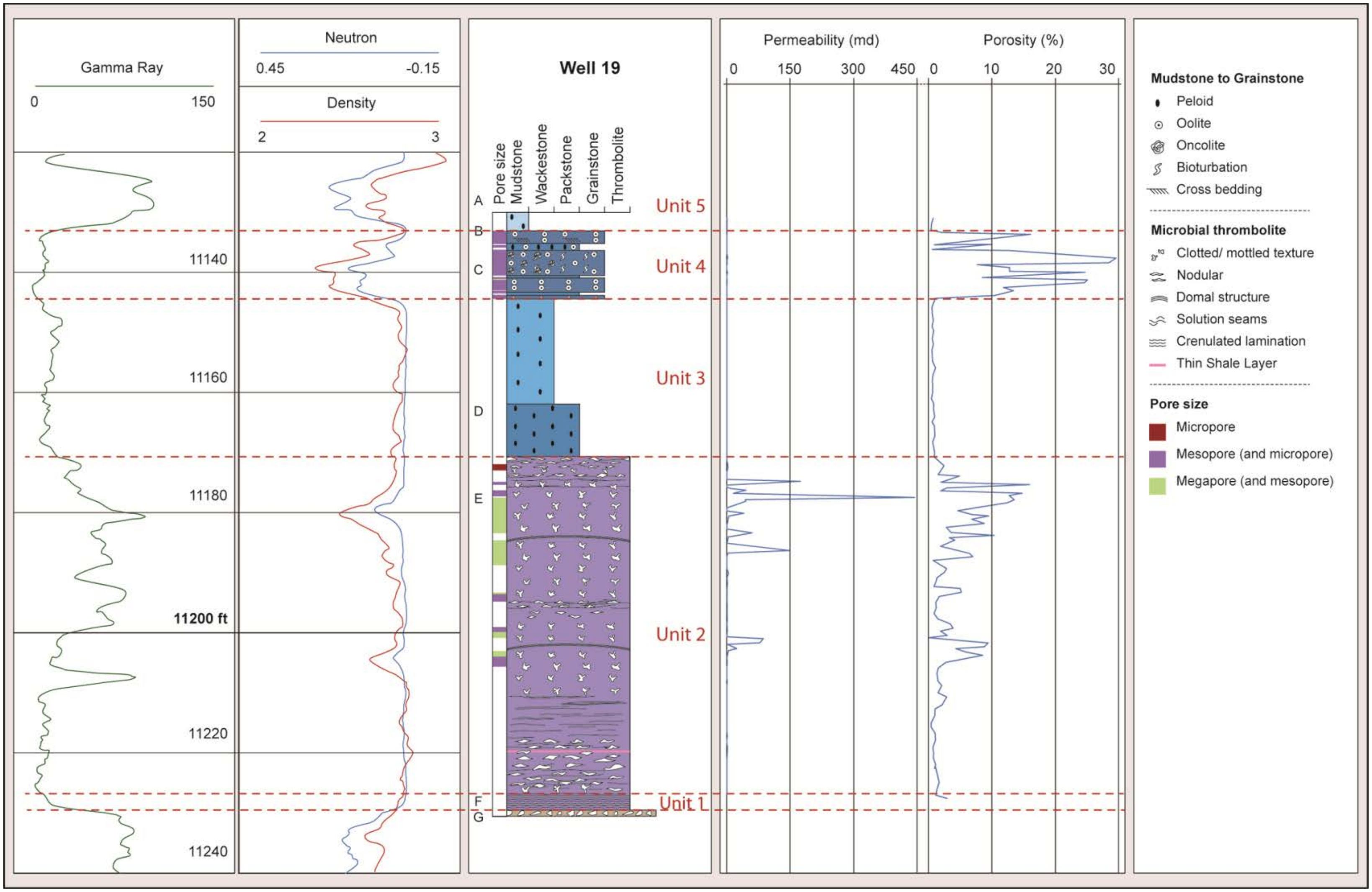
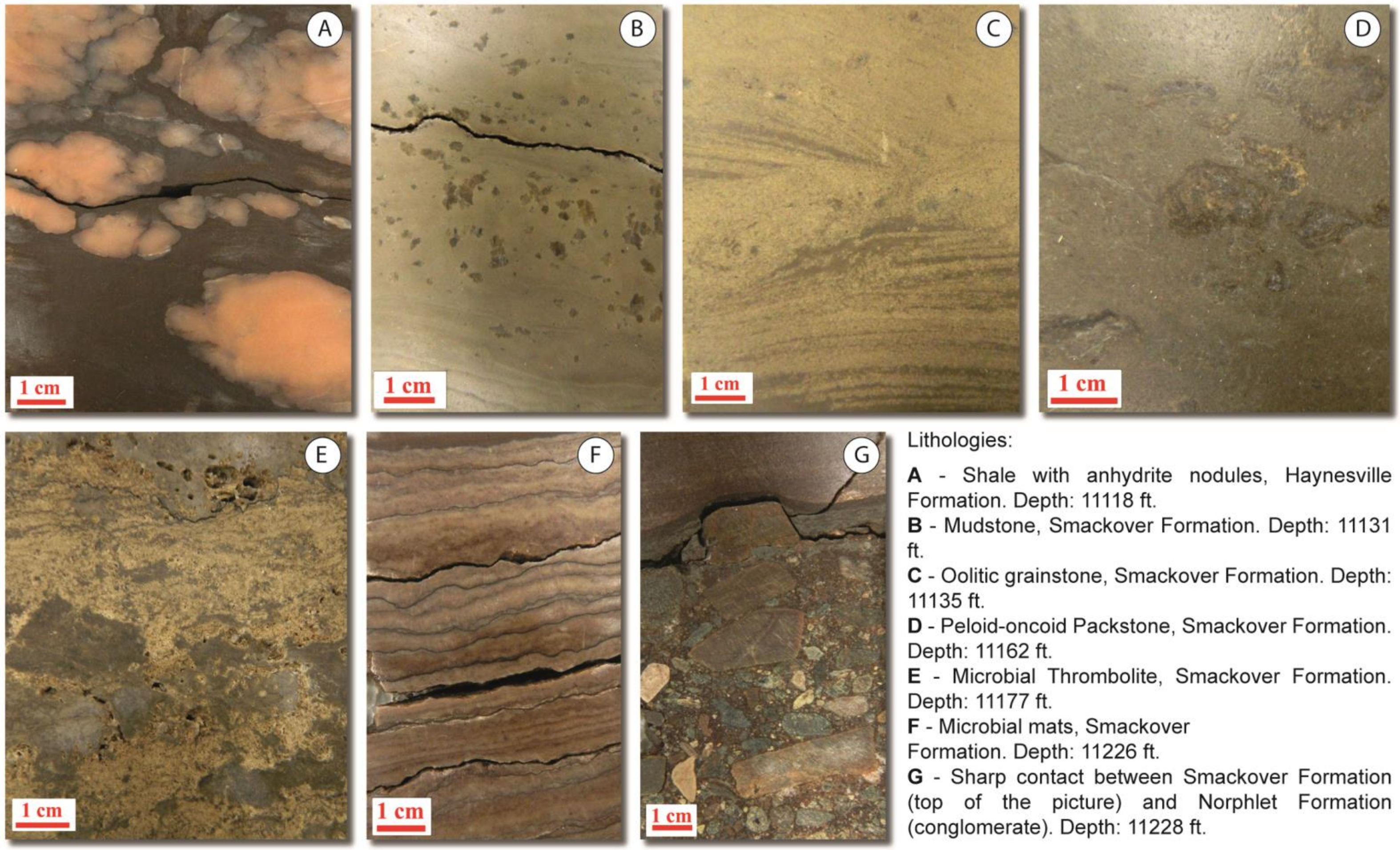


Figure I.4A. Type log of Smackover Formation, well 19, Conecuh County, including gamma ray, neutron, and density tracks, core description, porosity and permeability, and petrophysical analysis (plugs from cores). Units 1 through 5 are described in Figure I.4B and in text. See Figure I.2A for well location.



Lithologies:

A - Shale with anhydrite nodules, Haynesville Formation. Depth: 11118 ft.

B - Mudstone, Smackover Formation. Depth: 11131 ft.

C - Oolitic grainstone, Smackover Formation. Depth: 11135 ft.

D - Peloid-oncoid Packstone, Smackover Formation. Depth: 11162 ft.

E - Microbial Thrombolite, Smackover Formation. Depth: 11177 ft.

F - Microbial mats, Smackover Formation. Depth: 11226 ft.

G - Sharp contact between Smackover Formation (top of the picture) and Norphlet Formation (conglomerate). Depth: 11228 ft.

Figure I.4B. Core photos of lithologies in well 19. The location of the samples in the core is shown on Figure I.4A. See Figure I.2A for well location.

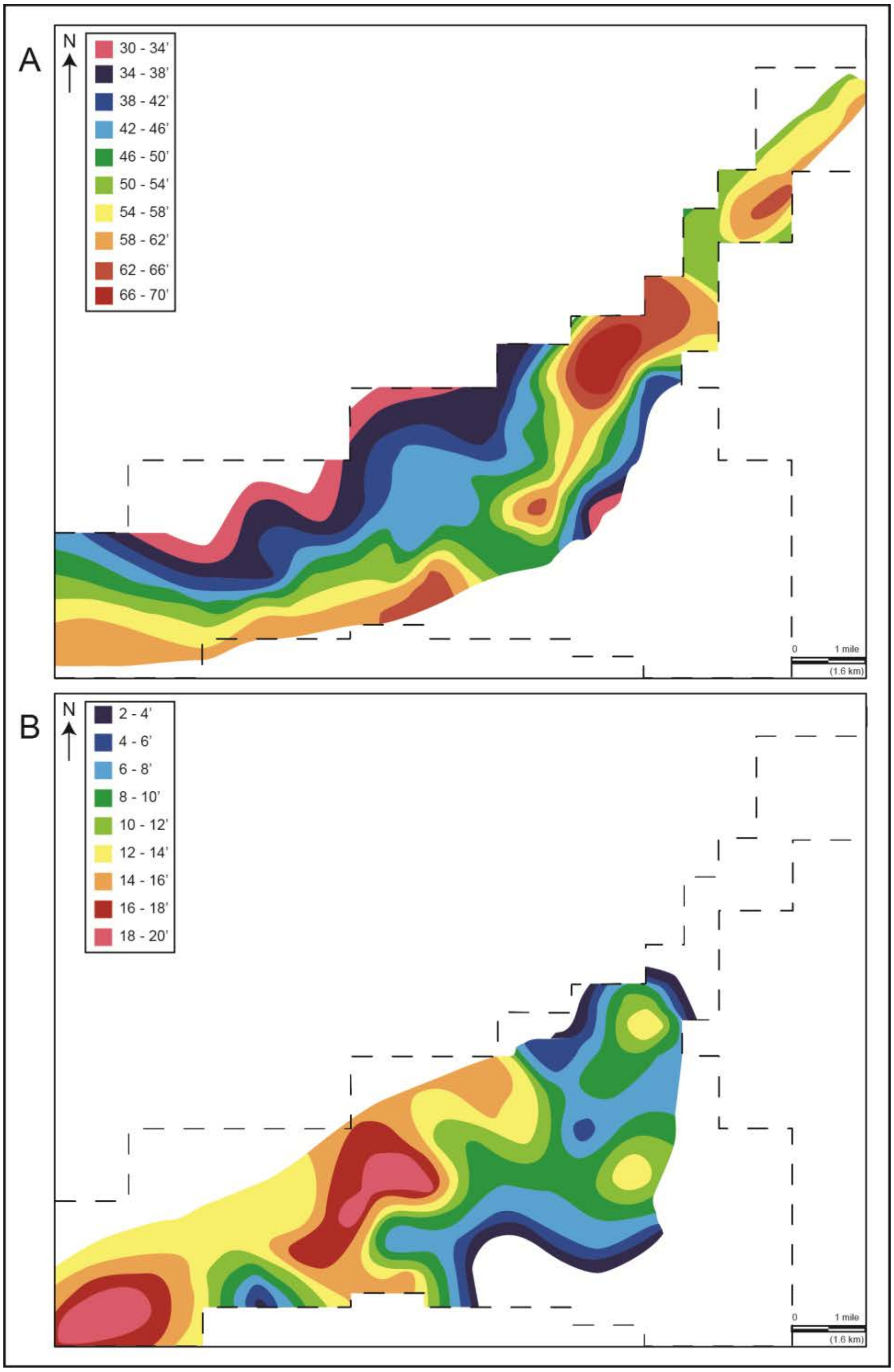


Figure I.5. A - Isopach map of microbial thrombolite facies in LCCF. B - Isopach map of ooid-oncoid-peloid facies in LCCF.

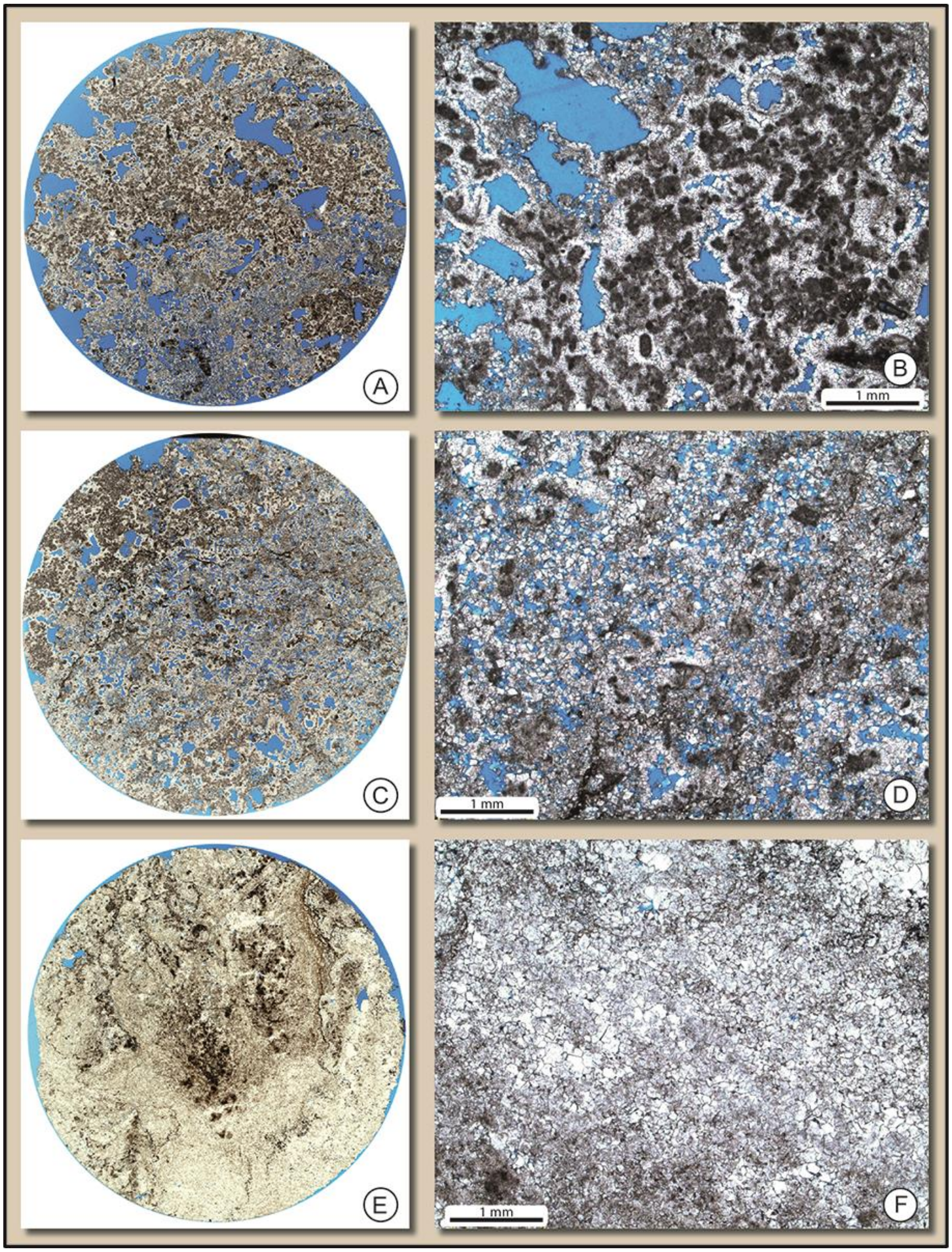


Figure I.6. Paired images of scanned thin section of the thrombolite reservoir facies from 1 in (2.5 cm) diameter plugs (A, C, and E) and photomicrographs from the plugs (D, E, and F). A/B - Microbial thrombolite. Peloids are the main constituent of the rock, being rimmed by calcite cement. Porosity: 21 %; permeability: 2.5 darcys. Well 3, depth 11,609.5 ft. C/D - Intensely dolomitized microbial thrombolite. Original peloidal texture was replaced by fine to very fine dolomite crystals. Porosity: 21 %; permeability: 370 md. Well 2, depth 11,787.9 ft. E/F - Microbial thrombolite extensively cemented by coarse mosaic and blocky calcite. Porosity: 1 %; permeability: < 1 md. Well 17, depth: 11283.8 ft.

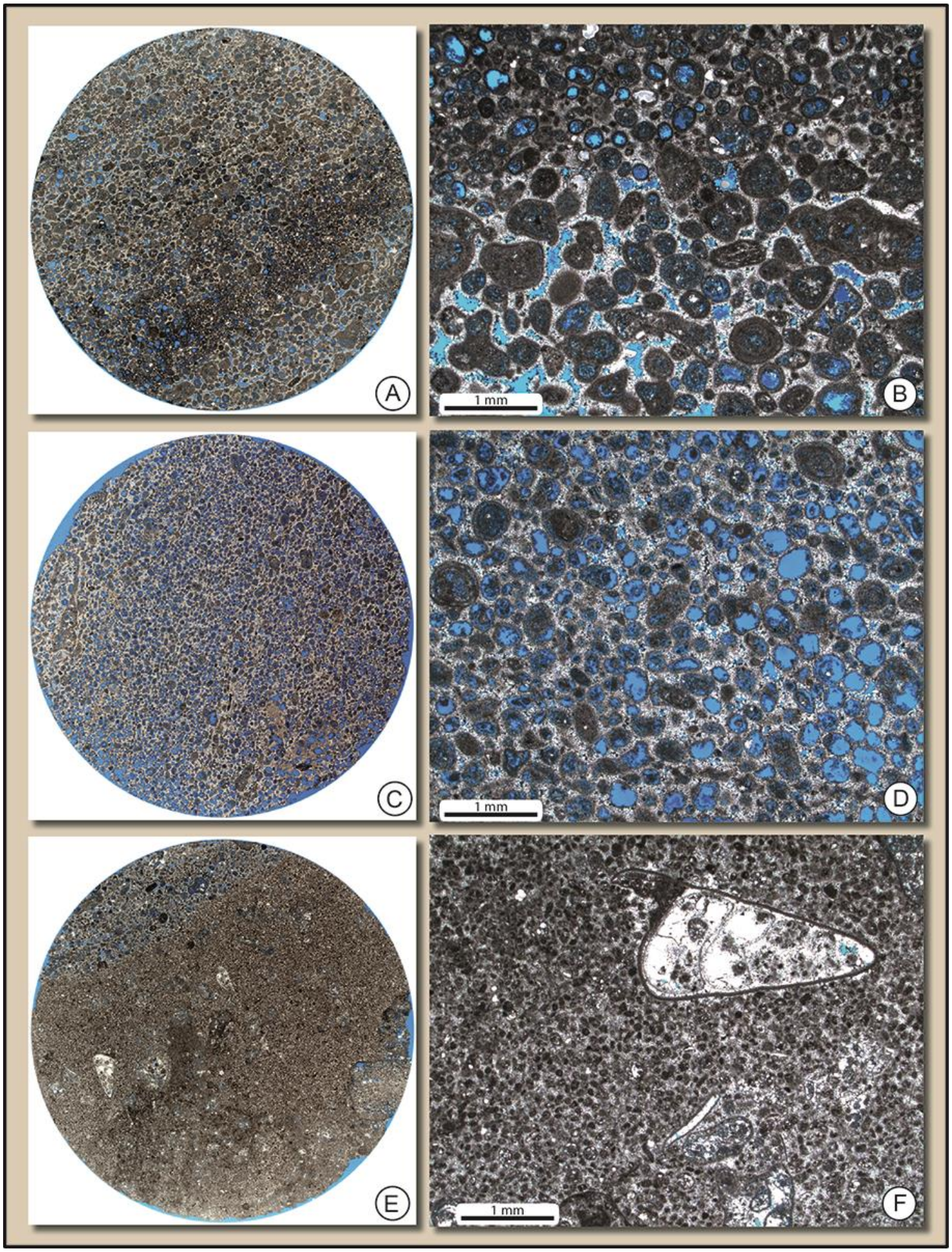


Figure I.7. Paired images of scanned thin section of the ooid-oncoid-peloid reservoir facies from 1 in (2.54 cm) diameter plugs (A, C and E) and photomicrographs of thin sections from core plugs (B, D, and F). A/B - Ooid grainstone with fringing calcite cement. Porosity: 20 %; permeability: 6 md. Well 4, depth: 11,506 ft. C/D - Ooid grainstone with oomoldic porosity. Porosity: 30 %; permeability: 0.7 md. Well 21, depth 11,223.3 ft; E/F - peloid-oncoid grainstone with bioclasts. Porosity: 3 %; permeability: 1.6 md. Well 15, depth 11,266.5 ft.

benthic foraminifera, ostracods, and green algae), coarse to very coarse sand-sized oncolites and very fine to fine-sand sized peloids.

The peloid-oncoid grainstone is composed of very fine to fine sand-sized peloids, coarse-sand to pebble-sized oncolites and a minor amount of bioclasts (mollusk, echinoid, benthic foraminifera, ostracods, and green algae) and ooids. Low to moderate bioturbation occurs in both sub-units.

The vertical distribution of the two grainstone sub-units changes in portions of the field. The facies distribution, when plotted in map view (Fig. I.8) indicates that originally there were two main areas of ooid grainstone facies, almost isolated, which expanded laterally and prograded southeastward through time, forming a larger shoal, over the lower peloid-oncoid grainstone to packstone facies.

I.5.1.2 Paragenetic Sequence

The paragenetic relationships and geochemistry of the carbonate diagenetic components occurring in the Smackover Formation microbial thrombolite and ooid-oncoid-peloid grainstone to packstone units of LCCF are described to determine their diagenetic environments and evolution of the diagenesis.

The microbial thrombolite was deposited during a TST and was exposed only to marine waters during early diagenesis, but the ooid-oncoid-peloid grainstone was deposited during a HST (Benson, 1988; Mancini et al., 1990; Prather, 1992a) and also was exposed to meteoric phreatic waters.

The following paragenetic sequence characterizes the microbial thrombolite facies (in temporal order): marine fibrous calcite rim cement, marine to early burial bladed to

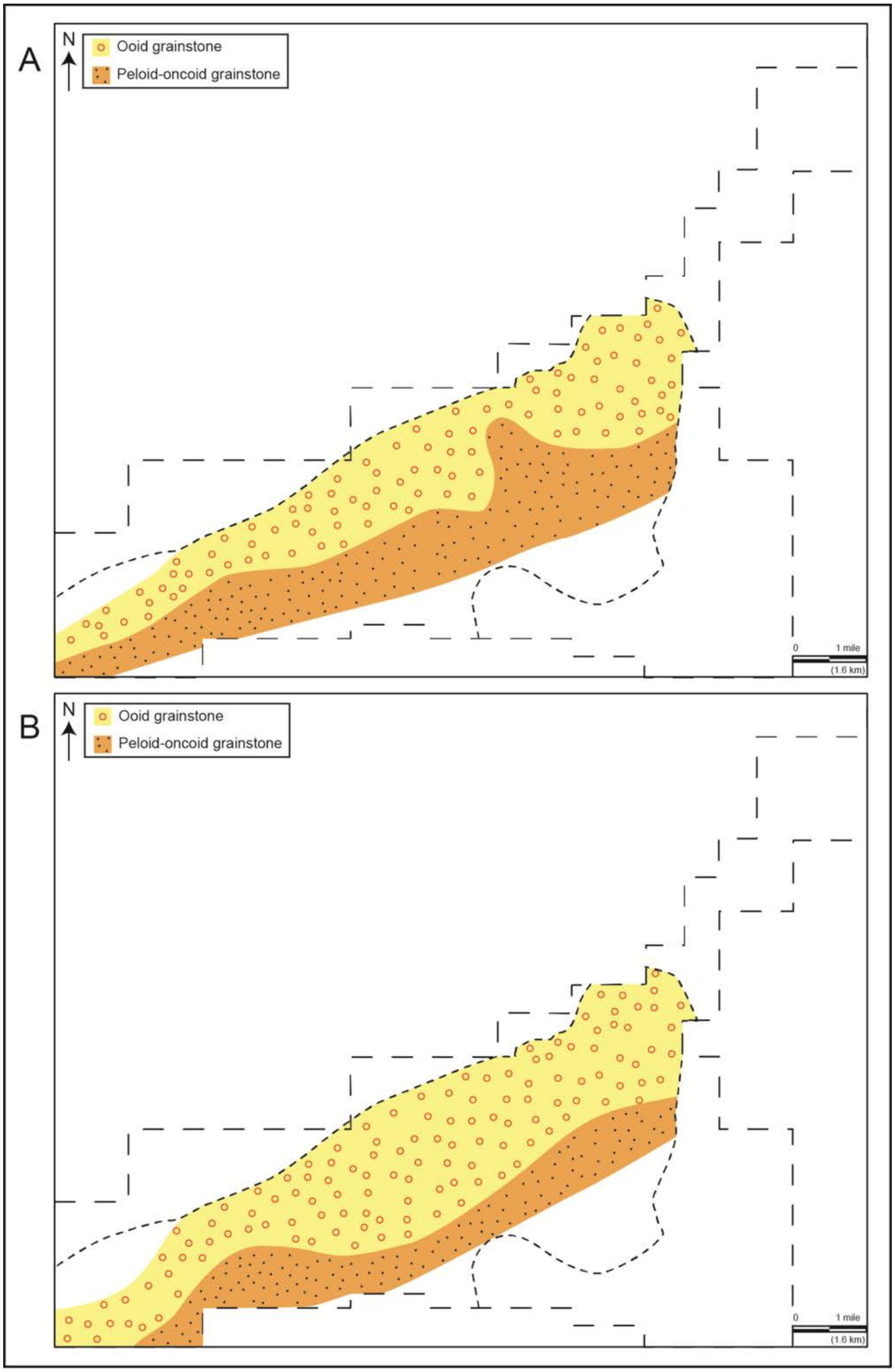


Figure I.8. A - Facies map of the base of the ooid-oncoid-peloid grainstone unit. B - Facies map of the top of the ooid-oncoid-peloid grainstone unit. See Figure I.2 for map location.

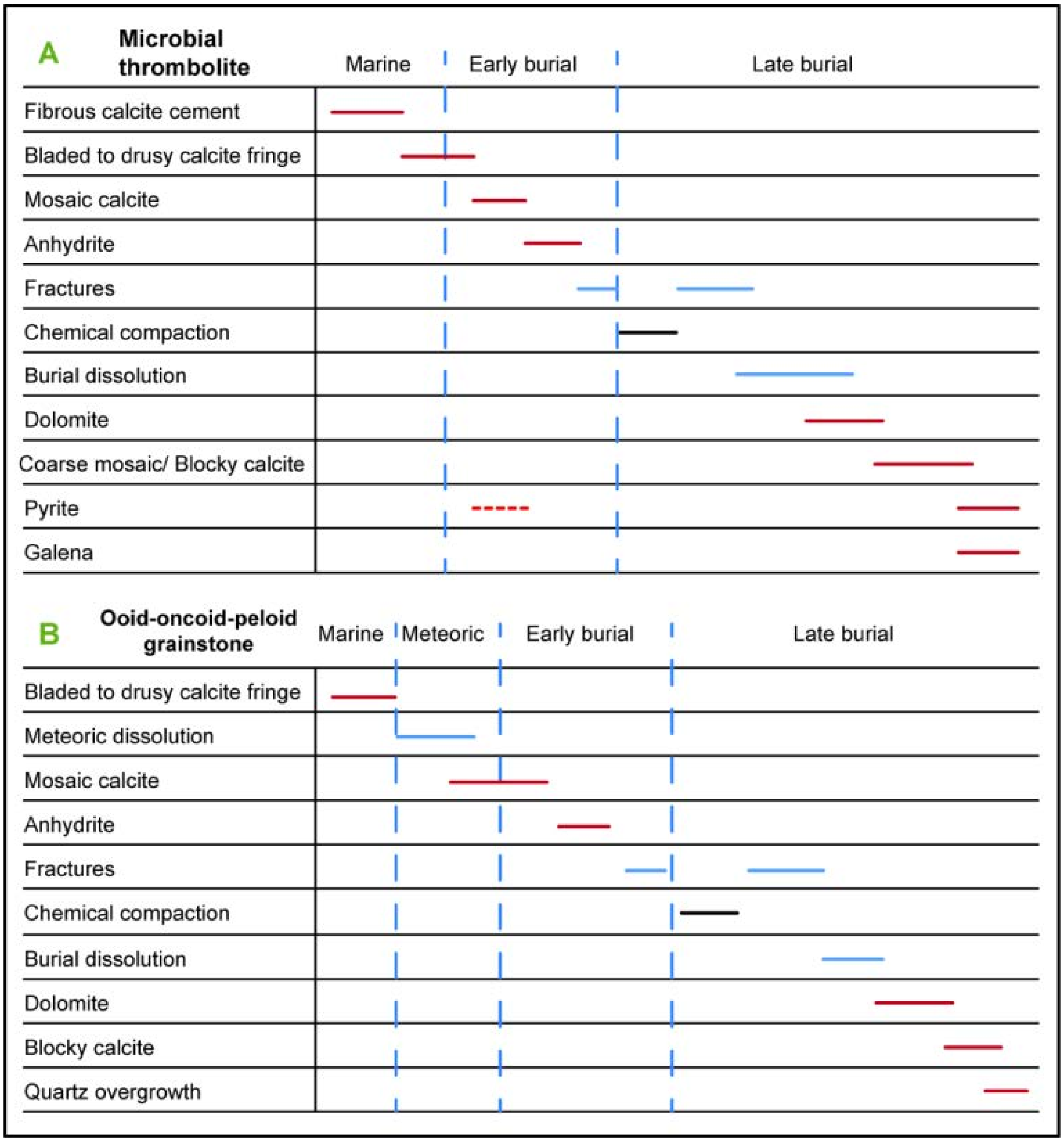


Figure I.9. A - Paragenetic evolution of the microbial thrombolite unit. B - Paragenetic evolution of the ooid-oncoid-peloid grainstone unit. Events depicted as black lines destroyed or did not impact porosity; those depicted in blue enhanced porosity. Chemical compaction marks the boundary between early burial and late burial diagenesis. Uncertainty in the occurrence of events is indicated by the dash line.

drusy calcite fringing cement, early burial mosaic calcite cement, anhydrite replacement and cementation cross-cutting all previous phases, fractures (closed or cemented), chemical compaction, fractures (open microfractures), burial dissolution, dolomitization, late burial coarse mosaic to blocky calcite cement, and pyrite nucleation (Fig. I.9 A).

The ooid-oncoid-peloid grainstone facies underwent the following paragenetic sequence (in temporal order): marine bladed calcite rimming cement, meteoric dissolution, meteoric drusy calcite fringe cement, meteoric to early burial mosaic calcite cement, anhydrite replacement, fractures (closed or cemented), chemical compaction (generating stylolites), fractures (open microfractures), burial dissolution, dolomitization, late burial blocky calcite cement, and locally quartz cement (Fig. I.9 B).

Bladed calcite cement in the ooid-oncoid-peloid grainstone facies and fibrous calcite cement in the thrombolite facies formed within the marine environment. These cements form narrow crusts (usually less than 30 µm thick) rimming grains, and are non-luminescent.

After marine cementation, the ooid-oncoid-peloid grainstone was exposed to meteoric phreatic waters, which dissolved most of the oolites and precipitated a non-luminescent drusy calcite fringe cement and very fine mosaic calcite cement (Fig. I.10). The drusy calcite fringe does not contain the trace-elements Fe, Sr and Mn, and Na is low (318 ppm average) or absent. The absence of Mn causes the non-luminescent characteristic of this calcite cement phase. The low Na and the absence of Sr are indicative of non-marine environment. Moldic and intragranular porosity was generated during this phase, whereas depositional intergranular porosity was partially or locally entirely obliterated. In the peloid-oncoid grainstone sub-unit, dissolution of the grains is less intense and intergranular porosity dominates, whereas in the oolitic grainstone the moldic porosity predominates.

In the microbial thrombolite reservoir facies, marine to early burial bladed to drusy calcite fringe cement rims peloid clusters and constructional voids (Fig. I.11). This cementation phase has three distinct luminescent zones, from the center to the edge: zone 1 - dull brown to nonluminescent; zone 2 - light brown luminescence; and zone 3 – orange luminescence. Generally in the smaller primary pores only the first or first and second zones developed. Increasing luminescence and trace element analysis from the center to the edge of the cement indicates increasing amounts of Mn (Figs. I.12 A and I.12 B), as a result of a continued growth of the marine drusy calcite fringe with burial. This shallow burial phase of bladed to drusy calcite cementation also occurs in the grainstone reservoir facies.

Early burial mosaic calcite cement was precipitated after the bladed to drusy calcite fringe cement, and its luminescence is similar to that of zones 2 and 3 of the bladed to drusy calcite cement (i.e., dark to light brown and orange luminescence) but its crystals are larger, and do not rim the grains or peloid clusters. Mn content is similar to slightly higher than in the bladed to drusy calcite cement.

An uncommon characteristic of the meteoric mosaic calcite cement in the grainstone unit of LCCF is its high Sr content, with an average of 4121 ppm (up to 6796 ppm). The meteoric mosaic calcite cement was precipitated by interstitial waters rich in Sr, which are interpreted as being derived from dissolved aragonitic oolites. High Sr content is unusual in ancient limestones, which has shown a median concentration of 400 to 700 ppm (Kinsman, 1969), although values range widely. High Sr content is common in aragonite (3,000 to 10,000 ppm), and also occurs in calcite cements that formed by

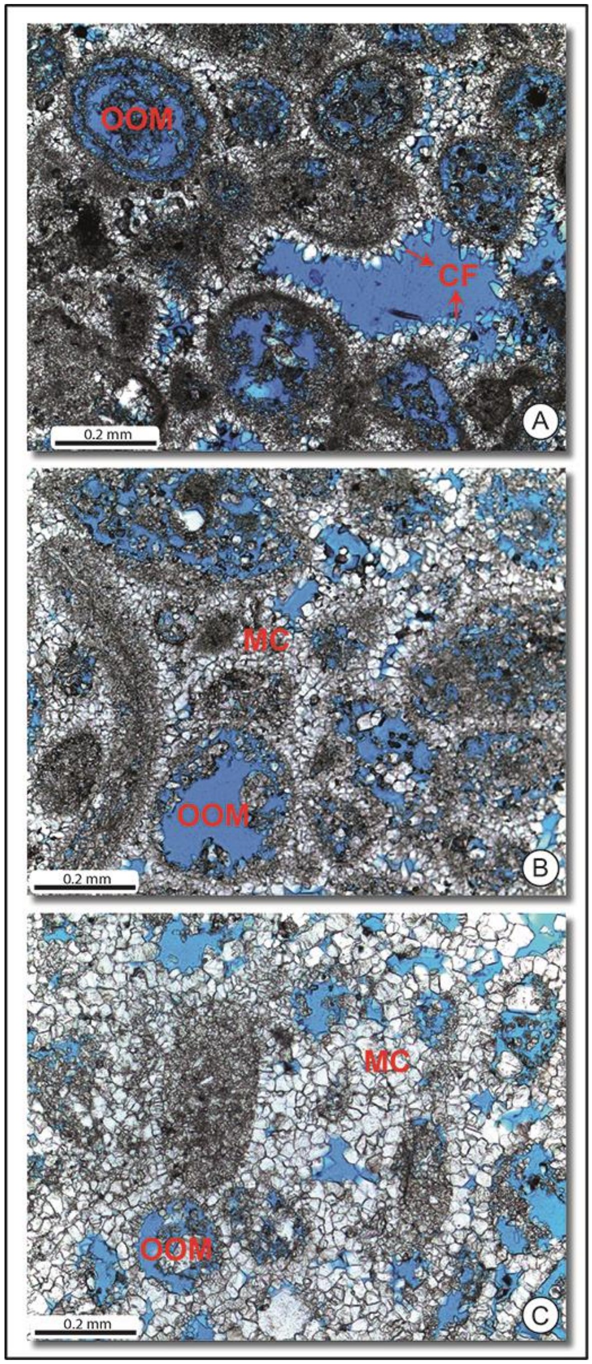


Figure I.10. Photomicrographs illustrating degrees of diagenetic change in the ooid-oncoid-peloid grainstone, gradually increasing in intensity from A to C. A – Partially dissolved ooids rimmed by bladed to drusy fringing calcite cement. Well 6, depth: 11,346.2 ft. B – Oomoldic grainstone with intergranular porosity mostly occluded by bladed to drusy fringing cement and fine mosaic calcite. Well 7, depth: 11,802.5 ft. C – Oomoldic grainstone with intergranular porosity completely filled by coarse, mosaic calcite. Well 15, depth: 11,255.4 ft. CF = bladed to drusy calcite fringe cement; OOM = oomoldic porosity; MC = fine mosaic calcite cement.

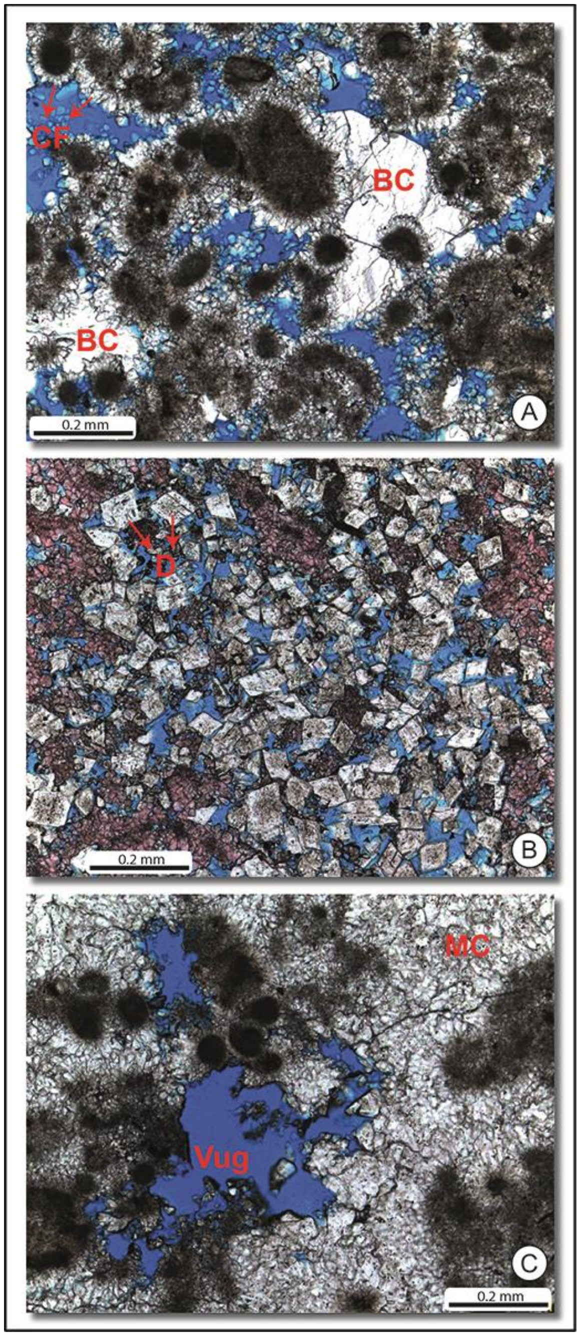


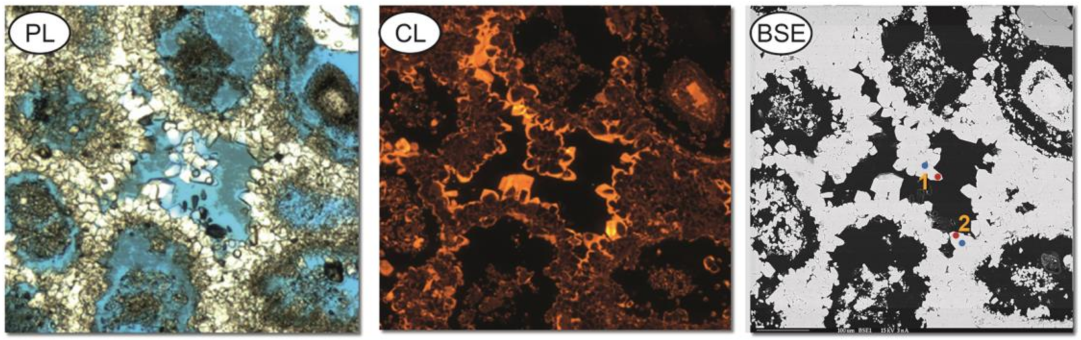
Figure I.11. Photomicrographs of the microbial thrombolite facies. A – Microbial peloids with fibrous calcite rims and blocky calcite partially cementing the pore space. Well 4, depth: 11,531.5 ft. B – Intensely dolomitized microbial thrombolite. Well 2, depth: 11,789 ft. C – Microbial thrombolite extensively cemented by mosaic calcite. Vuggy porosity created by late burial dissolution. Well 17, depth: 11,271.1 ft. CF – bladed to drusy calcite fringe cement; MC = fine mosaic calcite cement; BC = blocky calcite cement; D = dolomite; Vug = vuggy pore type.

alteration or dissolution of aragonite (Budd and Land, 1990; Khale, 1965; Singh, 1987). The diagenetic alteration of typical aragonitic sediments can produce calcite with 700 to 10,000 ppm of Sr (Kinsman, 1969), and the mosaic calcite cement in the grainstone unit of LCCF is interpreted to be an example of this process.

Due to early cementation, there is little or no evidence of grain compaction in either reservoir facies. However, deep burial compaction features, such as stylolites and solution seams, are abundant in both reservoir facies. Subvertical, inclined, and subhorizontal fractures are common, but their frequency is variable from approximately every 2 ft (60 cm) or 4 ft (120 cm), to approximately every 25 ft (7.6 m). All of the macroscopic fractures are closed or cemented by calcite, and most of them are discontinuous. Several fractures are crosscut by stylolites, indicating that this first fracturing event occurred before pressure dissolution caused by compaction. A second fracturing event produced open microfractures that crosscut stylolites and blocky calcite. A post-compaction dissolution event produced enlargement of primary depositional constructed vugs, and this process was more intense closer to major fractures.

Anhydrite cement occurs as millimeter-diameter patches that occlude pore space and replace grains and older calcite cements. It occurs in both reservoir facies but in very small amounts (commonly less than 1%). Dolomite forms as a replacing and cementing mineral, with euhedral to subhedral crystal shapes, with red luminescence. Fe content varies from one dolomite crystal to another and throughout the same crystal (Fig. I.12 C). Locally, Fe content increases from center to border (dull luminescent border – zoned crystals); elsewhere it decreases toward the border (unzoned crystals).

Figure I.12. Plain light (PL) photomicrograph, cathodoluminescence (CL) image, and backscatter electron image (BSE) of (A) ooid-oncoid-peloid grainstone, (B) microbial thrombolite, and (C) partially dolomitized microbial thrombolite. Tables show microprobe analysis results (minor and trace elements). The exact points of the analyses are shown on the BSE images as colored dots. PL and CL images were taken after microprobe analysis, so it is possible to see the small holes (10 μ diameter) made by the microprobe electron beam. In (A) points 1 and 2 are bladed to drusy calcite fringing cement. In slide (B) point 4 is a microbial peloid; point 5 is fibrous calcite fringing cement; points 6 and 7 are drusy calcite fringing cement; and points 8 and 9 are blocky calcite cement. In slide (C) points 10 and 11 are rhombic dolomite.

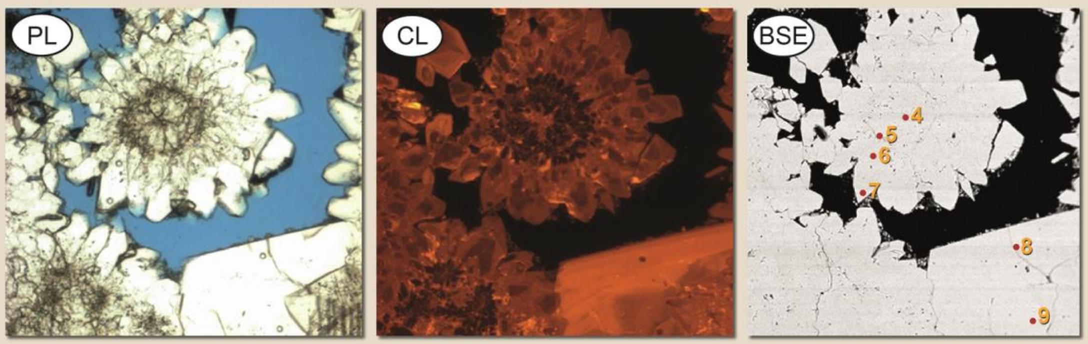


Well 13
Permit 14325
Depth: 10954.8 ft
Facies: Thrombolite

A

Microprobe analysis (minor and trace elements) in the bladed to drusy calcite fringe cement:

Analysis	Fe (ppm)	Mn (ppm)	Sr (ppm)	S (ppm)	Na (ppm)
1_base	0	0	878	784	582
1_tip	0	932	0	121	0
2_base	0	0	688	790	434
2_tip	921	989	0	0	273

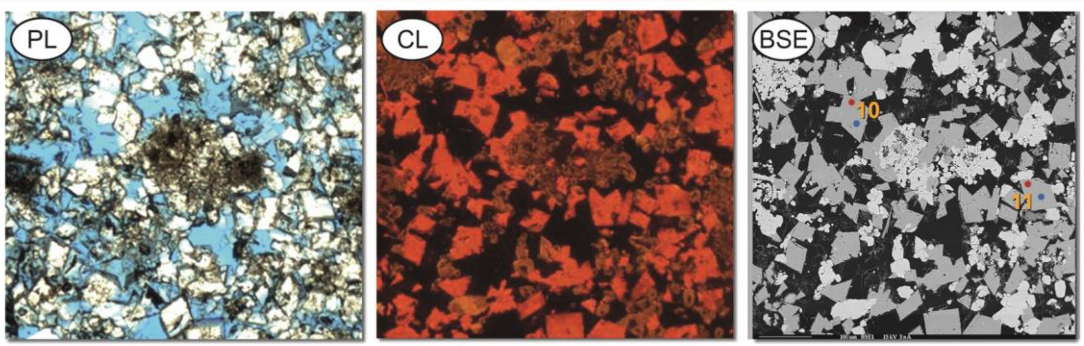


Well 27
Permit 15497
Depth: 10954.8 ft
Facies: Thrombolite

B

Microprobe analysis (minor and trace elements):

Analysis	Fe (ppm)	Mn (ppm)	Sr (ppm)	S (ppm)	Na (ppm)
Peloid					
4	0	373	700	382	130
Fibrous calcite fringe cement:					
5	0	339	849	489	239
Drusy calcite fringe cement:					
6	0	0	831	1007	104
7	1162	731	0	0	139
Blocky calcite cement:					
8	0	913	0	0	0
9	0	444	0	0	0



Well 9
Permit 14112
Depth: 11314.4 ft
Facies: Thrombolite

C

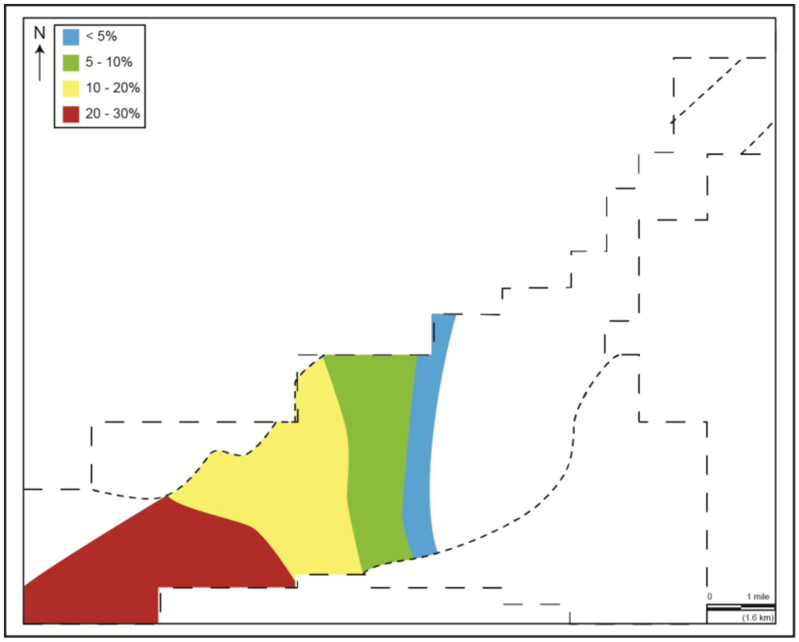
Microprobe analysis (minor and trace elements) in dolomites:

Analysis	Fe (ppm)	Mn (ppm)	Sr (ppm)	S (ppm)	Na (ppm)
10_center	3800	1210	0	0	0
10_border	830	1000	0	0	0
11_center	1630	1160	0	0	0
11_border	790	1000	0	0	0

In general, dolomite is rare in the ooid-oncoid-peloid grainstone, commonly less than 3%, replacing portions of grains. In the microbial thrombolite reservoir facies, dolomite is more abundant, composing as much as 30% of the rock and gradually decreasing from south to north in LCCF. It is absent from the center to the northeast portion of LCCF (Fig. I.13 A). The dolomite preferentially replaces the bladed to drusy calcite fringe cement, but it also replaces depositional grains and other cements. It is common for dissolution of calcite to be associated with dolomitization. Microprobe analysis shows that Sr, S and Na are absent in most of the dolomite crystals (or occur in a very small amount, close to the lower limit of detection), indicating the dolomitizing fluid was not marine, and together with crosscuting relationships, supports its interpretation as a late burial dolomitization.

Late-burial, coarse mosaic to blocky calcite cement occurs in both reservoirs, but it is more abundant in the microbial thrombolite reservoir facies. The crystals commonly are zoned, with two to five luminescent zones, but some crystals are unzoned. The order of the luminescent zones is variable, with dark brown, light brown, orange, and light orange colors visible. Trace-element analyses shows that Sr and Na are absent, and Fe and Mn content are higher than in the bladed to drusy calcite fringe cement. In the microbial thrombolite facies the amount of coarse mosaic to blocky calcite increases to the north, where calcite cements compose more than 70% of the rock (Fig. I.13 B). Quartz cement (overgrowth) occurs only in the grainstone reservoir, being a localized diagenetic phase. Pyrite and galena are common accessory minerals in the thrombolite reservoir across the field.

A



B

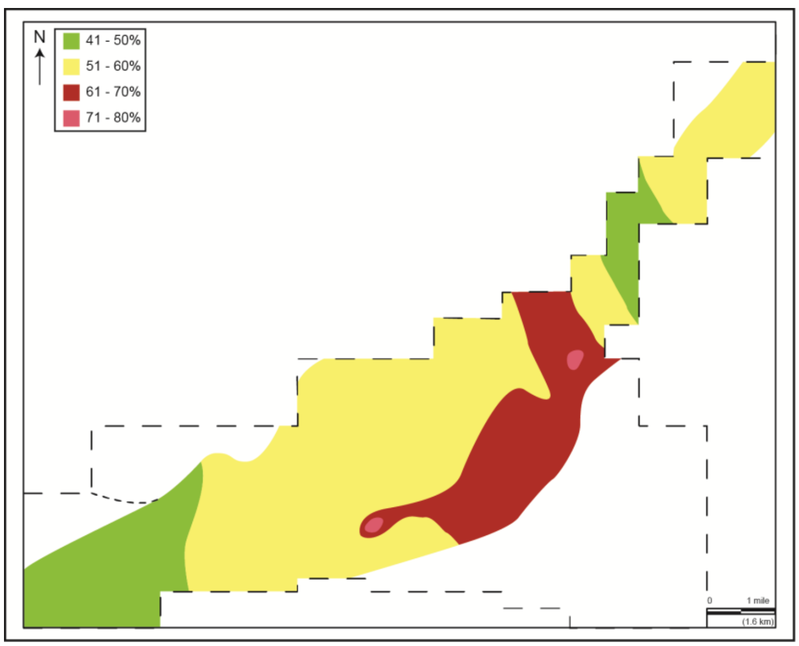


Figure I.13. A - Areal variation in dolomite content in the microbial thrombolite reservoir facies in LCCF. B - Areal variation in cement (calcite and dolomite) in the microbial thrombolite reservoir facies in LCCF. C - Lateral pore size variation in the microbial thrombolite reservoir facies in LCCF. See Figure I.2 for map location.

C

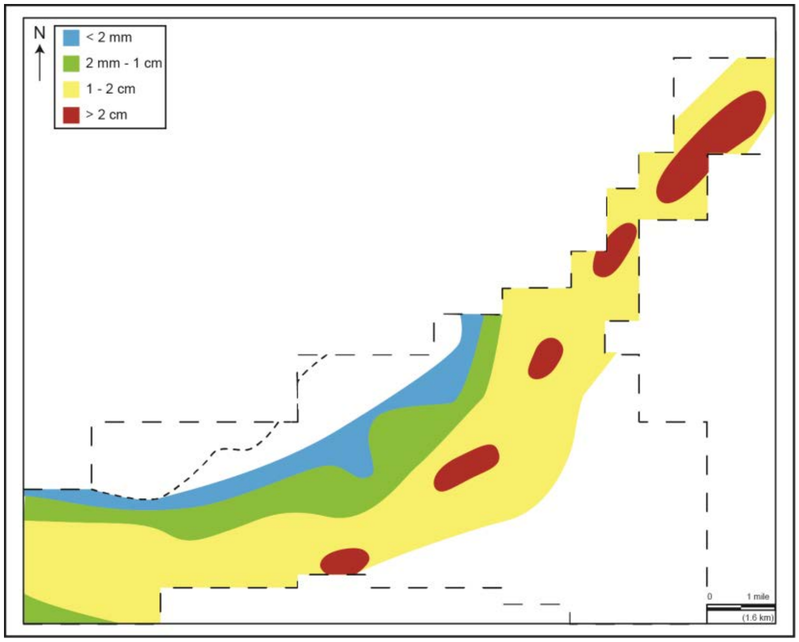


Figure I.13. Continued.

I.5.1.2 Petrophysical Properties

The pore types in the microbial thrombolite are depositional constructional voids, vugs, intercrystalline porosity (when dolomitized), intergranular, and microfractures. Most of the vugs were created by enlargement (dissolution) of constructional voids formed during microbial thrombolite development. Petrophysical characteristics are highly variable laterally and vertically inside the microbial thrombolite. The thickness of the microbial thrombolite increases from west (protected side) to east (greater paleoenvironmental energy), and the lateral pore size distribution follows the same trend, increasing from mesopores near the west border to megapores near the east border (Fig. I.13 C) where dissolution produced vugs from 0.8 to 2.4 in (2 to 6 cm) in diameter. In non-dolomitized thrombolite, core-plug analysis shows that porosity values vary from 3 to 19% (Fig. I.14 A), and permeability values commonly vary from less than

1 to 100 md, but locally are as much as 500 md where late dissolution is more intense. In partially dolomitized intervals of the thrombolite, porosity varies from 10 to 21%, and permeability varies from 150 to 850 md, locally as much as 1200 md (Fig. I.14 B). Large vugs and fractures cause local permeability values to be 1 to 4 darcys, and rarely as much as 7 darcys.

The ooid-oncoid-peloid grainstone has intergranular, intragranular, moldic and vuggy porosity. Microfractures are rare in this facies. The largest porosity values are associated with intense dissolution of the oolites, and consequently to the presence of moldic porosity. Porosity values vary from 5 to 32% (Fig. I.15 A), and the areas where the ooid grainstone is thicker have the greatest porosity values (16 to 26% in average). The rimming calcite cements obstruct pore throats; therefore, permeability in the ooid-oncoid-peloid grainstone is low, commonly between 1 and 10 md, and has only small variations across the reservoir (Fig. I.15 B). Depositional intergranular porosity is more abundant where grains are coarser (medium to very coarse sand size) and cementation did not completely fill pore space. Locally, where vuggy porosity is abundant, permeability can have values from 100 to 500 md.

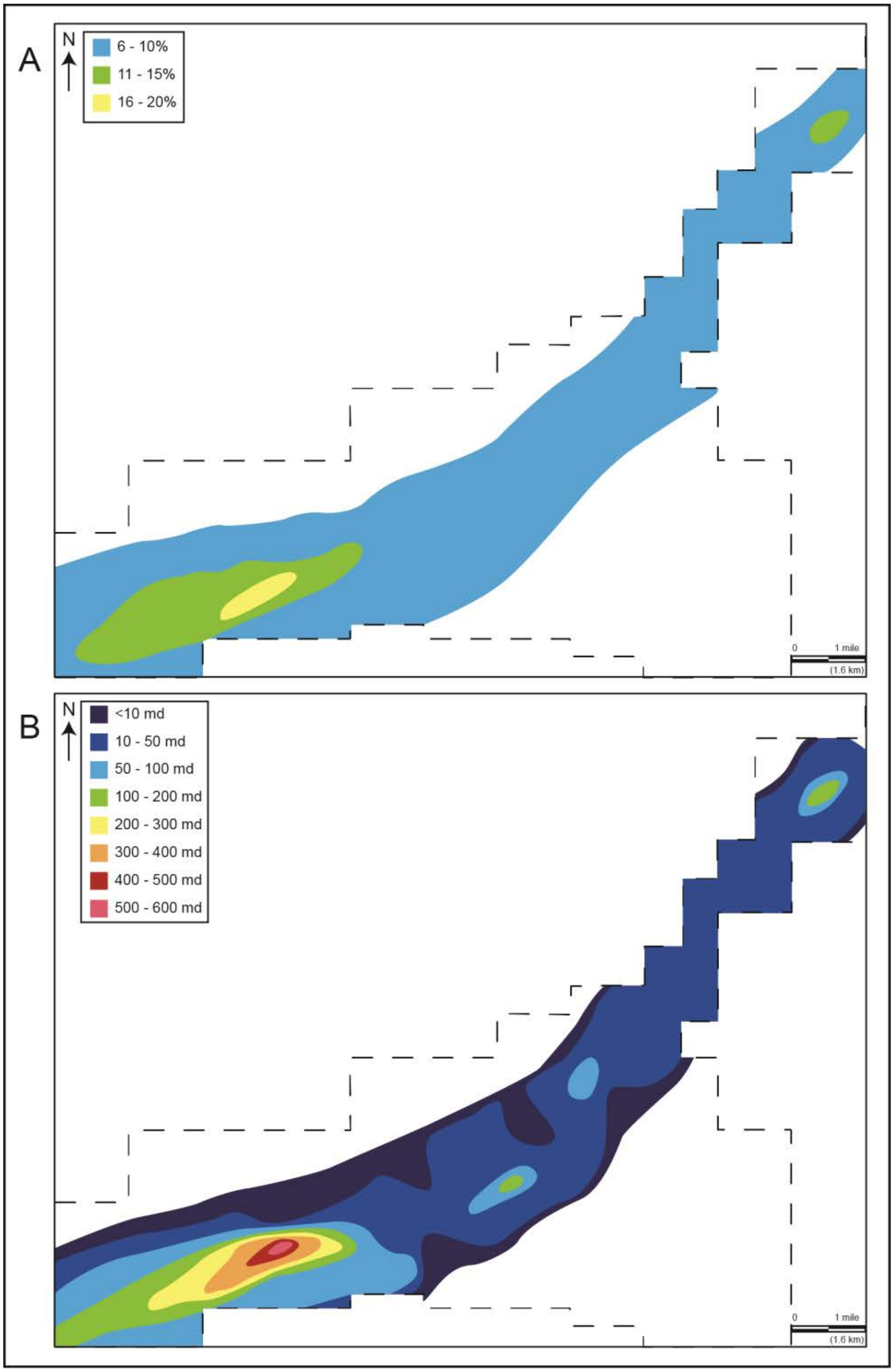


Figure I.14. A - Map of average porosity of the microbial thrombolite reservoir facies. B - Map of the average permeability of the microbial thrombolite reservoir facies. See Figure I.2 for map location.

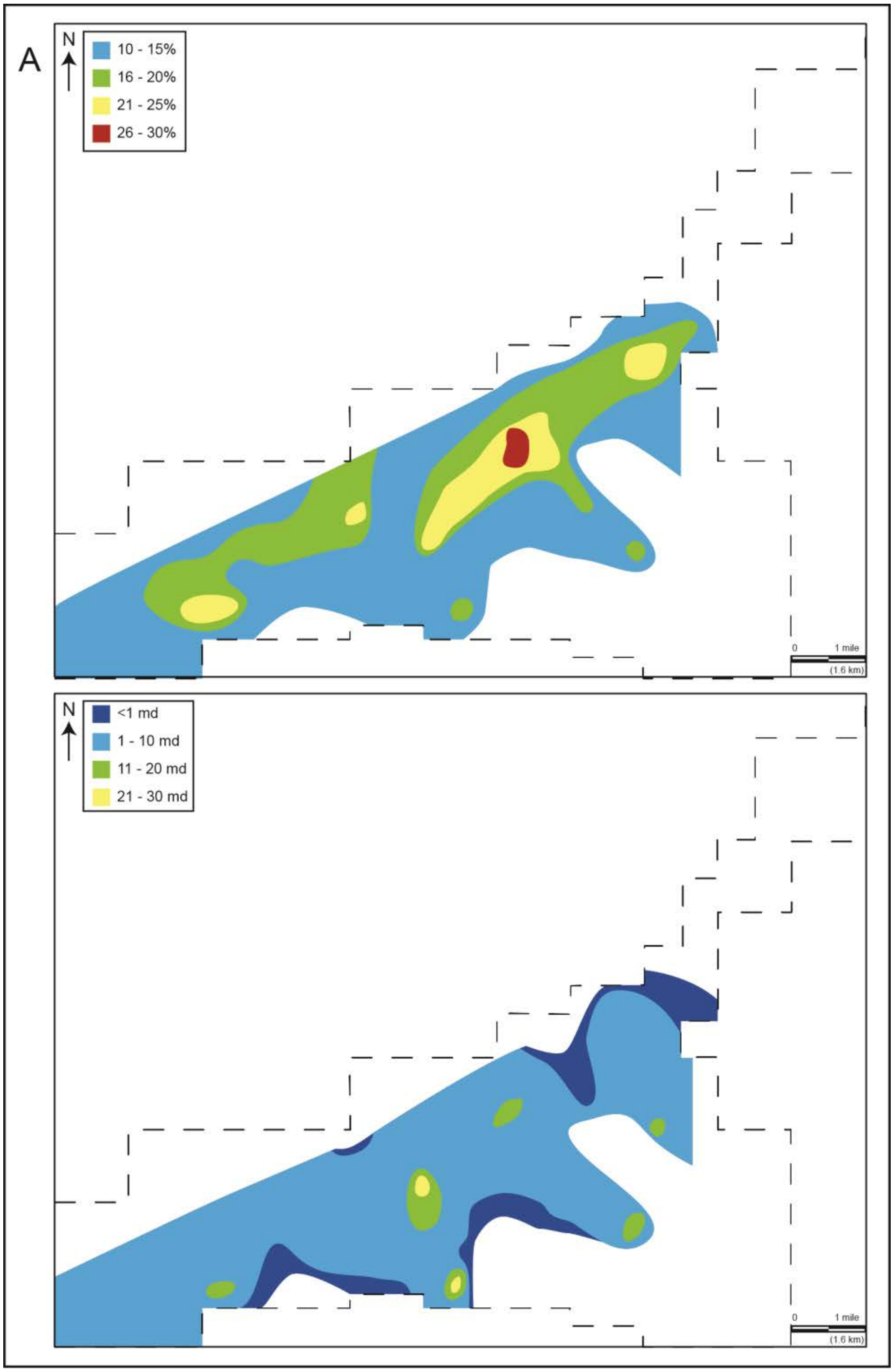


Figure I.15. A - Map of the average porosity of the ooid-oncoid-peloid grainstone reservoir facies. B - Map of the average permeability of the ooid-oncoid-peloid grainstone reservoir facies. See Figure I.2 for map location.

I.6 Discussion

Early diagenesis of the Smackover Formation grainstone was regionally variable and was driven by meteoric waters to mixed and marine waters (Ahr and Palko, 1981; Benson and Mancini, 1999; Llinas, 2002; Moore and Druckman, 1981). The ooid-oncoid-peloid grainstone unit in LCCF is characterized by an early diagenetic phase similar to that of the Smackover Formation oolitic grainstone in Midway field (southwest Arkansas) and Lincoln Parish (Louisiana), where early diagenesis was dominated by meteoric events (Ahr and Palko, 1981; Moore and Druckman, 1981). In these areas, the ooid grainstone is dominated by precompaction diagenetic fabrics, an absence of compactional features, and abundant moldic porosity, with little preserved depositional intergranular porosity. Original intergranular porosity commonly was filled with mosaic calcite cement. However, burial diagenesis varied between LCCF and Midway fields. In Midway field, the only late burial event was the local replacement by massive anhydrite laths that crosscut molds as well as cements (Moore and Druckman, 1981). The grainstone unit in LCCF underwent anhydrite replacement and several other burial events, such as chemical compaction, fracturing, late burial blocky calcite cementation, late burial dissolution and locally dolomitization. The diagenetic phases of the microbial thrombolite facies in LCCF cannot be compared with similar ones in other fields, because all other Smackover Formation microbial thrombolite reservoirs studied are intensely or totally dolomitized, with no depositional microtexture, primary porosity features and pre-dolomitization diagenetic features preserved (e.g. Llinas, 2002; Petta and Rapp, 1990).

Both Smackover Formation reservoirs in LCCF record distinct early diagenetic phases, but both facies underwent a similar burial diagenetic evolution. Diagenesis significantly affected the pore system in both reservoirs. In the ooid-oncoid-peloid grainstone facies, marine cementation created the depositional framework, but meteoric diagenesis modified the pore system. Its interconnected depositional intergranular pore system was transformed into an unconnected moldic, vuggy, and intragranular pore system by diagenesis. Meteoric drusy calcite fringe cement caused significant reduction of primary intergranular porosity, and pore throats were blocked. Meteoric dissolution formed secondary oolite molds that enhanced porosity but not permeability.

The early-burial, bladed to drusy calcite cementation phase formed in both the microbial thrombolite and ooid-oncoid-peloid reservoir facies. The marine and early burial calcite cements have uniform cathodoluminescence patterns across both reservoir facies, indicating uniform pore-water chemistry during cementation. However, later diagenetic phases formed in non-uniform ways within the reservoir facies, producing significant variation in the porosity and permeability of each reservoir.

During late burial diagenesis, vuggy porosity formed and locally enhanced permeability. Late calcite cementation did not significantly alter porosity and permeability in the ooid-oncoid-peloid grainstone facies. However, late diagenetic calcite and dolomite significantly altered porosity and permeability throughout the microbial thrombolite reservoir facies. Dolomite is restricted to the southwest portion of the microbial thrombolite reservoir, where blocky calcite occurs only in small amounts. The northeast portion of the reservoir has abundant coarse mosaic to blocky calcite cementation and local recrystallization of the calcite, but no dolomite. As the reservoir dips southwest, this heterogeneous cement distribution indicates that the deeper portion had a distinct pore water chemistry, different than the shallower northeast portion of the reservoir during late diagenesis.

Dolomitization is an important diagenetic process in changing pore system characteristics in LCCF. Dolomitization was associated with calcite dissolution, and resulted in changes in pore system geometry and enhancement of permeability. Dolomitization also created a more uniform vertical and lateral distribution of porosity and permeability in the microbial thrombolite facies.

Other Smackover Formation reservoirs, for example in Appleton and Vocation fields (Conecuh and Manila Sub-basins) record extensive dolomitization, that occurred in several steps: seawater-seepage, reflux, near-surface mixed-water, shallow-burial mixed-water, and deeper burial. The dolomites formed by these processes in Appleton and Vocation fields overlapped in time and space to form dolostone bodies composed of a complex mixture of dolomite types (Benson and Mancini, 1999; Prather, 1992b). In LCCF only one dolomitization process occurred. The dolomite in LCCF has morphological and cathodoluminescence characteristics similar to the late rhombic dolomite cement in Appleton and Vocation fields, but it formed by a distinct process. In Appleton and Vocation fields the rhombic dolomite is interpreted to be pre-compactional, shallow-burial mixed-water in origin (Prather, 1992b), but in LCCF it is interpreted to have formed in the deep burial environment. Trace-element composition of rhombic dolomites from LCCF and Appleton/Vocation fields are very different. The shallow-burial mixed-water dolomites in Appleton and Vocation fields have an average of 819 ppm of Na and 475 ppm of Sr (Prather, 1992b), whereas in the LCCF late burial dolomite these elements are absent. It is important to determine the origin and timing of the dolomitizing fluid to better characterize the reservoirs, to understand differences in petrophysical characteristics and to predict similar reservoir characteristic in other fields. Appleton and Vocation fields have a different dolomite than LCCF, and the reservoir quality responds to this difference. Appleton and Vocation thrombolitic reservoir units have higher mean porosity and permeability values, with a more homogeneous distribution of these petrophysical characteristics in the reservoir than in the thrombolitic reservoir of LCCF, due to its intense early dolomitization process.

Good porosity and permeability in the Smackover Formation microbial thrombolite reservoir facies in LCCF also are related to late burial dissolution and fracturing, not dolomitization. Fluid percolation in the microbial thrombolite was more intense in the thicker portions of the bioherm, where a larger interval with good primary porosity and larger depositional constructional voids formed. Consequently, the largest secondary vugs, which can be as much as 2.4 in (6 cm) in diameter, occur in the areas where the microbial thrombolite is thicker. This process enhanced porosity and permeability in small, discontinuous intervals, and fractures also acted as conduits to fluid flow. The occurrence of large vugs intensely or completely cemented by calcite close to fractures, indicates dissolving and cementing fluids percolated through the fractures. Some stylolites also acted as local flow paths.

I.7 Conclusions

Lateral and vertical distribution of facies, cements, pore size, porosity, and permeability of the Smackover Formation in LCCF indicates that the reservoirs are controlled mainly by depositional facies, and secondarily by diagenesis, which caused significant changes in the pore system. The ooid-oncoid-peloid grainstone facies of LCCF can be subdivided in two sub-units: ooid grainstone and oncoid-peloid grainstone. These sub-units have distinct pore system geometry. The highest porosity values occur where the ooid-oncoid-peloid grainstone unit is thicker, and the ooid grainstone sub-unit dominates.

The ooid-oncoid-peloid grainstone and microbial thrombolite reservoirs facies were modified by a distinct early diagenetic process and similar late diagenetic evolution. The ooid-oncoid-peloid grainstone was exposed to meteoric waters, whereas the microbial thrombolite was not. Meteoric waters caused dissolution of the grains, generating secondary moldic porosity, and precipitation of drusy calcite fringe and very fine mosaic cement. The drusy calcite fringe blocked the pore throats, which significantly decreased permeability to 1 and 10 md. Late burial diagenetic processes were more intense in the microbial thrombolite facies. Dolomitization associated with calcite dissolution occurred in the south portion of the field, enhancing permeability and causing permeability values to be more uniform vertically and laterally. Late burial coarse mosaic to blocky calcite cementation was more intense in the north portion of the field, reducing primary porosity. Late burial dissolution process, which caused enlargement of depositional pores and created large vugs, was more intense in the thicker portions or the microbial thrombolite, and provided enhanced porosity and permeability.

CHAPTER II

PORE GEOMETRY AND PETROPHYSICAL CHARACTERISTICS OF THE UPPER JURASSIC SMACKOVER FORMATION THROMBOLITE RESERVOIRS IN SOUTHWESTERN ALABAMA

II.1 Synopsis

Depositional facies define good quality reservoirs in the Upper Jurassic Smackover Formation, but diagenesis plays an important role in enhancing or reducing their porosity and permeability. The Smackover Formation thrombolite unit is a prolific reservoir in southwestern Alabama. Most of the Smackover Formation thrombolite discovered so far was dolomitized, and the original depositional characteristics of the rock are obscured. However, the thrombolite at Little Cedar Creek Field has only a minor amount of dolomitization, and most of its depositional texture is preserved. Samples of dolomitized thrombolite from Appleton and Vocation Fields were studied for comparison.

Dolomitization accompanied by calcite dissolution caused important changes in the Smackover Formation thrombolite reservoir in Little Cedar Creek Field. During the dolomitization process, the grains and early calcite cements were progressively replaced by dolomite crystals, and intercrystalline porosity was generated. As the number of meso and macropores increased, pore geometry became more homogeneous. Pore-throats are smaller in intercrystalline porosity (generated by dolomitization) than in connected vuggy porosity (depositional vugs, commonly enhanced by late dissolution), but dolomitization enhances connectivity in originally low permeable intervals.

The south portion of the Smackover Formation thrombolite at Little Cedar Creek Field is partially dolomitized, which caused porosity and permeability average values to increase significantly, from less than 10% to 15 - 20% porosity average, and from less than 50 md to 100 – 600 md permeability in average. The thrombolite units at Appleton and Vocation fields are intensely dolomitized, more homogeneous vertically and laterally, and also have higher porosity and permeability values than at Little Cedar Creek Field.

II.2 Introduction

Depositional facies define good quality reservoirs of Smackover Formation, but diagenesis plays an important role in enhancing or reducing their porosity and permeability. Thrombolite and ooid grainstone are the two most prolific reservoir facies of the Smackover Formation (Benson and Mancini, 1999; Kopaska-Merkel and Mann, 1991; Mancini et al., 1991; Mancini et al., 2006), whereas dolomitization and dissolution are the main diagenetic processes improving porosity and permeability (Benson and Mancini, 1999; Benson, 1988; Kopaska-Merkel and Mann, 1991; Mancini et al., 1991; Moore and Druckman, 1981; Prather, 1992b).

The thrombolite unit of the Smackover Formation at Little Cedar Creek Field, in Alabama, USA (Fig. II.1), has only a minor amount of dolomite, and most of its depositional texture is well preserved, making Little Cedar Creek Field a unique location to study facies distribution and diagenetic alteration. Smackover Formation thrombolitic reservoir facies in all its other fields were intensely dolomitized, (Barrett, 1986; Benson and Mancini, 1999; Mancini et al., 1991; Prather, 1992b) and most of the depositional characteristics of these rocks were obscured. Appleton and Vocation fields are also located in Alabama (Fig. II.1), being geographically close to Little Cedar Creek Field, but they are intensely dolomitized thrombolite reservoirs. Therefore, Appleton and Vocation fields thrombolite reservoirs were compared with the Little Cedar Creek Field thrombolite reservoir. Comparing the pore geometry and petrophysical properties of calcitic, partially dolomitized and completely dolomitized thrombolite provides a better understanding of changes reservoir characteristics caused by dolomitization. This paper discusses the relationship between rock texture, pore geometry and petrophysical properties and the modifications caused by dolomitization in Smackover Formation thrombolite reservoirs.

II.3 Geological Setting

The Upper Jurassic (Oxfordian) Smackover Formation records carbonate deposition on a carbonate ramp (Ahr, 1973). Local variations in topography on the ramp were produced by pre-Jurassic salients or salt tectonics (Ahr, 1973; Driskill et al., 1988). Paleozoic ridges and Mesozoic horst blocks produced a number of paleohighs in the eastern Gulf of Mexico that separated southwest Alabama into a series of sub-basins or embayments (Benson, 1988; Mancini and Benson, 1980; Prather, 1992). The Conecuh Ridge separates the Manila Sub-basin from the Conecuh Sub-basin, which is bordered to the southeast by the Pensacola Ridge (Fig. II.1).

The Oxfordian was characterized by a widespread sea level rise that progressively affected larger parts of the Gulf of Mexico Basin and surrounding areas (Salvador, 1987). Four Upper Jurassic (Oxfordian) to Lower Cretaceous (Valanginian) transgressive to regressive (T-R) sequences formed across the Gulf Coast and the offshore northeastern Gulf of Mexico region (Mancini et al. 2008).

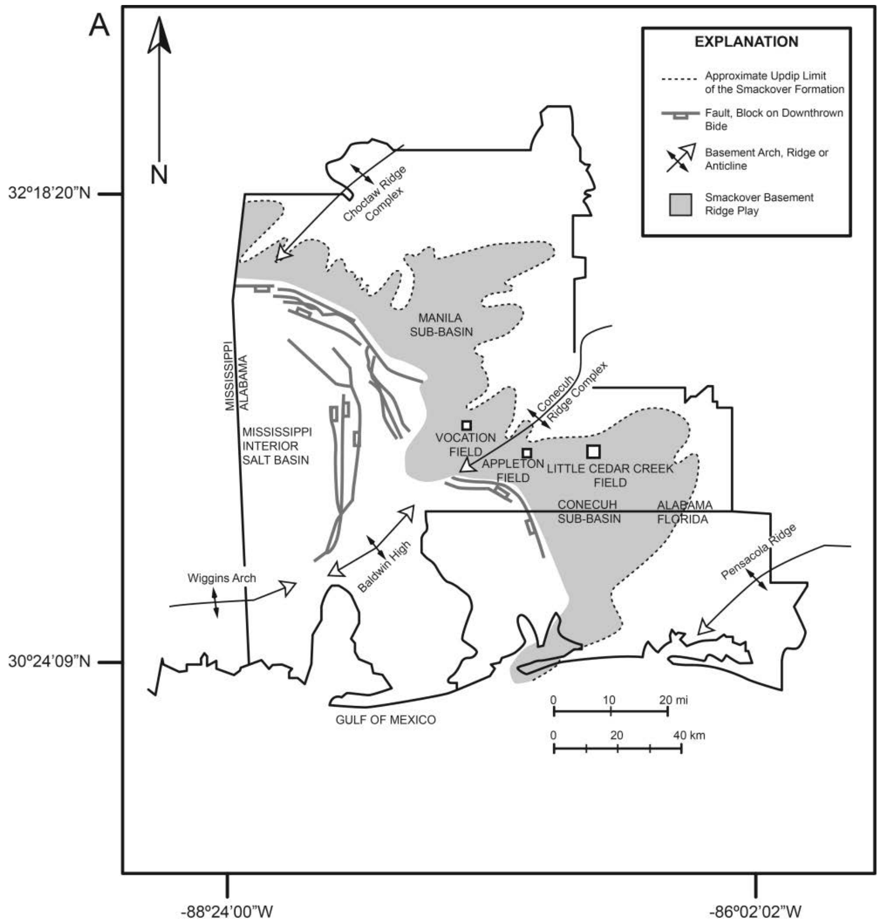


Figure II.1. Location map of Little Cedar Creek, Appleton and Vocation fields, Southwestern Alabama, U.S.A. (modified from Mancini et al. 2008).

The Smackover Formation is sub-divided into two systems tracts. The lower and middle Smackover Formation compose a transgressive systems tract (TST). Microbial reefs developed in the TST, and their growth ended before the maximum flooding zone (MFZ) that is characterized by a marine condensed section composed of relatively deep subtidal carbonate mudstone. The upper Smackover Formation (oncoid, peloid and ooid grainstone to wackestone) and the Buckner Anhydrite Member of the Haynesville Formation (Fig. II.2) represent the subsequent highstand systems tract (HST) (Mancini et al., 1990).

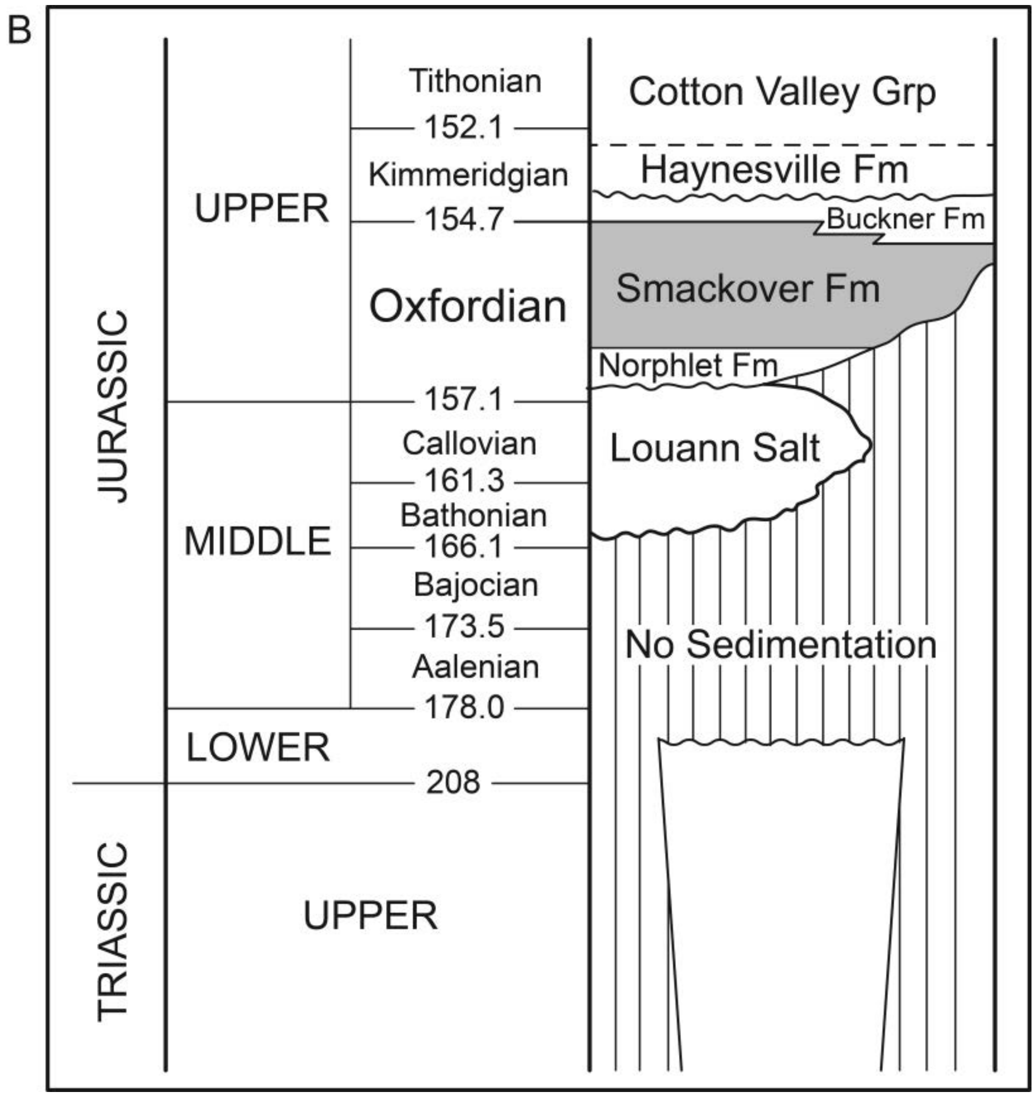


Figure II.2. Stratigraphic column of the Upper Jurassic formations of the northern U. S. Gulf Coast (modified from Heydari and Baria 2006).

II.3.1 Smackover Formation Reefs

Smackover Formation reefs occur from Arkansas to Florida as elongate features, 3 to 43 m (10 to 141 ft) thick, and several square kilometers in plan view. The reefs consist of cyanobacteria (microbial thrombolite buildups) or a more diverse coral-algal assemblage. Smackover Formation reef diversity is higher in southern Arkansas and northern Louisiana than in Alabama and Florida, where its depositional environment was more restricted (Baria et al., 1982). The reefs developed seaward of oolite shoals on three types of paleostructures that created subtle topographic relief: (1) basement ridges, (2) faulted basement highs, and (3) upthrown salt-cored fault blocks (Baria et al., 1982). However, the microbial buildups in the Little Cedar Creek Field area developed in paleogeographic settings including nearshore, shallow subtidal paleoenvironments along the updip margin of the Smackover Formation rather than on Paleozoic basement paleohighs (Koralegadara and Parcell, 2008; Mancini et al., 2006; Mancini et al., 2008).

II.4 Methods

Cores of 32 wells from Little Cedar Creek Field, 2 wells from Appleton Field, and 1 well from Vocation Field (Fig. II.3) were described using the Dunham (1962) classification of carbonate textures. Structures and macrotextures, porous intervals, and pore size also were documented. Samples include 153 plugs (1 inch diameter) taken in a variety of textures and porosity features of the reservoirs. Porosity and permeability measurements were determined from 115 plugs, and capillary pressure measurements by mercury injection were performed on 30 plugs. 320 pre-existing porosity and permeability data also were analyzed and compared with the data generated in this study.

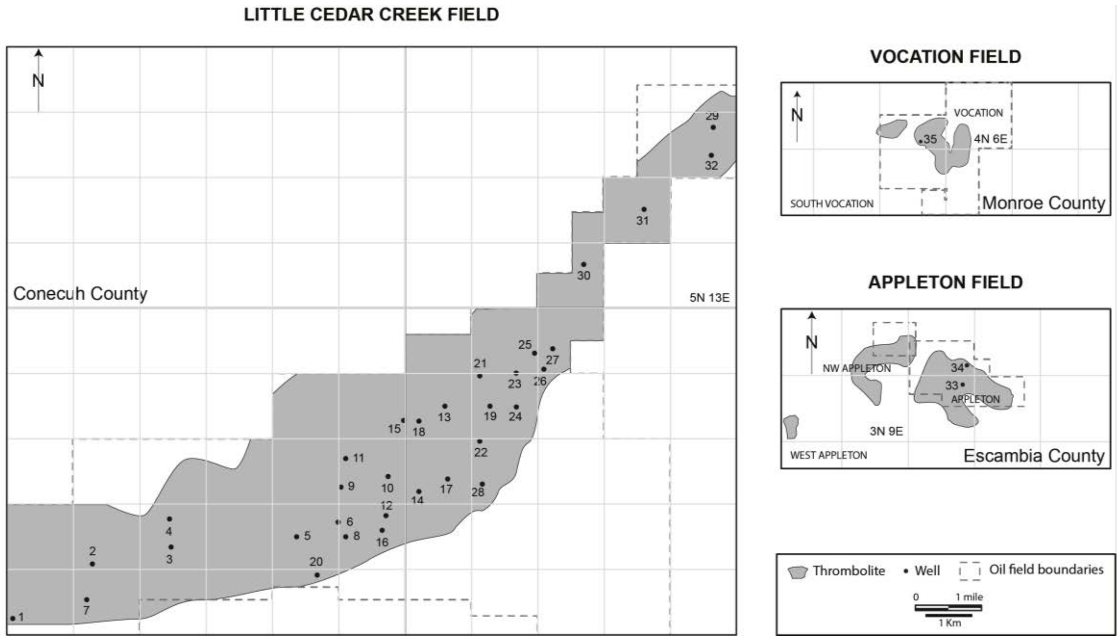


Figure II.3. Thrombolite map in Little Cedar Creek, Appleton and Vocation fields with the location of the wells (Appleton and Vocation fields maps - modified from Llinás 2004).

Standard petrographic analysis of 153 thin sections, 40 of which were stained with Alizarin Red-S and Potassium ferricyanide (Dickson 1966) were used to characterize microfabrics, diagenetic features and porosity. Pore geometry analysis was done in 50 thin section images using the Image-Pro Premier® software. The number of pores measured in each thin section varied from 1,000 to 20,000. Area, perimeter, maximum and minimum diameter were measured for each pore. Percentage of micropores (< 50 μm), mesopores (50 – 100 μm), and macropores (> 100 μm), as well as roughness (perimeter over area) and elongation (maximum diameter over minimum diameter) of each pore were calculated.

II.5 Results

II.5.1 Smackover Formation Thrombolite Reservoir at Little Cedar Creek Field

Little Cedar Creek Field, discovered in 1994, contains significant oil accumulation in two zones in the Upper Jurassic Smackover Formation: a lower thrombolite reservoir and an upper ooid-oncoid-peloid grainstone to packstone reservoir (Heydari and Baria, 2005; Mancini et al., 2006; Mancini et al., 2008; Ridgway, 2010; Al Haddad and Mancini, 2013). The thrombolite reservoir facies in Little Cedar Creek Field is approximately 42 km (26 mi) long, 5 to 11 km (3 to 7 mi) wide and from 9 to 21 m (30 to 70 ft) thick, oriented along a NE-SW trend (Fig. I.5 A). The thrombolite has a clotted, mottled and nodular texture, with rare domal and branching structures. The thrombolite includes abundant peloids, with minor amounts of skeletal fragments of benthic foraminifera and ostracods. Dolomite can compose as much as 30% of the bioherm and its occurrence gradually decreases from south to north, being absent from near the center to the northeast portion of the field (Fig. I.13 B).

The pore types in the thrombolite are primary growth framework vugs and intergranular, and secondary diagenetic vugs (primary growth framework vugs enlarged by late dissolution), intercrystalline porosity (when calcite cement crystals or dolomite crystals have pore space between them) and microfractures. Petrophysical characteristics are highly variable laterally and vertically inside the thrombolite. The thickness of the thrombolite increases from west to east, and the lateral pore size distribution follows the same trend, increasing from mesopores near the western border to megapores near the eastern border where dissolution produced vugs from 2 to 6 cm (0.8 to 2.4 in) in diameter. In limestone thrombolite, core-plug analysis indicates that porosity values vary from 3 to 19% (Fig. I.14 A), and permeability values vary from less than 1 to 100 md, locally as much as 500 md where late dissolution is more intense. Large diagenetic vugs and fractures can cause local permeability values to be 1 to 4 darcys, rarely as much as 7 darcys. In partially dolomitized intervals of the thrombolite, porosity varies from 10 to 21%, and permeability generally varies from 150 to 850 md, but is locally as much as 1200 md (Fig. I.14 B).

II.5.2 Smackover Formation Thrombolite at Appleton and Vocation Fields

Appleton Field, located on the western margin of the Conecuh Sub-basin and on the eastern flank on the Conecuh Ridge (Fig. II.1), was discovered in 1983 in a well drilled on the top of a paleotopographic structure. Reservoir-grade porosity at Appleton field occurs in the thrombolite and in oolitic, oncoidal, and peloidal grainstone and packstone in the Upper Smackover Formation (Mancini et al., 2000). Porosity in the thrombolite is a mixture of primary growth framework vuggy porosity overprinted by secondary intercrystalline and vuggy porosity produced by dolomitization and dissolution that is pervasive throughout the field. Porosity in the microbial thrombolite ranges from 9.5 to 25.3 % and averages 16.9 %, whereas permeability ranges from 1.1 to 4106 md and averages 356 md (Benson et al., 1997).

Vocation Field, located in the southeastern margin of the Manila Sub-basin along the weastern flank of the Conecuh Ridge (Fig. II.1), was discovered in 1971. A thrombolite reservoir occurs in the lower part of the Smackover Formation, being deposited on the flank of a paleohigh. Pore types are vugs, interparticle and fracture pores (Llinas, 2002). Porosity ranges between 8 and 20% with an average of 13%, whereas permeability ranges from 30 to 410 md with an average of 175 md.

II.5.3 Modification in the Thrombolite Reservoir by Dolomitization

All the Smackover Formation thrombolite reservoirs discovered so far are intensely dolomitized, except at Little Cedar Creek Field, where most of the depositional features of the thrombolite are preserved. Samples from Little Cedar Creek, Appleton and Vocation fields were analyzed and compared. Porosity, permeability, capillary pressure and pore geometry analysis was completed on calcitic, partially and completely dolomitized thrombolite samples.

Change in the rock texture caused by the dolomitization process is the first observed feature. The Smackover Formation thrombolite depositional texture in Little Cedar Creek Field consists predominantly of peloids with some bioclasts. Early diagenetic marine calcite cement rims the grains (mainly peloids and peloid clusters). The dolomite crystals replace grains and calcite cements, locally growing in the pore space (Fig. II.4 – pictures A, AA, B, and BB). Dolomite forms a new framework, while calcite is progressively dissolved. As a result, depositional grains and early diagenetic cements disappear and a new texture forms, where dolomite crystals dominate (Fig. II.4 – pictures 1 to 3).

The next change in the thrombolite caused by the dolomitization process is modification to its pre-existing pore system geometry. Pore geometry will dictate the petrophysical characteristics of the rock, as well as resistivity and sonic velocity responses (Verwer et al., 2011; Weger et al., 2009), therefore the importance of its characterization. Previous studies demonstrated that the simple pore structure with large pores provides an easy flow path for fluids, whereas intricate pore structures have narrower pore throats that impede the flow of fluids (Verwer et al., 2011).

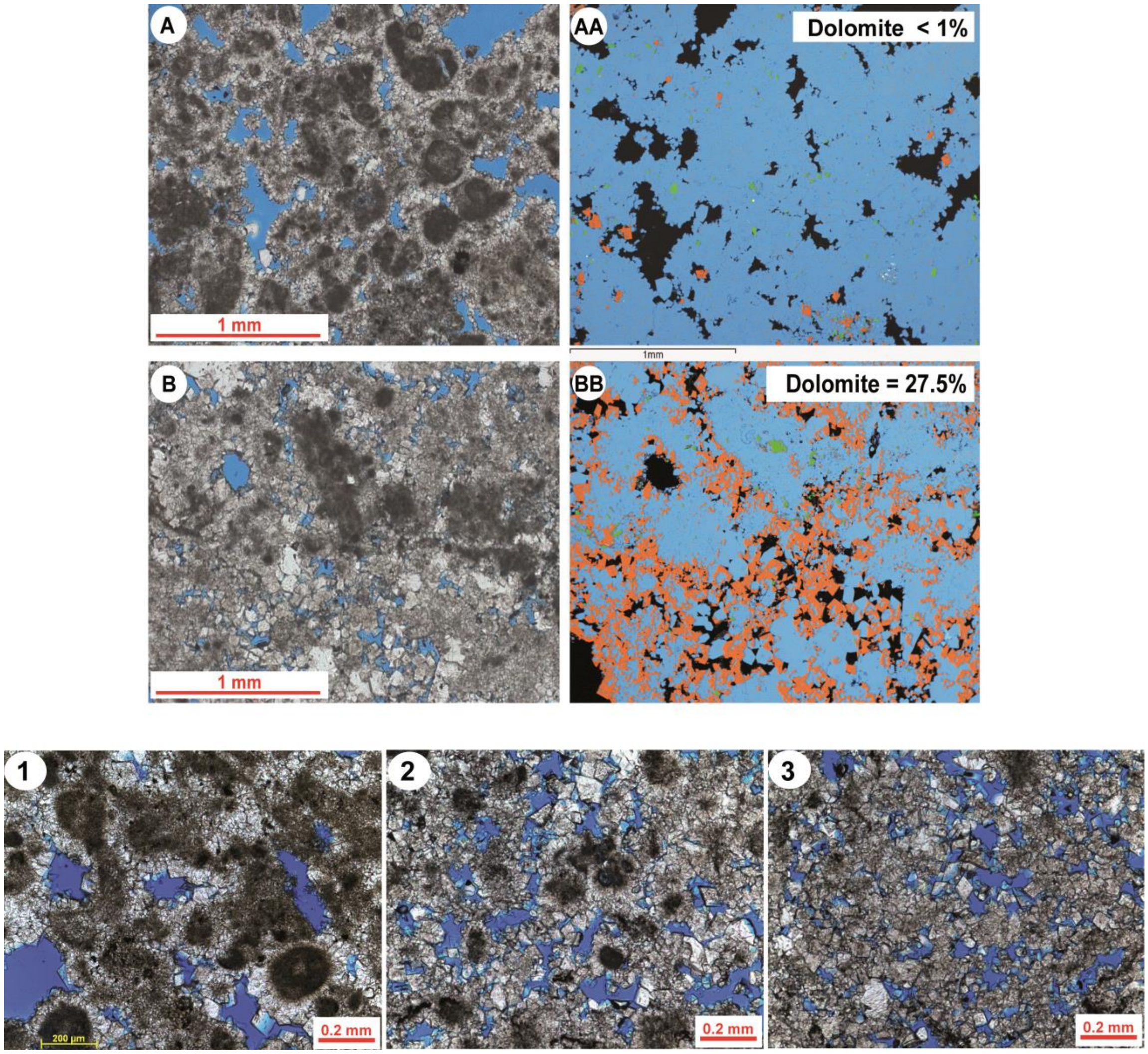


Figure II.4. Photomicrographs of the thrombolite unit on Little Cedar Creek Field. A – Plane-polarized photomicrography of the thrombolite, Little Cedar Creek Field. Dolomite is not significant. Well 1, depth: 11900.2ft. B – Plane-polarized photomicrography of partially dolomitized thrombolite, LCCF. The dolomite crystals replace grains and calcite cements, locally growing in the pore space. Well 5, depth: 11500.9 ft. AA and BB – Images paired with images A and B respectively. Colored x-ray compositional map made by the combination of x-ray maps of three elements: Ca, Si and Mg. Calcite = blue, dolomite = orange and quartz = green. 1, 2, and 3 – Modification of the depositional pore system by diagenesis in the Little Cedar Creek Field thrombolite reservoir. Increasing dolomitization from picture 1 to 3. The depositional texture (peloidal grains and clusters rimmed by marine calcite cements) gradually disappears with increasing dolomitization.

Primary macropores observed in Little Cedar Creek Field thrombolite consists mainly of growth framework vugs and intergranular porosity, both reduced by early diagenetic marine cements, and then locally enlarged by late burial dissolution. The dolomitization process causes significant modification in pore sizes and geometry, since the primary porosity is replaced by secondary intercrystalline pores.

Comparing calcitic, partially dolomitized and completely dolomitized thrombolite samples, it was observed that the number of macropores and mesopores increase with dolomitization (Figs. II.5 and II.6). The range of the pore sizes narrows in the dolomitized thrombolite, indicating a more homogeneous pore system (Fig. II.6). By reducing the percentage of micropores and increasing the percentage of mesopores and macropores, the effective porosity network is enhanced. The pores also became geometrically more homogeneous after the dolomitization process. A crossplot of the average roughness (perimeter over area) and elongation (maximum diameter over minimum diameter) of the macropores and mesopores in each thin section (Fig. II.7) shows that there is less variation in pore geometry with increasing dolomitization.

Capillary pressure analysis in the calcitic, partially dolomitized and completely dolomitized thrombolite shows distinct patterns of pore-throat size distribution for type of dominant porosity. In the calcitic thrombolite dominant pore types are isolated vugs, connected vugs (commonly enlarged by late dissolution), intergranular (between peloids and peloid clusters) and intercrystalline (between calcite cement crystals). In the partially dolomitized thrombolite dominant pore types are intercrystalline (between dolomite and calcite crystals) and vugs. In the dolomitized thrombolite dominant pore types are intercrystalline (between dolomite crystals) and connected vugs (Fig. II.8).

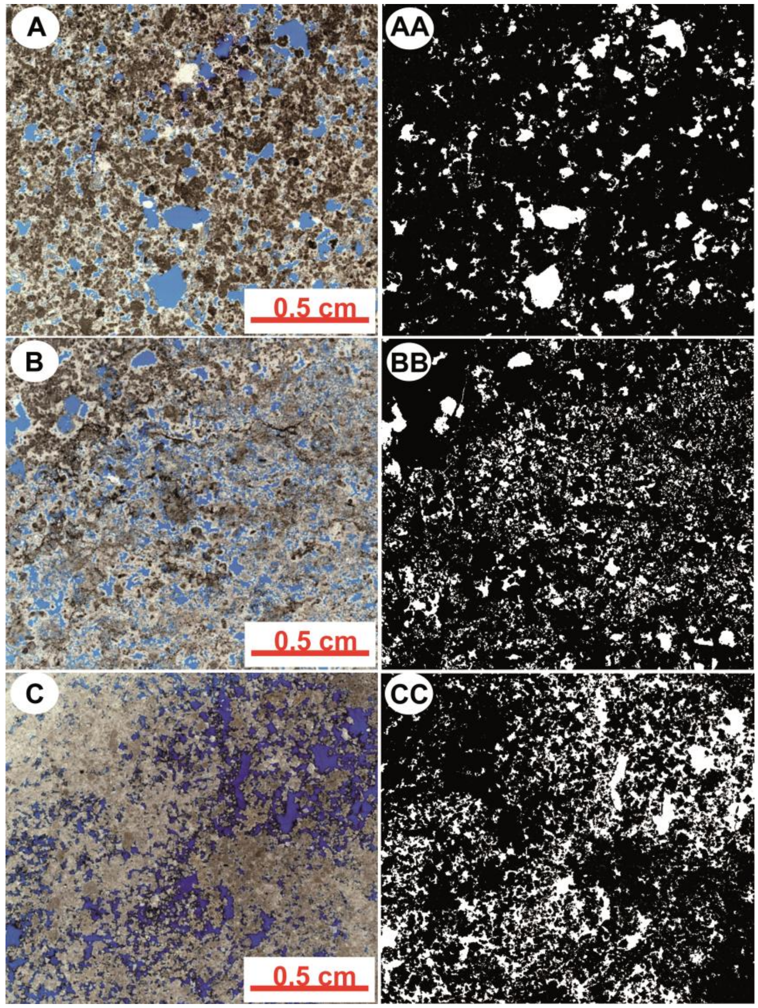


Figure II.5. Photomicrographs of the Smackover Formation thrombolite unit with distinct degrees of dolomitization. The figures on the left correspond to plane polarized petrographic images, where the pores are highlighted by blue epoxy. The figures on the right correspond to binary images, paired with the images on the left, where the pore system is highlighted in white. A / AA – Limestone Thrombolite. Intergranular and depositional growth framework vugs. Porosity = 12%. Permeability = 77 md. LCCF, well 2, depth: 11771 ft; B / BB – Partially dolomitized thrombolite. Some of the depositional texture (peloids) are still preserved. Intercrystalline porosity was created. Porosity = 16%. Permeability = 95.9 md. LCCF, well 2, depth: 11787.9ft; C / CC – Dolomitized thrombolite. Intercrystalline and vuggy porosity. No depositional texture preserved. Porosity = 18%. Permeability = 786 md. APPF, well 34, depth: 13149.4ft.

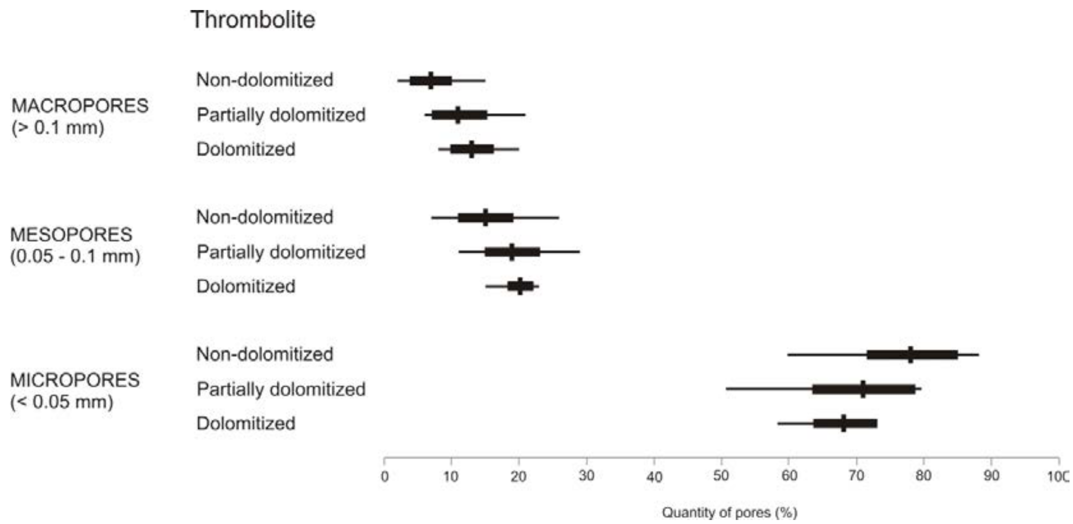


Figure II.6. Percentage of micropores (< 0.05 mm), mesopores (0.05 – 0.1 mm), and macropores (> 0.1 mm) measured in thrombolite thin sections from Little Cedar Creek, Appleton and Vocation fields using the software Image-Pro Premier®. Vertical bars are means, wide horizontal bars are ± one standard deviation, and narrow horizontal bars are ranges. The percentage of micropores decreases with dolomitization, whereas the percentage of mesopores and macropores increases.

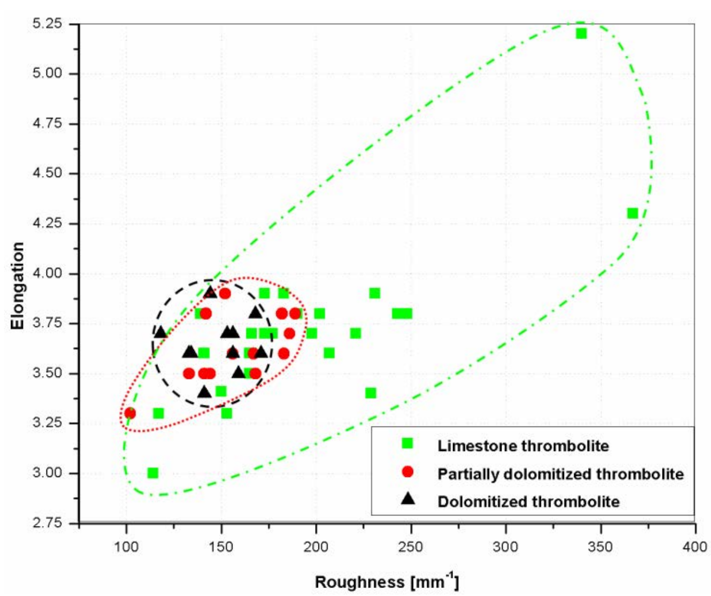


Figure II.7. Crossplot of the mean value of roughness (perimeter over area) and elongation (maximum diameter over minimum diameter) of macropores and mesopores measured through thin section image analysis using the software Image-Pro Premier®. Samples from Little Cedar Creek, Appleton and Vocation fields. There is less variation in pore geometry when the thrombolite is dolomitized.

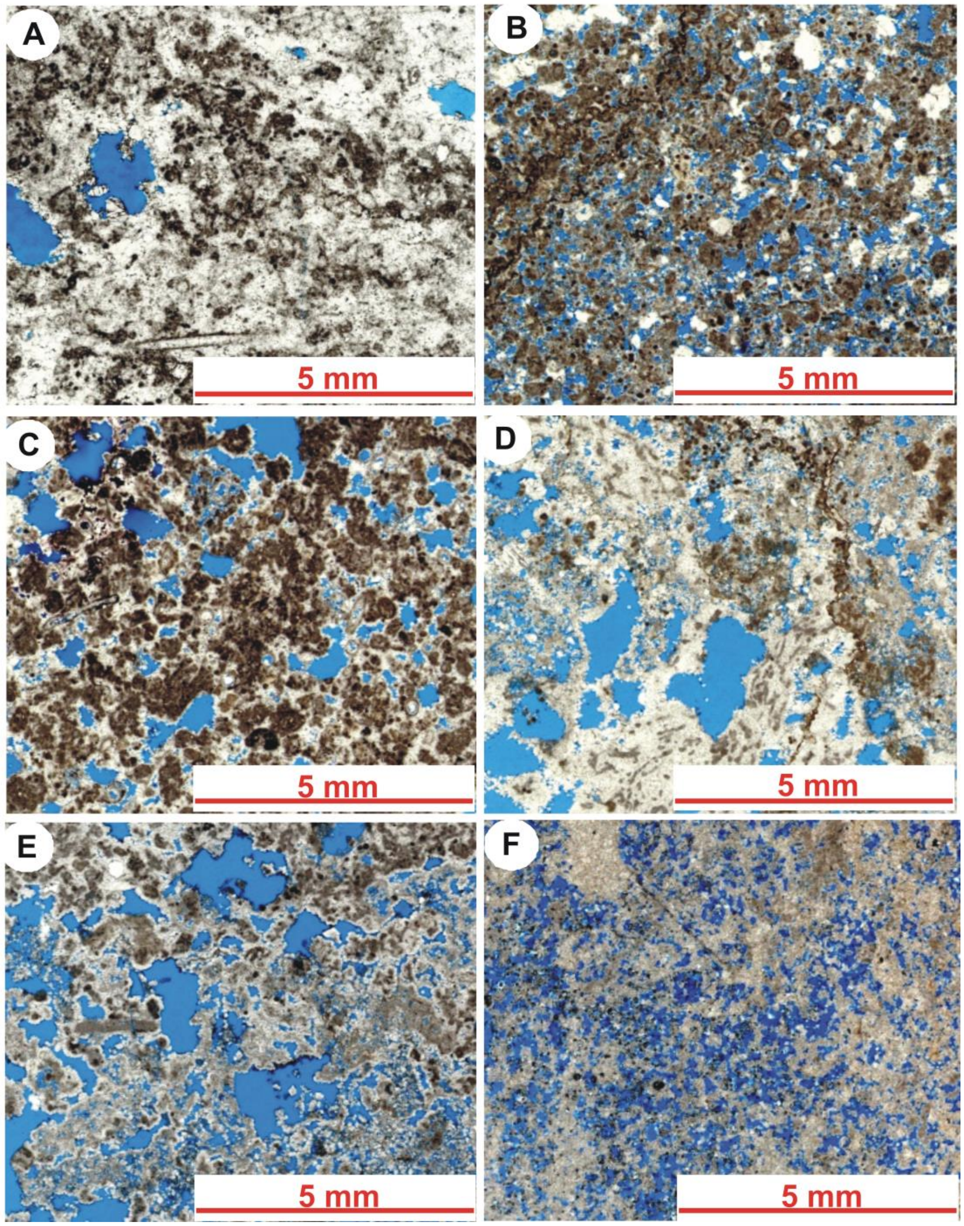
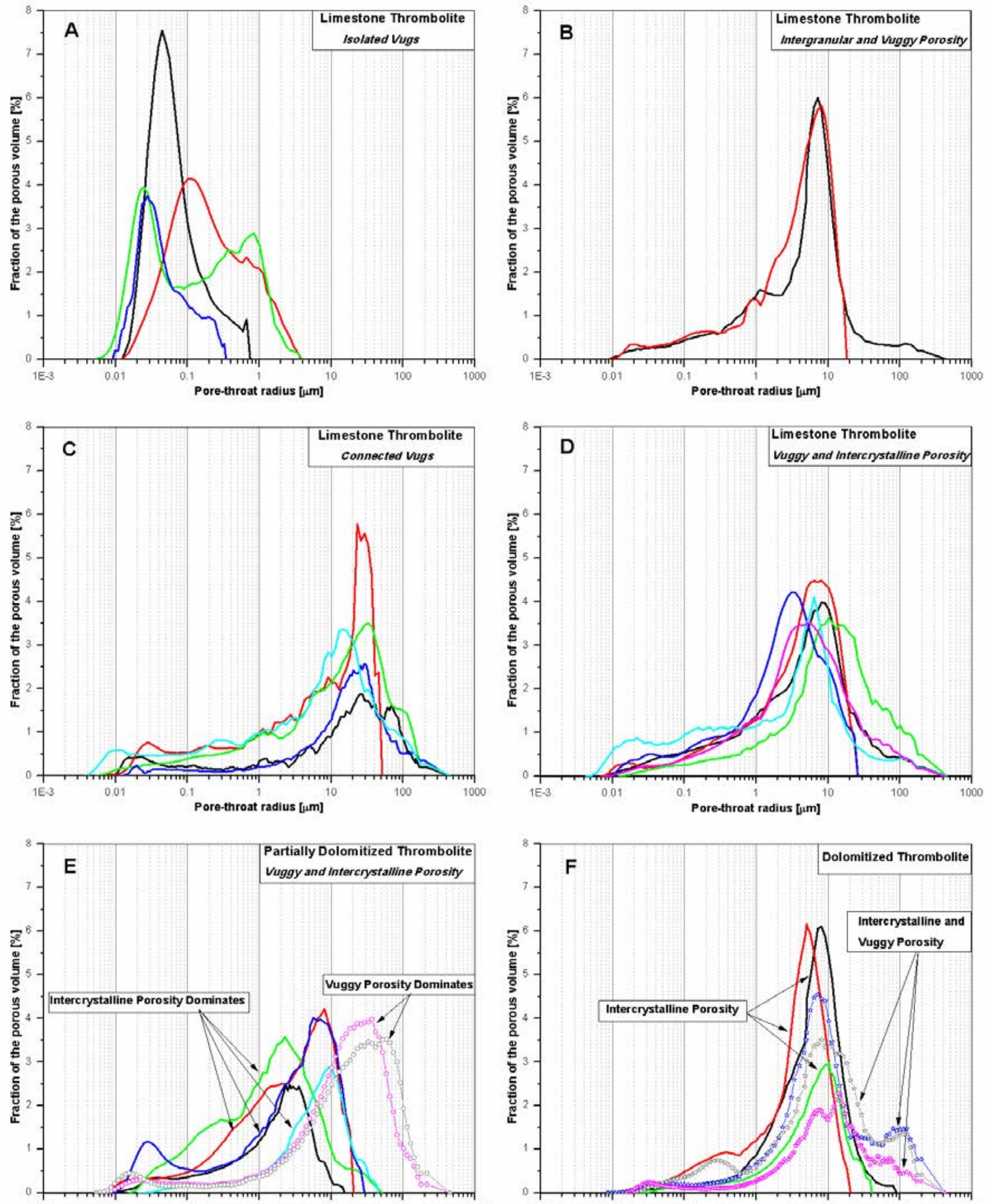


Figure II.8. Photomicrographs of the Smackover Formation thrombolite unit with distinct pore types. A – Limestone thrombolite, isolated vugs. Well 14, depth: 11314.7 ft. B – Limestone thrombolite, intergranular and vuggy porosity. Well 21, depth: 11249.3 ft. C – Limestone thrombolite, connected vugs. Well 2, depth: 11771 ft. D – Limestone thrombolite, vuggy and intercrystalline porosity. Well 21, depth: 11279.5 ft. E – Partially dolomitized thrombolite, vuggy and intercrystalline porosity. Well 3, depth: 11609.5 ft. F – Dolomitized thrombolite, intercrystalline porosity. Well 35, depth: 14182 ft. A to E – Little Cedar Creek Field. F – Vocation Field.

Samples with isolated vugs as the dominant pore type have low pore-throat size values (Fig. II.9 A), with a maximum pore-throat size of 3.7 μm, and average of 0.22 μm ±0.16. Connectivity between the vugs is poor, and cementation is very high (Fig. II.8 A). Few samples have intergranular porosity as the main pore type. Peloids are less clustered, and the rock texture is similar to a grainstone (Fig. II.8 B). Vugs also are present, causing high pore-throat sizes to occur. Pore-throat size can be as high as 201.3 μm, and the average mean is 7.8 μm ± 3.8 (Fig. II.9 B). Where depositional vugs are more abundant and larger, the pore system is originally better connected. Burial fluids percolated through the porous and permeable thrombolite, causing dissolution and enlargement of depositional vugs, as well as some late burial calcite cementation and dolomitization. When connected vugs occur as the dominant pore type the values of pore-throat size are larger (Figs. II.9 C, II.9 D and two curves on Fig. II.9 E), with maximum pore-throat size of 215 μm, and average mean from 11.5 μm ± 7.1 to 30.9 μm ± 5. In the samples with intercrystalline porosity as the dominant pore type, the maximum pore-throat size is 80.5 μm, and when vugs are present it can be as high as 199.5 μm. The average mean of pore-throat size varies from 4.7 μm ± 2.3 to 7.2 μm ± 2.1. A summary of pore-throat size distribution based on capillary pressure of 30 samples is shown on Table A.5 (Appendix A).

In the Smackover Formation thrombolite a combination of vuggy and intercrystalline porosity is very common. Late calcite cementation and dolomitization processes, associated with calcite dissolution generated intercrystalline porosity, causing pore-throat size distribution to be concentrated between 0.1 and 15 μm. Late burial dissolution also enhanced connectivity between vugs, causing pore-throat size distribution to concentrate between 1 and 215 μm.

Figure II.9. Fraction of the porous volume in percentage *versus* natural log of pore-throat radium in micrometers. Samples were grouped by lithology and dominant pore type. A to D – Limestone thrombolite. A – Isolated vugs. B – Intergranular and vuggy porosity. C – Connected vugs. D – Vuggy and intercrystalline porosity. E – Partially dolomitized thrombolite. Vuggy and intercrystalline porosity. F – Dolomitized thrombolite. Intercrystalline and intercrystalline and vuggy porosity. Thin section images in figure II.8 are examples of samples with curves shown in this picture. A resume of maximum and minimum and average mean of pore-throat size for these samples is shown on Table A.5 (Appendix A).


A
Limestone Thrombolite
Isolated Vugs
B
Limestone Thrombolite
Intergranular and Vuggy Porosity
C
Limestone Thrombolite
Connected Vugs
D
Limestone Thrombolite
Vuggy and Intercrystalline Porosity
E
Partially Dolomitized Thrombolite
Vuggy and Intercrystalline Porosity
Intercrystalline Porosity Dominates
Vuggy Porosity Dominates
F
Dolomitized Thrombolite
Intercrystalline Porosity
Intercrystalline and Vuggy Porosity
Fraction of the porous volume [%]
Pore-throat radius [μm]

The difference in pore-throat size distribution can also be visualized through capillary pressure curves (Fig. II.10). The samples with isolated vugs are the less efficient rock type in the reservoir, since connectivity between the vugs are poor, and the entry or displacement pressure is very high (Fig. II.10 A). Capillary pressure values in samples with connected vugs as the dominant pore type are lower than capillary pressure values in samples with intercrystalline porosity as the dominant pore type (Figs. II.10 C and II.10 D). Capillary pressure curves of thrombolite indicates that intercrystalline porosity increases capillary pressure values by reducing pore-throat radius size (Fig. II.10 B).

As a result of the changes in rock texture and pore system geometry by diagenesis, petrophysical properties of the Smackover Formation thrombolites also changed. The limestone thrombolite in Little Cedar Creek Field has large variation of petrophysical properties vertically, where high porosity and permeability values depend on the presence of a larger number of growth framework vugs and diagenetic vugs (Fig. II.11 A).

The dolomitized thrombolite in Appleton and Vocation fields has more homogeneous petrophysical properties vertically, being associated with the occurrence of intercrystalline pores. It also has higher average porosity and permeability values than the limestone thrombolite of Little Cedar Creek Field (Fig. II.11 B).

Porosity-permeability crossplots (Fig. II.12) show that limestone thrombolite has a greater range of values, from very low to very high porosity (3 to 22%) and permeability (<0.1 to 4000 md), whereas the partially dolomitized and totally dolomitized thrombolite have mainly high values of porosity and permeability (generally porosity > 10% and permeability > 10 md), but permeability values greater than 1000 md are less common.

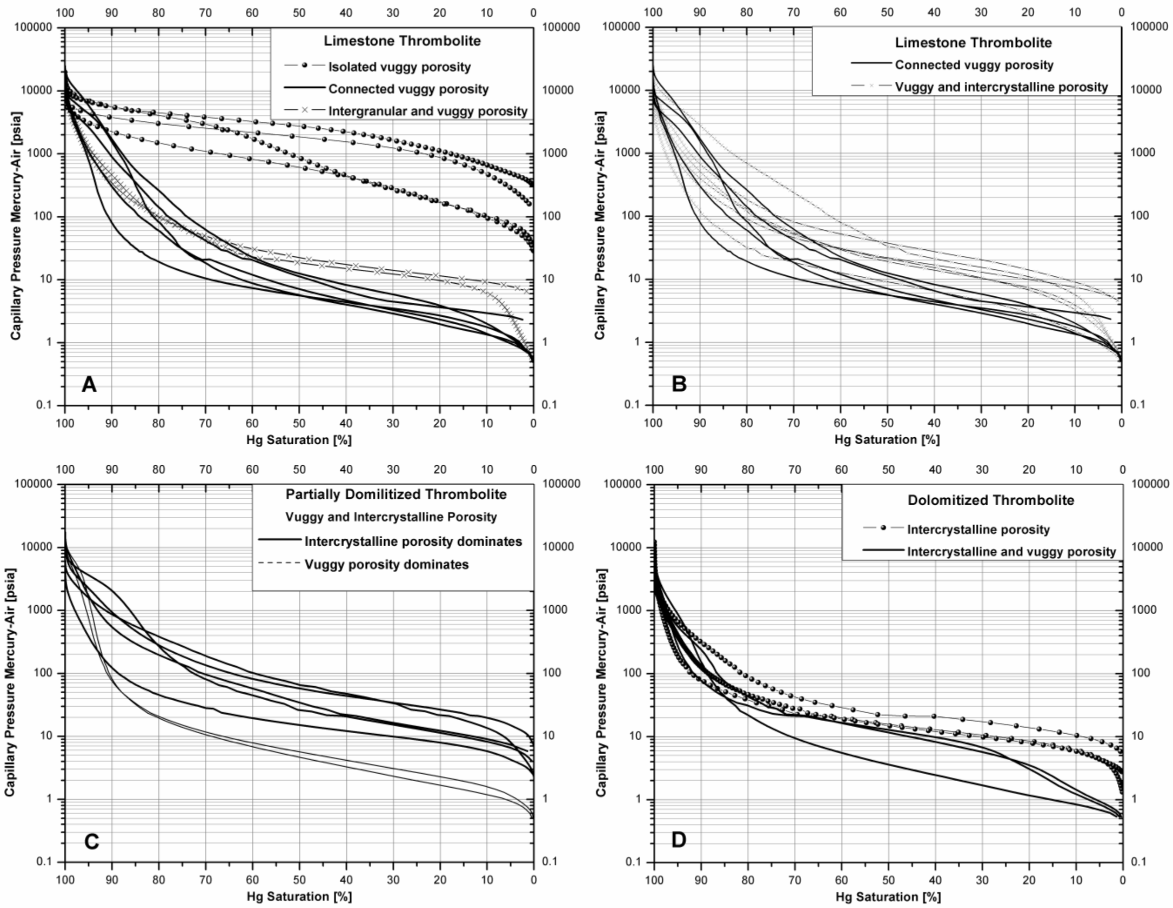


Figure II.10. Capillary pressure curves of Smackover Formation thrombolite samples. The samples were grouped by lithology, pore type and pore type abundance. Distinct dominant pore type (s) present distinct curve appearance, since pore-throat size is related to pore type. A – Samples with isolated vugs as the dominant pore type present small pore-throat sizes and high entry pressure values. Samples with connected vugs present low capillary pressure and entry pressure values. Samples with vuggy and intergranular porosity have higher capillary pressure values when compared with samples with only vuggy porosity. B – Samples with vuggy and intercrystalline porosity present higher capillary pressure values than samples with only vuggy porosity. C – In partially dolomitized thrombolite samples, capillary pressure values are higher when intercrystalline porosity dominates over vuggy porosity. D – In completely dolomitized thrombolite samples capillary pressure values are higher when intercrystalline porosity is the major pore type, and vuggy porosity is not significant. Capillary pressure curves observed in B, C and D show that samples with intercrystalline porosity as its dominant pore type present higher capillary pressure values, and consequently lower pore-throat sizes, than samples with connected vugs as the dominant pore type.

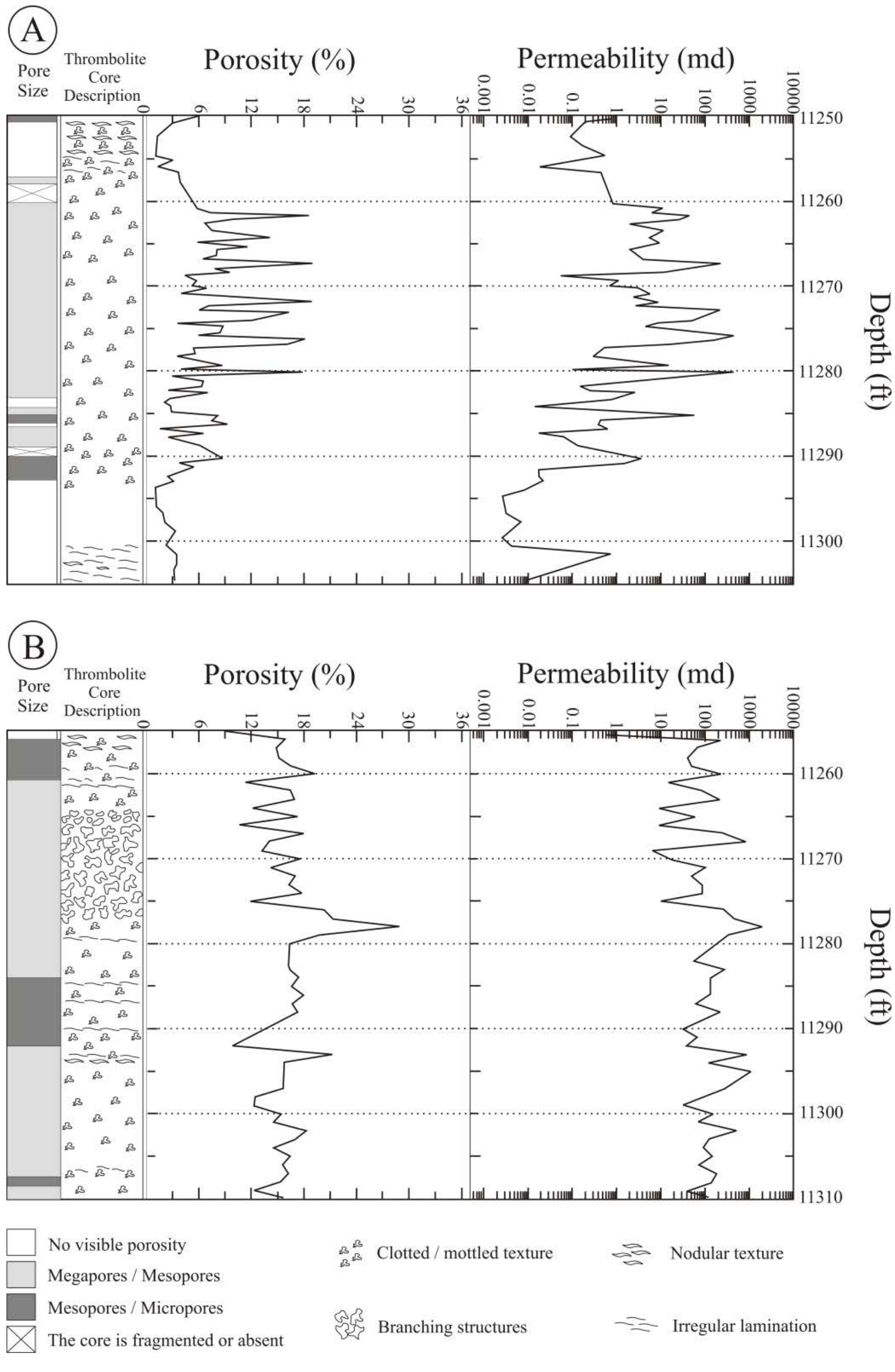


Figure II.11. Correlation of core description and vertical porosity and permeability trends (petrophysical data from core plugs) of Smackover Formation thrombolite reservoirs. A – Limestone thrombolite. LCCF, Well 21. B – Dolomitized microbial thrombolite. APPF, well 33. Micropore correspond to pore size smaller or equal than 0.0625 mm (silt size), mesopore correspond to pore size between 0.0625 mm and 4 mm (sand and granule size), and megapore correspond to pore size bigger than 4 mm (pebble size).

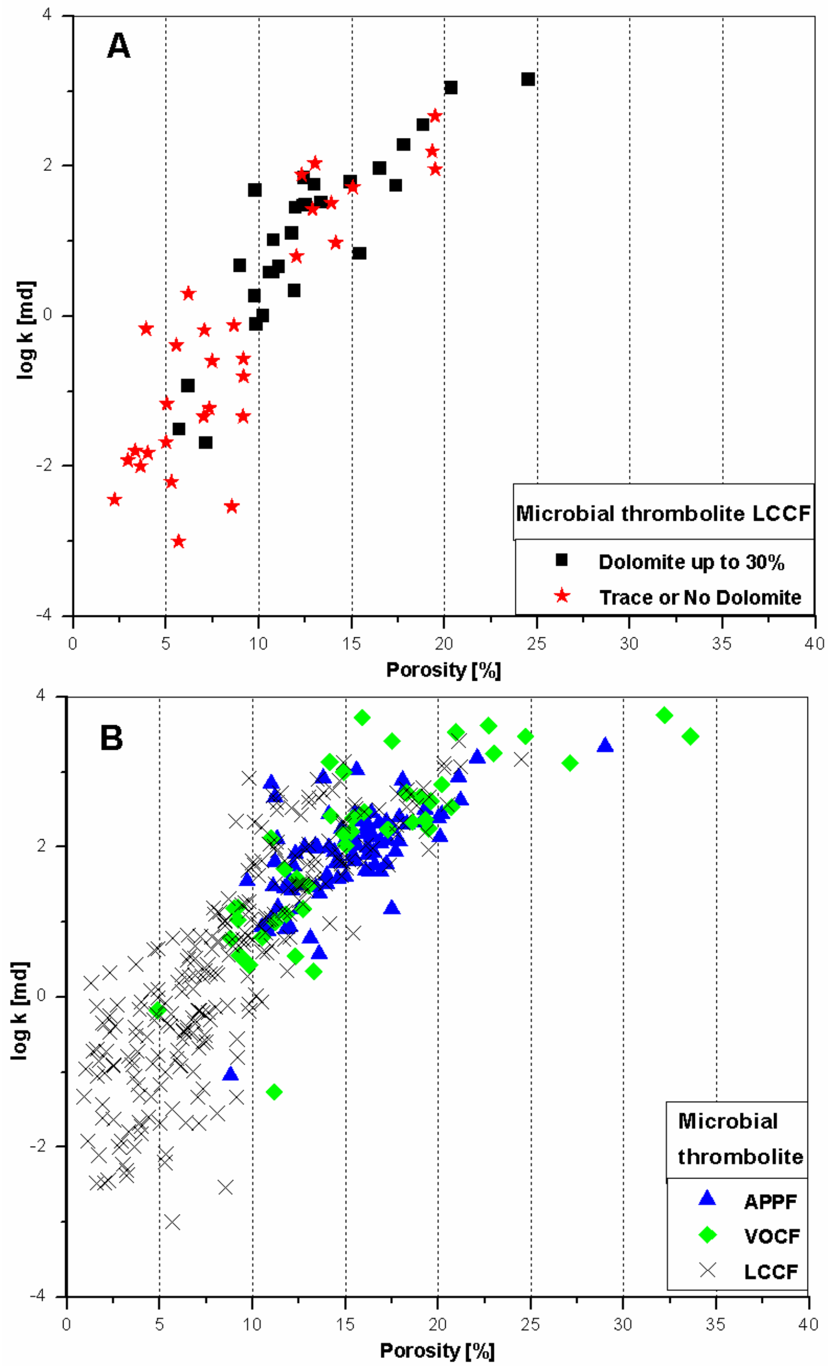


Figure II.12. Porosity-permeability crossplots. A – Thrombolite petrophysical data from Little Cedar Creek Field. The dolomitization process tends to increase porosity and permeability values in the reservoir. B –Thrombolite petrophysical data from Little Cedar Creek, Appleton and Vocation fields. The intense dolomitization in Appleton and Vocation fields increased porosity and permeability averages, and caused these reservoirs to be more homogeneous in their petrophysical characteristics.

Intervals with large connected vugs have very high permeability values (> 1000 md), but these intervals are thin and don't have lateral continuity in the reservoir. As dolomitization takes place, large vugs are reduced by dolomite crystals, but porosity is generated in originally low porosity-permeability intervals. Therefore, despite of the reduction of pore-throat sizes (and consequently reduction of permeability) by dolomitization, the increase on the amount of macro and mesopores in originally porous intervals and the genesis of a new pore framework in originally low porous intervals caused significant improvement in reservoir quality.

II.6 Discussion

Petrophysical rock types of Smackover Formation reservoirs in southwest Alabama were first characterized by defining their "pore facies", which are rock units that are defined by certain proportions of pore types. The only pore facies identified in the Smackover Formation thrombolite reservoirs in southwest Alabama in previous studies (Kopaska-Merkel and Mann, 1991) was the intercrystalline pore facies. However, vuggy porosity also is significant in thrombolite reservoirs (Baria et al., 1982; Mancini et al., 2000; Mancini et al., 2006; Mancini et al., 2008). With the discovery of the Little Cedar Creek Field thrombolite (Heydari and Baria, 2005; Mancini et al., 2006; Mancini et al., 2008), which is dominated by depositional growth framework vugs and diagenetic vugs, vuggy porosity in the Smackover Formation also needs to be considered.

The influence of dolomitization in the pore geometry and petrophysical properties of Smackover Formation thrombolites was not described in previous studies. The dolomitization process in the Smackover Formation thrombolite caused changes in rock mineralogy, texture and pore geometry. As a consequence of these changes, petrophysical properties were also modified.

The dolomitization process in Little Cedar Creek Field was accompanied by calcite dissolution. The new dolomite crystals created a new framework, replacing grains (mainly peloids) and early calcite cements. Some calcite crystals also grew as cement into the pore space. Dissolution of the calcite that remained between dolomite crystals created new intercrystalline pore space and a more homogeneous and connected pore system, enhancing porosity (Fig. II.13). Pore and pore-throat size, as well as pore geometry values became more homogeneous, and the number of meso and macropores increased.

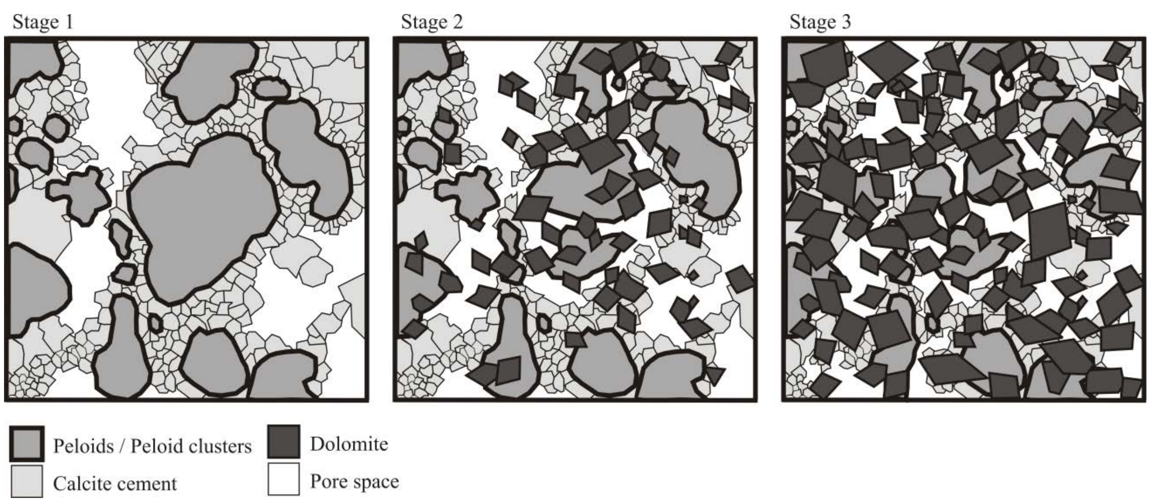


Figure II.13. Schematic drawing of the dolomitization process in the Smackover Formation thrombolite reservoir in Little Cedar Creek Field. Stage 1 – Vugs are the main pore type. Stage 2 – Dolomite crystals start to replace calcite and grow in the pore space. Grains and calcite cement are partially dissolved. Stage 3 – Dolomitization of the rock and dissolution of calcite continues. Vugs are replaced by intercrystalline porosity. The dolomitization process causes the number of pores to increase, and large vugs tends to disappear (compare with stage 1).

In the center to the northern portion of the Smackover Formation thrombolite reservoir in Little Cedar Creek Field a different diagenetic process created a similar modification in the pore system as the dolomitization. This process consisted of partial dissolution of the rock and the growth of very fine calcite crystals as non-compact cement, leaving pore space between the calcite cement crystals (Fig. II.8D). The major difference is in the spatial distribution of these diagenetic events. The dolomitization is more pervasive in the rock, and causes the reservoir to be more homogeneous horizontally and vertically. The dissolution of the rock combined with very fine calcite cementation is restricted to small portions of the rock, forming patches.

Dolomitization and calcite dissolution occurring simultaneously and enhancing reservoir quality also occur in Miocene carbonates (microbialite, grainstone, and packstone) of the Terminal Carbonate Complex (TCC), in the Cabo de Gata region in southeastern Spain (Goldstein et al., 2012, Lipinski et al., 2013). In these carbonates, dolomitization and dissolution were produced by subaerial exposure and associated meteoric diagenesis (Goldstein et al., 2012). Stromatolite facies have average porosity and permeability of 17 % and 70.5 md, dense thrombolite facies have average porosity and permeability of 19% and 68.9 md, and vuggy thrombolite facies have average porosity and permeability of 32% and 4201 md (Lipinski et al., 2013).

Other example of dolomitization and dissolution processes improving reservoir quality occurs in the Lower Ordovician Arbuckle Group microbialites (Franseen et al., 2003; Warusavitharana and Parcell, 2013, Gao et al., 1992). In central Missouri and Kansas the Arbuckle Group microbialites consist of dolomitized stromatolitic and thrombolitic facies, commonly with intercrystalline, vuggy, fenestral, and moldic pores (Franseen et al., 2003; Warusavitharana and Parcell, 2013). In Kansas, dolomitized Arbuckle stromatolites have porosity values up to 32% and permeability values up to 1500 md. Porosity in these rocks is related to depositional facies, early diagenesis, and dolomitization (Franseen et al., 2003). In southwestern Oklahoma, dolomitization and dissolution processes in the Arbuckle Group microbialites formed as early diagenetic events (marine and meteoric), producing abundant intercrystalline porosity, along with minor amounts of vuggy and fracture porosity (Gao et al., 1992).

II.7 Conclusions

Dolomitization accompanied by calcite dissolution caused significant changes in rock texture, pore geometry, and pore-throat size distribution in the Smackover Formation thrombolite reservoirs in southwestern Alabama. Consequently, the petrophysical characteristics of the thrombolite unit also changed.

During the dolomitization process, the grains and early calcite cements are progressively replaced by dolomite crystals, and intercrystalline porosity was generated. The number of meso- and macropores increased, and pore geometry became more homogeneous. Pore-throats are smaller in intercrystalline porosity (generated by dolomitization) than in connected vuggy porosity (depositional vugs, commonly enhanced by late dissolution), but dolomitization enhances connectivity in originally low permeable intervals.

The southern portion of the Smackover Formation thrombolite at Little Cedar Creek Field is partially dolomitized and porosity and permeability average values increased significantly in this portion of the field. The dolomitization process caused the petrophysical properties to be more homogeneous vertically and laterally in the Smackover Formation thrombolite, and it is the main diagenetic process that improved reservoir quality at Little Cedar Creek (southern portion of the field), Appleton and Vocation fields.

CHAPTER III

PORE TYPE CHARACTERIZATION AND CLASSIFICATION IN CARBONATE RESERVOIRS

III.1 Synopsis

Pore space geometry affects permeability and water saturation, and is an important aspect of reservoir characterization. Existing pore space classifications for carbonate reservoirs include some genetic, geometrical and petrophysical aspects, but the influence of diagenesis in the pore system is poorly described. The purpose of this study is to develop a new pore characterization applied to carbonate rocks that encompasses pore geometry, pore connectivity and the influence of diagenesis in the pore system by generating a quantitative result in order to identify and map reservoir flow units and diagenetic trends. This new pore characterization is based on features observed in thin-sections, being a fast and relatively inexpensive method to evaluate porosity characteristics.

Pore geometry data come from image analysis of scanned thin sections. Area, perimeter, maximum elongation and minimum width of the pores are measured. These data are used as input in an equation, and a numerical result gives information about the pore complexity and roughness. Pore connectivity data come from the definition of pore types, pore size distribution, and characteristics of cementation, dolomitization and dissolution processes. Giving values for each of these textural characteristics, a numerical result also is generated through an equation, which provides information about pore connectivity. The influence of diagenesis in the pore system is evaluated through the analysis of pore types, cement textures, characteristics of dissolution (if fabric selective or not), and dolomitization, combined with the intensity of each of these processes. The diagenetic parameter is calculated similarly to the connectivity parameter, but the numerical value for each textural characteristic is different, so it gives information about diagenesis instead of connectivity.

The final result is a two axis graph (pore geometry *versus* pore connectivity) with diagenetic data superimposed in color. This graph shows, for each sample, if the pores have simple or complex geometry, low or high connectivity, and their degree of diagenetic influence. This information helps to define petrophysical rock types and evaluate the role of diagenesis in enhancing or reducing reservoir quality. It can also be displayed as maps, so variations in the pore system geometry can be visualized in space and lateral diagenetic trends can be defined.

III.2 Introduction

Porosity is the proportion of pore space in any rock, expressed as a ratio or percentage, independent of geometry. The geometry of a pore space depends on its genesis. In sedimentary rocks it starts with the depositional rock fabric, and changes through the subsequent diagenetic alteration of the rock. In sedimentary carbonate rocks the pore system can be very complex because of the great diversity of possible depositional rock fabrics (carbonates can be clastic, chemical or biogenic in origin), and the great susceptibility to diagenetic alteration due to its mineralogy. Carbonate minerals can rapidly evolve through dissolution, cementation, recrystallization, and replacement at ambient conditions in a variety of diagenetic environments.

Pore space geometry affects permeability and water saturation, and is an important aspect of reservoir characterization. A classification of carbonate rock pore space was necessary in order to better characterize petrophysical reservoir properties, since very different kinds of pore space can have identical porosity values, and rocks with similar pore space can have greatly different porosity (Drummond, 1965).

Existing pore space classifications encompass some genetic, geometrical and petrophysical aspects, but the influence of diagenesis in the pore system is poorly described. Pore classification in carbonates were developed by Archie (1952), Choquette and Pray (1970), Lucia (1983, 1995), Ahr and Hammel (1999), Ahr et al. (2005), and Lonoy (2006).

The first attempt to classify pore space by relating it to petrophysical properties in carbonate rocks was by Archie (1952). His classification consisted of two parts: (a) the texture of the matrix; and (b) the character of the visible pore structure. He subdivided three textural categories are termed Type I (compact, crystalline), Type II (chalky) and Type III (granular, saccharoidal), and visible pore size was subdivided in four classes (Fig. III.1). These rock types produce different capillary-pressure curve shapes (Fig. III.2) resulting from the distinct effective pore-size distribution in each one, and different formation resistivity factor resulting from the distinct pore connectivity. Type I carbonates should have low porosity and poorly connected or isolated pores. Type II carbonates should have a wide range of pore size distribution, where microporosity dominates (resulting in relatively high porosity, but low permeability). Type III carbonates should have interconnected macroporosity, resulting in higher permeability values.

The Archie classification does not provide information of pore genesis, and he does not make a link between pore types, depositional facies and diagenetic modifications. Without this information it is difficult to map the spatial distribution of flow units at the field scale.

A classification that incorporated time and mode of origin of carbonate porosity (Fig. III.3) was proposed by Choquette and Pray (1970). It is a descriptive and genetic system in which 15 basic porosity types are recognized: seven abundant types (interparticle, intraparticle, intercrystal, moldic, fenestral, fracture, and vug), and eight more specialized types. The pore types were organized into three classes depending on whether they are fabric selective, not fabric selective, and fabric selective or not. Modifying terms are used to characterize genesis, size and shape, and abundance of porosity. The genetic modifiers involve (1) process of modification (solution, cementation, and internal sedimentation), (2) direction or stage of modification (enlarged, reduced, or filled), and (3) time of porosity formation (primary, secondary, predepositional, depositional, eogenetic, mesogenetic, and telogenetic).

Pore shapes are classed as irregular or regular, and the latter are subdivided into equant, tubular, and platy shapes. A grade scale for size of regular-shaped pores, utilizing the average diameter of equant or tubular pores and the width of platy pores, has three main classes: micropores ($< 1/16$ mm), mesopores (1/16-4 mm), and megapores (4-256 mm). Abundance is noted by percent volume and/or by ratios of porosity types.

Texture of matrix	Appearance of hand sample	Appearance under microscope (10x to 15x)
Type I Compact Crystalline	Crystalline, hard, dense, sharp edges and smooth faces on breaking. Resinous.	Matrix made up of crystals tightly interlocking, allowing no visible pore space between crystals.
Type II Chalky	Dull, earthy or “chalky”. Crystalline appearance absent. May be silicious or argilaceous.	Crystals, less effectively interlocking than the foregoing, joining at different angles. Grain size is less than about 0.05 mm. Coarser textures classes as Type III.
Type III Granular or Saccharoidal	Sandy or sugary appearing. Size of crystals or granules classed as: Very fine = 0.05 mm Fine = 0.1 mm Medium = 0.2 mm Coarse = 0.4 mm	Crystals interlocking at different angles, generally allowing space for considerable porosity between crystals.

Visible pore size classes:
Class A: no visible porosity under about 10-power microscope or where pore size is less than about 0.01 mm in diameter.
Class B: visible porosity, > 0.01 mm but < 0.1 mm.
Class C: visible porosity, > 0.1 mm but < size of cuttings.
Class D: visible porosity, > size of cuttings.

Frequency of the visible pores:

Description	**Frequency (% of surface covered by pores)**
Excellent	20
Good	15
Fair	10
Poor	5

Figure III.1. Archie (1952) pore classification.

Choquette and Pray (1970) classification is the most commonly used pore classification in carbonate rocks, because it gives information about pore origin, diagenetic modifications, pore size and abundance. However, pore size classes are not based on petrophysical data, thus there is no information about pore connectivity and little information about pore geometry.

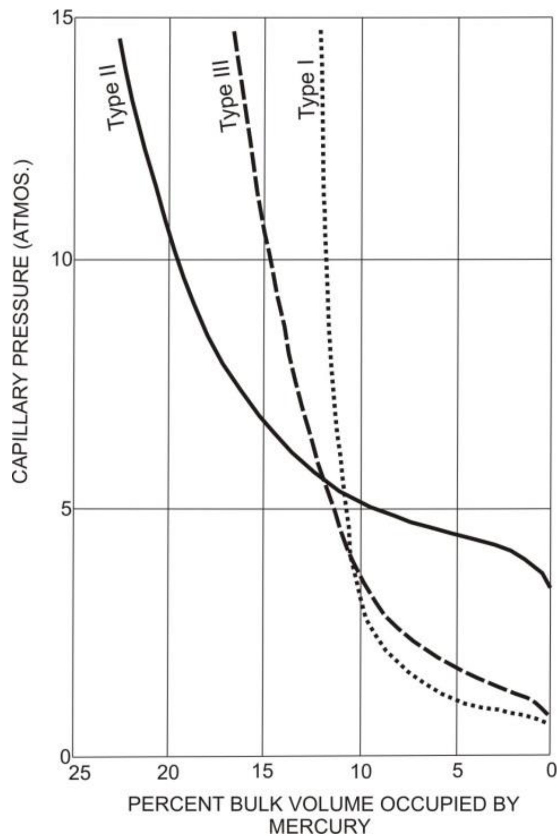


Figure III.2. Typical capillary pressure curves of each Archie rock type (Archie 1952).

Since the permeability of a carbonate rock cannot be measured directly by wireline tools and it is not directly related to total porosity, visual descriptions of the pore geometry, therefore, are needed to estimate permeability. Lucia (1983) developed a pore space classification to allow more accurate estimates of permeability in carbonate rocks, as well as to provide a relationship between pore types and Archie's *m* value (parameter related to resistivity) and capillarity. Hence, the petrophysical characteristics of a carbonate rock are controlled by two basic pore networks: interparticle and vuggy (Fig. III.4), with a special attention given to the significance of separate and touching vugs (moldic ooids and leached fossil are also considered vugs in this classification).

Basic porosity types		
Fabric selective	**Not fabric selective**	**Fabric selective or not**
Interparticle	Fracture	Breccia
Intraparticle	Channel	Boring
Intercrystal	Vug	Burrow
Moldic	Cavern	Shrincage
Fenestral		
Shelter		
Growth-framework		

Modifying terms		
Genetic modifiers	**Size modifiers**	**Abundance modifiers**
Process	Megapore	Percentage porosity
Solution	Large (32 - 256 mm)	
Cementation	Small (4 - 32 mm)	or
Internal sediment		
	Mesopore	Ratio of porosity
Direction or stage	Large (0.5 - 4 mm)	
Enlarged	Small (0.0625 - 0.5 mm)	
Reduced		
Filled	Micropore (< 0.0625 mm)	
Time of formation		
Primary		
Pre-depositional		
Depositional		
Secondary		
Eogenetic		
Mesogenetic		
Telogenetic		

Figure III.3. Choquette and Pray (1970) pore classification.

Particle size	Pore type	Abundance
Fine (F) < 20 μm Medium (M) 20 - 100 μm Large (L) >100 μm	Interparticle (P) Vuggy (V) Connection Separate (S) - connection through interparticle pores. Touching (T) - connection through other vugs.	Percentage of porosity (%)

Figure III.4. Lucia (1983) classification of carbonate pore space.

It was demonstrated that three porosity-permeability fields can be defined using particle-size boundaries of 100 and 20 μm, a relationship that appears to be limited to particle sizes less than 500 μm. These three fields are: greater than 100-μm permeability field, 100–20-μm permeability field, and less than 20-μm permeability field (Fig. III.5).

Sorting and particle size were considered important geological parameters that influence permeability (Lucia, 1995), and Dunham's (1962) carbonate rock classification was considered a base for rock fabric classification, with some modifications (Lucia, 1995). Dunham's classification focused on depositional texture, whereas Lucia's classification focused on petrophysical characteristics of the rock, what include depositional and diagenetic textures. He classified packstone as grain dominated or mud dominated, depending on the presence or absence of intergranular pore space. To describe particle size and sorting in dolostones, dolomite crystal size was added to the modified Dunham terminology.

Using the combination of rock texture and petrophysical properties, Lucia (1995) observed three "rock types" or classes: (1) Class 1: limestone and dolomitized grainstones, large crystalline grain-dominated dolopackstone and mud-dominated dolostone. These fabrics make up the greater than 100 μm permeability field; (2) Class 2: grain-dominated packstones, fine to medium crystalline grain-dominated dolopackstones, and medium crystalline mud-dominated dolostones. These fabrics make up the 100-20 μm field; and (3) Class 3: mud-dominated limestone and fine crystalline mud-dominated dolostones. These fabrics make up the less than 20 μm permeability field (Fig. III.6).

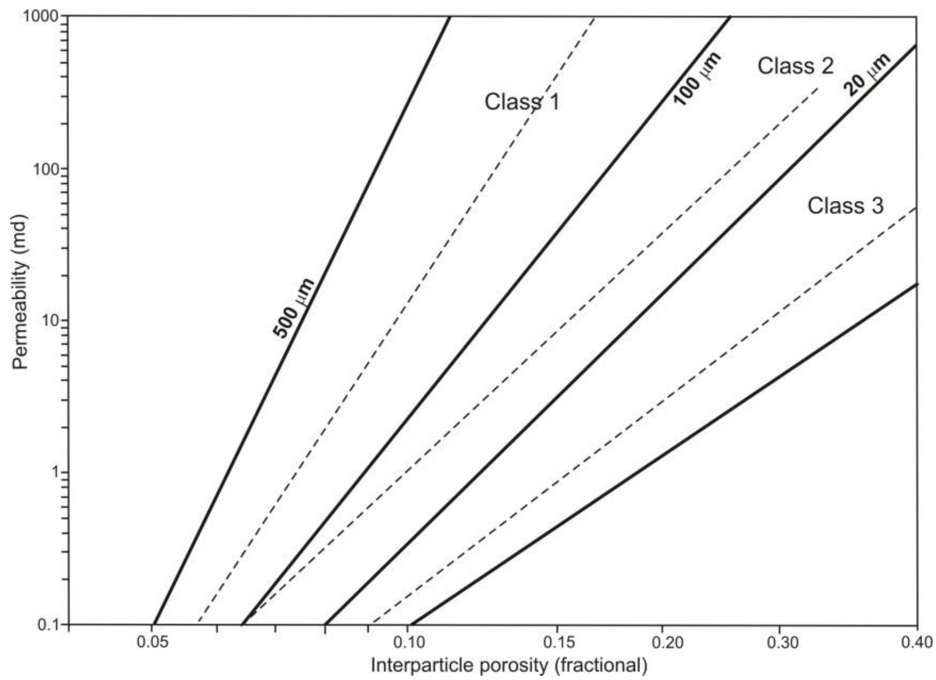


Figure III.5. Composite porosity-air permeability crossplot for nonvuggy limestones and dolostones showing statistical reduced-major-axis transforms for each class (dashed lines) (Lucia 1995).

Class 1	Class 2	Class 3
Grainstone Dolomitized grainstone (crystal size < 100 μm) Dolomitized Grainstone Packstone (grain-dominated) Packstone (mud-dominated) Wackestone Mudstone (crystal size > 100 μm)	Packstone (grain-dominated) Dolomitized packstone (grain-dominated) (crystal size < 100 μm) Dolomitized packstone (mud-dominated) (crystal size 20-100 μm) Dolomitized Packstone (grain dominated) Packstone (mud dominated) Wackestone Mudstone (crystal size 20-100 μm)	Packstone (mud-dominated) Wackestone Mudstone Dolomitized Packstone (mud dominated) Wackestone Mudstone (crystal size < 20 μm)

Figure III.6. Petrophysical and rock-fabric classes based on similar capillary properties and interparticle-porosity/permeability transforms (Lucia 1995).

The capillary pressure curves (Fig. III.7) for the three petrophysical classes indicate there is decreasing pore-throat size with decreasing porosity within a petrophysical class and a general decrease in pore-throat size form Class 1 to Class 3. The addition of vuggy pore space to interparticle pore space alters the petrophysical characteristics of the rock (Lucia 1995). Separate vugs will increase total porosity, but does not significantly increase permeability, whereas connected vugs will increase both porosity and permeability (Lucia 1983). The occurence of separate vugs causes the Archie's *m* factor (or cementation factor) to increase its value, that will have a great impact on water saturation calculations.

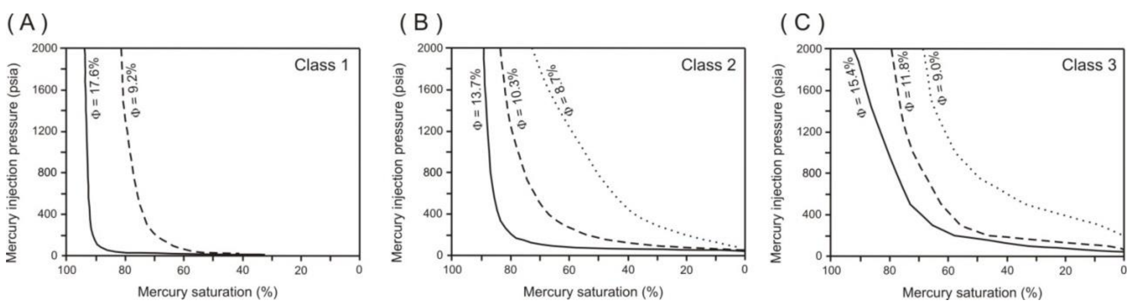


Figure III.7. Capillary pressure curves. (A) Class 1. Data are from dolograinstones. (B) Class 2. Data are from medium crystalline dolowackestones. (C) Class 3. Data are from fine crystalline dolowackestone (Lucia 1995).

Lucia classification is based on rock texture (particle or crystal size), and as Archie classification, it does not provide information about pore origin and diagenetic modifications.

Lonoy (2006) developed a pore classification (Fig. III.8) based on Choquette and Pray (1970) and Lucia (1983, 1995) pore classifications, where 20 pore-type classes are recognized. This classification has only five (interparticle, intercrystalline, vuggy, intraparticle, and moldic) of the fifteen pore types in Choquette and Pray (1970) classification, and one new pore type (mudstone microporosity), making a total of six pore types. The other ten pore types were not considered because they were of minor significance in studied reservoirs. The six pore types were then subdivided according to pore size (micropores, mesopores and macropores).

A new element incorporated by Lonoy (2006) was porosity distribution, which has a significant effect on porosity and permeability relationship. The distribution of interparticle pores, intercrystalline pores, and mudstone micropores was visually classified as either uniform or patchy. For similar porosities, a patchy porosity distribution results in significantly higher permeability than uniform porosity distribution because porosity is concentrated over a smaller volume and the pore system is better connected than for an equivalent, uniformly distributed pore volume (Lonoy, 2006). Furthermore, patchy porosity distribution is often related to secondary dissolution with slight corrosion of pore throats, and this process also tends to favor connected pores.

Porosity and permeability data plotted in the same graph according to rock types show higher values of coefficient of determination (R^2) for Lonoy (2006) rock types if compared to Choquette and Pray (1970) and Lucia (1983, 1995, 1999) rock types (Lonoy 2006). This result indicates that permeability is strongly dependent on pore geometry and distribution.

Pore type	Pore size	Pore distribution
Interparticle	Micropores (10 - 50 μm) Mesopores (50 - 100 μm) Macropores (> 100 μm)	Uniform or Patchy
Intercrystalline	Micropores (10 - 20 μm) Mesopores (20 - 60 μm) Macropores (> 60 μm)	
Intraparticle Moldic	Micropores (< 10 - 20 μm) Macropores (> 20 -30 μm)	
Vuggy Mudstone microporosity	Micropores (< 10 μm)	

Figure III.8. Lonoy (2006) porosity classification system.

Choquette and Pray classification subdivided pore size into micropore (< 62.5μm), mesopore (62.5μm – 4 mm) and megapores (> 4 mm). Lonoy (2006) classification subdivided pore size divided into micropores, mesopores and macropores, but each of these three classes has different range of values depending on the pore type (Fig. III.8). Lonoy (2006) pore size values are much smaller than the ones used by Choquette and Pray. Lonoy (2006) pore size classes were based on petrophysical data.

Carbonate porosity is created or altered by depositional processes, diagenetic processes and mechanical fracturing. In a new pore classification (Ahr and Hammel, 1999; Ahr et al., 2005; Humbolt and Ahr, 2008; and Ahr 2008), these three main processes were plotted as end members on a triangular diagram (Fig. III.9) and the sides of the triangle represent hybrid pore types: Hybrid 1 - hybrids of depositional and diagenetic processes; Hybrid 2 - hybrids of diagenetic and fracture processes; and

Hybrid 3 -hybrids of depositional and fracture processes. Depositional pores are closely related to original rock texture and fabric, and in this classification include interparticle, intraparticle, shelter, fenestral, and reef porosity. Diagenetic porosity is formed through dissolution, recrystallization, cementation, compaction, replacement, and pressure solution processes. Fracture porosity results from brittle failure of the rock under differential stress.

The Ahr-Humbolt (2008) genetic pore classification focused on the side of the triangular diagram between depositional and diagenetic processes (Hybrid 1), because it is difficult to characterize fracture systems with well data. The fracture end member would be better used in outcrops or with seismic data, where fracture systems can be better visualized and measured. This classification provides information about variation on the degree of diagenetic alteration of the rock (vertically and horizontally), and its relationship with petrophysical characteristics of the rock.

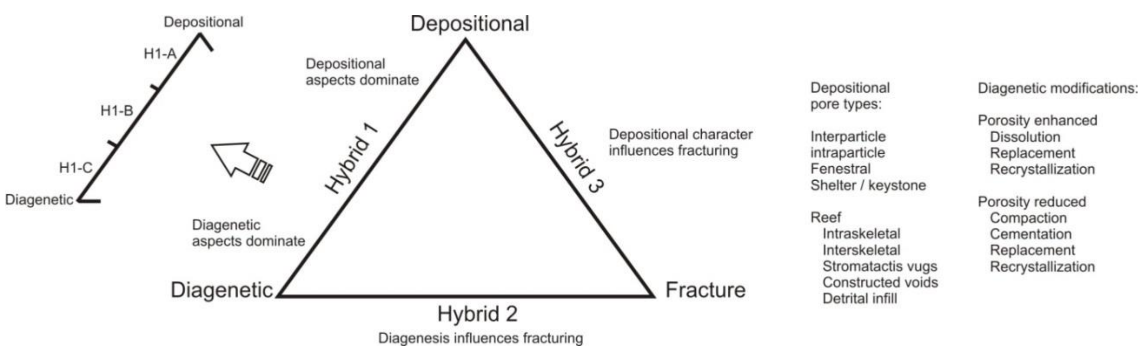


Figure III.9. Genetic classification of carbonate porosity (Ahr and Hammel, 1999; Ahr et. al. 2005; Ahr 2008) and modification of the genetic classification of carbonate porosity made by Humbolt and Ahr 2008, based on how much the porosity was modified by diagenesis (Hybrid 1 – A, Hybrid 1 – B or Hybrid 1 – C).

The Hybrid 1 pore class was subdivided into three members, according to the degree of diagenetic alteration of the rock (H1-A, H1-B and H1-C). A major problem with this classification is that there is no clear limit established between the hybrids A, B and C. It is subjective, and depends on the analyst interpretation. Other modifying terms used in this classification are if the original porosity was enhanced (e) or reduced (r) by diagenetic processes.

Since depositional porosity is distinct for different depositional facies, this classification has to be applied to each facies separately. The H1-Ae pore type of a grainstone will certainly be distinct of a H1-Ae pore type of a wackestone, for example. The Humbolt-Ahr (2008) classification also does not provide information about pore connectivity, size, abundance and distribution.

These classifications are very useful, however some aspects of pore geometry, specifically connectivity and diagenetic influence on the pore system are not described or evaluated by them. This study presents the results of a new pore characterization model applied to carbonate rocks that encompasses information about pore geometry, connectivity and diagenetic modifications on the pore system, with a quantitative result, in order to identify and map reservoir flow units and diagenetic trends.

III.3 Methods

The new pore characterization describes three coefficients: geometry, connectivity and diagenesis. Each coefficient value ranges from 1 to 10. To constrain the equations 90 thin sections were analyzed, which represent several types of carbonate facies and pore characteristics. 53 of these thin-sections are of to Smackover Formation carbonates, 34 of them have corresponding porosity and permeability measurements.

The other 37 thin-sections are of various carbonates from different formations, with a larger variety of facies and pore types (Table A.5, Appendix A).

Image-Pro Premier® software was used for pore geometry analysis. The number of pores measured in each thin section varied from 1,000 to 236,000. One pixel corresponded to 6.4 μm. Area, perimeter, maximum and minimum diameter were measured for each pore. Percentage of micropores (< 50 μm), mesopores (50 – 100 μm), and macropores (> 100 μm), as well as roughness (perimeter over area) and elongation (maximum diameter over minimum diameter) of each pore were calculated. Standard petrography techniques were used to characterize and quantify cement types, cementation intensity, dissolution intensity, dolomitization, recrystallization, and pore types.

III.4 Results

III.4.1 The Triplet Pore Characterization: Geometry, Connectivity, and Diagenesis

The Ahr and Hammel (1999) and Ahr et al. (2005) pore classification introduced the idea of hybrid pore types, as a result of the mixture of depositional and diagenetic features in the pore system, but this classification scheme is qualitative, and subjective in some aspects. This new pore characterization emerged from the desire to turn diagenetic information into quantitative data and combines it with pore geometry and connectivity data. These three aspects of the pore system provide information about the complexity of the pore system, permeability, and the influence of diagenesis in improving or reducing the reservoir quality.

III.4.1.1 Geometry Coefficient

Pore geometry data was derived from image analysis of scanned thin sections, so it is a two-dimensional evaluation of a three-dimensional pore system. Area, perimeter, maximum and minimum diameter of the pores are measured. These data are used as input in an equation, and a numerical result, the geometry coefficient, provides information about the pore roughness and elongation (Equation 1). Roughness (perimeter over area) and elongation (maximum diameter over minimum diameter) of each pore was calculated, along with the average value of each parameter for each thin section. Geometry data from micropores was not considered, since each micropore corresponds approximately to one pixel size and the area equals zero. Macropores and mesopores also have the most influence on the effective porosity and the permeability, so it is reasonable to consider their geometry as representative of the pore system.

Roughness values from the thin sections analyzed varied from 98 to 662 mm^{-1}, so the maximum value for roughness considered in the equation is 700 mm^{-1}. Elongation values from the thin sections analyzed varied from 3 to 5.7, so the maximum value for elongation considered in the equation is 6. The maximum roughness and elongation values could change according to the database used. In the geometry coefficient equation (Equation 1) the weight for the roughness was accorded 80% (roughness is multiplied by 8 in the equation), whereas elongation was weighted 20% (elongation is multiplied by 2 in the equation), as the variation in the roughness is larger and it better reflects the variation in the pore geometry. The lower geometry coefficient value is 1 and it corresponds to simple pore geometry, whereas the highest geometry coefficient value is 10 and it corresponds to a very complex pore geometry.

Equation 1 $$Geometry\ coefficient\ = \left(\frac{P}{A} \times \frac{8}{700}\right) + \left(\frac{MaxD}{MinD} \times \frac{2}{6}\right)$$

Where: P = perimeter, A = area, MaxD = maximum diameter, MinD = minimum diameter

III.4.1.2 Connectivity Coefficient

Pore connectivity data was derived from porosity, pore size distribution, pore types, and characteristics of cementation and dissolution. Giving values for each of these textural characteristics, according to its influence on enhancing or reducing connectivity, Equation 2 generated results, which give information about pore connectivity.

Porosity and pore size distribution were derived from image analysis, where the software calculated the area corresponding to the pores, which are filled with blue epoxy, and recognized each pore as an object, measuring its maximum diameter. In the dataset used the maximum porosity value measured was 34%, so the maximum value considered for porosity in the equation was 35%. Percentage of the porosity corresponding to micropores (< 50 μm), mesopores (50 – 100 μm), and macropores (> 100 μm) was measured. Pore types were divided in two groups: “low connectivity” and “high connectivity”. Pore type 1 is the dominant pore type, whereas pore type 2 is the second abundant pore type. The combination of pore type 1 and pore type 2 provides a value for the equation according to its impact on the connectivity characteristics of the rock (Fig. III.10). Pore type 2, when present, should correspond to at least 20% of the porosity, to be considered a pore type that is significantly influence permeability. Most of the pore types described in this study corresponds to Choquette and Pray (1970) pore classification terms.

If a sample presents 35% porosity (maximum value considered here), high connectivity pore 1 and pore 2 (value of 1.5), no cementation, and high dissolution (value of 1.3), the multiplication of these values (Equation 2) gives us a result of 68.25. This value will correspond to the highest connectivity coefficient, but to scale it from 1 to 10 it is multiplied by 9 and added to 1 (Equation 2). So, if a sample presents all of the characteristics above described, it will have a connectivity coefficient of 10. The maximum porosity value could change according to the database used, and in this case the value of 68.25 should be replaced by a number calculated using the new maximum porosity value.

Commonly pores are not uniformly distributed in carbonate rocks, so differences between porosity measured in a thin-section and porosity measured in the correspondent plugs occur frequently. This is one of the limitations of a thin-section analysis, a way to reduce this error is to analyze a greater number of thin sections from the same reservoir interval.

Dissolution intensity data was derived from the percentage of secondary porosity generated by dissolution. If this secondary porosity is more than 15% it is considered high, between 5 and 15% is moderate, and less than 5% is low. For example, in a mudstone with 10% porosity, all the porosity corresponding to secondary porosity created by dissolution, the dissolution intensity is moderate. Each dissolution intensity level provides the equation a value according to its impact on the connectivity (Fig. III.10).

Cementation intensity corresponds to the percentage of the original (primary) porosity that is now cemented. If more than 50% of the primary porosity is cemented, the cementation intensity is classified as high, between 20 and 50% is moderate, and less than 20% is low. The type of cement can also impact pore connectivity. Two types of cements were considered: rimming / meniscus cement and non-rimming cement. The rimming / meniscus cement impacts connectivity more because it can block pore throats, significantly reducing permeability. Each of these cementation types and intensity levels provides the equation a value according to its impact on the connectivity (Fig. III.10).

Equation 2 $$Connectivity\ coefficient = Porosity \times Macroporosity\ (in\ fraction) \times Pore\ type \times Dissolution\ intensity \times Cement\ type \times Cementation\ intensity \times \left(\frac{9}{68.25}\right) + 1$$

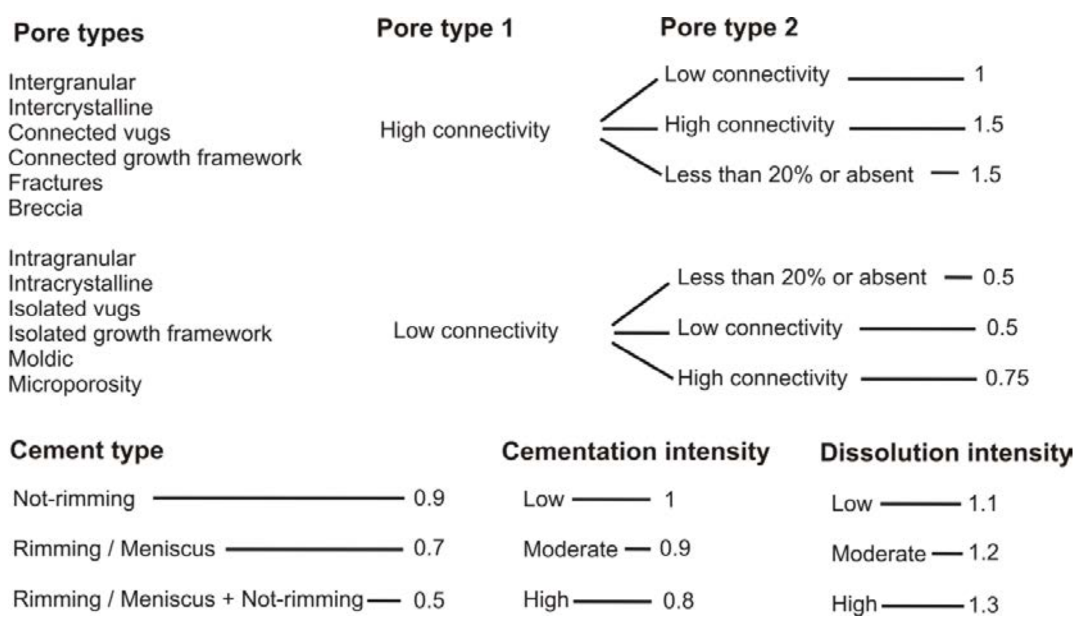


Figure III.10. Pore type, cement type, cementation intensity, and dissolution intensity and their correspondent numerical values to be used in the connectivity coefficient equation. Pore types are separated in two groups, according to their connectivity characteristics: high or low. The combination of the major pore type (pore type 1) and the minor pore type (pore type 2) leads to a number to be used in the equation. The cement type, cementation and dissolution intensities also indicate the number to be applied to the equation.

III.4.1.3 Diagenesis Coefficient

The influence of diagenesis on the pore system is evaluated through the analysis of pore types, intensity of cementation and/or dissolution, and dolomitization or recrystallization (if it is associated with intercrystalline porosity). The diagenetic parameter is calculated similarly to the connectivity parameter, but the numerical value for each textural characteristic is different, so it provides information about diagenetic or depositional origin, instead of connectivity (Equation 3). Pore types were divided in two groups: “depositional” and “diagenetic”. Pore type 1 is the dominant pore type, whereas pore type 2 is the second abundant pore type. The combination of pore type 1 and pore type 2 provides the equation a value according to the degree of diagenetic influence (Fig. III.11). Pore type 2, if present, should correspond to at least 20% of the porosity to be considered a pore type that significantly influence the characterization of the pore system origin. Most of the pore types correspond to Choquette and Pray (1970) pore classification terms. Dissolution intensity levels and cementation intensity levels provide the equation values according to the diagenetic influence in the rock (Fig. III.11).

Dolomitization and recrystallization are diagenetic modifications in the rock, but they have impact on the pore system only if intercrystalline pore types are created during these processes. Dolomitization / recrystallization is considered high if it affects more than 30% of the rock (generating intercrystalline pores), moderate if it affects between 10 and 30%, and low if it affects less than 10%. The dolomitization / recrystallization intensity levels provide the equation a value according to its influence on the pore system (Fig. III.11).

Equation 3 $Diagenesis\ coefficient = Pore\ type\ \times Dissolution\ intensity\ \times$
$Cementation\ intensity\ \times Dolomitization\ or\ recrystallization\ intensity$

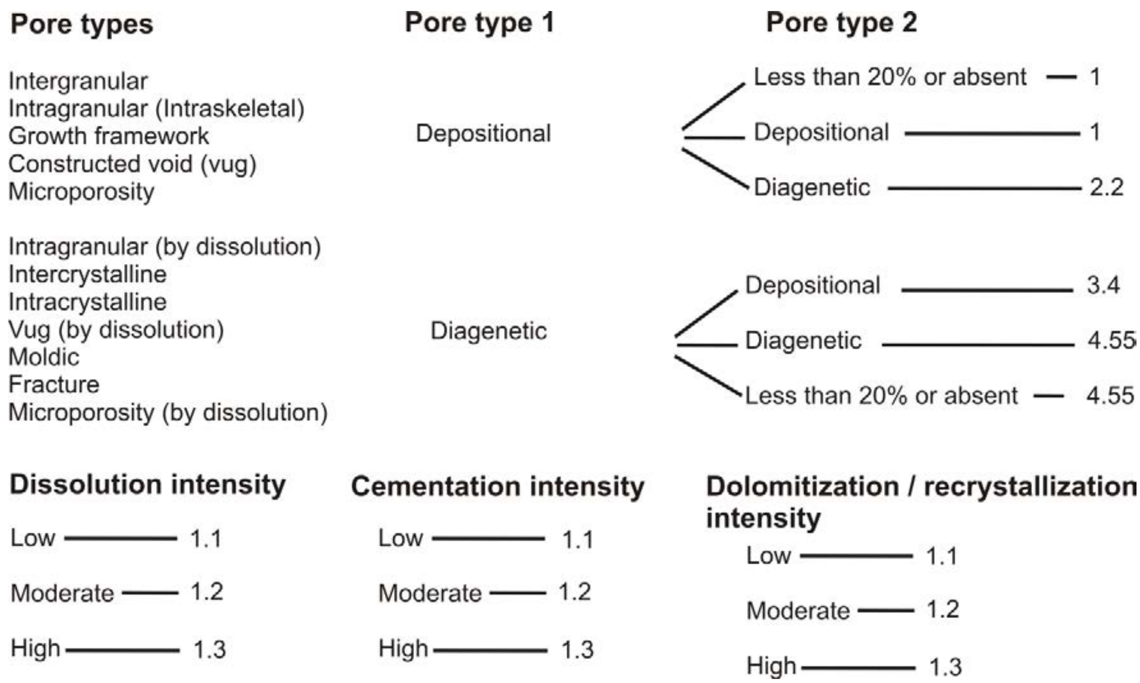


Figure III.11. Pore type, dissolution intensity, cementation intensity, and dolomitization or recrystallization intensity and their correspondent numerical values to be used in the diagenesis coefficient equation. Pore types are separated in two groups, according to their genesis: depositional or diagenetic. The combination of the major pore type (pore type 1) and the minor pore type (pore type 2) leads to a number to be used in the equation. The dissolution, cementation, and dolomitization / recrystallization intensities also indicate the number to be applied to the equation.

III.4.1.4 Results

The final result can be displayed as a two axis graph (pore geometry *vs* pore connectivity) with diagenetic data superimposed in color or a three axis graph. These graphs show, for each sample, if the pores have simple or complex geometry (in average), low or high connectivity, and the degree of diagenetic influence on the pore system. This information helps to define petrophysical rock types and evaluate the role of diagenesis in enhancing or reducing reservoir quality. The final values also can be displayed as maps, so variations in the pore system geometry can be visualized in space and lateral diagenetic trends can be defined. The results from the thin-section analysis are displayed in the Table A.5 (Appendix A).

Pore geometry characterization can be useful as a complementary method to understand petrophysical behavior of carbonates. For example, carbonate samples with large simple pores and a small amount of microporosity display higher acoustic velocity at a given porosity than samples with small, complicated pores (Weger et al., 2009). Additionally, both pore structure and the absolute number of pores (and pore connections) seem more important in controlling the electrical resistivity of carbonate rocks, rather than the size of the pore throats (Verwer et al., 2011).

Defining porosity, pore type(s), cementation, and dissolution in a sample provides useful information about pore connectivity. Pore connectivity characterization can have reasonable results through thin-section analysis, although it is not a permeability value. However, it is a value that, on a relative scale, reflects the expected permeability value for that rock, high or low.

Diagenesis is an aspect of the rock that can be described only though thin-section analysis, being the main component of the new pore characterization. By characterizing the impact of diagenesis in the pore system, enhancing or reducing permeability, it is possible to map diagenetic trends and predict reservoir quality.

III.4.2 Case Study – Thrombolite Unit of the Smackover Formation, Southwestern Alabama

The Upper Jurassic Smackover Formation thrombolite unit is a prolific reservoir in southwestern Alabama forming isolated bioherms (Benson and Mancini, 1999;

Kopaska-Merkel and Mann, 1991; Mancini et al., 1991; Mancini et al., 2006). Most of the Smackover Formation thrombolite discovered so far was dolomitized, and the original depositional characteristics of the rock were obscured (Barrett, 1986; Benson and Mancini, 1999; Mancini et al., 1991; Prather, 1992). However, the Smackover Formation thrombolite unit at Little Cedar Creek Field (Fig. I.1) has only a minor amount of dolomitization, and most of its depositional texture is preserved (Heydari and Baria, 2005).

The thrombolite reservoir facies in Little Cedar Creek Field is approximately 42 km (26 mi) long, 5 to 11 km (3 to 7 mi) wide and from 9 to 21 m (30 to 70 ft) thick, oriented along a NE-SW trend (Fig. I.5A). The thrombolite has a clotted, mottled and nodular texture, with rare domal and branching structures. The thrombolite includes abundant peloids, with minor amounts of benthic foraminifera and ostracods. Dolomite can compose as much as 30% of the bioherm and its occurrence gradually decreases from south to north, being absent from near the center to the northeast portion of the field.

The pore types in the thrombolite are primary growth framework vugs and intergranular, and secondary diagenetic vugs (primary growth framework vugs enlarged by late dissolution), intercrystalline porosity (when calcite cement crystals or dolomite crystals have pore space between them), and microfractures.

III.4.2.1. New Pore Characterization Applied to Little Cedar Creek Field Thin-sections

The triplet pore characterization was applied to 33 thin-sections of Little Cedar Creek Field thrombolite unit, simulating a situation where the only material available to evaluate the quality of a reservoir are thin-sections. Three maps were generated: a pore geometry distribution map (Fig. III.12A), a pore connectivity map (Fig. III.12 B), and a map of the degree of the diagenetic influence in the pore system (Fig. III.12 C).

These maps were compared with maps generated in a previous detailed study on this field (see Chapter I), to test applicability of the new pore classification. Permeability data from hundreds of plugs was used to construct the permeability map (Fig. I.14 B), detailed petrography and cathodoluminescence of 153 thin sections were used to construct a dolomite distribution map (Fig. I.13 A) and a cement distribution map (Fig. I.13 B). Pore size was described in cores from 32 wells and a map of the lateral distribution of pore sizes was produced (Fig. I.13 C).

The connectivity map and the permeability map have the same trend. The diagenesis map resulted from the mixture of dolomitization, cementation, and dissolution trends of the reservoir. The pore geometry map indicates that in the southern portion of the reservoir, intensive dolomitization produced a simpler pore geometry.

The results could also be plotted as graphs. A crossplot of the connectivity coefficient versus the geometry coefficient, and diagenesis coefficient values superimposed in color was generated (Fig. III.13). This is a practical way to visualize how diagenesis is influencing pore connectivity and pore geometry, and compare the pore characteristics of the samples.

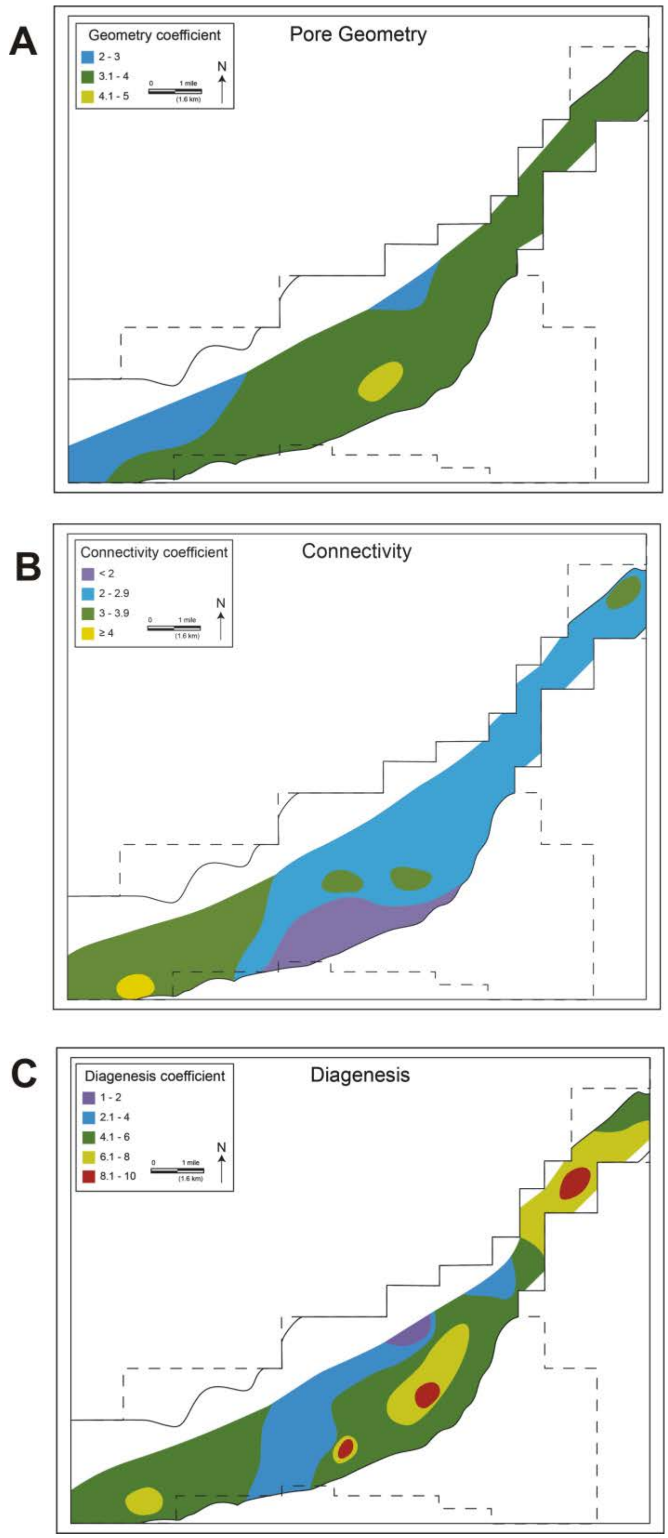


Figure III.12. Little Cedar Creek Field, thrombolite unit. A – geometry coefficient map. B – connectivity coefficient map. C – Diagenesis coefficient map.

A crossplot of permeability (md) versus porosity (%), and geometry coefficient values superimposed in color was generated (Fig. III.14 A). This graph shows that the samples with higher porosity and permeability have lower pore geometry coefficient values, due to its simpler pore geometry. A crossplot of permeability (md) versus porosity (%), and connectivity coefficient values superimposed in color was generated (Fig. III.14 B). The higher connectivity coefficient values correspond to the samples with higher porosity and permeability values. A crossplot of permeability (md) versus porosity (%), and diagenesis coefficient values superimposed in color was generated (Fig. III.14 C). Both depositional and diagenetic features influence good reservoir quality in the Smackover Formation thrombolite unit, but there is a tendency of higher porosity and permeability values in samples with higher diagenetic influence in the pore system. Different diagenetic events can enhance or reduce reservoir quality. Data from Appleton and Vocation fields were also used in this graph, since the Smackover Formation thrombolite units in these fields are intensely dolomitized, and could be compared with samples from Little Cedar Creek Field thrombolite unit, which are not-dolomitized or partially dolomitized.

III. 5 Discussion

The new pore characterization proposed here combines information about pore geometry, connectivity, and the influence of diagenesis in the pore system using only thin-sections, and it encompasses some terms from the Choquette & Pray (1970) pore classification. It is a cheap method to quickly evaluate reservoir quality and diagenetic trends, since it uses only thin-section data.

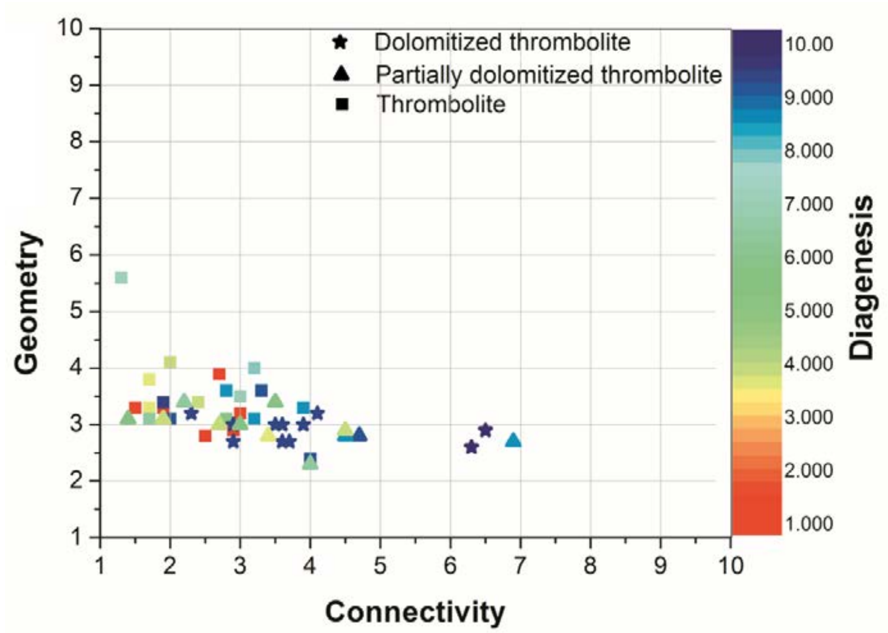


Figure III.13. Crossplot of connectivity coefficient versus geometry coefficient where diagenesis coefficient values are superimposed in color. Samples from the Smackover Formation thrombolite unit from Little Cedar Creek, Appleton, and Vocation fields.

A

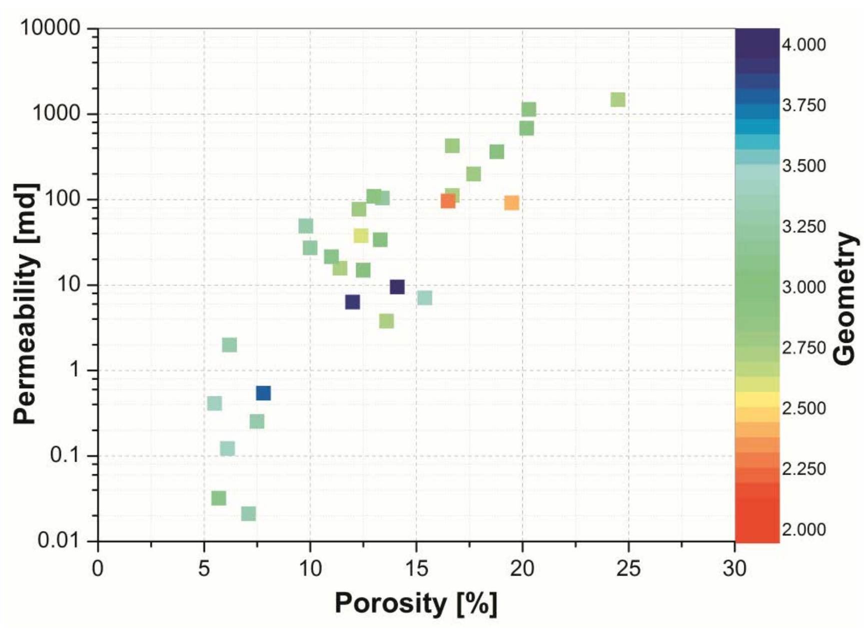
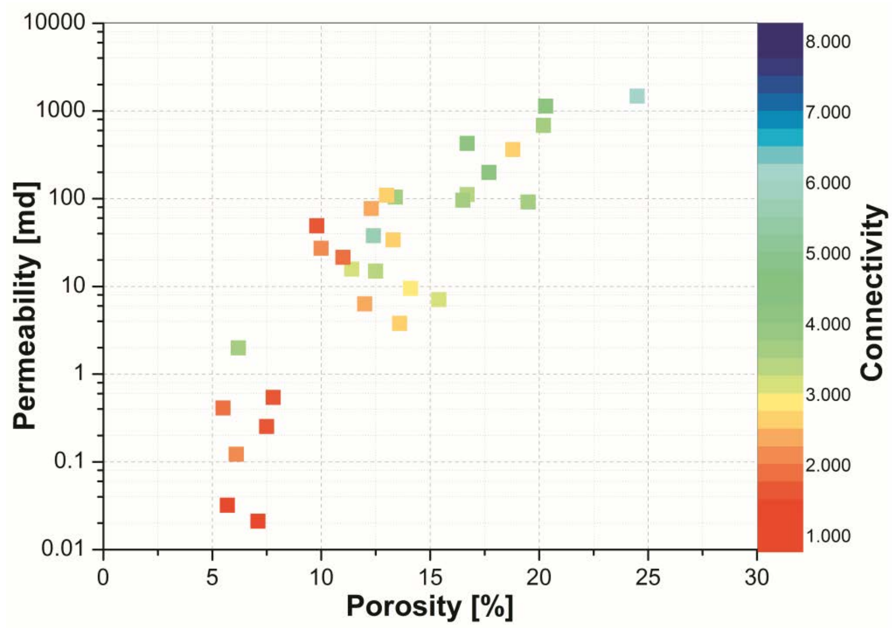


Figure III.14. Crossplots of permeability (md) versus porosity (%) where: A - geometry coefficient values are superimposed in color; B – connectivity coefficient values are superimposed in color; C – diagenesis coefficient values are superimposed in color. Porosity and permeability values were obtained by petrophysical analysis of the plug. Samples from the Smackover Formation thrombolite unit from Little Cedar Creek, Appleton, and Vocation fields.

B



C

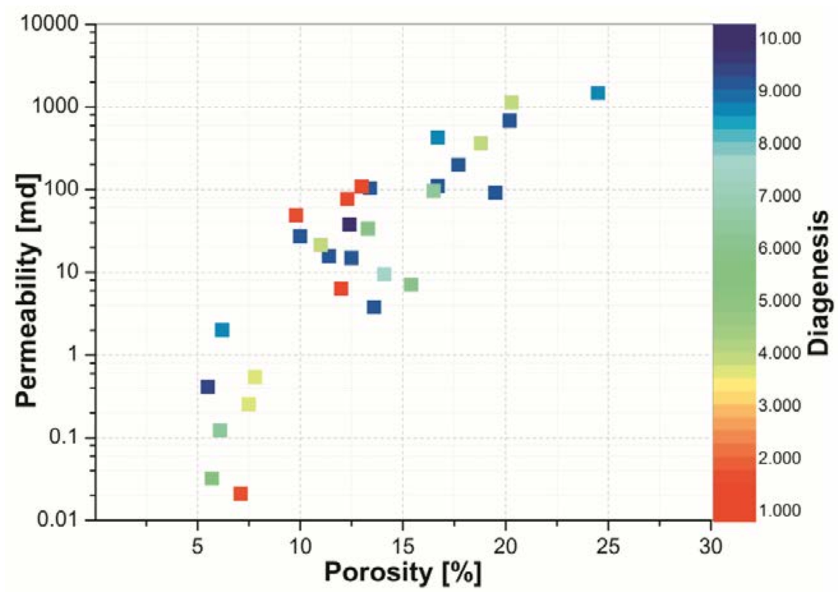


Figure III.14. Continued.

The dataset used here was limited, mainly regarding to the number of samples with petrophysical analysis to calibrate and validate the new pore characterization. Further work needs to be done, comparing results from the thin-section analysis with the correspondent petrophysical analysis for a larger amount of different types of carbonate facies and pore types. The next step in this project will be to look for available plugs from several carbonate reservoirs which should encompass the greatest possible amount of distinct carbonate facies and pore types. These plugs will have porosity and permeability analysis and a correspondent thin-section for the analyses. An estimated amount of 250 plugs should be analyzed.

The new pore characterization was tested in one field so far, but the results were encouraging. The connectivity trends matched with the permeability map, the pore geometry characterization showed lower values where dolomitization occurs in the field, and the diagenesis map correlates well with the dolomitization, cementation, and dissolution maps.

In addition to the new pore characterization, an idea for a new pore classification is under development. The new pore classification has the new pore characterization as its base, but some parameters still need to be developed. The new pore classification has pore connectivity and pore geometry as the main characteristics of the pore system, and the influence of diagenesis in the pore system as a complementary information.

In the new pore classification six pore system types are recognized: Low Connectivity + Simple Geometry (LCSG); Low Connectivity + Complex Geometry (LCCG); Moderate Connectivity + Simple Geometry (MCSP); Moderate Connectivity + Complex Geometry (MCCP); High Connectivity + Simple Geometry (HCSG); and High

Connectivity + Complex Geometry (HcCg). Information about the influence of diagenesis in the pore system will be added to the new pore classification as: Low Diagenesis (LD); Moderate Diagenesis (MD); and High Diagenesis (HD). The parameters to define limits between low, moderate, and high connectivity and diagenesis, as well as simple and complex geometry, will be established based on petrophysical and petrographycal characteristics of the rock.

III.6 Conclusions

There are very efficient methods to study a three-dimensional pore system in detail. Measuring porosity, permeability, and capillary pressure in plugs or whole-core samples, and computed microtomography of small fragments of rock can precisely characterize pore system geometry and connectivity. However these methods are very expensive and time consuming compared to the simple thin-section analysis described here. Although the three-dimensional measurements are more accurate, none of them provide information about the influence of diagenesis within the pore system. The new pore characterization proposed here is a cheap and quick method to characterize pore geometry and connectivity through the analysis of thin sections. Additionaly, although it is not as accurate as some of the three-dimensional methods, it provides diagenesis information about the sample.

The new pore characterization transforms information from standard petrography analysis into numerical values, enabling to visualize differences and similarities of the pore system from different samples through graphs and maps. It also brings a new concept of turning diagenetic information into a quantitative data. The new pore characterization was tested in one field so far, but the results were encouraging. Further work should be done to test and validate the new pore characterization using data from carbonate reservoirs with distinct facies and pore system characteristics.

A new pore classification is under development. It has the new pore characterization as its base, but some parameters still need to be developed. The new pore classification has pore connectivity and pore geometry as the main characteristics of the pore system, resulting in six possible pore system types, and it gives information about the influence of diagenesis in the pore system as a complementary data.

REFERENCES

Ahr, W. M., 1973,The carbonate ramp: an alternative to the shelf model: Gulf Coast Association of Geological Societies Transactions, v. 23, p. 221-225.

Ahr, W. M., and G. J. Palko, 1981, Depositional and diagenetic cycles in Smackover limestone-sandstone sequences, Lincoln Parish, Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 31, p. 7-17.

Ahr, W. M., 2008, Geology of carbonate reservoirs: the identification, description, and characterization of hydrocarbon reservoirs in carbonate rocks, John Wiley & Sons, Inc, New Jersey, 277 p.

Ahr, W. M., and B. Hammel, 1999, Identification and mapping of flow units in carbonate reservoirs: an example from Happy Spraberry (Permian) Field, Garza County, Texas USA: Energy Exploration and Exploitation, v. 17, p. 311-334.

Archie, G. E., 1952, Classification of carbonate reservoir rocks and petrophysical considerations: The American Association of Petroleum Geologists Bulletin, v. 36, no. 2, p. 278-298.

Al Haddad, S., and E. A. Mancini, 2013, Reservoir characterization, modeling, and evaluation of Upper Jurassic Smackover microbial carbonate and associated facies in Little Cedar Creek field, southwest Alabama, eastern Gulf coastal plain of the United States: The American Association of Petroleum Geologists Bulletin, v. 97, no. 11, p. 2059-2083, doi 10.1306/07081312187.

Baria, L. R., D. L. Stoudt, P. M. Harris, and P. D. Crevello, 1982, Upper Jurassic reefs of Smackover Formation, United States Gulf Coast: The American Association of Petroleum Geologists Bulletin, v. 66, no. 10, p. 1449-1482.

Barrett, M. L., 1986, Replacement geometry and fabrics of the Smackover (Jurassic) dolomite, southern Alabama: Gulf Coast Association of Geological Societies Transactions, v. 36, p. 9-18.

Benson, D. J., and E. A. Mancini, 1999, Diagenetic influence on reservoir development and quality in the Smackover updip basement ridge play, southwest Alabama: Gulf Coast Association of Geological Societies Transactions, v. 49, p. 96-101.

Benson, D. J., E. A. Mancini, R. H. Groshong, J. H. Fang, L. M. Pultz, and E. S. Carlson, 1997, Petroleum geology of Appleton field, Escambia County, Alabama: Gulf Coast Association of Geological Societies Transactions, v. 47, p. 35-42.

Benson, J. D., 1988, Depositional history of the Smackover Formation in southwest Alabama: Gulf Coast Association of Geological Societies Transactions, v. 38, p. 197-205.

Budd, D. A., and L. S. Land, 1990, Geochemical imprint of meteoric diagenesis in Holocene ooid sands, Schooner Cays, Bahamas: correlation of calcite cement geochemistry with extant groundwaters: Journal of sedimentary Petrology, v. 60, no. 3, p. 361-378.

Choquette, P. W., and L. C. Pray, 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: The American Association of Petroleum Geologists Bulletin, v. 54, no.2, p. 207-250.

Dickson, J. A. D., 1966. Carbonate identification and genesis as revealed by staining: Journal of Sedimentary Petrology, v. 36, no. 2, p. 491-505.

Driskill, B. W., J. A. Nunn, R. Sassen, and R. H. Pilger Jr, 1988, Tectonic Subsidence, crustal thinning and petroleum generation in the Jurassic trend of Mississippi, Alabama and Florida: Gulf Coast Association of Geological Societies Transactions, v. 38, p. 257-265.

Drummond, J. M., 1965, A note on pore space classification: Geological Note: Bulletin of Canadian Petroleum Geology, v. 13, no.2, p. 335-339.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture: The American Association of Petroleum Geologists, Mem. 1, p. 108-121.

Franseen, E. K., A. P. Byrnes, J. R. Cansler, D. M. Steinhauff, T. R. Carr, and M. K. Dubois, 2003, Geological controls on variable character of Arbuckle reservoirs in Kansas: An emerging picture, Kansas Geological Survey, Kansas.

Gao G., L. S. Land, and, R. L. Folk., 1992, Meteoric modification of early dolomite and late dolomitization by basinal fluids, Upper Arbuckle Group, Slick Hills, Southwestern Oklahoma: The American Association of Petroleum Geologists Bulletin, v. 76, no. 11, p. 1649-1664.

Goldstein, R. H., Z. Li, and E. K. Franseen, 2012, Duration and climate effects on meteoric diagenesis: non-karstic control on distribution of porosity and permeability, Search and discovery Article 120054, Search and Discovery.com.

Heydari, E., and L. R. Baria, 2005, A microbial Smackover Formation and the dual reservoir-seal system at the Little Cedar Creek Field in Conecuh County of Alabama: Gulf Coast Association of Geological Societies Transactions, v. 55, p. 294-320.

Humbolt, A., 2008, Genetic pore typing as a means of characterizing reservoir flow units: San Andres, Sunflower Field, Terry Country, Texas, Master’s thesis, Texas A&M University, College Station, 175 p.

Kahle, C. F., 1965, Strontium in oolitic limestones: Journal of Sedimentary Petrology, v. 35, no. 4, p. 846-856.

Kinsman, D. J. J., 1969, Interpretation of Sr^{+2} concentrations in carbonate minerals and rocks: Journal of Sedimentary Petrology, v. 39, no. 2, p. 486-508.

Kopaska-Merkel, D. C., and S. D. Mann, 1991, Pore facies of Smackover carbonate reservoirs in southwest Alabama: Gulf Coast Association of Geological Societies Transactions, v. 41, p. 374-382.

Kopaska-Merkel, D. C., and S. D. Mann, 1993, Upward shoaling cycles in Smackover carbonates of southwest Alabama: Gulf Coast Association of Geological Societies Transactions, v. 43, p. 173-181.

Koralegadara, G., and W. C. Parcell, 2008, Reservoir characterization of microbial reef reservoirs at Little Cedar Creek Field, Conecuh County, Alabama, 4th Annual GRASP Symposium, Wichita State University, Wichita.

Lipinski, C. J., E. K. Franseen, and R. H. Goldstein, 2013, Reservoir analog model for oolite-microbialite sequences, Miocene terminal carbonate complex, Spain: The American Association of Petroleum Geologists Bulletin, v. 97, no. 11, p. 2035-2057, doi 10.1306/06261312182.

Llinas, J. C., 2002, Diagenetic history of the Upper Jurassic Smackover Formation and its effects on reservoir properties: Vocation field, Manila sub-basin, eastern Gulf Coastal Plain: Gulf Coast Association of Geological Societies Transactions, v. 52, p. 631-644.

Llinas, J. C., 2004, Geologic characterization and modeling of the updip basement ridge play of the Smackover Formation in the Vocation and Appleton field areas, southwest Alabama, Doctor of Philosophy's thesis, University of Alabama, Tuscaloosa, 291 p.

Lonoy, A., 2006, Making sense of carbonate pore systems: The American Association of Petroleum Geologists Bulletin, v. 90, no. 9, p. 1381-1405.

Lucia, F. J., 1983, Petrophysical parameters estimated from visual descriptions of carbonate rocks: a field classification of carbonate pore space: Journal of Petroleum Technology, v. 35, no. 629-637.

Lucia, F. J, 1995, Rock-fabric/petrophysical classification of carbonate pore space for reservoir characterization: The American Association of Petroleum Geologists Bulletin, v. 79, no. 9, p. 1275-1300.

Machel, H. G., 2000. Application of cathodoluminescence to carbonate diagenesis. In Pagel, M., V. Barbin, P. Blanc, and D. Ohnenstetter (eds.): Cathodoluminescence in Geosciences, Springer-Verlag, Berlin, p. 271-301.

Mancini, E. A., and D. J. Benson, 1980, Regional stratigraphy of Upper Jurassic Smackover carbonates of southwest Alabama: Gulf Coast Association of Geological Societies Transactions, v. 30, p. 151-165.

Mancini, E. A., D. J. Benson, B. S. Hart, R. S. Balch, W. C. Parcell, and B. J. Panetta, 2000, Appleton field case study (eastern Gulf coastal plain): Field development model for Upper Jurassic microbial reef reservoirs associated with paleotopographic basement structures: The American Association of Petroleum Geologists Bulletin, v. 84, no. 11, p. 1699-1717.

Mancini, E. A., R. M. Mink, B. H. Tew, D. C. Kopaska-Merkel, and S. D. Mann, 1991, Upper Jurassic Smackover oil plays in Alabama, Mississippi and the Florida panhandle: Gulf Coast Association of Geological Societies Transactions, v. 41, p. 475-480.

Mancini, E. A., W. C. Parcell, and W. M. Ahr, 2006, Upper Jurassic Smackover thrombolite buildups and associated nearshore facies, southwest Alabama: Gulf Coast Association of Geological Societies Transactions, v. 56, p. 551-563.

Mancini, E. A., W. C. Parcell, W. M. Ahr, V. O. Ramirez, J. C. Llinas, and M. Cameron, 2008, Upper Jurassic updip stratigraphic trap and associated Smackover microbial and nearshore carbonate facies, eastern Gulf coastal plain: The American Association of Petroleum Geologists Bulletin, v. 92, no. 4, p. 417-442, doi 10.1306/11140707076.

Mancini, E. A., T. M. Puckett, and W. C. Parcell, 1999, Modeling of the burial and thermal histories of strata in the Mississippi Interior Salt Basin: Gulf Coast Association of Geological Societies Transactions, v. 49, p. 332-341.

Mancini, E. A., B. H. Tew, and R. M. Mink, 1990, Jurassic sequence stratigraphy in the Mississippi Interior Salt Basin of Alabama: Gulf Coast Association of Geological Societies Transactions, v. 40, p. 521-529.

Marshall, D. J., 1988, Cathodoluminescence of geological materials, Unwin Hyman Boston, 146p.

Moore, C. H., and Y. Druckman, 1981, Burial diagenesis and porosity evolution, Upper Jurassic Smackover, Arkansas and Louisiana: The American Association of Petroleum Geologists Bulletin, v. 67, no. 4, p. 597-628.

Nunn, J. A., A. D. Scardina, and R. H. Pilger, 1984, Thermal evolution of the north-central Gulf Coast: Tectonics, v. 3, p. 723-740.

Parcell, W. C., 1999, Stratigraphic architecture of Upper Jurassic (Oxfordian) Reefs in the Northestern Gulf Coast, U. S. and the Eastern Paris Basin, France: Gulf Coast Association of Geological Societies Transactions, v. 49, p. 412-417.

Petta, T. J., and S. D. Rapp, 1990, Appleton field - U.S.A. Gulf of Mexico Basin, Alabama, Structural Traps IV: Tectonic and Nontectonic Fold Traps: The American Association of Petroleum Geologists Special Volumes, A018, p. 299-318.

Prather, B. E., 1992a, Evolution of a Late Jurassic carbonate / evaporite platform, Conecuh Embayment, Northeastern Gulf Coast, U.S.A.: The American Association of Petroleum Geologists Bulletin, v. 76, no. 2, p. 164-190.

Prather, B. E., 1992b, Origin of dolostone reservoir rocks, Smackover Formation (Oxfordian), northeastern Gulf Coast, U.S.A.: The American Association of Petroleum Geologists Bulletin, v. 76, no. 2, p. 133-163.

Richter, D.K., T. Goette, J. Goetze, and R. D. Neuser, 2003, Progress in application of cathodoluminescence (CL) in sedimentary petrology: Mineralogy and Petrology, v.79, no. 3-4, p.127–166.

Ridgway, J. G., 2010, Upper Jurassic (Oxfordian) Smackover facies characterization at Little Cedar Creek Field, Conecuh County, Alabama, Master's thesis, University of Alabama, Tuscaloosa, 84 p.

Salvador, A., 1987, Late Triassic-Jurassic paleogeography and origin of Gulf of Mexico Basin: The American Association of Petroleum Geologists Bulletin, v. 71, no. 4, p. 419-451.

Singh, U., 1987, Ooids and cements from the Late Precambrian of the Flinders Ranges, South Australia: Journal of sedimentary Petrology, v. 57, no. 1, p. 117-127.

Tonietto, S. N., and Pope, P. C., 2013, Diagenetic Evolution and its Influence on Petrophysical Properties of the Jurassic Smackover Formation Thrombolite and Grainstone Units of Little Cedar Creek Field, Alabama: Gulf Coast Association of Geological Societies Journal, v. 2, p. 68-84.

Verwer, K., G. P. Eberli, and R. J. Weger, 2011, Effect of pore structure on electrical resistivity in carbonates: The American Association of Petroleum Geologists Bulletin, v. 95, no. 2, p. 175-190, doi 10.1306/06301010047.

Warusavitharana, C., and W. C. Parcell, 2013, Sedimentary features, occurrence, and cyclicity of microbialite facies in the Roubidoux and Jefferson City Formations of Missouri and Kansas: The American Association of Petroleum Geologists Bulletin, v. 97, no. 11, p. 1849-1870, doi 10.1306/06261312174.

Weger, R. J., G. P. Eberli, T. Baechle, J. L. Massaferro, and Y. Sun, 2009, Quantification of pore structure and its effect on sonic velocity and permeability in carbonates: The American Association of Petroleum Geologists Bulletin, v. 93, no. 10, p. 1297-1317, doi 10.1306/05270909001.

Williams, K. L., 1987, An Introduction to X-Ray Spectrometry: X-ray Fluorescence and Electron Microprobe, Sydney, Allen & Unwin, 384 p.

APPENDIX A

Table A.1. Effective reservoir thickness in core (ERTC), number of core plugs (Pgs), and average values of porosity and permeability of each of the two reservoir units, and percentage of cement (cem) in the microbial thrombolite reservoir. Porosity cutoff values are 10% in the grainstone reservoir and 6% in the thrombolite reservoir.

		Thrombolite					Grainstone			
Well	API	ERTC (ft)	Pgs	Poros. (%)	Perm. (md)	Cem (%)	ERTC (ft)	Pgs	Poros. (%)	Perm. (md)
1	1035200770000	27.0	21	10	—	39	12.0	16	14	2.4
2	1035200880000	20.5	21	12	82.6	46	9.0	19	19	10.1
3	1035200910000	24.5	32	13	336.4	52	8.5	19	15	3.9
4	1035200940000	16.0	19	9	13.4	47	13.5	24	17	3.6
5	1035201020000	17.5	28	9	77.1	53	13.0	28	17	3.9
6	1035201050000	6.5	13	9	16.6	50	4.5	11	22	18.3
7	1035201080000	20.0	21	13	299.5	44	9.0	19	14	3
8	1035201100000	5.0	15	8	2.5	71	—	—	—	—
9	1035201110000	11.0	25	8	7.8	51	12.0	25	19	21.9
10	1035201130000	8.0	17	8	38.0	52	6.0	17	22	5.2
11	1035201190000	18.0	35	10	47.6	53	10.0	23	16	1.3
12	1035201210000	6.5	15	8	56.1	63	1.0	3	12	0.4
13	1035201220000	5.0	10	10	40.0	57	5.0	10	22	2.1
14	1035201260000	9.0	20	8	124.3	56	—	—	—	—
15	1035201280000	—	—	—	—	56	6.0	13	20	3.2
16	1035201290000	9.0	19	10	39.3	55	2.5	6	13	1.3
17	1035201390000	6.5	13	10	48.6	62	—	—	—	—
18	1035201400000	11.0	23	8	5.6	53	6.0	13	26	18.6
19	1035201430000	11.0	18	10	68.0	61	10.5	15	17	0.4
20	1035201440000	30.0	56	10	72.4	50	1.5	3	14	1.9
21	1035201470000	23.0	42	9	47.7	55	6.5	13	18	0.2
22	1035201500000	14.5	31	8	12.1	62	—	—	—	—
23	1035201530000	20.0	43	9	31.4	64	7.0	13	20	2.2
24	1035201560000	1.5	3	9	2.2	48	3.5	9	15	2.9
25	1035201590000	18.5	35	9	28.4	57	12.0	23	21	1.9
26	1035201600000	4.5	9	9	16.2	70	8.5	17	24	8.9
27	1035201610000	14.0	26	10	47.9	68	8.0	16	23	2.1
28	1035201720000	—	—	—	—	—	5.5	10	18	7.6
29	1035201870000	7.0	14	13	169.9	53	—	—	—	—
30	1035201960000	7.0	14	9	39.0	47	—	—	—	—
31	1035202000000	10.0	19	10	31.9	52	—	—	—	—
32	1035202090000	7.5	14	9	42.5	56	—	—	—	—

Table A.2. Effective reservoir thickness in core (ERTC), number of core plugs, and average values of porosity and permeability of the two reservoir facies. Porosity cutoff values are 10% in the grainstone reservoir and 6% in the thrombolite reservoir.

		Thrombolite				Grainstone			
		ERTC	Plugs	Poros.	Perm.	ERTC	Plugs	Poros.	Perm.
Well	API	(ft)		(%)	(md)	(ft)		(%)	(md)
33	1035200900000	8.0	15	7	4.1	4.0	8	14	4.1
34	1035200920000	26.0	38	13	375.7	9.0	19	14	2.7
35	1035200960000	14.5	25	16	579.3	6.0	12	13	0.6
36	1035200980000	23.5	44	10	36.4	0.5	1	11	0.4
37	1035200990000	25.0	37	10	35.1	16.5	27	17	6.4
38	1035201010000	9.5	20	7	13.0	3.5	5	15	1.3
39	1035201040000	5.0	10	9	7.8	9.0	18	19	2.7
40	1035201060000	2.5	6	7	2.1	14.5	32	16	5.2
41	1035201070000	—	—	—	—	—	—	—	—
42	1035201140000	4.0	3	6	0.8	19.0	37	21	3.8
43	1035201150000	—	—	—	—	—	—	—	—
44	1035201160000	—	—	—	—	—	—	—	—
45	1035201170000	3.0	5	6	1.1	12.0	24	19	5.3
46	1035201180000	—	—	—	—	30.0	32	22	3.3
47	1035201200000	—	—	—	—	—	—	—	—
48	1035201230000	9.0	9	17	312.7	10.0	20	22	14.6
49	1035201240000	6.5	11	8	7.5	12.0	23	26	7.2
50	1035201250000	—	—	—	—	—	—	—	—
51	1035201270000	—	—	—	—	—	—	—	—
52	1035201300000	—	—	—	—	5.0	10	13	2.2
53	1035201310000	—	—	—	—	2.0	6	17	0.3
54	1035201340100	22.5	33	10	38.2	—	—	—	—
55	1035201360000	20.5	39	10	80.2	1.5	3	12	1.3
56	1035201380000	5.5	11	8	9.5	6.5	13	22	4.8
57	1035201410000	—	—	—	—	5.0	10	16	8.1
58	1035201420100	—	—	—	—	6.0	10	17	1.9
59	1035201460000	—	—	—	—	—	—	—	—
60	1035201550000	—	—	—	—	—	—	—	—
61	1035201580000	—	—	—	—	2.5	5	11	2.2
62	1035201620200	3.5	9	8	10.0	—	—	—	—
63	1035201640000	3.5	8	8	9.7	2.5	4	14	0.3
64	1035201660000	—	—	—	—	3.5	7	16	0.3

Table A.2. Continued.

65	1035201700000	—	—	—	—	—	—	—	—
66	1035201740000	—	—	—	—	1.5	5	11	3.1
67	1035201750000	—	—	—	—	2.0	5	13	11.3
68	1035201760100	—	—	—	—	—	—	—	—
69	1035201790000	—	—	—	—	0.5	1	11	0.2
70	1035201800000	4.0	9	9	1.3	3.5	9	17	15.8
71	1035201820000	—	—	—	—	2.0	4	16	32.2
72	1035201850000	—	—	—	—	—	—	—	—
73	1035201890000	—	—	—	—	—	—	—	—
74	1035201910000	7.5	16	9	73.5	—	—	—	—
75	1035202020000	—	—	—	—	—	—	—	—
76	1035202050000	3.5	7	9	33.4	—	—	—	—
77	1035202100000	6.5	13	7	8.7	—	—	—	—

Table A.3. Microbial thrombolite microprobe analysis results.

		Ca (wt%)	Mg (wt%)	Fe (ppm)	Mn (ppm)	Sr (ppm)	S (ppm)	Na (ppm)
Fibrous calcite Fringe	**AVERAGE**	**39.58**	**0.40**	**0**	**508**	**849**	**455**	**221**
	STDV	0.26	0.08	0	311	0	141	48
	Range	39.24/39.83	0.30/0.50	0	315/970	0	205/616	148/282
	Analysis	**6**	**6**	0	**4**	1	**6**	**6**
	below LLD	0	0	**6**	2	**5**	0	0
Drusy calcite fringe (all analysis)	**AVERAGE**	**39.71**	**0.31**	**0**	**806**	**693**	**476**	**207**
	STDV	0.31	0.16	0	795	97	243	64
	Range	39.05/40.29	0.05/0.68	0	320/3570	617/831	165/1007	122/334
	Analysis	**27**	**27**	0	**15**	5	**17**	12
	below LLD	0	0	**26**	12	**22**	10	**15**
Drusy calcite fringe Fringe base	**AVERAGE**	**39.65**	**0.39**	**0**	**502**	**748**	**499**	**237**
	STDV	0.23	0.09	0	232	111	215	58
	Range	39.29/39.96	0.23/0.54	0	315/970	617/849	205/1007	148/334
	Analysis	**9**	**9**	0	4	3	**8**	4
	below LLD	0	0	**9**	**5**	**6**	1	**5**
Drusy calcite fringe Fringe tip	**AVERAGE**	**39.90**	**0.20**	**0**	**705**	**0**	**339**	**167**
	STDV	0.34	0.13	0	299	0	143	40
	Range	39.38/40.29	0.05/0.47	0	507/1281	0	183/465	139/195
	Analysis	**9**	**9**	0	**6**	0	3	2
	below LLD	0	0	**8**	3	**9**	**6**	**7**
Mosaic calcite	**AVERAGE**	**40.01**	**0.15**	**0**	**817**	**935**	**0**	**139**
	STDV	0.19	0.14	0	662	13	0	0
	Range	39.86/40.39	0.07/0.46	0	421/2385	926/944	0	0
	Analysis	**8**	**8**	0	**8**	2	0	1
	below LLD	0	0	**8**	0	**6**	**8**	**7**
Blocky calcite	**AVERAGE**	**40.06**	**0.19**	**809**	**735**	**0**	**166**	**159**
	STDV	0.26	0.09	380	258	0	97	42
	Range	39.53/40.59	0.03/0.33	400/1432	339/1300	0	124/237	130/221
	Analysis	**29**	**29**	10	**27**	0	3	4
	below LLD	0	0	**19**	2	**29**	**26**	**25**

Table A.3. Continued.

Dolomite (all analysis)	**AVERAGE**	**22.62**	**12.63**	**2336**	**1157**	**0**	**0**	**210**
	STDV	0.20	0.21	2131	187	0	0	0
	Range	22.31/22.87	12.35/12.88	790/6520	980/1500	0	0	0
	Analysis	**7**	**7**	**7**	**7**	0	0	1
	below LLD	0	0	0	0	**7**	**7**	**1**
Dolomite center	**AVERAGE**	**22.54**	**12.62**	**2083**	**1117**	**0**	**0**	**0**
	STDV	0.29	0.24	1541	121	0	0	0
	Range	22.31/22.87	12.35/12.81	820/3800	980/1210	0	0	0
	Analysis	**3**	**3**	**3**	**3**	0	0	0
	below LLD	0	0	0	0	**3**	**3**	**3**
Dolomite border	**AVERAGE**	**22.70**	**12.49**	**4240**	**1375**	**0**	**0**	**210**
	STDV	0.10	0.19	3224	177	0	0	0
	Range	22.63/22.77	12.35/12.62	1960/6520	1250/1500	0	0	0
	Analysis	**2**	**2**	**2**	**2**	0	0	1
	below LLD	0	0	0	0	**2**	**2**	**1**

Practical Lower Limit of Detection (LLD)

Ca (wt%)	Mg (wt%)	Fe (ppm)	Mn (ppm)	Sr (ppm)	S (ppm)	Na (ppm)
0.034	0.021	300	260	580	120	120

Table A.4. Ooid-oncoid-peloid grainstone microprobe analysis results.

		Ca (wt%)	Mg (wt%)	Fe (ppm)	Mn (ppm)	Sr (ppm)	S (ppm)	Na (ppm)
Bladed to drusy calcite fringe (all analyses)	**AVERAGE**	**39.73**	**0.30**	**731**	**740**	**722**	**570**	**318**
	STDV	0.20	0.14	284	294	97	237	124
	Range	39.41/40.04	0.10/0.56	405/921	378/989	623/878	121/924	174/582
	Analysis	**18**	**18**	3	4	8	**13**	**10**
	below LLD	0	0	**15**	**14**	**10**	5	8
Bladed to drusy calcite fringe crystal base	**AVERAGE**	**39.73**	**0.35**	**0**	**0**	**755**	**649**	**378**
	STDV	0.23	0.15	0	0	90	238	126
	Range	39.43/40.04	0.11/0.56	0	0	641/878	252/924	239/582
	Analysis	**8**	**8**	**0**	**0**	**6**	**7**	**6**
	below LLD	0	0	8	8	2	1	2
Bladed to drusy calcite fringe crystal tip	**AVERAGE**	**39.73**	**0.26**	**663**	**795**	**623**	**477**	**229**
	STDV	0.22	0.12	365	288	0	220	41
	Range	39.41/39.97	0.10/0.46	405/921	464/989	623	121/806	0/273
	Analysis	**8**	**8**	2	3	**2**	**6**	**4**
	below LLD	0	0	**6**	**5**	0	2	4
Blocky calcite	**AVERAGE**	**39.72**	**0.19**	**755**	**863**	**0**	**0**	**156**
	STDV	0.44	0.01	99	192	0	0	0
	Range	38.65/40.17	0.18/0.22	598/916	574/1147	0	0	0
	Analysis	**11**	**11**	**11**	**11**	0	0	1
	below LLD	0	0	0	0	**11**	**11**	**10**
Dolomite	**AVERAGE**	**22.52**	**12.75**	**1167**	**1080**	**0**	**0**	**150**
	STDV	0.10	0.06	133	121	0	0	0
	Range	22.48/22.63	12.70/12.81	1090/1320	950/1190	0	0	0
	Analysis	**3**	**3**	**3**	**3**	0	0	1
	below LLD	0	0	0	0	**3**	**3**	**2**

Practical Lower Limit of Detection (LLD)

Ca (wt%)	Mg (wt%)	Fe (ppm)	Mn (ppm)	Sr (ppm)	S (ppm)	Na (ppm)
0.034	0.021	300	260	580	120	120

Table A.5. Data from thin-section analysis - Sample, Facies, Roughness (R), Elongation (E), Porosity (Phi), Macropores (Mp), Dominant Pore Type (PT 1), Minor Pore Type (PT 2), Cement (Cm) type, Cementation (Cmt) intensity, Dissolution (Diss) intensity, Dolomitization (Dol), Recrystallization (Rec). Data from plug analysis – Porosity (Phi), Permeability (K).

		Thin-section										Plug		Coefficients		
Sample	Facies	R (mm^{-1})	E	Phi (%)	Mp (fraction)	PT 1	PT 2	Cm type	Cmt	Diss	Dol / Rec	Phi (%)	K (md)	G	C	D
1	dol TB	156	3.7	11	0.945	VUG	IX	-	-	Mod	High	20.2	682	3	3.5	9.2
2	dol TB	118	3.7	19	0.921	IX	-	-	-	High	High	12.4	37.7	2.6	5.5	10
3	dol TB	141	3.4	12	0.817	IX	VUG	-	-	Mod	High	16.7	111.2	2.7	3.3	9.2
4	dol TB	159	3.5	9	0.744	IX	VUG	-	-	Mod	High	-	-	3	2.6	9.2
5	dol TB	144	3.9	20	0.920	IX	-	-	-	High	High	-	-	2.9	5.7	10
6	dol TB	153	3.7	10	0.920	IX	VUG	-	-	Mod	High	-	-	3	3.2	9.2
7	dol TB	133	3.6	8	0.863	IX	VUG	-	-	Mod	High	13.6	3.78	2.7	2.6	9.2
8	dol TB	156	3.6	11	0.864	IX	VUG	-	-	Mod	High	12.5	14.9	3	3.3	9.2
9	dol TB	134	3.6	11	0.845	IX	-	-	-	Mod	High	11.4	15.7	2.7	3.2	9.2
10	dol TB	168	3.8	5	0.940	IX	VUG	-	-	Mod	High	10	27.2	3.2	2.1	9.2
11	dol TB	171	3.6	13	0.862	IX	VUG	-	-	Mod	High	13.4	104	3.2	3.7	9.2
12	Oo-G	162	3.5	25	0.924	MO	IG	R/NR	High	High	-	-	-	3	2.2	5.7
13	TB-A	141	3.6	15	0.920	VUG	IX	R	Mod	Mod	Low	-	-	2.8	3.1	3.5
14	TB-A	150	3.4	14	0.957	VUG	IG	R/NR	Mod	Low	-	12.3	77	2.8	2.3	1.3
15	TB-B	102	3.3	19	0.900	IX	VUG	R	Mod	Mod	High	16.5	95.9	2.3	3.6	6.4
16	TB-A	141	3.5	21	0.933	VUG	IX	R	Mod	High	High	17.7	199	2.8	4.2	9.2
17	oo-pl-sk G	156	3.4	19	0.753	IG	MO	R	High	Mod	-	17.3	7.99	2.9	2.3	3.4
18	TB-A	144	3.5	27	0.956	VUG	IX	R/NR	Mod	High	High	16.7	426	2.8	4	8.5
19	TB-C	168	3.5	6	0.683	IX	IG	R/NR	High	Low	Low	5.7	0.032	3.1	1.4	5.3
20	TB-A	142	3.8	21	0.962	VUG	IX	R	Mod	Mod	Mod	20.3	1130	2.9	4	3.8
21	TB-B	156	3.6	15	0.820	IX	VUG	R	Mod	Low	High	13.3	33.9	3	2.7	5.8
22	oo-pl-G	124	3.2	23	0.904	IG	MO	R	Mod	Mod	-	14.8	0.28	2.5	3.1	3.2
23	TB-C	221	3.7	8	0.825	IG	VUG	R/NR	High	Low	Low	7.8	0.543	3.8	1.6	3.5
24	TB-B	167	3.6	10	0.870	VUG	IX	R/NR	High	Low	Mod	11	21.4	3.1	1.8	3.8
25	TB-C	177	3.7	8	0.850	VUG	IG	R/NR	High	Low	Low	7.5	0.252	3.3	1.6	3.5
26	TB-B	182	3.8	8	0.950	VUG	IG	R/NR	Mod	Low	Low	9.8	49	3.3	1.7	1.5
27	TB-B	186	3.7	13	0.846	IX	VUG	R/NR	High	Mod	Mod	6.1	0.122	3.4	2	6.4
28	TB-A	133	3.5	32	0.981	VUG	IX	R	Mod	High	Mod	24.5	1470	2.7	6.1	8.5
29	TB-A	190	3.8	9	0.944	NT-VUG	IX	R/NR	High	Mod	Low	5.5	0.41	3.4	1.8	9.4
30	oo-G	127	3.4	32	0.934	MO	IG	R/NR	High	High	-	27.1	5.63	2.6	2.5	5.7
31	TB-B	189	3.8	22	0.927	IX	VUG	R/NR	Mod	Mod	Mod	15.4	7.07	3.4	3.2	5.9
32	TB-C	183	3.6	7	0.686	IG	VUG	R/NR	High	Low	Low	7.1	0.021	3.3	1.4	1.6
33	TB-A	152	3.9	20	0.685	VUG	IX	R/NR	Mod	Mod	Mod	18.8	362	3	2.5	3.8

Table A.5: Continued.

Sample	Facies	Thin-section R (mm^{-1})	E	Phi (%)	Mp (fraction)	PT 1	PT 2	Cm type	Cmt	Diss	Dol / Rec	Plug Phi (%)	K (md)	Coefficients G	C	D
34	TB-A	340	5.2	5	0.986	FR	NT-VUG	R/NR	High	Low	-	-	-	5.6	1.2	7.2
35	oo-G	145	3.4	26	0.935	MO	IG	R/NR	High	Mod	-	24	0.85	2.8	2.2	5.3
36	TB-A	139	3.8	17	0.982	VUG	IG	R/NR	Mod	Low	-	13	109	2.9	2.6	1.3
37	TB-A	243	3.8	19	0.979	VUG	-	R/NR	High	High	-	14.1	9.5	4	2.9	7.7
38	TB-A	173	3.9	24	0.994	VUG	IX	R/NR	High	High	Low	6.2	1.99	3.3	3.5	8.5
39	TB-B	198	3.7	12	0.833	IX	VUG	NR	High	Mod	High	-	-	3.5	2.7	6.9
40	oo-on-G	111	3	34	0.935	MO	IG	R/NR	High	High	-	-	-	2.3	2.6	5.7
41	TB-C	173	3.7	18	0.878	IG	VUG	R/NR	Low	Low	-	-	-	3.2	2.7	1.2
42	TB-A	167	3.5	18	0.911	VUG	IX	R/NR	Mod	High	Mod	-	-	3.1	2.9	8.5
43	oo-on-G	125	3	27	0.933	MO	IG	R/NR	High	High	-	-	-	2.4	2.3	5.7
44	TB-A	183	3.9	13	0.977	VUG	IX	R/NR	High	Mod	Low	-	-	3.4	2.2	3.8
45	in-G	174	3.5	11	0.955	MO	IX	NR	High	Mod	-	-	-	3.2	1.9	7.1
46	TB-B	231	3.9	14	0.950	VUG	IG	R/NR	Mod	Mod	-	12	6.3	3.9	2.4	1.4
47	TB-A	117	3.3	15	0.940	VUG	IX	NR	High	High	Mod	19.5	91.2	2.4	3.6	9.2
48	TB-B	165	3.6	14	0.964	VUG	IG	R/NR	Mod	High	Low	-	-	3.1	2.6	5.8
49	TB-A	166	3.7	11	0.855	IX	VUG	R/NR	High	Mod	High	-	-	3.1	1.9	9.2
50	TB-A	207	3.6	20	0.940	IX	VUG	R/NR	High	High	Mod	-	-	3.6	2.9	9.2
51	sk-pl-G	159	3.6	16	0.925	MO	VUG	R/NR	High	Mod	-	-	-	3	1.7	7.1
52	TB-A	165	3.5	8	0.800	IX	VUG	R/NR	High	Mod	Mod	-	-	3.1	1.6	6.4
53	TB-A	202	3.8	15	0.980	VUG	IX	R/NR	High	High	Low	-	-	3.6	2.5	8.5
54	W	291	4.5	15	0.980	VUG	IX	NR	High	Mod	-	-	-	4.8	2.6	7.1
55	sk-G	365	4.4	25	0.980	IG	VUG	NR	Low	Low	-	-	-	5.6	5.8	2.7
56	DL	178	3.6	9	0.956	VUG	FR	-	-	Mod	High	-	-	3.2	2.8	7.1
57	sk-G	165	3.7	10	0.910	IG	WG	NR	Mod	-	-	-	-	3.1	2.5	2.6
58	R	179	4.2	12	0.997	IG	-	R/NR	Mod	Low	-	-	-	3.4	1.8	2.9
59	M	414	4.3	15	0.773	MP	VUG	-	-	High	-	-	-	6.2	3	5.9
60	M	307	4.3	28	0.743	MP	VUG	-	-	High	-	-	-	4.9	4.6	5.9
61	M	356	4.1	15	0.827	VUG	MO	-	-	High	-	-	-	5.4	3.1	5.9
62	W	396	4.5	25	0.940	MO	MP	-	-	High	-	-	-	6	3	5.9
63	sk-P	662	4.3	17	0.524	MP	IG	R	Low	Mod	-	-	-	9	1.7	4.5
64	sk-P	234	4.2	14	0.864	IG	MP	NR	Low	Mod	-	-	-	4.1	2.7	2.9
65	sk-G	98	4.1	17	0.924	IG	WG	NR	Low	Mod	-	-	-	2.5	3.2	2.9
66	sk-G	175	4.2	14	0.921	IG	MO	NR	Mod	Mod	-	-	-	3.4	2.7	3.2
67	W	606	5.7	7	0.979	FR	WG	NR	High	Low	-	-	-	8.8	2.1	4.9
68	oo-G	155	3.7	13	0.892	IG	MO	R	Mod	Mod	-	-	-	3	2.2	3.2

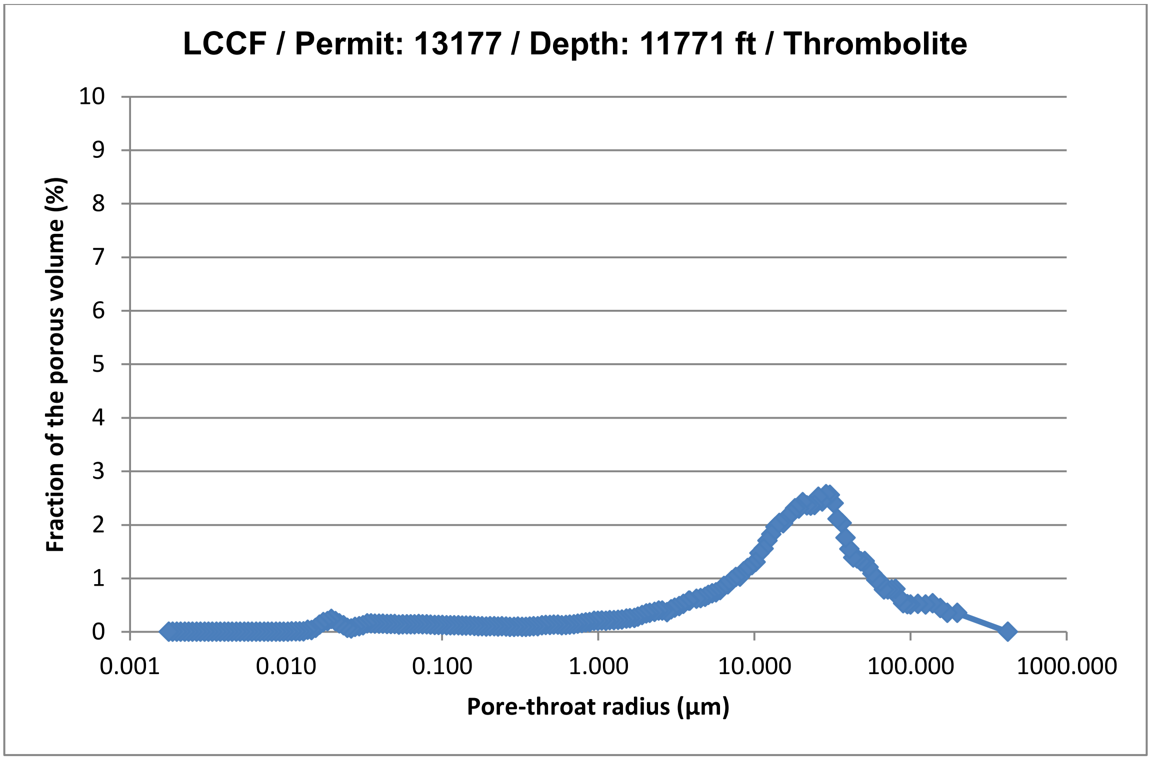
Table A.5: Continued.

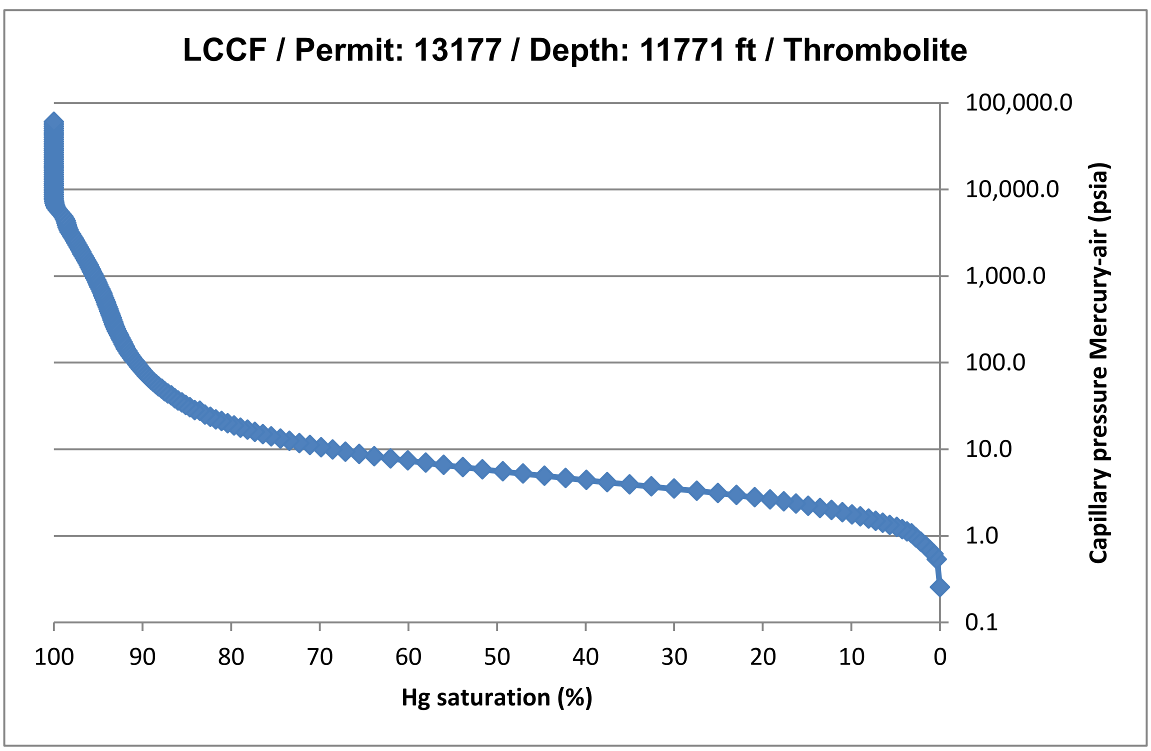
Sample	Facies	Thin-section R (mm^{-1})	E	Phi (%)	Mp (fraction)	PT 1	PT 2	Cm type	Cmt	Diss	Dol / Rec	Plug Phi (%)	K (md)	Coefficients G	C	D
69	sk-G	179	4.1	11	0.900	IG	WG	R	Low	Low	-	-	-	3.4	2	2.7
70	oo-G	255	3.6	20	0.810	MO	WG	R/NR	High	High	-	-	-	4.1	1.6	5.7
71	oo-G	157	3.9	13	0.877	IG	-	NR	Low	-	-	-	-	3.1	3	2.4
72	oo-G	141	4	15	0.873	IG	-	NR	Low	Low	-	-	-	2.9	3.6	2.7
73	oo-pl-G	186	3.7	8	0.538	IG	VUG	NR	Low	Low	-	-	-	3.4	1.8	2.7
74	on-pl-G	130	3.7	10	0.960	IG	WG	R/NR	Low	Low	-	-	-	2.7	1.7	2.7
75	W	312	4	19	0.868	VUG	IG	-	-	Mod	-	-	-	4.9	4.9	4.1
76	on-G	276	4.1	16	0.731	IG	WG	R	Low	Mod	-	-	-	4.5	2.3	2.9
77	pl-P	251	4.1	19	0.889	MP	VUG	-	-	High	-	-	-	4.2	3.2	5.9
78	pl-P	292	4	24	0.754	VUG	MP	-	-	High	-	-	-	4.7	4.1	5.9
79	pl-G	277	3.9	14	0.557	IG	-	-	-	Low	-	-	-	4.5	2.7	1.1
80	oo-G	377	3.7	27	0.904	MO	-	R/NR	High	High	-	-	-	5.5	1.8	7.7
81	oo-G	272	3.9	18	0.883	WG	IG	R/NR	Mod	Mod	-	-	-	4.4	1.8	4.9
82	on-G	204	3.9	13	0.869	IG	WG	-	-	Low	-	-	-	3.6	2.6	2.4
83	oo-G	165	3.9	26	0.927	MO	VUG	R/NR	High	High	-	-	-	3.2	2.2	7.7
84	sk-G	229	4.1	11	0.936	MO	WG	NR	High	Mod	-	-	-	4	1.6	5.3
85	sk-P	241	4.2	9	0.844	MP	VUG	NR	Mod	High	-	-	-	4.1	1.8	7.1
86	oo-sk-G	151	3.9	23	0.943	MO	WG	R/NR	High	High	-	-	-	3	1.7	7.7
87	oo-G	164	3.5	13	0.954	MO	-	R/NR	High	Mod	-	-	-	3	1.4	7.1
88	oo-G	161	3.7	13	0.854	MO	IG	R/NR	High	Mod	-	-	-	3.1	1.5	5.3
89	sk-G	205	4	15	0.873	WG	IG	R/NR	High	Mod	-	-	-	3.7	1.6	5.3
90	sk-G	177	3.8	25	0.956	MO	VUG	R/NR	High	High	-	-	-	3.3	2.2	8.5

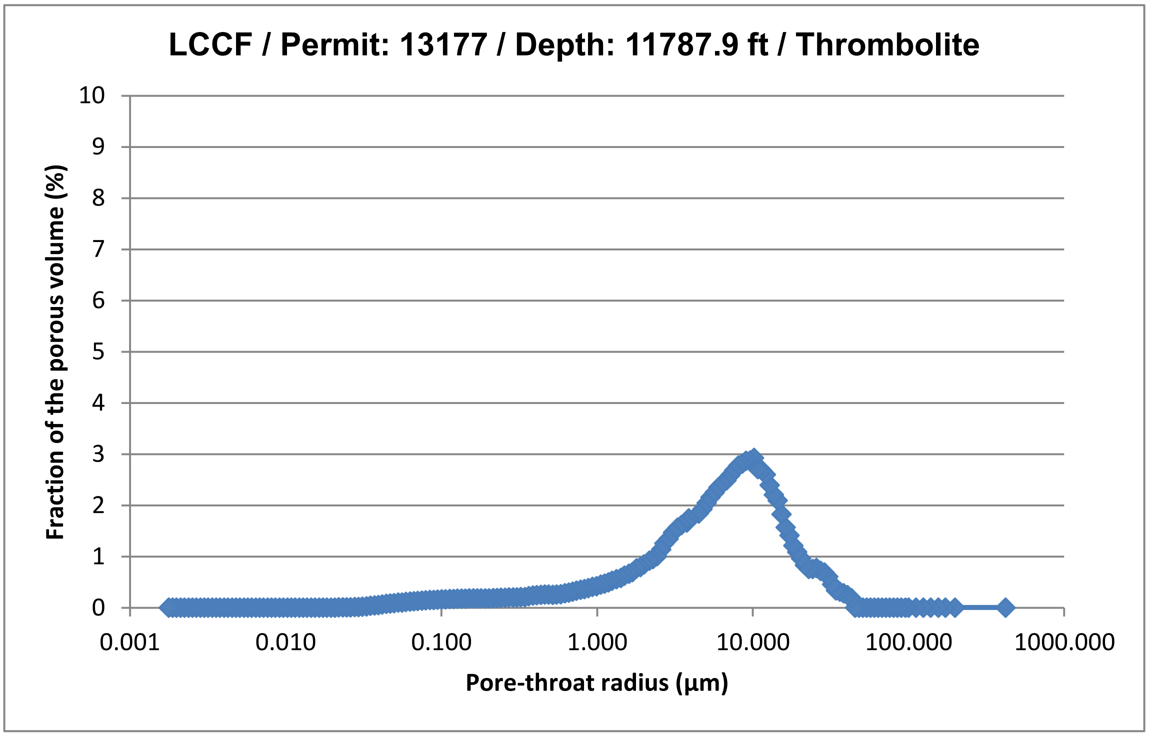
Facies: G – grainstone; P – packstone; W – wackestone; M – mudstone; R – rudstone; DL – dolostone; TB – thrombolite; dol – dolomitized; oo – oolitic; on – oncolitic; pl – peloidal; sk – skeletal; in – intraclastic
Pore type: IG – intergranular; IX – intercrystalline; WG – intragranular; MO – moldic; VUG – vuggy; FR – fracture; MP – microporosity
Cement type: R – rimming; NR – non-rimming

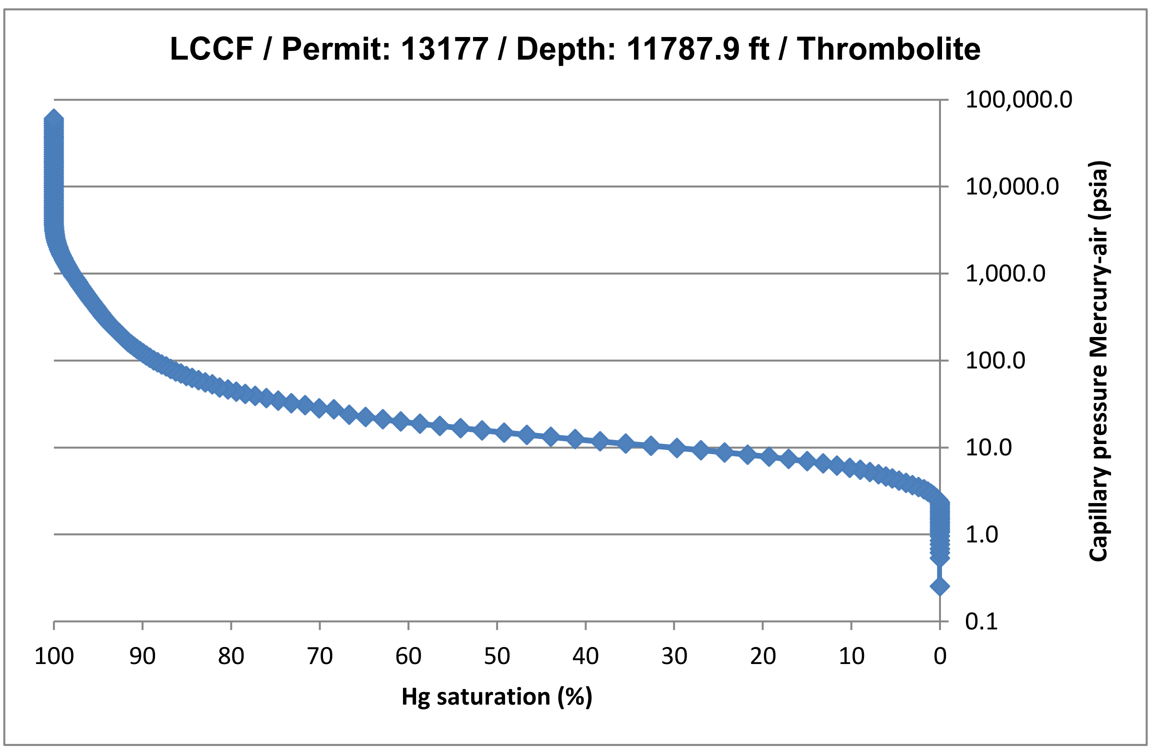
APPENDIX B

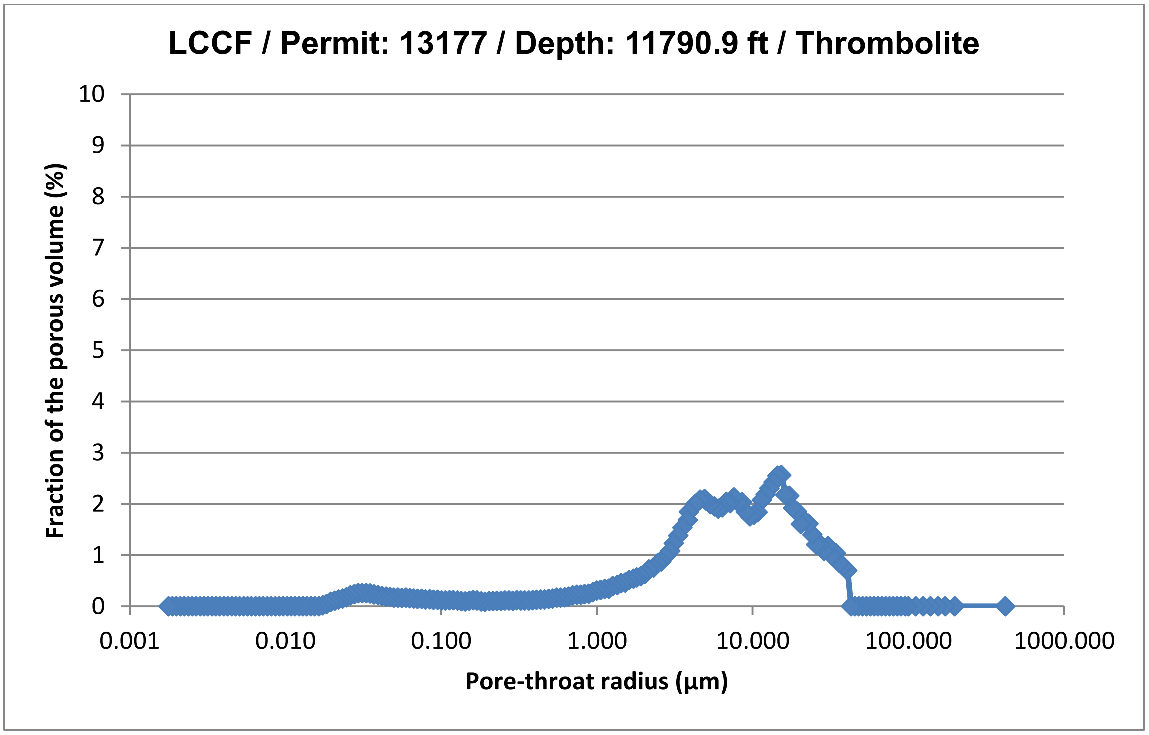
Little Cedar Creek Field – Thrombolite – Capillary pressure data

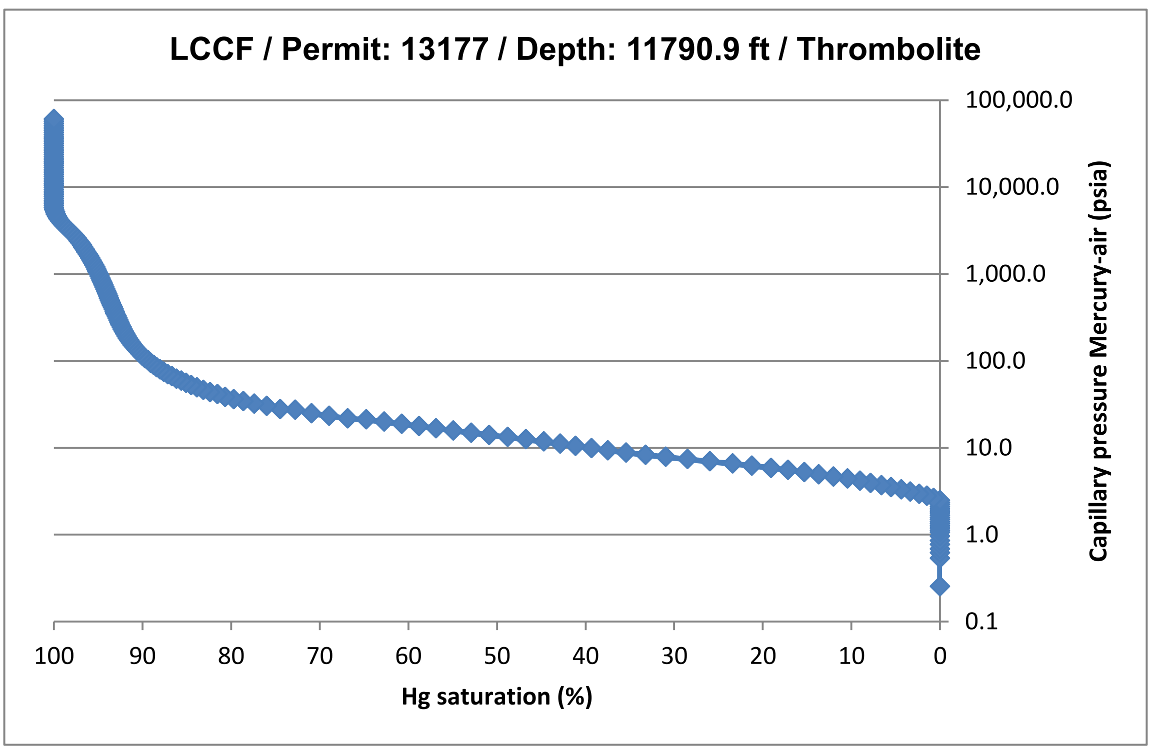


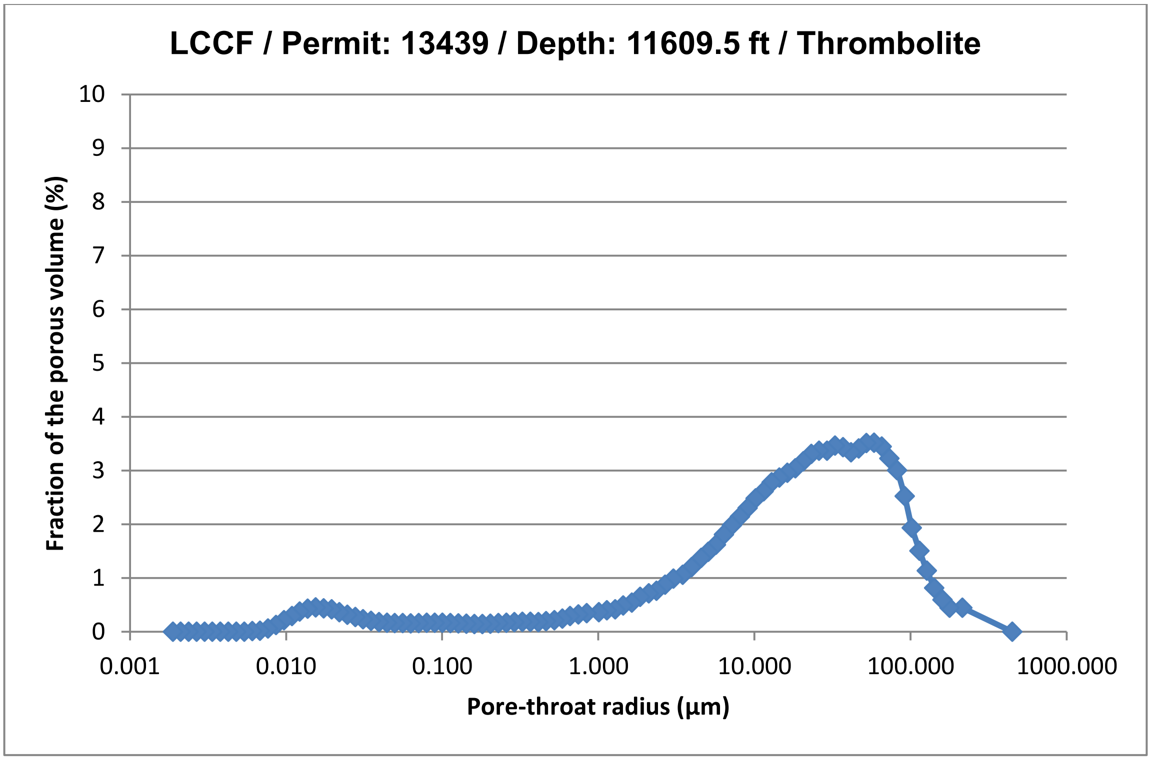



LCCF / Permit: 13177 / Depth: 11787.9 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

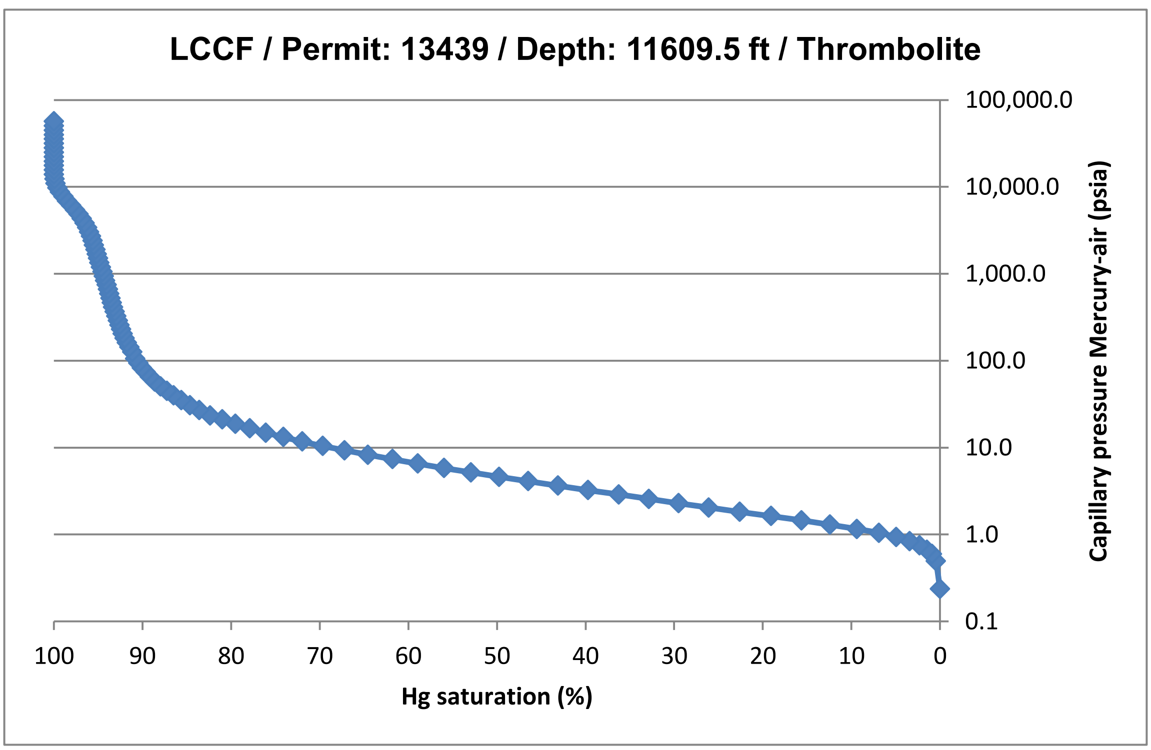

LCCF / Permit: 13177 / Depth: 11787.9 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


LCCF / Permit: 13177 / Depth: 11790.9 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

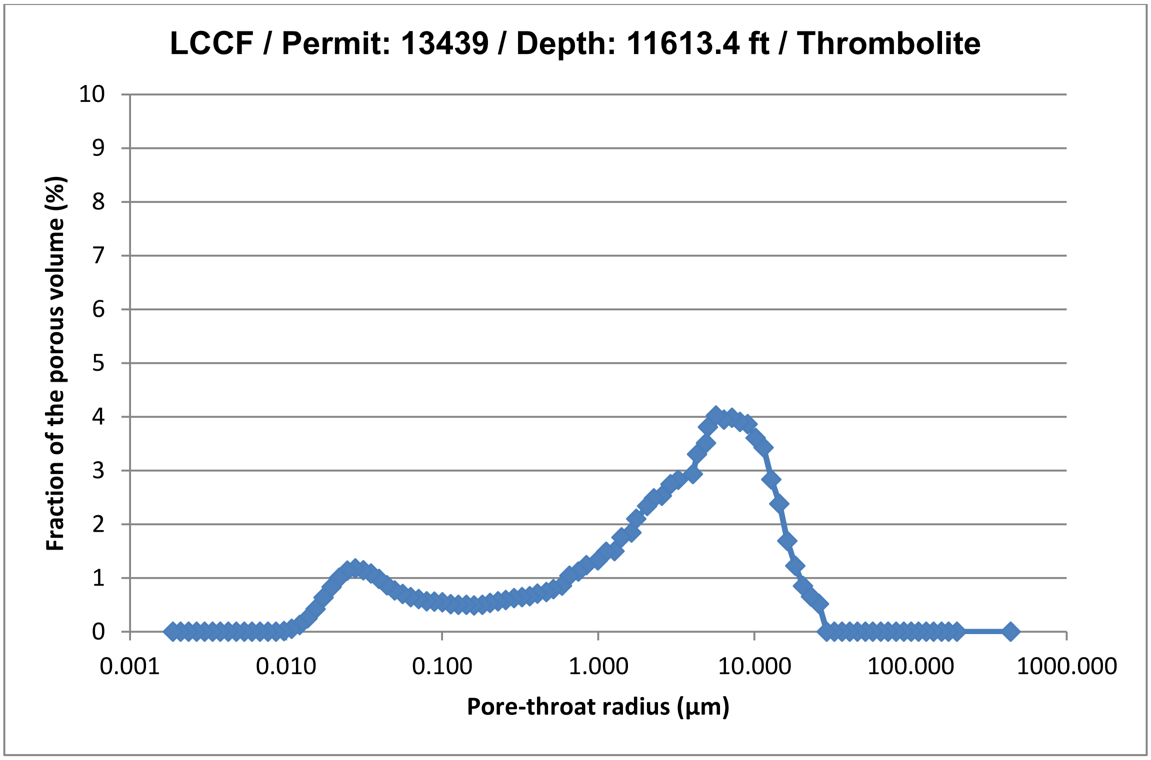

LCCF / Permit: 13177 / Depth: 11790.9 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

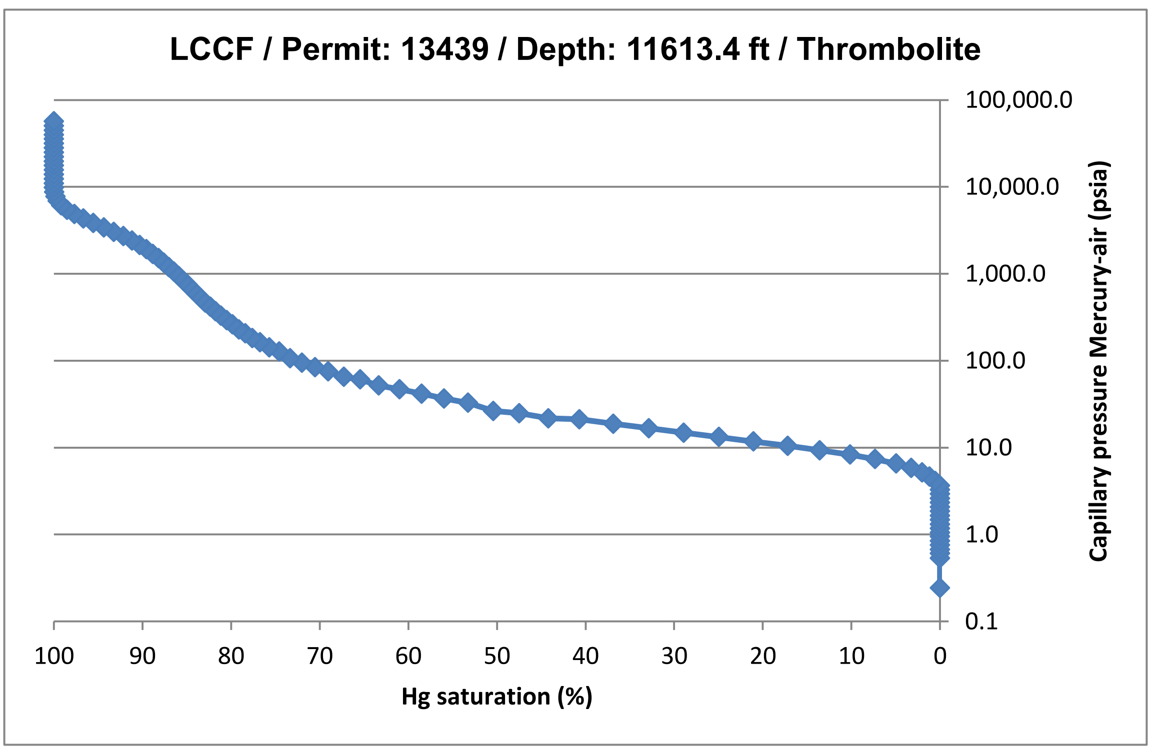


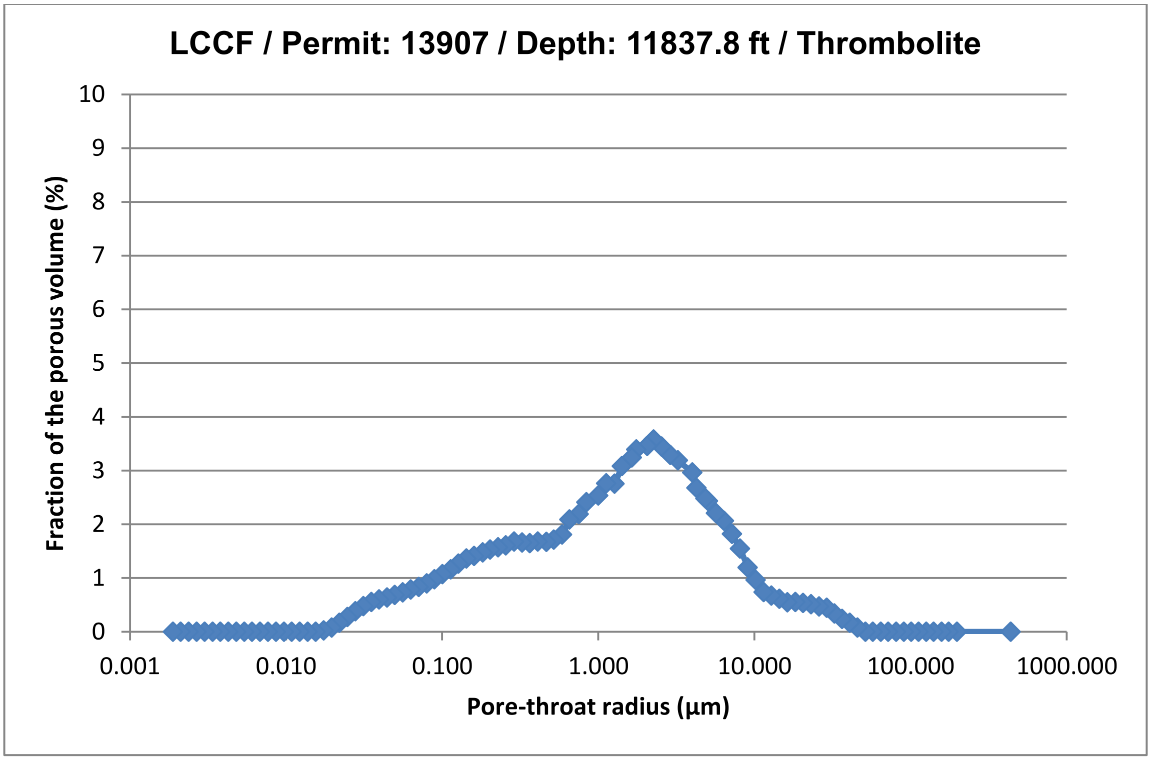
LCCF / Permit: 13439 / Depth: 11609.5 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

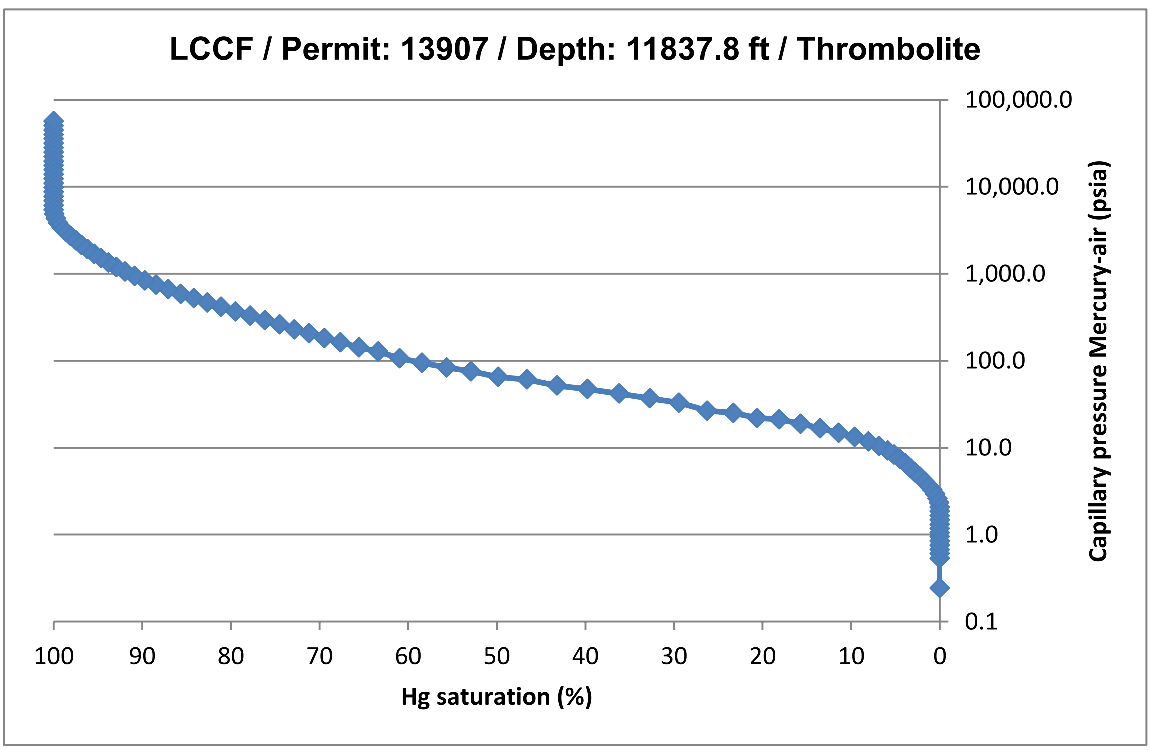


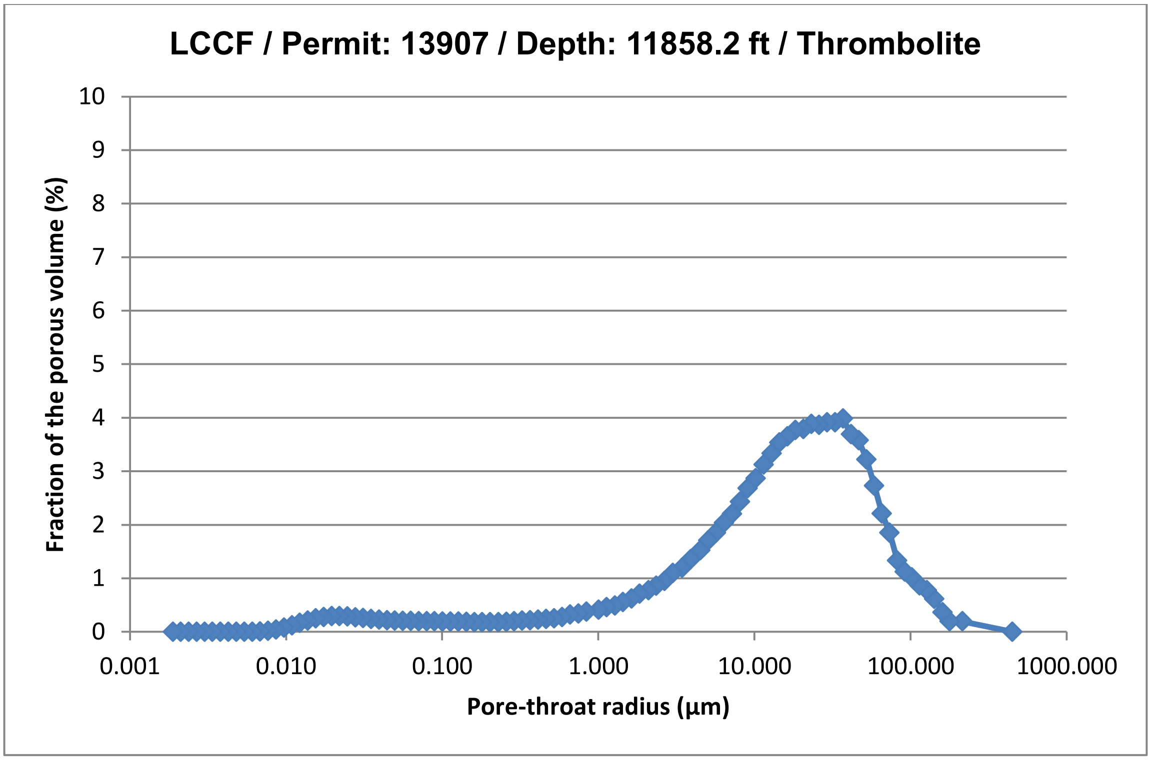
LCCF / Permit: 13439 / Depth: 11609.5 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

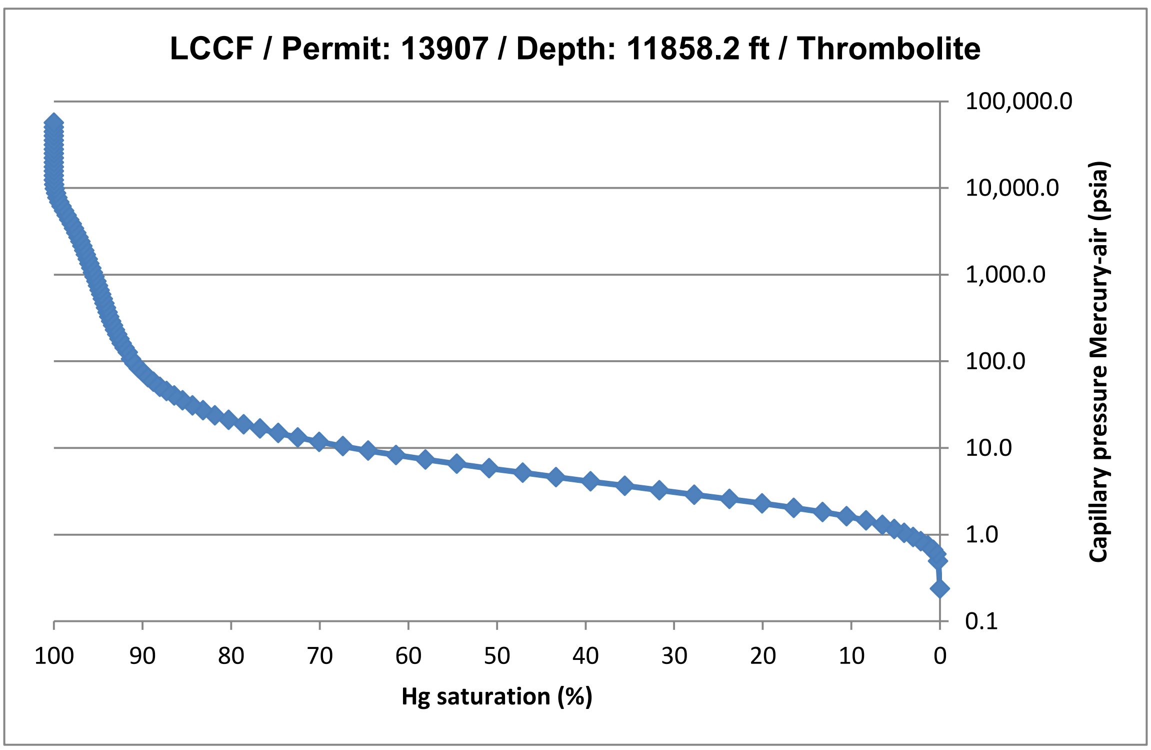

LCCF / Permit: 13439 / Depth: 11613.4 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

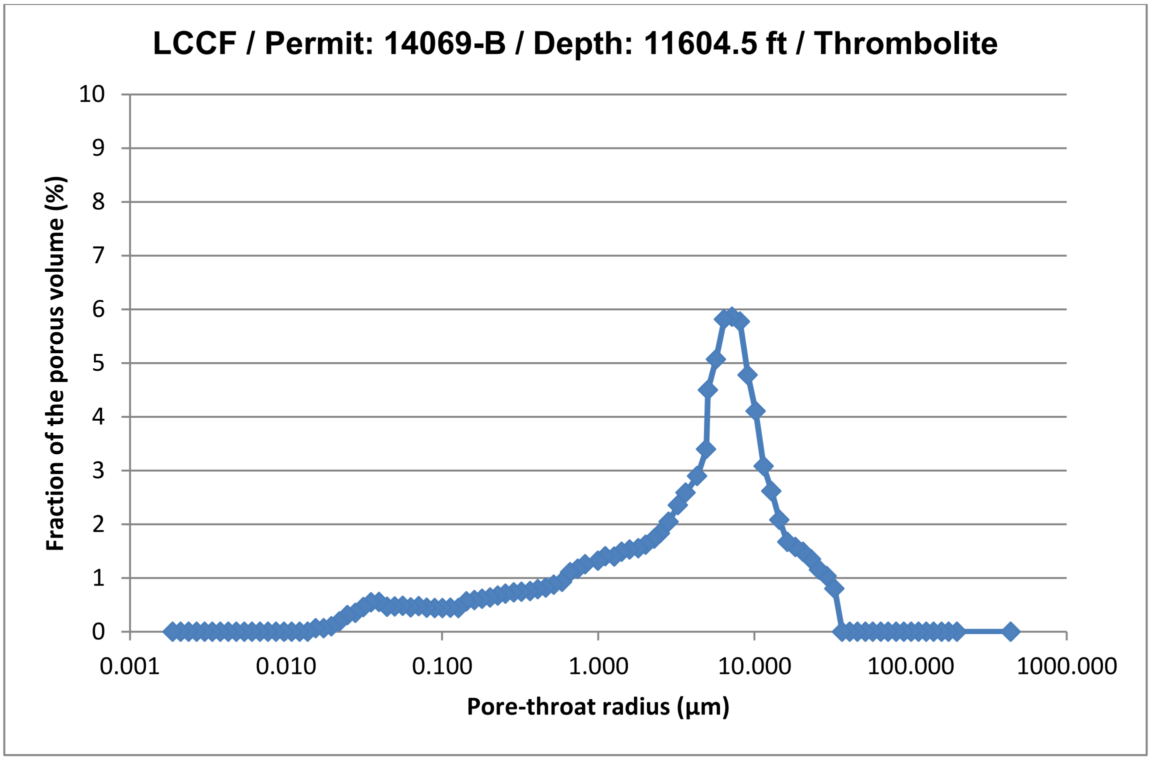

LCCF / Permit: 13439 / Depth: 11613.4 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

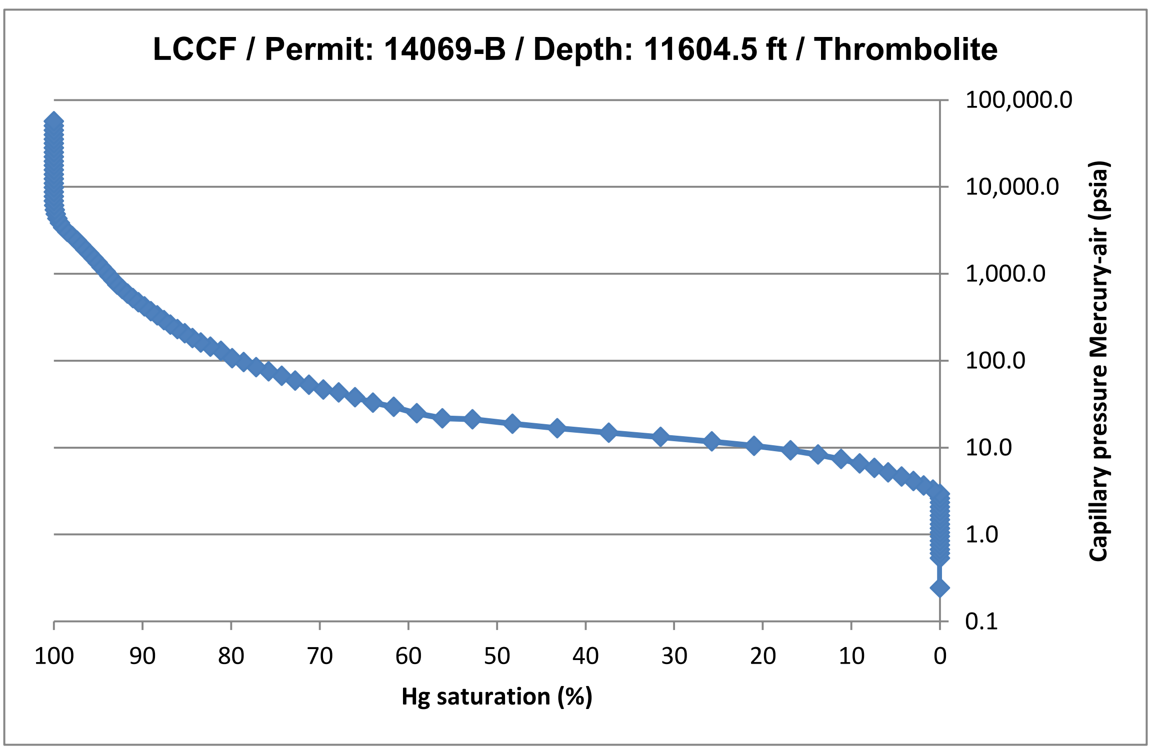

LCCF / Permit: 13907 / Depth: 11837.8 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

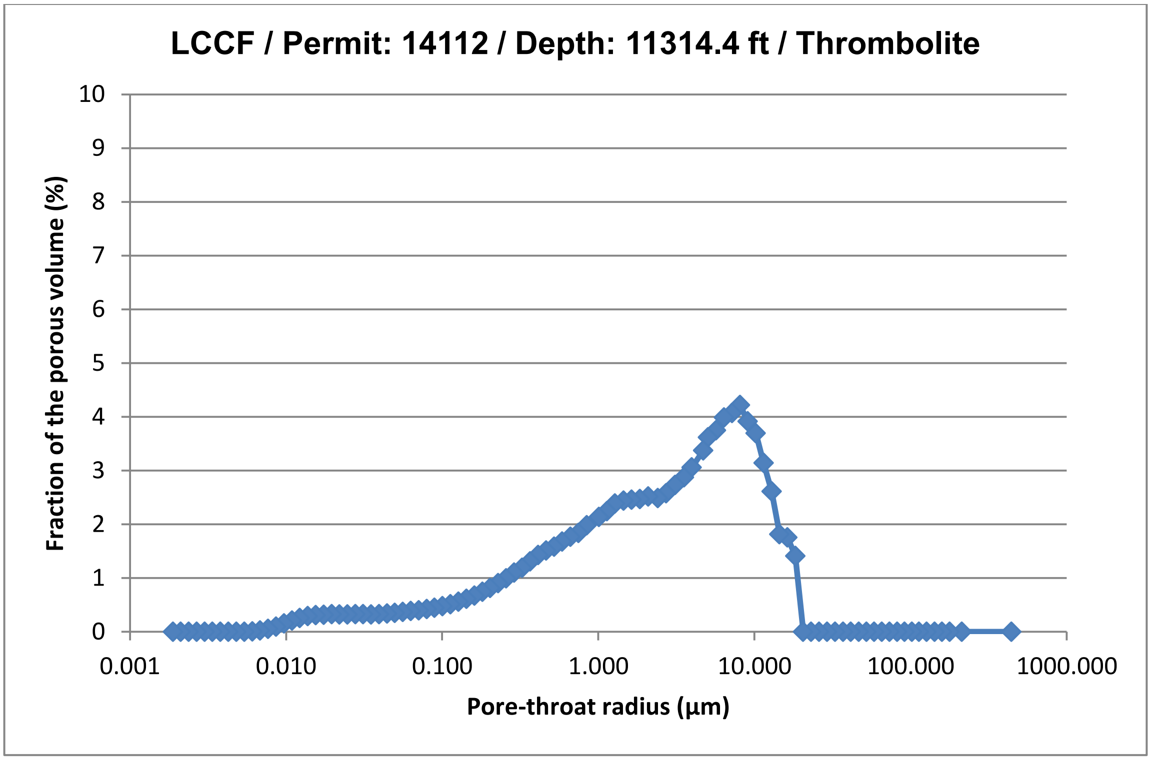

LCCF / Permit: 13907 / Depth: 11837.8 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

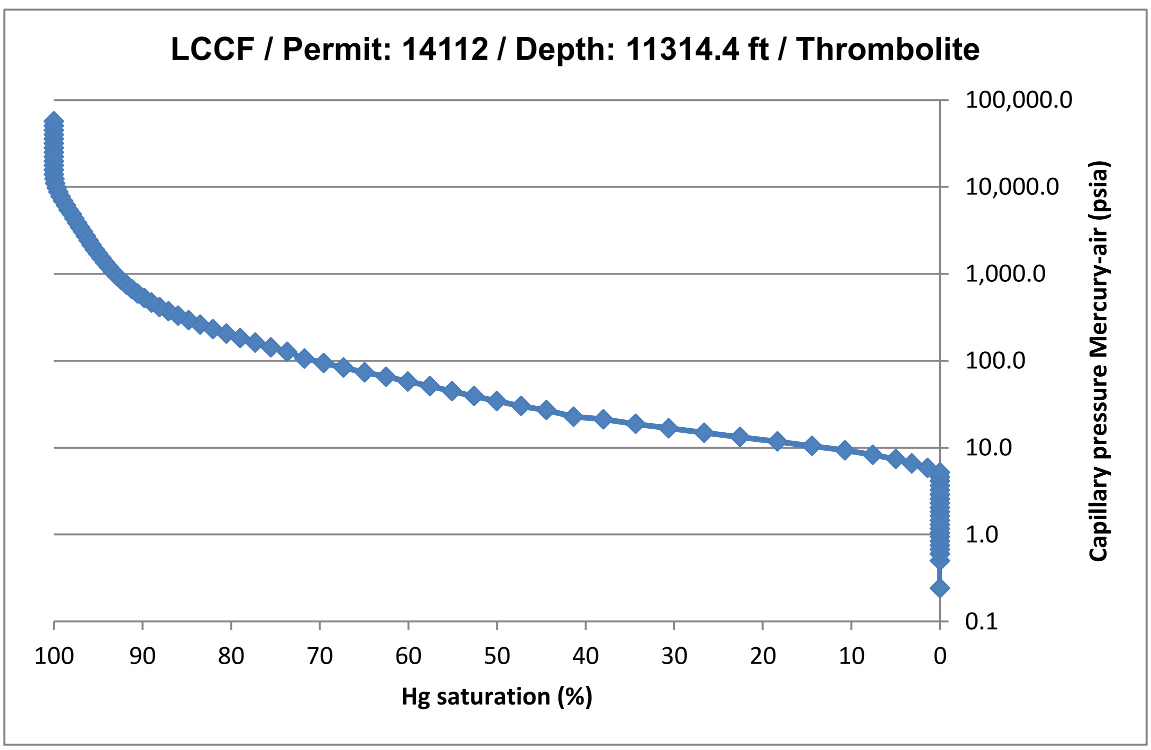

LCCF / Permit: 13907 / Depth: 11858.2 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

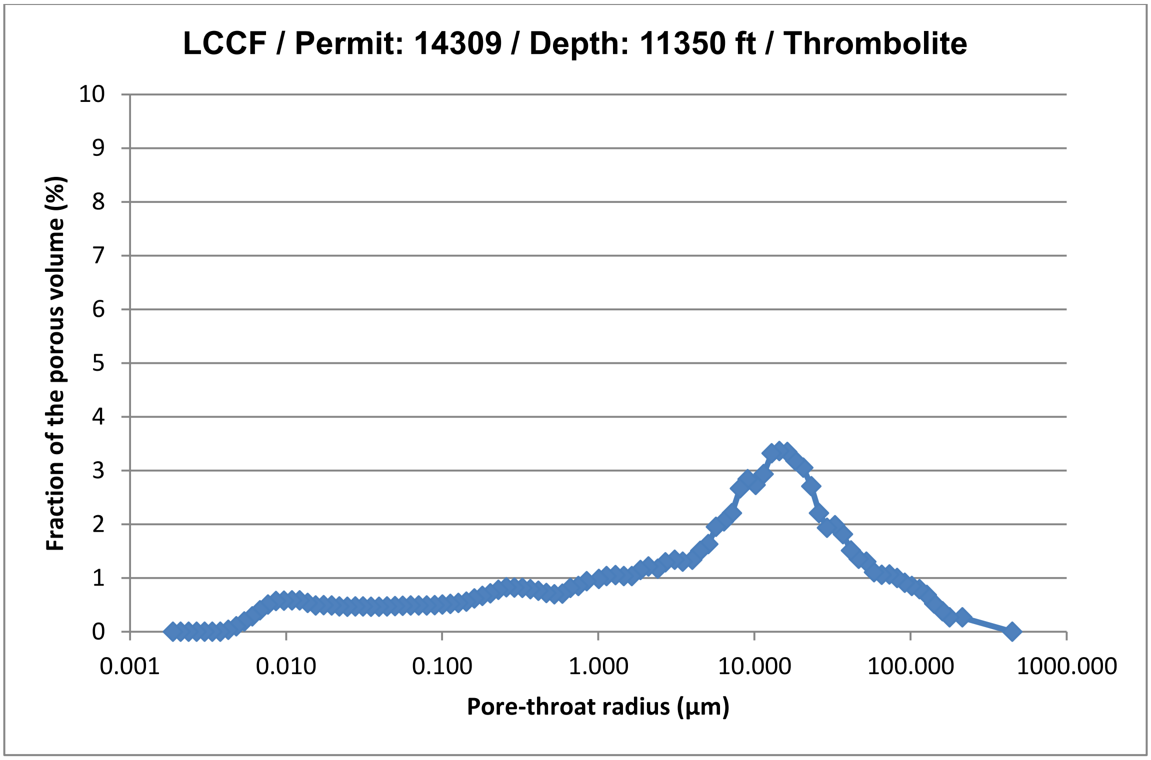

LCCF / Permit: 13907 / Depth: 11858.2 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

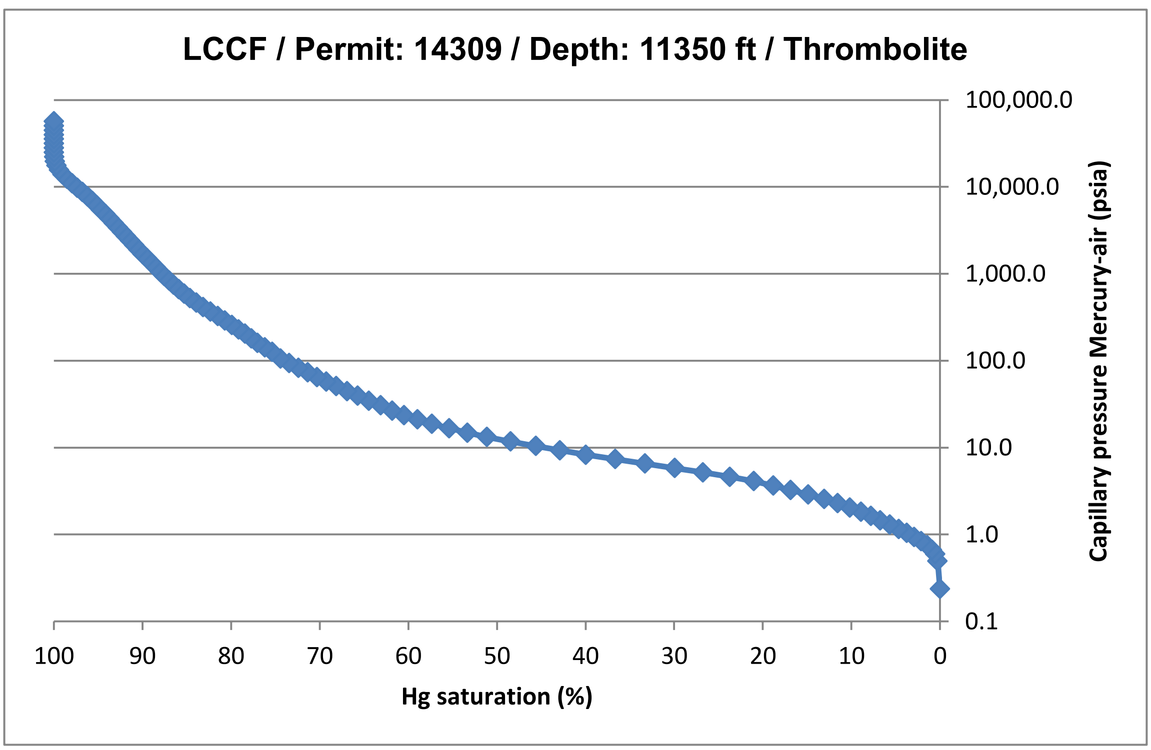

LCCF / Permit: 14069-B / Depth: 11604.5 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

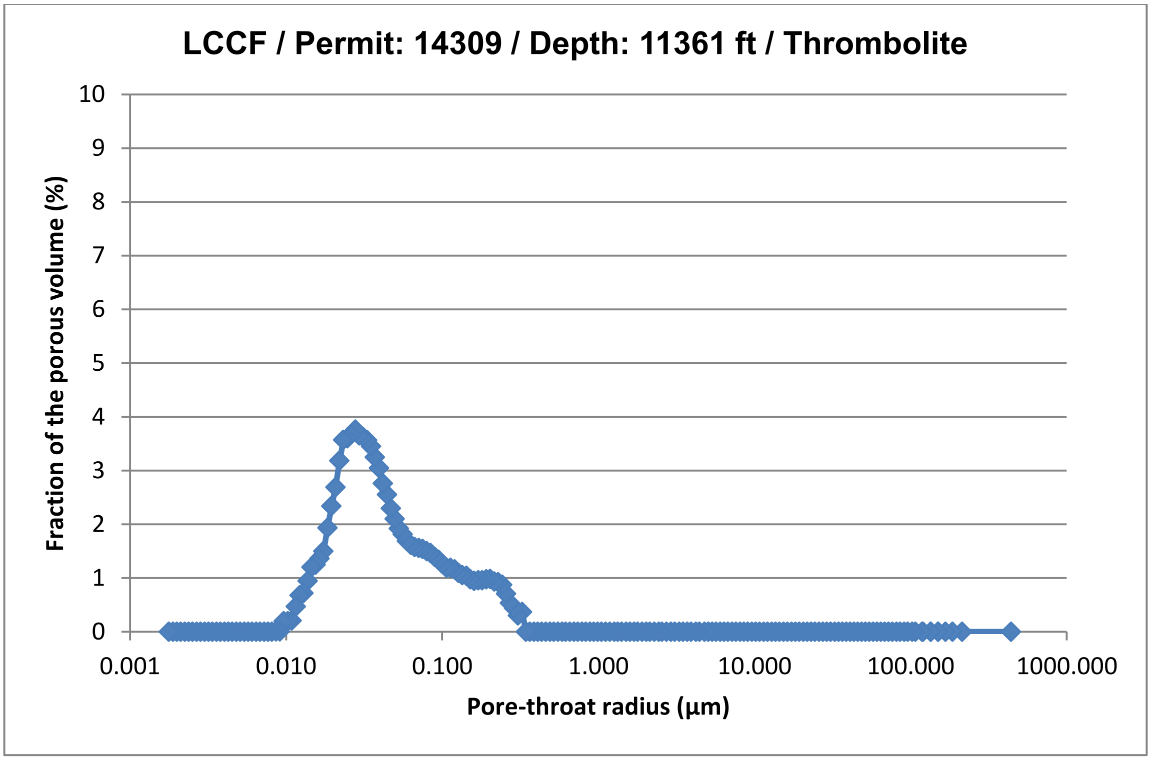

LCCF / Permit: 14069-B / Depth: 11604.5 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

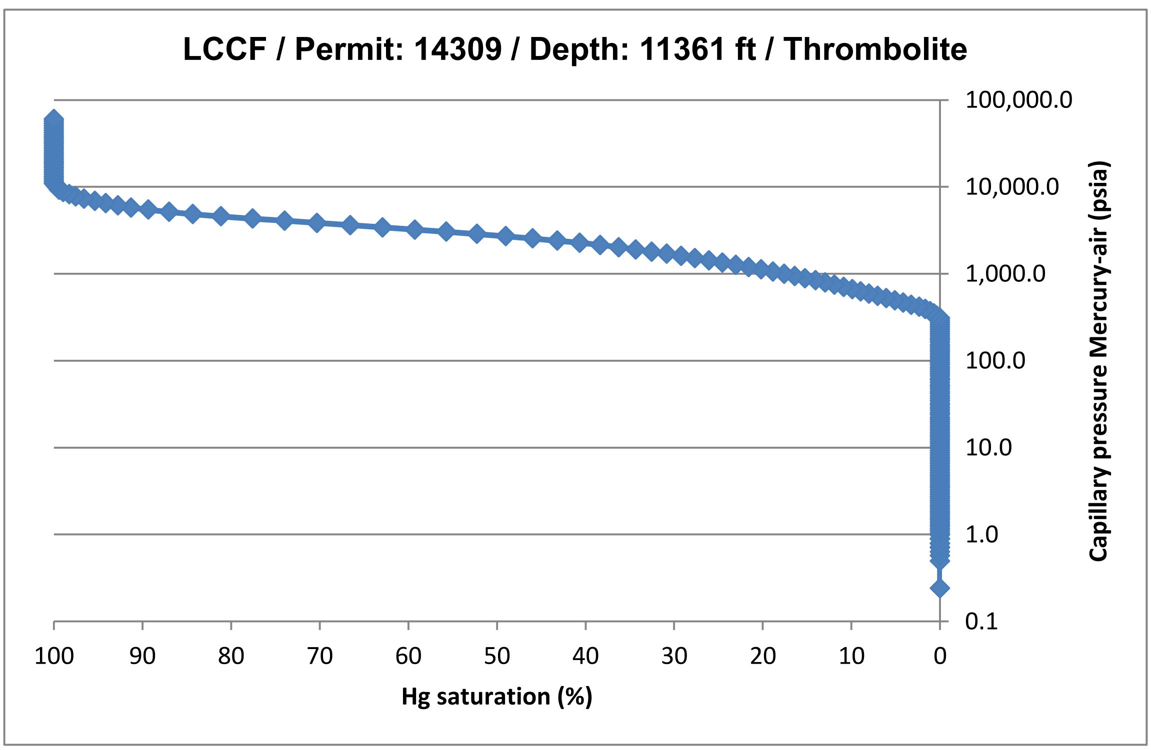

LCCF / Permit: 14112 / Depth: 11314.4 ft / Thrombolite
Fraction of the porous volume (%)
0
1
2
3
4
5
6
7
8
9
10
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

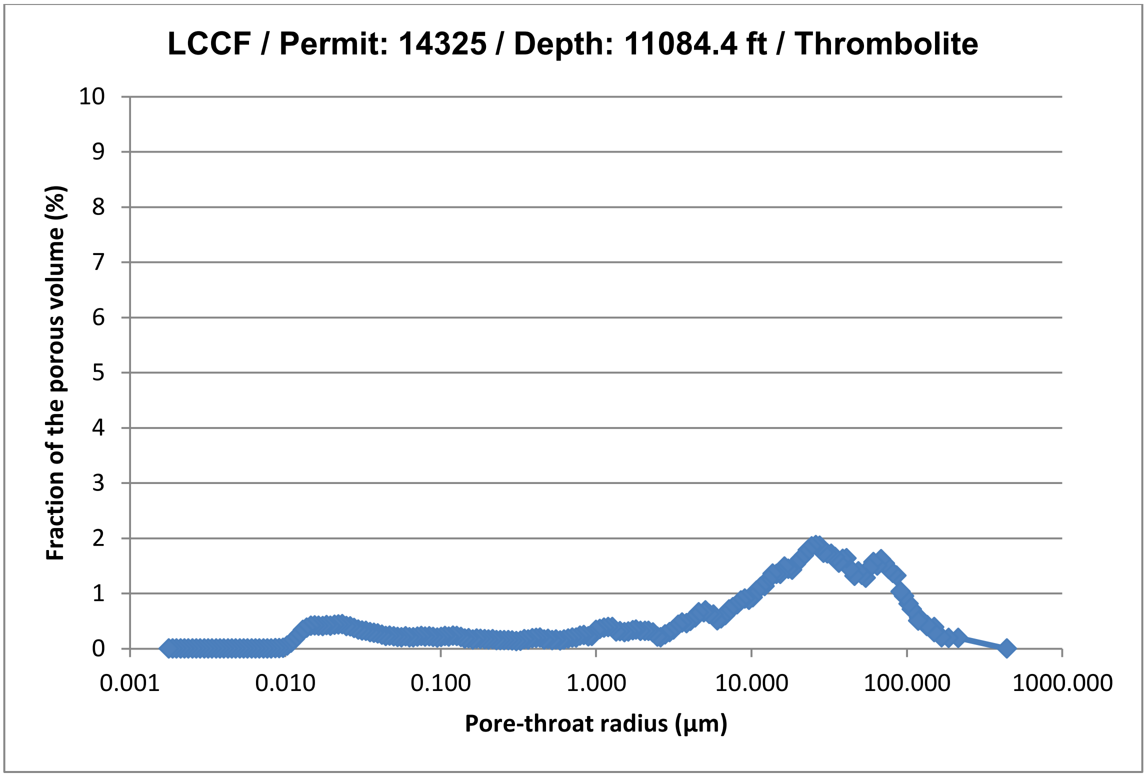

LCCF / Permit: 14112 / Depth: 11314.4 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

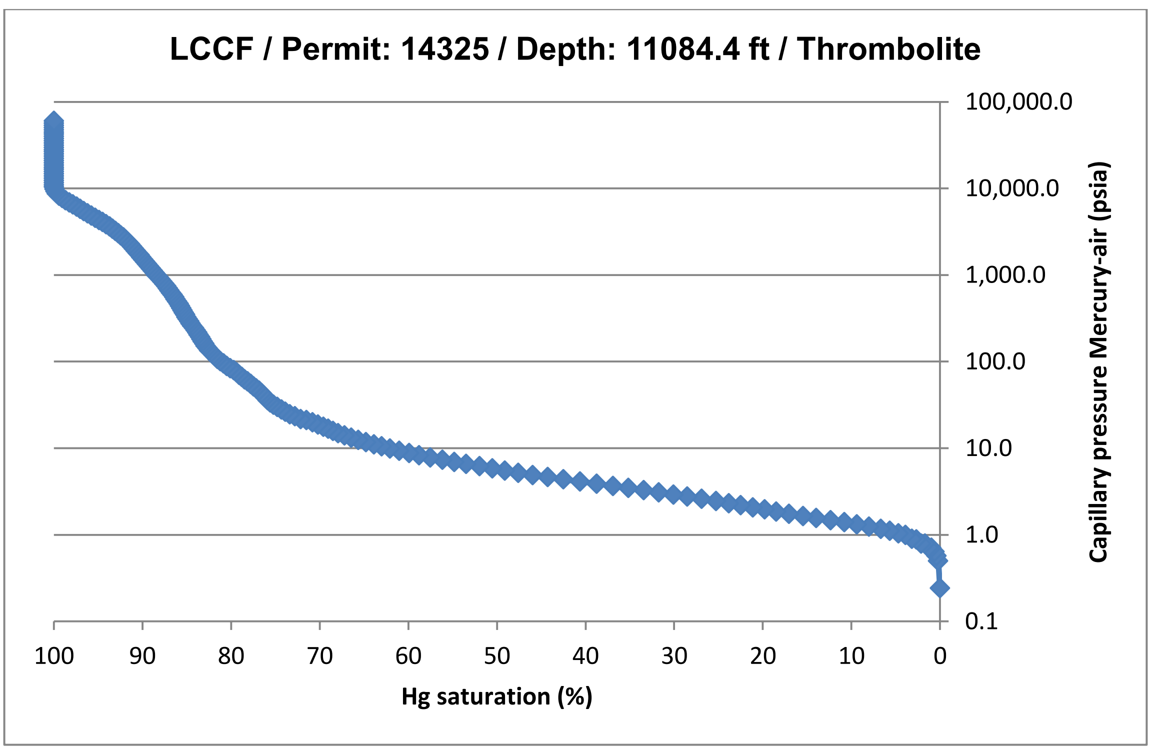

LCCF / Permit: 14309 / Depth: 11350 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

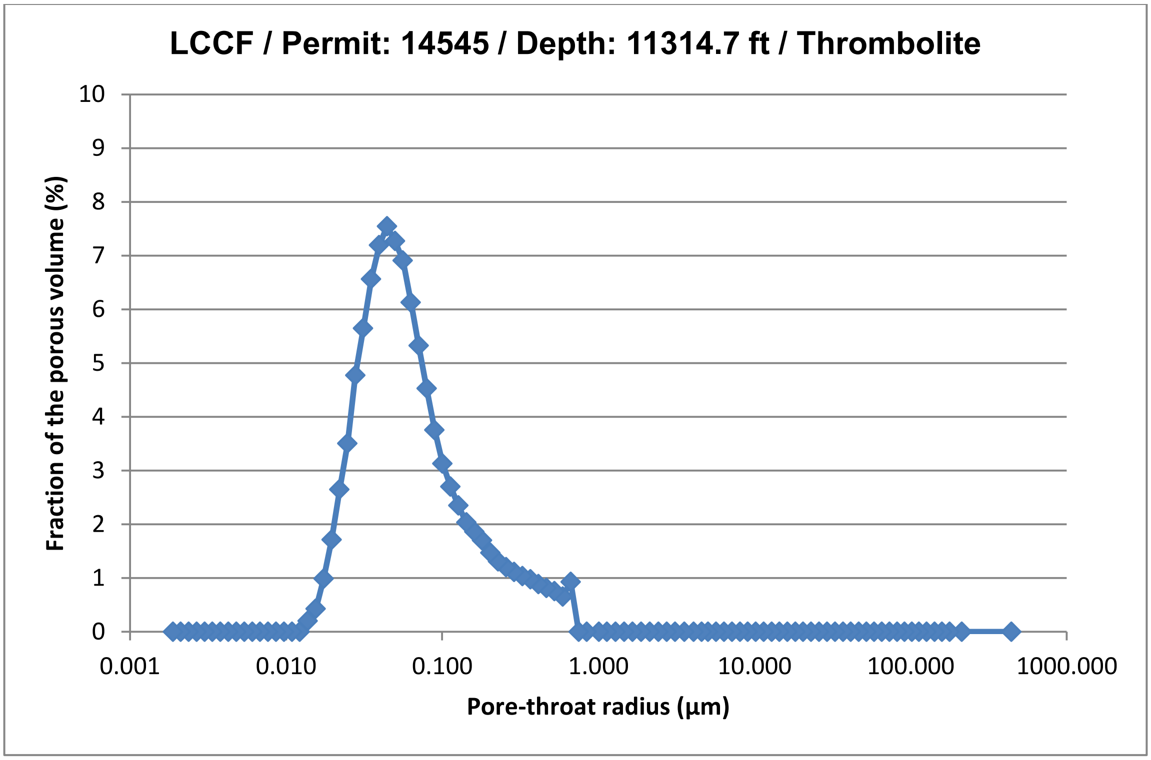

LCCF / Permit: 14309 / Depth: 11350 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

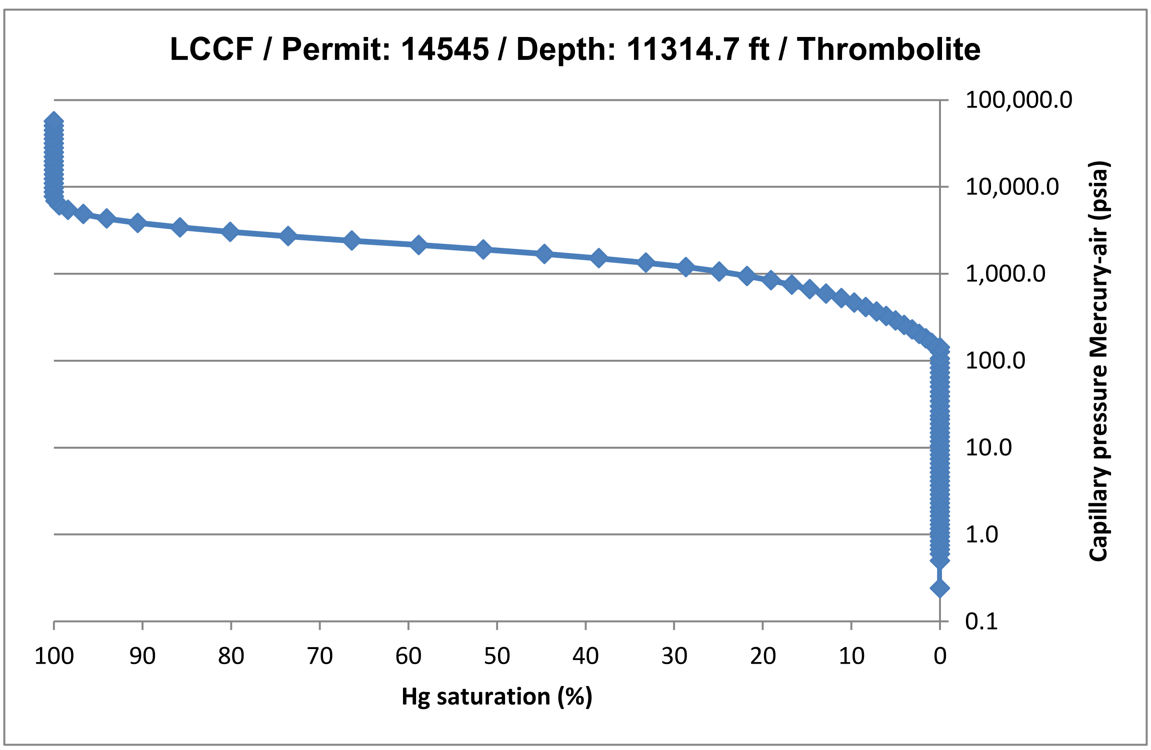

LCCF / Permit: 14309 / Depth: 11361 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

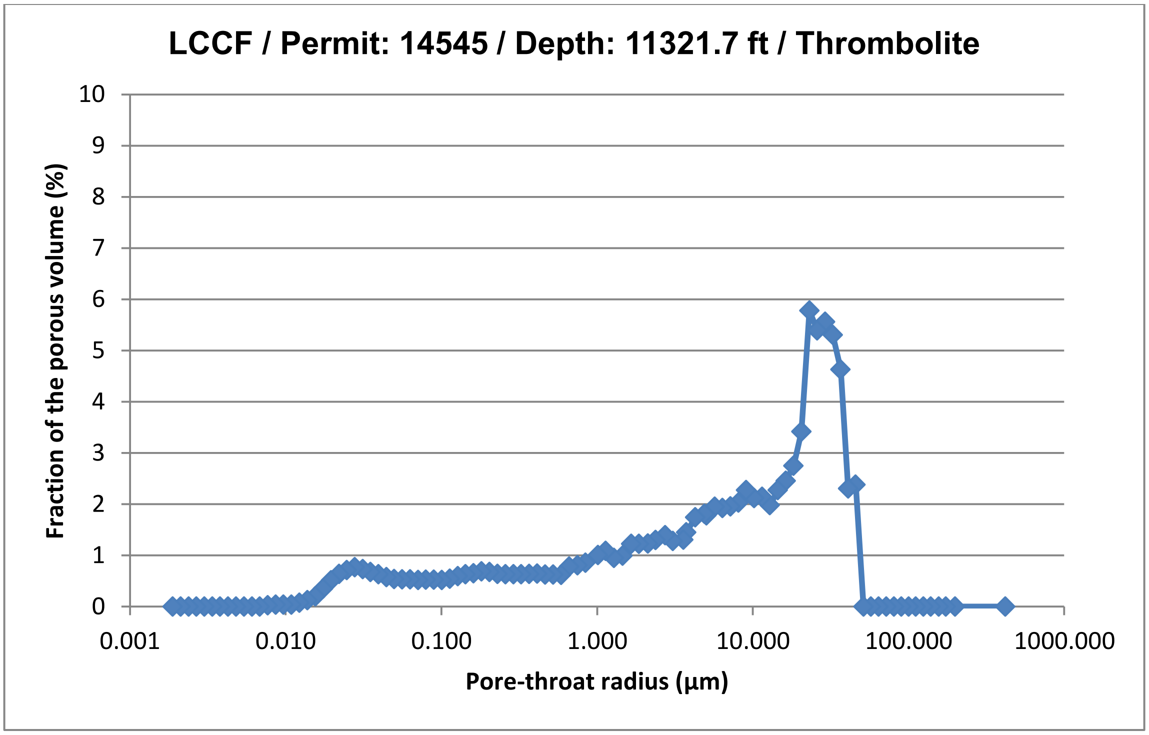

LCCF / Permit: 14309 / Depth: 11361 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

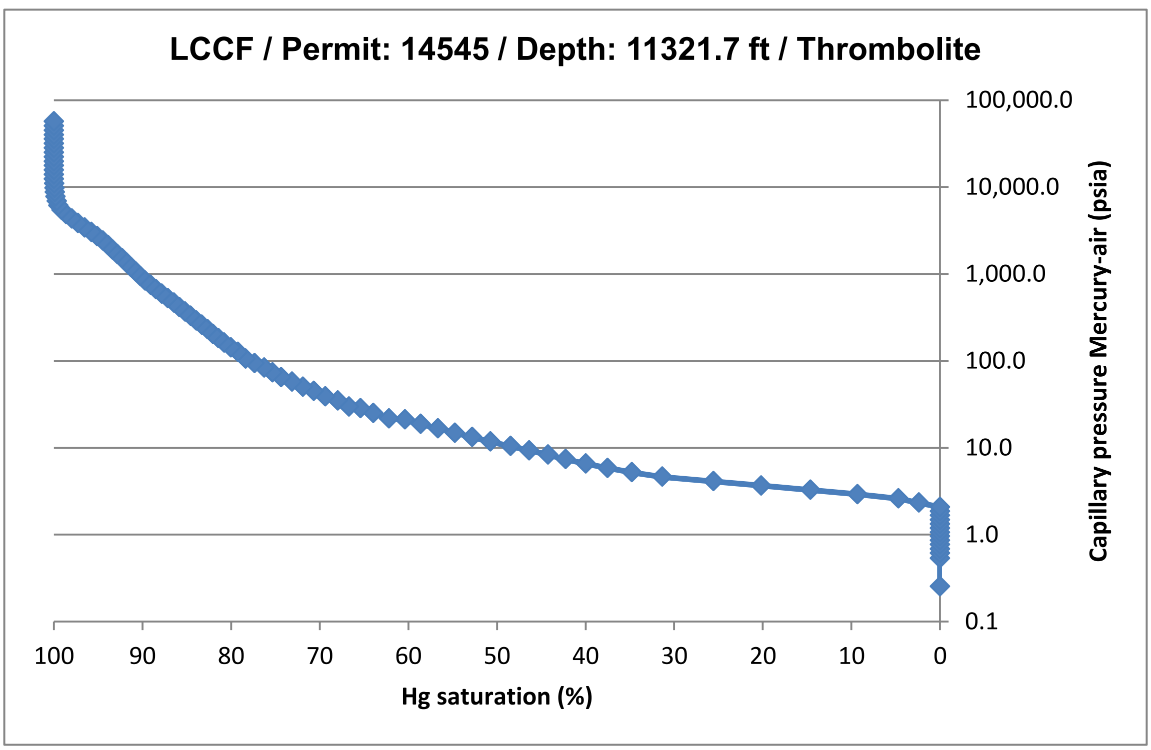

LCCF / Permit: 14325 / Depth: 11084.4 ft / Thrombolite
Fraction of the porous volume (%)
Pore-throat radius (µm)
0
1
2
3
4
5
6
7
8
9
10
0.001
0.010
0.100
1.000
10.000
100.000
1000.000

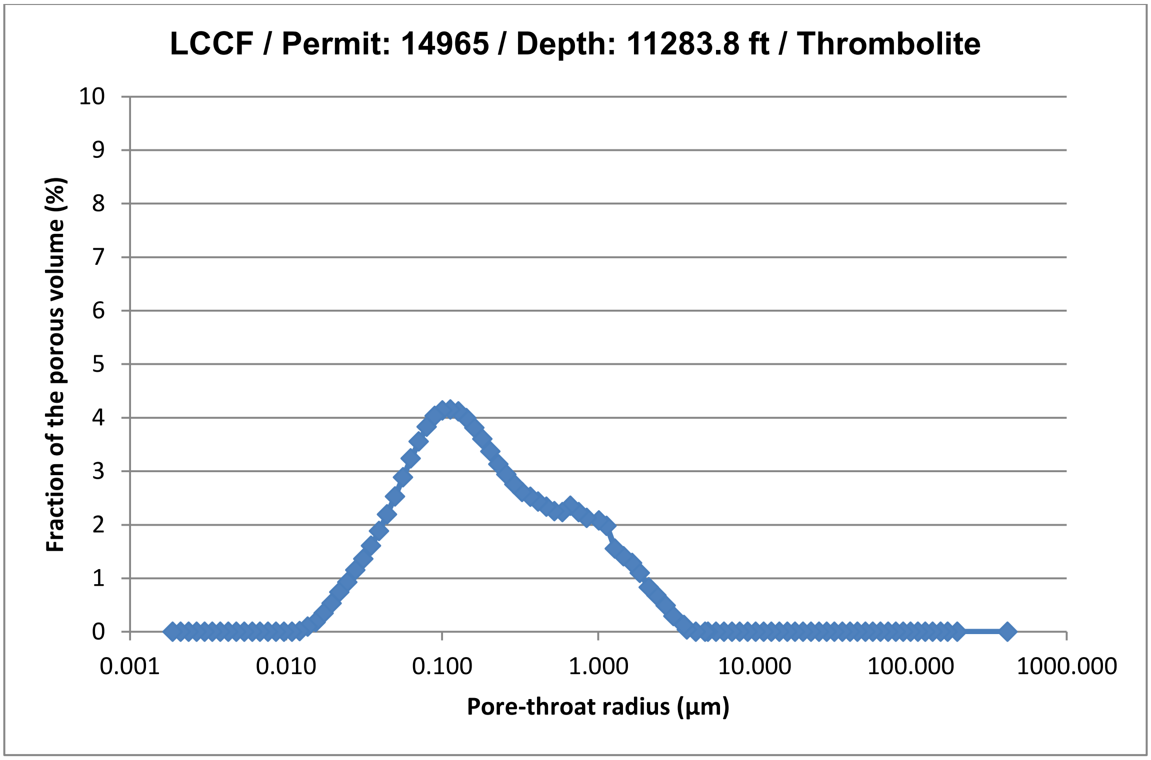

LCCF / Permit: 14325 / Depth: 11084.4 ft / Thrombolite
Capillary pressure Mercury-air (psia)
Hg saturation (%)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
100
90
80
70
60
50
40
30
20
10
0

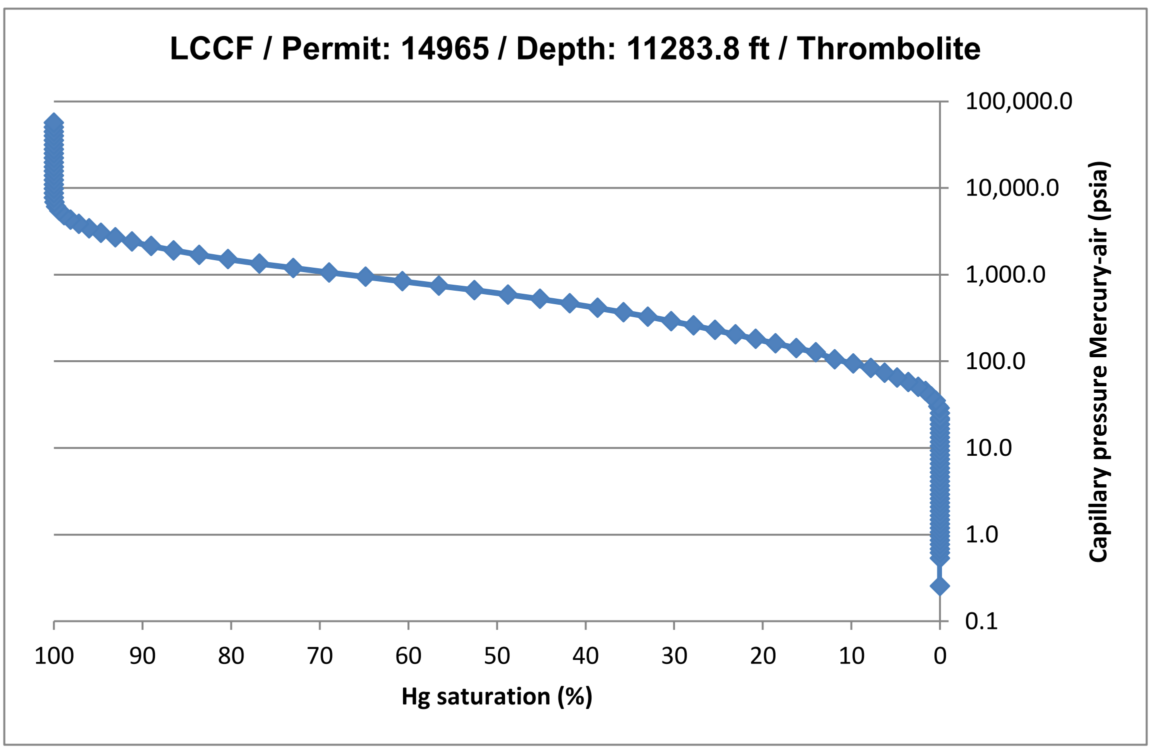

LCCF / Permit: 14545 / Depth: 11314.7 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

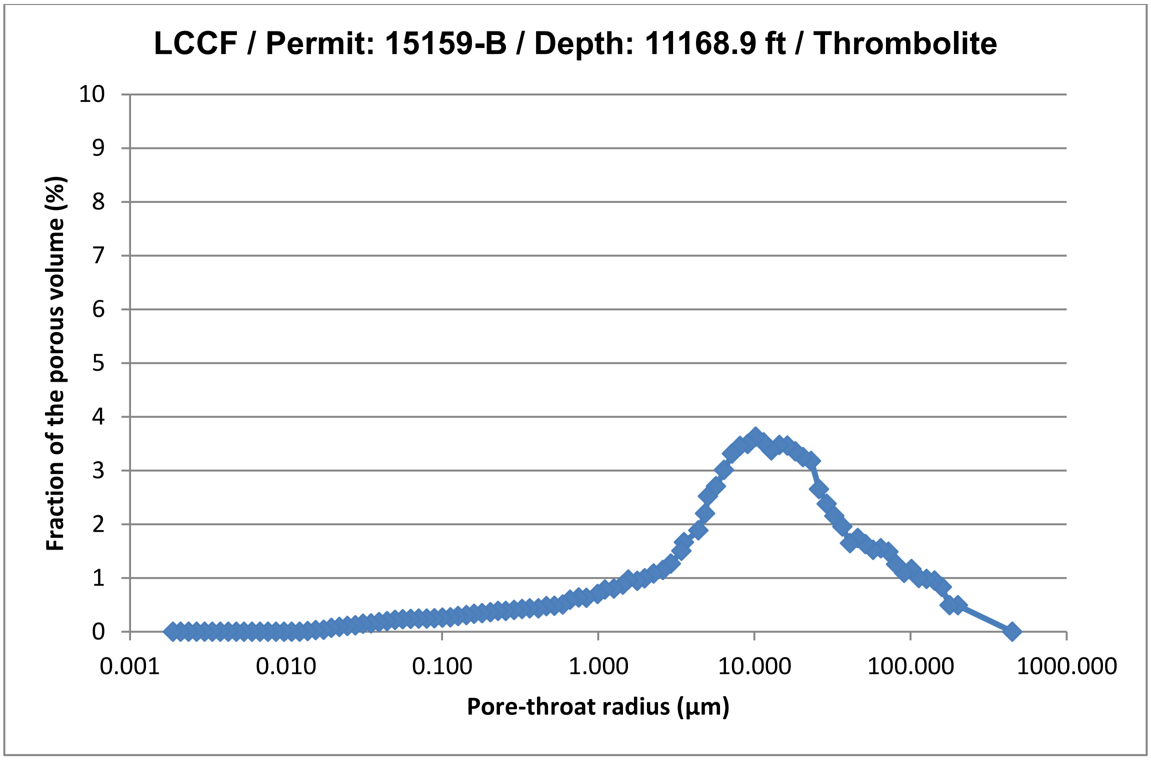

LCCF / Permit: 14545 / Depth: 11314.7 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


LCCF / Permit: 14545 / Depth: 11321.7 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

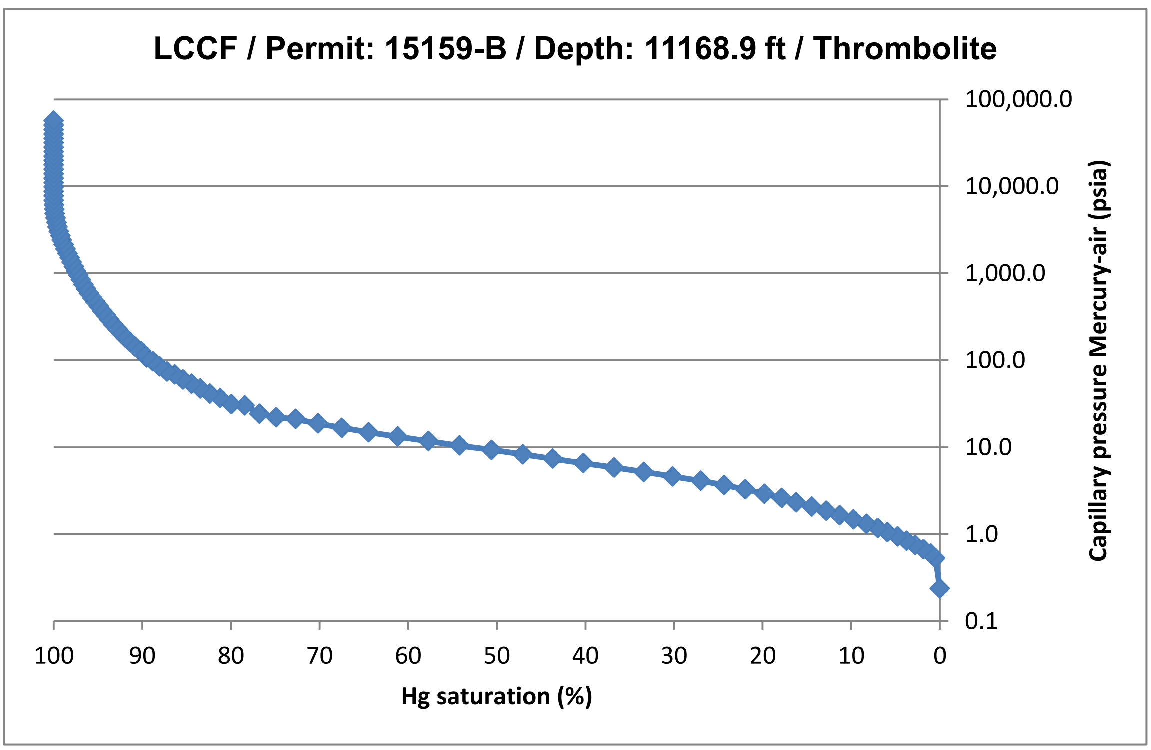

LCCF / Permit: 14545 / Depth: 11321.7 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


LCCF / Permit: 14965 / Depth: 11283.8 ft / Thrombolite
Fraction of the porous volume (%)
0
1
2
3
4
5
6
7
8
9
10
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

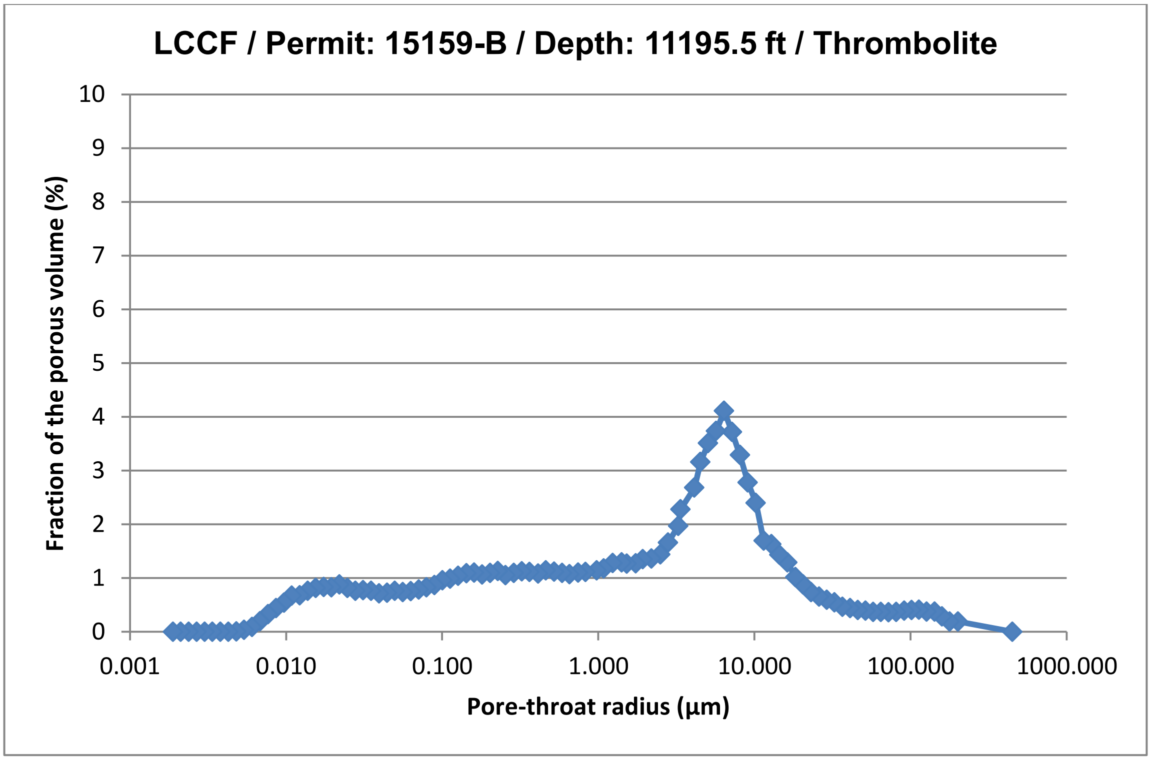

LCCF / Permit: 14965 / Depth: 11283.8 ft / Thrombolite
Capillary pressure Mercury-air (psia)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

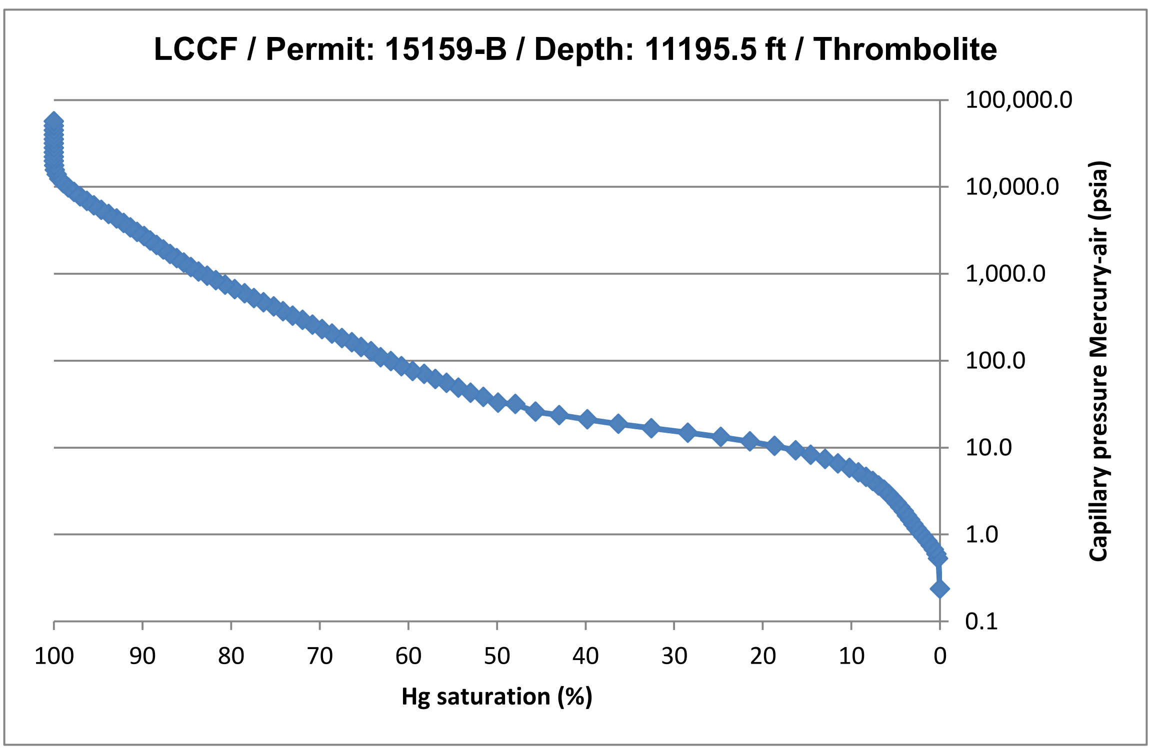


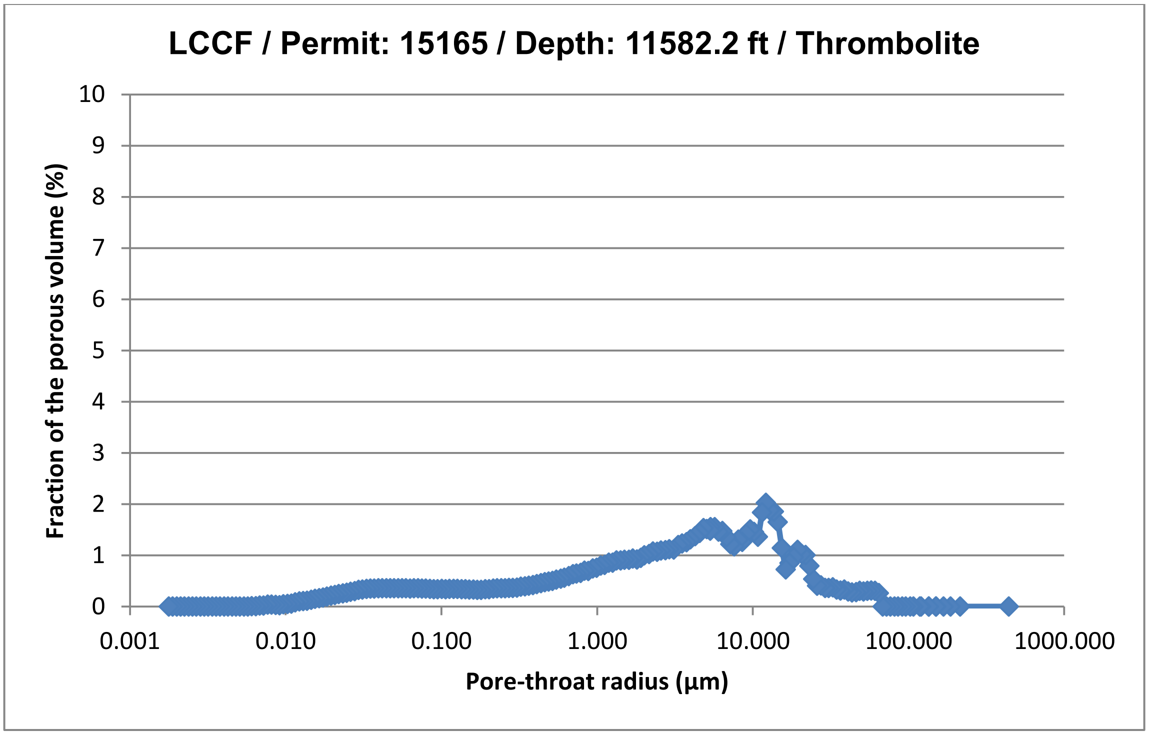
LCCF / Permit: 15159-B / Depth: 11168.9 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

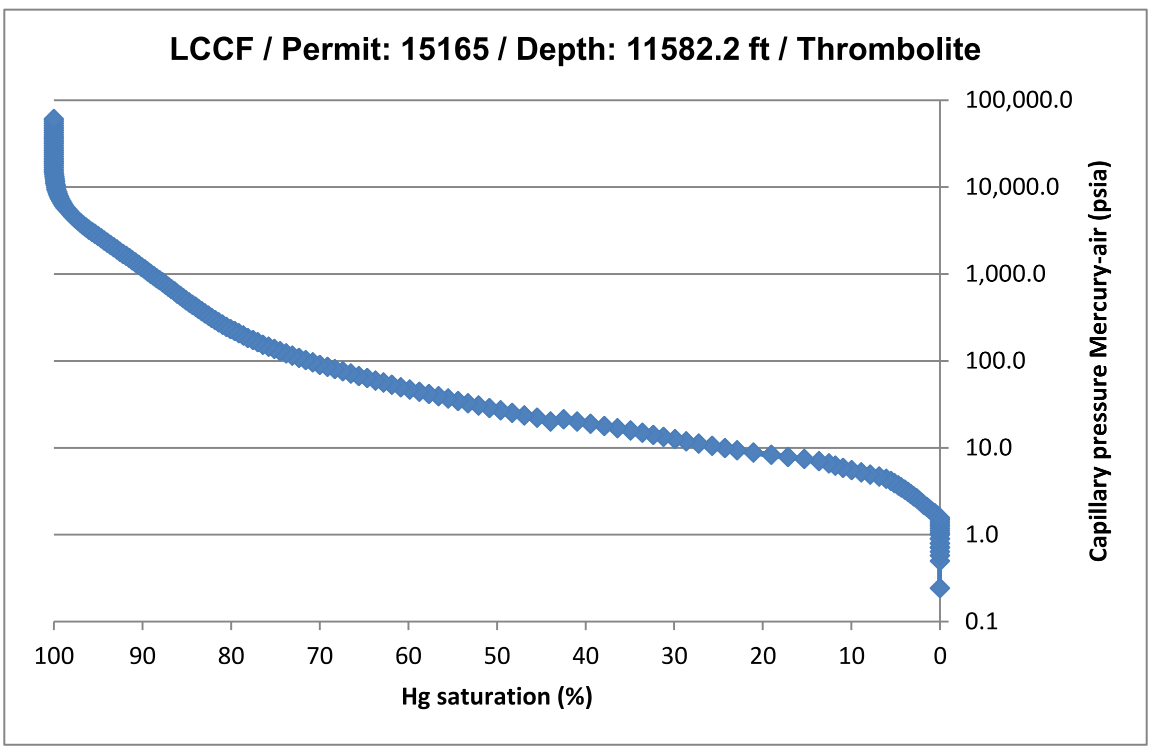


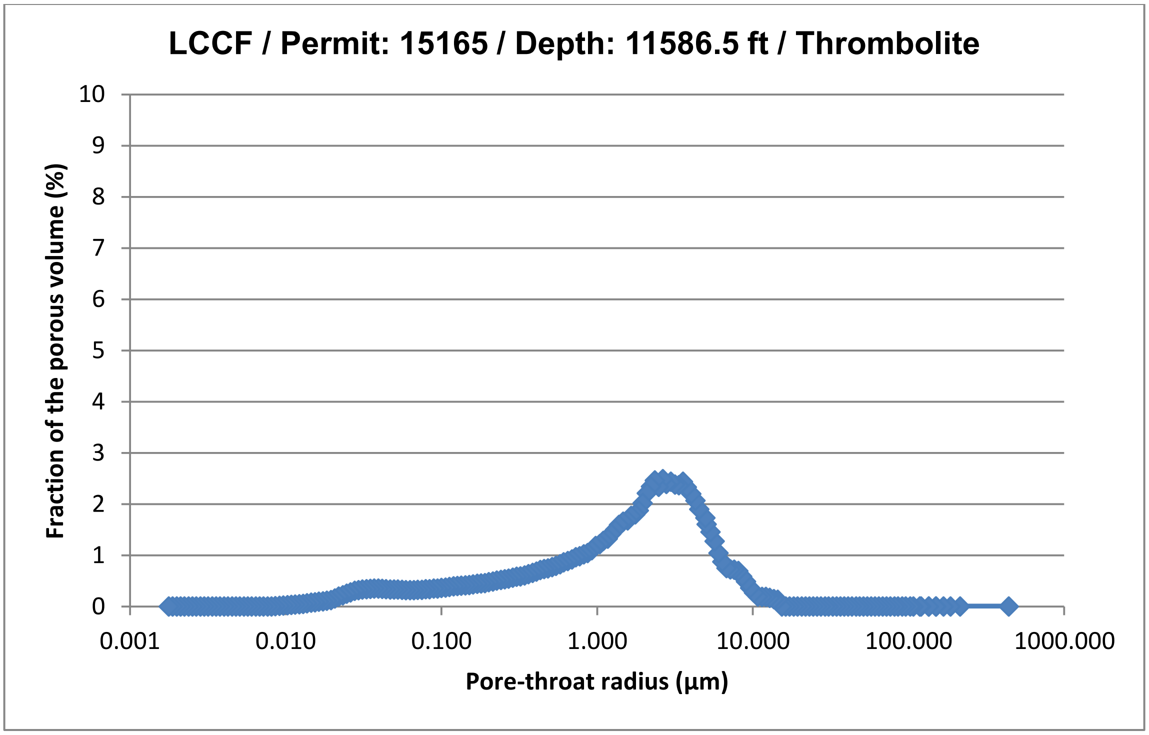
LCCF / Permit: 15159-B / Depth: 11168.9 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

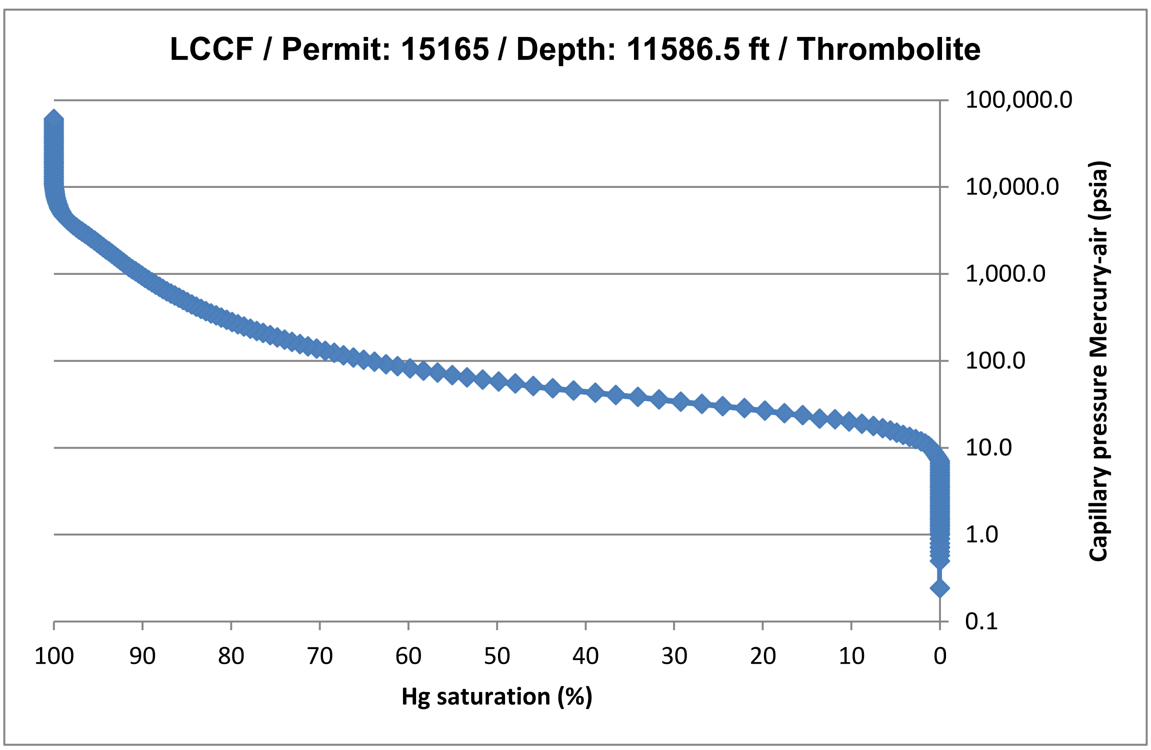

LCCF / Permit: 15159-B / Depth: 11195.5 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (μm)

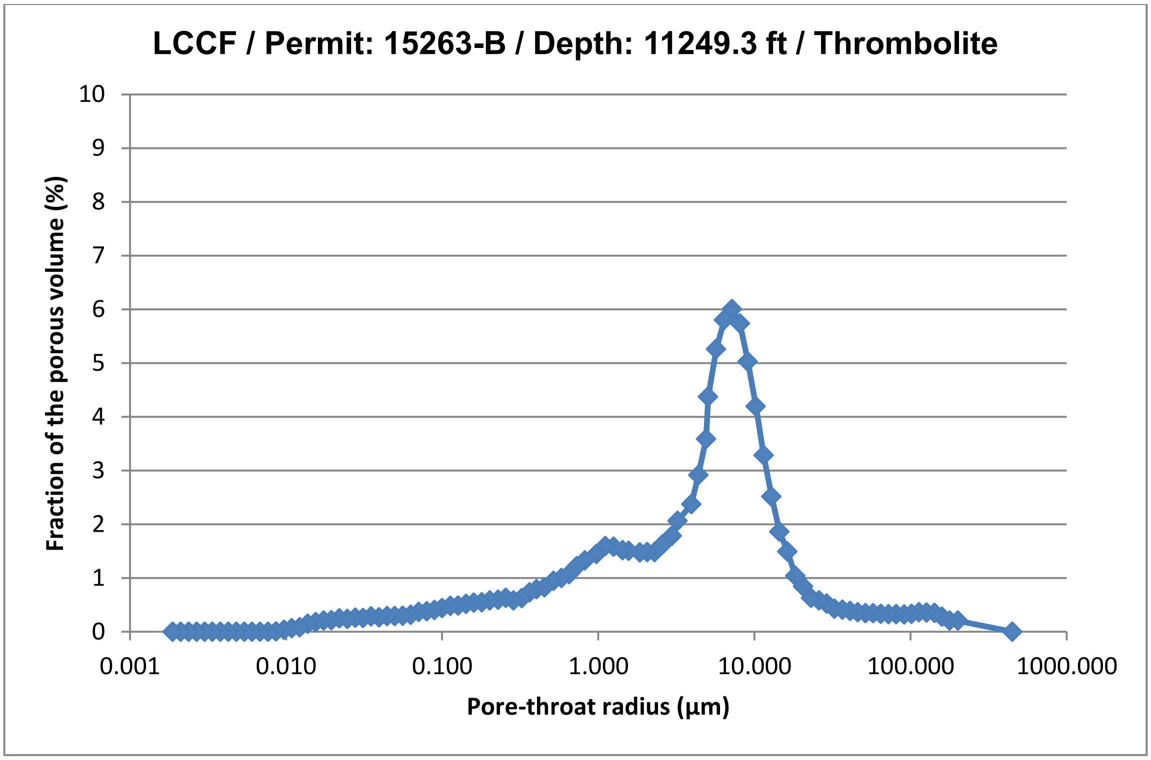

LCCF / Permit: 15159-B / Depth: 11195.5 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

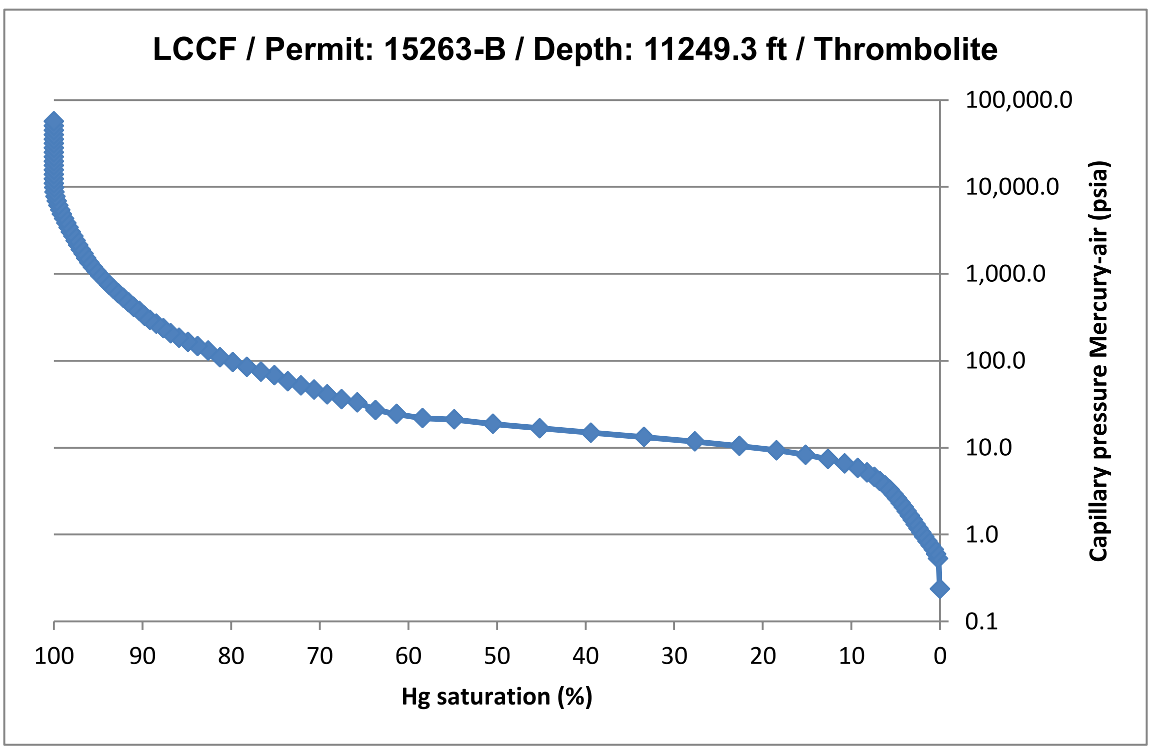

LCCF / Permit: 15165 / Depth: 11582.2 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

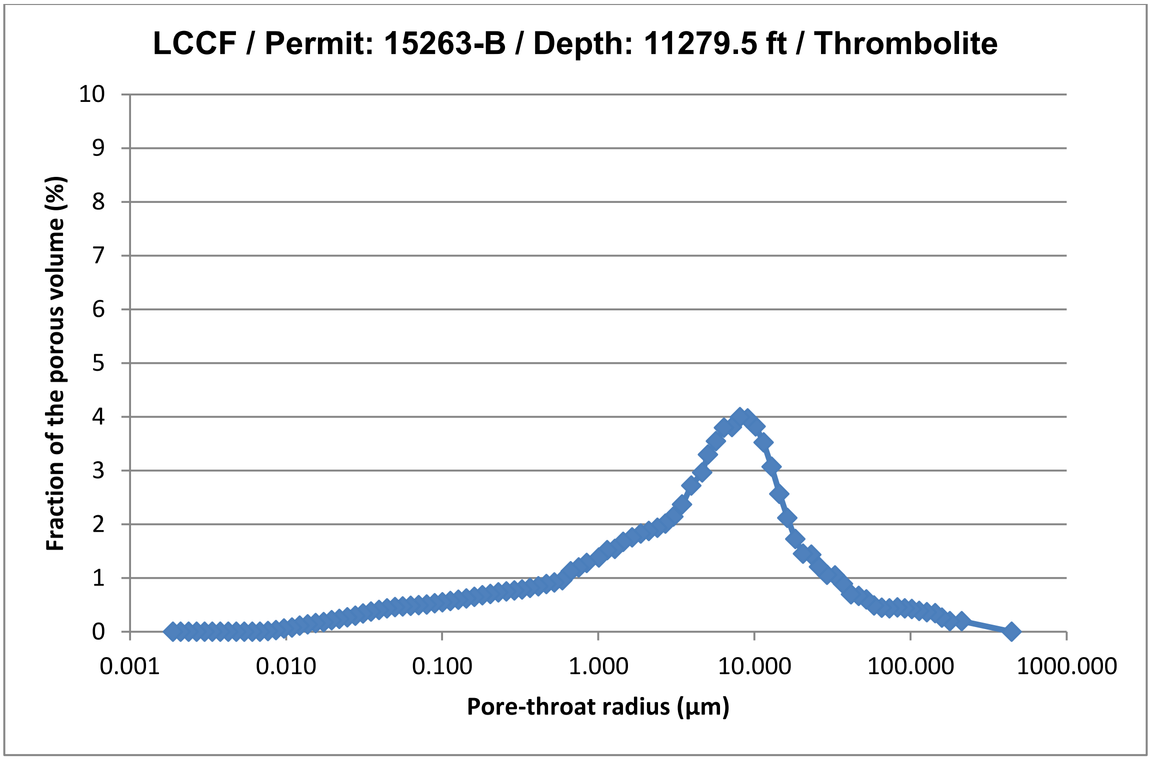

LCCF / Permit: 15165 / Depth: 11582.2 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

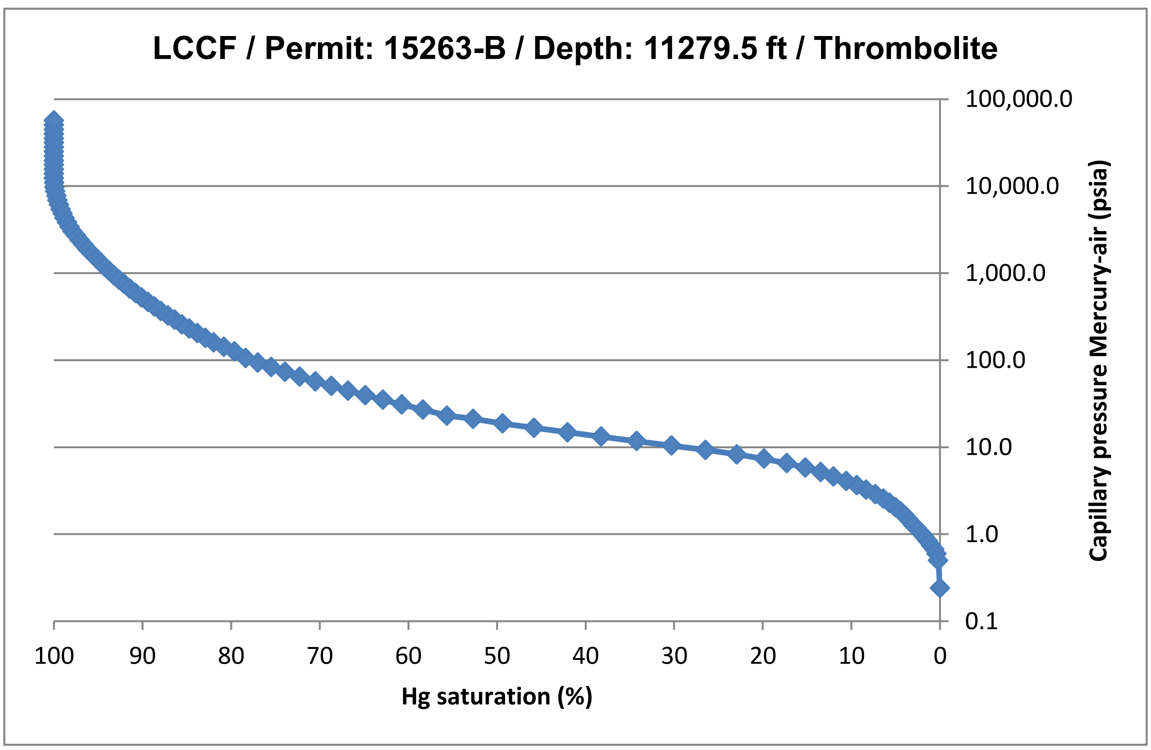

LCCF / Permit: 15165 / Depth: 11586.5 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

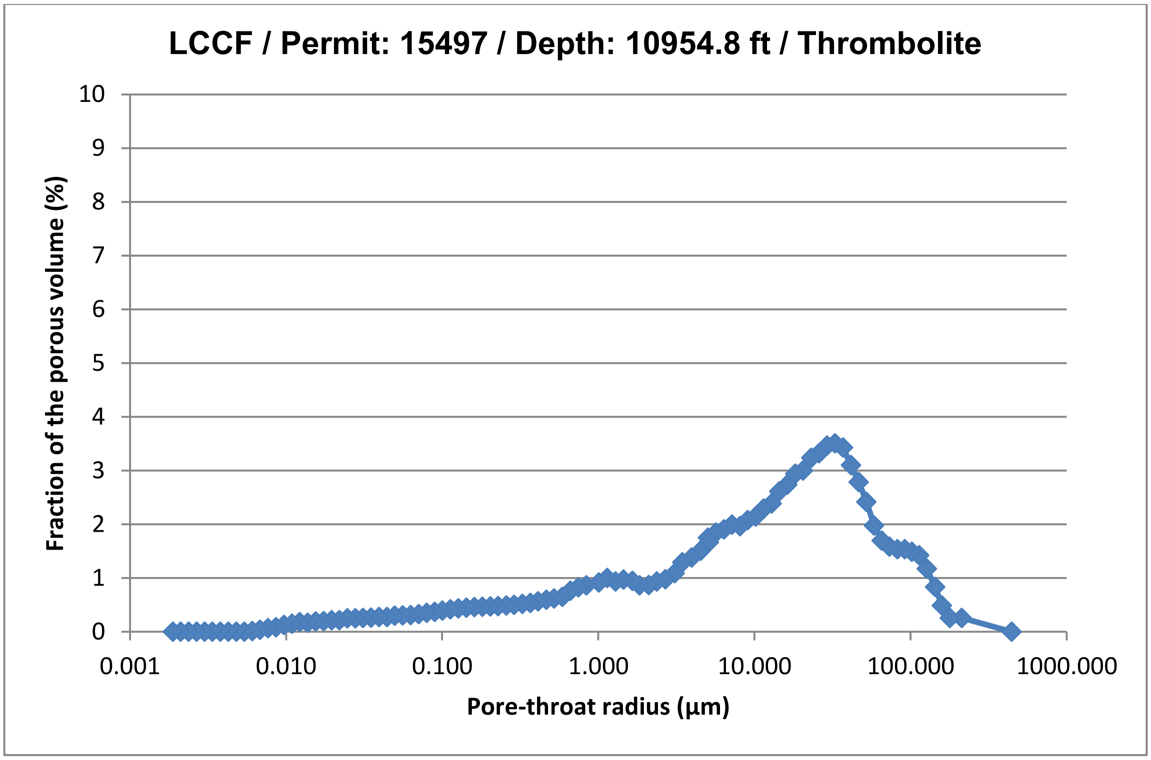

LCCF / Permit: 15165 / Depth: 11586.5 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


LCCF / Permit: 15263-B / Depth: 11249.3 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

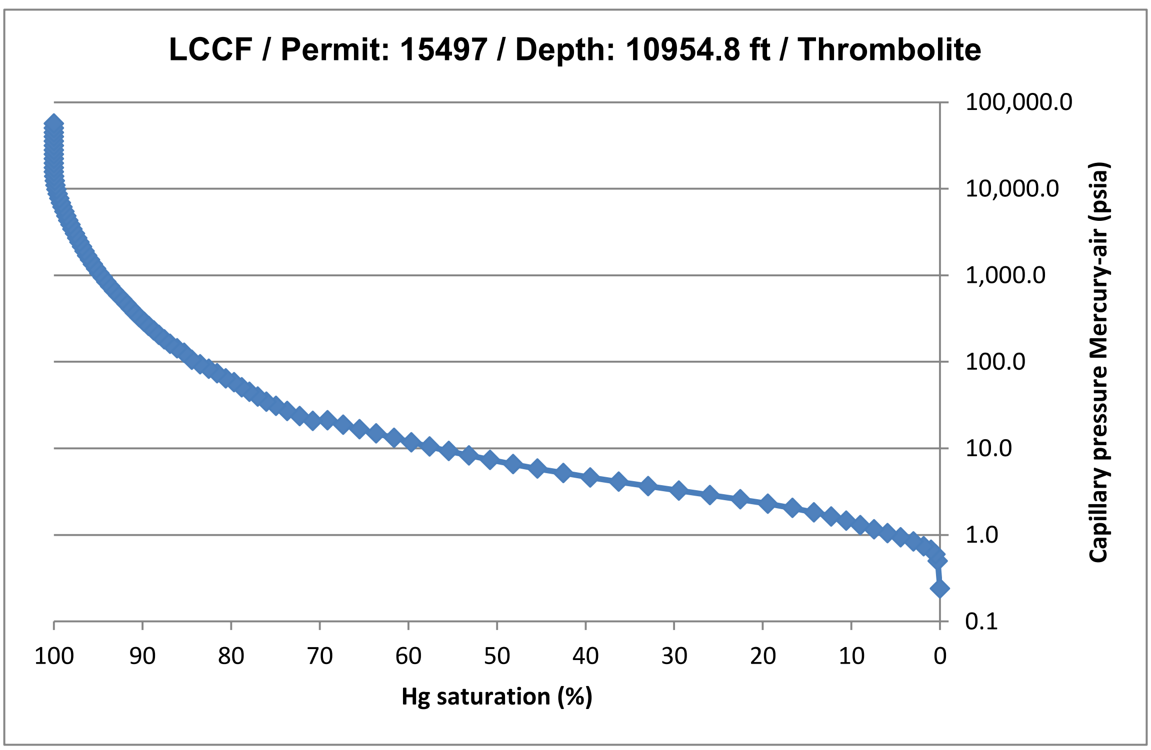

LCCF / Permit: 15263-B / Depth: 11249.3 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


LCCF / Permit: 15263-B / Depth: 11279.5 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

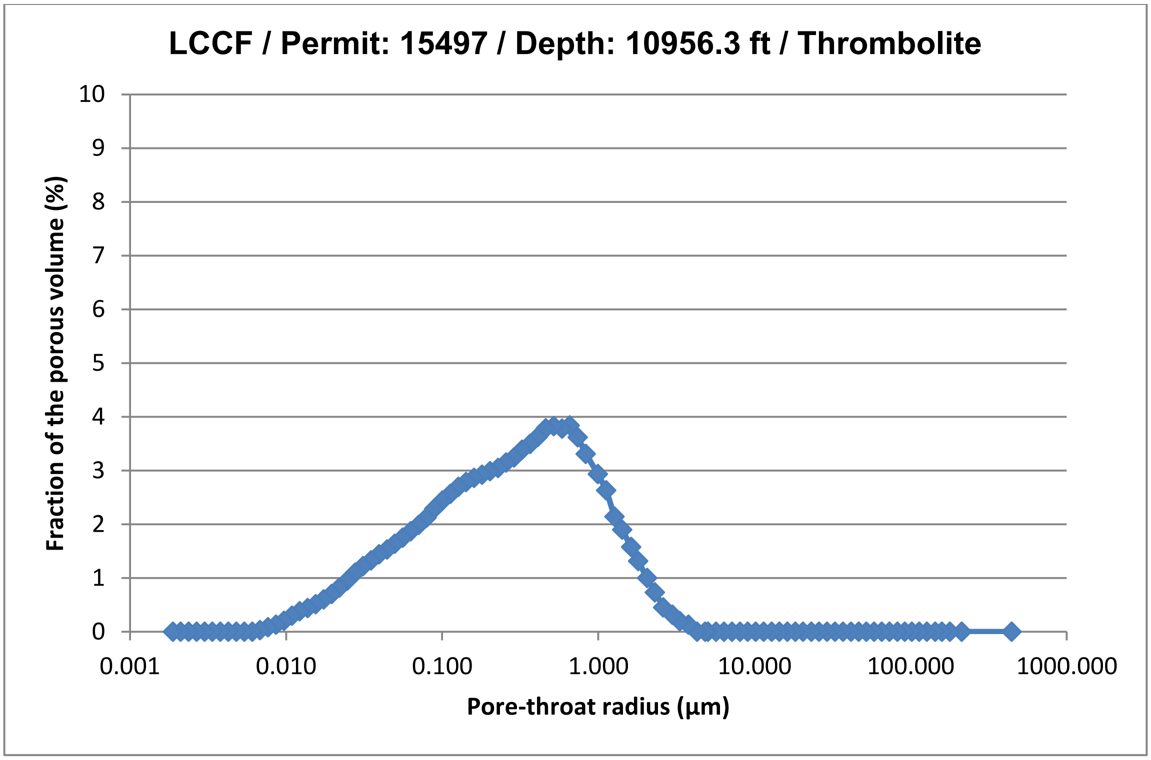

LCCF / Permit: 15263-B / Depth: 11279.5 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)



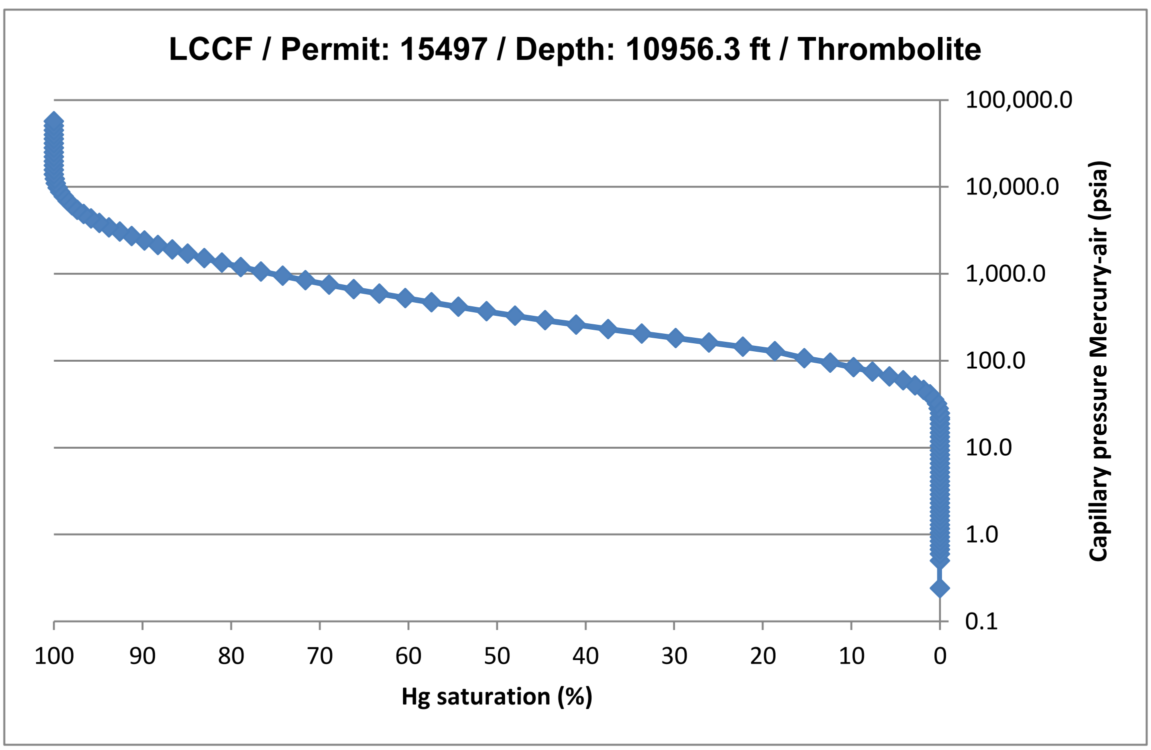
LCCF / Permit: 15497 / Depth: 10954.8 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)



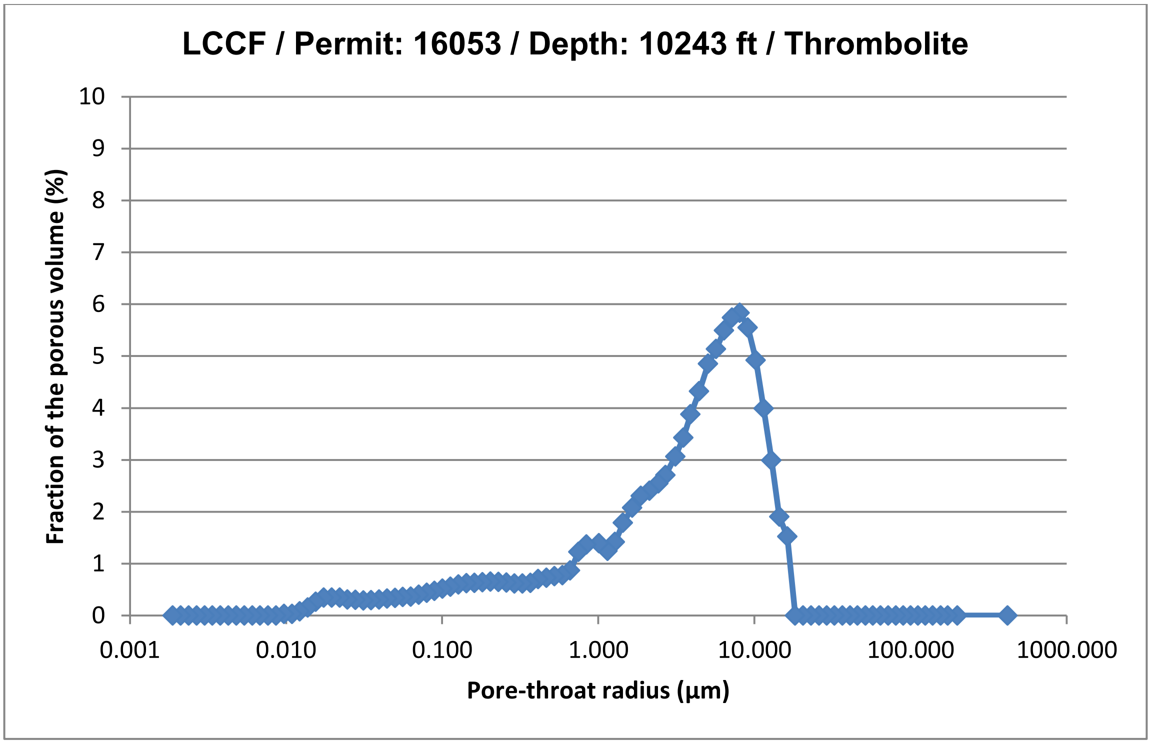
LCCF / Permit: 15497 / Depth: 10954.8 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)



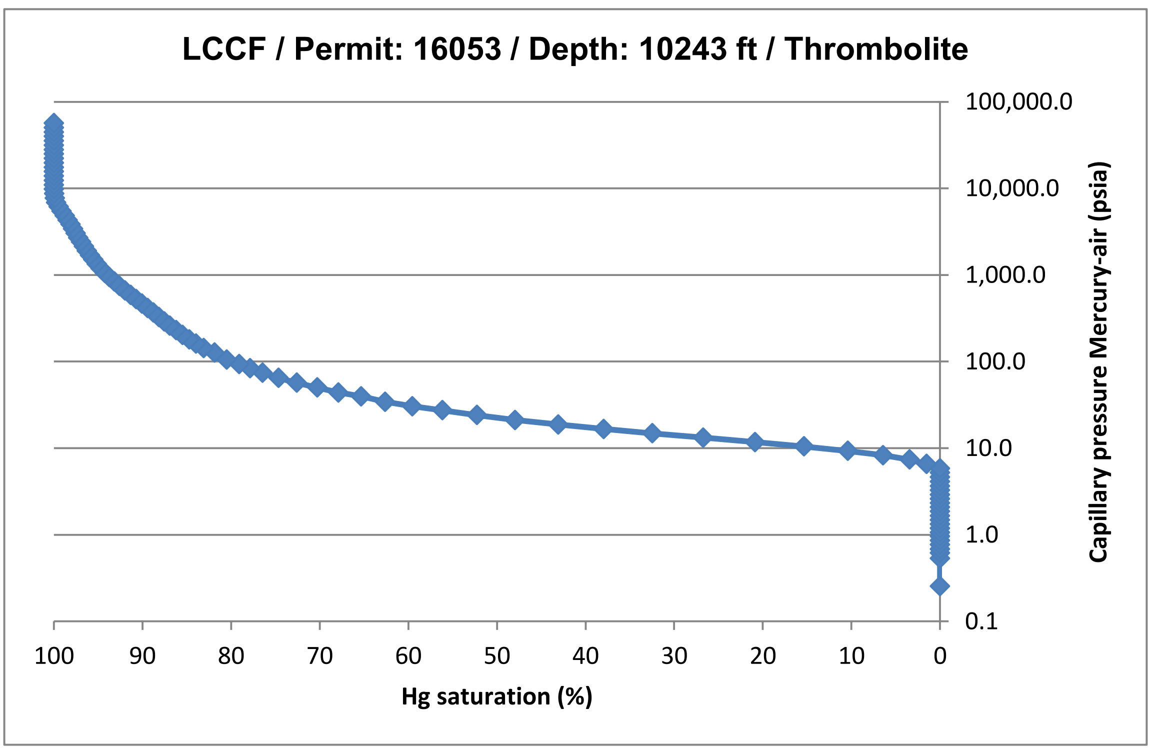
LCCF / Permit: 15497 / Depth: 10956.3 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)



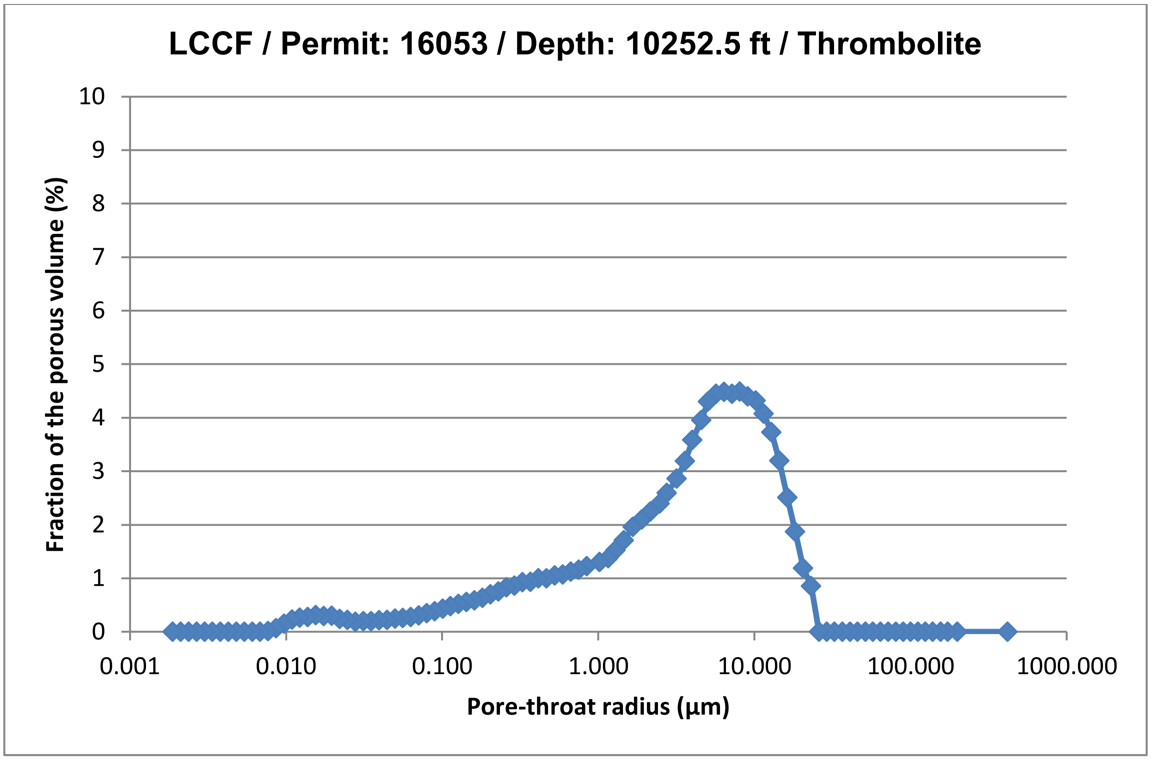
LCCF / Permit: 15497 / Depth: 10956.3 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

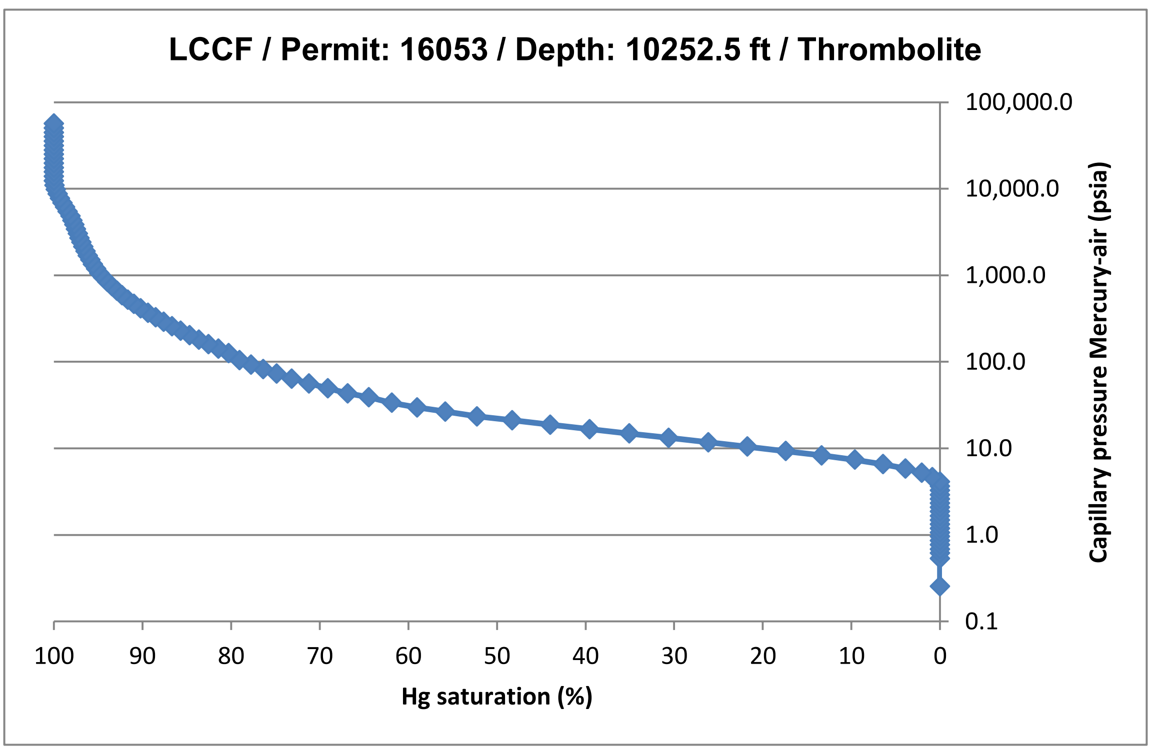


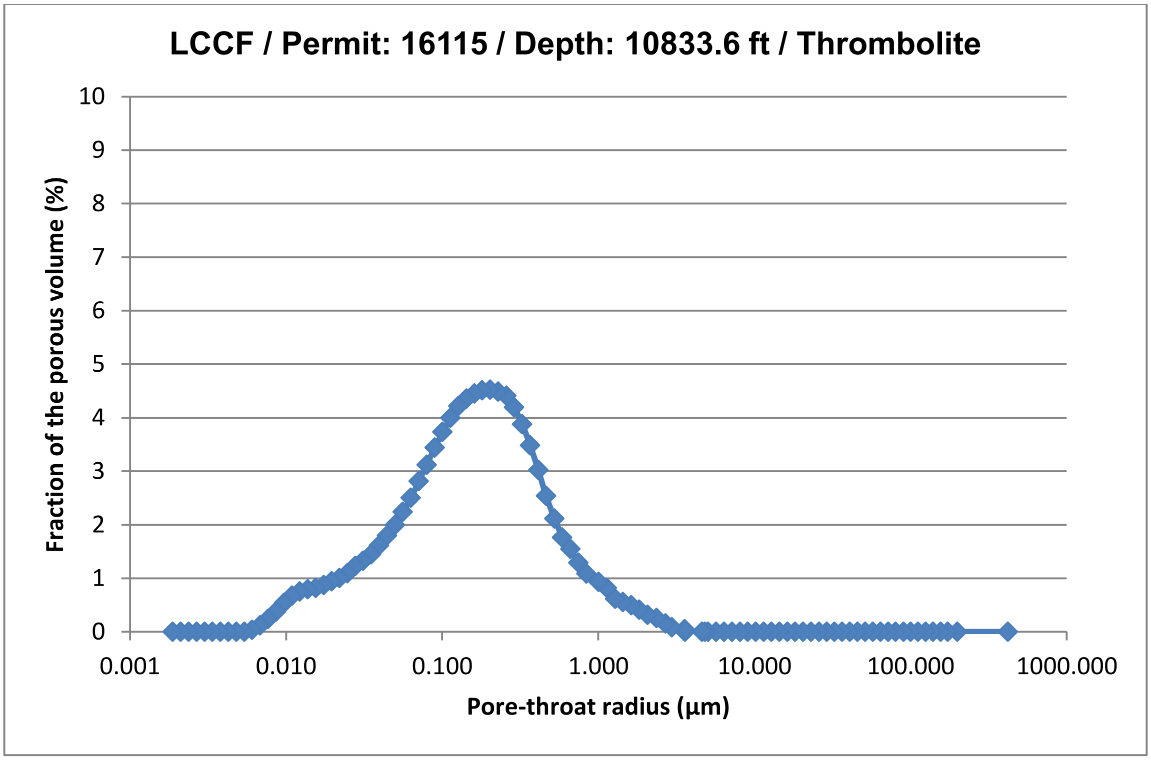
LCCF / Permit: 16053 / Depth: 10243 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)



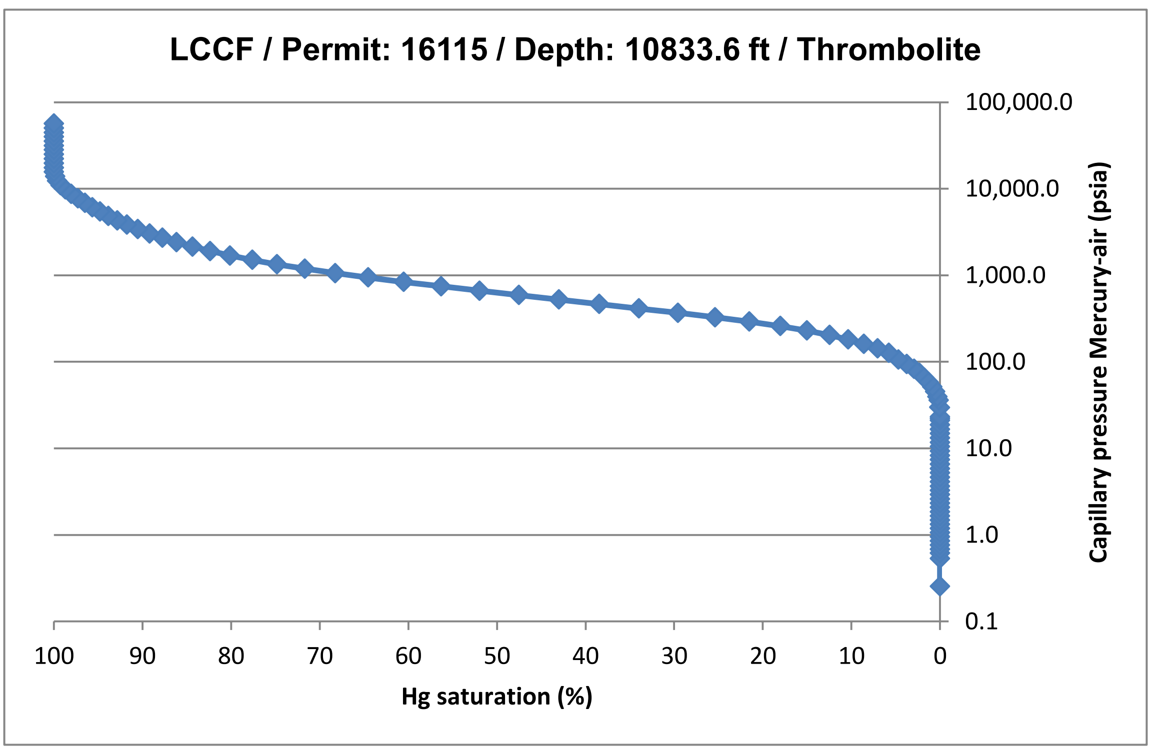
LCCF / Permit: 16053 / Depth: 10243 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


LCCF / Permit: 16053 / Depth: 10252.5 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

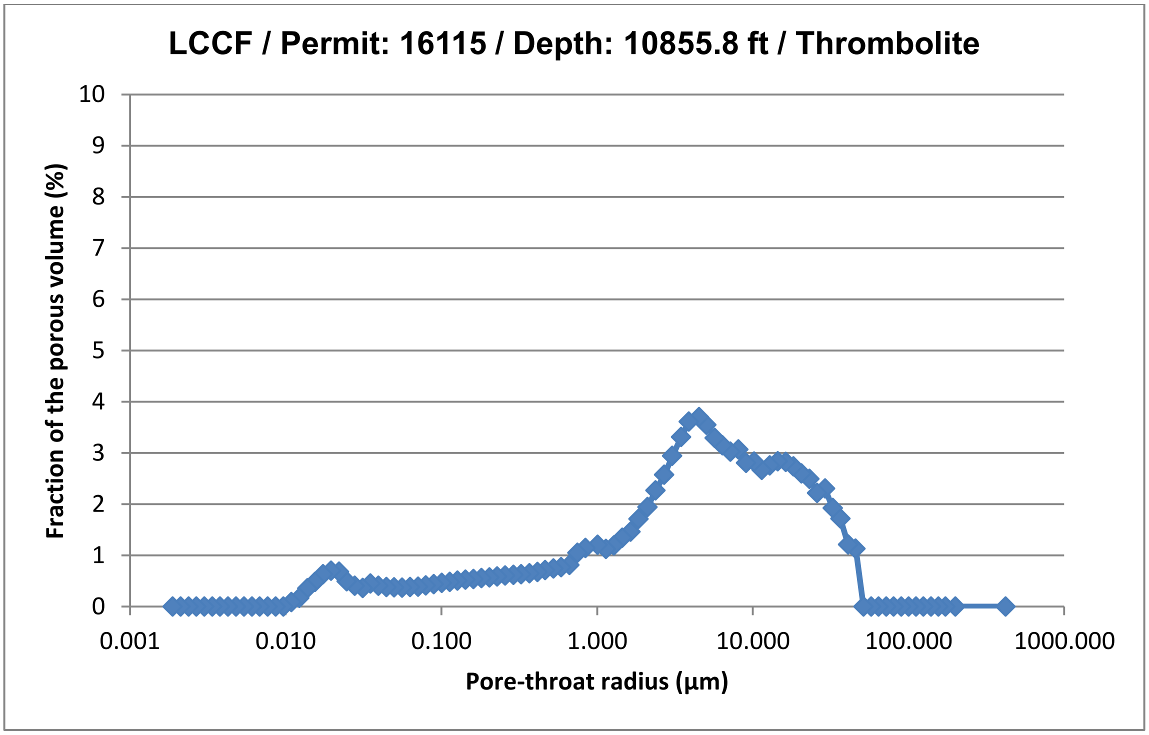

LCCF / Permit: 16053 / Depth: 10252.5 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

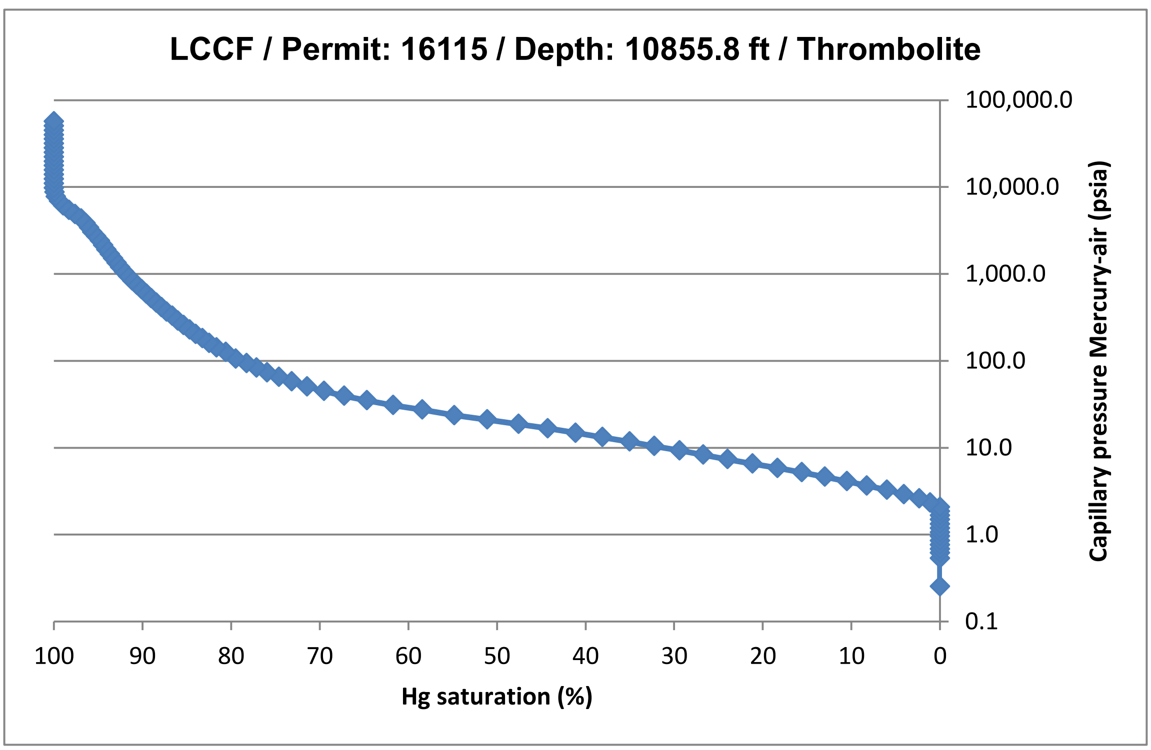


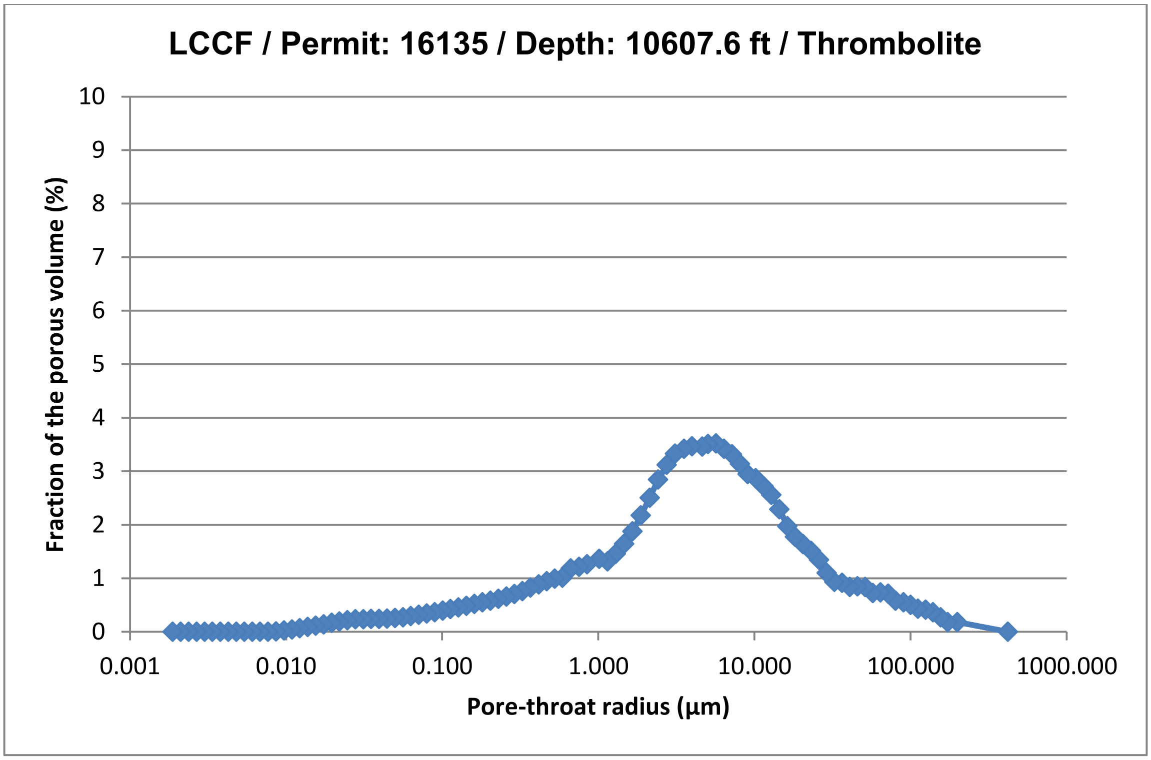
LCCF / Permit: 16115 / Depth: 10833.6 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

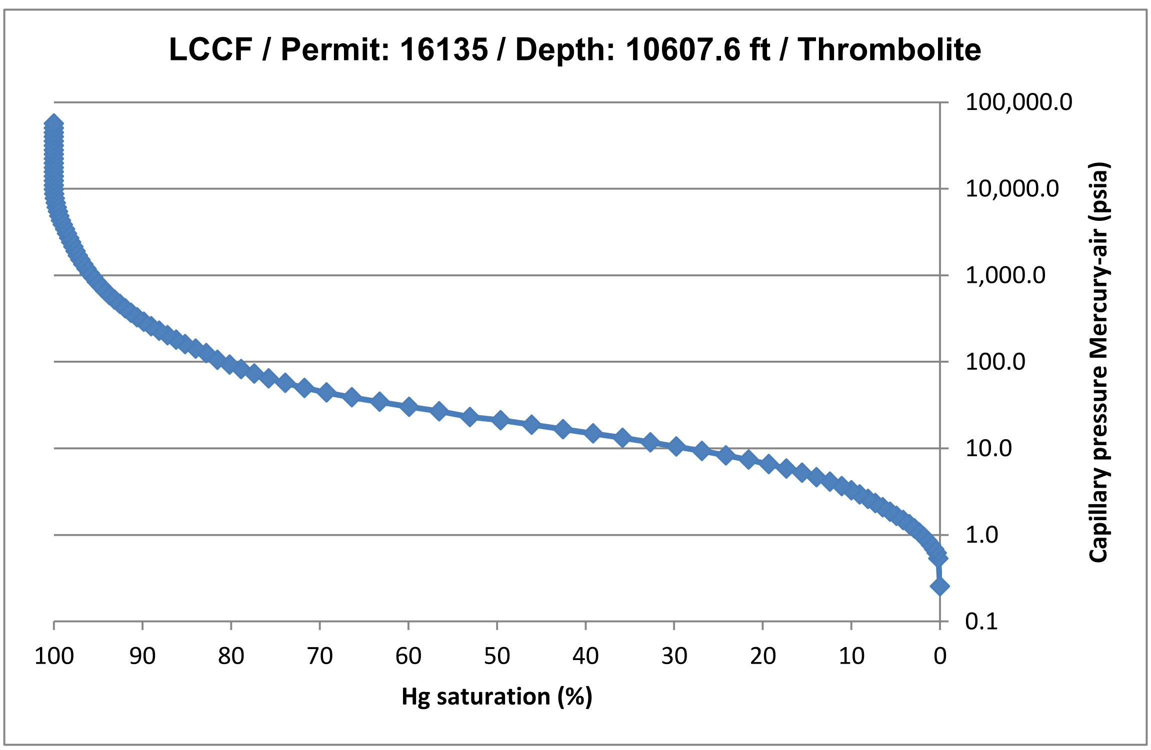


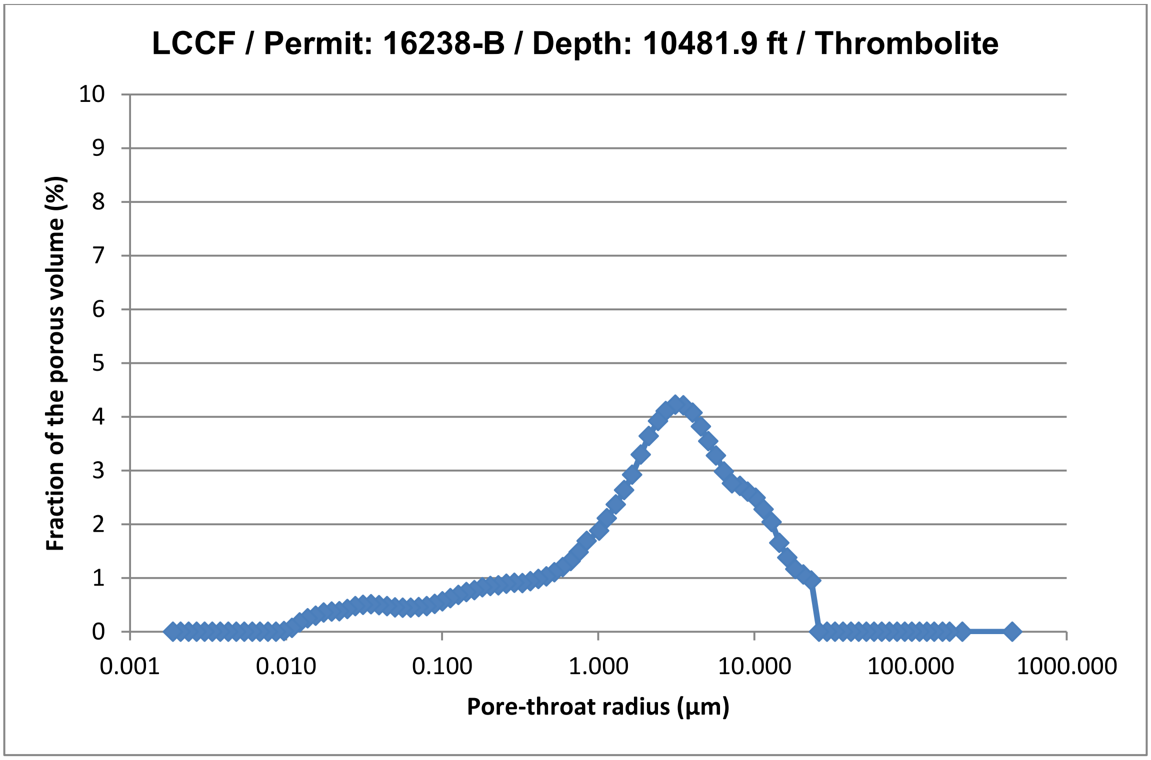
LCCF / Permit: 16115 / Depth: 10833.6 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

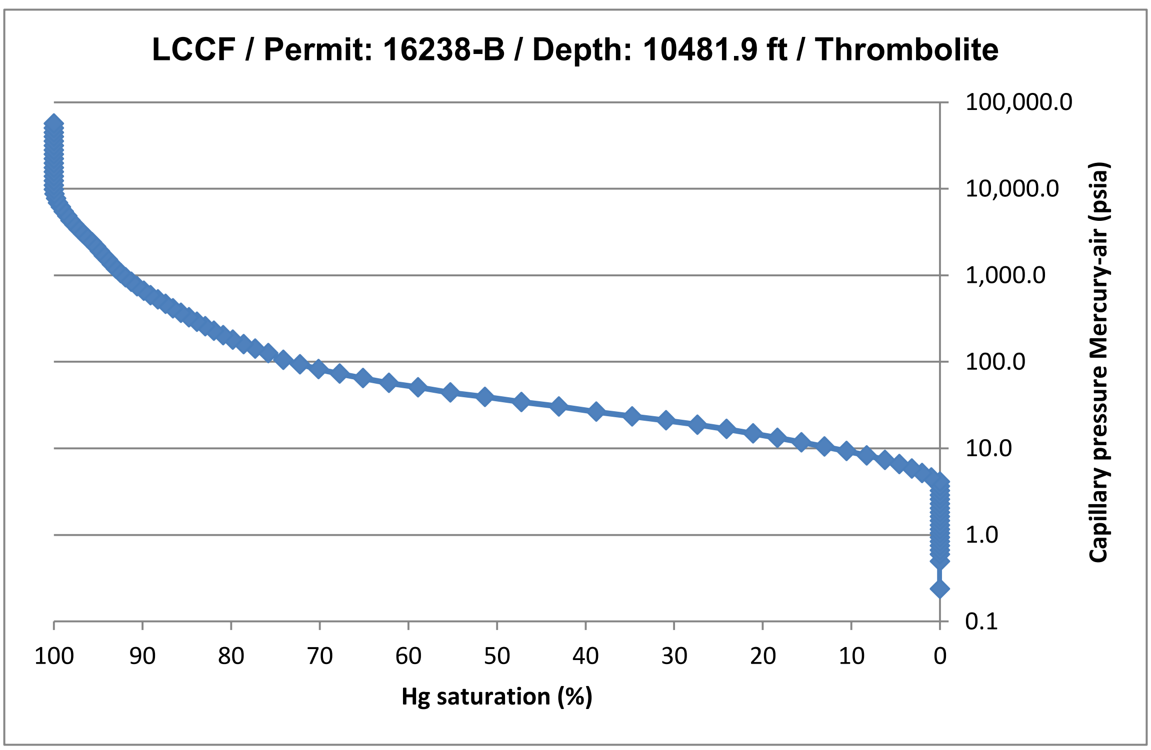

LCCF / Permit: 16115 / Depth: 10855.8 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

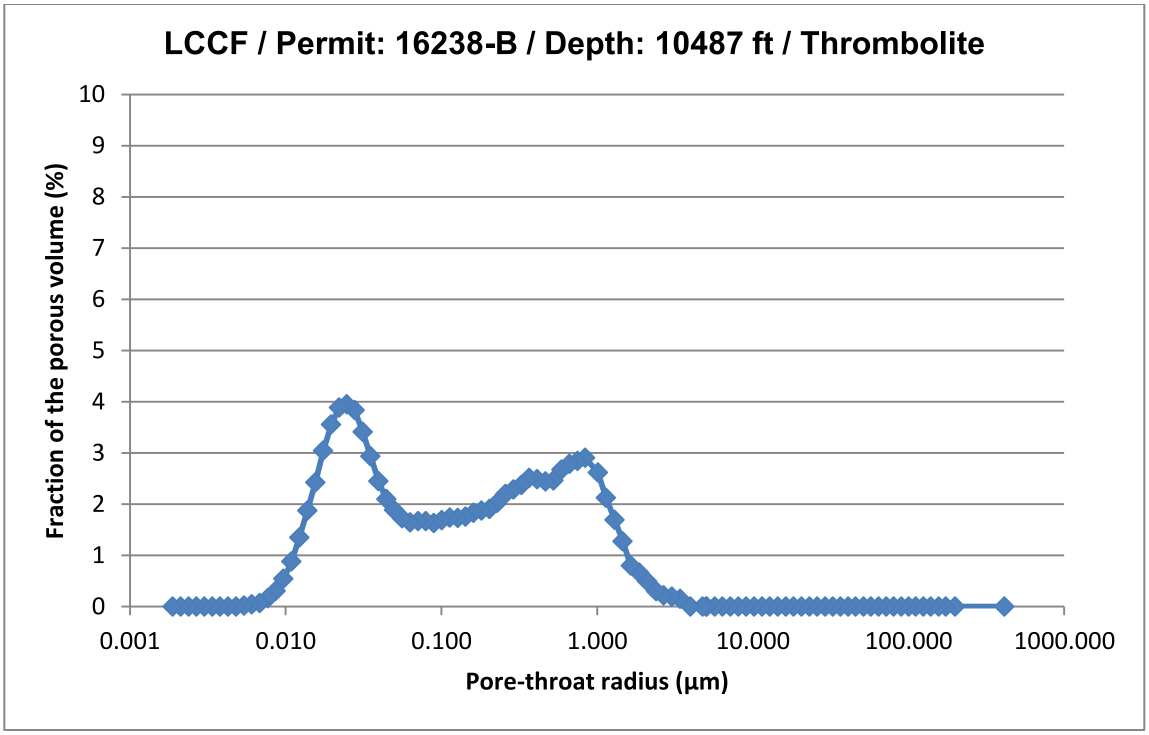

LCCF / Permit: 16115 / Depth: 10855.8 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


LCCF / Permit: 16135 / Depth: 10607.6 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

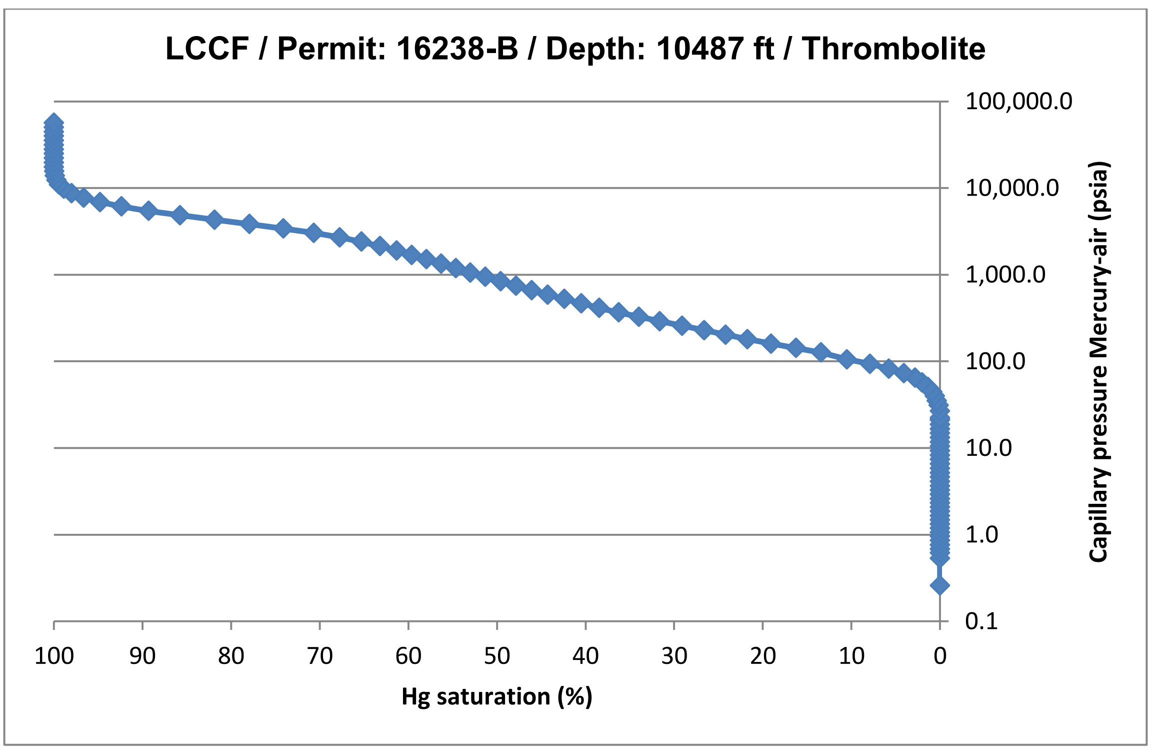

LCCF / Permit: 16135 / Depth: 10607.6 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


LCCF / Permit: 16238-B / Depth: 10481.9 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)


LCCF / Permit: 16238-B / Depth: 10481.9 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

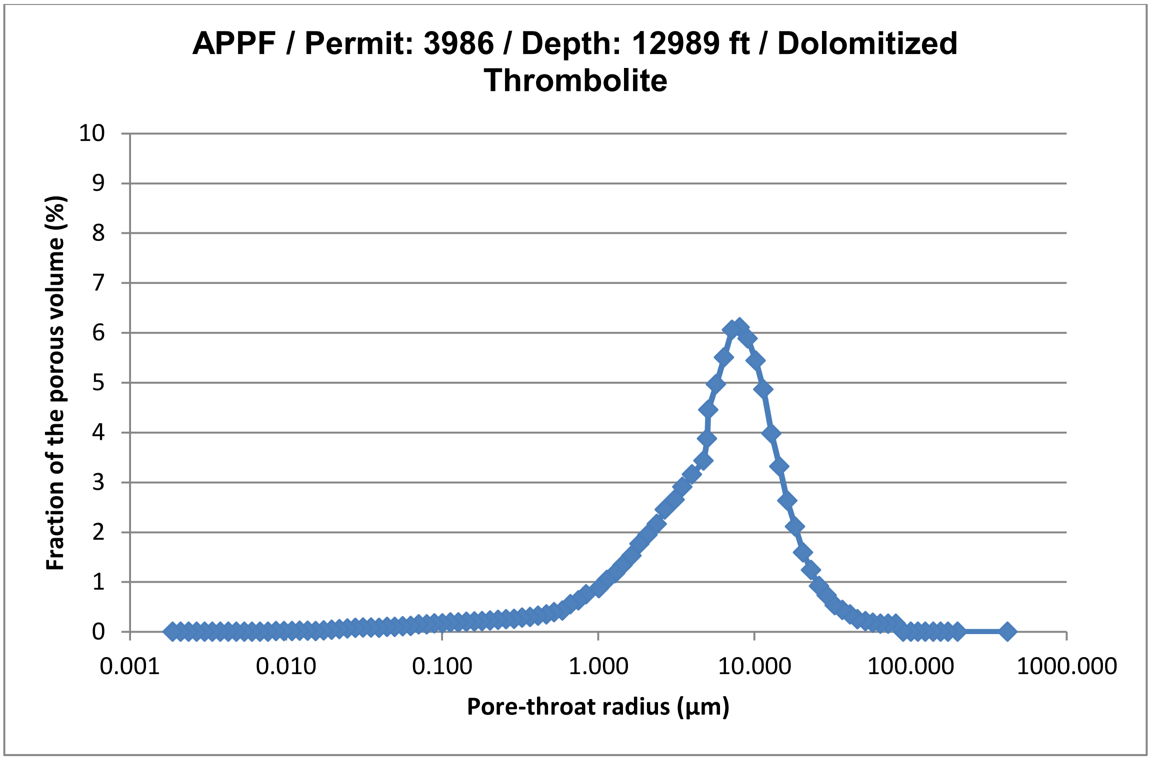


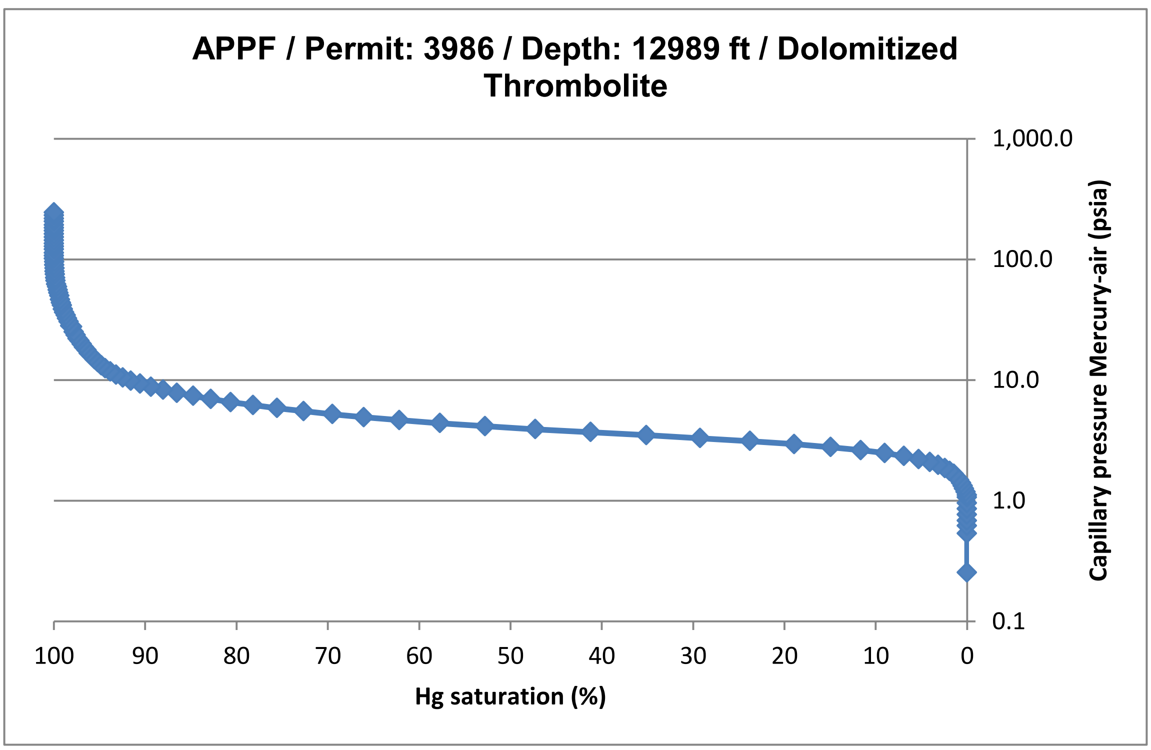
LCCF / Permit: 16238-B / Depth: 10487 ft / Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

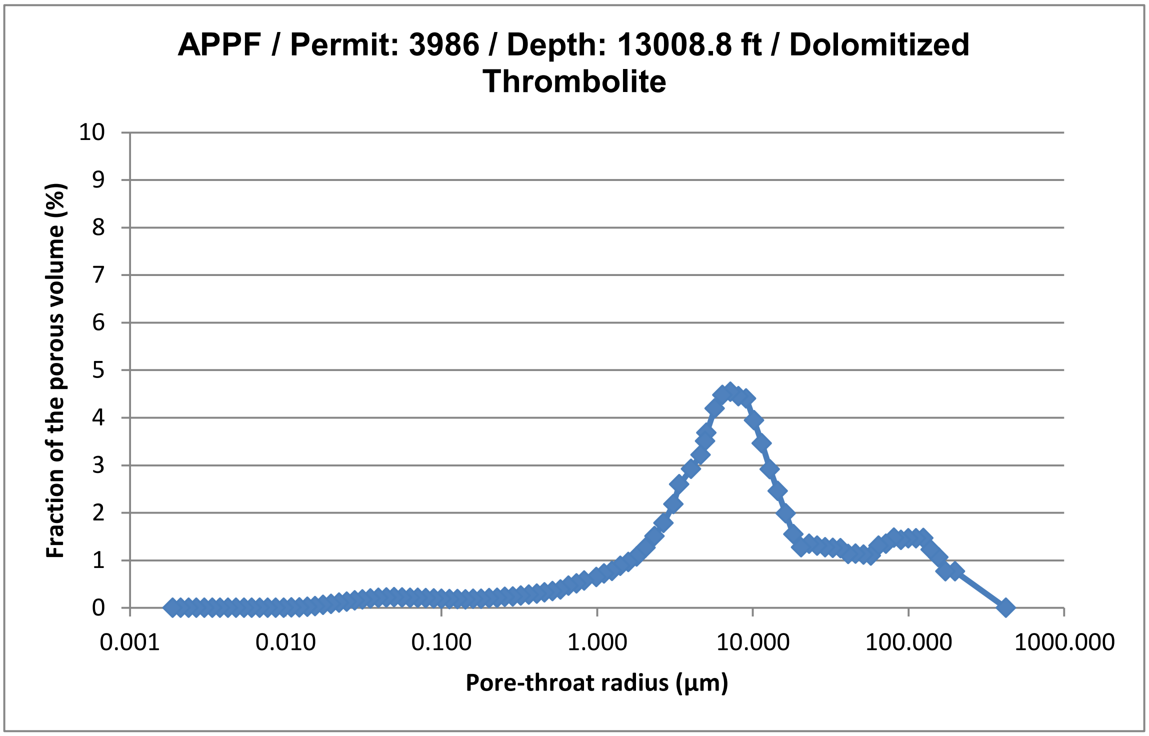


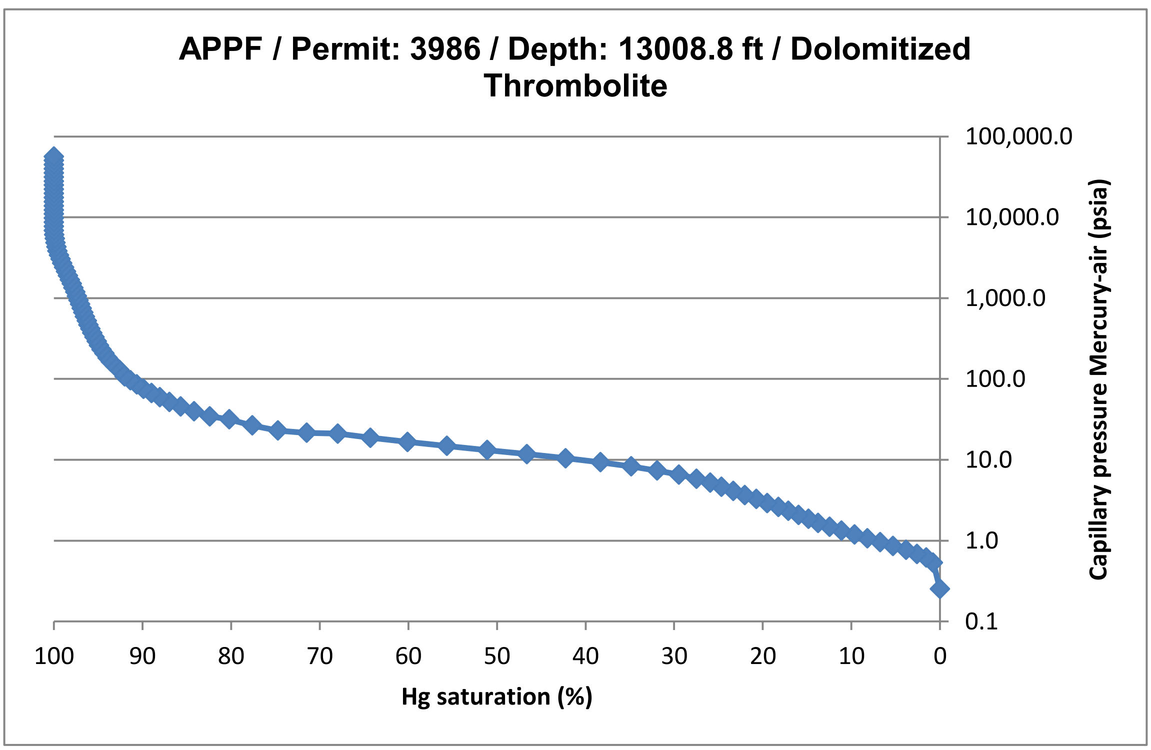
LCCF / Permit: 16238-B / Depth: 10487 ft / Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

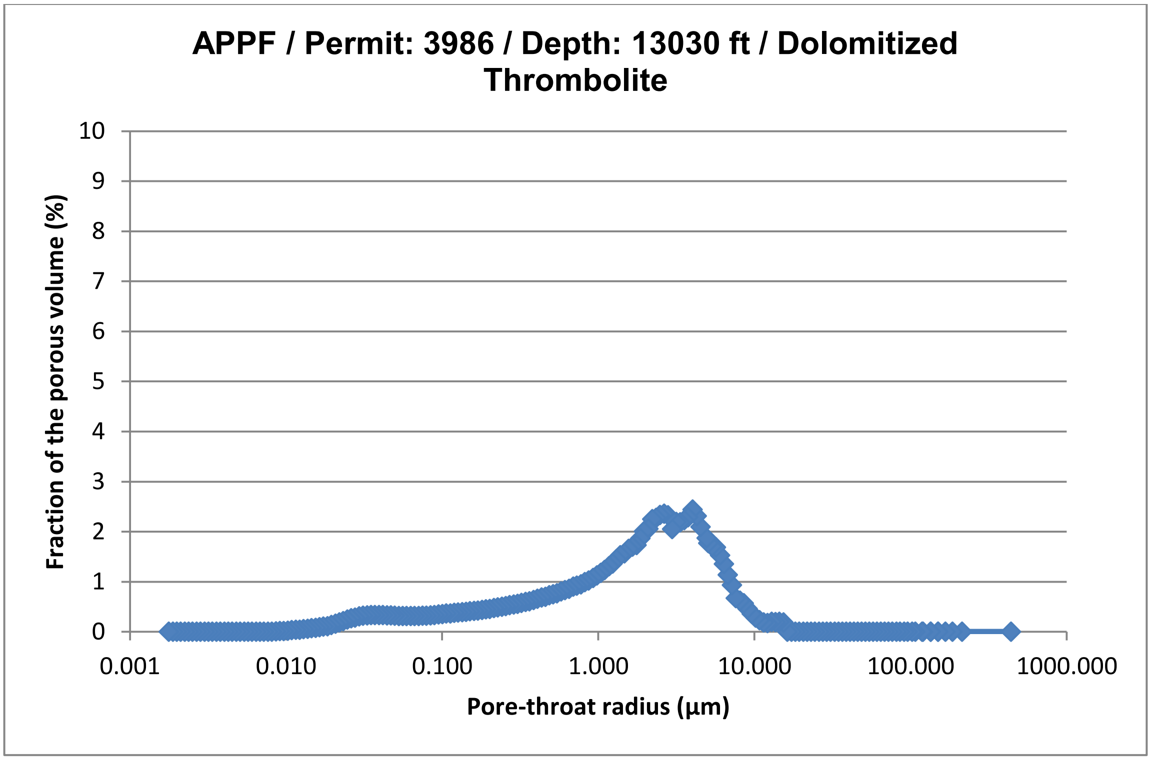
Appleton Field – Dolomitized thrombolite – Capillary pressure data

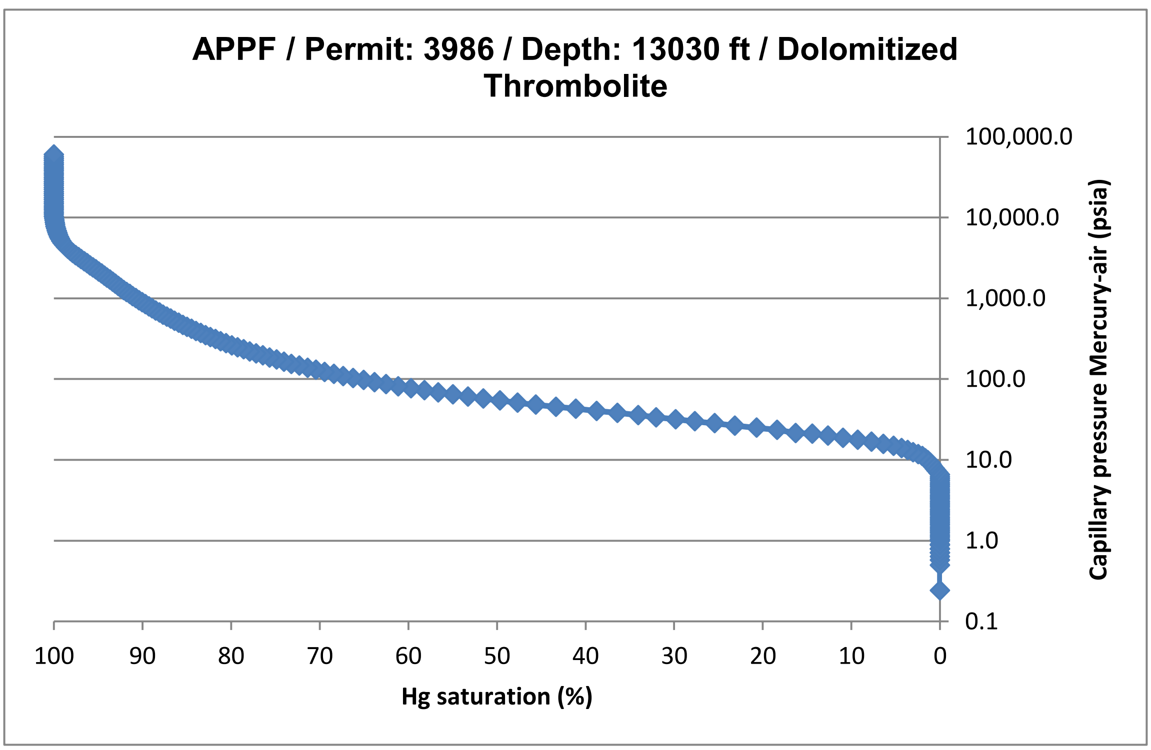


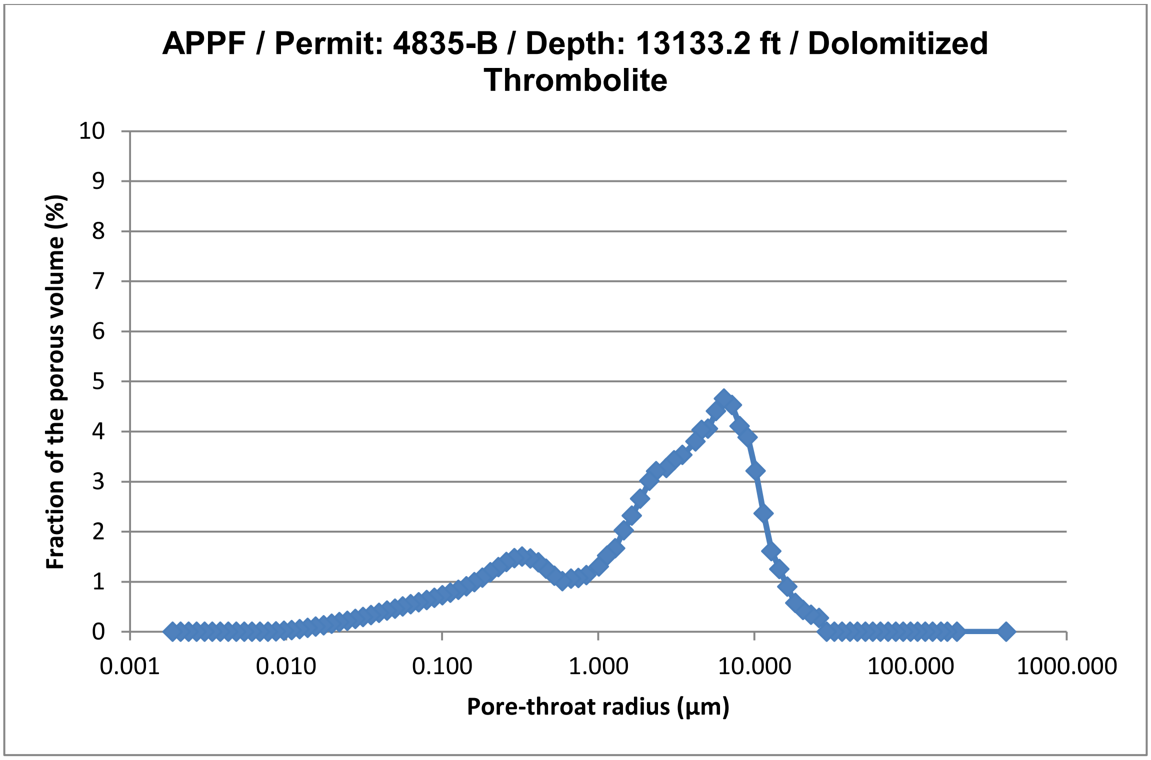



APPF / Permit: 3986 / Depth: 13008.8 ft / Dolomitized Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

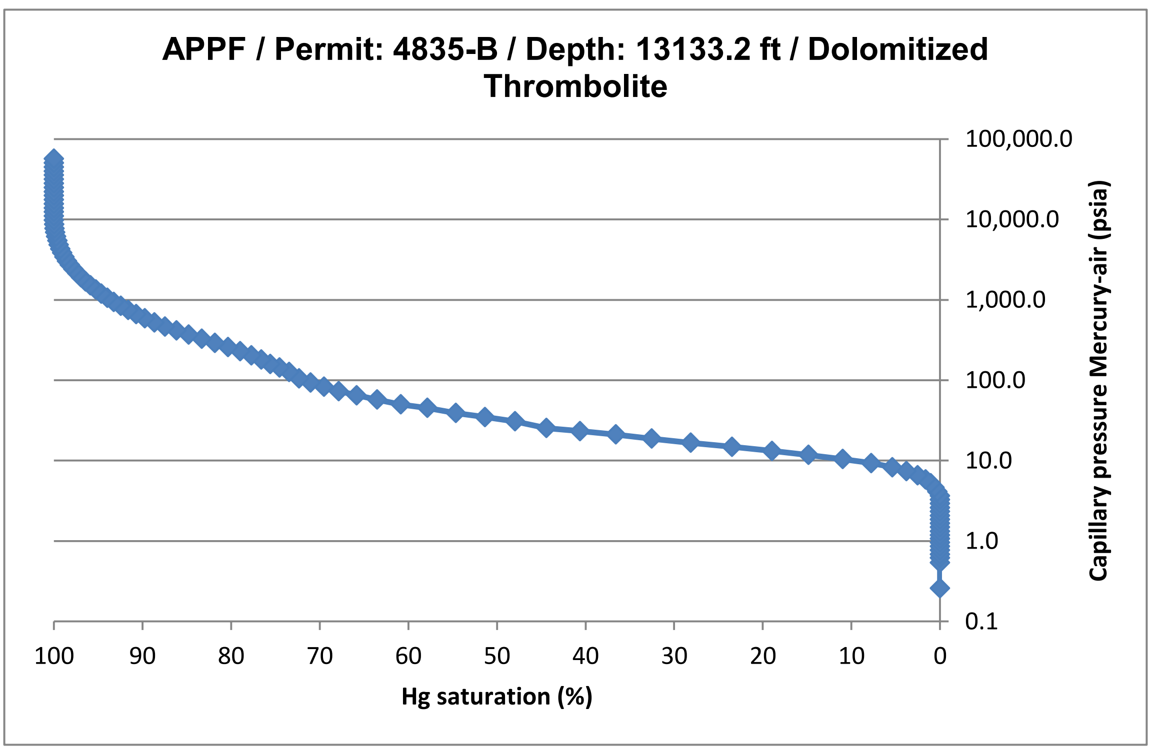

APPF / Permit: 3986 / Depth: 13008.8 ft / Dolomitized Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


APPF / Permit: 3986 / Depth: 13030 ft / Dolomitized Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

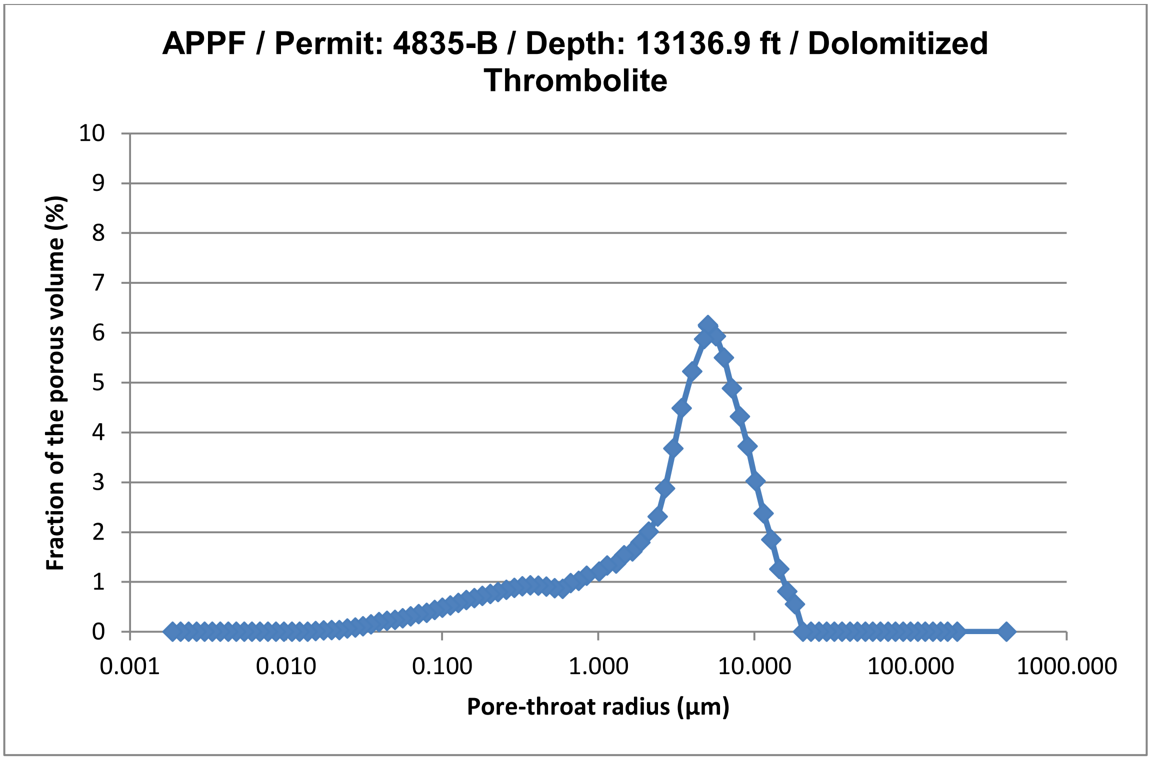

APPF / Permit: 3986 / Depth: 13030 ft / Dolomitized Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

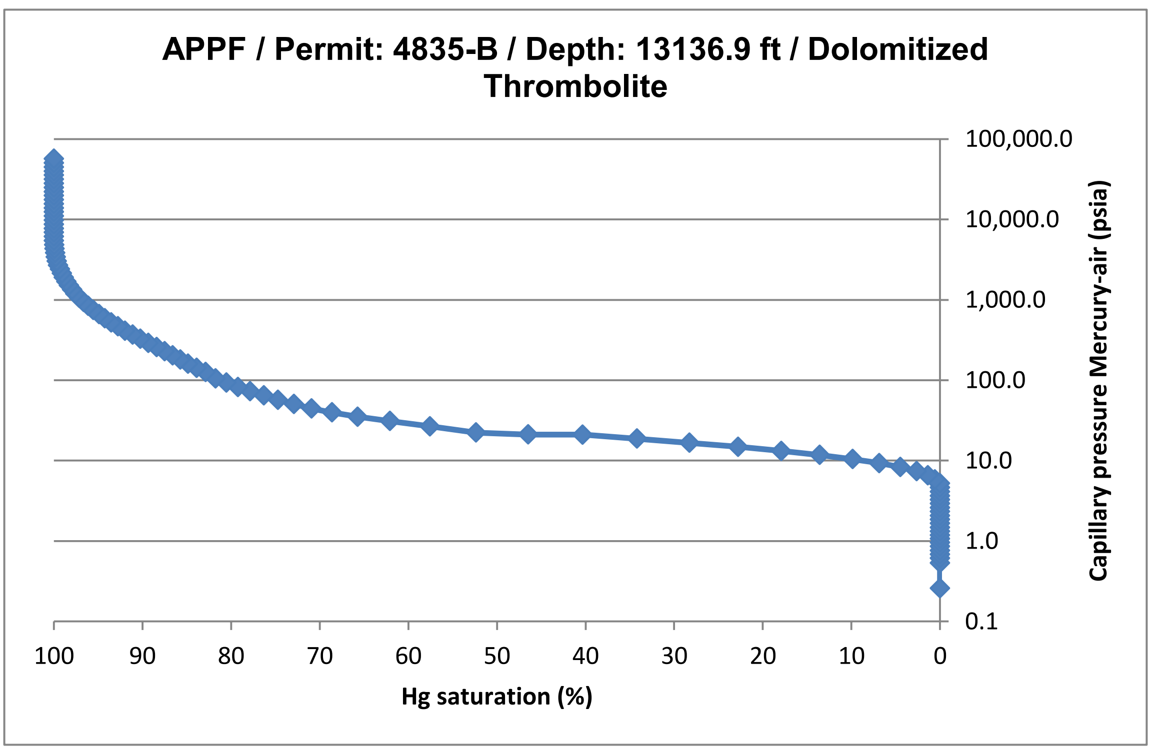


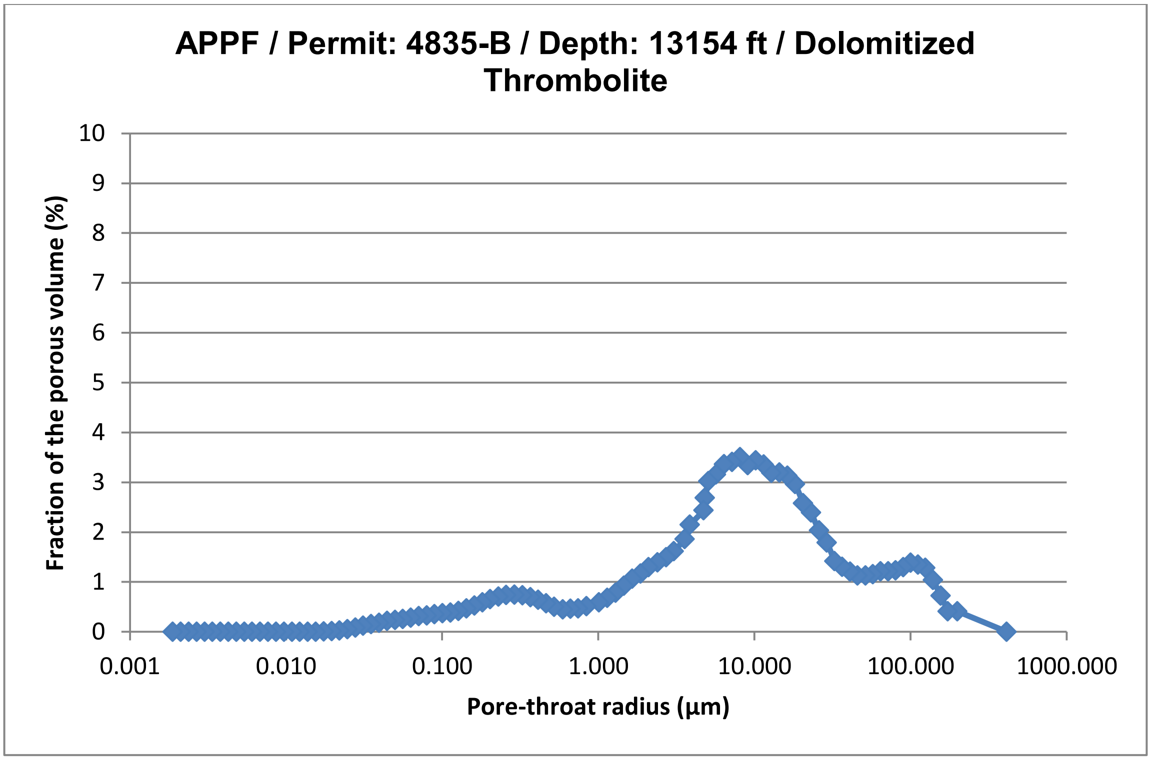
APPF / Permit: 4835-B / Depth: 13133.2 ft / Dolomitized Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)



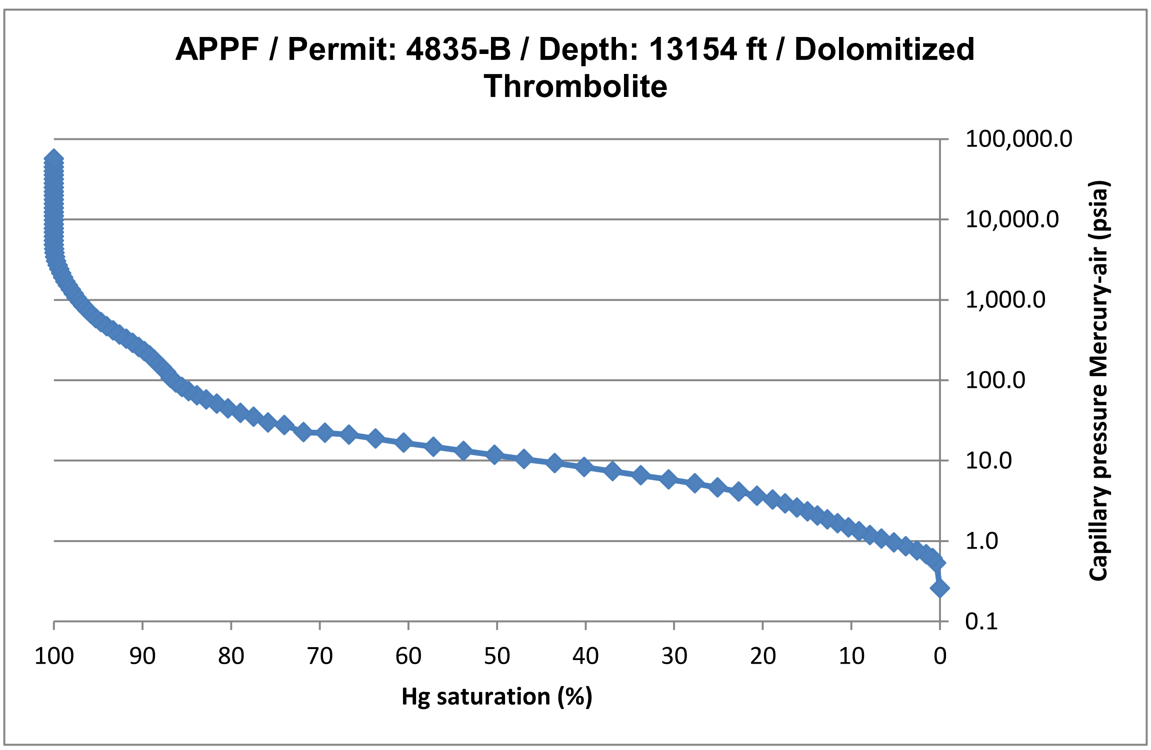
APPF / Permit: 4835-B / Depth: 13133.2 ft / Dolomitized Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)


APPF / Permit: 4835-B / Depth: 13136.9 ft / Dolomitized Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)


APPF / Permit: 4835-B / Depth: 13136.9 ft / Dolomitized Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

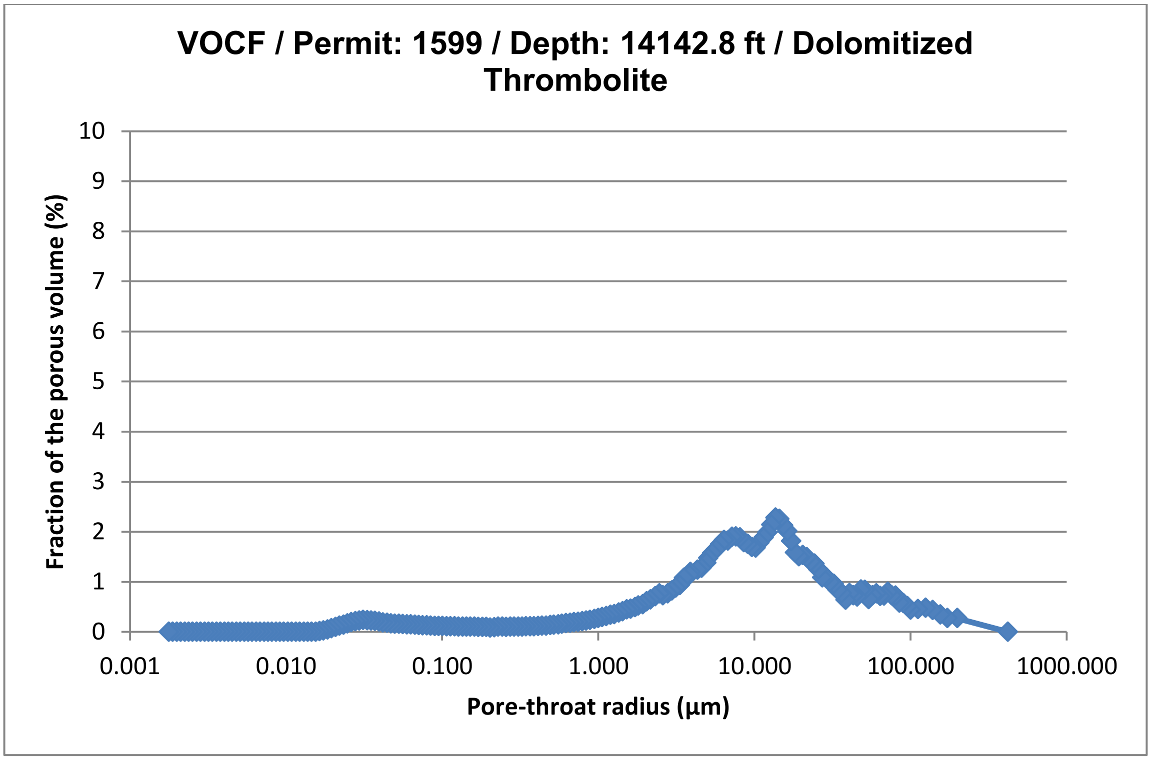


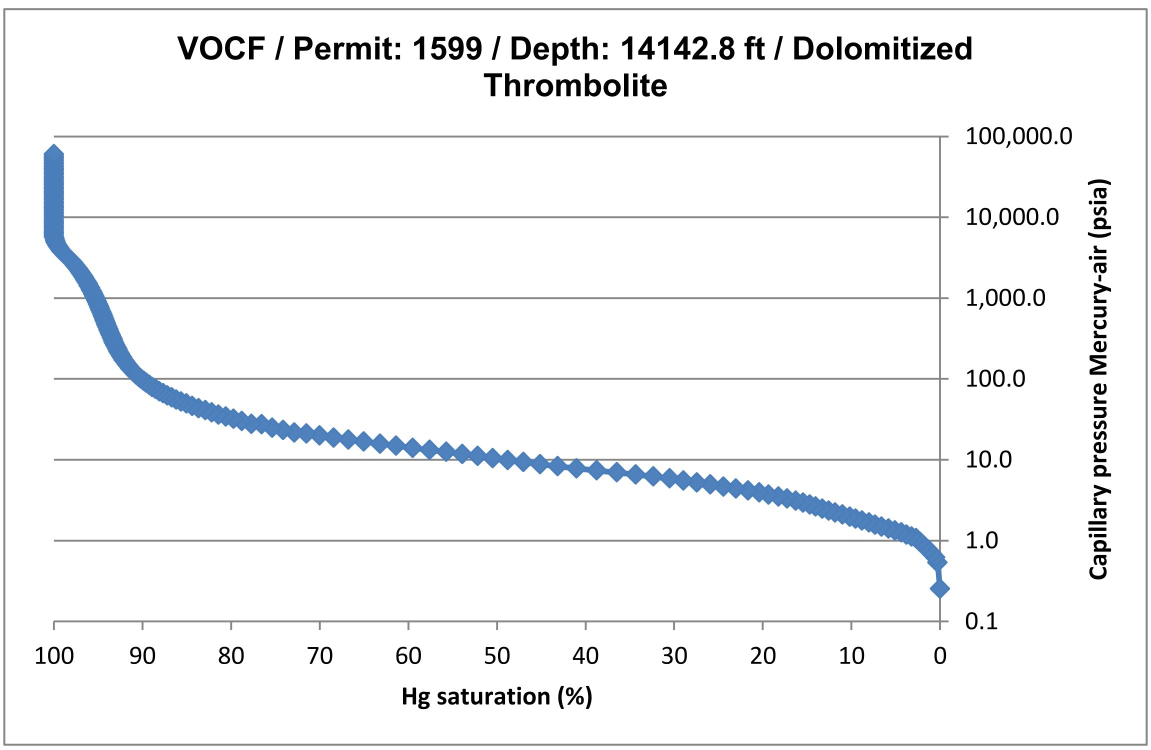
APPF / Permit: 4835-B / Depth: 13154 ft / Dolomitized Thrombolite
Fraction of the porous volume (%)
0
1
2
3
4
5
6
7
8
9
10
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

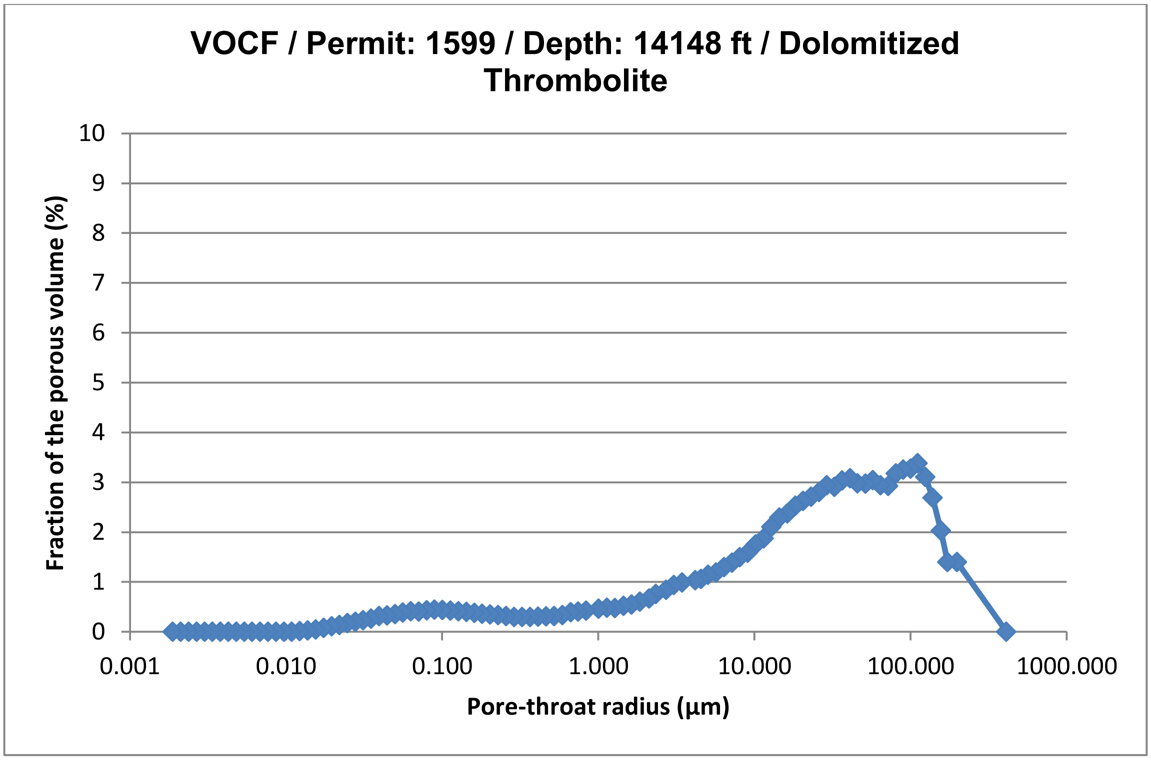


APPF / Permit: 4835-B / Depth: 13154 ft / Dolomitized Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

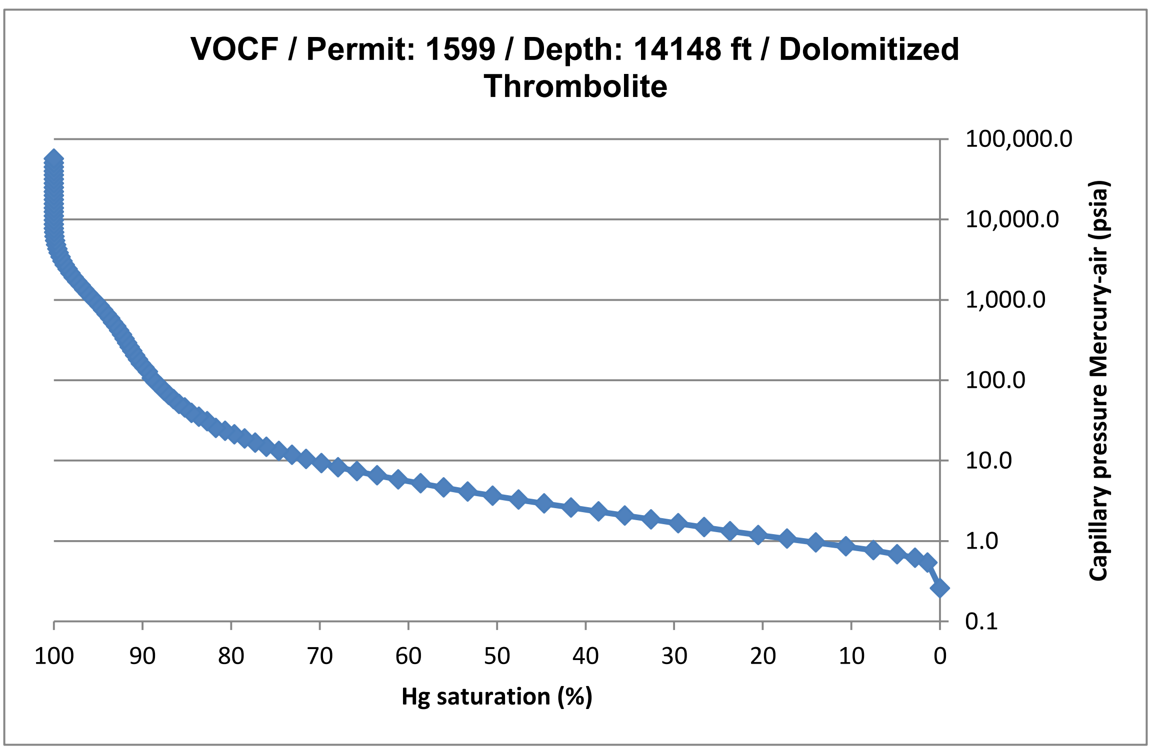
Vocation Field – Dolomitized thrombolite – Capillary pressure data



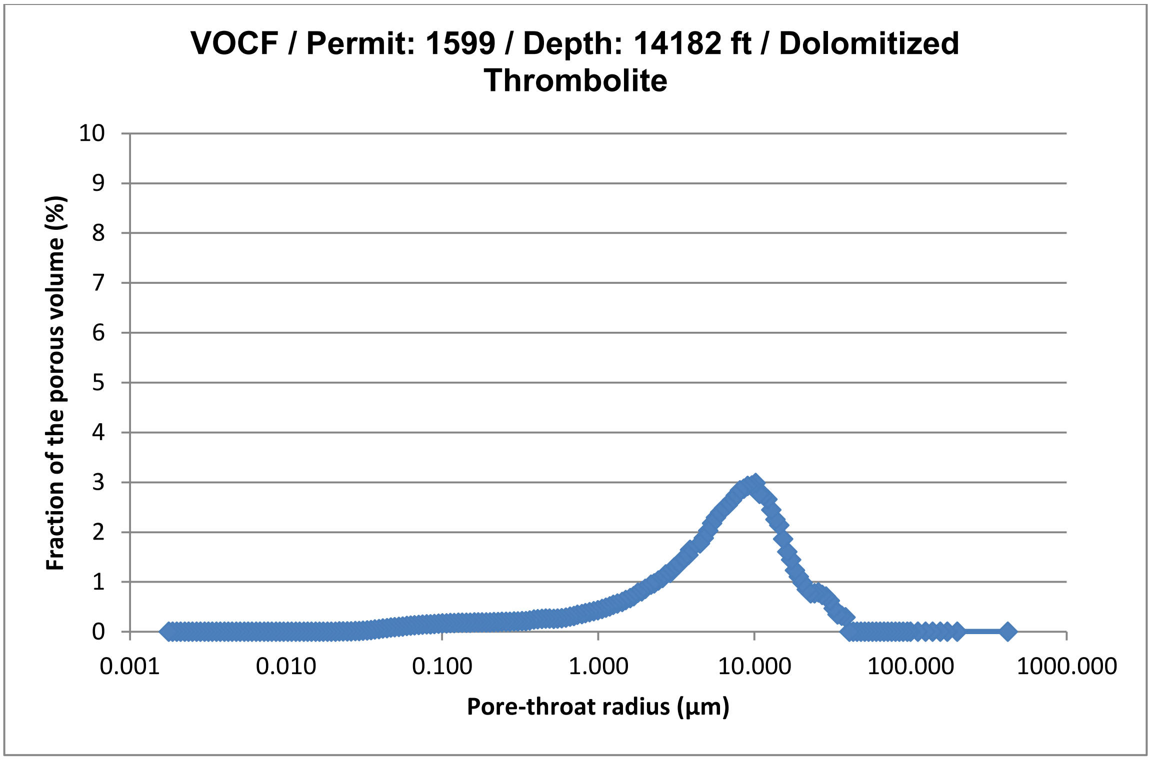




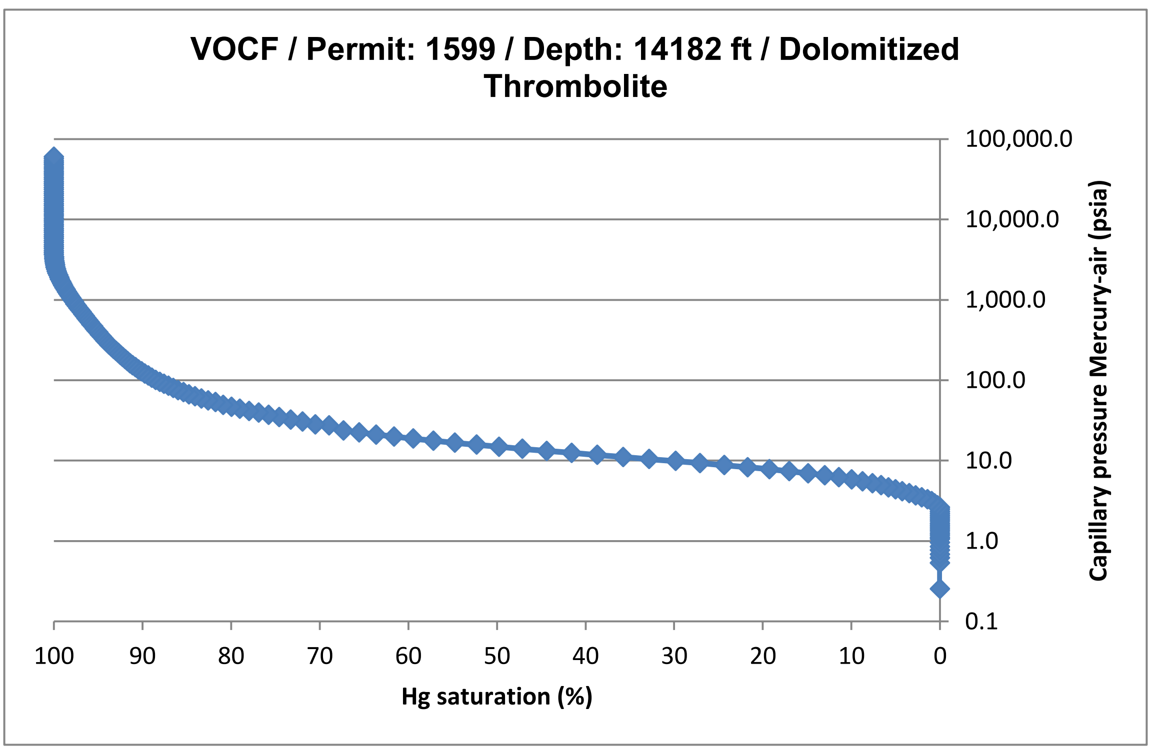
VOCF / Permit: 1599 / Depth: 14148 ft / Dolomitized Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)



VOCF / Permit: 1599 / Depth: 14148 ft / Dolomitized Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

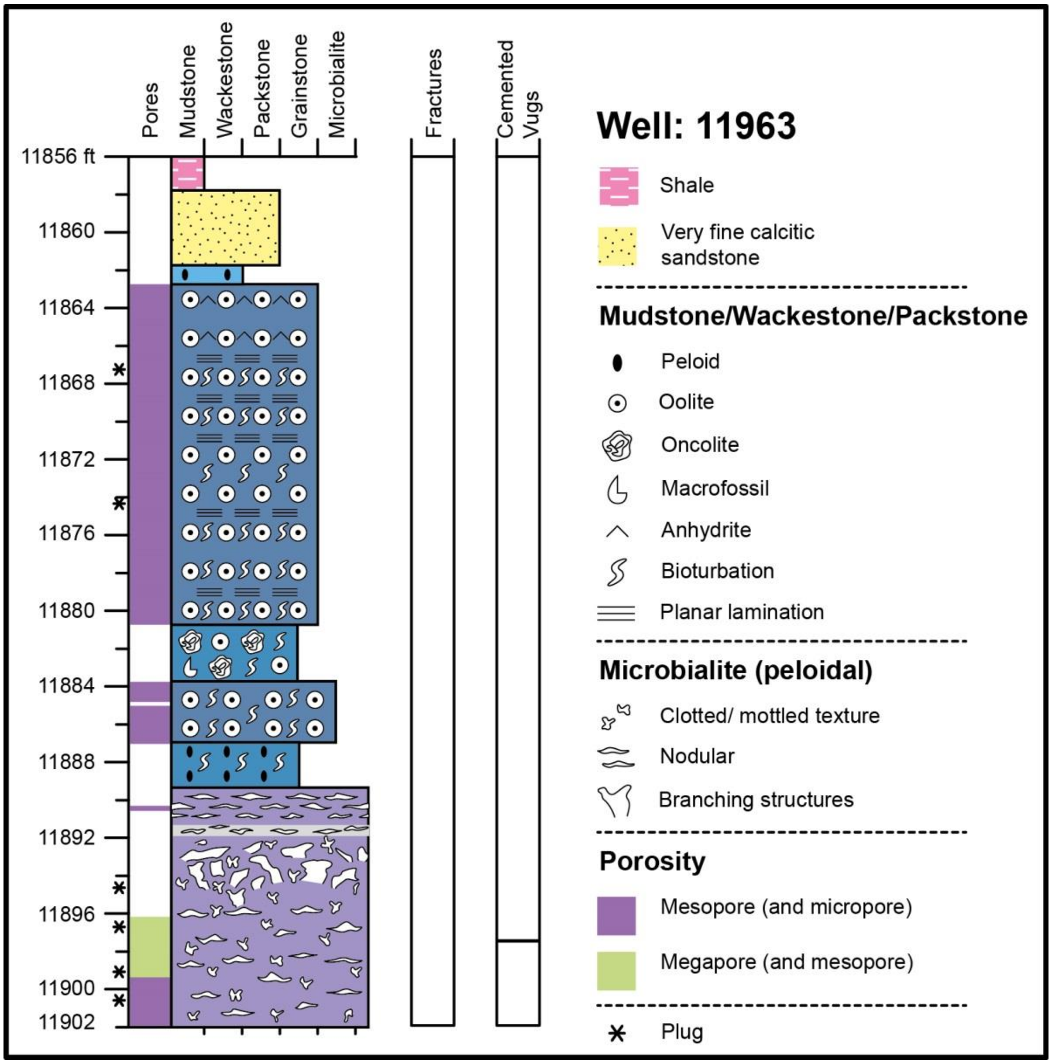


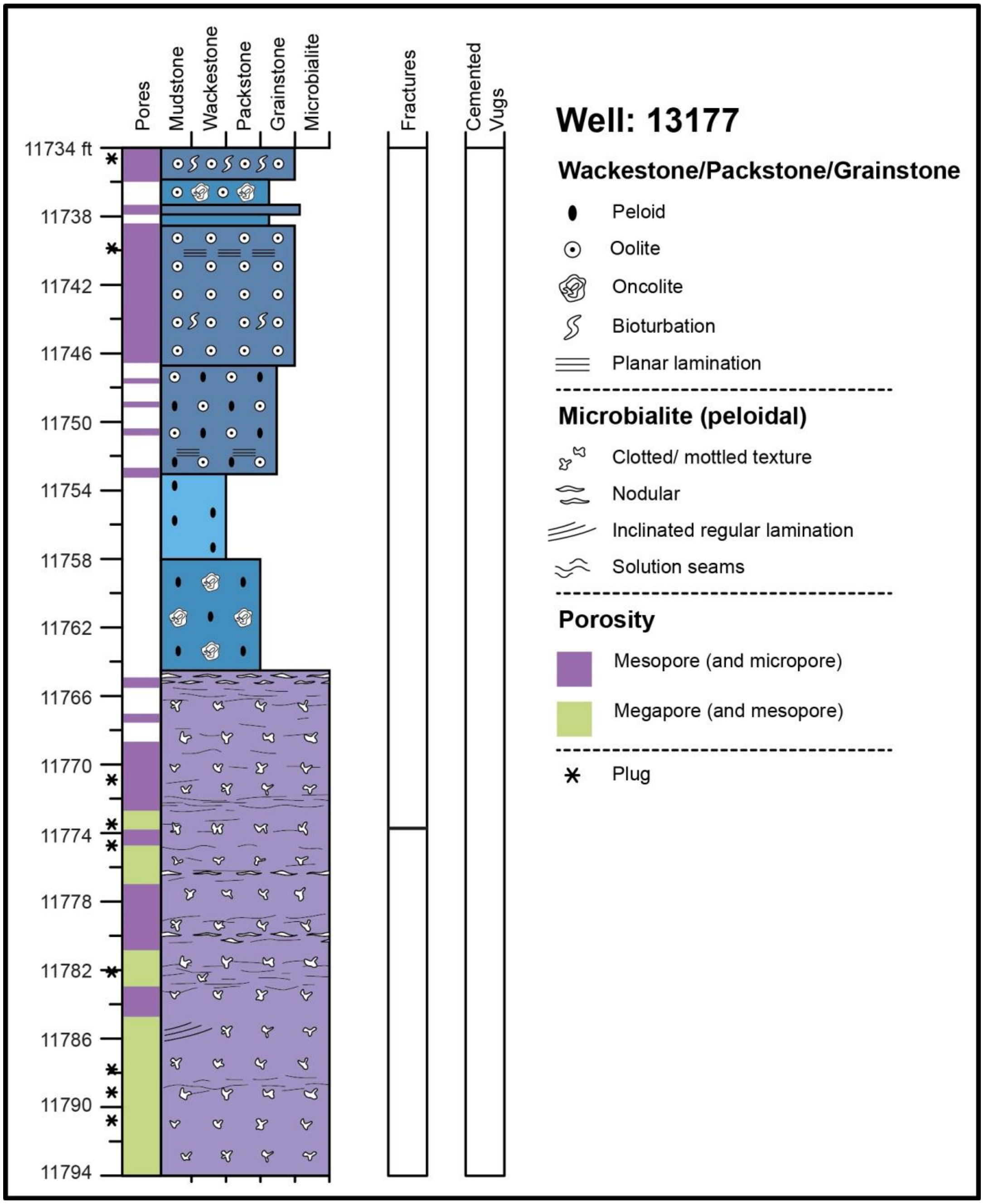
VOCF / Permit: 1599 / Depth: 14182 ft / Dolomitized Thrombolite
Fraction of the porous volume (%)
10
9
8
7
6
5
4
3
2
1
0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Pore-throat radius (µm)

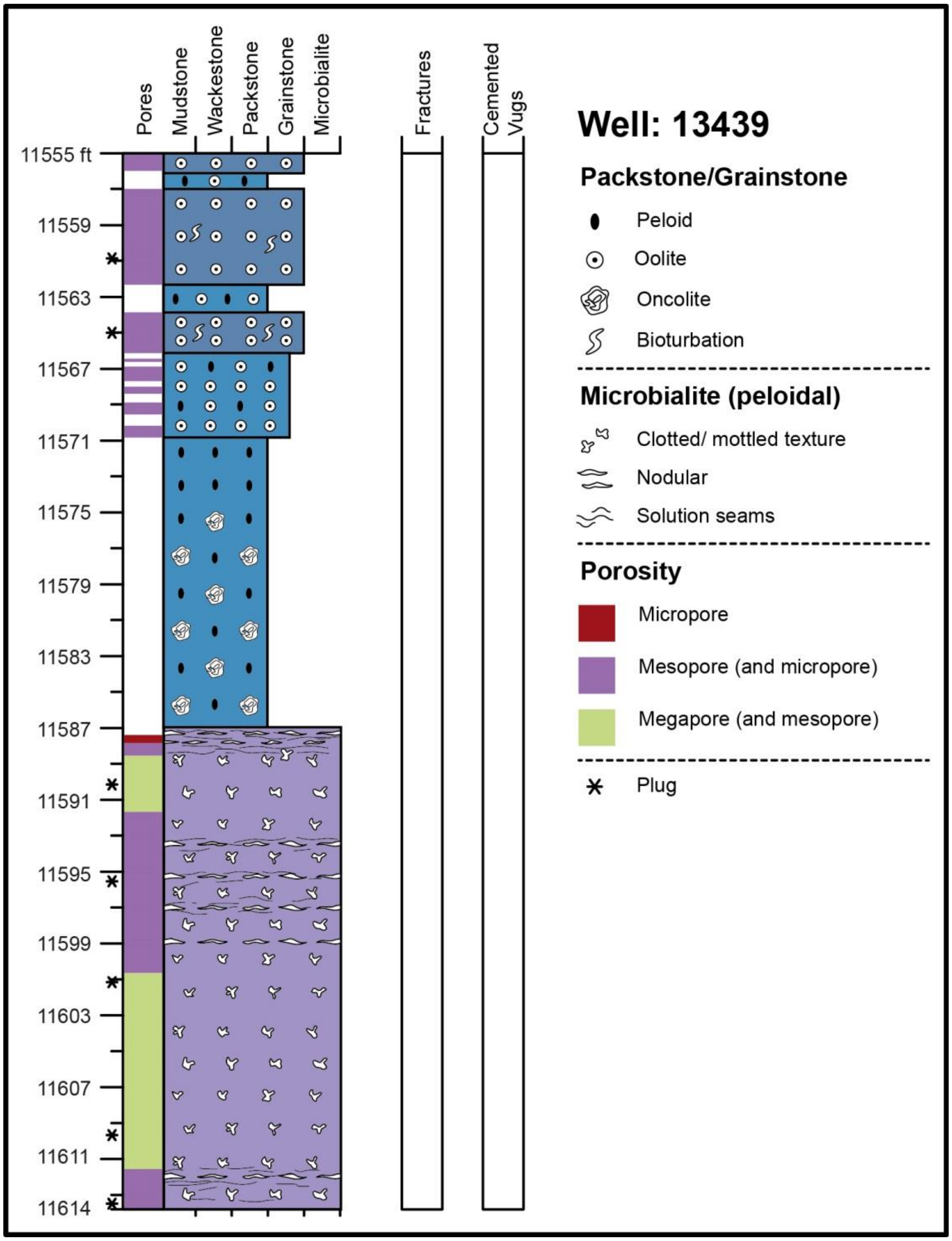


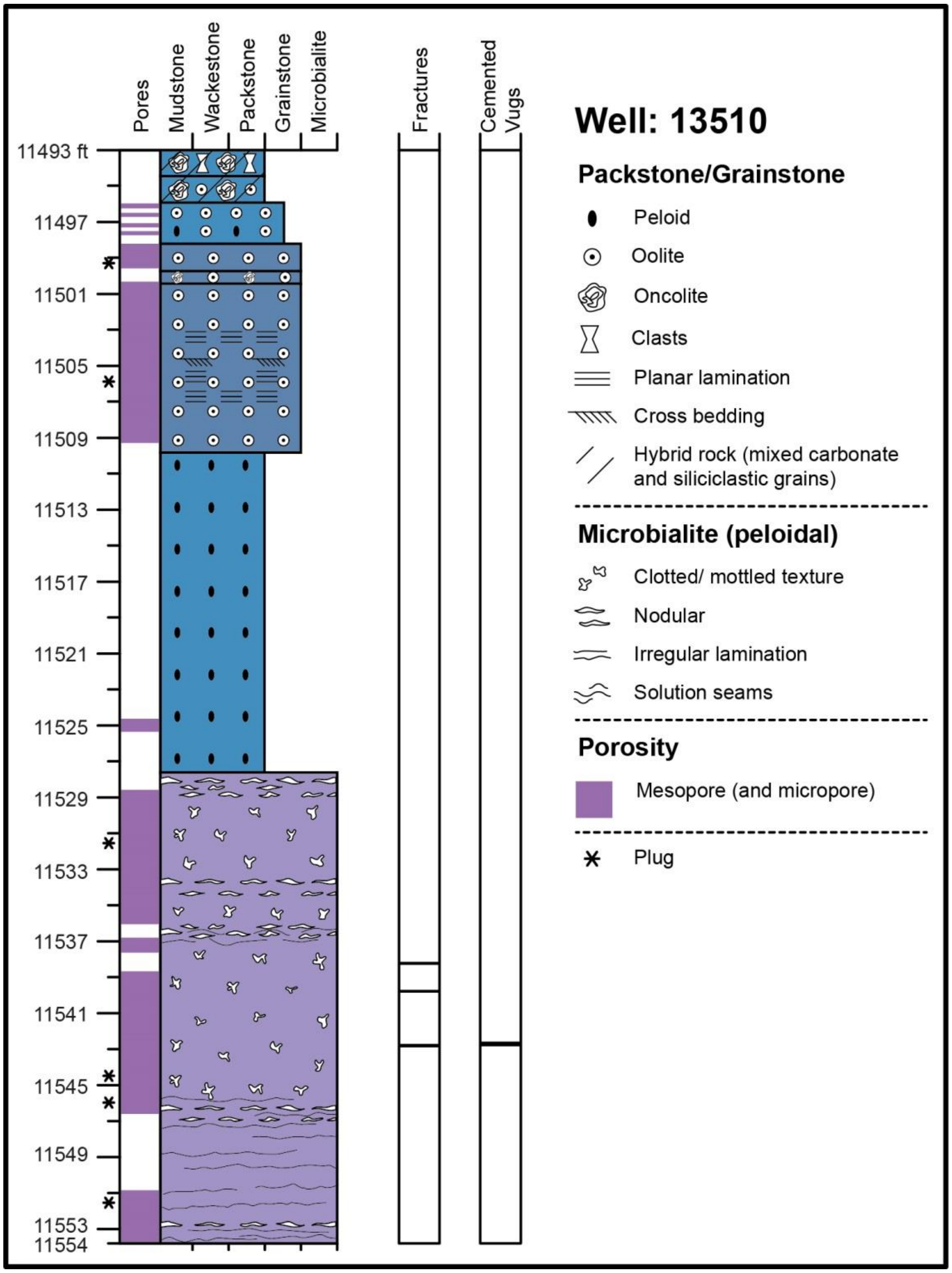
VOCF / Permit: 1599 / Depth: 14182 ft / Dolomitized Thrombolite
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Capillary pressure Mercury-air (psia)
100
90
80
70
60
50
40
30
20
10
0
Hg saturation (%)

APPENDIX C

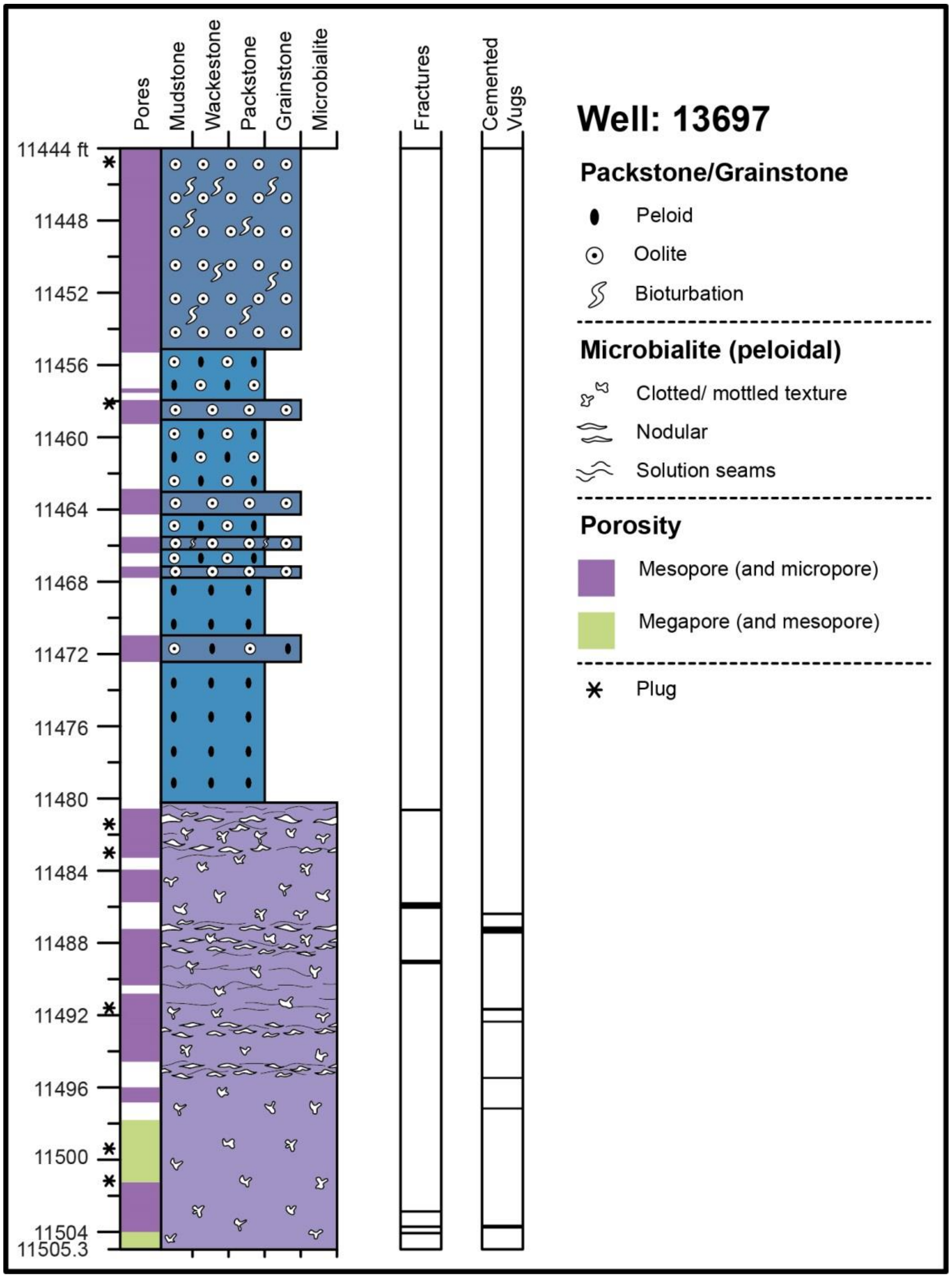

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11856 ft
11860
11864
11868
11872
11876
11880
11884
11888
11892
11896
11900
11902
Well: 11963
Shale
Very fine calcitic sandstone
Mudstone/Wackestone/Packstone
Peloid
Oolite
Oncolite
Macrofossil
Anhydrite
Bioturbation
Planar lamination
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Branching structures
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug

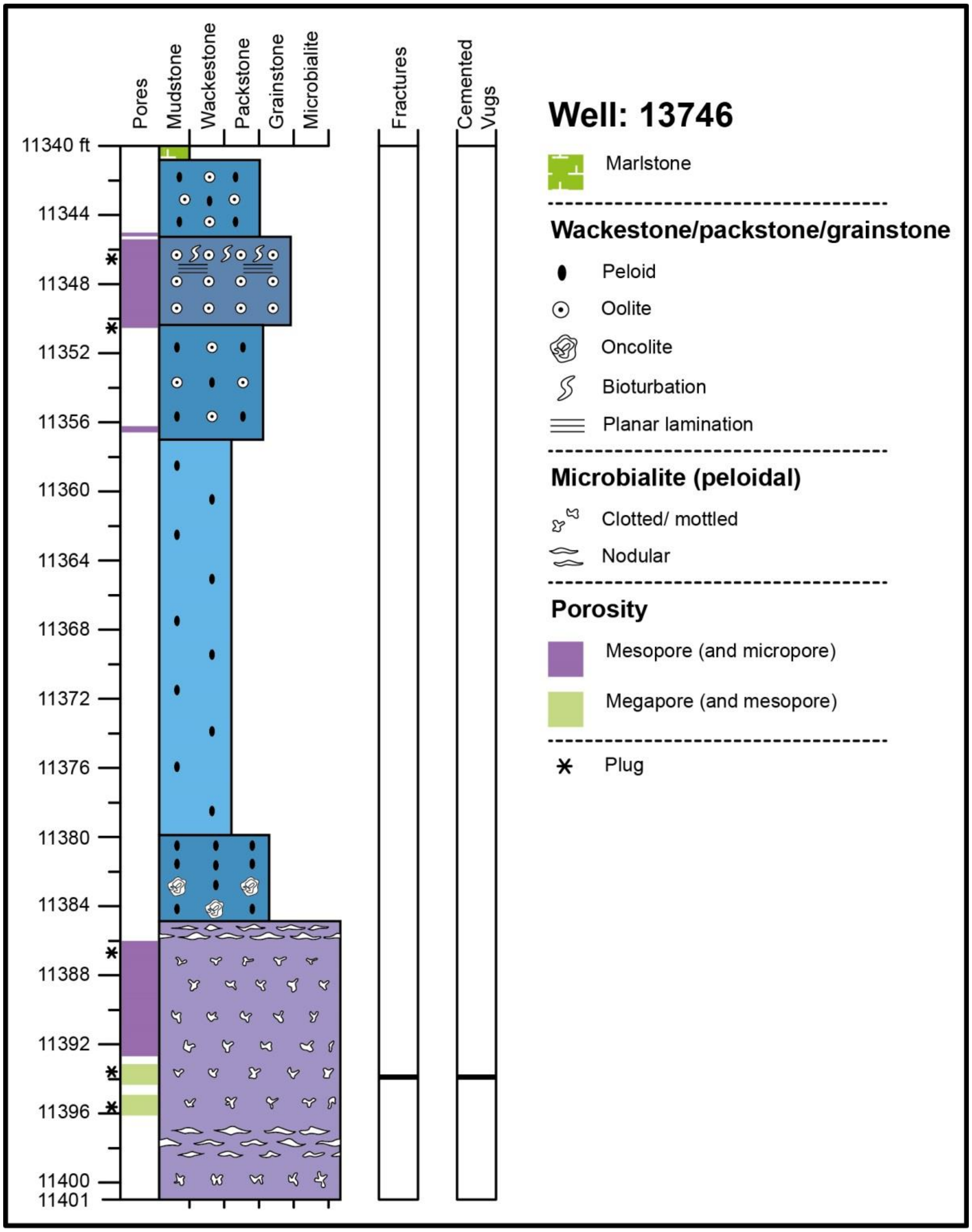

Well: 13177
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11734 ft
11738
11742
11746
11750
11754
11758
11762
11766
11770
11774
11778
11782
11786
11790
11794
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Bioturbation
Planar lamination
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Inclinated regular lamination
Solution seams
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug

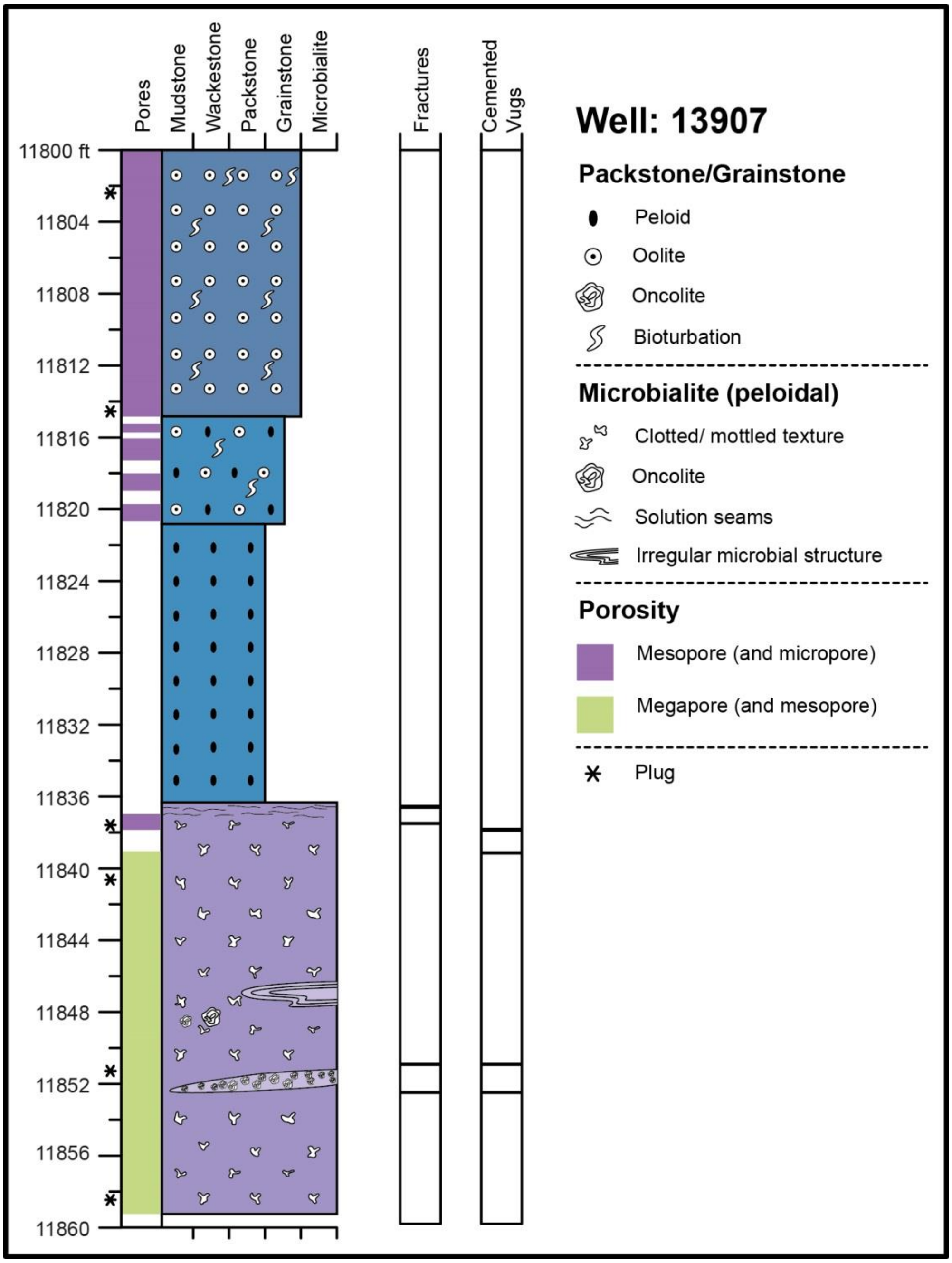

Well: 13439
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11555 ft
11559
11563
11567
11571
11575
11579
11583
11587
11591
11595
11599
11603
11607
11611
11614
Packstone/Grainstone
Peloid
Oolite
Oncolite
Bioturbation
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Solution seams
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
Plug

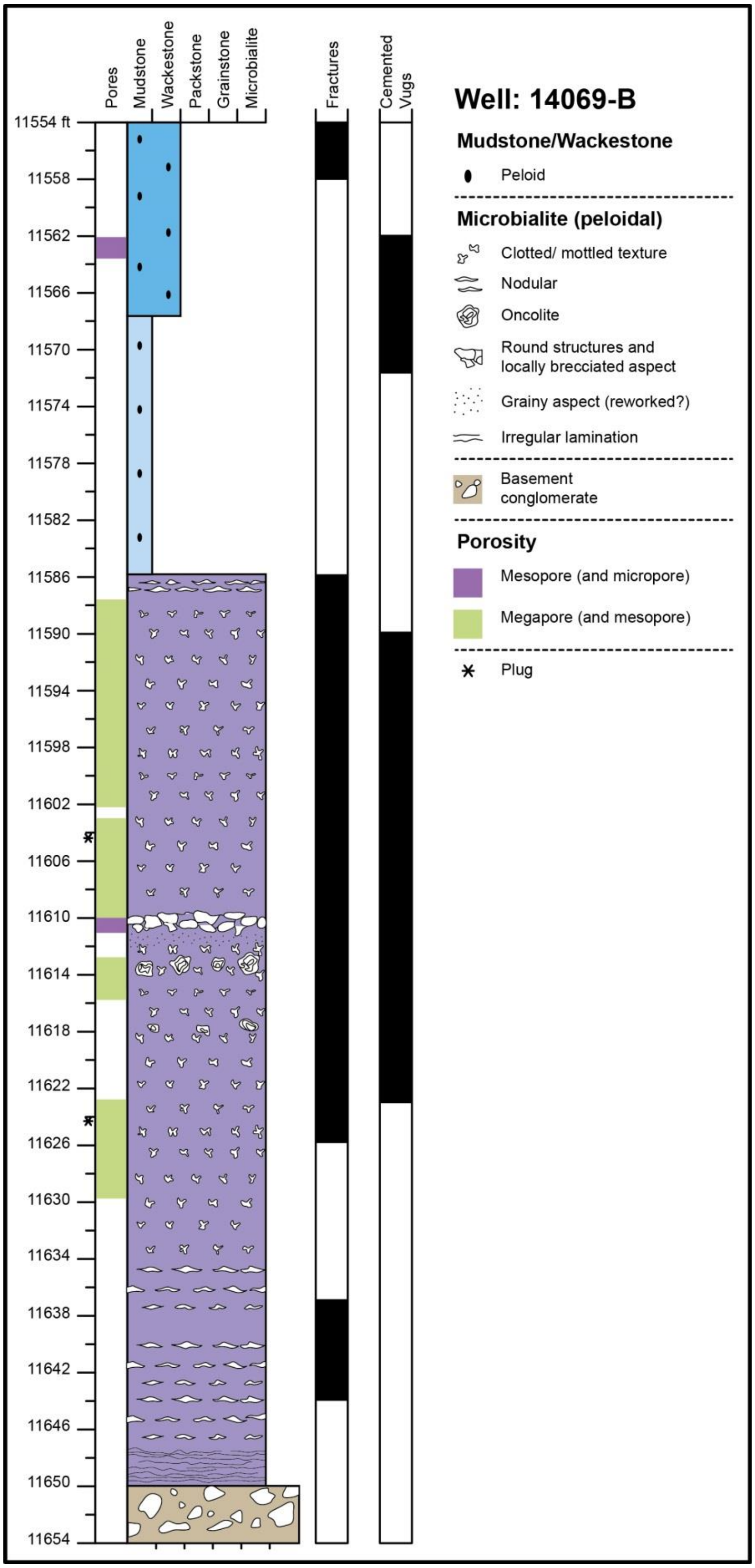


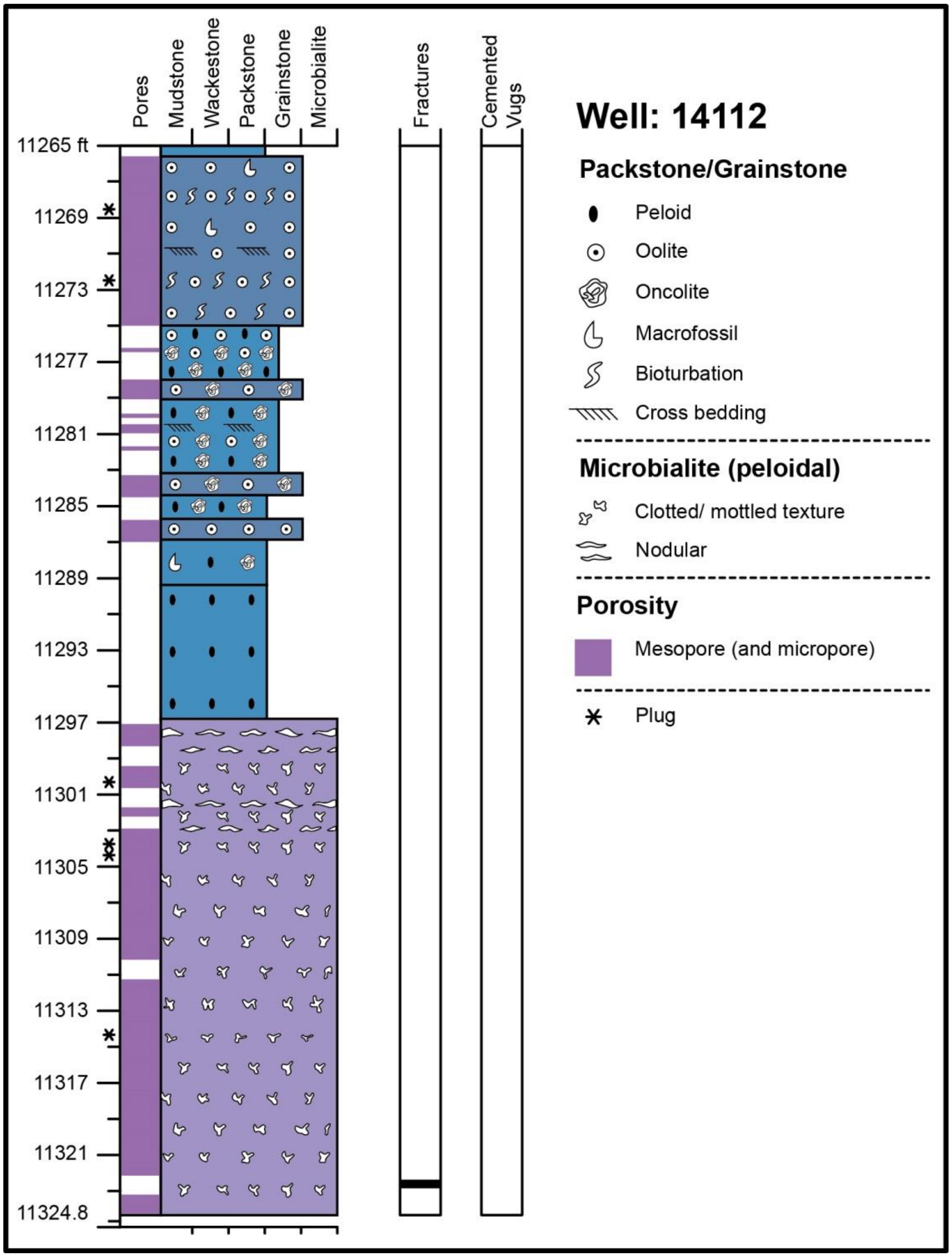
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11493 ft
11497
11501
11505
11509
11513
11517
11521
11525
11529
11533
11537
11541
11545
11549
11553
11554
Well: 13510
Packstone/Grainstone
Peloid
Oolite
Oncolite
Clasts
Planar lamination
Cross bedding
Hybrid rock (mixed carbonate and siliciclastic grains)
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Irregular lamination
Solution seams
Porosity
Mesopore (and micropore)
Plug


Well: 13697
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11444 ft
11448
11452
11456
11460
11464
11468
11472
11476
11480
11484
11488
11492
11496
11500
11504
11505.3
Packstone/Grainstone
Peloid
Oolite
Bioturbation
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Solution seams
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug

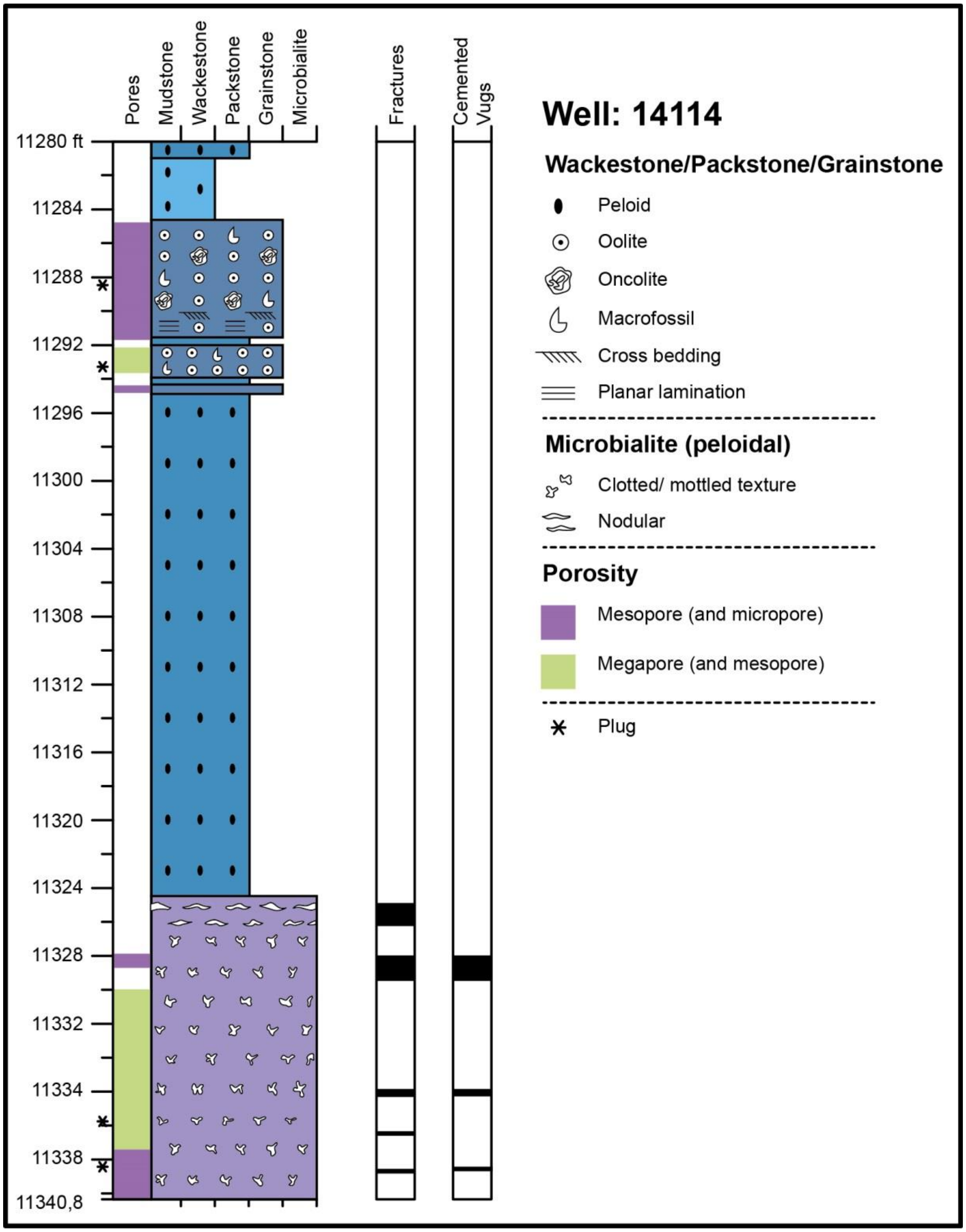

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11340 ft
11344
11348
11352
11356
11360
11364
11368
11372
11376
11380
11384
11388
11392
11396
11400
11401
Well: 13746
Marlstone
Wackestone/packstone/grainstone
Peloid
Oolite
Oncolite
Bioturbation
Planar lamination
Microbialite (peloidal)
Clotted/ mottled
Nodular
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug

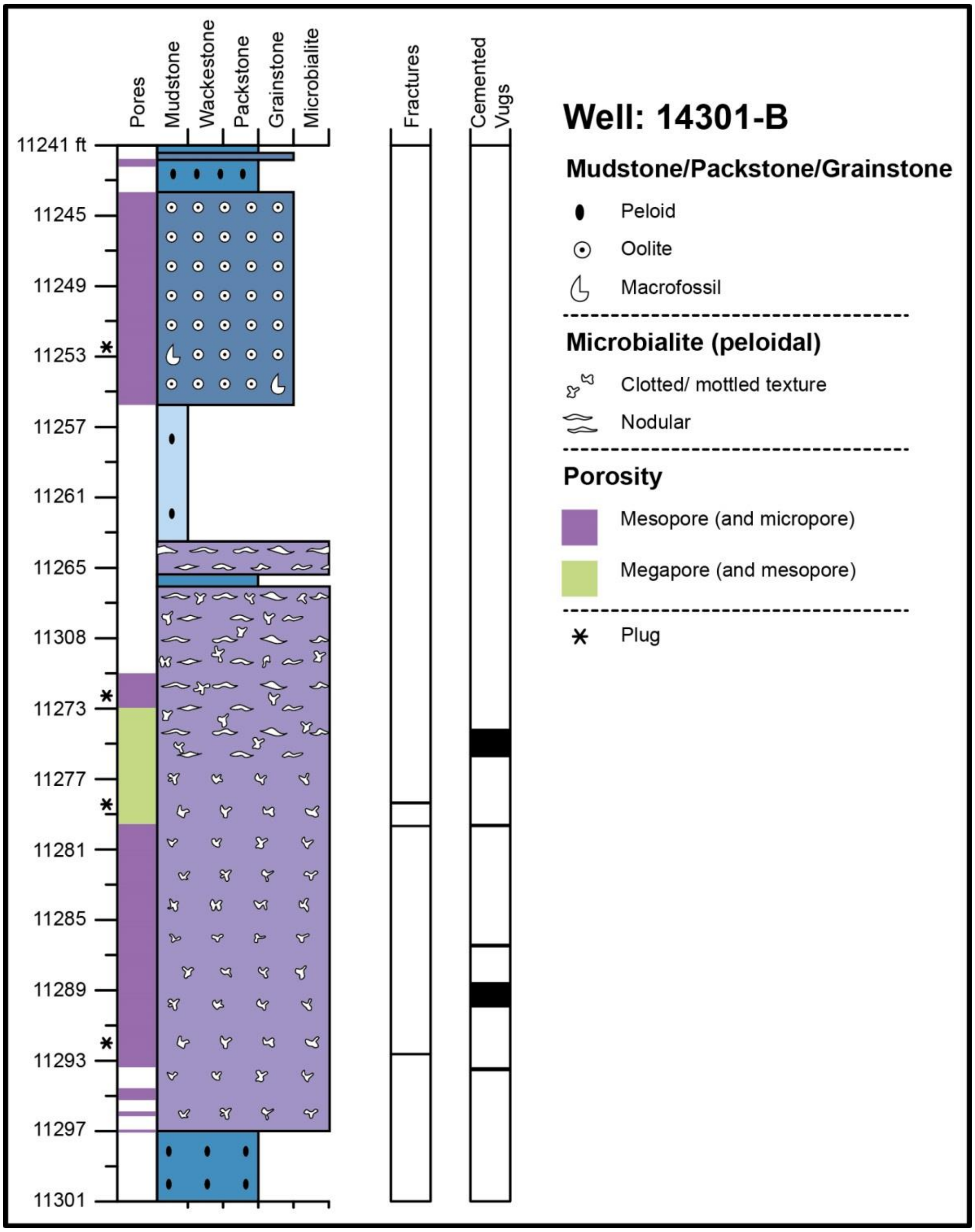

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11800 ft
11804
11808
11812
11816
11820
11824
11828
11832
11836
11840
11844
11848
11852
11856
11860
Well: 13907
Packstone/Grainstone
Peloid
Oolite
Oncolite
Bioturbation
Microbialite (peloidal)
Clotted/ mottled texture
Oncolite
Solution seams
Irregular microbial structure
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug

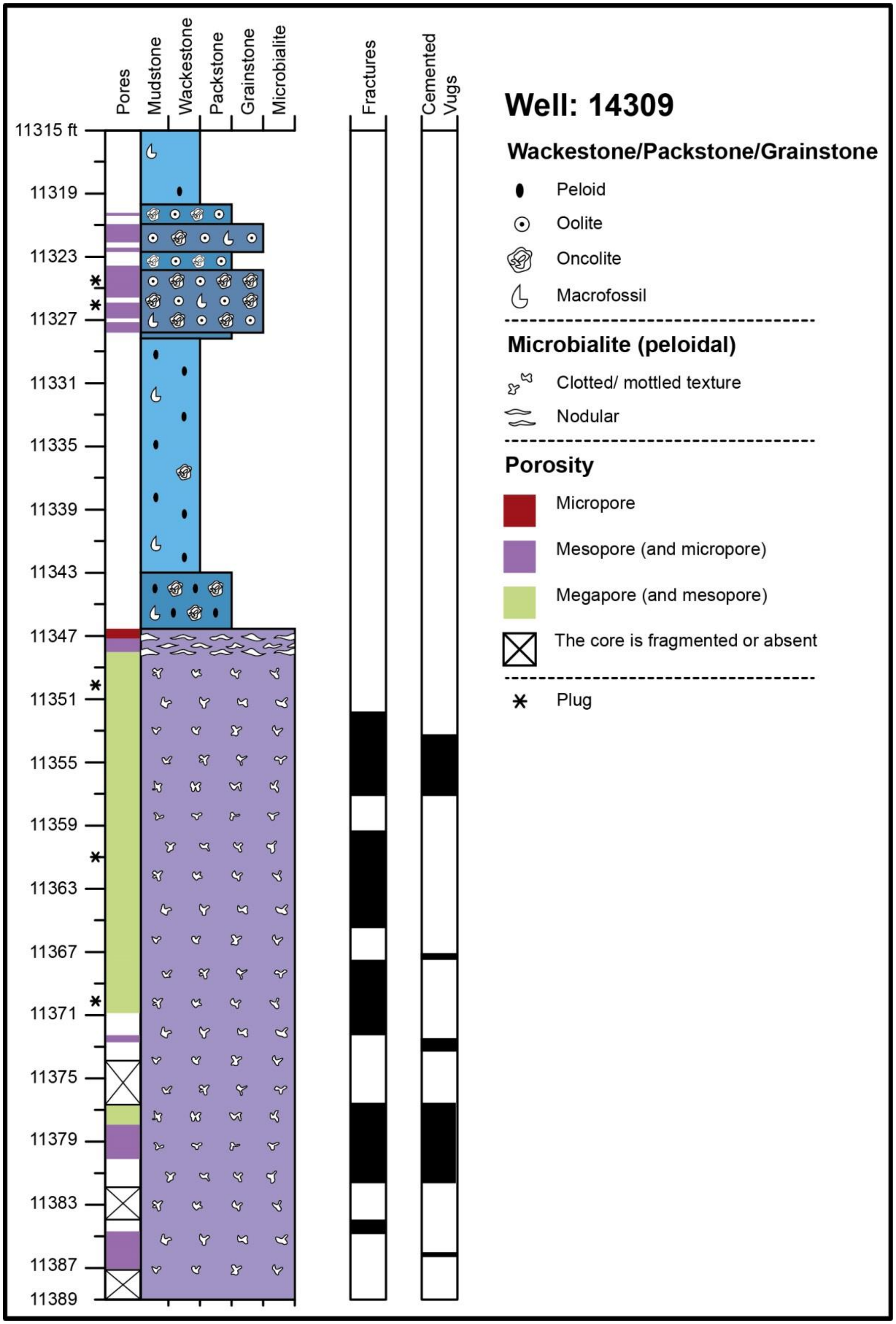

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
Well: 14069-B
11554 ft
11558
11562
11566
11570
11574
11578
11582
11586
11590
11594
11598
11602
11606
11610
11614
11618
11622
11626
11630
11634
11638
11642
11646
11650
11654
Mudstone/Wackestone
Peloid
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Oncolite
Round structures and locally brecciated aspect
Grainy aspect (reworked?)
Irregular lamination
Basement conglomerate
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug

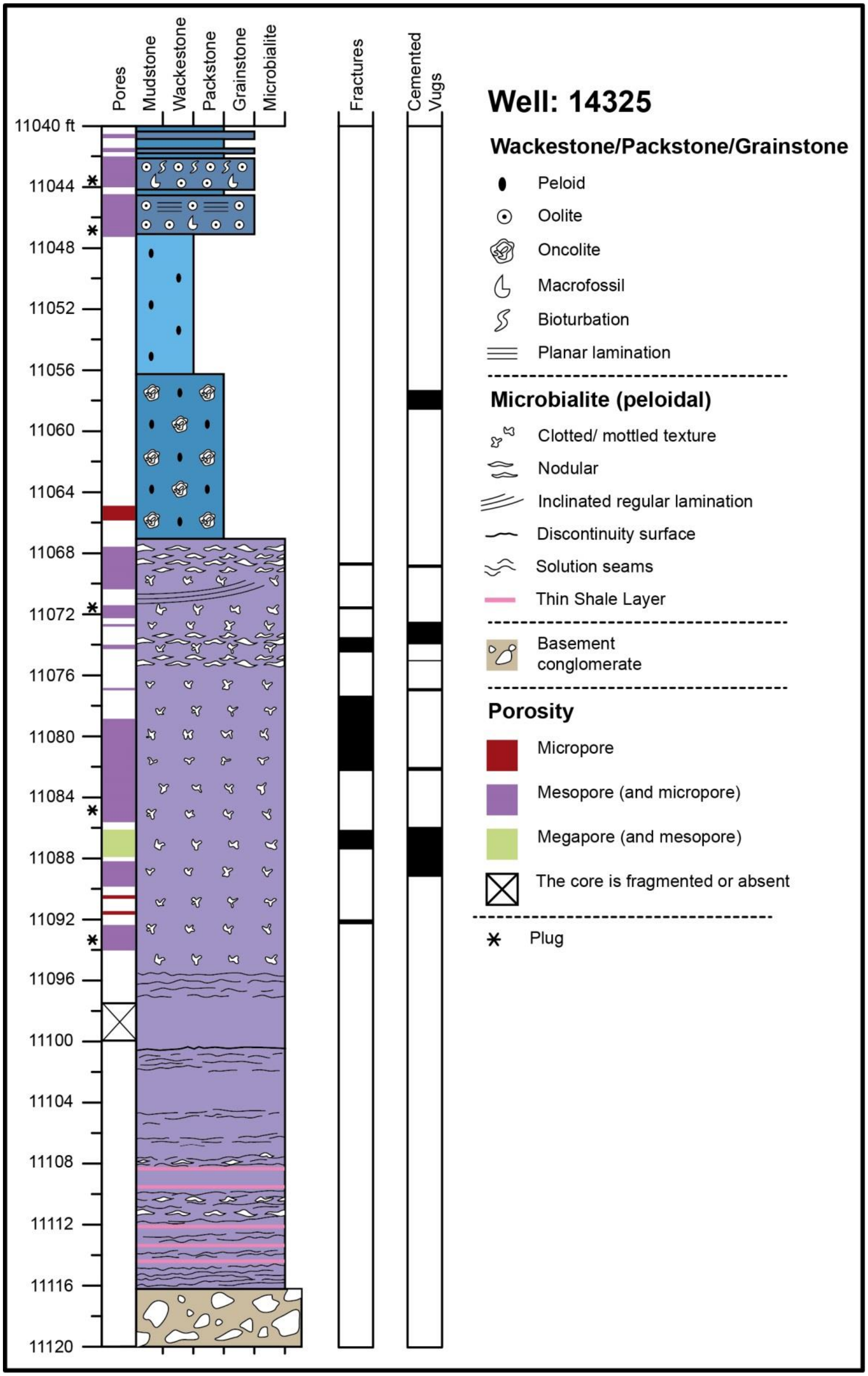


Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11265 ft
11269
11273
11277
11281
11285
11289
11293
11297
11301
11305
11309
11313
11317
11321
11324.8
Well: 14112
Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Bioturbation
Cross bedding
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Porosity
Mesopore (and micropore)
Plug

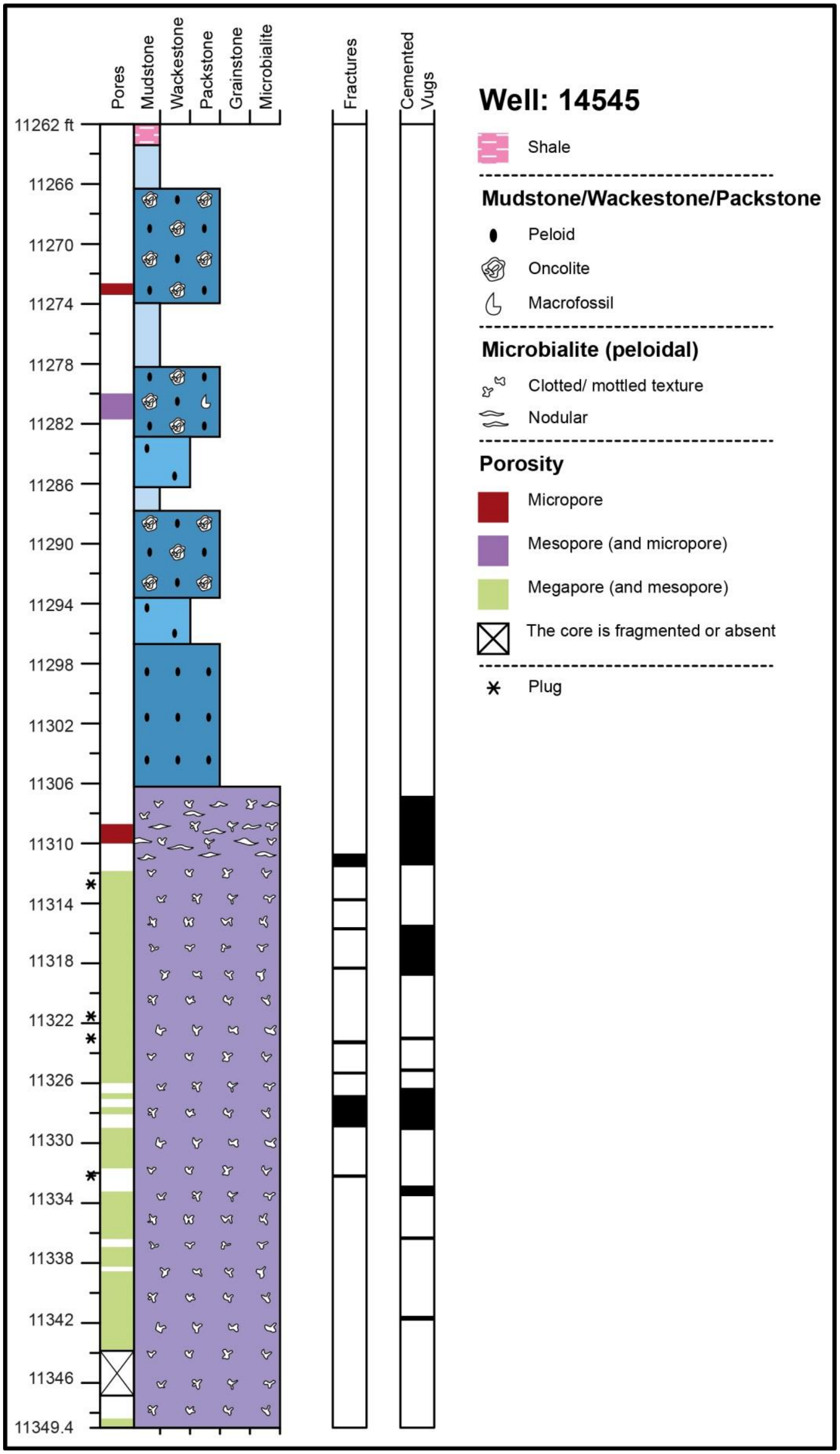

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11280 ft
11284
11288
11292
11296
11300
11304
11308
11312
11316
11320
11324
11328
11332
11334
11338
11340,8
Well: 14114
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Cross bedding
Planar lamination
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug


Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
Well: 14301-B
Mudstone/Packstone/Grainstone
Peloid
Oolite
Macrofossil
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug
11241 ft
11245
11249
11253
11257
11261
11265
11308
11273
11277
11281
11285
11289
11293
11297
11301

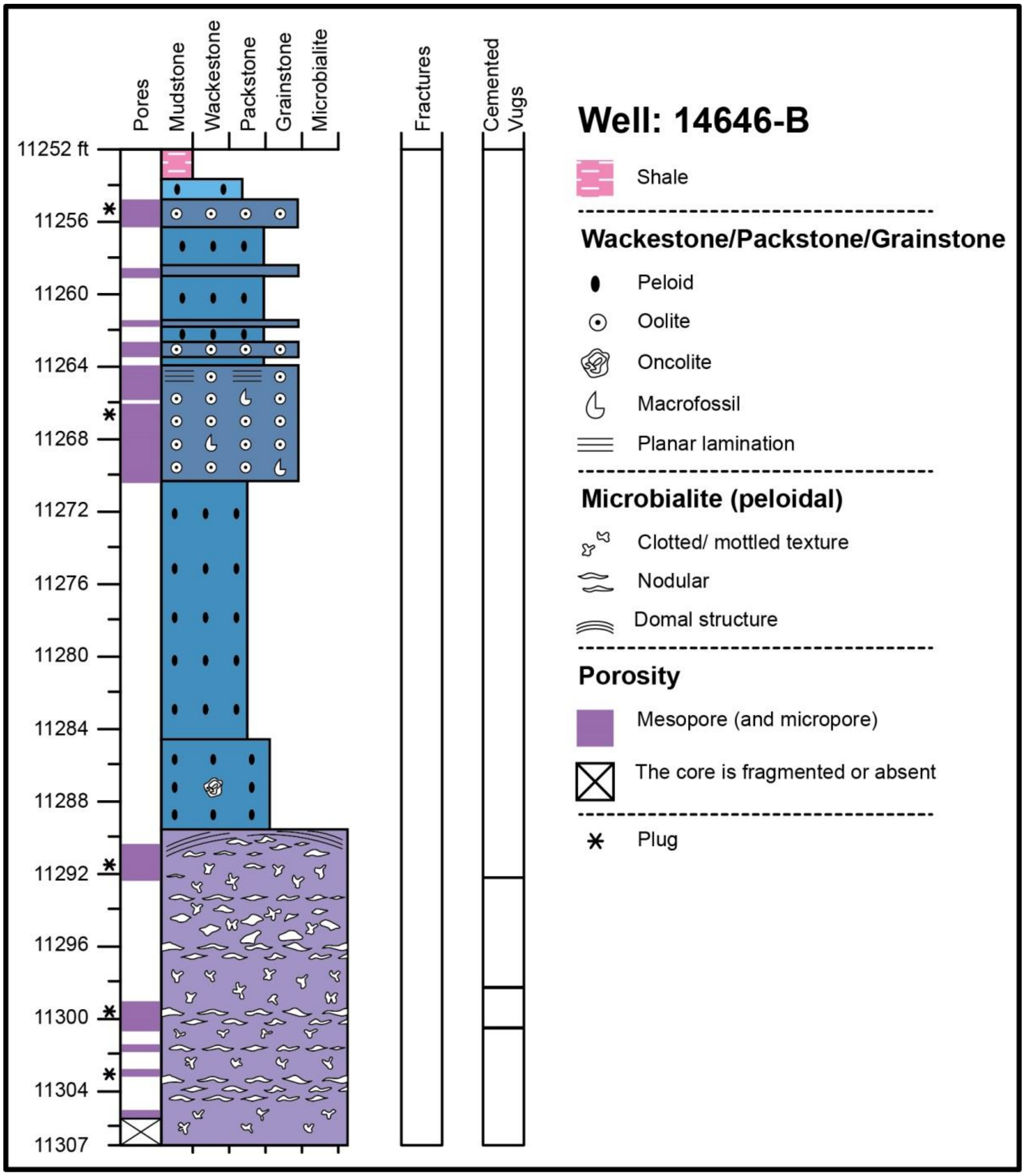

Well: 14309
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11315 ft
11319
11323
11327
11331
11335
11339
11343
11347
11351
11355
11359
11363
11367
11371
11375
11379
11383
11387
11389
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

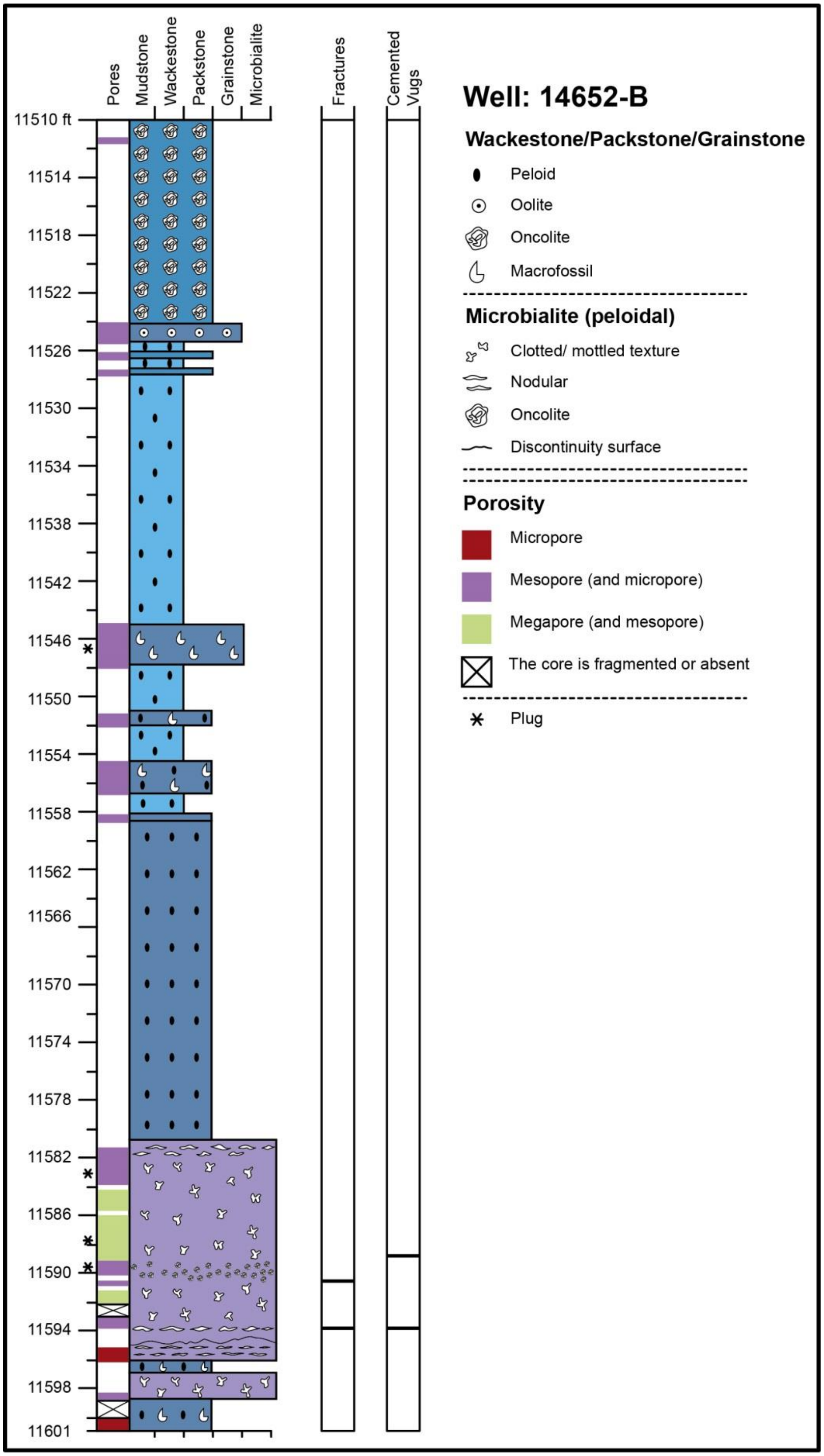


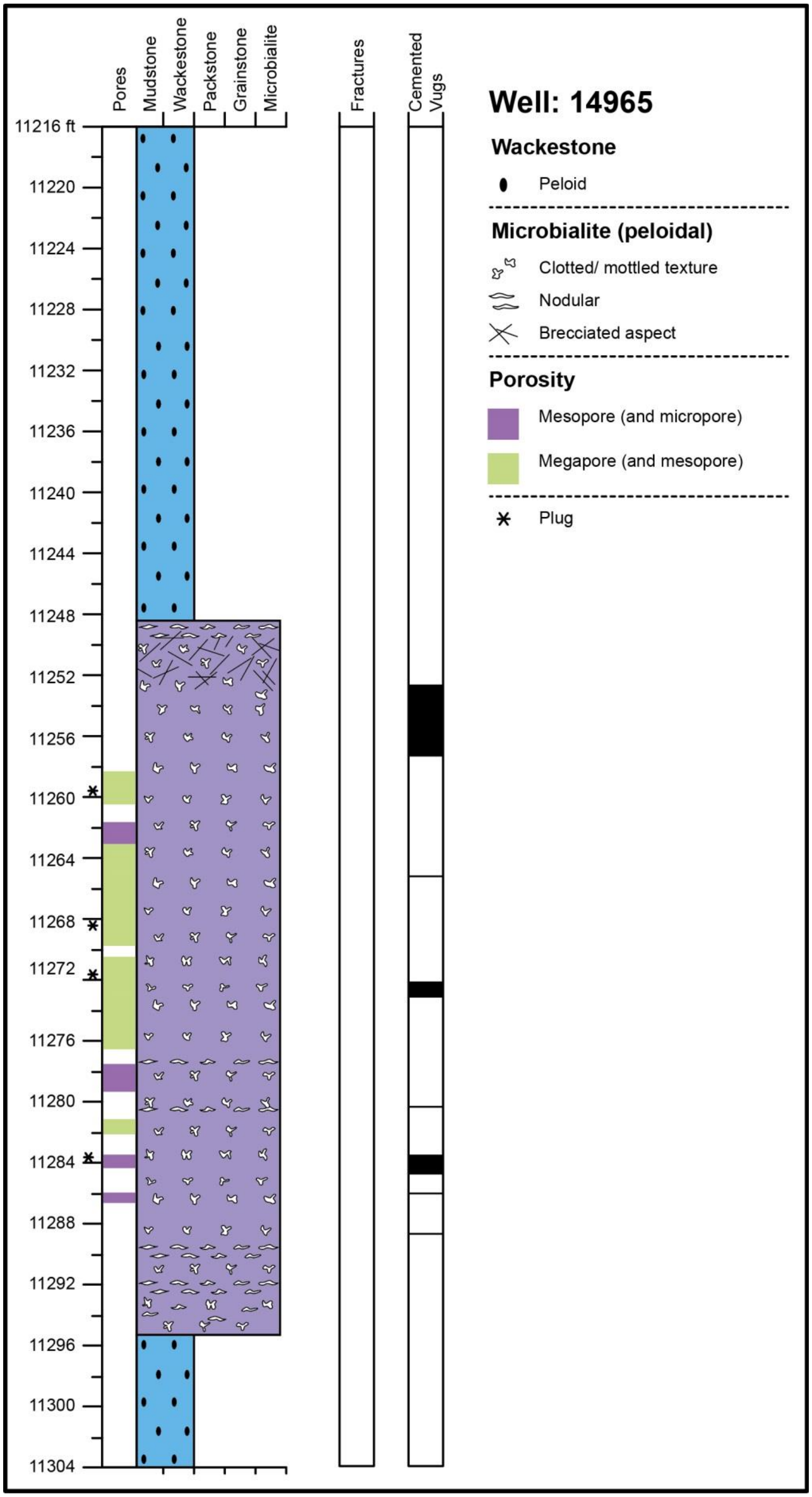
Well: 14325
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11040 ft
11044
11048
11052
11056
11060
11064
11068
11072
11076
11080
11084
11088
11092
11096
11100
11104
11108
11112
11116
11120
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Bioturbation
Planar lamination
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Inclinated regular lamination
Discontinuity surface
Solution seams
Thin Shale Layer
Basement conglomerate
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

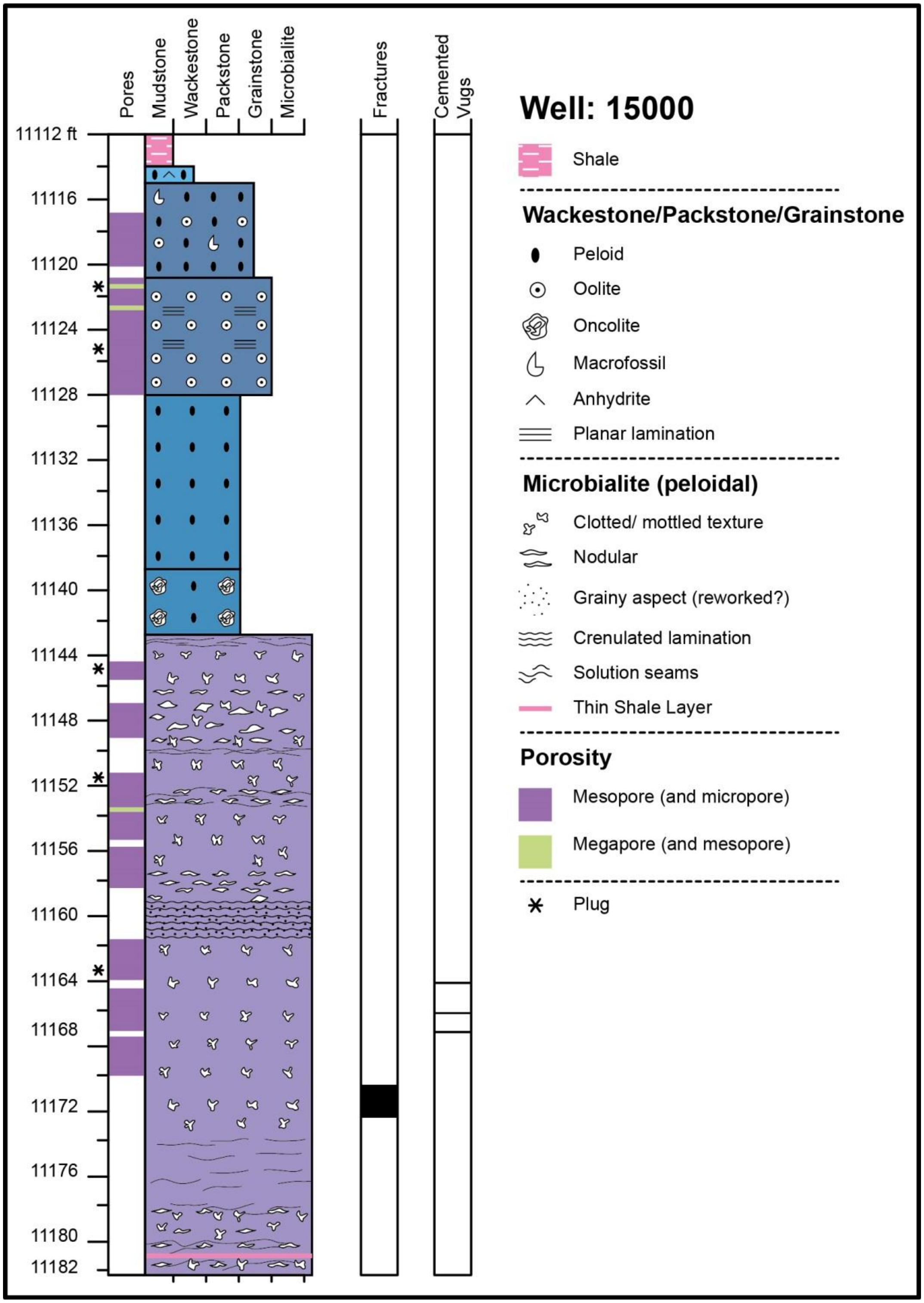


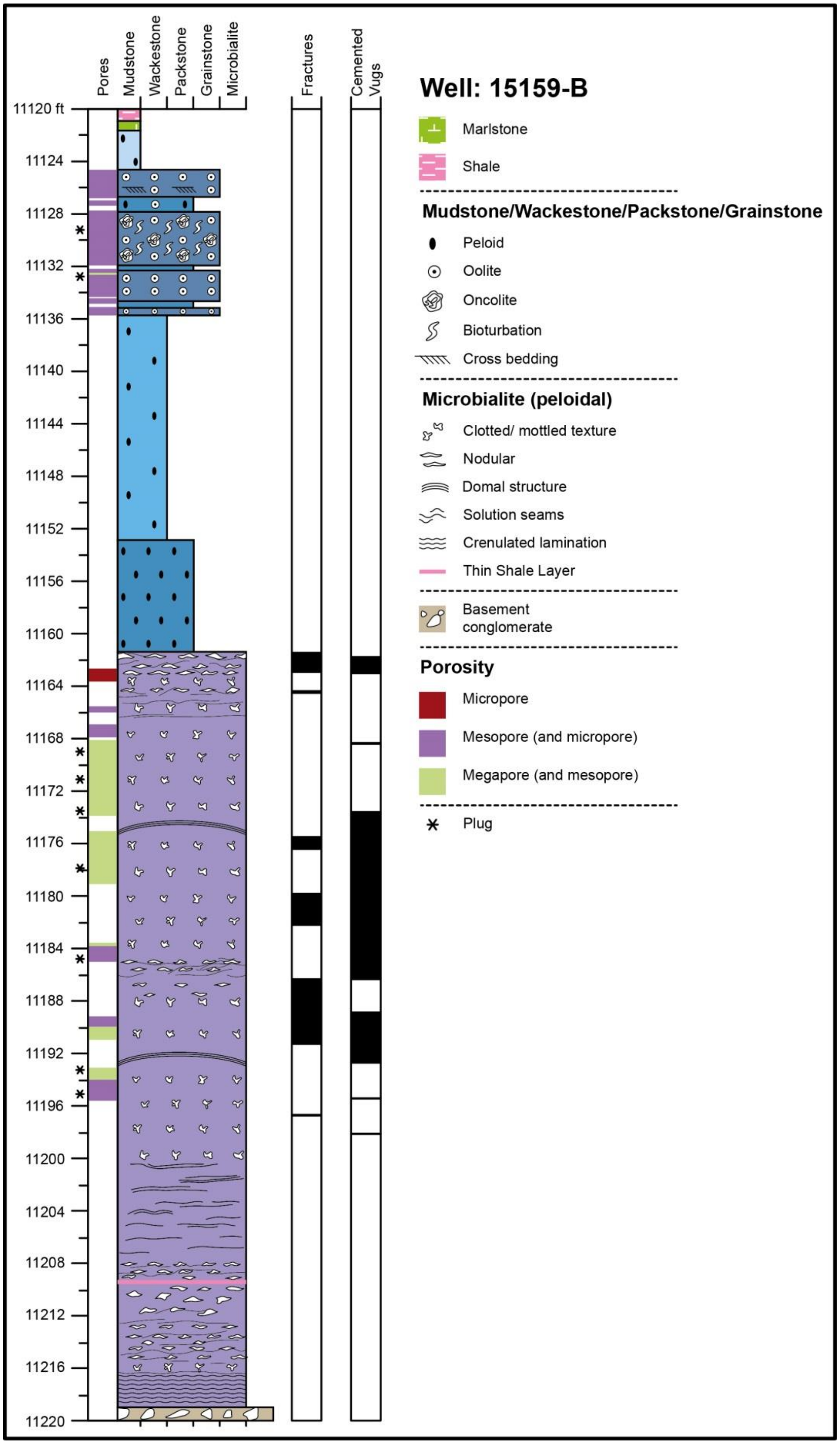
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11262 ft
11266
11270
11274
11278
11282
11286
11290
11294
11298
11302
11306
11310
11314
11318
11322
11326
11330
11334
11338
11342
11346
11349.4
Well: 14545
Shale
Mudstone/Wackestone/Packstone
Peloid
Oncolite
Macrofossil
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

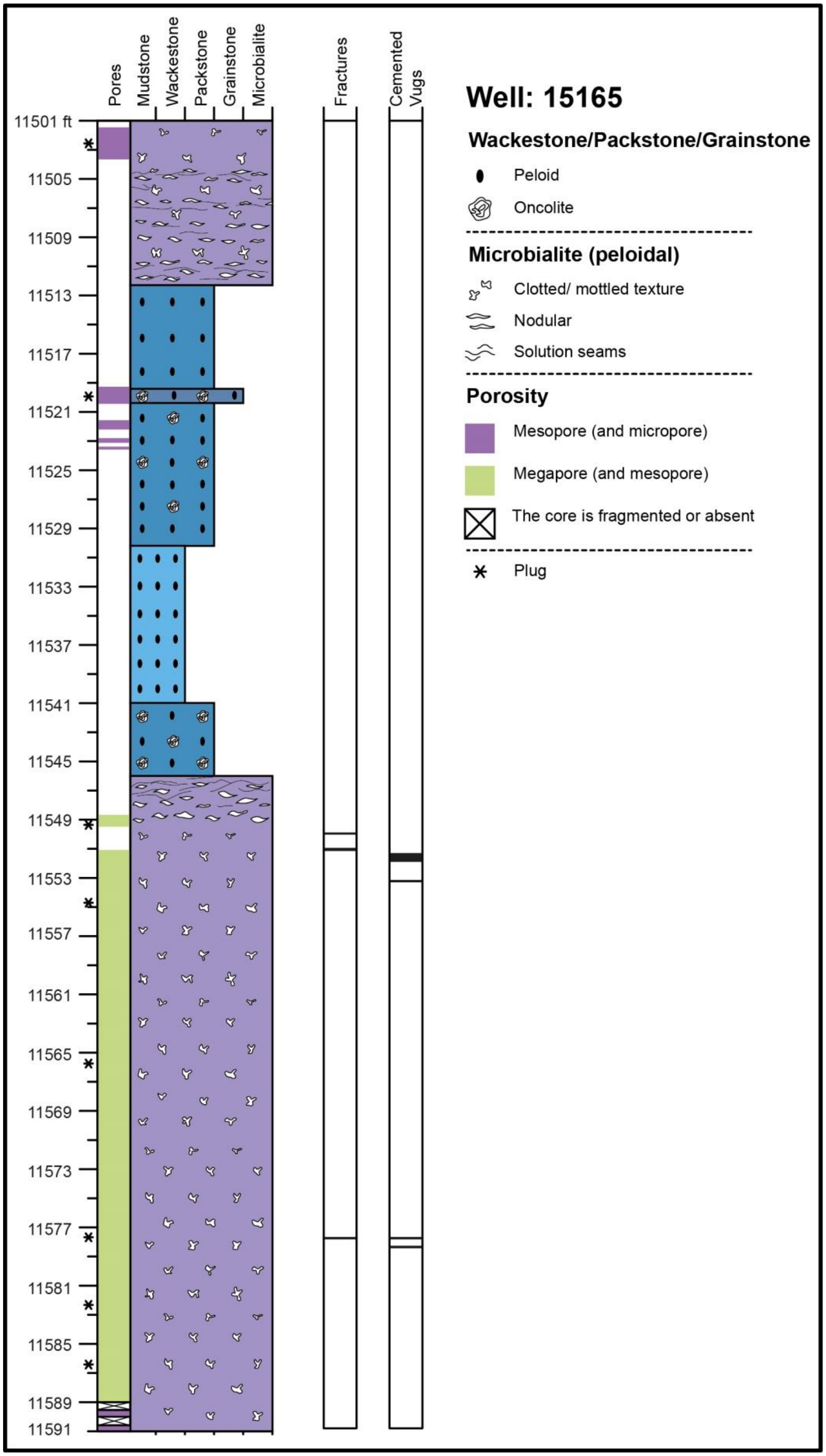

Well: 14646-B
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11252 ft
11256
11260
11264
11268
11272
11276
11280
11284
11288
11292
11296
11300
11304
11307
Shale
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Planar lamination
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Domal structure
Porosity
Mesopore (and micropore)
The core is fragmented or absent
Plug

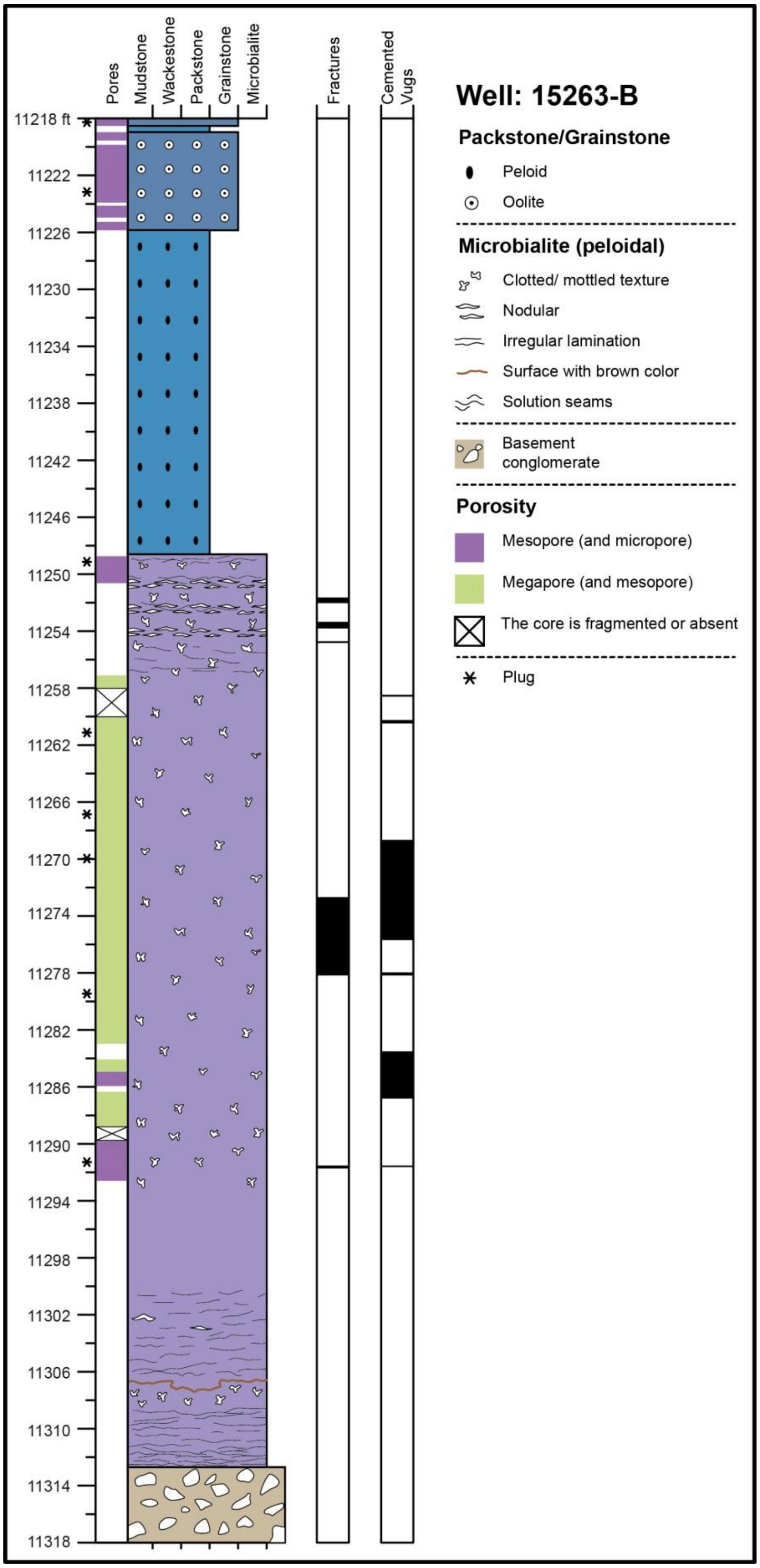

Well: 14652-B
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11510 ft
11514
11518
11522
11526
11530
11534
11538
11542
11546
11550
11554
11558
11562
11566
11570
11574
11578
11582
11586
11590
11594
11598
11601
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Oncolite
Discontinuity surface
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug


Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
Well: 14965
Wackestone
Peloid
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Brecciated aspect
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug
11216 ft
11220
11224
11228
11232
11236
11240
11244
11248
11252
11256
11260
11264
11268
11272
11276
11280
11284
11288
11292
11296
11300
11304

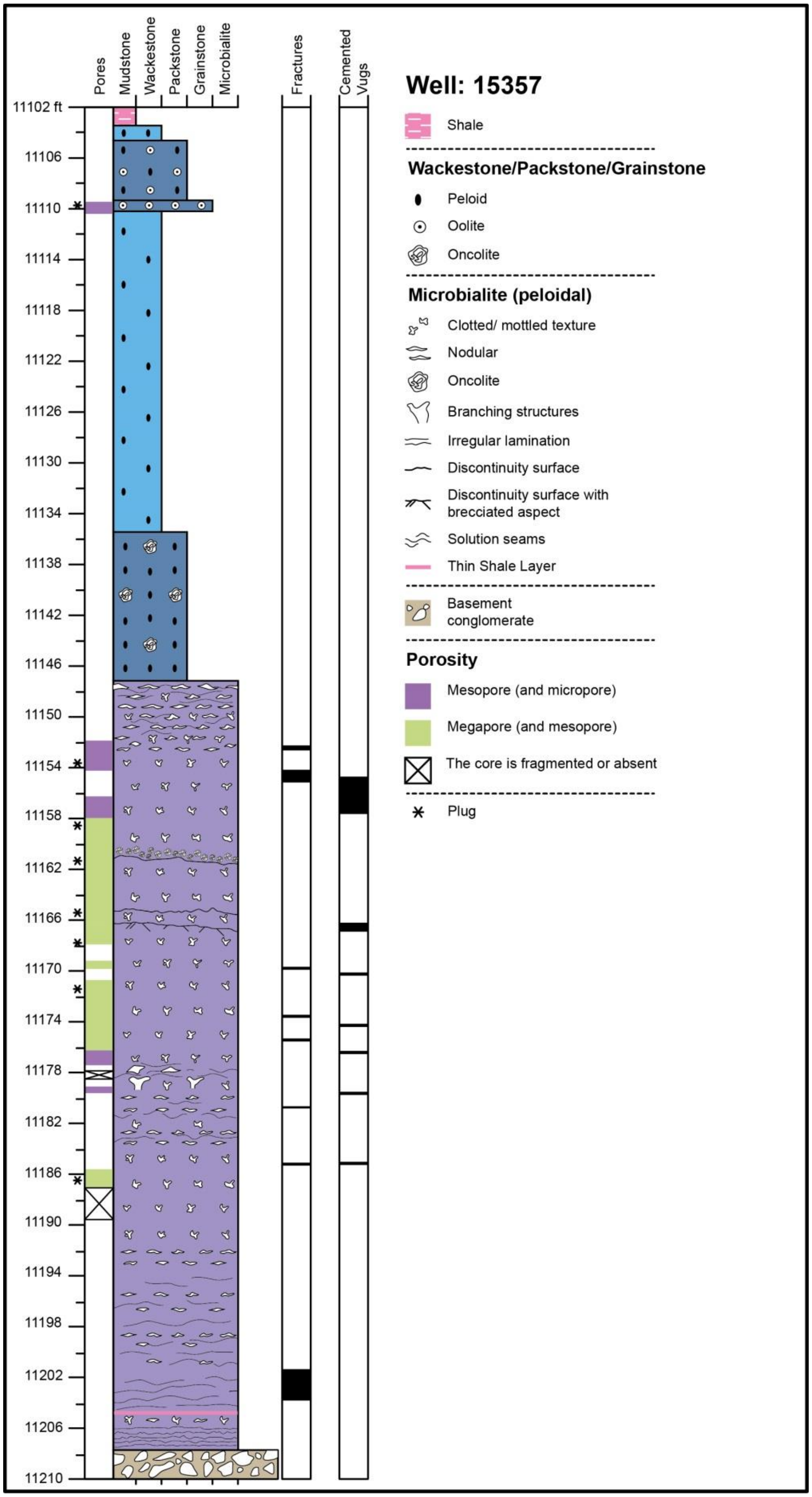

Well: 15000
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11112 ft
11116
11120
11124
11128
11132
11136
11140
11144
11148
11152
11156
11160
11164
11168
11172
11176
11180
11182
Shale
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Anhydrite
Planar lamination
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Grainy aspect (reworked?)
Crenulated lamination
Solution seams
Thin Shale Layer
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug

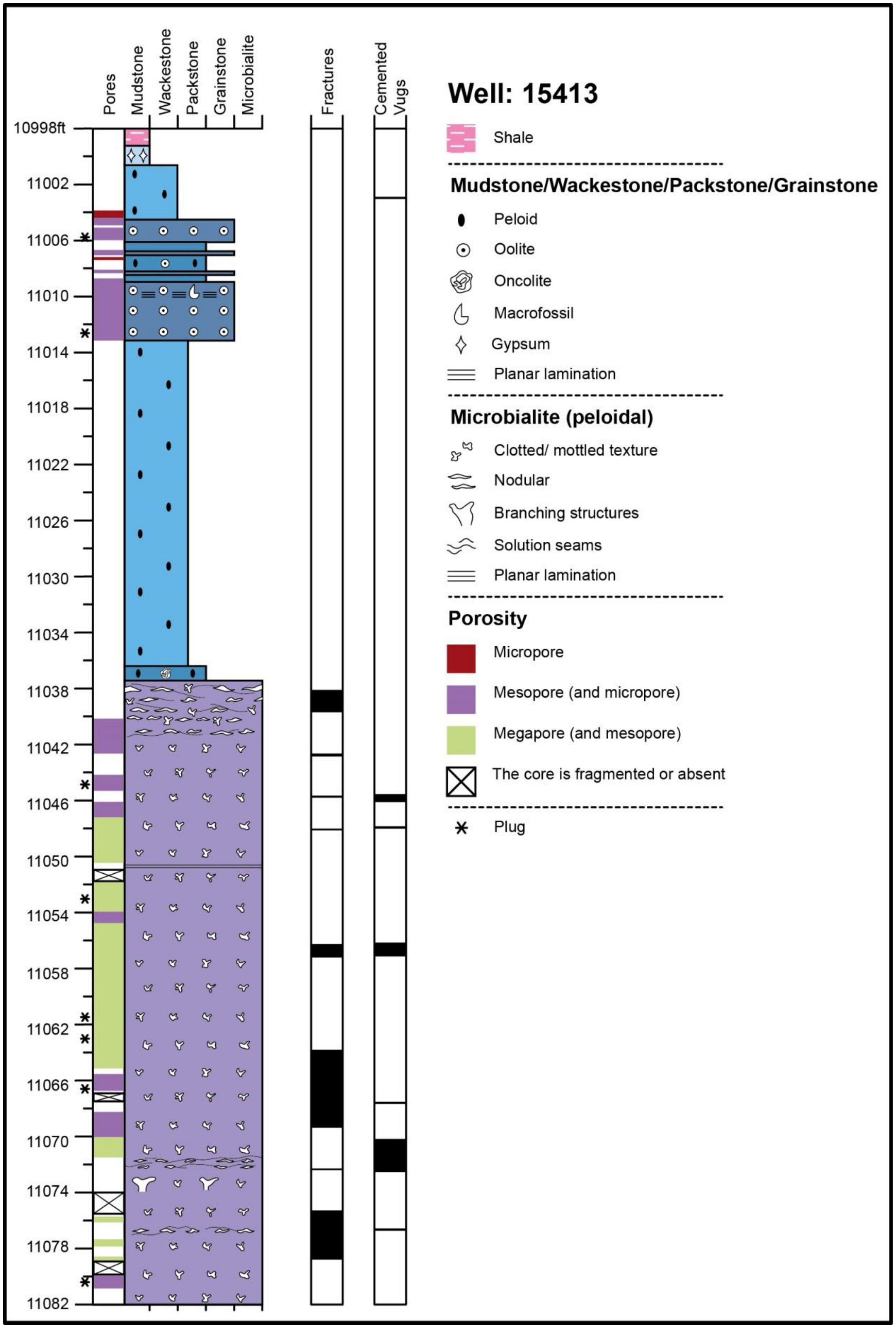

Well: 15159-B
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11120 ft
11124
11128
11132
11136
11140
11144
11148
11152
11156
11160
11164
11168
11172
11176
11180
11184
11188
11192
11196
11200
11204
11208
11212
11216
11220
Marlstone
Shale
Mudstone/Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Bioturbation
Cross bedding
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Domal structure
Solution seams
Crenulated lamination
Thin Shale Layer
Basement conglomerate
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
Plug

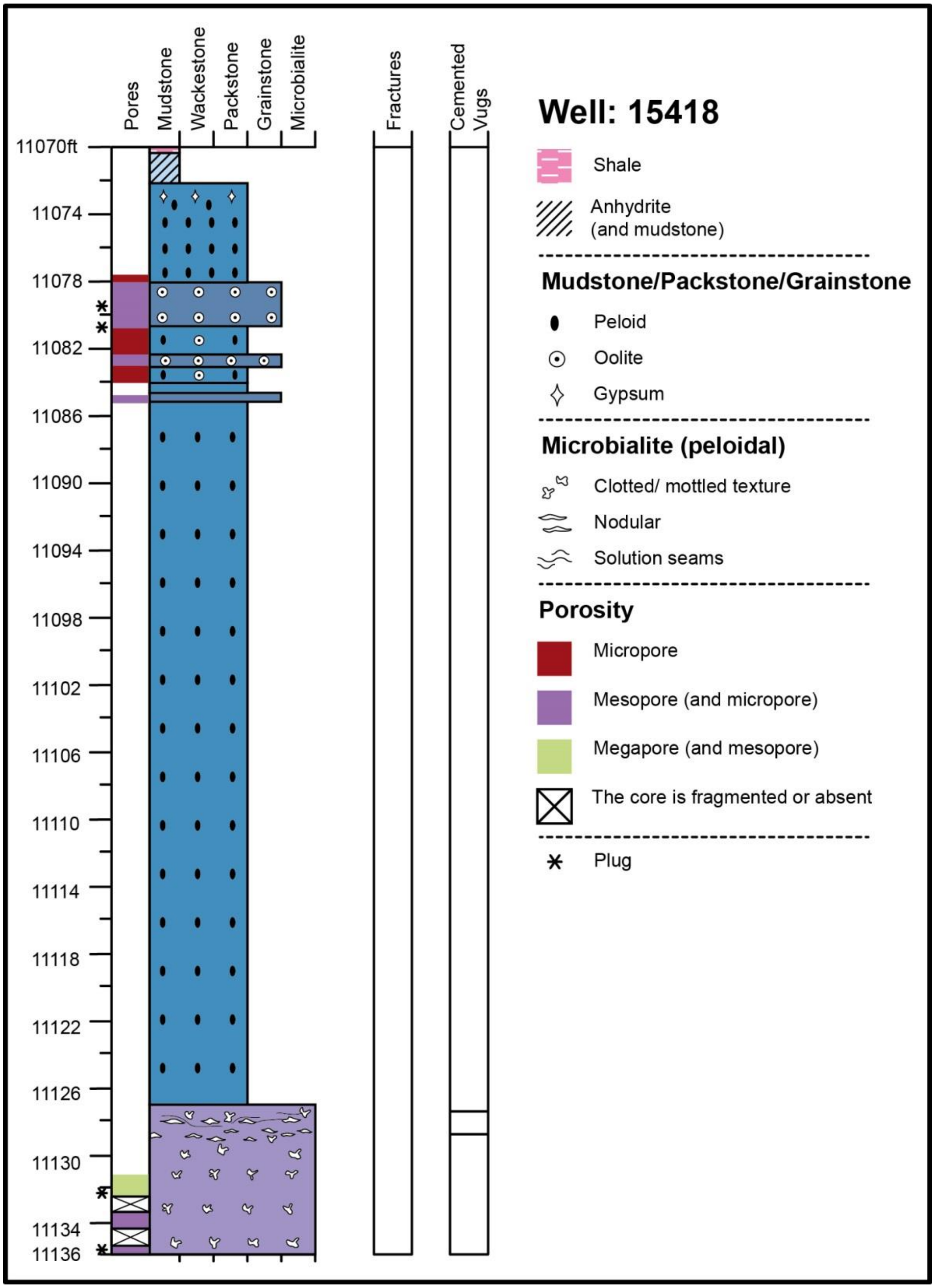

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11501 ft
11505
11509
11513
11517
11521
11525
11529
11533
11537
11541
11545
11549
11553
11557
11561
11565
11569
11573
11577
11581
11585
11589
11591
Well: 15165
Wackestone/Packstone/Grainstone
Peloid
Oncolite
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Solution seams
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

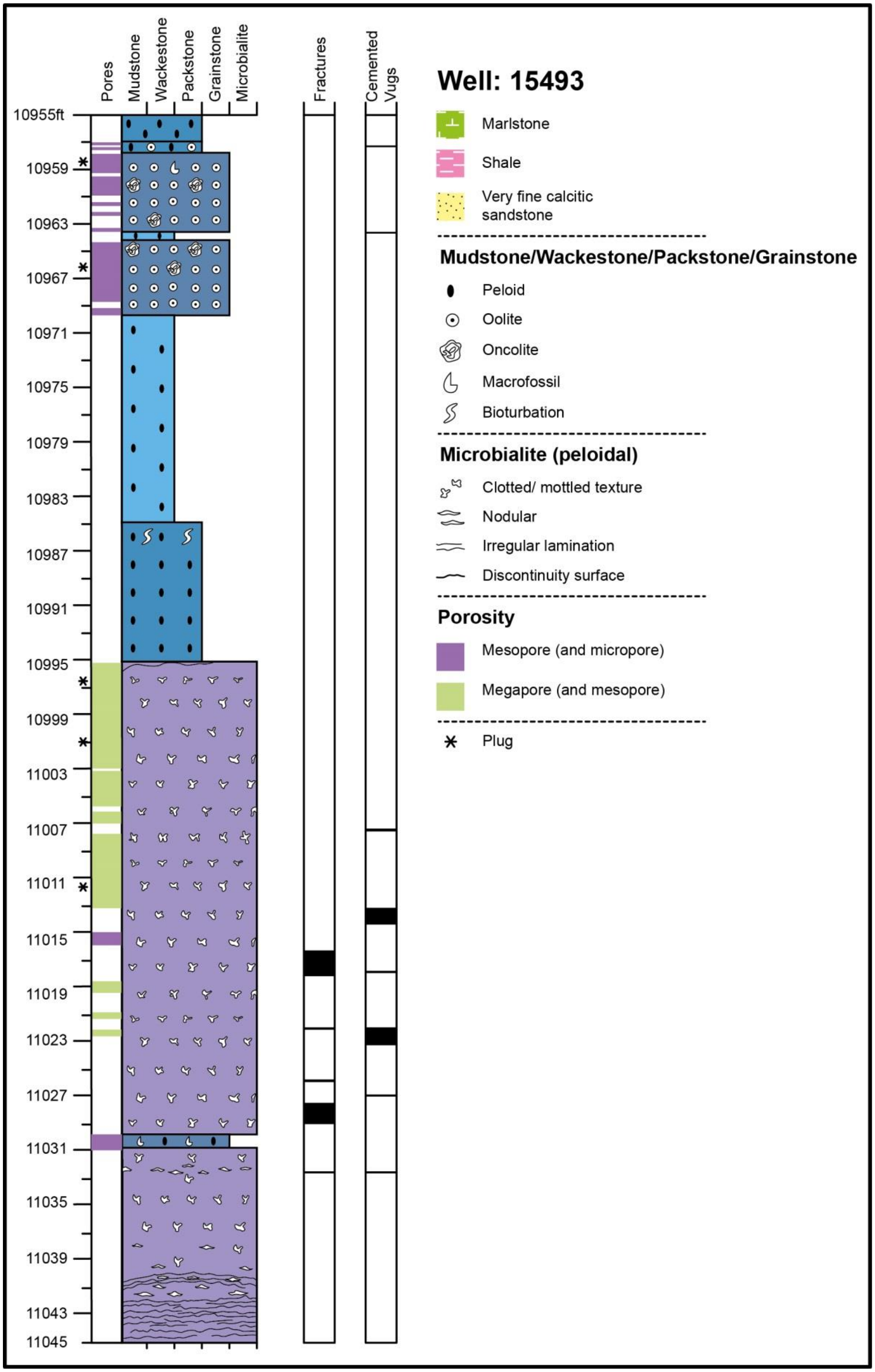


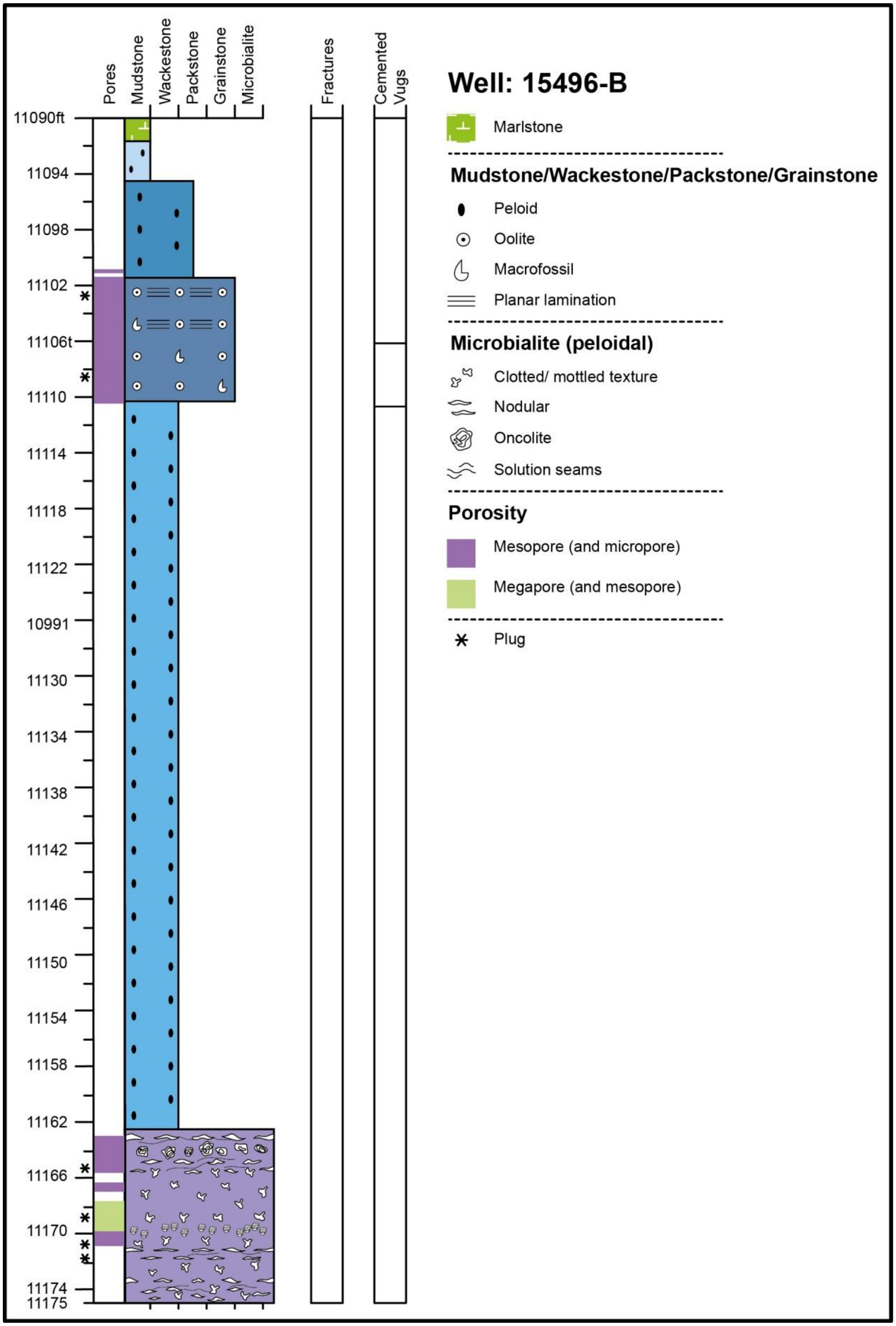
Well: 15263-B
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11218 ft
11222
11226
11230
11234
11238
11242
11246
11250
11254
11258
11262
11266
11270
11274
11278
11282
11286
11290
11294
11298
11302
11306
11310
11314
11318
Packstone/Grainstone
Peloid
Oolite
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Irregular lamination
Surface with brown color
Solution seams
Basement conglomerate
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

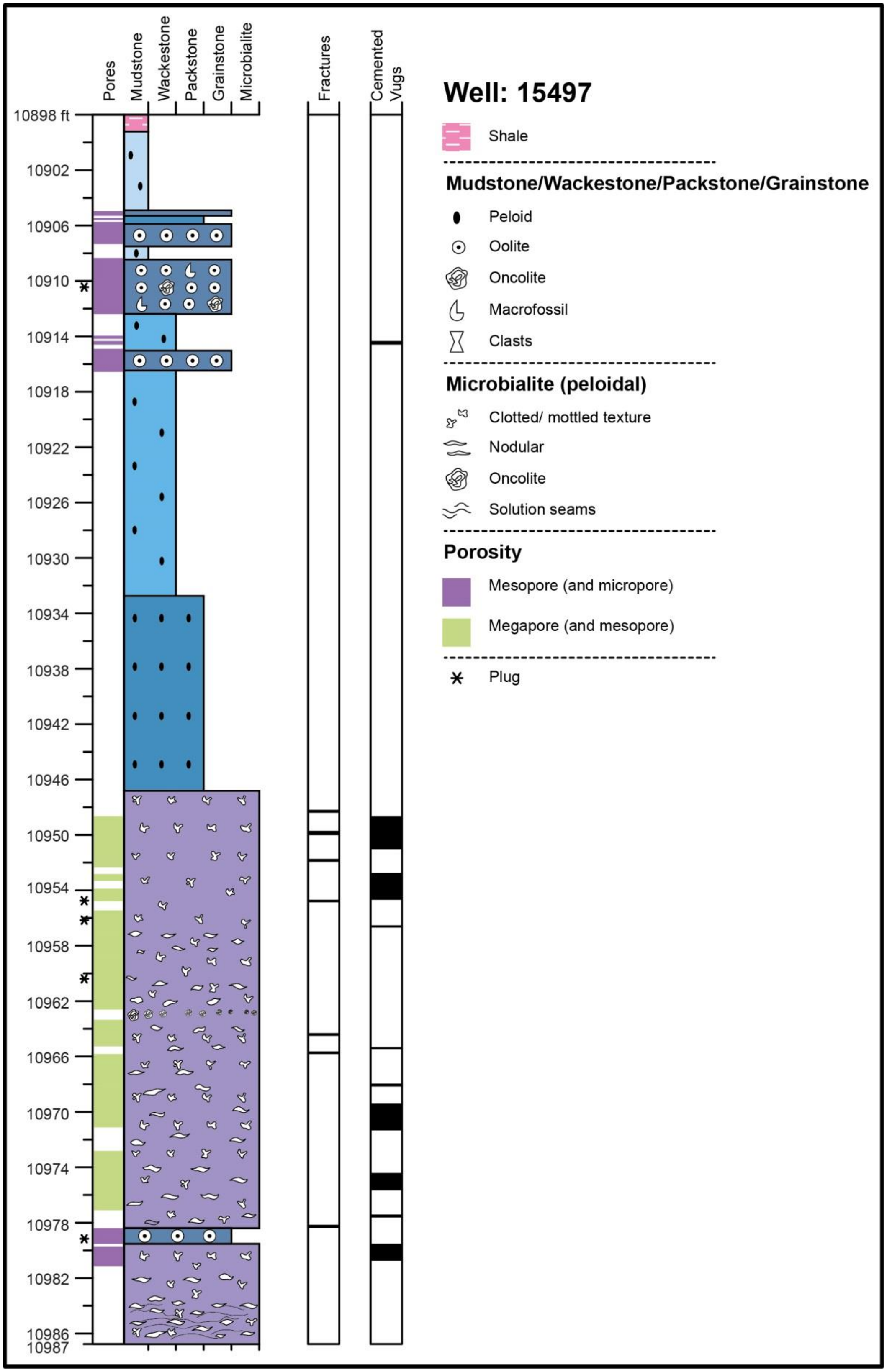

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
Well: 15357
11102 ft
11106
11110
11114
11118
11122
11126
11130
11134
11138
11142
11146
11150
11154
11158
11162
11166
11170
11174
11178
11182
11186
11190
11194
11198
11202
11206
11210
Shale
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Oncolite
Branching structures
Irregular lamination
Discontinuity surface
Discontinuity surface with brecciated aspect
Solution seams
Thin Shale Layer
Basement conglomerate
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

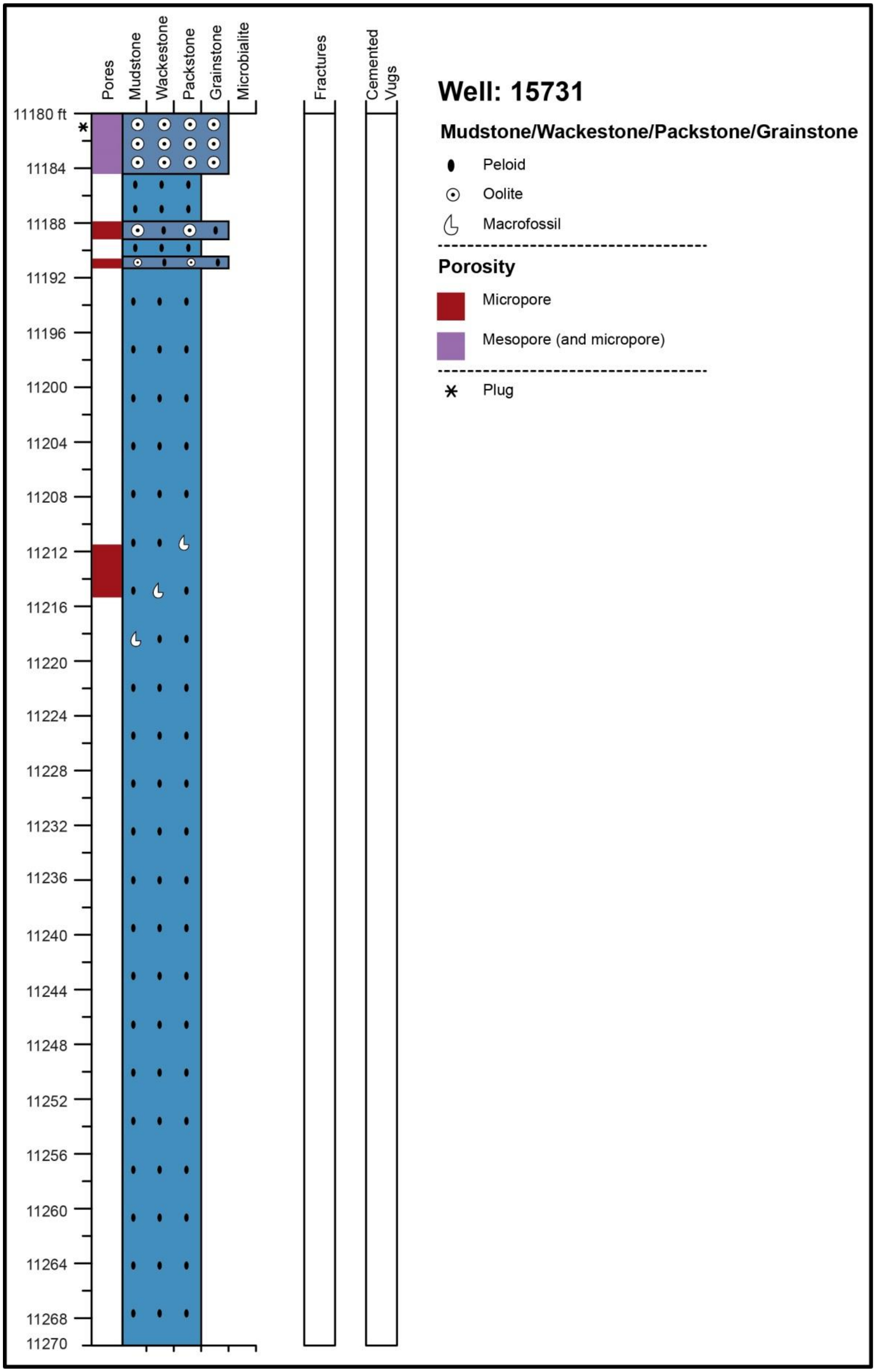

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
10998ft
11002
11006
11010
11014
11018
11022
11026
11030
11034
11038
11042
11046
11050
11054
11058
11062
11066
11070
11074
11078
11082
Well: 15413
Shale
Mudstone/Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Gypsum
Planar lamination
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Branching structures
Solution seams
Planar lamination
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

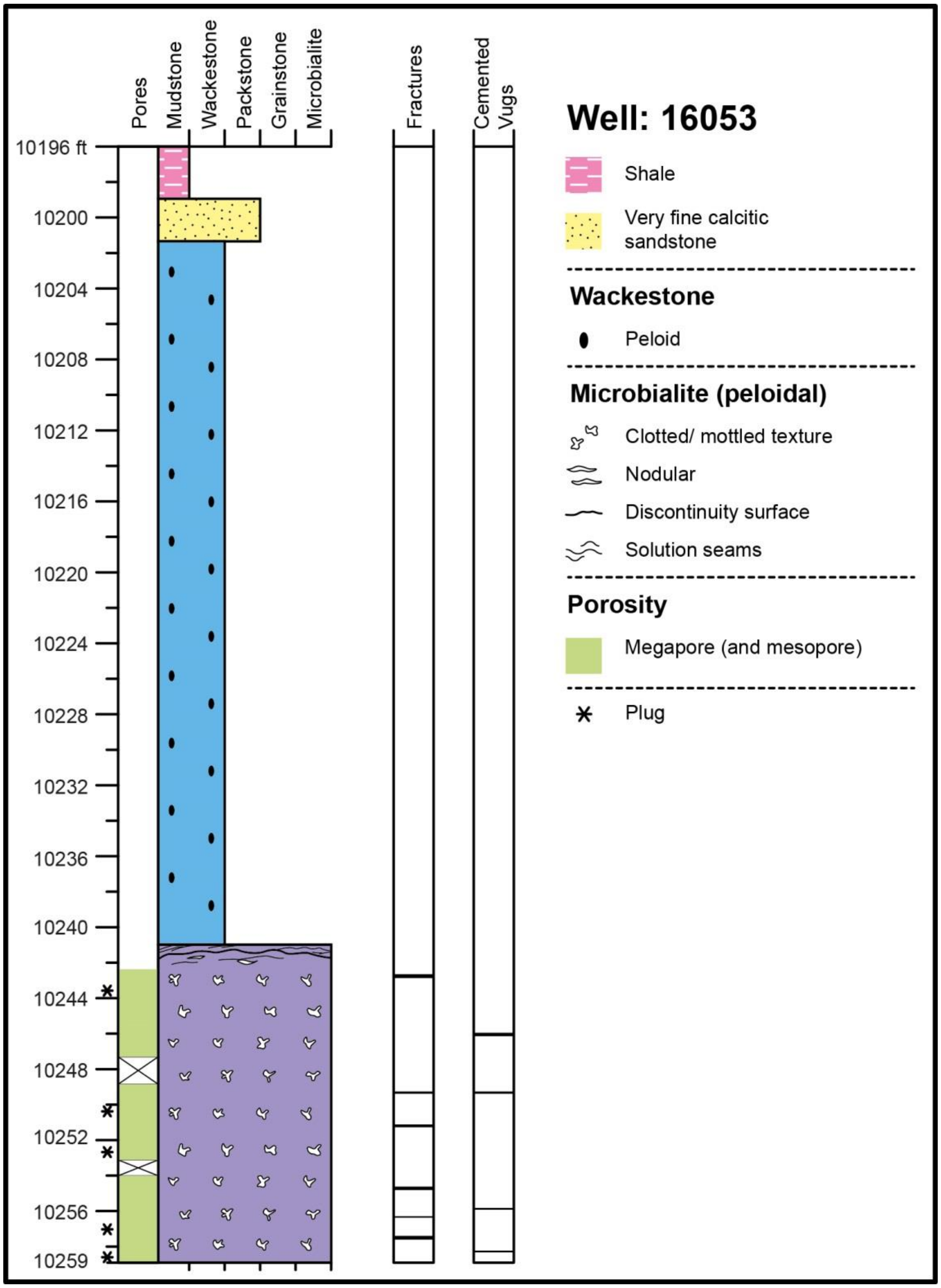

Well: 15418
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11070ft
11074
11078
11082
11086
11090
11094
11098
11102
11106
11110
11114
11118
11122
11126
11130
11134
11136
Shale
Anhydrite (and mudstone)
Mudstone/Packstone/Grainstone
Peloid
Oolite
Gypsum
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Solution seams
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

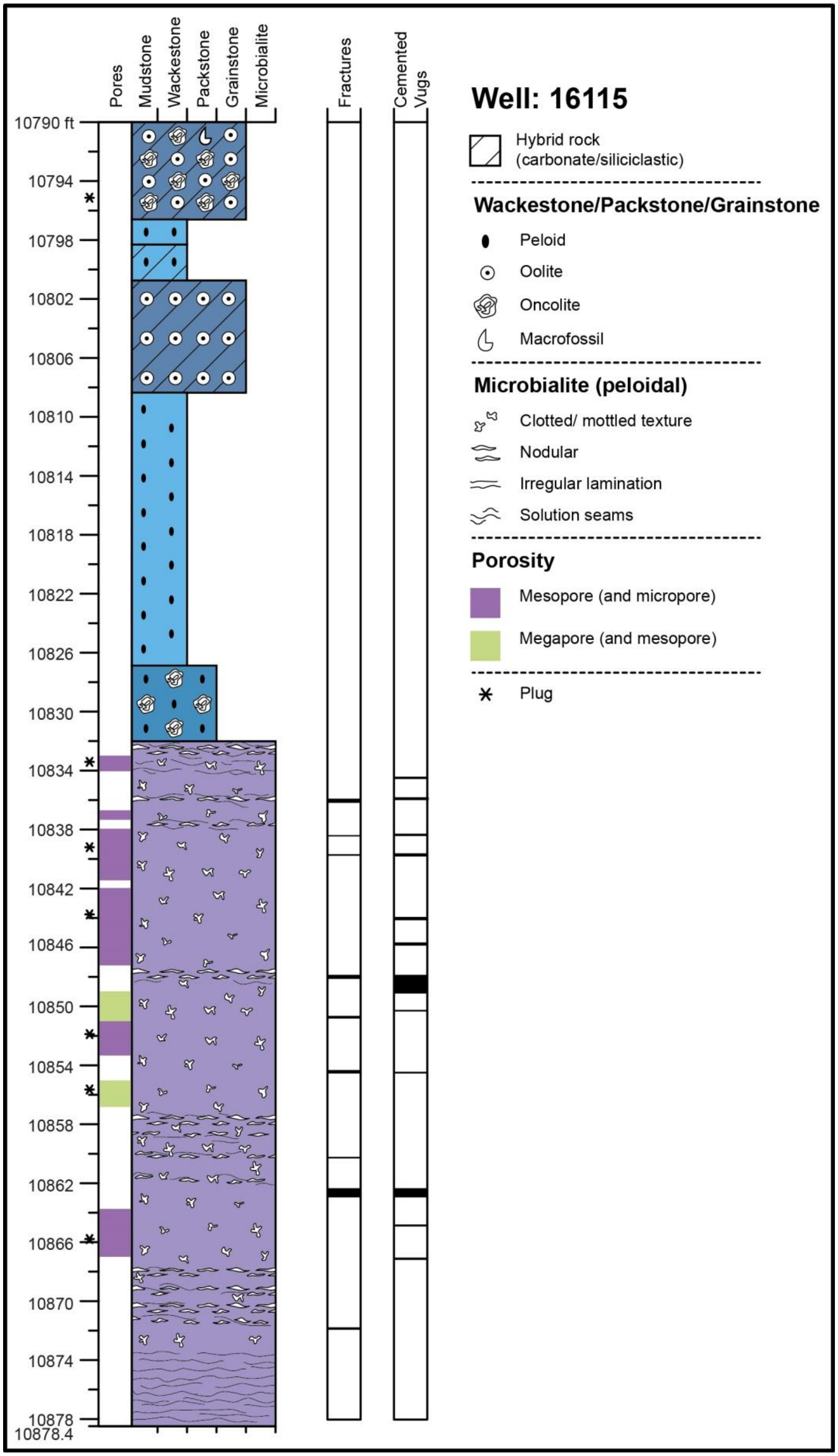

Well: 15493
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
10955ft
10959
10963
10967
10971
10975
10979
10983
10987
10991
10995
10999
11003
11007
11011
11015
11019
11023
11027
11031
11035
11039
11043
11045
Marlstone
Shale
Very fine calcitic sandstone
Mudstone/Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Bioturbation
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Irregular lamination
Discontinuity surface
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug


Well: 15496-B
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11090ft
11094
11098
11102
11106t
11110
11114
11118
11122
10991
11130
11134
11138
11142
11146
11150
11154
11158
11162
11166
11170
11174
11175
Marlstone
Mudstone/Wackestone/Packstone/Grainstone
Peloid
Oolite
Macrofossil
Planar lamination
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Oncolite
Solution seams
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug

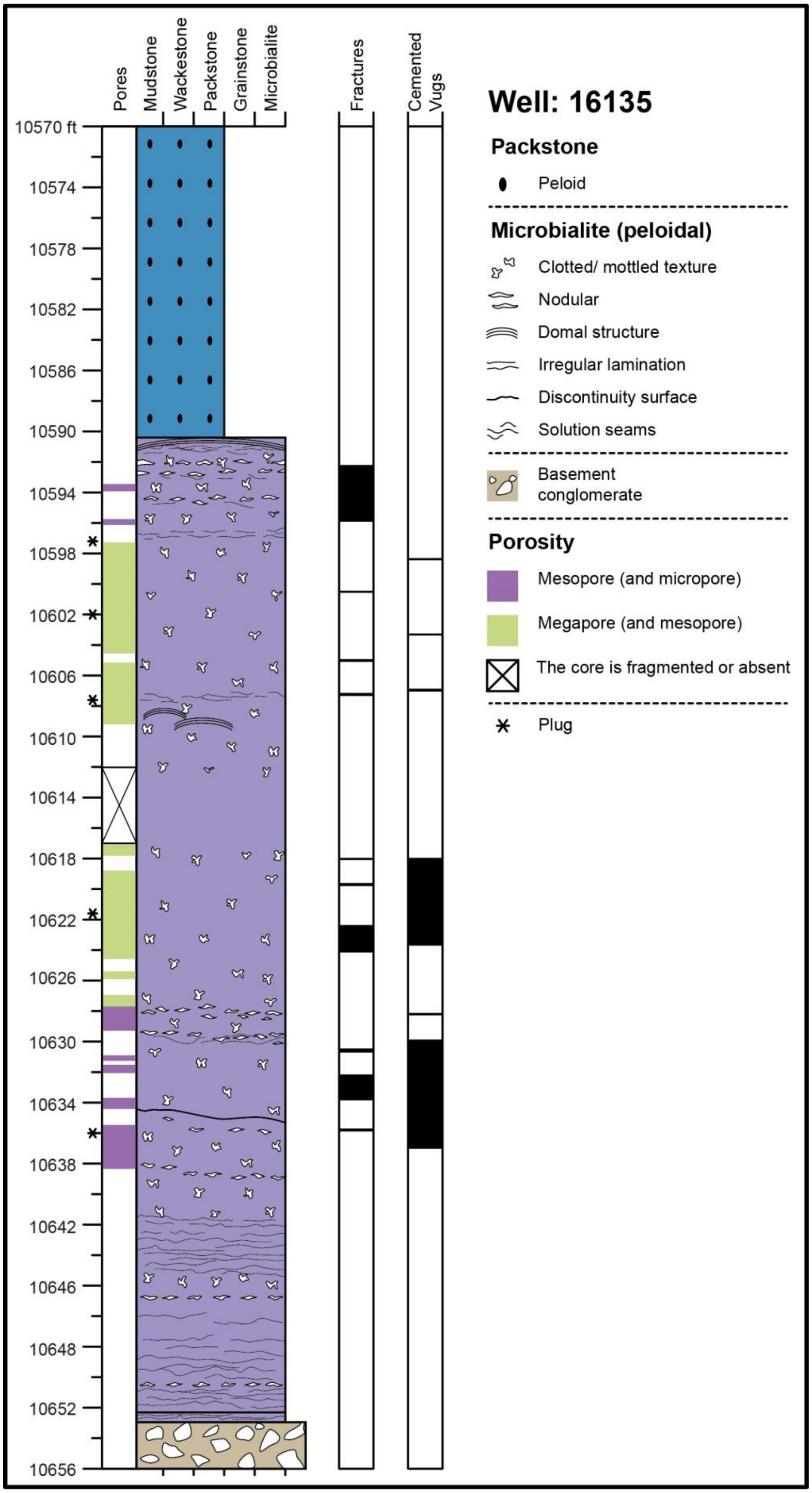

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
10898 ft
10902
10906
10910
10914
10918
10922
10926
10930
10934
10938
10942
10946
10950
10954
10958
10962
10966
10970
10974
10978
10982
10986
10987
Well: 15497
Shale
Mudstone/Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Clasts
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Oncolite
Solution seams
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug


Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
11180 ft
11184
11188
11192
11196
11200
11204
11208
11212
11216
11220
11224
11228
11232
11236
11240
11244
11248
11252
11256
11260
11264
11268
11270
Well: 15731
Mudstone/Wackestone/Packstone/Grainstone
Peloid
Oolite
Macrofossil
Porosity
Micropore
Mesopore (and micropore)
Plug

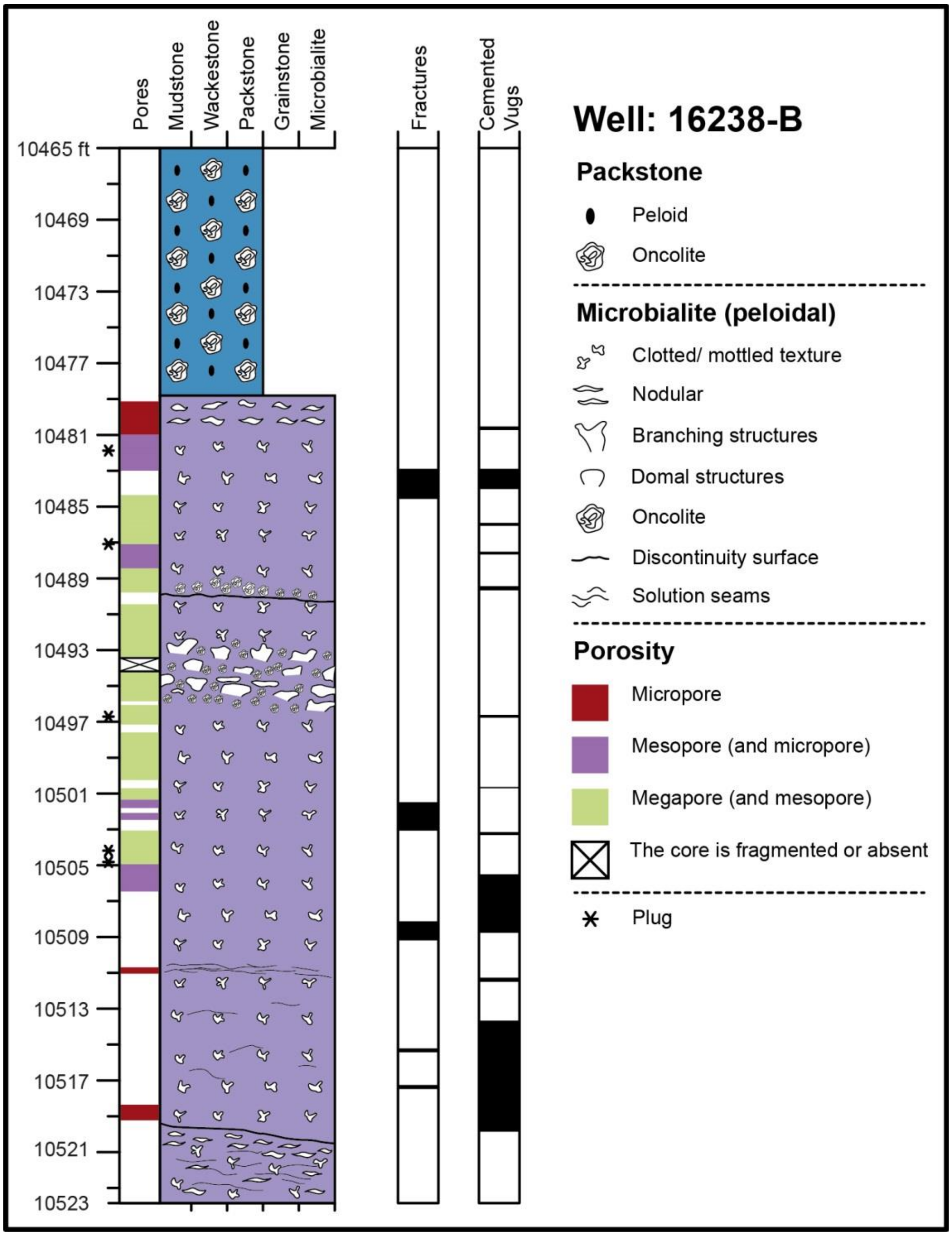

Well: 16053
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
10196 ft
10200
10204
10208
10212
10216
10220
10224
10228
10232
10236
10240
10244
10248
10252
10256
10259
Shale
Very fine calcitic sandstone
Wackestone
Peloid
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Discontinuity surface
Solution seams
Porosity
Megapore (and mesopore)
Plug

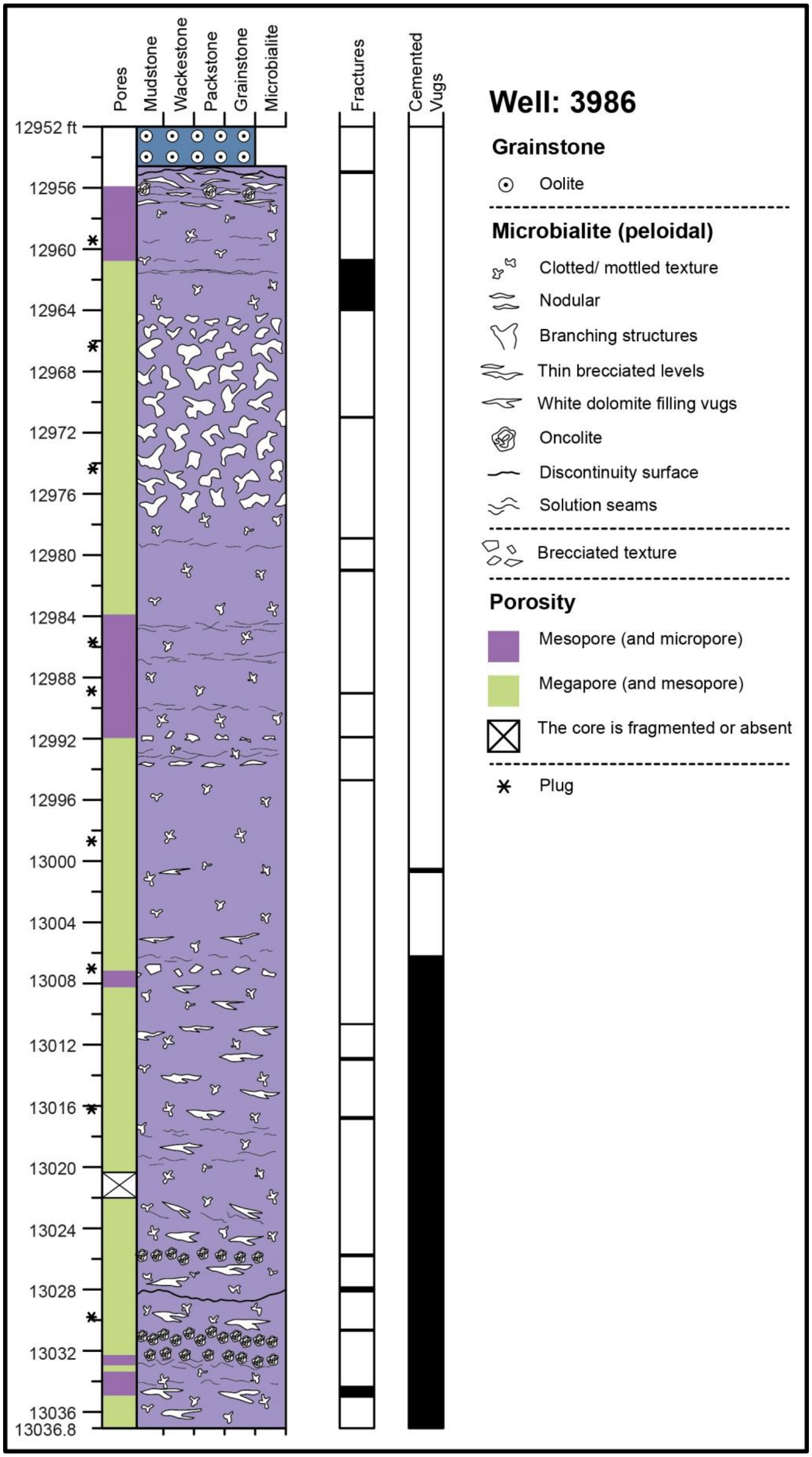


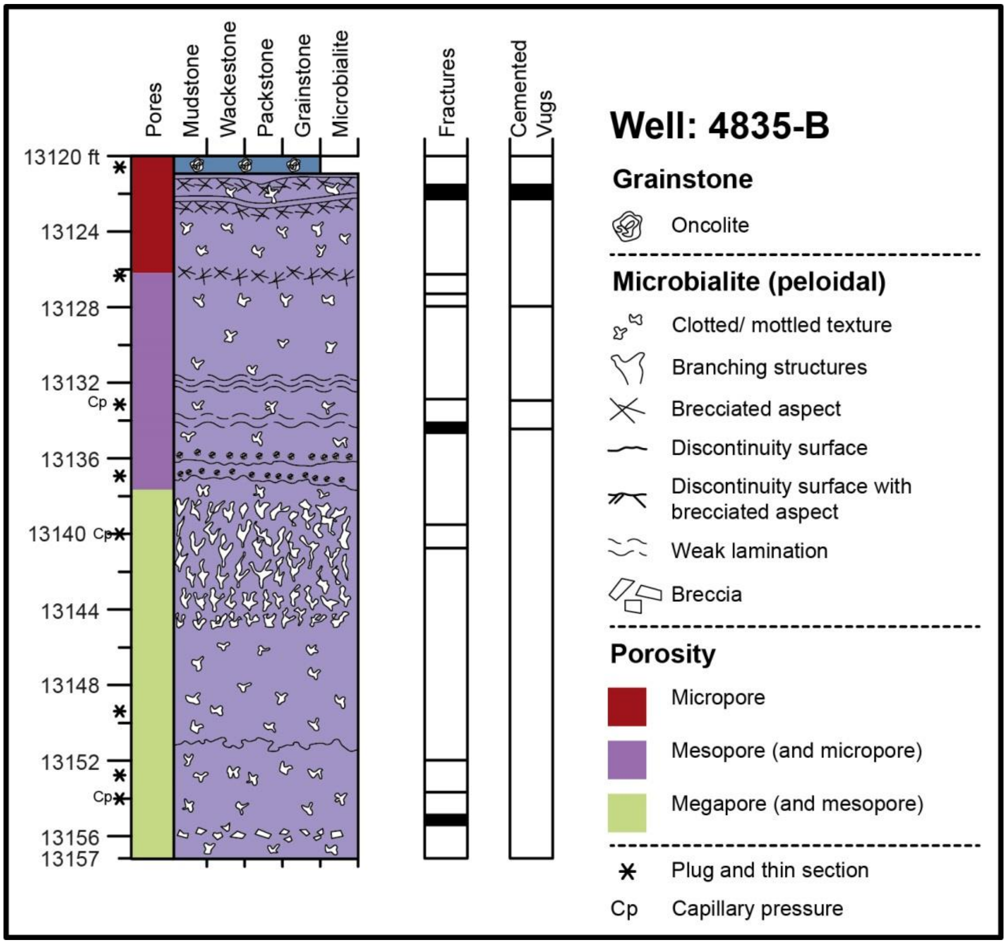
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
Well: 16115
Hybrid rock (carbonate/siliciclastic)
Wackestone/Packstone/Grainstone
Peloid
Oolite
Oncolite
Macrofossil
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Irregular lamination
Solution seams
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
Plug
10790 ft
10794
10798
10802
10806
10810
10814
10818
10822
10826
10830
10834
10838
10842
10846
10850
10854
10858
10862
10866
10870
10874
10878
10878.4

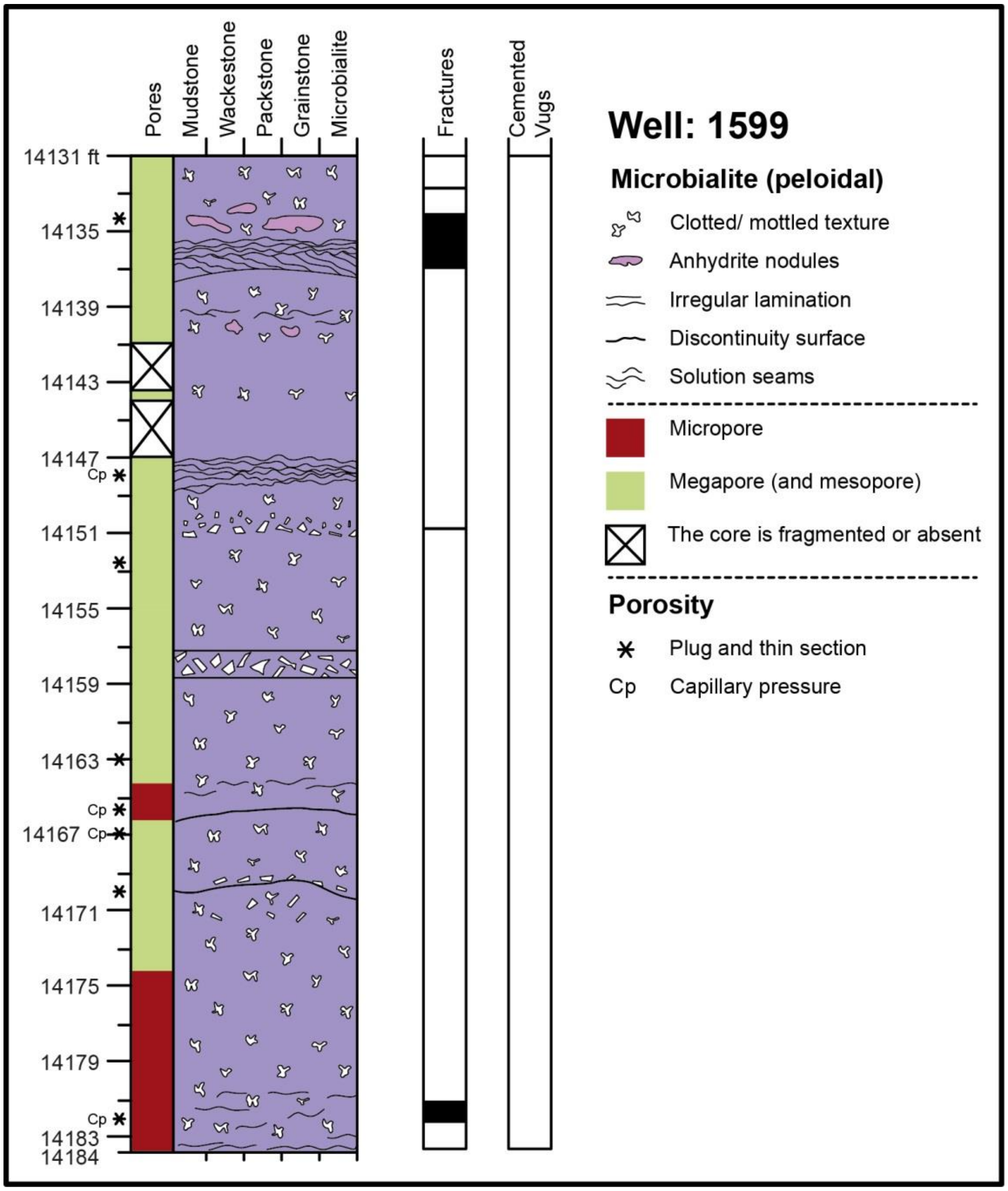


Well: 16135
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
10570 ft
10574
10578
10582
10586
10590
10594
10598
10602
10606
10610
10614
10618
10622
10626
10630
10634
10638
10642
10646
10648
10652
10656
Packstone
Peloid
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Domal structure
Irregular lamination
Discontinuity surface
Solution seams
Basement conglomerate
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug


Well: 16238-B
Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
10465 ft
10469
10473
10477
10481
10485
10489
10493
10497
10501
10505
10509
10513
10517
10521
10523
Packstone
Peloid
Oncolite
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Branching structures
Domal structures
Oncolite
Discontinuity surface
Solution seams
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug


Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
12952 ft
12956
12960
12964
12968
12972
12976
12980
12984
12988
12992
12996
13000
13004
13008
13012
13016
13020
13024
13028
13032
13036
13036.8
Well: 3986
Grainstone
Oolite
Microbialite (peloidal)
Clotted/ mottled texture
Nodular
Branching structures
Thin brecciated levels
White dolomite filling vugs
Oncolite
Discontinuity surface
Solution seams
Brecciated texture
Porosity
Mesopore (and micropore)
Megapore (and mesopore)
The core is fragmented or absent
Plug

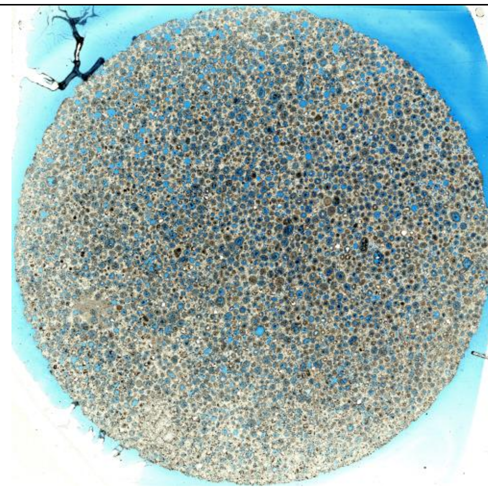

Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
13120 ft
13124
13128
13132
13136
13140
13144
13148
13152
13156
13157
Cp
Cp
Cp
Well: 4835-B
Grainstone
Oncolite
Microbialite (peloidal)
Clotted/ mottled texture
Branching structures
Brecciated aspect
Discontinuity surface
Discontinuity surface with brecciated aspect
Weak lamination
Breccia
Porosity
Micropore
Mesopore (and micropore)
Megapore (and mesopore)
Plug and thin section
Cp Capillary pressure


Pores
Mudstone
Wackestone
Packstone
Grainstone
Microbialite
Fractures
Cemented Vugs
14131 ft
14135
14139
14143
14147
14151
14155
14159
14163
14167
14171
14175
14179
14183
14184
Cp
Well: 1599
Microbialite (peloidal)
Clotted/ mottled texture
Anhydrite nodules
Irregular lamination
Discontinuity surface
Solution seams
Micropore
Megapore (and mesopore)
The core is fragmented or absent
Porosity
Plug and thin section
Cp Capillary pressure

APPENDIX D

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11866.8ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Fine to medium sand oolitic grainstone.

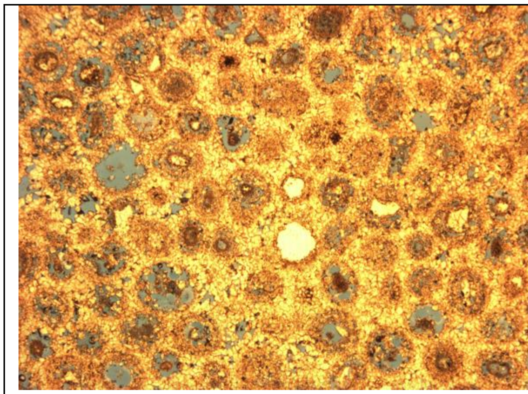
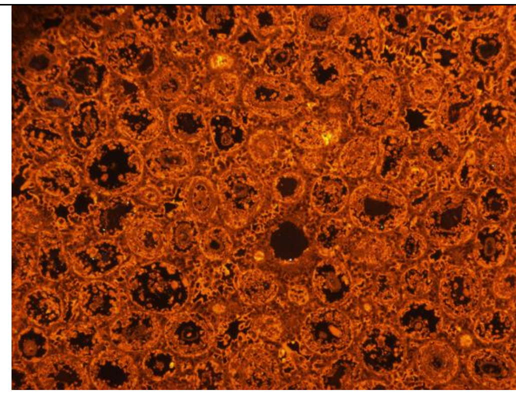
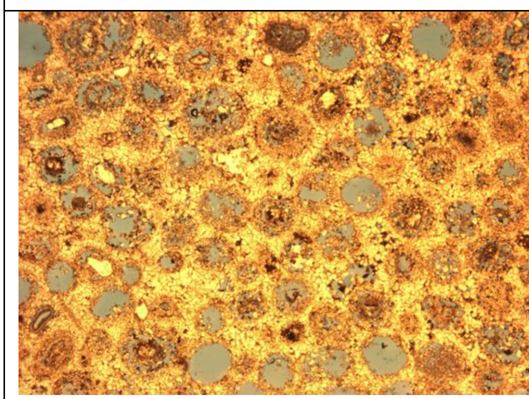
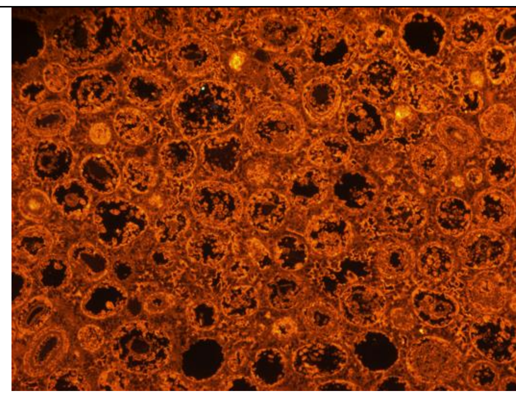
Description: Oolitic grainstone, fine to medium sand size, with rare coarse sand size grains. Fine quartz and feldspar grains commonly occur as oolite nucleus. Some muscovite grains were observed. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, oolite dissolution, no compaction features, rare equinoid fragment with sintaxial calcite cement.

Pore types: Moldic, intergranular.

Porosity (image analysis): 25%

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11866.8ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminescent image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminescent image – same field of the picture on the left side

Cathodoluminescence image analysis:

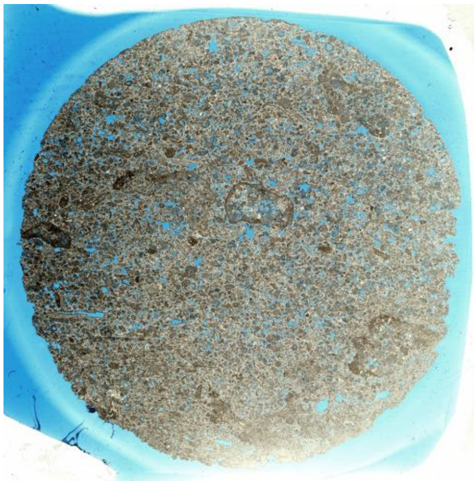
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 and 3 zones). Locally it occurs inside the moldic or intragranular porosity, growing from the border to the center. The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, the second zone has light brown luminescence and the third zone (edge) has light orange-yellow luminescence. In most of the intergranular porosity the first cementation phase presents 2 zones, filling all the pore space (no space left for the third cement zone).
Very fine to fine mosaic calcite cement, light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11874,2ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Very fine to medium sand oolitic grainstone.

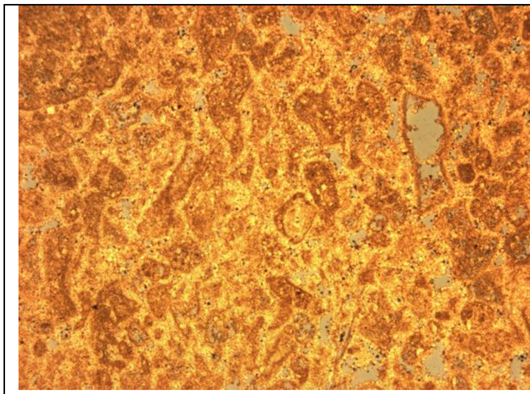
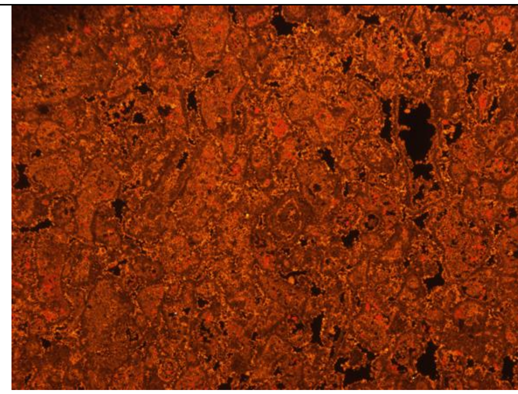
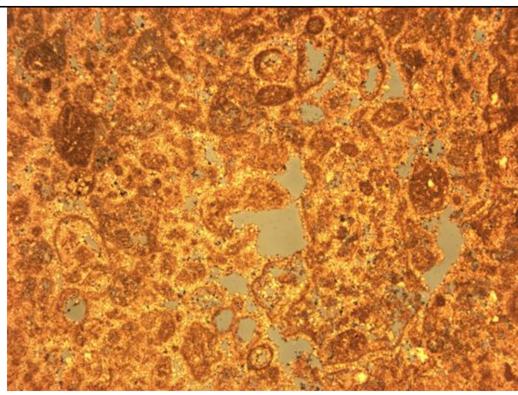
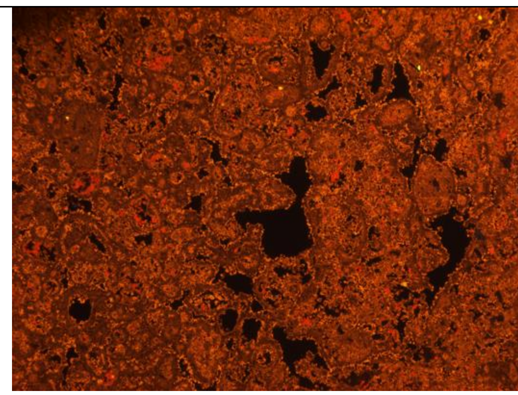
Description: Oolitic grainstone, very fine to coarse sand size, bioturbated. Some grapestones and oncolites (medium to coarse sand size), as well as some bivalve shell fragments are present. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, some euhedral to subhedral fine dolomites replacing small portions of the grains, ooid dissolution, no compaction features, rare calcite blocky cement.

Pore types: Intergranular, moldic, intragranular, vuggy.

Porosity (image analysis): 15%

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11874,2ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminescent image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminescent image – same field of the picture on the left side

Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). Locally it occurs inside the moldic or intragranular porosity, growing from the border to the center. The first zone (inner part of the crystal) has dark to light brown luminescence (locally is nonluminescent) and the second zone (edge) has orange-yellow luminescence. Locally in the intergranular and intragranular / moldic porosity the first cementation phase presents only the first luminescent zone.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Some dolomite crystals occur in the intergranular and intragranular space, replacing the bladed to drusy calcite fringe and grains.

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11894.5ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Very fine sand size quartz and muscovite grains occur. The bioclasts are mollusks, ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , chemical compaction (stylolite), blocky calcite cement, rare quartz cement, micro-fracture cuts stylolite and all the cement phases. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase.

Pore type: Intergranular, intercrystalline, and some intragranular.

Porosity (image analysis): 2%

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11894.5ft

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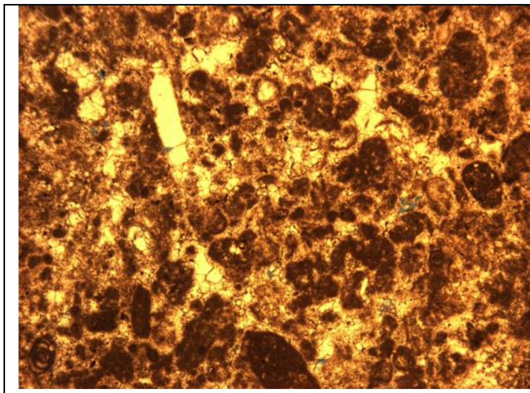
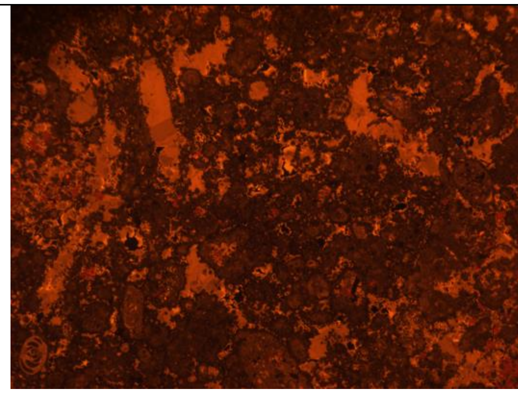
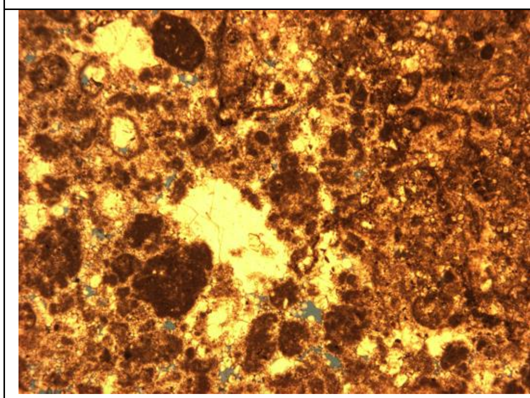
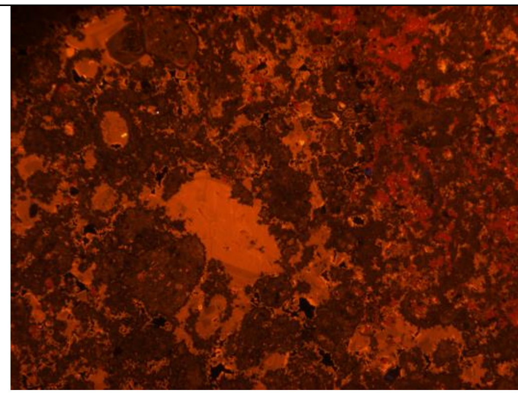
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminescent image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminescent image – same field of the picture on the left side</td></tr>
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Cathodoluminescence image analysis:

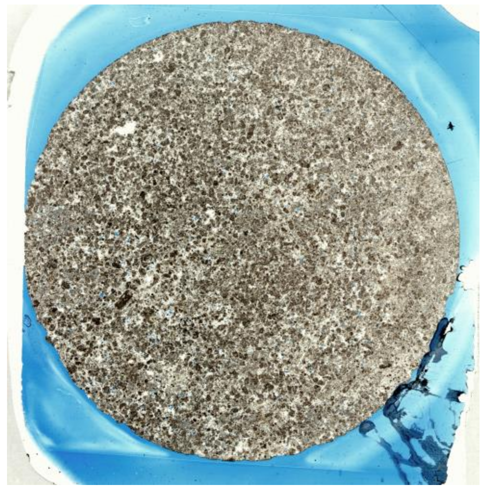
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In many of the intergranular porosity the first cementation phase presents only the first zone, and it fills all the pore space.
Blocky calcite cement, zoned. The number of zones varies from 2 to 3. Two zones are the most common. The zones generally present the following sequence of luminescence: light brown – orange-yellow, when 2 zones are present; orange-yellow – light brown – orange-yellow luminescence, when 3 zones are present. Some crystals do not have zonation, and present light brown or orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. The dolomite crystals generally do not present zonation and have red luminescence, but locally presents 2 zones: red – light red luminescence. Dolomite replaces portions of grains and cements.

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11896.7ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

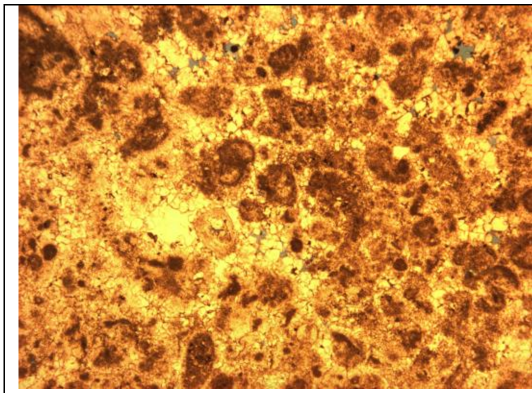
Description: Peloidal thrombolite, with some bioclasts. Very fine to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement) and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, blocky calcite cement, rare quartz and anhydrite cements. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase.

Pore type: Intergranular, intercrystalline, and some intragranular.

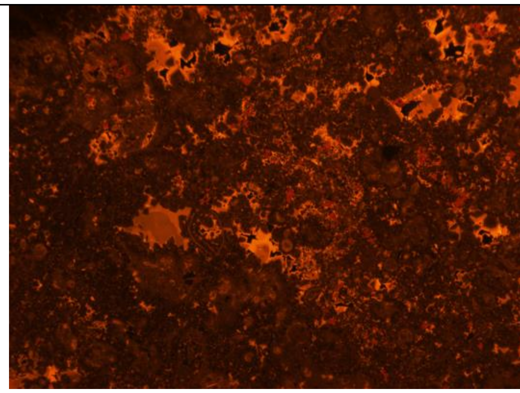
Porosity (image analysis) : 2%

Little Cedar Creek Field **Well: 1** **Permit: 11963**

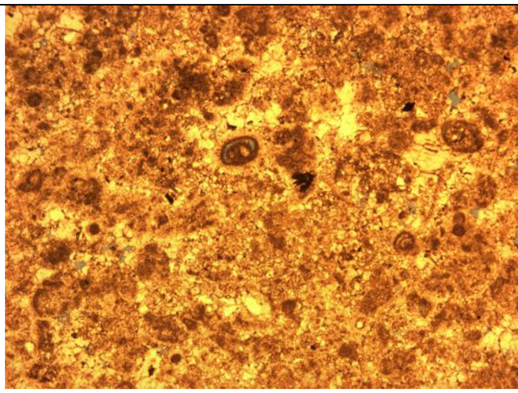
Depth: 11896.7ft



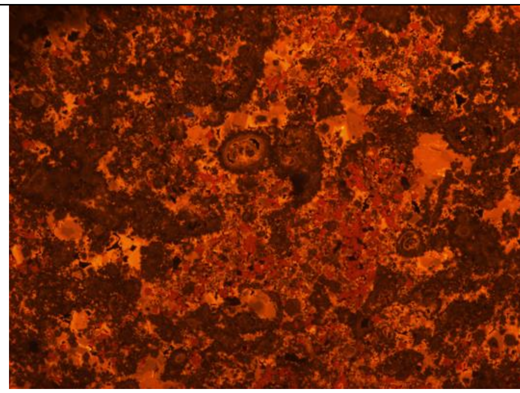
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminescent image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



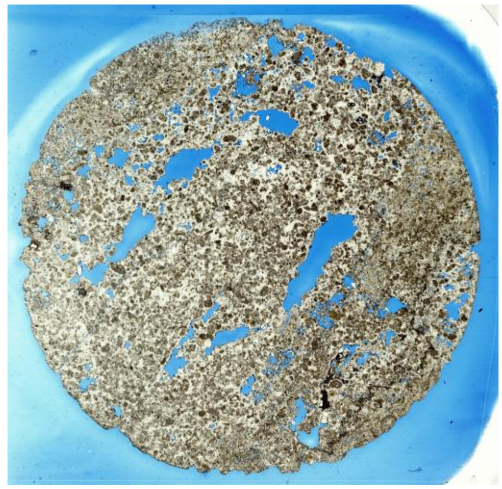
Cathodoluminescent image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 and 3 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In many of the intergranular porosity the first cementation phase presents only the first two zones, and it fills all the pore space (no space left for the third cement zone).
Blocky calcite cement, zoned (2 zones). The zones present the following sequence of luminescence: light brown – orange-yellow. Some crystals do not have zonation, and present the color light brown or orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. Most of the dolomite crystals do not present zonation and have red luminescence, but locally zoned crystal do occur presenting a dark red luminescent center and a red luminescent border. Dolomite replaces portions of grains and cements.

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11899.2ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

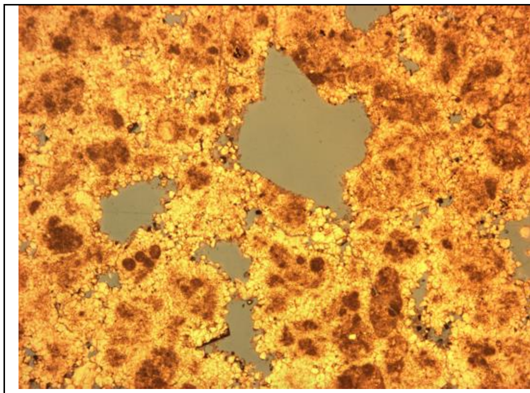
Description: Peloidal thrombolite, with some bioclasts. Very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement) and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , chemical compaction (stylolite), blocky calcite cement, rare quartz cement, micro-fracture cuts stylolite and all the cement phases. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

Pore type: vuggy, intergranular, and intercrystalline.

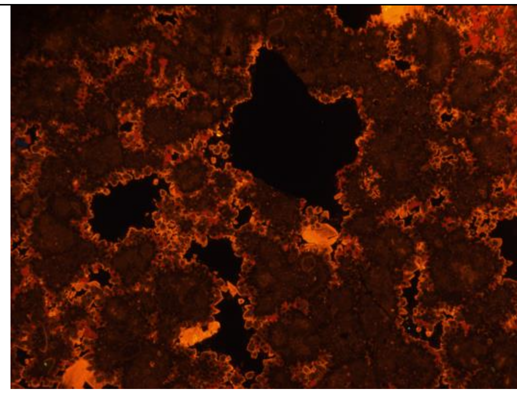
Porosity (image analysis): 12%

Little Cedar Creek Field **Well: 1** **Permit: 11963**

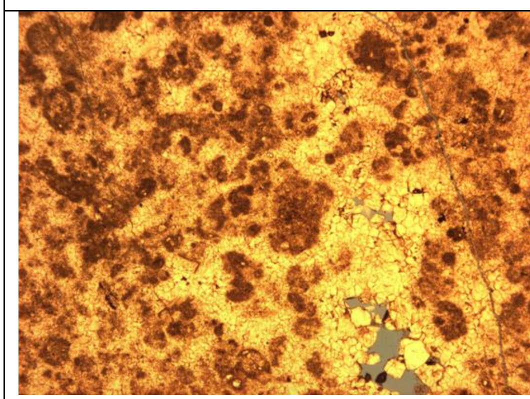
Depth: 11899.2ft



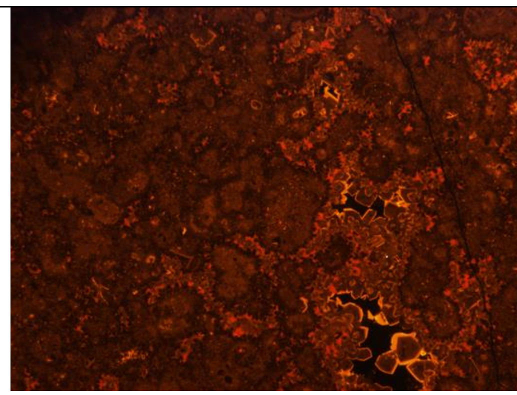
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminescent image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminescent image – same field of the picture on the left side

Cathodoluminescence image analysis:

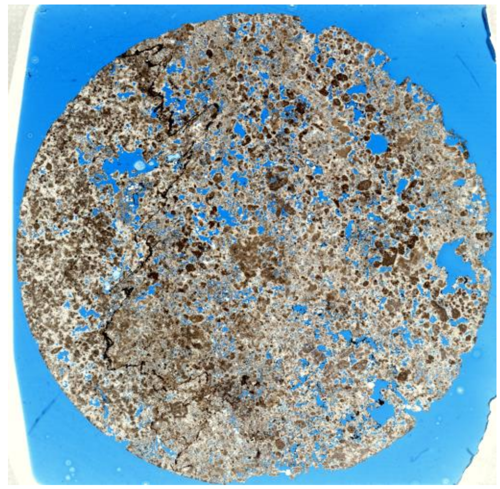
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 and 3 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In many of the intergranular porosity the first cementation phase presents only the first two zones, and it fills all the pore space. Locally coarser drusy calcite crystals grows on the top of the previous drusy calcite cementation. The crystals are zoned (2 zones): light brown – light orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following sequence of luminescence: light brown – orange-yellow. Some crystals do not have zonation, and present light brown or orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite replaces preferentially the bladed to drusy cementation phase, and locally replaces portions of grains.

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11900.2ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

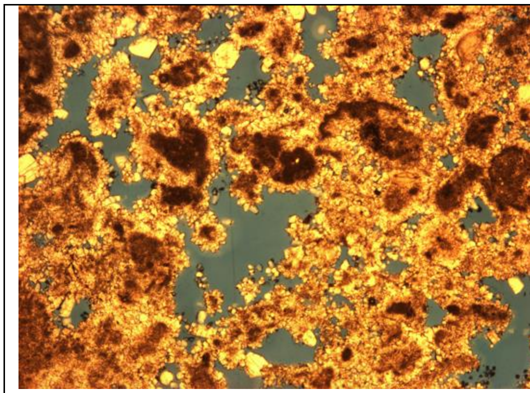
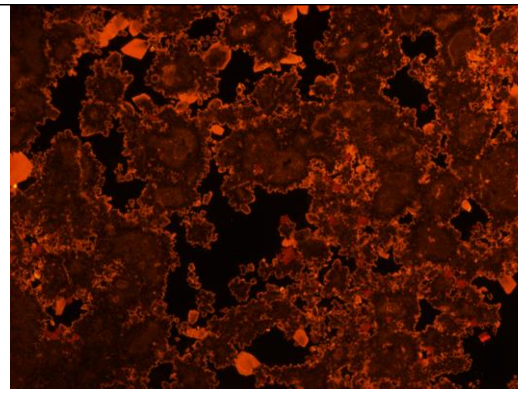
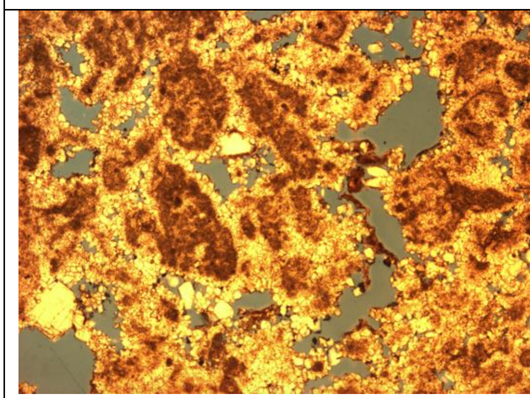
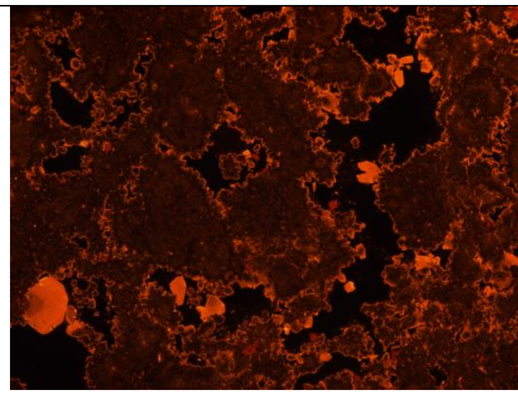
Description: Peloidal thrombolite, with some bioclasts. Very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement) and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , chemical compaction (stylolite), blocky calcite cement, rare quartz and anhydrite cement, micro-fracture cuts stylolite and all the cement phases. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Partial dissolution of some dolomite crystals. Primary growth framework vugs present enlargement by dissolution.

Pore type: vuggy, intergranular, and intercrystalline. Rare intracrystalline and moldic.

Porosity (image analysis): 15%

Little Cedar Creek Field **Well: 1** **Permit: 11963**

Depth: 11900.2ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminescent image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminescent image – same field of the picture on the left side

Cathodoluminescence image analysis:

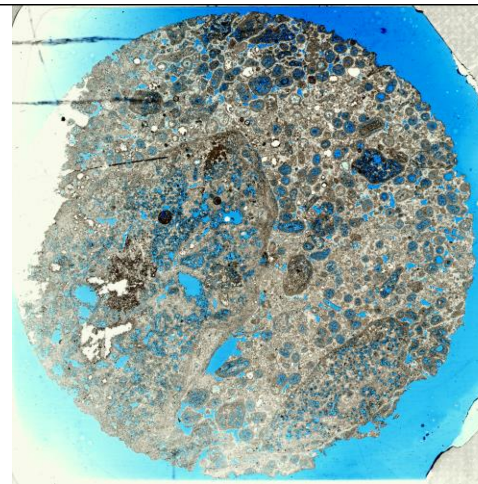
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe rimming the grains, zoned (2 to 4 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, the second zone has light brown luminescence, the third zone has dark brown luminescence and the fouth zone (edge) has orange-yellow luminescence. The presence of the only 2 zones is more common (the third and the fouth zones).
Blocky calcite, zoned (2 zones). The zones present the following sequence of luminescence: moderate luminescent yellowish brown - light yellow. Some crystals do not have zonation, and present the color moderate luminescent yellowish brown or light yellow.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and have moderate red luminescence, but locally present 2 or 3 zones: red – dark red or red – dark red – light red luminescence. Dolomite replaces portions of grains and cements.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11734.6ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Bimodal oncolitic-oolitic grainstone

Description: Oncolitic-oolitic grainstone, bioturbated. The oolites are fine to medium sand size, while the oncolites are coarse to very coarse sand size. Some quartz grains occur, very fine to fine sand size. Diagenesis: Bladed do drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, dissolution of grains and calcite fringe cement, no compaction features, some dolomite crystals replacing grains, pyrite crystals occur locally replacing calcite mosaic cement, anhydrite crystals replace grains and calcite cements, rare euhedral quartz cement.

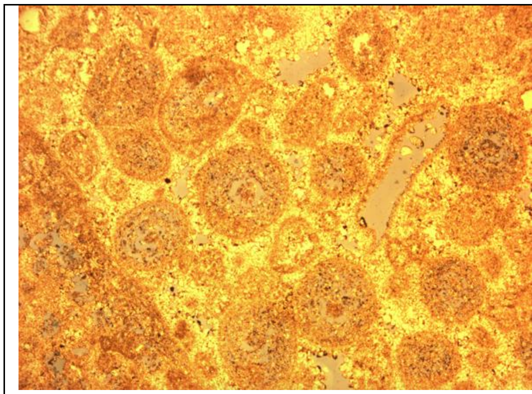
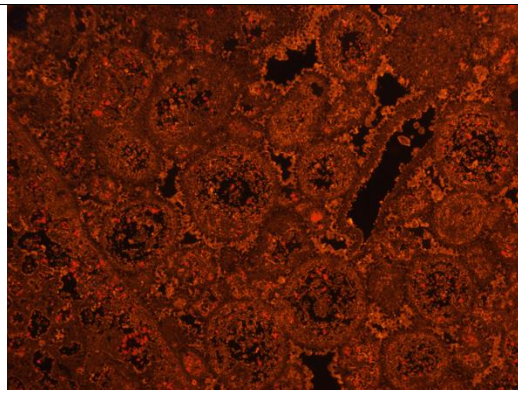
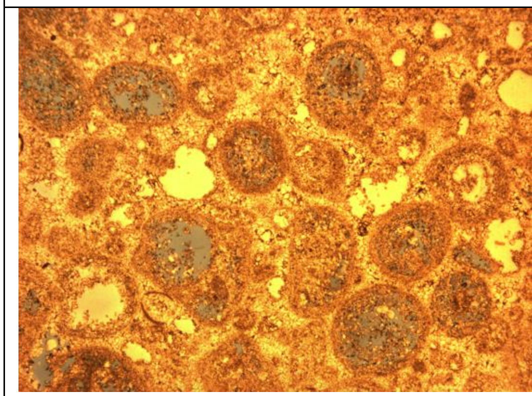
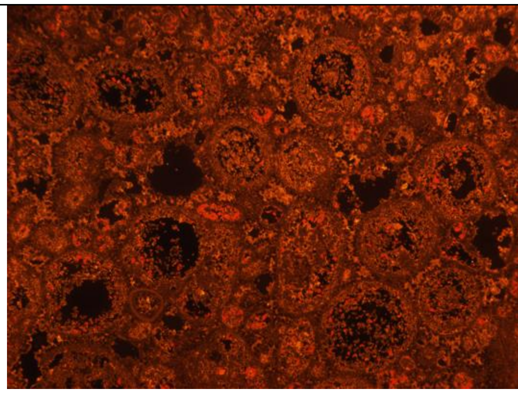
Pore types: Intergranular, moldic, intragranular, vuggy.

Porosity (image analysis): 20%

Petrophysical analysis:
Porosity – 23%
Permeability – 63.6 md

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11734.6 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

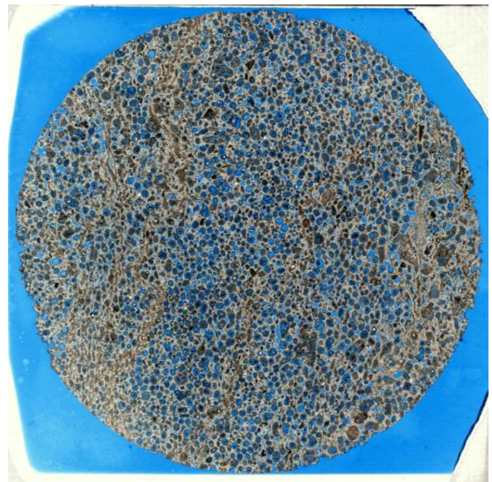
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). It locally occurs inside the moldic or intragranular porosity, mainly growing from the border to the center. The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In some portions where the grains are very close, only the first zone occurs.
Very fine to fine mosaic calcite cement, light brown to orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11740 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone with grapestones and bioclasts (bivalves). Oolites are fine to medium sand size and grapestones are coarse to very coarse sand size. Some quartz grains, fine sand size, are observed. Local bioturbation.
There is a level with elongated grains, possibly early deformation by compaction. Diagenesis: Bladed to drusy fringe calcite cement rimming grains, fine mosaic calcitic cement, dissolution of grains, pyrite crystals occur locally replacing calcite fringe cement and growing in pore space.

Pore types: moldic, intragranular, intergranular.

Porosity (image analysis): 33%

Petrophysical analysis:
Porosity – 23%
Permeability – 2.33 md

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11740 ft

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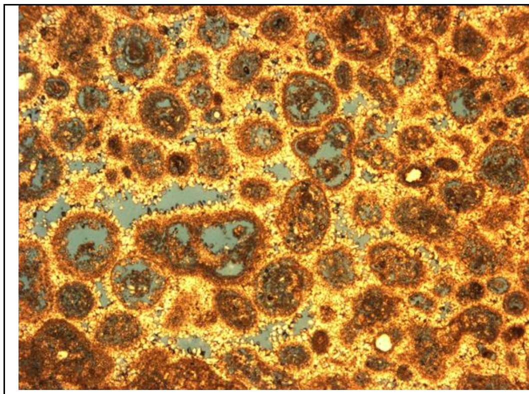
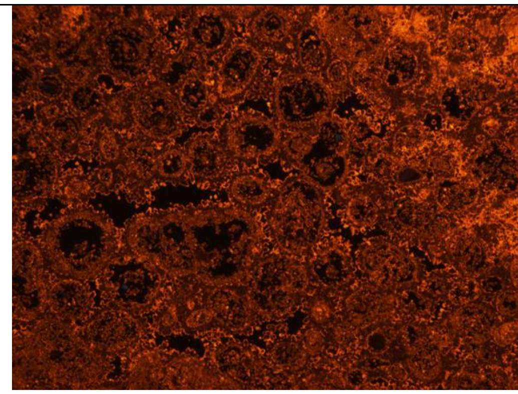
<td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td>
<td>
Cathodoluminesce image – same field of the picture on the left side</td>
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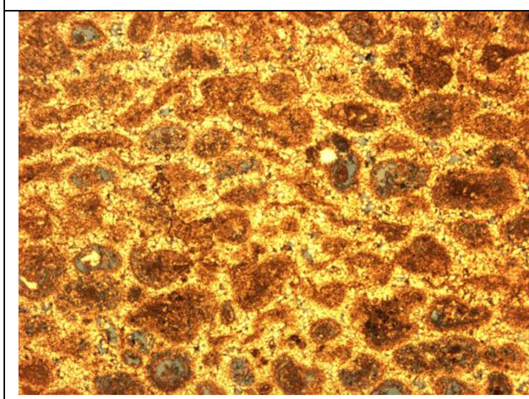
<td>
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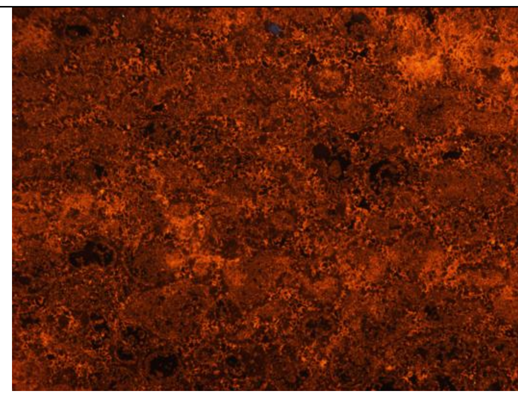
Full horizontal axis = 3.5 mm</td>
<td>
Cathodoluminesce image – same field of the picture on the left side</td>
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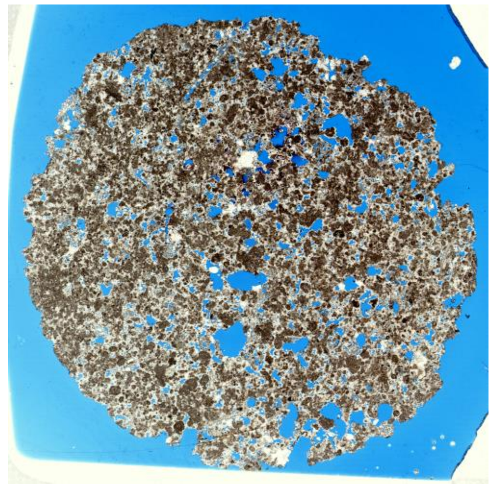
Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). It locally occurs inside moldic and intragranular porosity, growing from the border to the center, and generally presenting only the first luminescent zone. The first luminescent zone (inner part of the crystal) is dark brown luminescent to nonluminescent ,and the second zone (edge) has orange-yellow luminescence. In some portions where the grains are very close, only the first zone occurs. Rare **euhedral to subhedral very fine dolomite** crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11771 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and green algae. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters ,mosaic calcite cement, blocky calcite cement, rare anhydrite and quartz cement, micro-fracture. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Partial dissolution of some dolomite crystals. Primary growth framework vugs present enlargement by dissolution.

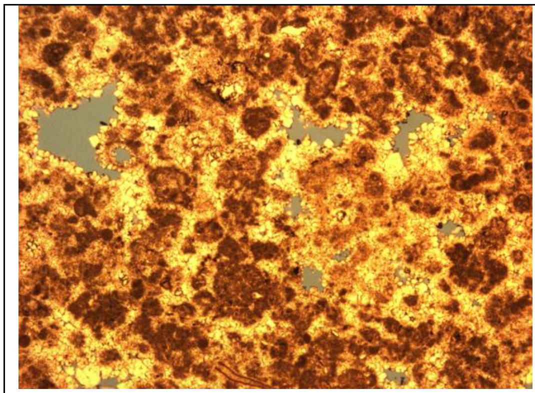
Pore type: vuggy, intergranular, and intercrystalline. Rare moldic (dissolution of green algae fragment) and intragranular porosity.

Porosity (image analysis): 14%

Petrophysical analysis:
Porosity – 12%
Permeability – 77 md

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11771 ft

<table>
<tr><td>
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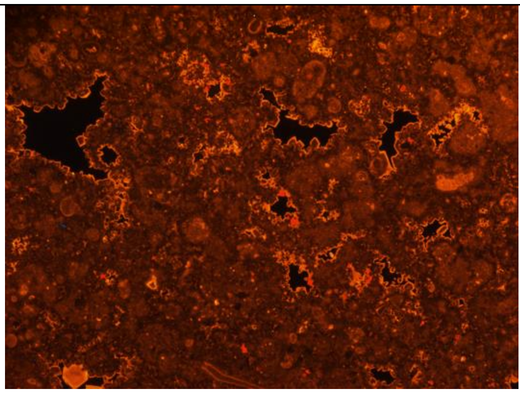
Full horizontal axis = 3.5 mm</td><td>
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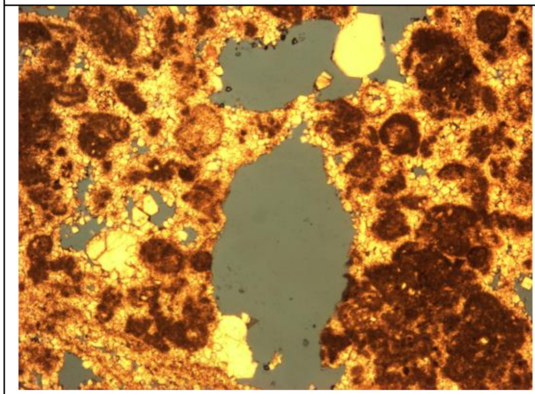
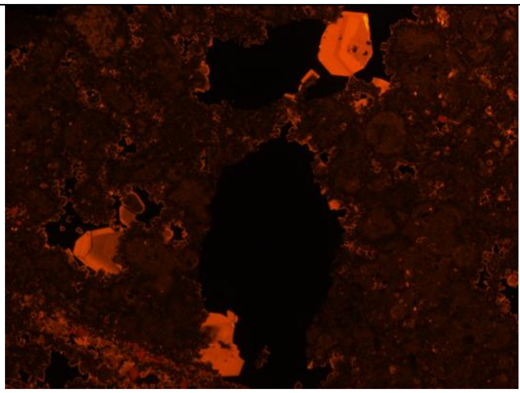
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
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Cathodoluminescence image analysis:

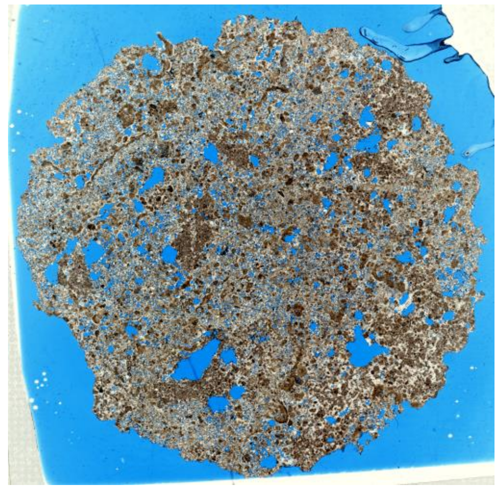
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe rimming the grains, zoned (2 to 4 zones). The zones present the following sequence of luminescence (from de center to the edge): dark brown to nonluminescent – light brown to orange-yellow – dark brown – orange-yellow luminescence. In many of the intergranular porosity the first cementation phase presents only the first and second zones, and it fills all the pore space.
Blocky calcite, zoned. The number of zones varies from 2 to 4. Two zones are the most common. The zones generally present the following sequence of luminescence: light brown – orange-yellow; where 4 zones are present the sequence is: light brown –orange yellow – light brown –orange yellow luminescence. Some crystals do not have zonation, and present light brown or orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and present red luminescence or, rarely, dark red luminescence. Locally dolomite presents 2 zones: red – dark red luminescence. Dolomite crystals replace preferentially the drusy calcite cement.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11773.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , rare anhydrite cement, micro-fractures. High dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

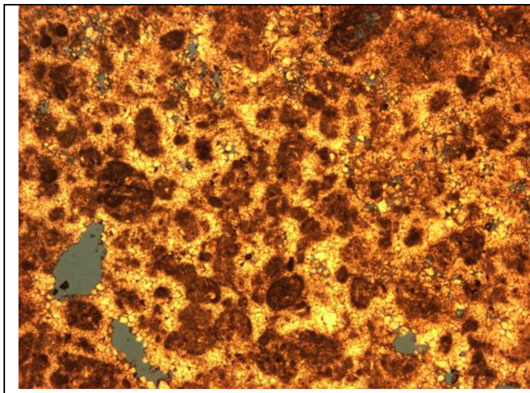
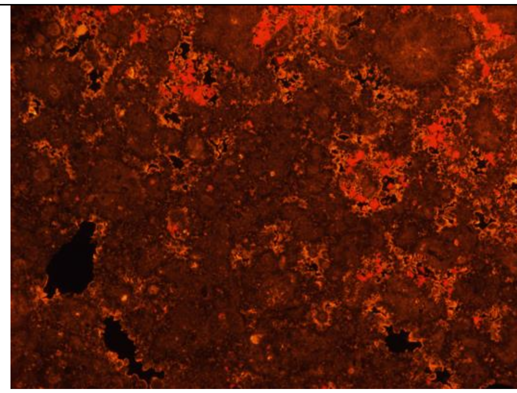
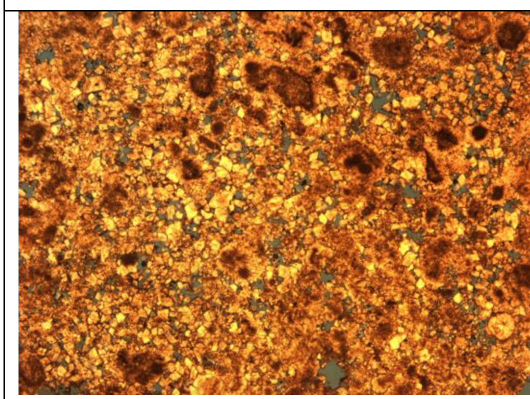
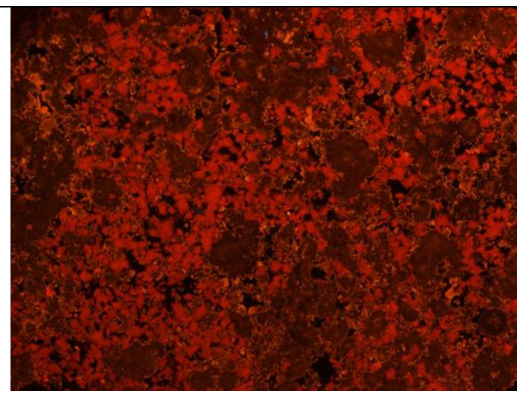
Pore type: Intercrystalline, vuggy, and intergranular.

Porosity (image analysis) : 17%

Petrophysical analysis:
Porosity – 12%
Permeability – 72 md

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11773.8 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

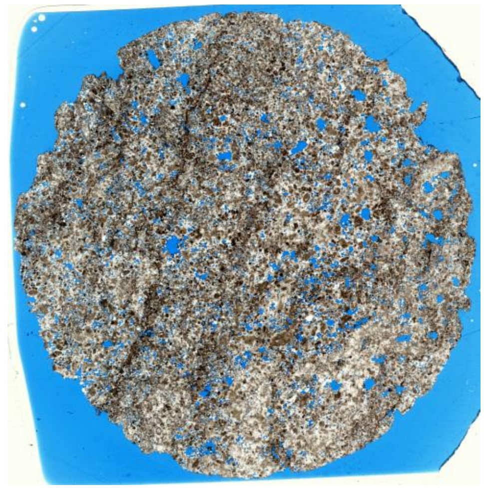
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 4 zones). The zones present the following sequence of luminescence, from de center to the edge: non-luminescent to dark brown – light brown – dark brown – orange-yellow luminescence. Generally this cementation phase presents only 2 zones (dark brown and orange-yellow luminescence).
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and have red luminescence, but locally presents 2 zones: red – dark red luminescence. Dolomite crystals replace preferentially the drusy calcite fringe.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11774.7 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , blocky calcite cement, rare quartz cement, and chemical compaction (solution seams). Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

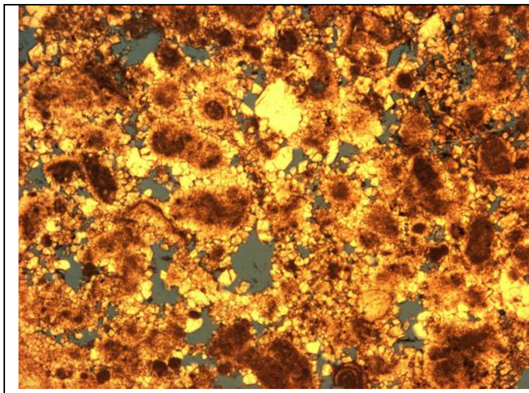
Pore type: vuggy, intergranular, and intercrystalline.

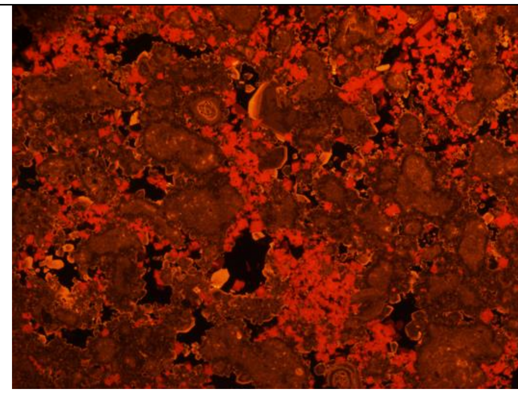
Porosity (image analysis): 11%

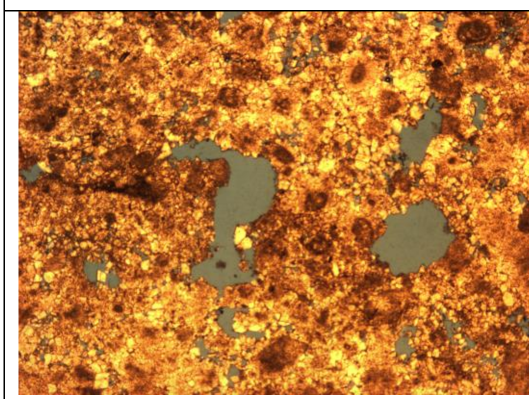
Petrophysical analysis:
Porosity – 11%
Permeability – 4,740 md

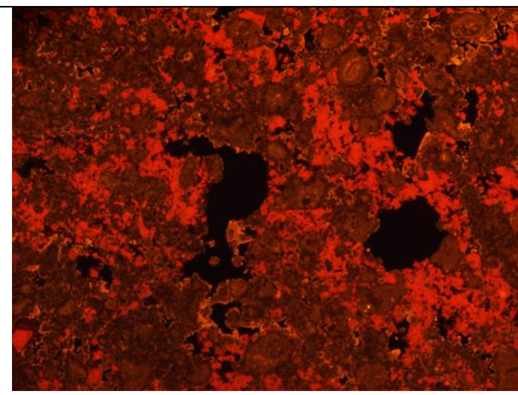
Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11774.7 ft


Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm


Cathodoluminesce image – same field of the picture on the left side


Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

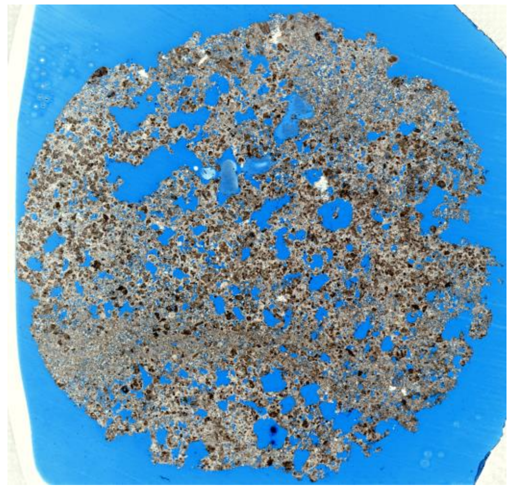

Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe rimming the grains, zoned (2 to 4 zones). The zones present the following sequence of luminescence (from de center to the edge): dark brown to nonluminescent – light brown – dark brown – orange-yellow luminescence. In many of the intergranular porosity the first cementation phase presents only the first and second zones, and it fills all the pore space.
Blocky calcite cement, zoned. The number of zones varies from 2 to 5. The zones generally present the following sequence of luminescence: dark brown - light brown – orange-yellow – light brown – orange-yellow – light orange-yellow. Two zones are the most common (orange-yellow – light orange-yellow).
Euhedral to subhedral very fine to fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and present red luminescence. Locally dolomite presents 2 zones: red – dark red luminescence. Dolomite crystals replace preferentially the drusy calcite cement.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11782 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , blocky calcite cement, some anhydrite cement. Moderate dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

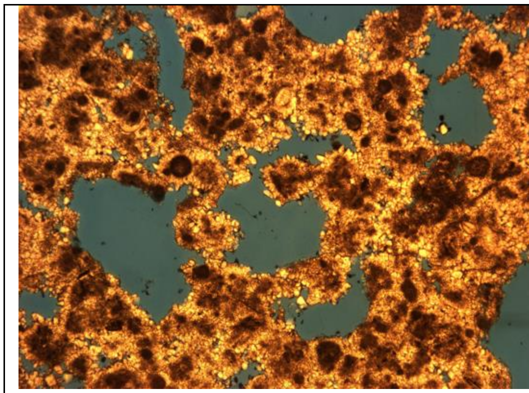
Pore type: Vuggy, intergranular, and intercrystalline.

Porosity (image analysis): 27%

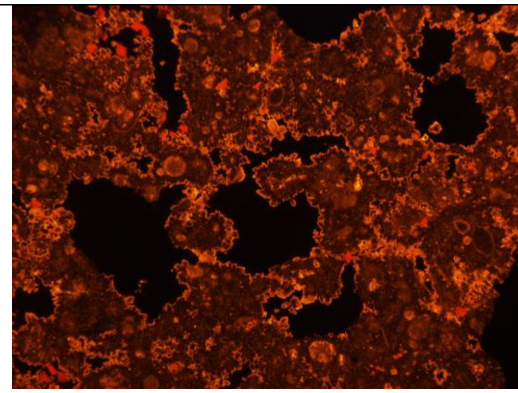
Petrophysical analysis:
Porosity – 12%
Permeability – 30.8 md

Little Cedar Creek Field **Well: 2** **Permit: 13177**

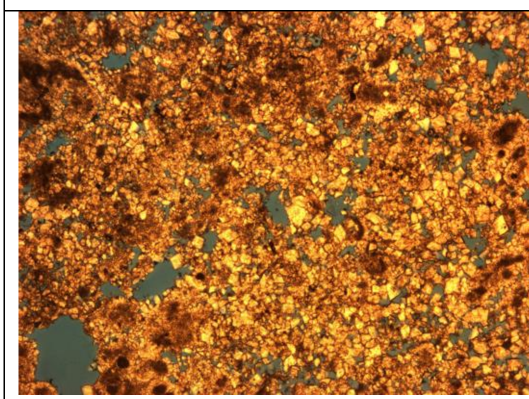
Depth: 11782 ft



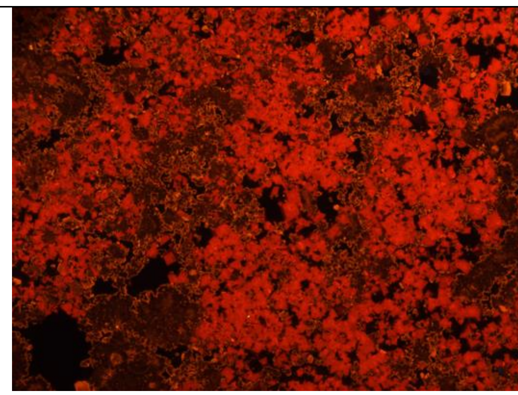
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



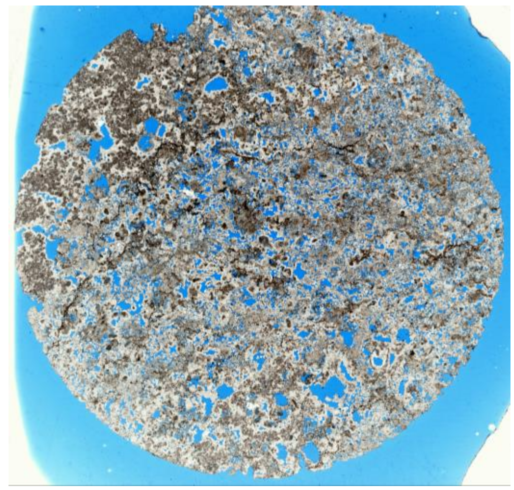
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The zones present the following sequence of luminescence (from de center to the edge): dark brown to nonluminescent – light brown – orange-yellow luminescence. In some places the first cementation phase presents only the first and second zones, and it fills all the pore space.
Rare **blocky calcite** cement, presenting light orange-yellow luminescence.
Euhedral to subhedral very fine to fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and present red luminescence. Locally dolomite presents 2 zones: red – dark red luminescence.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11787.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , mosaic calcite cement, some anhydrite cement. Moderate to high dolomitization. Chemical compaction (stylolites). Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase.

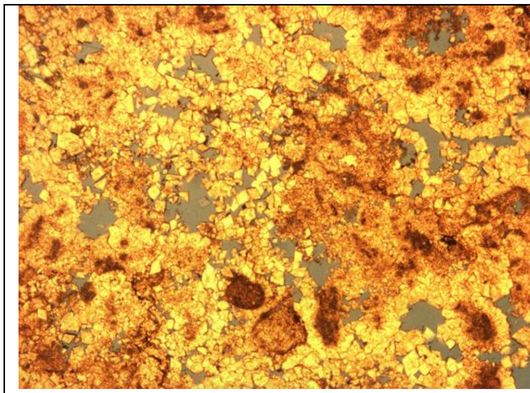
Pore type: Vuggy, intergranular, and intercrystalline. Some moldic porosity (dissolution of peloids).

Porosity (image analysis): 19%

Petrophysical analysis:
Porosity – 17 %
Permeability – 95.9 md

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11787.9 ft

<table>
<tr><td>
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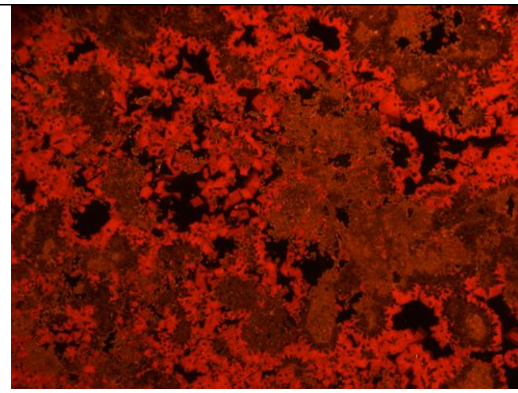
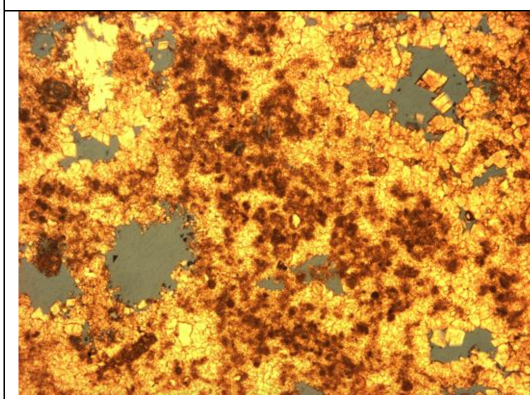
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
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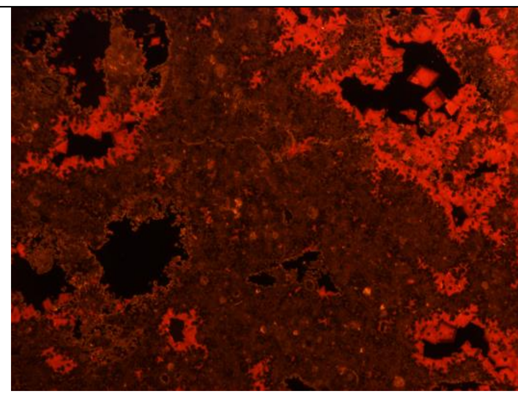
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

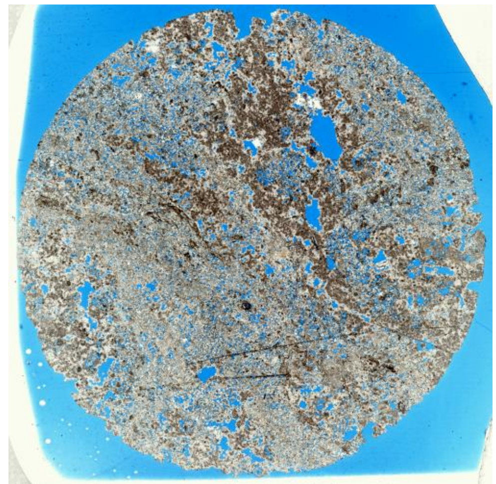
Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, and the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In many of the intergranular porosity the first cementation phase presents only the first and second zones, filling all the pore space.
Euhedral to subhedral very fine to fine dolomite crystals occur as a replacing phase. The dolomite crystals generally do not present zonation and present red luminescence. Locally dolomite presents 2 zones: red – dark red luminescence. Dolomite crystals replace preferentially the drusy calcite fringe cement.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11789 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
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Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , blocky calcite cement, some anhydrite cement. Chemical compaction (stylolites). High dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

Pore type: Intercrystalline, vuggy, and intergranular. Rare intracrystalline porosity (dissolution of dolomite core).

Porosity (image analysis): 20%

Petrophysical analysis:
Porosity – 17%
Permeability – 56.8 md

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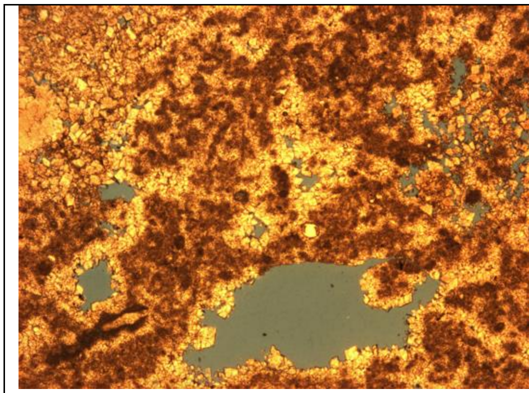
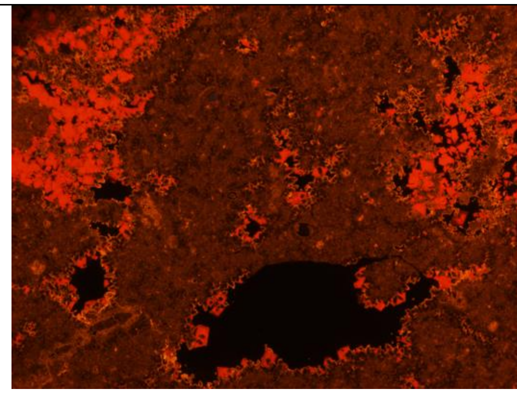
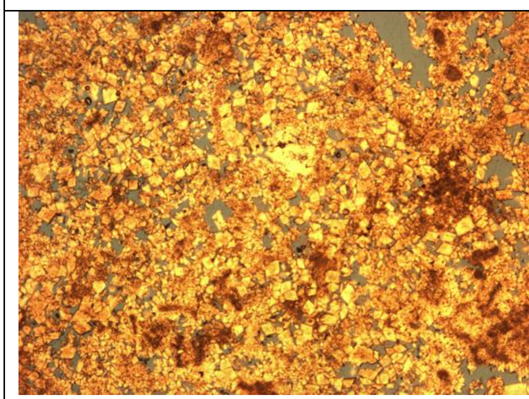
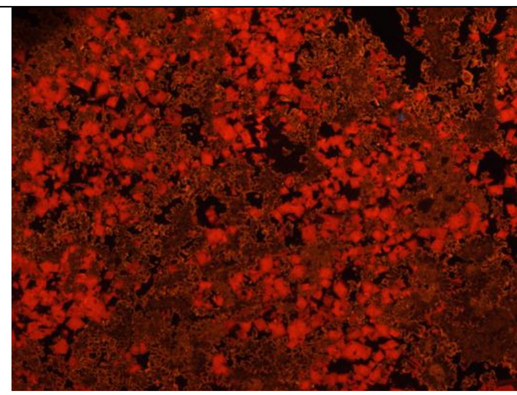
</table>

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11789 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

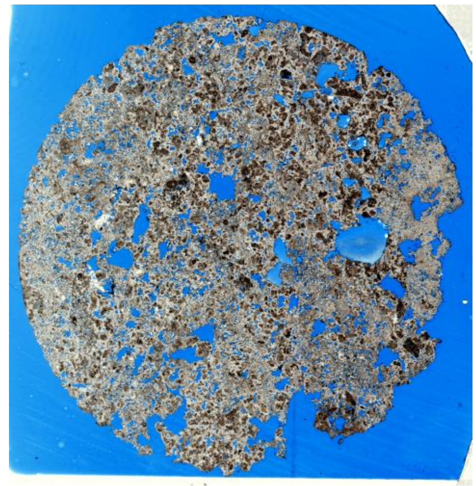
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, and the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In many of the intergranular porosity the first cementation phase presents only the first and second zones, filling all the pore space.
Euhedral to subhedral very fine to fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and present red luminescence. Locally dolomite presents 2 zones: red – dark red luminescence. Dolomite crystals replace preferentially the drusy calcite fringe cement.

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11790.9 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, some anhydrite cement. Moderate dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

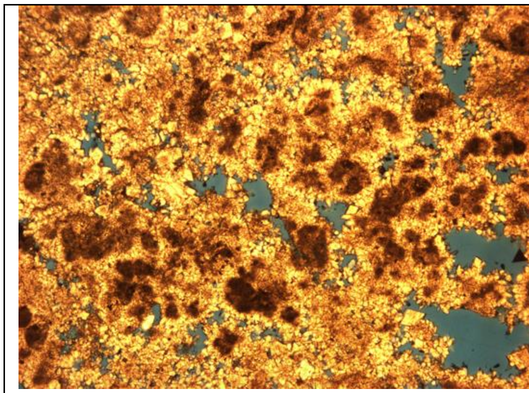
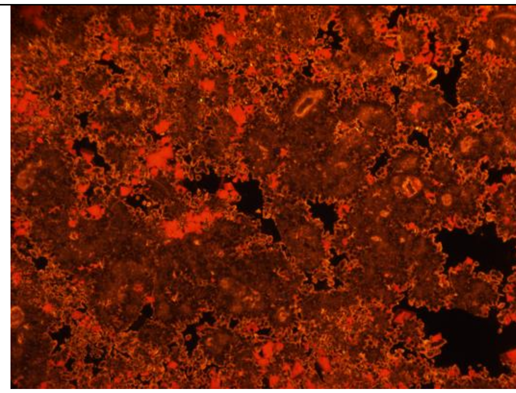
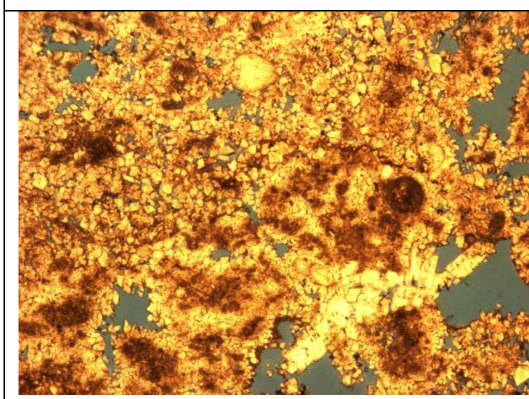
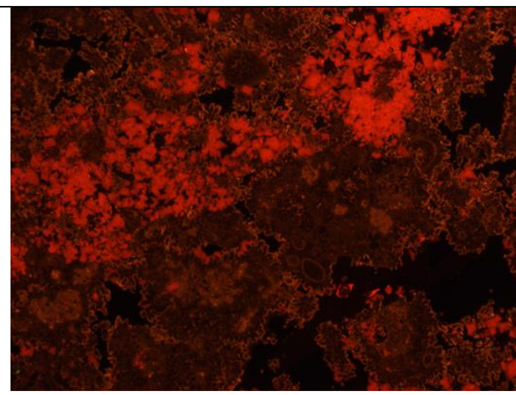
Pore type: Vuggy, intercrystalline, and intergranular.

Porosity (image analysis): 21%

Petrophysical analysis:
Porosity – 18%
Permeability – 199 md

Little Cedar Creek Field **Well: 2** **Permit: 13177**

Depth: 11790.9 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

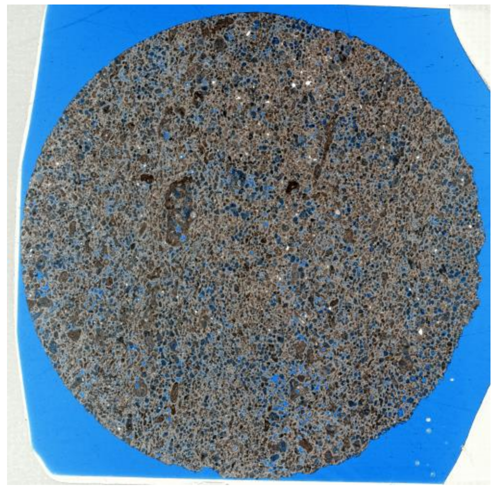
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, and the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In some of the intergranular porosity the first cementation phase presents only the first and second zones, filling all the pore space.
Euhedral to subhedral very fine to fine dolomite crystals occur as a replacing phase. The dolomite crystals generally do not present zonation and present red luminescence. Locally dolomite presents 2 zones: red – dark red luminescence. Dolomite crystals replace preferentially the drusy calcite fringe cement.

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11561 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Very fine to medium sand oolitic-oncolitic-peloidal grainstone.

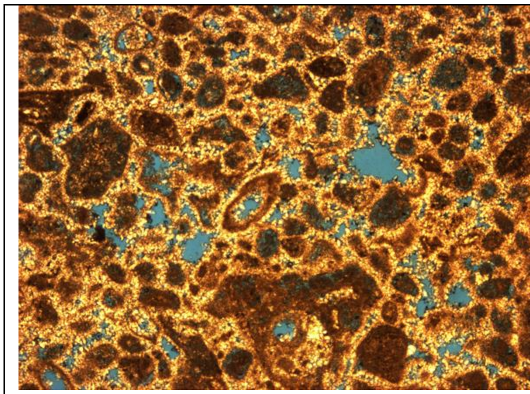
Description: Oolitic-oncolitic-peloidal grainstone, very fine to medium sand size, with some coarse to very coarse sand size grapestones. Several elongated grains present orientation. Some fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, rare blocky calcite cement, rare quartz cement, oolite dissolution, very fine pyrite crystals replace grains and cement, no compaction features.

Pore type: Intergranular, intragranular, moldic and some vugs.

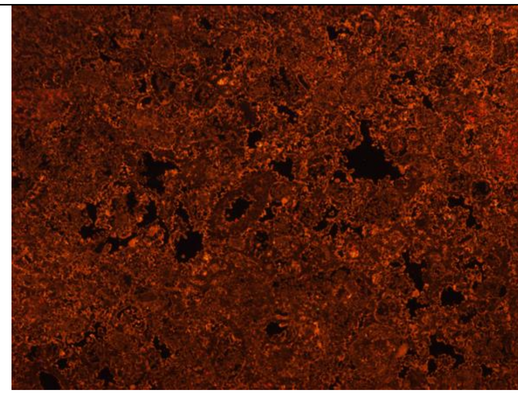
Porosity (image analysis): 19%

Little Cedar Creek Field **Well: 3** **Permit: 13439**

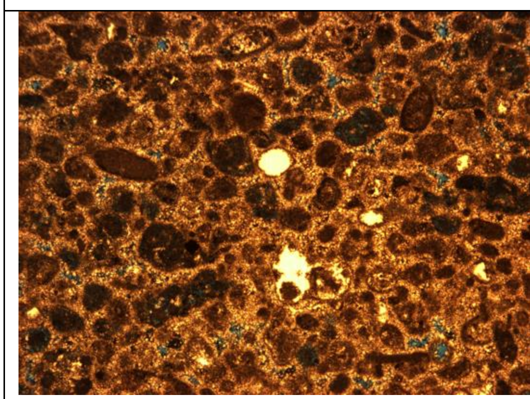
Depth: 11561 ft



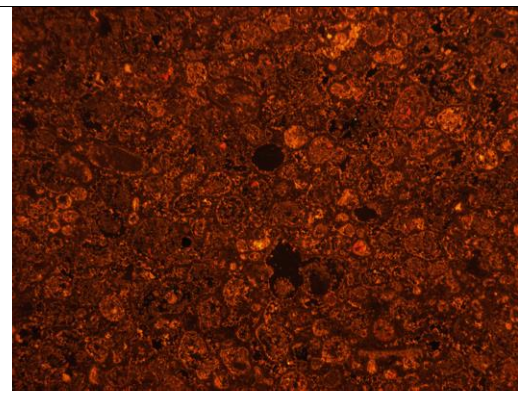
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement around the grains, zoned (2 zones). It locally occurs inside the moldic and the intragranular porosity, growing from the border to the center. The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11564.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Very fine to fine sand peloidal-oncoidal grainstone.

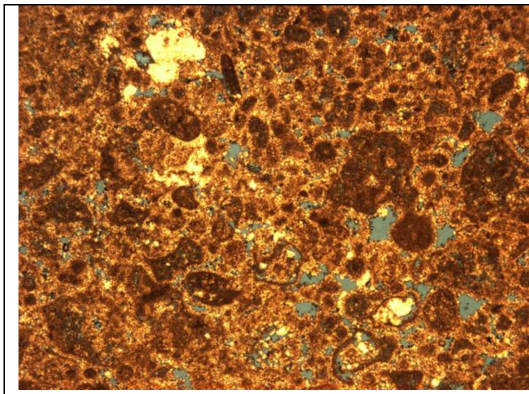
Description: Peloidal-oncoidal grainstone, very fine to fine sand size, bioturbated. Some oolites and benthic foraminifera occur. A small amount of very fine to fine quartz and muscovite grains are present. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, blocky calcite cement (cementing moldic and intergranular porosity), rare quartz cement, grain dissolution, very fine pyrite crystals replace grains /cement and grow in pore space, no compaction features.

Pore type: intergranular, intragranular and moldic.

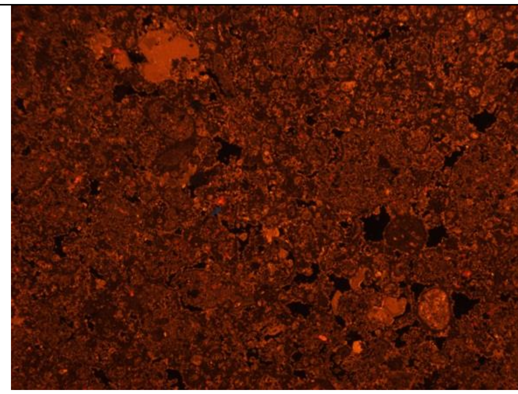
Porosity (image analysis): 15%

Little Cedar Creek Field **Well: 3** **Permit: 13439**

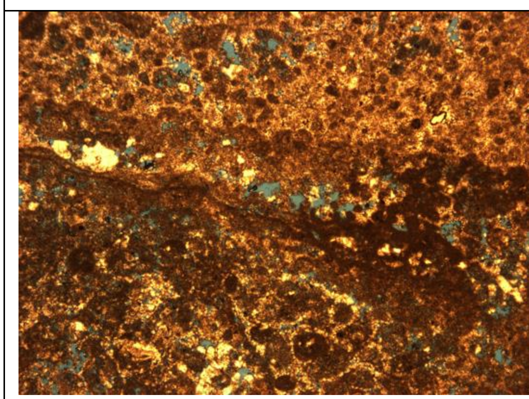
Depth: 11564.9 ft



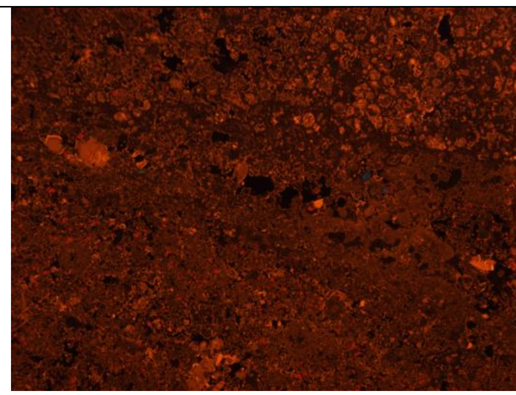
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

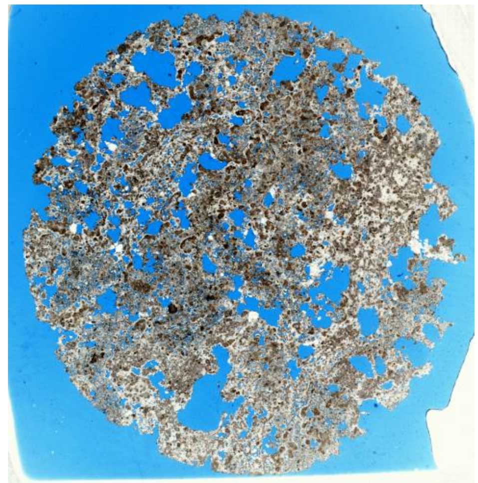
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned. The number of zones varies from 2 to 3. The zones present the following sequence of color: light brown – dark brown – orange-yellow luminescence. When the crystals have 2 zones they are: dark brown – orange-yellow.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11589.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

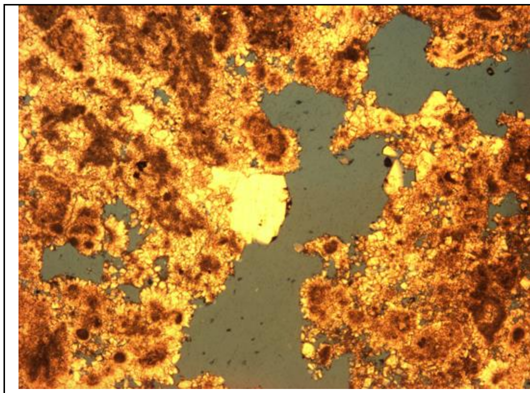
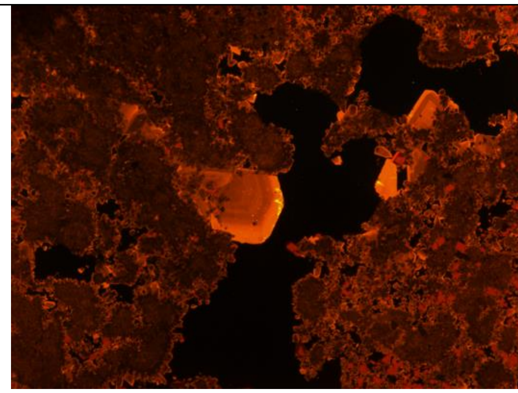
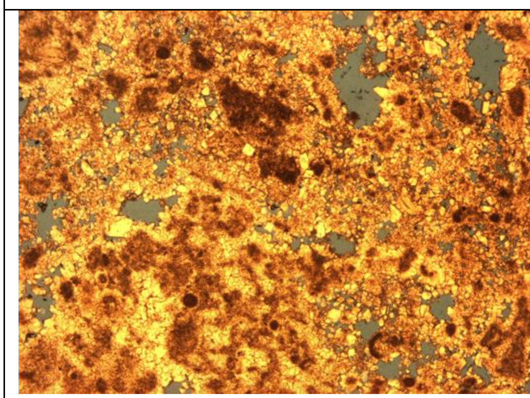
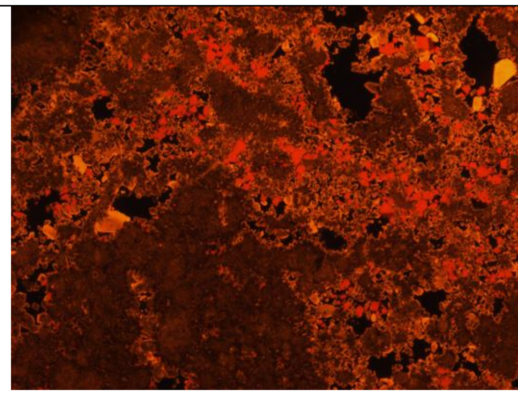
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , mosaic calcite cement, blocky calcite cement, some anhydrite cement. Moderate dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

Pore type: Vuggy, intergranular, and intercrystalline.

Porosity (image analysis): 27%

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11589.8 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

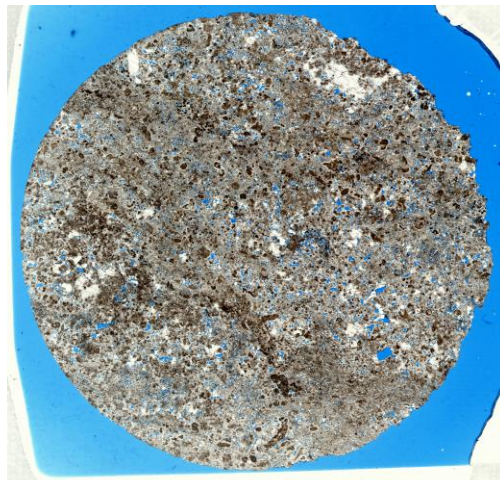
Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement around the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. When the crystal present 2 zones they are the first and the second or the second and the third.
Blocky calcite cement, zoned. The number of zones varies from 2 to 6. The zones present the following sequence of color: light brown – dark brown – light brown – dark brown – light brown – orange-yellow luminescence. When the crystals have 2 zones they are: light brown – orange-yellow.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals usually do not present zonation and have red luminescence, but locally it present 2 or 3 zones: red – dark red – light red luminescence. When the crystal presents 2 zones, they are: red – dark red luminescence.

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11595.4 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
</table>

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , mosaic calcite cement, blocky calcite cement, some anhydrite cement. Low to moderate dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase.

Pore type: Intercrystalline, intergranular, and some vuggy porosity.

Porosity (image analysis): 6%

Petrophysical analysis:
Porosity – 6%
Permeability – 0.032 md

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11595.4 ft

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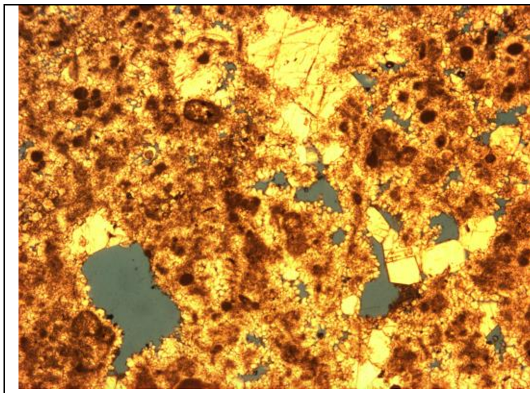
<tr><td>
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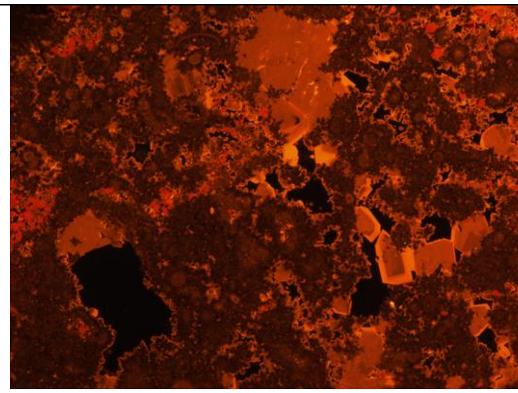
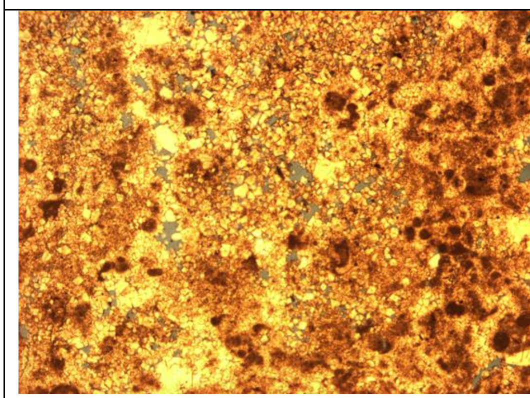
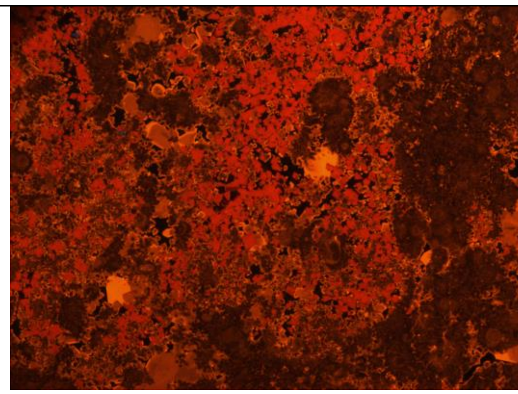
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

Cathodoluminescence image analysis:

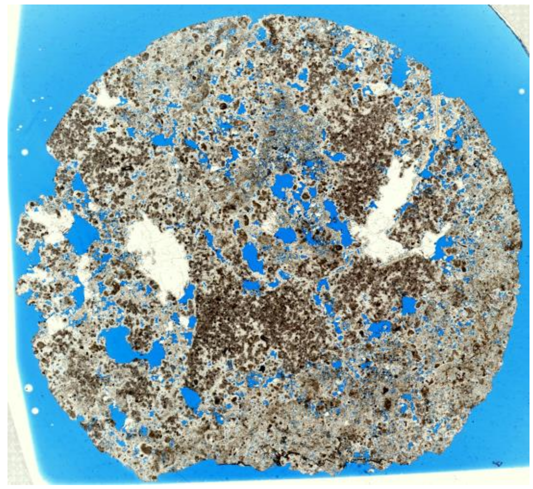
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. When the crystal present 2 zones they are the first and the second or the second and the third.
Blocky calcite cement, zoned. The number of zones varies from 2 to 3. The zones present the following sequence of color: dark brown – light brown – orange-yellow luminescence. When the crystals have 2 zones they are: light brown – orange-yellow.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals usually do not present zonation and have red luminescence, but locally it present 2 zones: red – dark red.

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11601.2 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and mollusks. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, some anhydrite cement.Chemical compaction (stylolite). Low dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution. Some discontinuous microfractures.

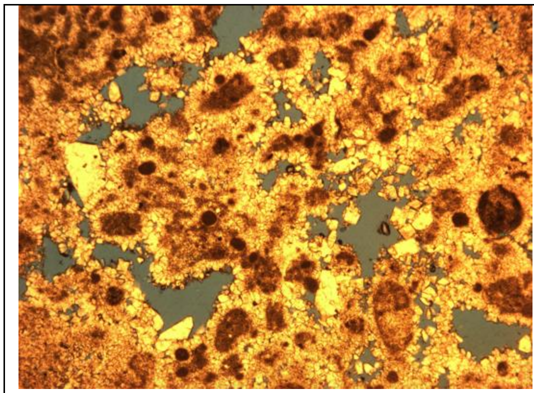
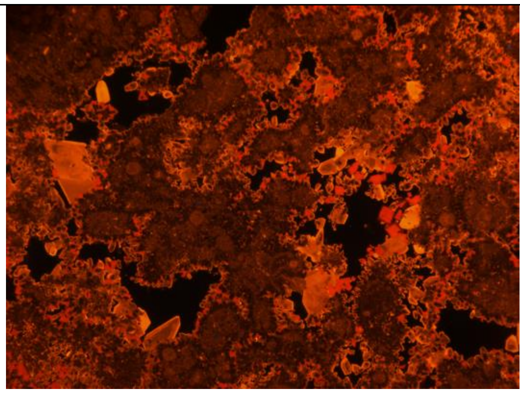
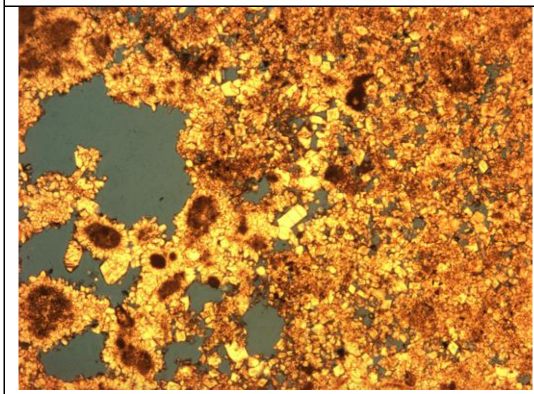
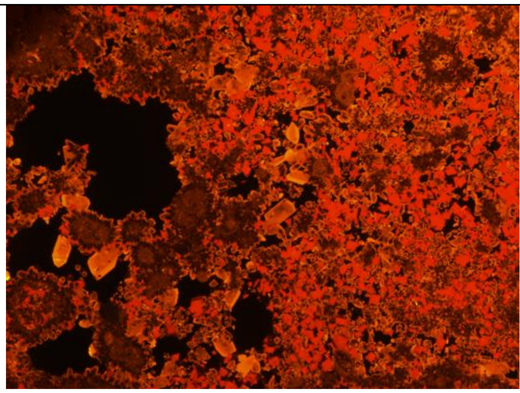
Pore type: Vuggy, intergranular, and intercrystalline.

Porosity (image analysis): 22%

Petrophysical analysis:
Porosity – 13%
Permeability – 58.2 md

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11601.2 ft

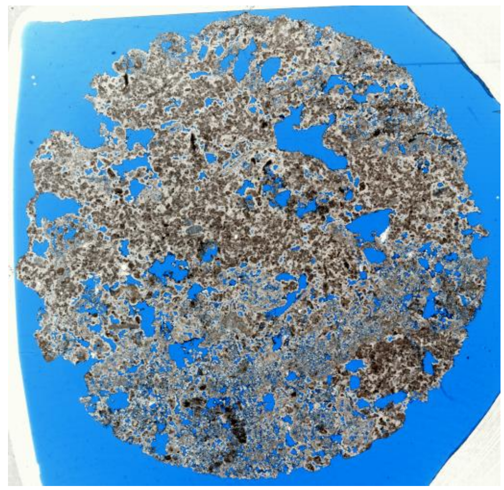
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement around the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. When the crystal present 2 zones they are the first and the second or the second and the third luminescent zones.
Blocky calcite cement, zoned. The number of zones varies from 2 to 3. The zones present the following sequence of color: dark brown – light brown – orange-yellow luminescence. When the crystals have 2 zones they are: light brown – orange-yellow.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals usually do not present zonation and have red luminescence, but locally it can present 2 or 3 zones: red – dark red – light red luminescence. When the crystal presents 2 zones, they are: red – dark red luminescence.

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11609.5 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and rare mollusks. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, some anhydrite cement.Chemical compaction (stylolite). Moderate to high dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

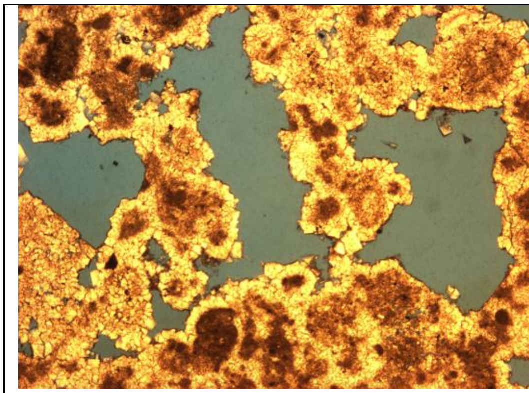
Pore type: Vuggy, intercrystalline, and itergranular.

Porosity (image analysis): 21%

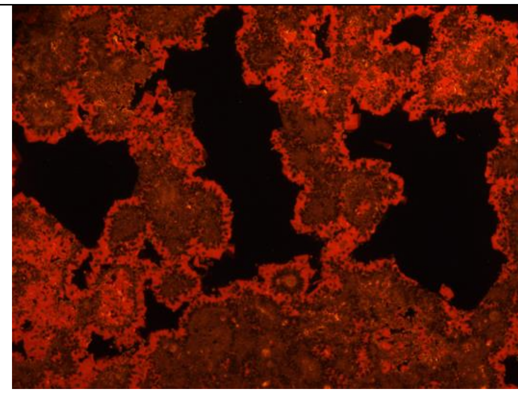
Petrophysical analysis:
Porosity – 20%
Permeability – 1,130 md

Little Cedar Creek Field **Well: 3** **Permit: 13439**

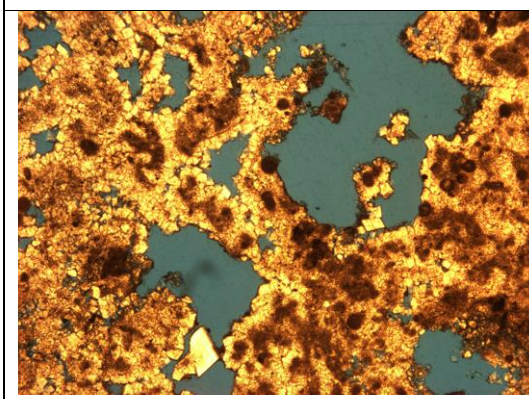
Depth: 11609.5 ft



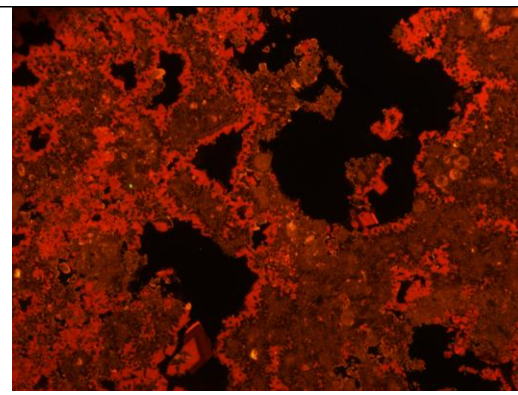
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



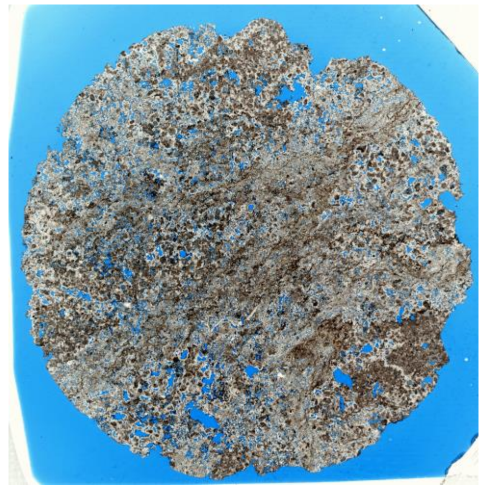
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, presenting dark brown luminescence. Locally it is zoned: first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, and the second zone has light brown luminescence.
Euhedral to subhedral very fine to fine dolomite crystals occur as a replacing / cementing phase. The dolomite replaces mainly the drusy calcite fringe cement. The dolomite crystals usually do not present zonation and have red luminescence, but locally it can present 2 to 5 zones, following the order: red – dark red – moderate dark red – dark red – light red luminescence.

Little Cedar Creek Field **Well: 3** **Permit: 13439**

Depth: 11613.4 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal Thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and some mollusks. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, rare anhydrite cement. Chemical compaction (stylolite). High dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution. Some discontinuous microfractures.

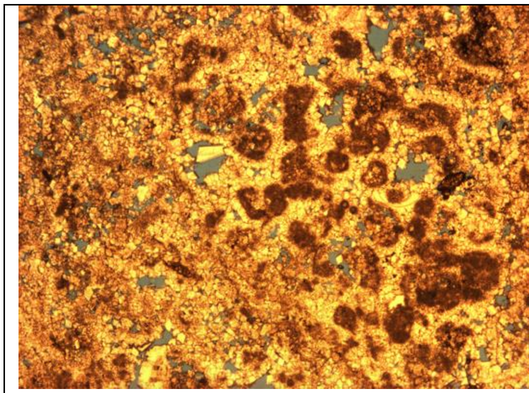
Pore type: Intercrystalline, vuggy and some intergranular.

Porosity (image analysis) : 15%

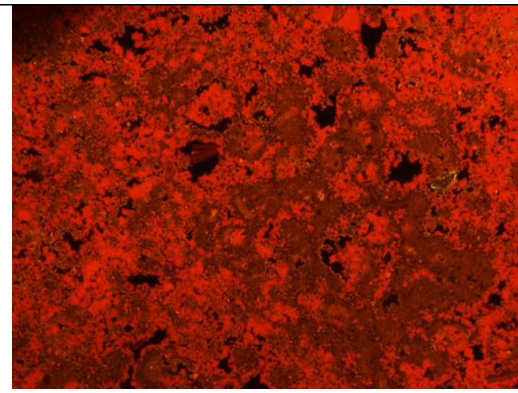
Petrophysical analysis:
Porosity – 13%
Permeability – 33.9 md

Little Cedar Creek Field **Well: 3** **Permit: 13439**

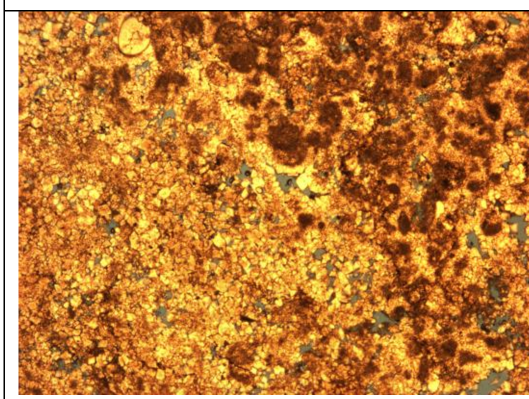
Depth: 11613.4 ft



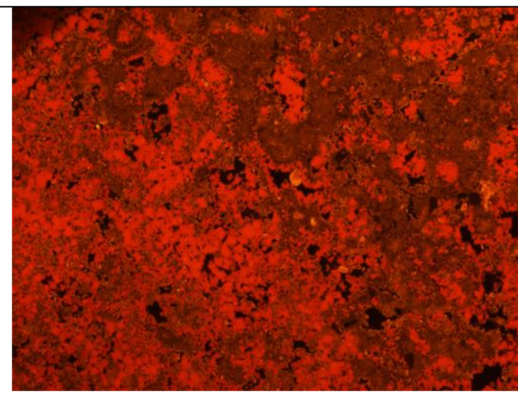
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

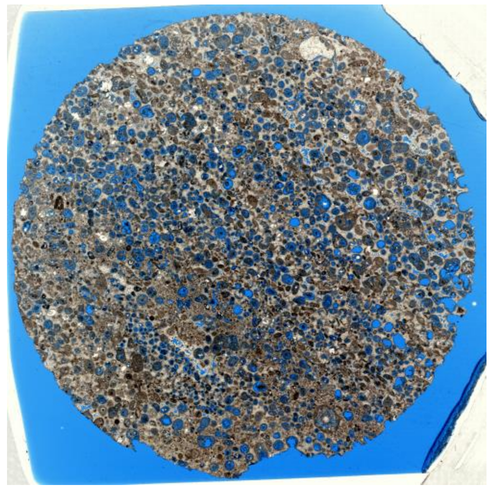
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown luminescent to nonluminescent, and the second zone has orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite replaces mainly the calcite cements. The dolomite crystals usually do not present zonation and have red luminescence, but locally it can present 2 to 3 zones, following the order: red – dark red – light red luminescence. When the crystal presents 2 zones, they are: red – dark red luminescence.

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11499.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Bimodal oolitic-peloidal grainstone.

Description: Oolitic-peloidal grainstone. Very fine to fine sand size peloids, fine to coarse sand size oolites, and some very coarse sand size grapestones. Gastropod and green algae fragments were observed. Fine sand size quartz and feldspar grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, small amount of anhydrite replacing grains and cement, oolite dissolution, very fine pyrite crystals replace grains and cement, no compaction features.

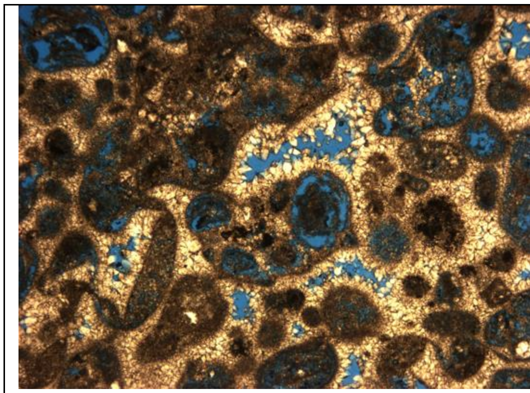
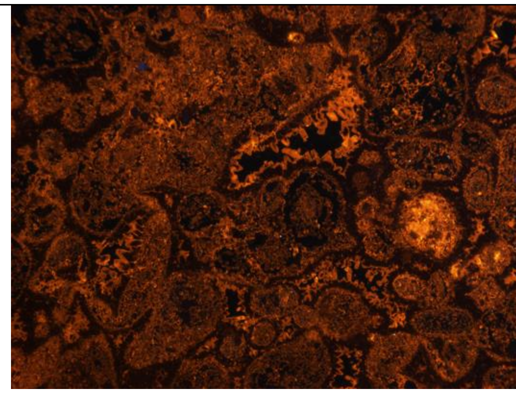
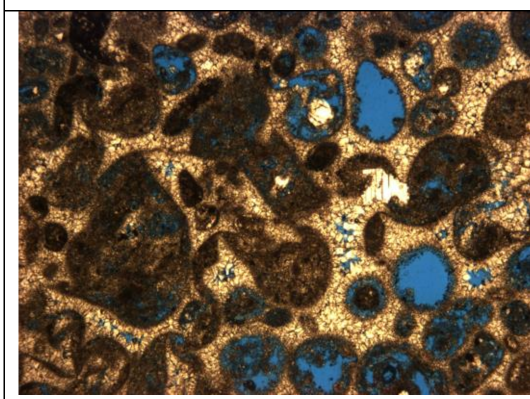
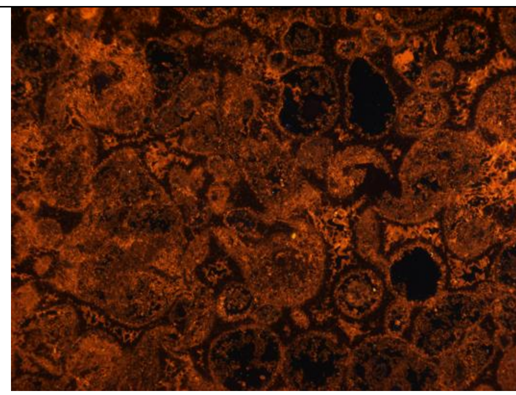
Pore type: moldic, intragranular and intergranular.

Porosity (image analysis) : 25%

Petrophysical analysis:
Porosity – 23%
Permeability – 0.081 md

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11499.4 ft

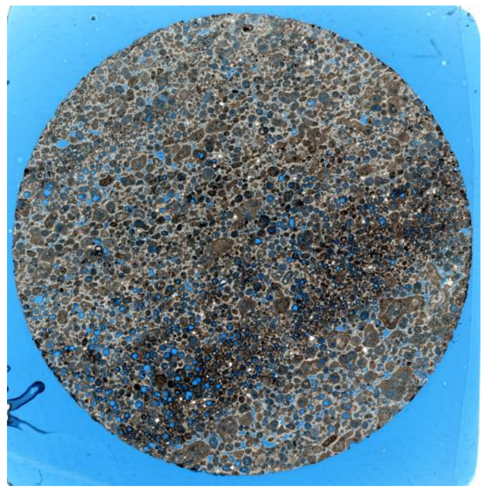
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). Locally it occurs inside the moldic and the intragranular porosity, growing from the border to the center. The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Very fine to fine mosaic calcite cement, orange-yellow luminescent.

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11506 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone, fine to medium sand size, with very fine sand size peloids and coarse sand to gravel size grapestones. A fining upward cycle is observed. Some very fine to fine sand quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, rare anhydrite replacing grains, rare blocky calcite cement, fine euhedral dolomite crystals replacing grains, oolite dissolution, very fine pyrite crystals replace grains and growing in pore space, no compaction features.

Pore type: Intergranular, moldic, and intragranular.

Porosity (image analysis) : 21%

Petrophysical analysis:
Porosity – 21%
Permeability – 0.309 md

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11506 ft

<table>
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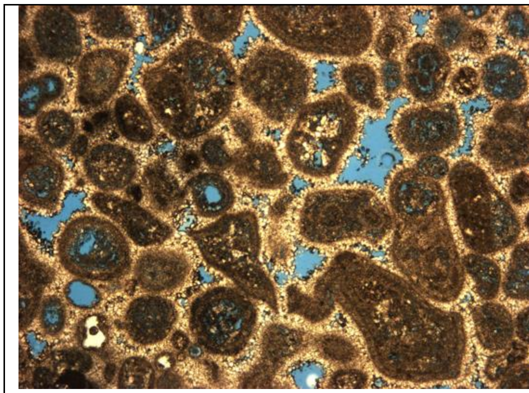
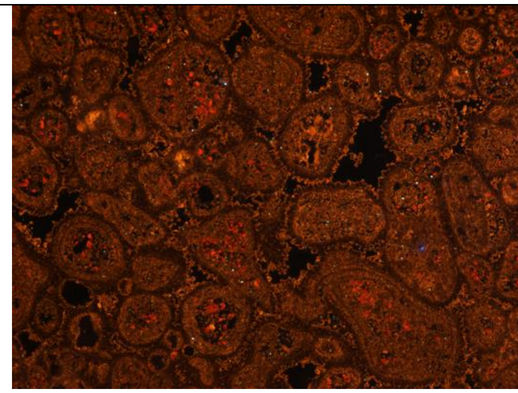
<td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td>
<td>
Cathodoluminesce image – same field of the picture on the left side</td>
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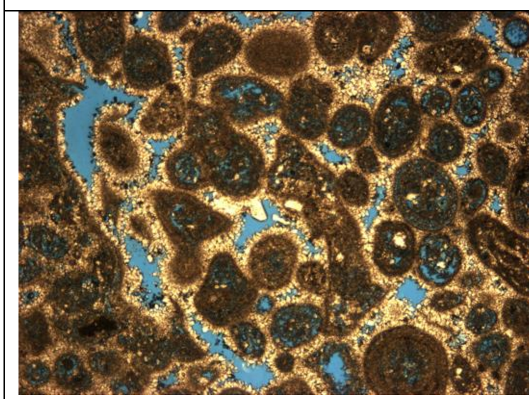
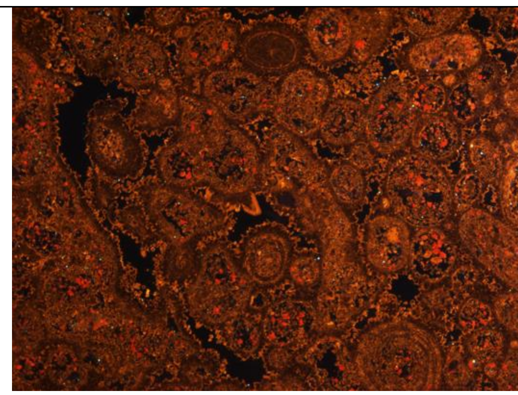
<td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td>
<td>
Cathodoluminesce image – same field of the picture on the left side</td>
</tr>
</table>

Cathodoluminescence image analysis:

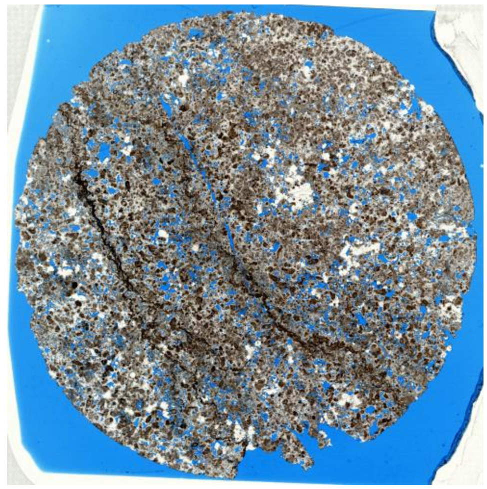
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone is light brown and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs, because all the space was filled, the second and third zones did not grow.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11531.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, some anhydrite cement.Chemical compaction (stylolite). Low dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution. Fractures cutting stylolites.

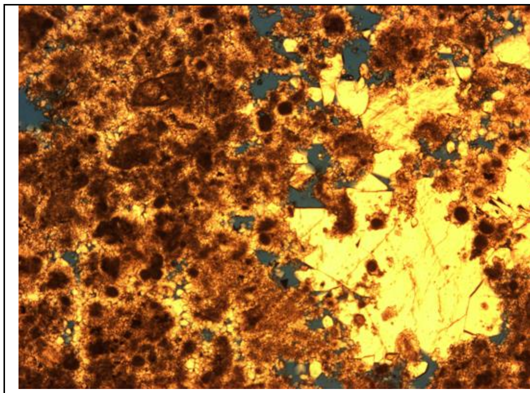
Pore type: Intergranular, intercrystalline, and vuggy.

Porosity (image analysis) : 15%

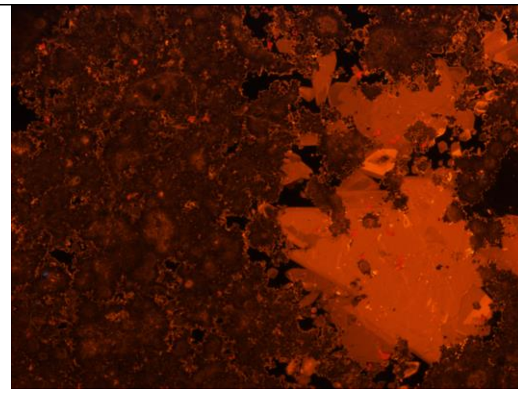
Petrophysical analysis:
Porosity – 11%
Permeability – 13 md

Little Cedar Creek Field **Well: 4** **Permit: 13510**

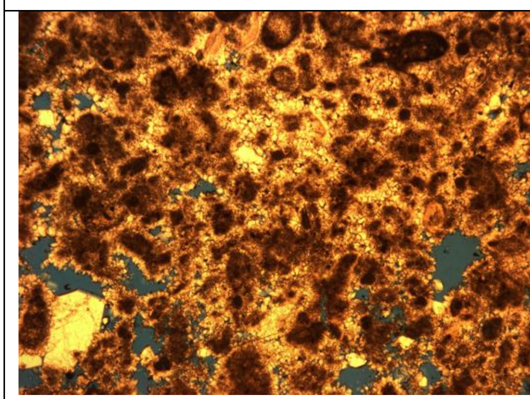
Depth: 11531.5 ft



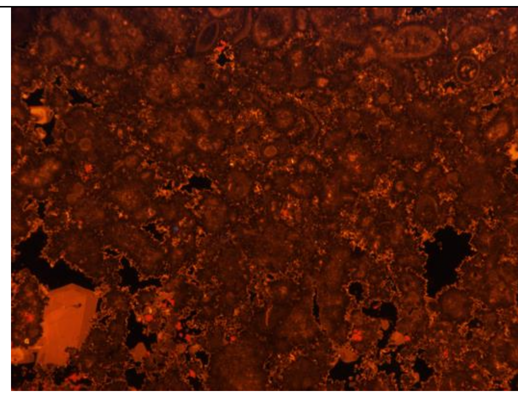
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The zones present the following sequence of luminescence (from de center to the edge): dark brown to nonluminescent – light brown – orange-yellow luminescence.
Blocky calcite cement, zoned. The number of zones varies from 2 to 4. Two zones are the most common. The zones generally present the following sequence of luminescence: light brown – orange-yellow; where 4 zones are present the sequence is: light brown –orange yellow – light brown-orange – light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals generally do not present zonation and present red luminescence. Locally dolomite presents 2 zones: red – dark red luminescence. Dolomite replaces grains and cements.

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11544.9 ft

<table>
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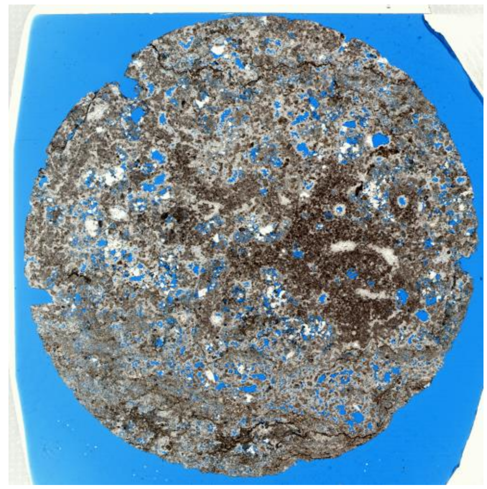
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
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<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Very small amount of silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, some anhydrite cement.Chemical compaction (stylolite). Low to moderate dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

Pore type: Vuggy, intercrystalline, and intergranular.

Porosity (image analysis): 11%

Petrophysical analysis:
Porosity – 11%
Permeability – 3.92 md

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</table>

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11544.9 ft

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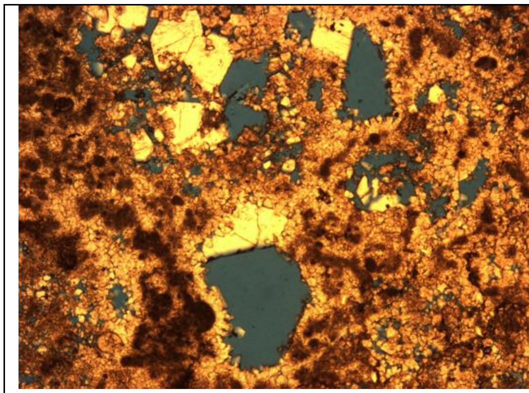
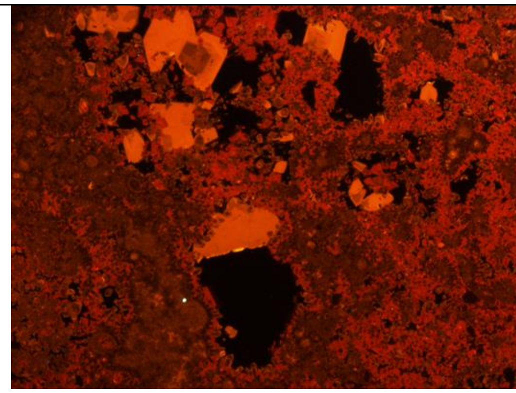
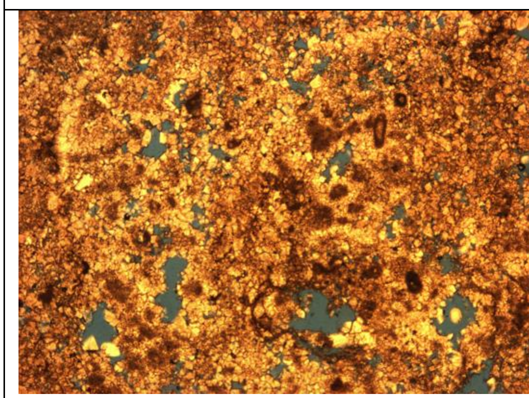
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
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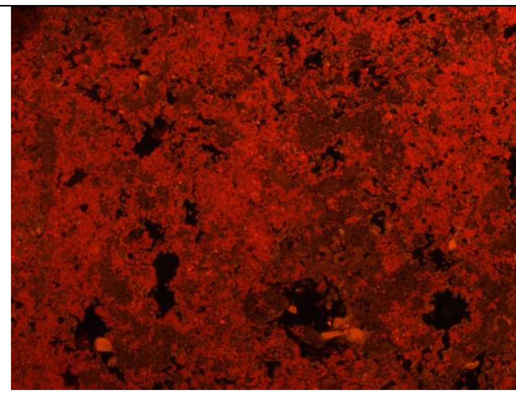
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

Cathodoluminescence image analysis:

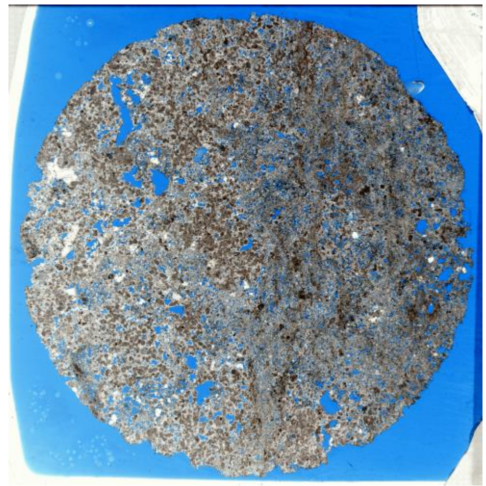
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 4 zones). The zones present the following sequence of luminescence (from de center to the edge): dark brown – orange-yellow - light brown – orange-yellow. In many cases only the two first zones occur.
Blocky calcite cement, zoned. The number of zones varies from 2 to 3. Two zones are the most common. The zones generally present the following sequence of luminescence: light brown –orange yellow – light brown.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and present red luminescence. Locally dolomite presents 2 zones: red – dark red luminescence. Dolomite replaces preferentially the drusy calcite cement fringe.

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11546 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloid thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, blocky calcite cement, some anhydrite cement. Chemical compaction (stylolite). Moderate to high dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

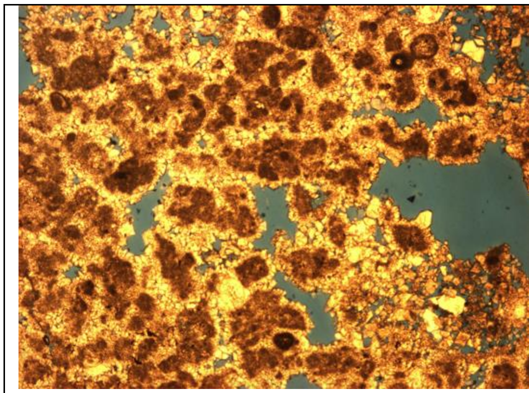
Pore type: Intercrystalline, vuggy and intergranular.

Porosity (image analysis): 18%

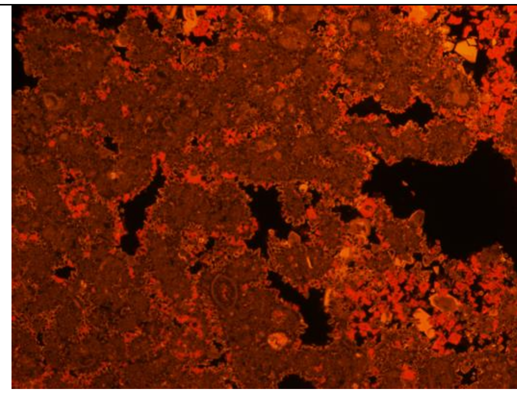
Petrophysical analysis:
Porosity – 12%
Permeability – 13.2 md

Little Cedar Creek Field **Well: 4** **Permit: 13510**

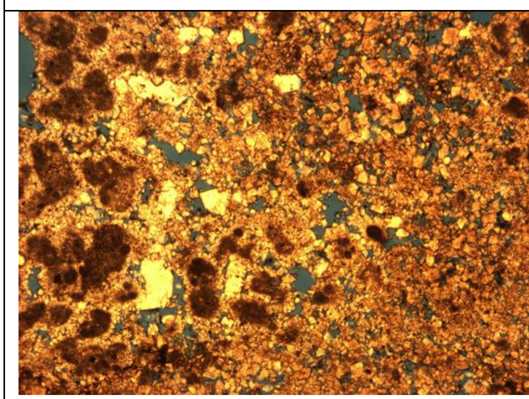
Depth: 11546 ft



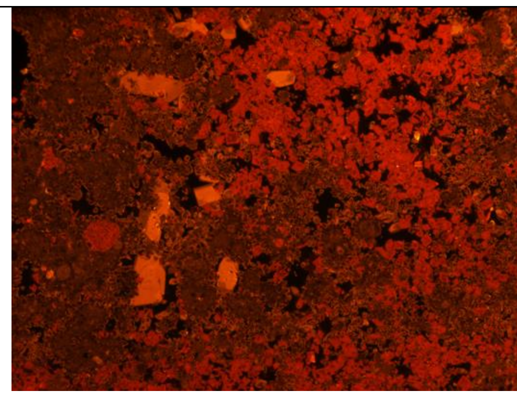
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

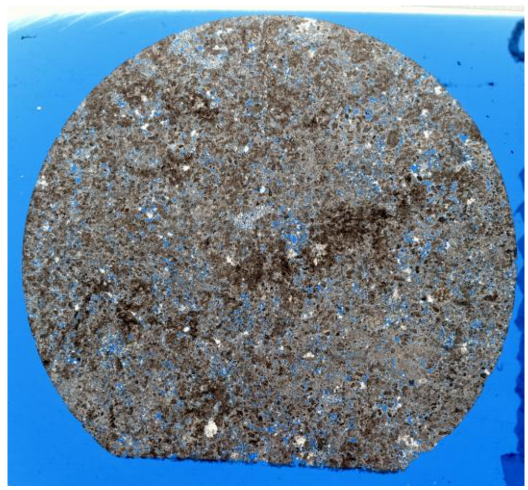
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The zones present the following sequence of luminescence: dark brown – orange-yellow (edge).
Blocky calcite cement, zoned. The number of zones varies from 2 to 3. Two zones are the most common. The zones generally present the following sequence of luminescence: dark to light brown – light brown – orange-yellow. **Euhedral to subhedral very fine dolomite** crystals occur as a replacing / cementing phase. The dolomite crystals have red luminescence, and generally present an irregular nucleous, darker than the edge. Locally dolomite presents a third zone, dark red luminescent. Dolomite replaces preferentially the drusy calcite fringe cement or dolomite crystals occur as patches.

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11551.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, some anhydrite cement. Chemical compaction (stylolite). Low to moderate dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase.

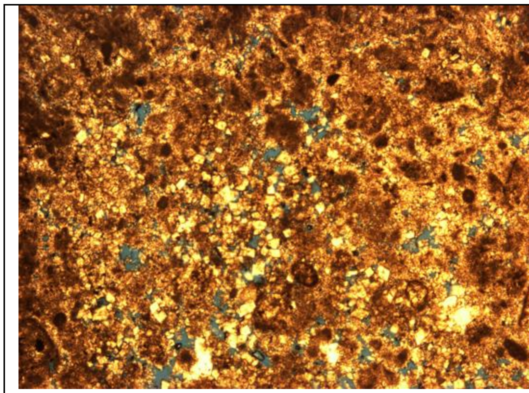
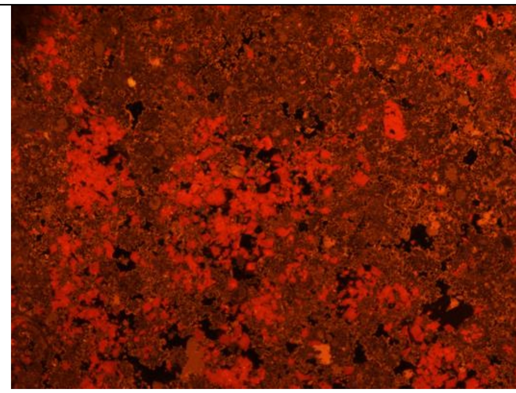
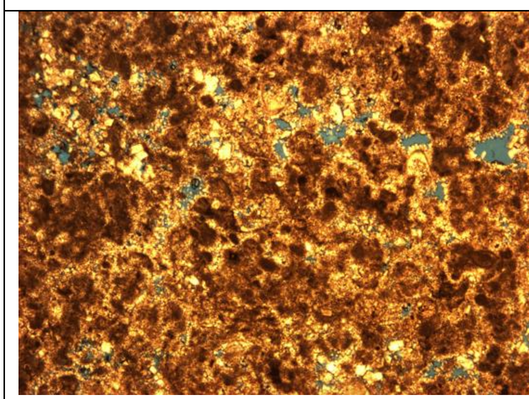
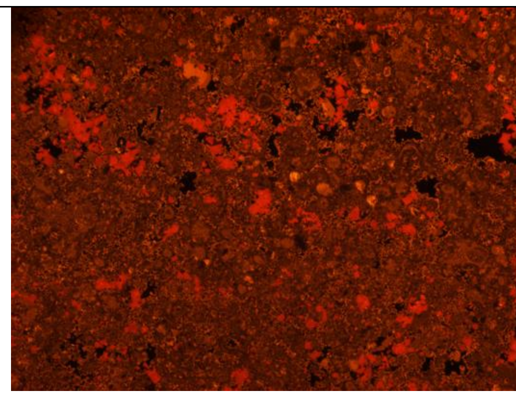
Pore type: Intergranular, intercrystalline, some intragranular and vuggy porosity.

Porosity (image analysis) : 11%

Petrophysical analysis:
Porosity – 10%
Permeability – 1.04 md

Little Cedar Creek Field **Well: 4** **Permit: 13510**

Depth: 11551.8 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

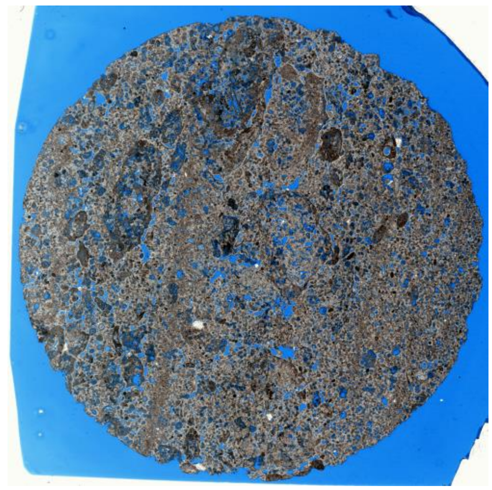
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The zones present the following sequence of luminescence: dark brown – orange-yellow (edge).
Blocky calcite cement, zoned (2 zones). The zones present the following sequence of luminescence: light brown to orange-yellow – light to dark brown.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals are generally not zoned, presenting red luminescence. Locally dolomite presents 2 zones: red – dark red.

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11444.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Very fine to fine sand oolitic-peloidal grainstone.

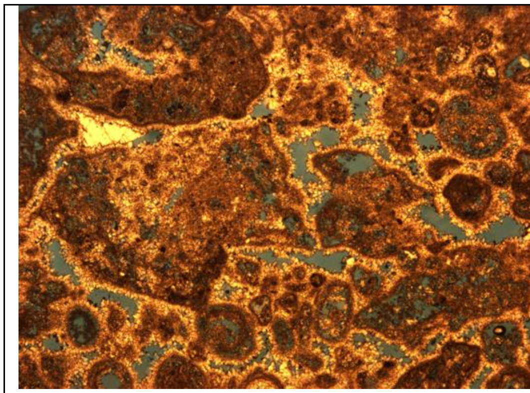
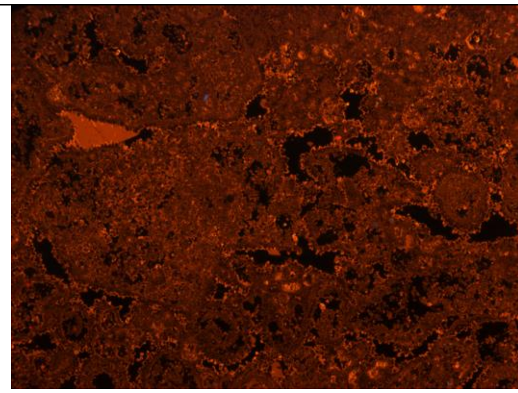
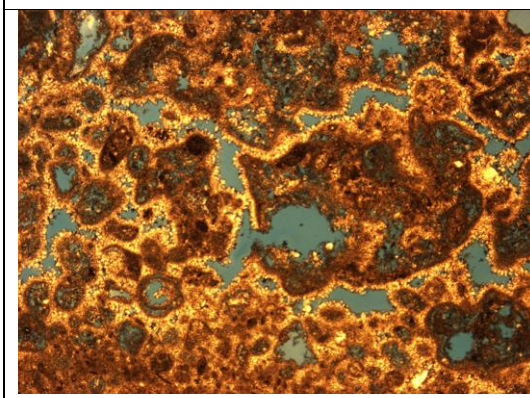
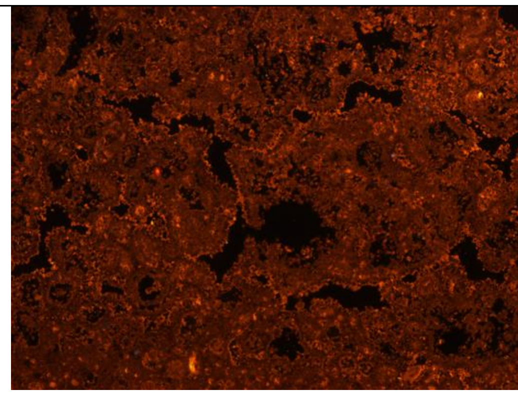
Description: Oolitic-peloidal grainstone, bioturbated. Fine sand size oolites, very fine to fine sand size peloids, and coarse sand to pebble size grapestones. Rare very fine sand quartz and green algae fragments occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, some blocky calcite cement, oolite dissolution, very fine pyrite crystals replace grains and cement, no compaction features.

Pore type: Intergranular, vuggy, intragranular and moldic.

Porosity (image analysis) : 23%

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11444.5 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

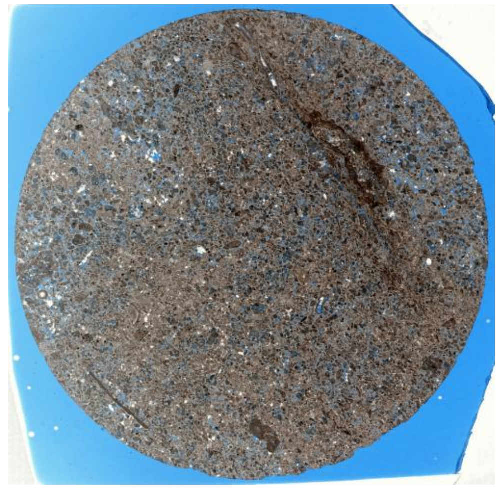
Bladed to drusy calcite fringe rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, presenting orange-yellow luminescence, unzoned.
Rare **Euhedral to subhedral very fine dolomite** crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11458.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Very fine to fine sand peloidal-skeletal grainstone.

Description: Peloidal-skeletal grainstone. Very fine to fine sand size peloids, medium to coarse sand size oncolites, green algae, echinoid (with sintaxial calcite cement), benthic foraminifera, and ostracods fragments. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement, fine euhedral dolomite crystals replacing grains, grain dissolution, botryoidal pyrite crystals replace grains, fracture cutting stylolite.

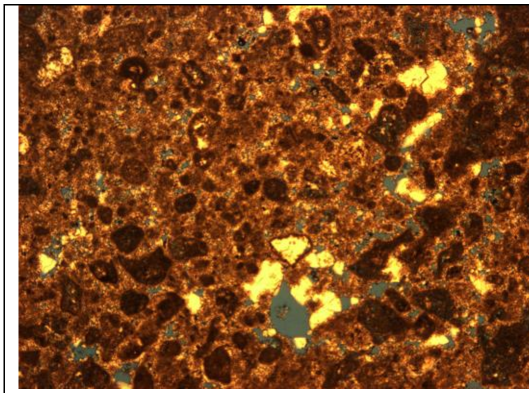
Pore classification: Intergranular, intragranular, and some moldic.

Porosity (image analysis): 7%

Petrophysical analysis:
Porosity – 15%
Permeability – 0.336 md

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11458.4 ft

<table>
<tr><td>
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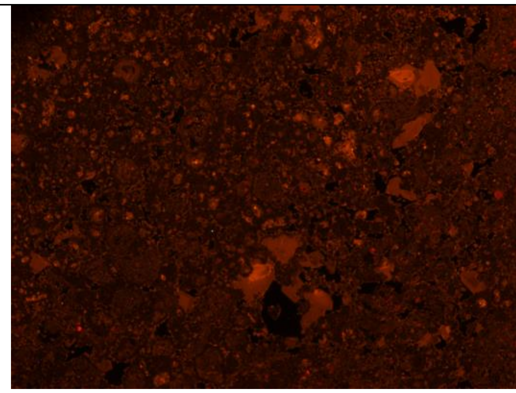
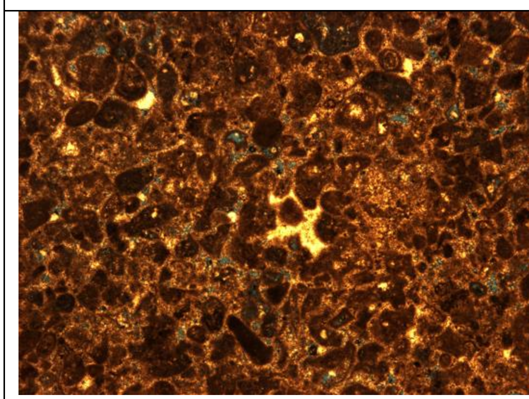
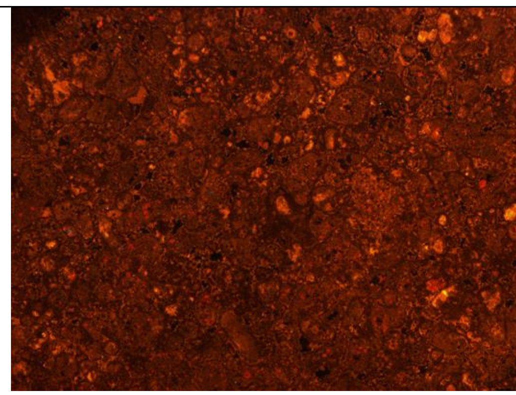
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

Cathodoluminescence image analysis:

Bladed to drusy calcite fringe rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.

Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: yellow-orange – light brown – brown luminescence. The crystals present generally 2 zones or are non-zoned. The non-zoned crystals present light brown luminescence.

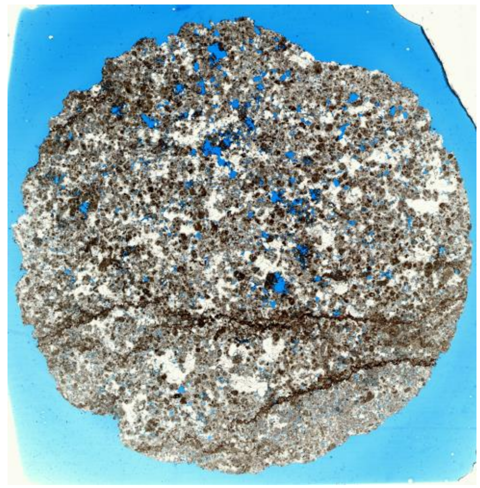
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in very small amount.

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11481 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

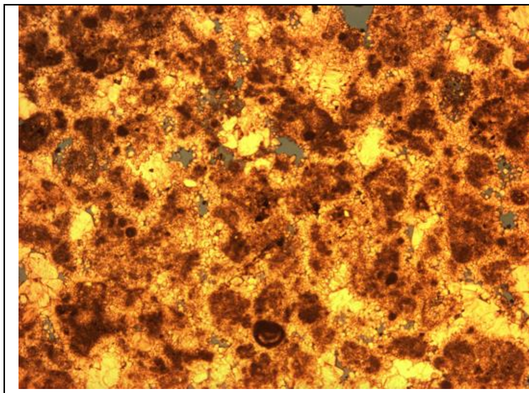
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, significant amount of blocky calcite cement. Chemical compaction (stylolite). Very low dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

Pore type: Intergranular, vuggy, and some intercrystalline.

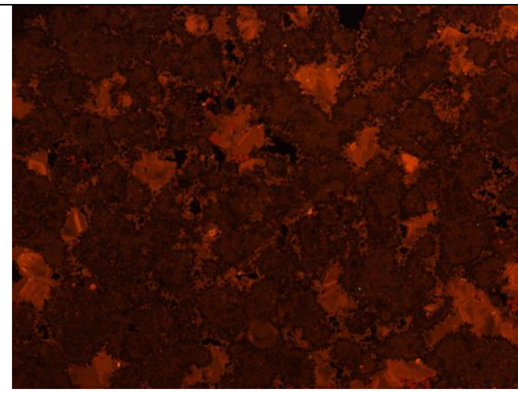
Porosity (image analysis): 8%

Little Cedar Creek Field **Well: 5** **Permit: 13697**

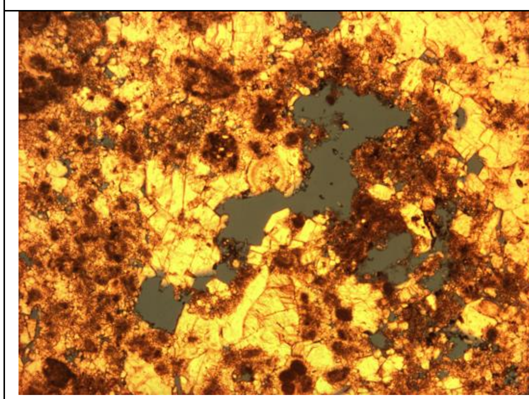
Depth: 11481 ft



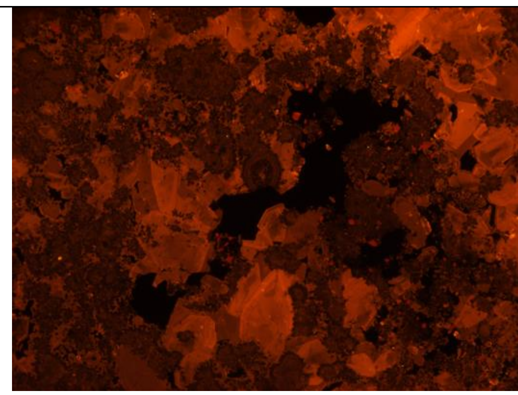
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



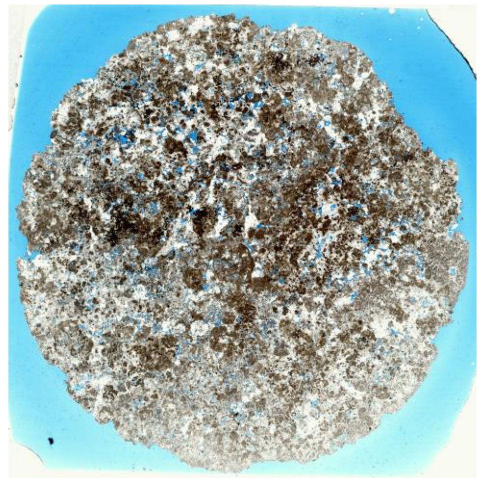
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 to 5 zones). The zones present the following order: dark brown – light brown - yellow-orange – light brown – orange-yellow luminescence. The crystals present generally 2 zones: orange-yellow and light brown.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in very small amount.

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11482.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

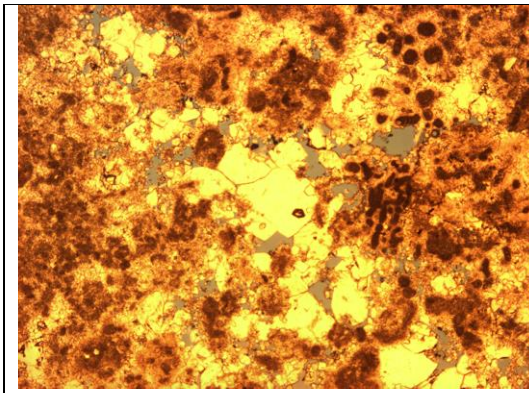
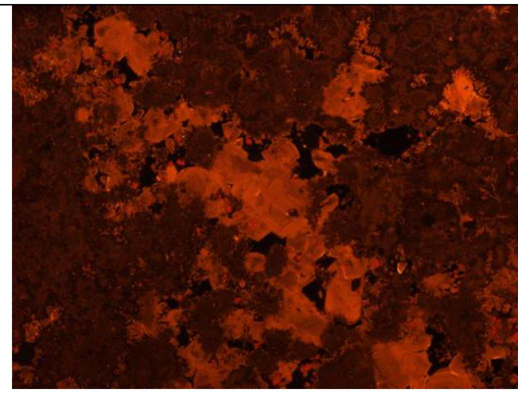
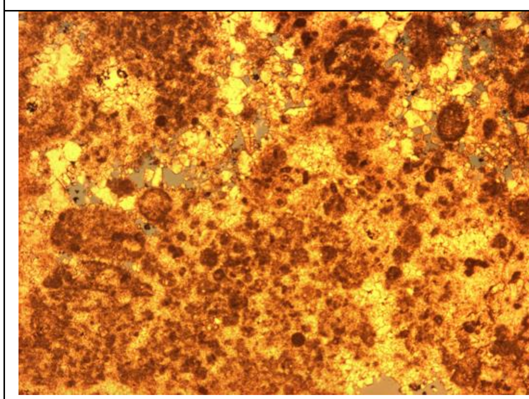
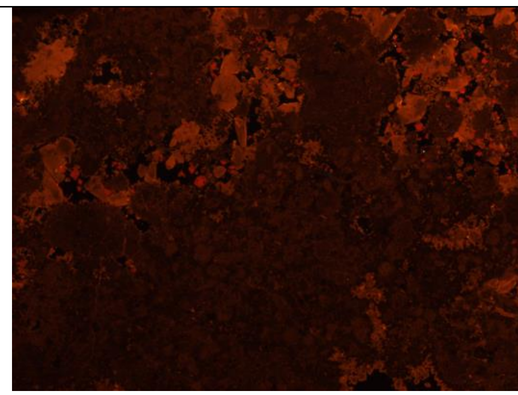
Description: Peloidal thrombolite, with some tubular structures and bioclasts. The tubules are cylindrical and sparsely branched. Silt to fine sand size quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and green algae. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement, mosaic calcite cement, significant amount of blocky calcite cement. Chemical compaction (stylolite). Very low dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Some discontinuos microfractures partially cemented by blocky calcite.

Pore type: Intergranular, vuggy, and intercrystalline.

Porosity (image analysis): 8%

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11482.9 ft

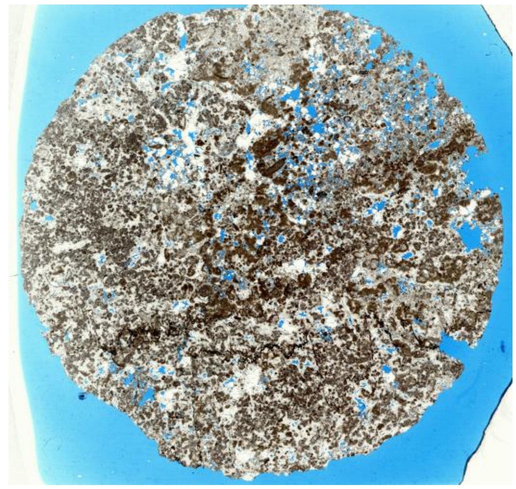
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: dark brown – light brown - yellow-orange luminescence. The crystals present generally 2 zones: orange-yellow and light brown.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in very small amount.

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11491 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some tubular structures and bioclasts. The tubules are cylindrical and sparsely branched. Silt to fine sand size quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement, mosaic calcite cement, blocky calcite cement. Chemical compaction (stylolite). Very low dolomitization. Primary growth framework vugs present enlargement by dissolution.

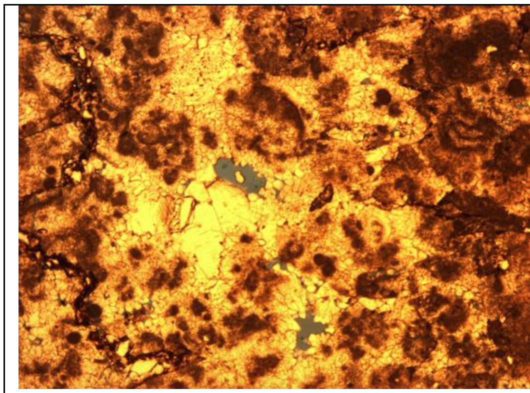
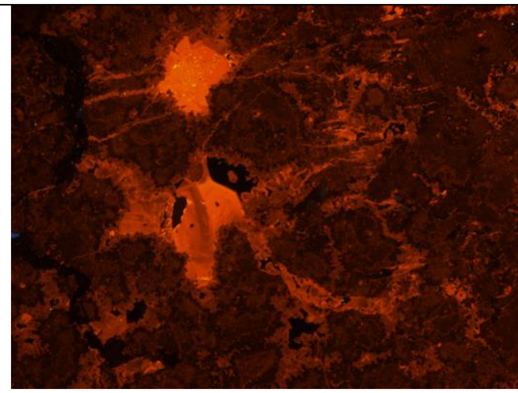
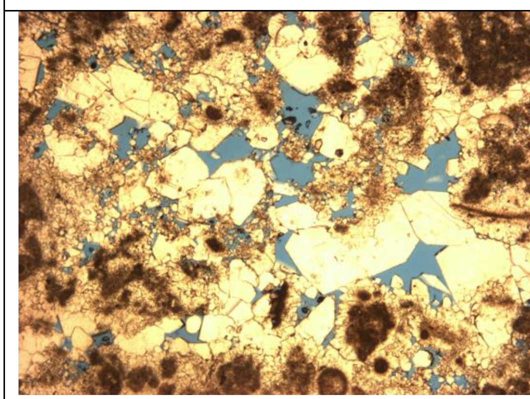
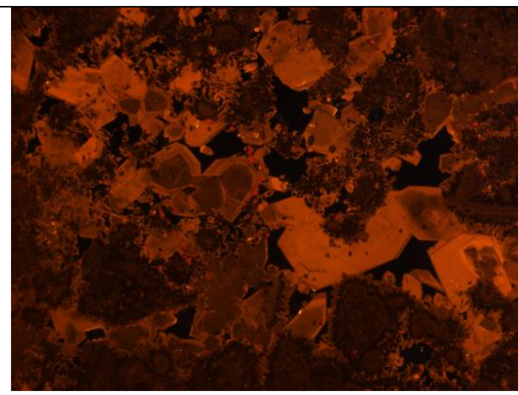
Pore type: vuggy, intergranular, and intercrystalline.

Porosity (image analysis): 9%

Petrophysical analysis:
Porosity – 5%
Permeability – 0.068 md

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11491 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

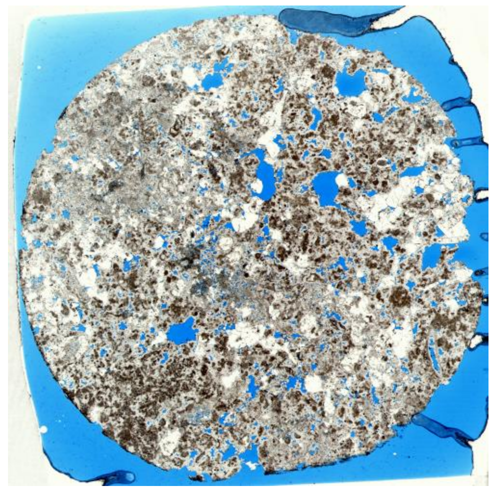
Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Blocky calcite cement, zoned (2 to 4 zones). The zones present the following order: dark brown – yellow-orange - light brown - yellow-orange luminescence. The crystals present generally 2 zones: orange-yellow and light brown.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Locally it presents 2 zones: red – dark red luminescence. Dolomite occurs in very small amount.
Microfractures – the CL highlighted the local presence of pre-compaction microfractures filled with orange-yellow luminescent calcite.

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11498.8 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
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Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and green algae (?). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, significant amount of blocky calcite cement. Low dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution. Some discontinuous microfractures partially cemented by blocky calcite.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 9%

Petrophysical analysis:
Porosity – 10%
Permeability – 0.803 md

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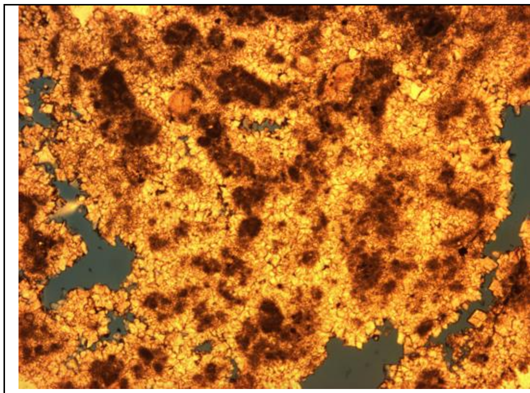
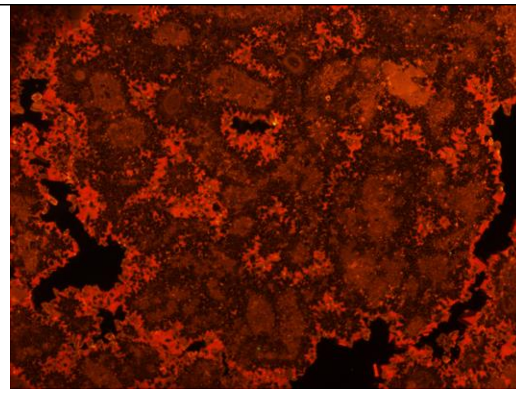
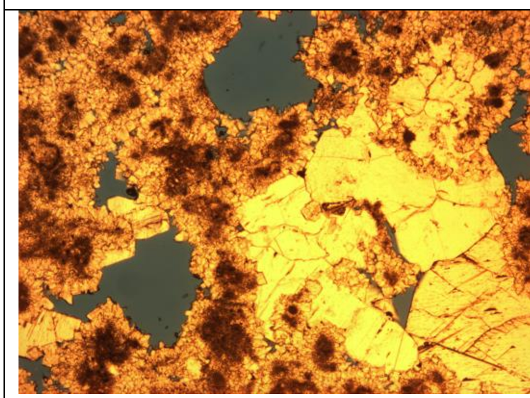
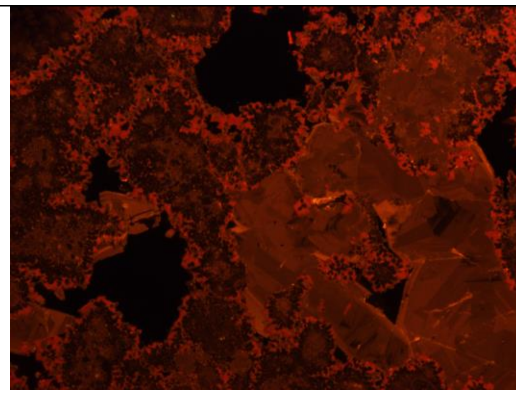
</table>

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11498.8 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

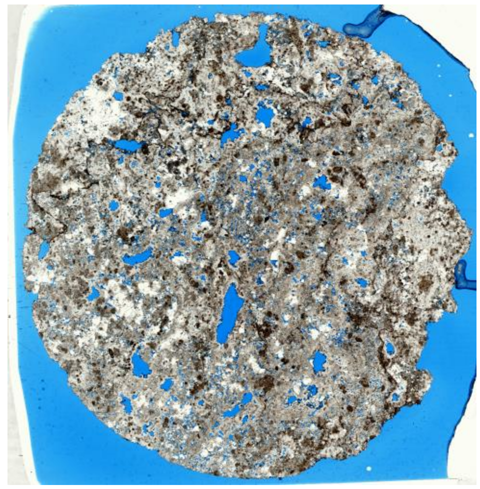
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: dark brown – light brown – yellow-orange luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. The dolomite replaces preferentially the drusy calcite fringe.

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11500.9 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

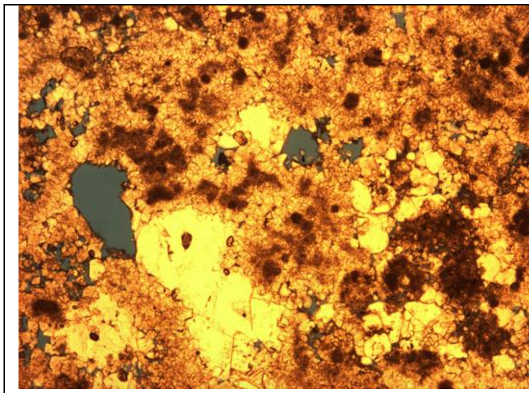
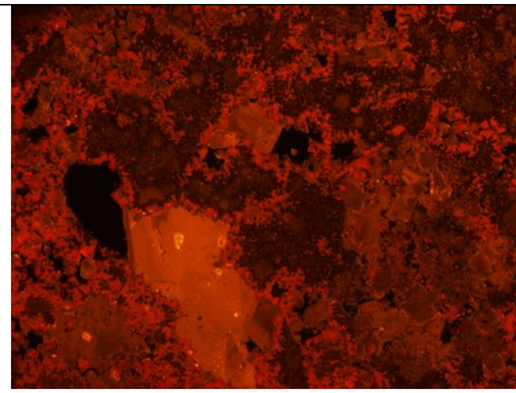
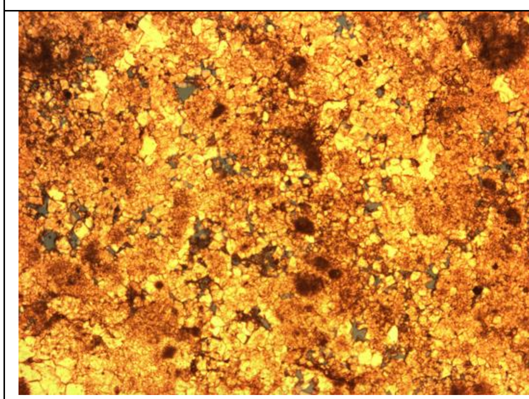
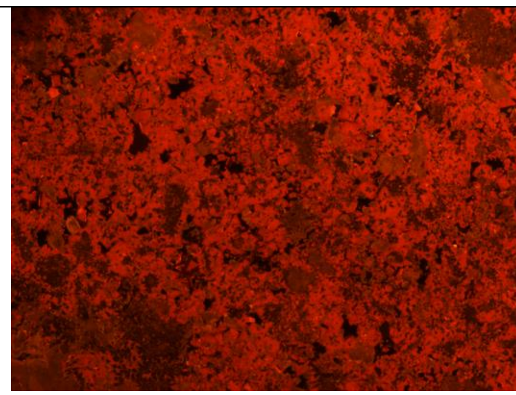
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz, feldspar and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement. Chemical compaction (stylolite). Moderate dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 10%

Little Cedar Creek Field **Well: 5** **Permit: 13697**

Depth: 11500.9 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

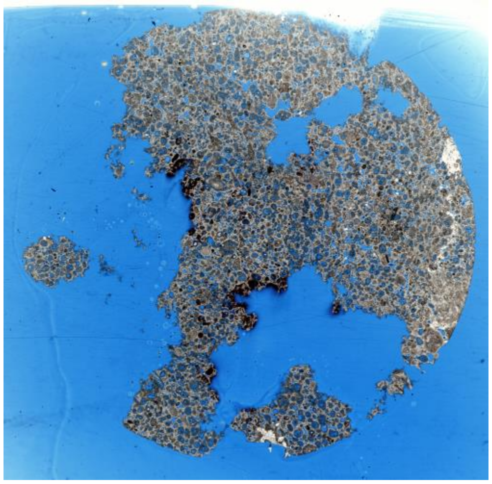
Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has light brown luminescence.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: dark brown – light brown – dark brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and have red luminescence, but locally present 2 or 3 zones: red – dark red – light red luminescence. The dolomite replaces preferentially the drusy calcite fringe, but also it occurs as patches.

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11346.2 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone. Fine to medium sand size oolites, very fine to fine sand size peloids and rare benthic foraminifera. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, some blocky calcite cement, some anhydrite crystals replacing grains and cements, oolite dissolution, no compaction features.

Pore type: Intergranular, intragranular, moldic and vuggy.

Porosity (image analysis): 25%

Petrophysical analysis:
Porosity – 26%
Permeability – 2.58 md

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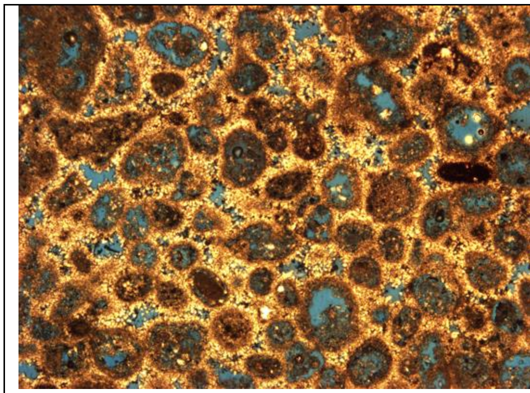
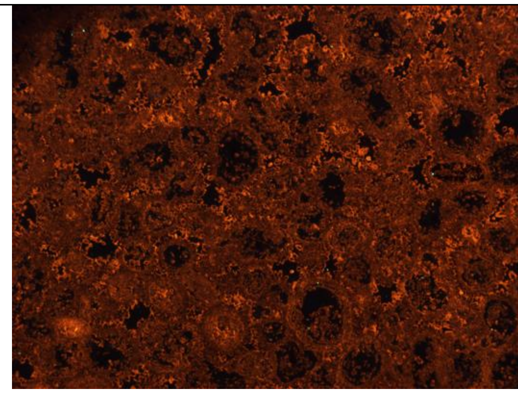
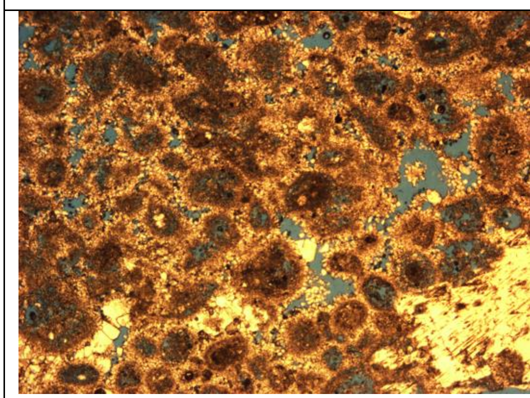
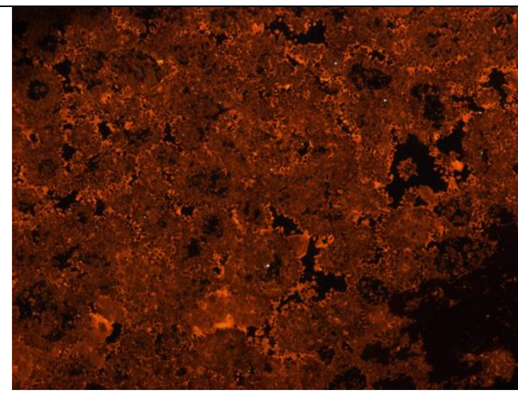
</table>

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11346.2 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

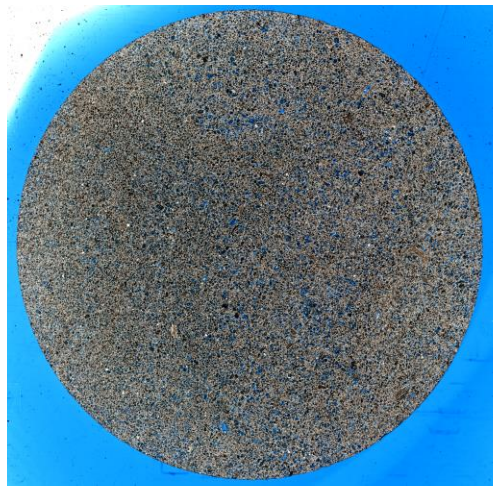
Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (4 zones). The zones present the following order: dark brown – light brown – dark brown – light brown to orange-yellow.

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11350.5 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
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</table>

Lithology: Very fine sand peloidal grainstone.

Description: Peloidal grainstone. Very fine sand size peloids, some fine to very fine sand quartz and muscovite grains, and echinoid (with sintaxial calcite cement), ostracods (with sintaxial calcite cement), bivalve fragments. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, rare blocky calcite cement, rare quartz cement, grain dissolution, no compaction features.

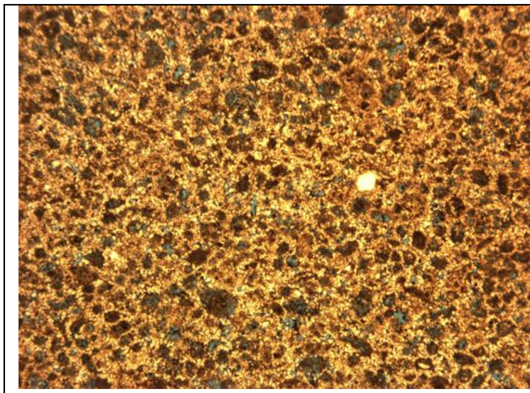
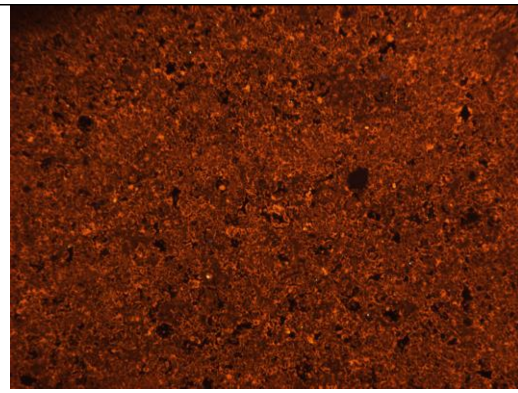
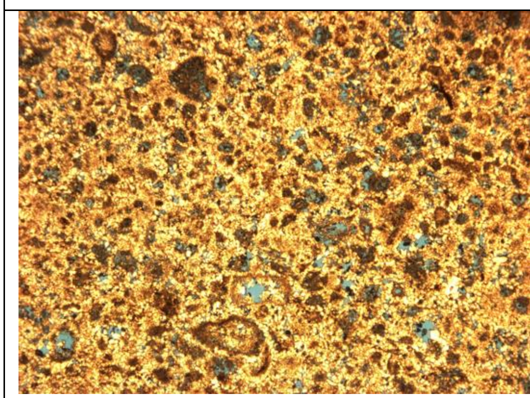
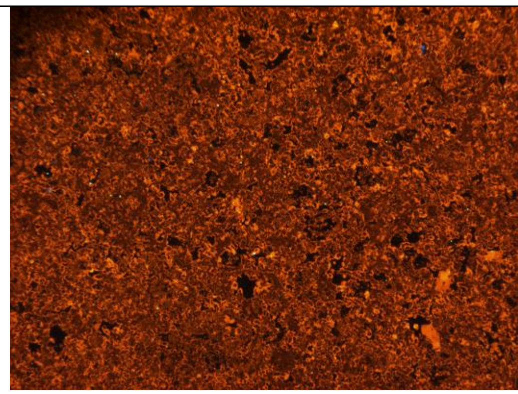
Pore type: Intragranular, moldic and intergranular.

Porosity (image analysis): 20%

Petrophysical analysis:
Porosity – 20%
Permeability – 3.26 md

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11350.5 ft

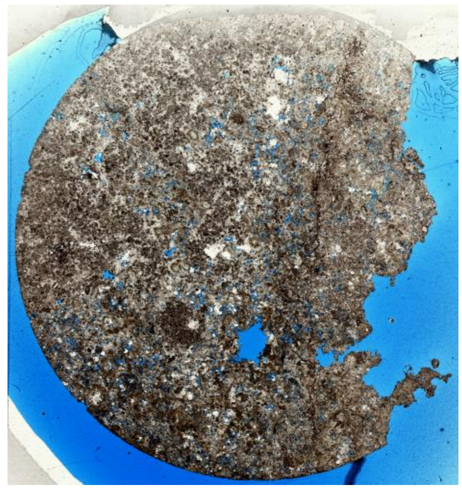
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow. A very small amount of the blocky calcite was observed.

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11386.3 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and green algae. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolite). Very low dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. Presence of microfracture. Late dissolution.

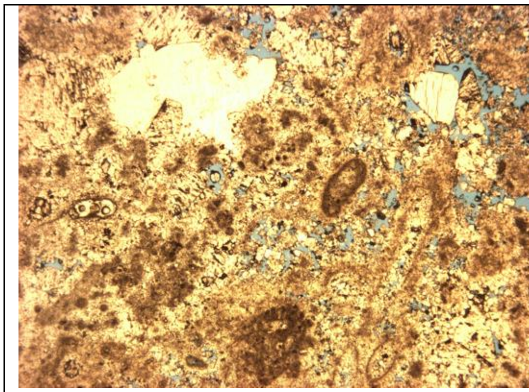
Pore type: Vuggy, intergranular, and intercrystalline.

Porosity (image analysis): 8%

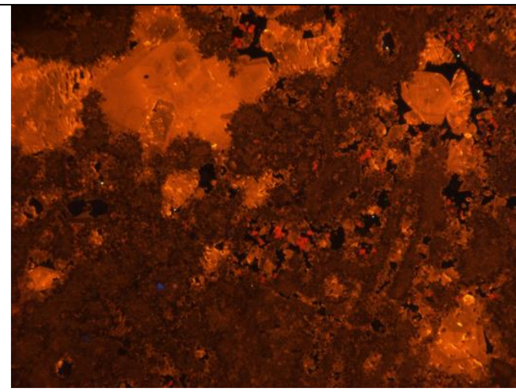
Petrophysical analysis:
Porosity – 8%
Permeability – 0.252 md

Little Cedar Creek Field **Well: 6** **Permit: 13746**

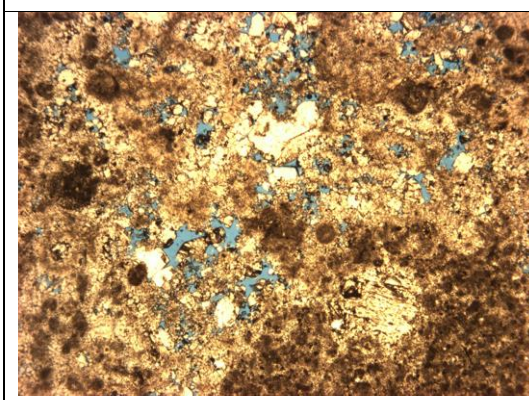
Depth: 11386.3 ft



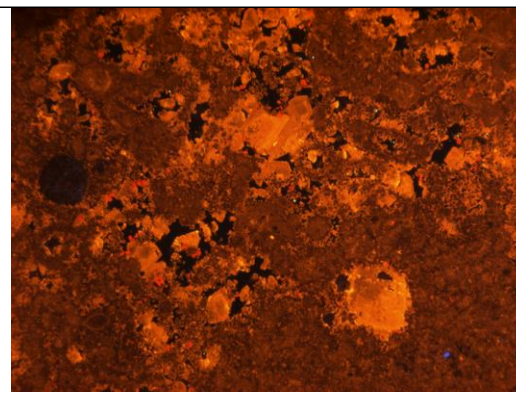
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

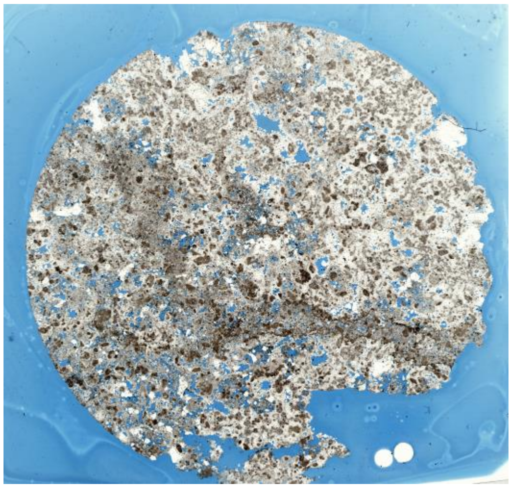
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has light brown luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 to 3 zones): light brown – orange-yellow – light brown.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in small amount.

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11391.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolite). Moderate dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution.

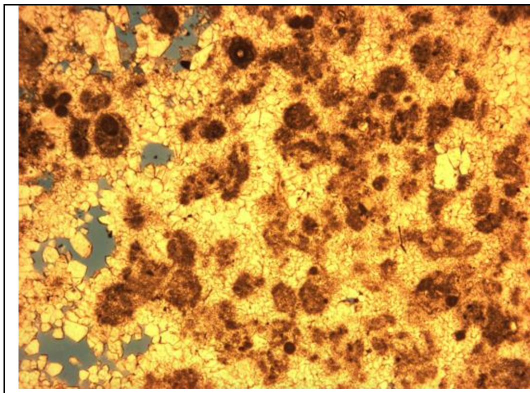
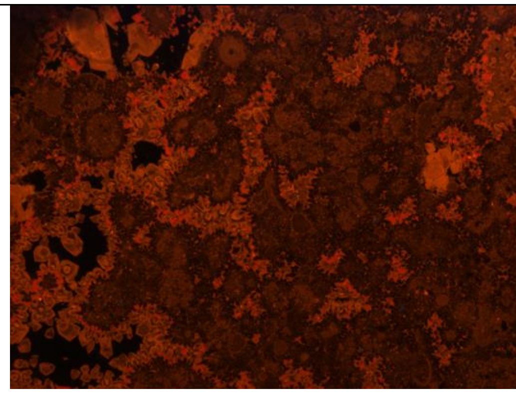
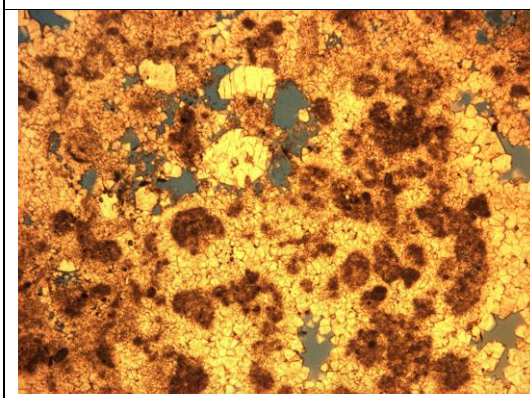
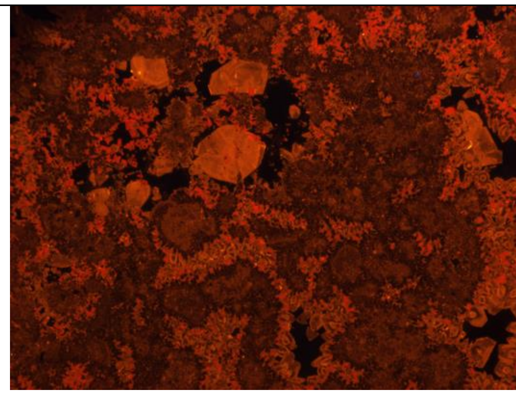
Pore type: Vuggy, intergranular, and intercrystalline.

Porosity (image analysis): 13%

Petrophysical analysis:
Porosity – 13%
Permeability – 31.7 md

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11391.6 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

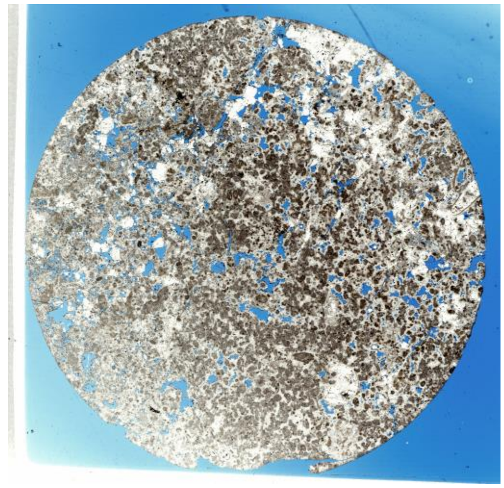
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Drusy calcite cement, zoned (4 zones). It grows on the top of the first cementation phase. The zones present the following order: light brown – orange-yellow – light brown – orange yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence. Some crystals are not zoned, presenting orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite replaces preferentially the first cementation phase.

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11395.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some tubular structures and bioclasts. Silt to fine sand size quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and green algae (?). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Low dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Primary growth framework vugs present enlargement by dissolution. Microfractures are partially cemented by blocky calcite.

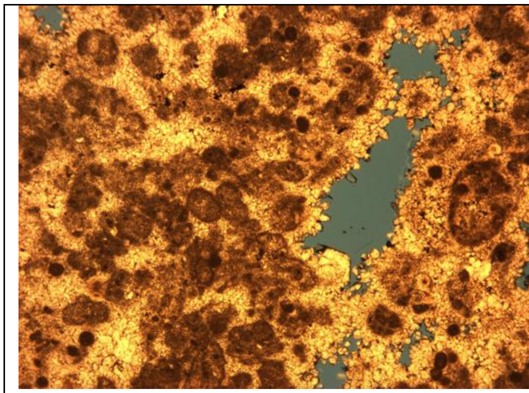
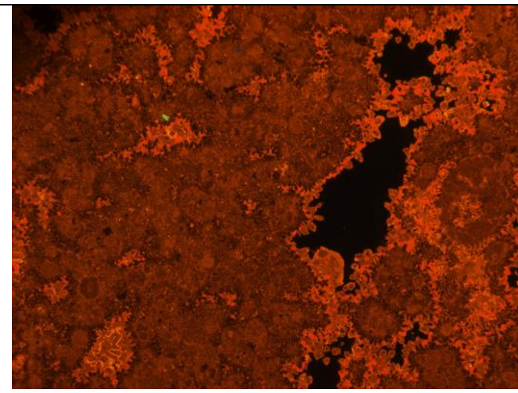
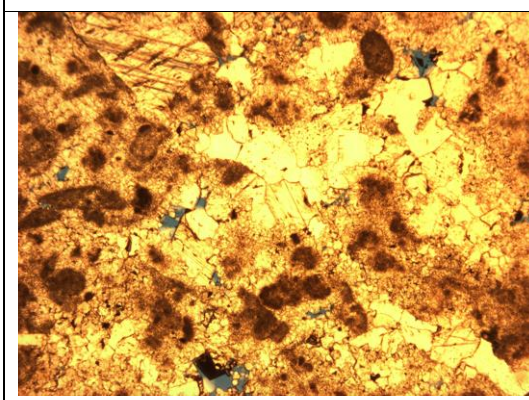
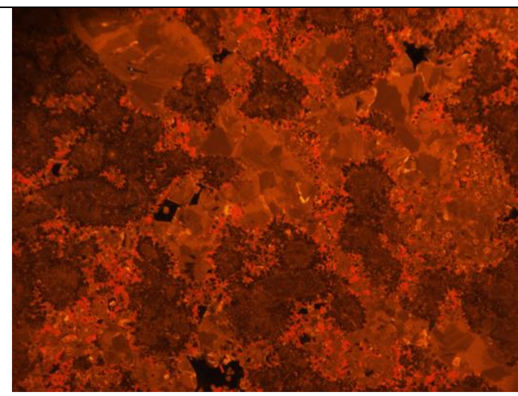
Pore type: Vuggy and some intergranular.

Porosity (image analysis): 8%

Petrophysical analysis:
Porosity – 10%
Permeability – 49 md

Little Cedar Creek Field **Well: 6** **Permit: 13746**

Depth: 11395.6 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

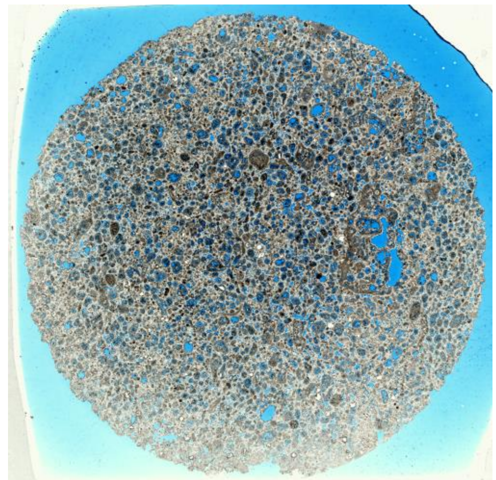
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. The third zone occurs locally. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: dark brown – light brown - yellow-orange yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite replaces preferentially the drusy calcite fringe cement.

Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11802.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone, with some bioturbation. Fine to medium (some coarse) sand size oolites, benthic foraminifera, and grapestones. Very fine sand quartz and feldspar grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, oolite dissolution, local dissolution of the bladed to drusy calcite cement, very fine pyrite crystals replace grains and cement, no compaction features.

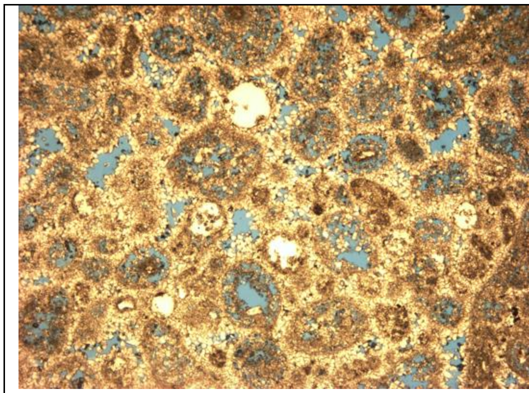
Pore type: moldic, intragranular, intergranular and vuggy.

Porosity (image analysis) : 22%

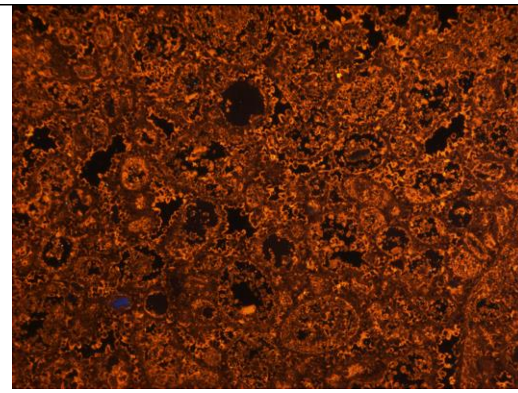
Petrophysical analysis:
Porosity – 20%
Permeability – 1.49 md

Little Cedar Creek Field **Well: 7** **Permit: 13907**

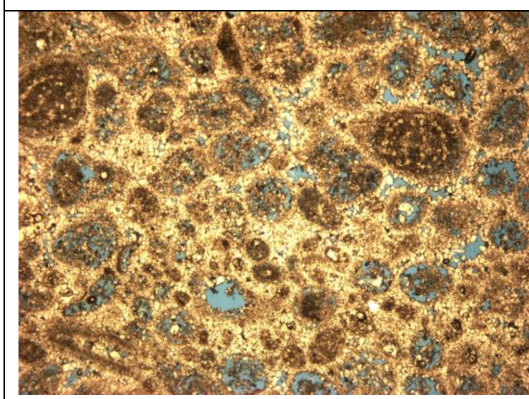
Depth: 11802.5 ft



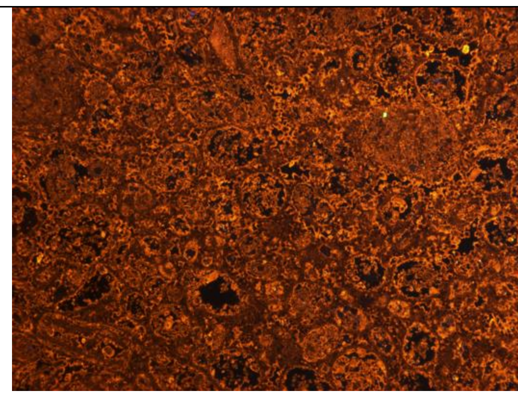
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

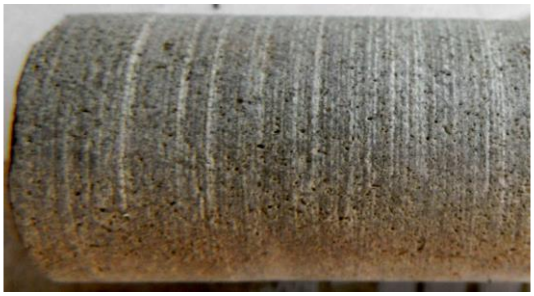
Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow. A very small amount of the blocky calcite was observed.

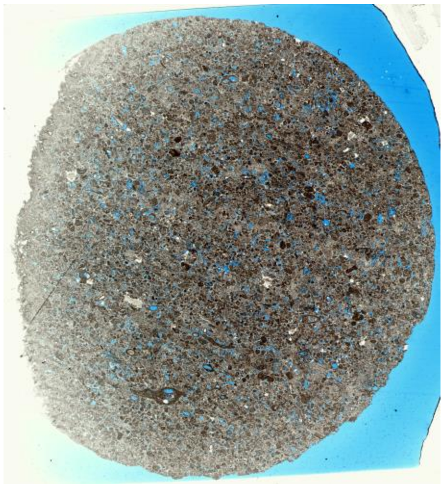
Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11815.5 ft

Plug – 2.15 cm (diameter)



Macroscopic photo



Scanned thin section

Lithology: Very fine to medium sand peloidal-skeletal grainstone.

Description: Peloidal-skeletal grainstone. Very fine to fine sand size peloids, fine to medium sand size skeletal fragments: benthic foraminifera, echinoid (with sintaxial calcite cement) and green algae. Rare fine sand quartz grains. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, blocky calcite cement, oolite dissolution, local dissolution of the bladed to drusy calcite cement, very fine pyrite crystals replace grains and cement, very fine dolomite crystals replace grains, no compaction features.

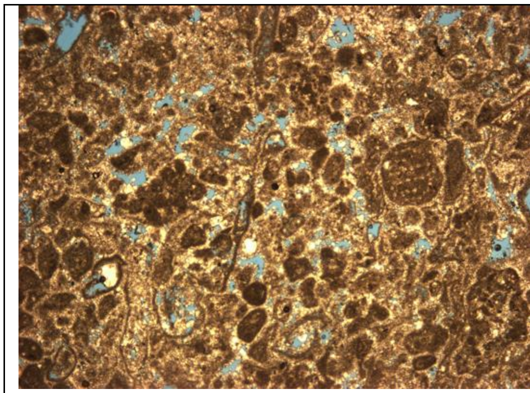
Pore type: Intergranular, intragranular, some moldic.

Porosity (image analysis): 9%

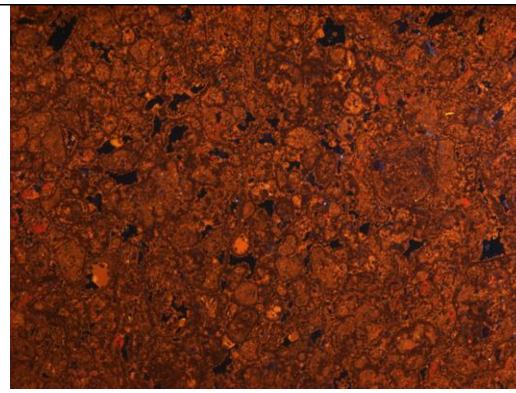
Petrophysical analysis:
Porosity – 13%
Permeability – 1.14 md

Little Cedar Creek Field **Well: 7** **Permit: 13907**

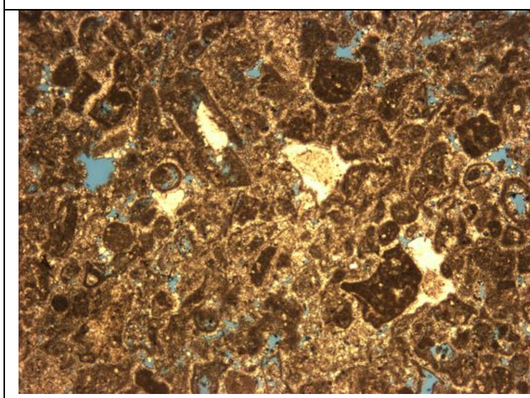
Depth: 11815.5 ft



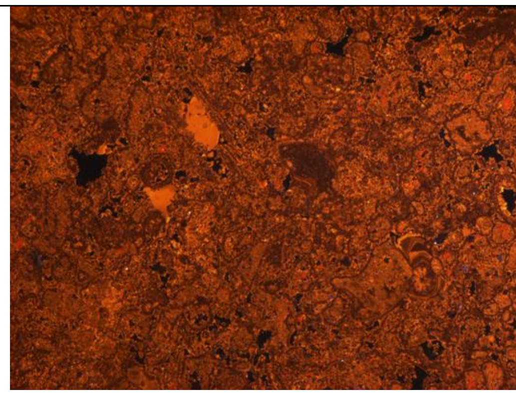
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



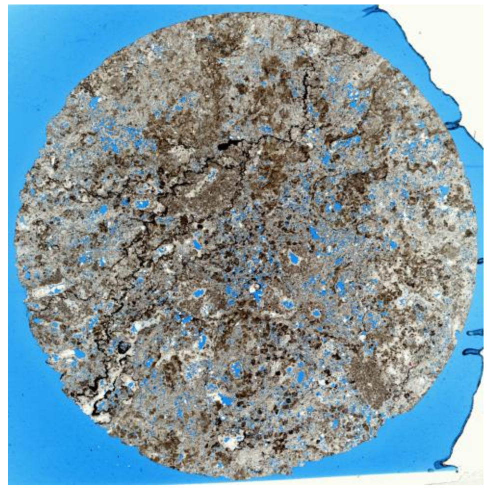
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Sintaxial calcite cement around equinoid fragments, zoned (5 zones, up to 16 subzones). The five major zones are, from the center to the edge: light brown – orange-yellow – dark brown – light brown – orange yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow. A very small amount of the blocky calcite was observed.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in a very small amount.

Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11837.8 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some tubular structures and bioclasts. Silt to fine sand size quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolite). High dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase.

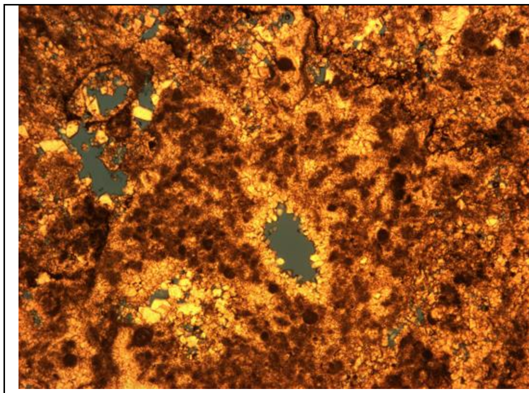
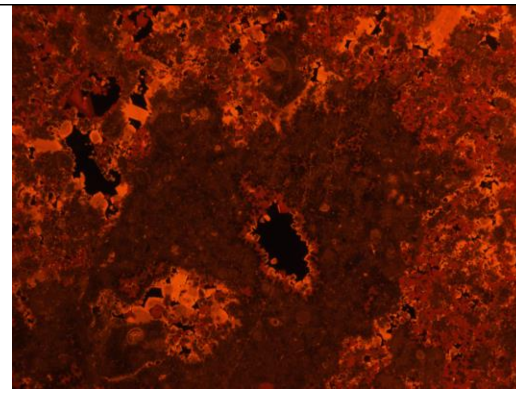
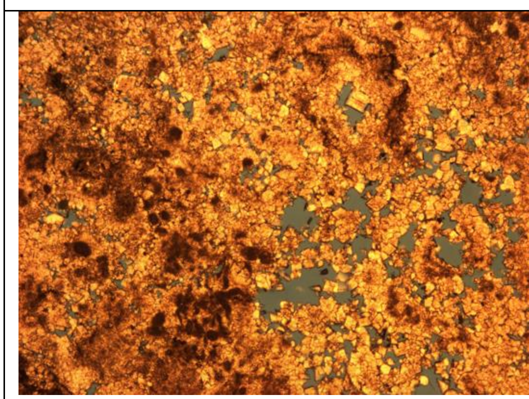
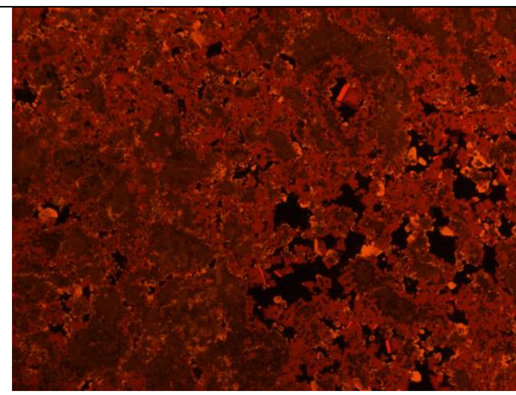
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 13%

Petrophysical analysis:
Porosity – 6%
Permeability – 0.122 md

Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11837.8 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

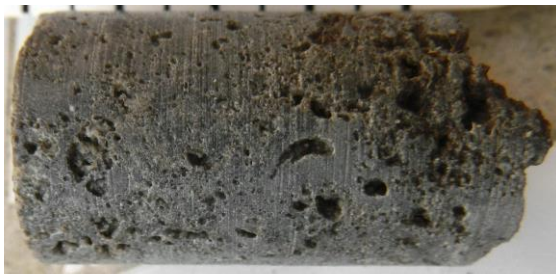
Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown - yellow-orange luminescence. The nonzoned crystals present orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals generally do not present zonation and have red luminescence, but some crystals present 2 or 3 zones: red – dark red or red – dark red – light red.

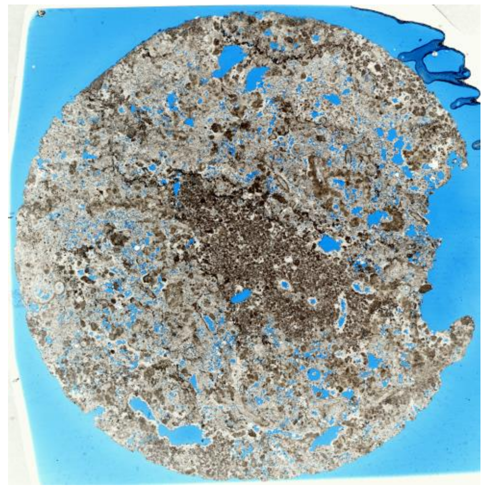
Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11840.3 ft

Plug – 2.15 cm (diameter)



Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some tubular structures and bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and some anhydrite cement. Chemical compaction (stylolite). Moderate to high dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Some primary growth framework vugs present enlargement by dissolution.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 9%

Petrophysical analysis:
Porosity – 15%
Permeability – 62.9 md

Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11840.3 ft

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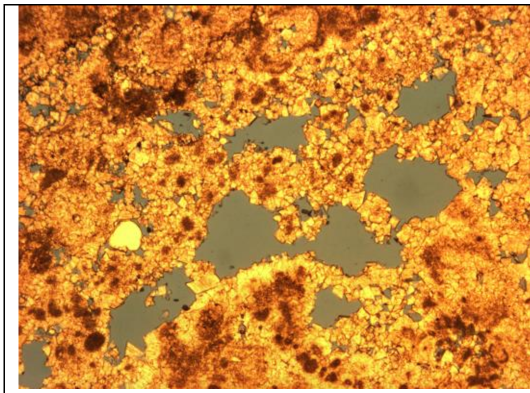
<tr><td>
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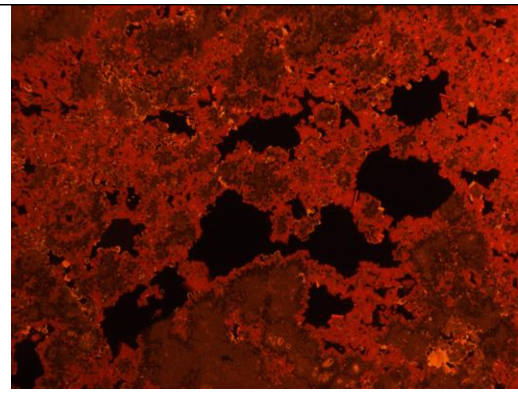
Full horizontal axis = 3.5 mm</td><td>
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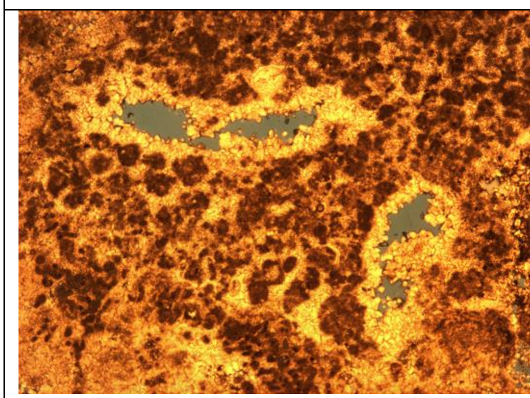
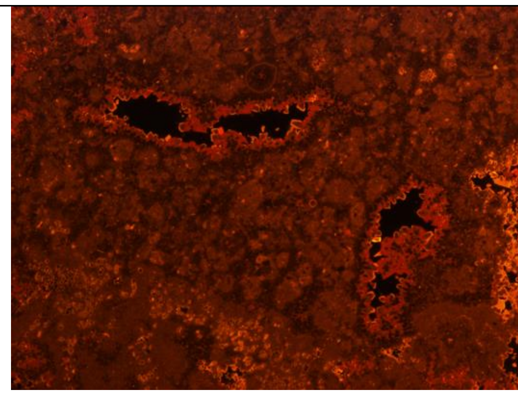
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

Cathodoluminescence image analysis:

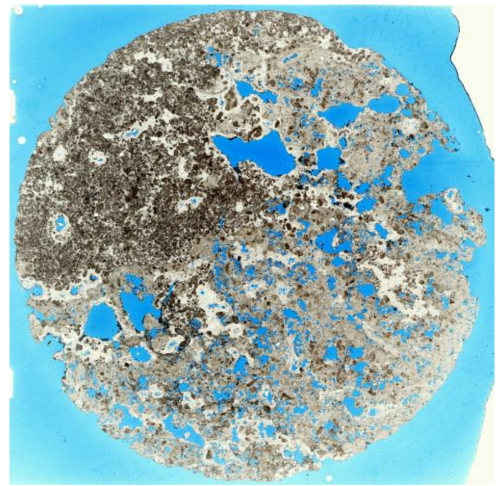
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: dark brown - light brown - yellow-orange luminescence. The blocky calcite cement occurs in a very small amount.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and have red luminescence, but some crystals present 2 or 3 zones: red – dark red or red – dark red – light red. The dolomite replaces preferentially the drusy calcite fringe.

Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11851.2 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters. Chemical compaction (stylolite). Moderate to high dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Late dissolution.

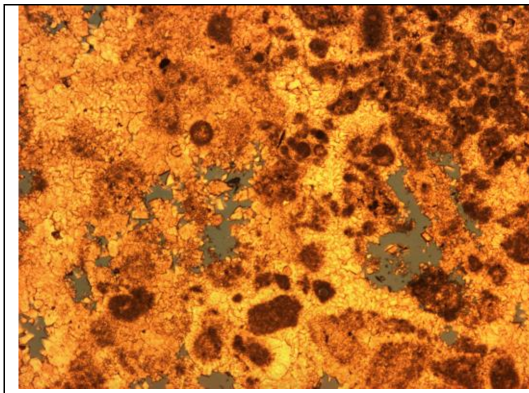
Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 17%

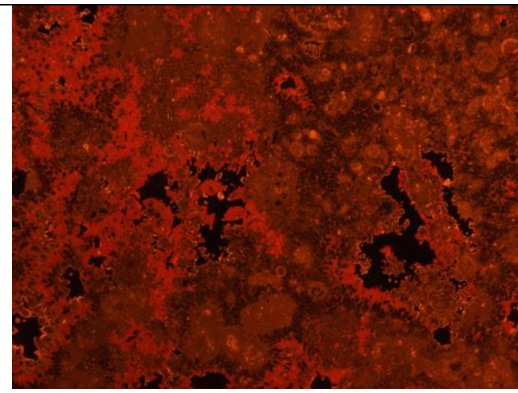
Petrophysical analysis:
Porosity – 12%
Permeability – 28.6 md

Little Cedar Creek Field **Well: 7** **Permit: 13907**

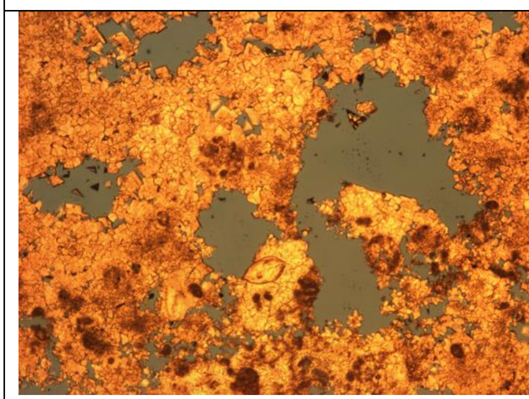
Depth: 11851.2 ft



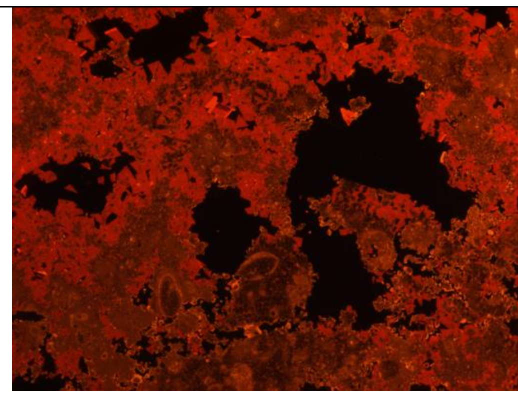
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

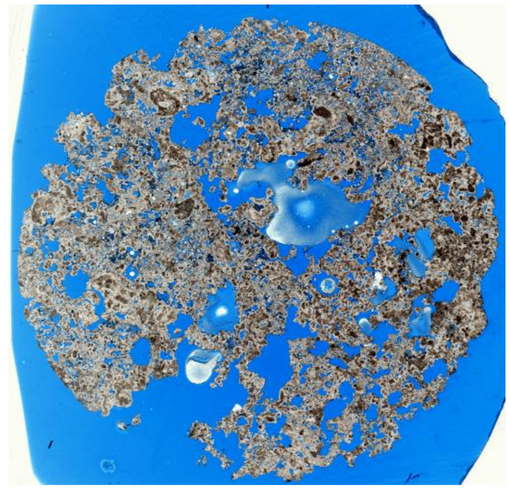
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals generally do not present zonation and have red luminescence, but some crystals present 2 or 3 zones: red – dark red or red – dark red – light red. The dolomite replaces preferentially the drusy calcite fringe.

Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11858.2 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters. Rare anhydrite cement. Moderate to high dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Late dissolution.

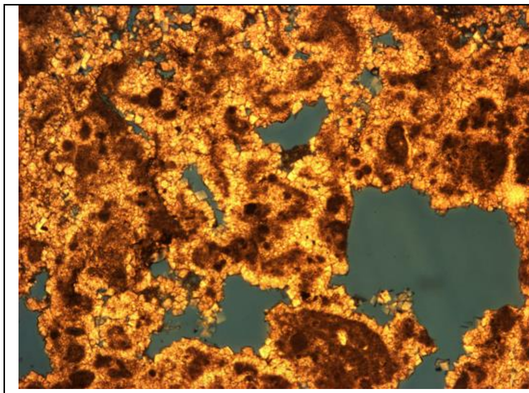
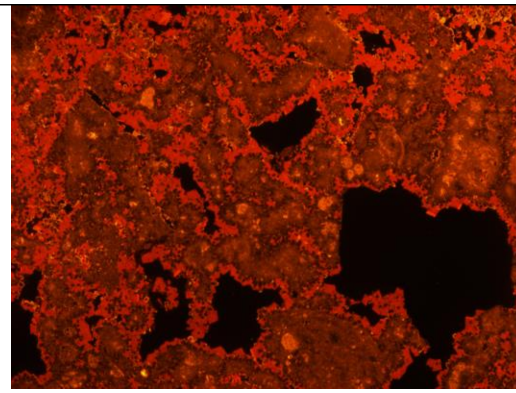
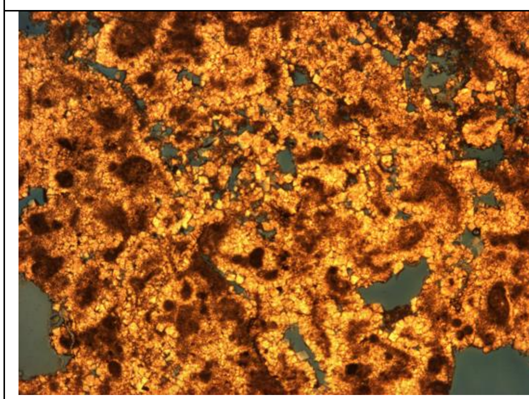
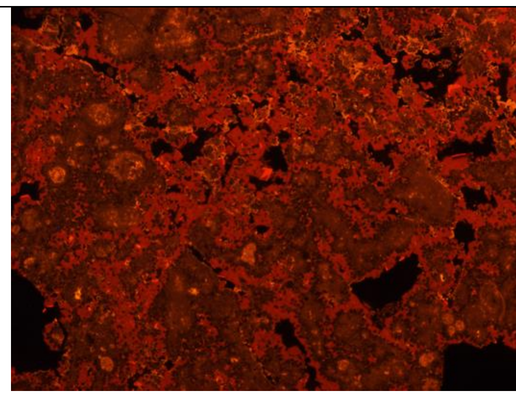
Pore type: Vuggy, intercrystalline and intergranular.

Porosity (image analysis): 32%

Petrophysical analysis:
Porosity – 25%
Permeability – 1,470 md

Little Cedar Creek Field **Well: 7** **Permit: 13907**

Depth: 11858.2 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

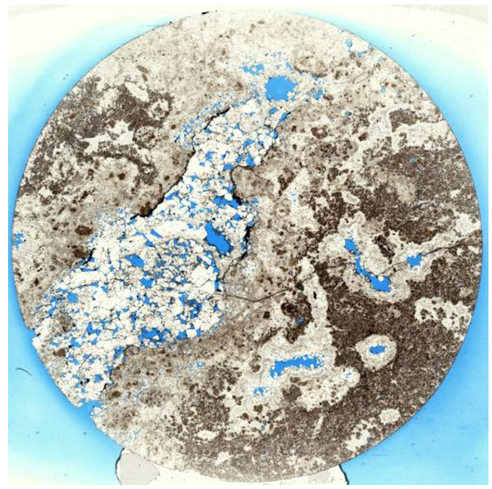
Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals generally do not present zonation and have red luminescence, but some crystals present 2 or 3 zones: red – dark red or red – dark red – light red. The dolomite replaces preferentially the drusy calcite fringe.

Little Cedar Creek Field **Well: 8** **Permit: 14069-B**

Depth: 11604.5 ft

<table>
<tr>
<td>
Plug – 2.15 cm (diameter)

Macroscopic photo
</td>
<td>

Scanned thin section
</td>
</tr>
</table>

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloids occur mainly as clusters. Diagenesis: fibrous calcite cement fringe, drusy calcite cement rimming grains, peloid clusters, and vuggy porosity, and mosaic calcite cement. A very large vug occur, partially filled by blocky calcite. Presence of microfracture.

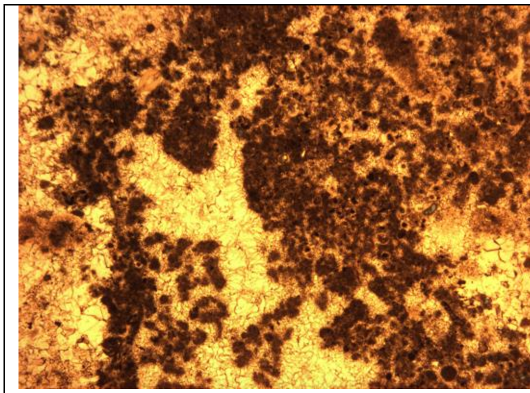
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 9%

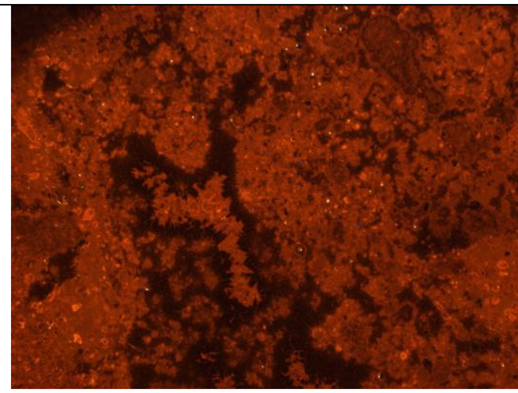
Petrophysical analysis:
Porosity – 6%
Permeability – 0.41 md

Little Cedar Creek Field **Well: 8** **Permit: 14069-B**

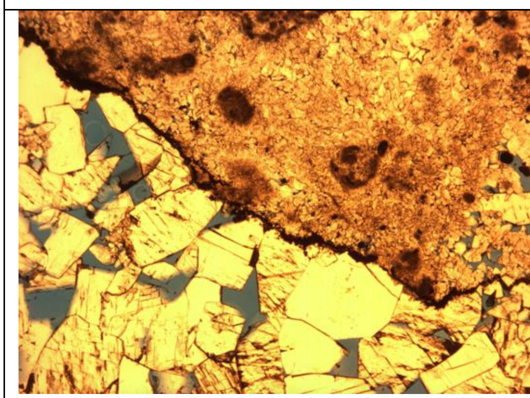
Depth: 11604.5 ft



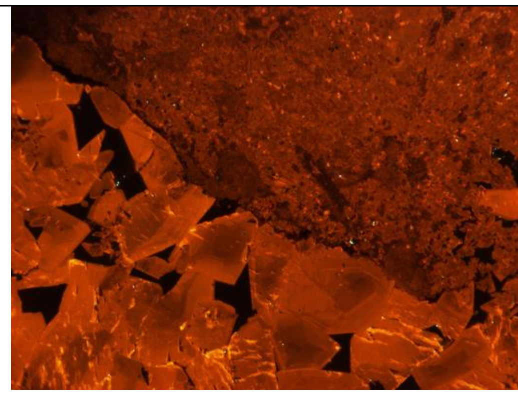
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

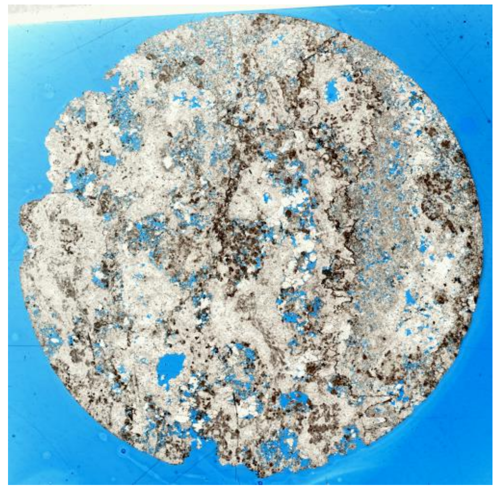
Drusy to mosaic calcite cement, zoned (2 zones). The first zone (inner part of the crystal has light brown luminescence and the second zone (edge) has orange-yellow luminescence. It grows on the top of the first cementation phase.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown - yellow-orange luminescence. The nonzoned crystals present orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and have red luminescence. Dolomite represents less than 1% of the rock.

Little Cedar Creek Field **Well: 8** **Permit: 14069-B**

Depth: 11624.5 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: drusy calcite cement, mosaic calcite cement, blocky calcite cement. Part of the rock is recrystallized. Intense calcite cementation and recrystallization. Low dolomitization. Anhedral very fine dolomite crystals occur as a replacing / cementation phase. Chemical compaction (stylolite).

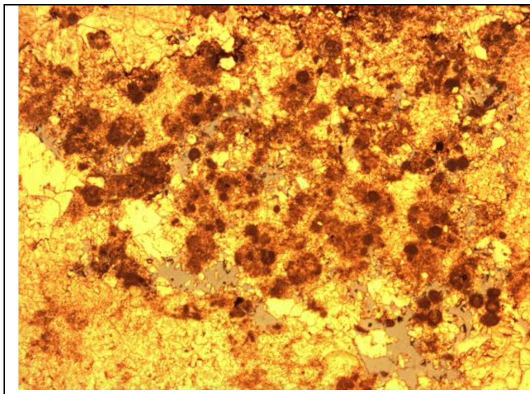
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 11%

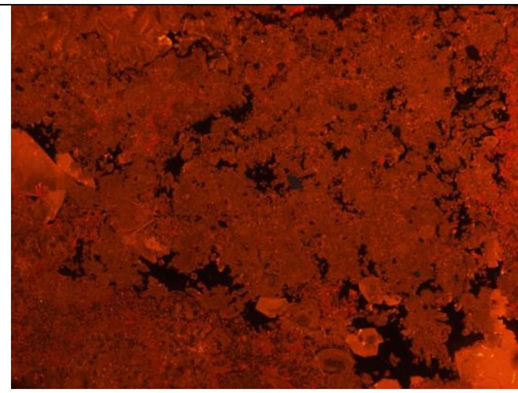
Petrophysical analysis:
Porosity – 9%
Permeability – 4.11 md

Little Cedar Creek Field **Well: 8** **Permit: 14069-B**

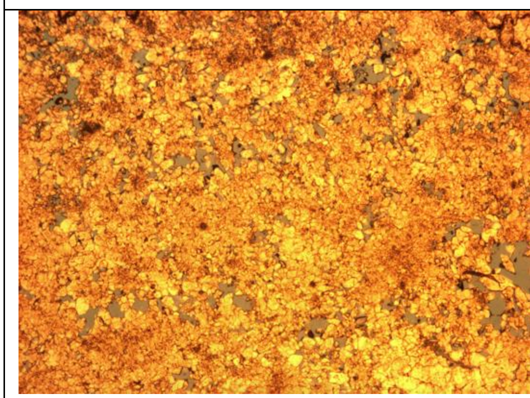
Depth: 11624.5 ft



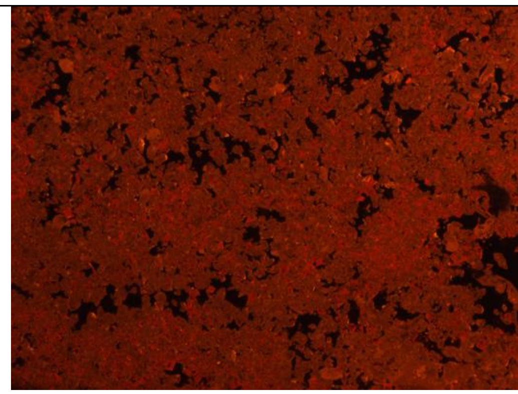
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Drusy to mosaic calcite cement, zoned (2 to 3 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone present light brown luminescence and the third zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown - yellow-orange luminescence. The nonzoned crystals present orange-yellow luminescence.
Recrystallization – some portions of the rock present recrystallization of the calcite, and the original texture of the rock is lost. This process does not obliterate porosity.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals generally do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 8** **Permit: 14069-B**

Depth: 11634 ft

Macroscopic photo

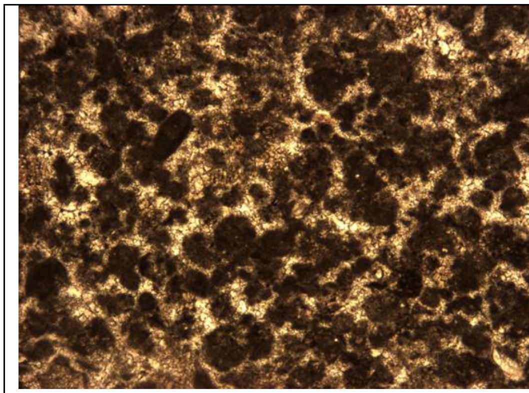
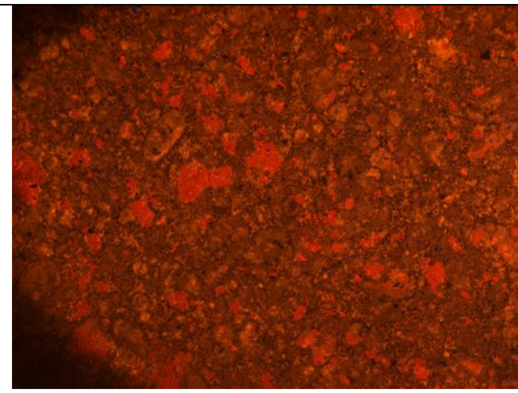
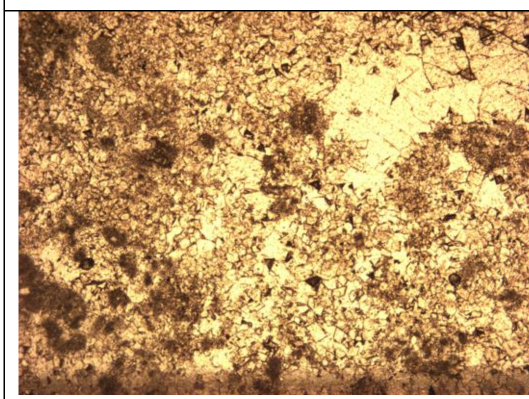
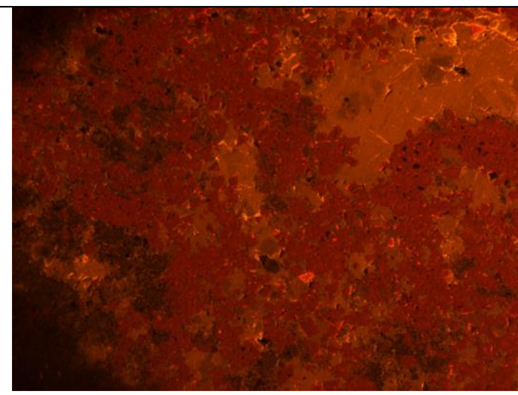

Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite. Peloid clusters are common. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Moderate dolomitization. Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementation phase. No visible porosity.

Little Cedar Creek Field **Well: 8** **Permit: 14069-B**

Depth: 11634 ft

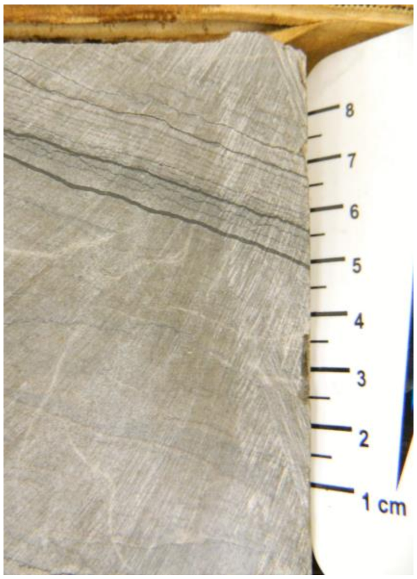
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Very narrow bladed to drusy calcite fringe cement rimming the grains, presenting luminescence dark brown or nonluminescent.
Mosaic calcite cement, presenting light brown to orange-yellow color.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown - yellow-orange luminescence. The nonzoned crystals present orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite replaces grains and cements.

Little Cedar Creek Field **Well: 8** **Permit: 14069-B**

Depth: 11649 ft



Macroscopic photo

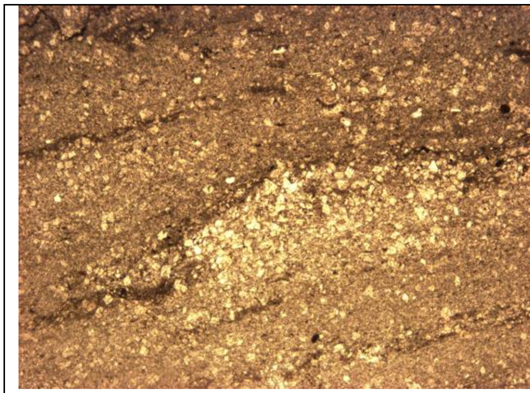
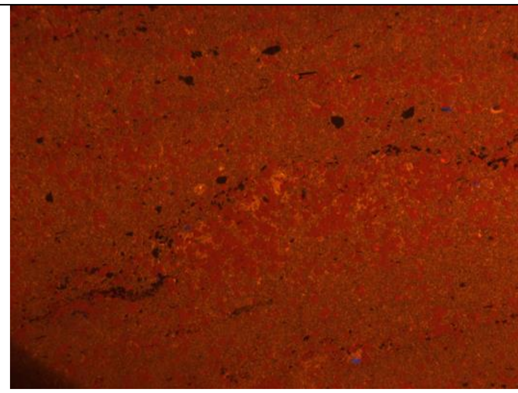
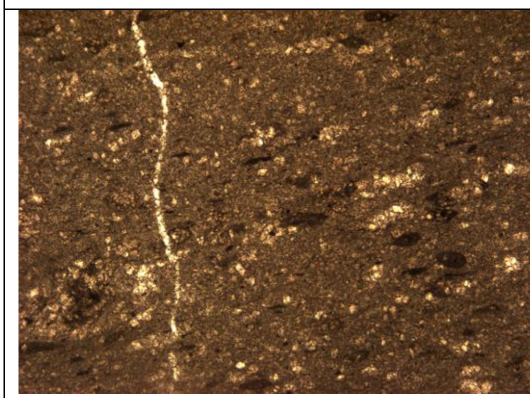
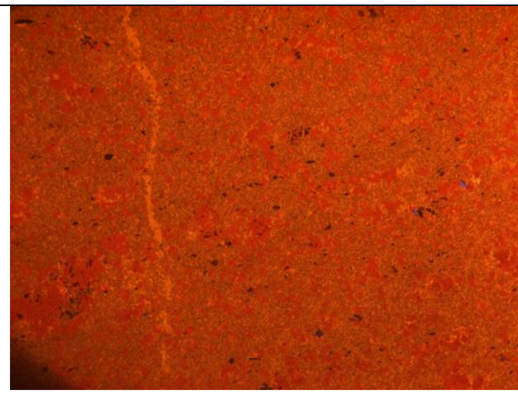
Scanned thin section

Lithology: Peloidal wackestone.

Description: Peloidal wackestone. Some silt to very fine sand size quartz grains. Abundant stylolites. Very fine euhedral to subhedral dolomite crystals disperse or concentrated in patches. Presence of discontinuous microfractures. Some of the fractures are open, some are closed, and one is cemented by calcite. No visible porosity.

Little Cedar Creek Field **Well: 8** **Permit: 14069-B**

Depth: 11649 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

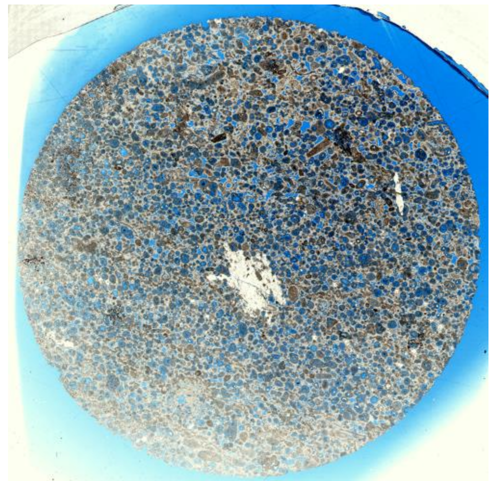
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals do not present zonation and have red luminescence.
Microfractures cemented by orange-yellow luminescent calcite.

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11267.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone. Fine to medium (some coarse) sand size oolites, some oncolites, green algae and mollusk fragments. Some very fine sand quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, mosaic calcite cement, rare blocky calcite cement, rare quartz cement, oolite dissolution, anhydrite crystals replacing grain and cement, no compaction features.

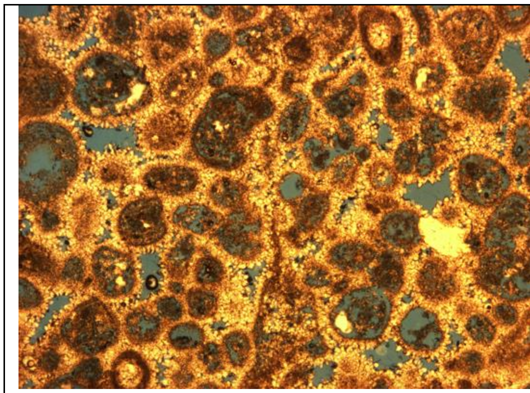
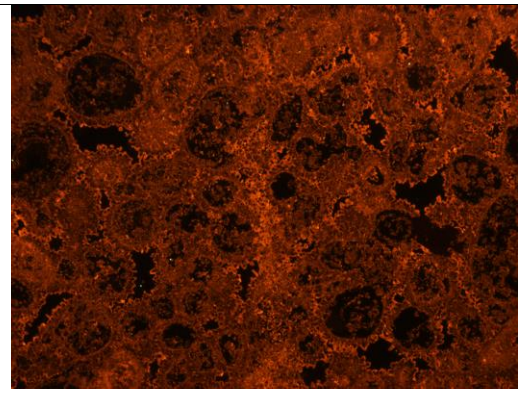
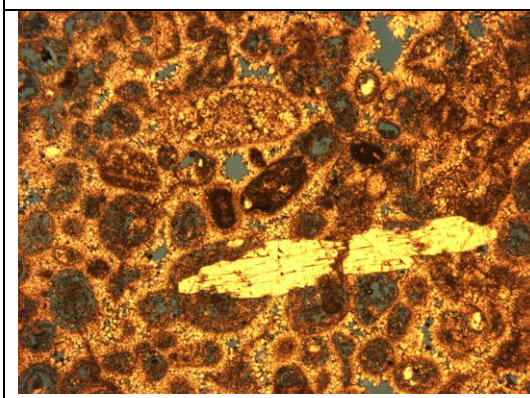
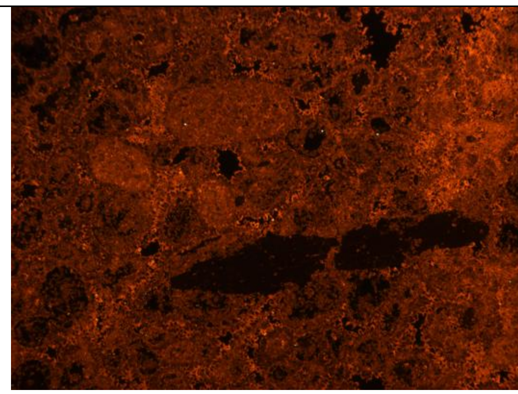
Pore type: Intragranular, moldic, and intergranular.

Porosity (image analysis): 32%

Petrophysical analysis:
Porosity – 27.1%
Permeability – 5.63 md

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11267.6 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

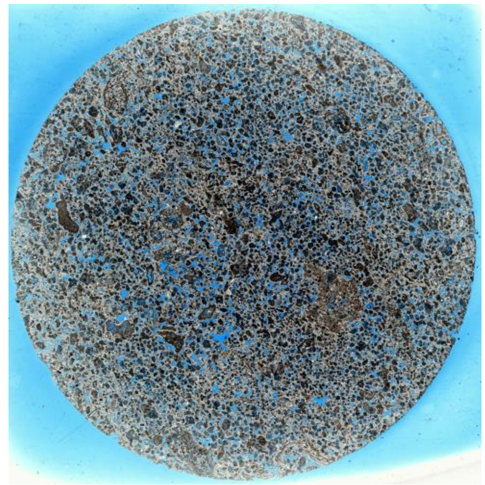
Bladed to drusy calcite fringe rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11272.6 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone. Fine to medium sand size oolites, some coarse to very coarse grapestones, benthic foraminifera, and ostracods. Some medium do coarse sand size muscovite grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, mosaic calcite cement, rare blocky calcite cement, oolite dissolution, no compaction features.

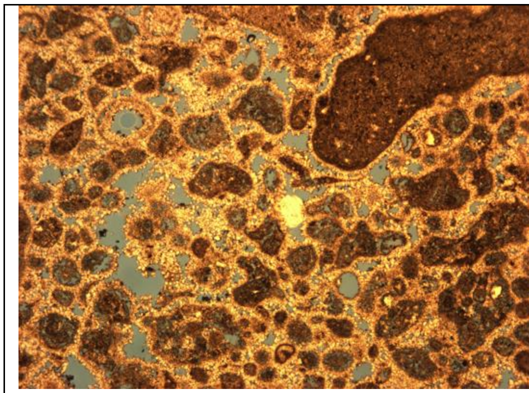
Pore type: Intergranular, intragranular and moldic.

Porosity (image analysis): 25%

Petrophysical analysis:
Porosity – 26%
Permeability – 63 md

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11272.6 ft

<table>
<tr><td>
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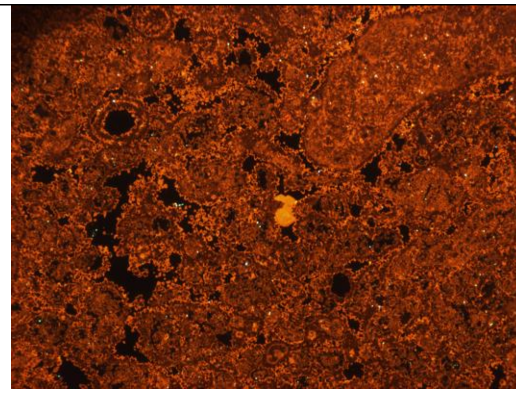
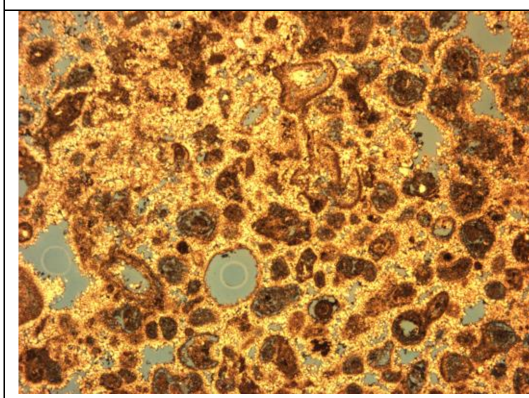
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
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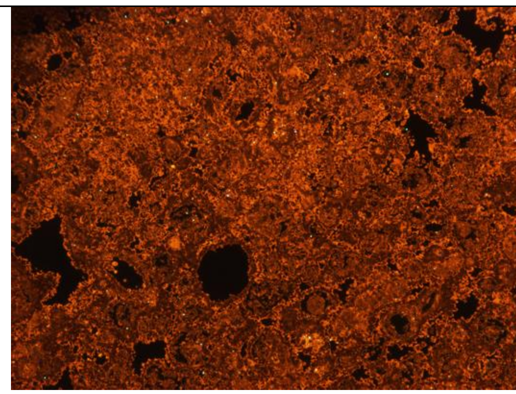
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:

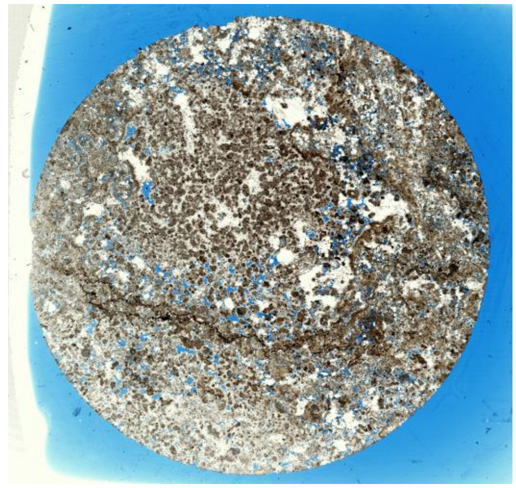
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, presenting orange-yellow luminescence. A very small amount of the blocky calcite was observed.</td></tr>
</table>

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11300.7 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and rare green algae (?). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolite). Some open discontinuous microfractures.

Pore type: Intergranular, vuggy, and some intercrystalline.

Porosity (image analysis): 6%

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11300.7 ft

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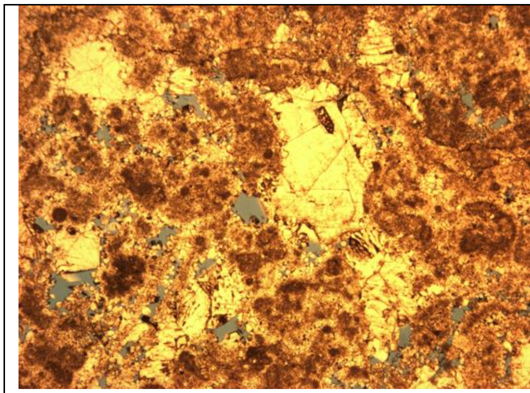
<tr><td>
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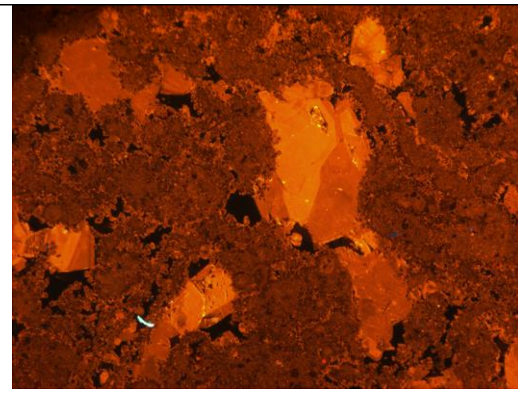
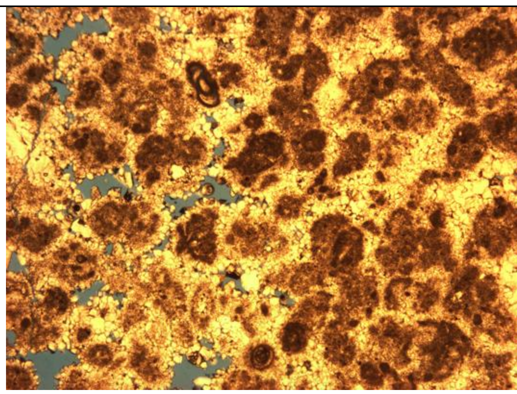
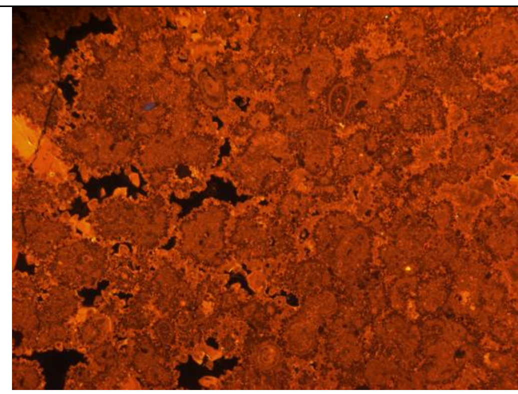
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

Cathodoluminescence image analysis:

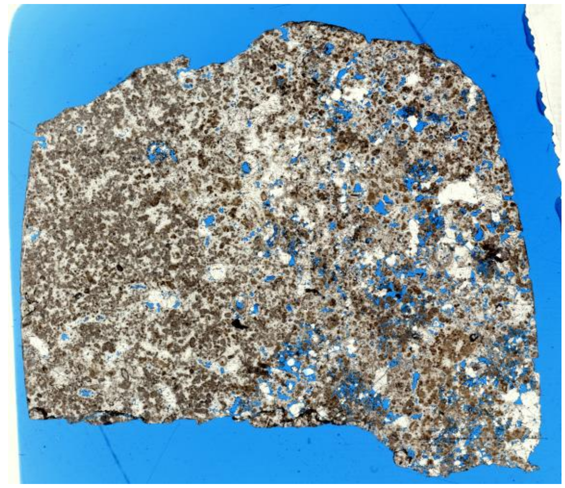
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: dark brown – light brown - yellow-orange luminescence.

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11303.8 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

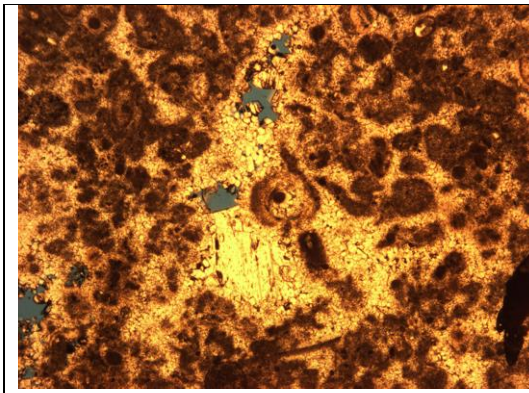
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolite). Very low dolomitization. Anhedral very fine dolomite crystals occur as a replacing / cementation phase. Presence of open microfracture.

Pore type: Vuggy, intergranular, and some intercrystalline.

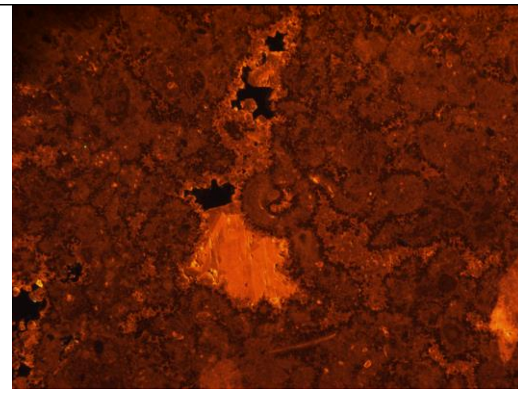
Porosity (image analysis): 8%

Little Cedar Creek Field **Well: 9** **Permit: 14112**

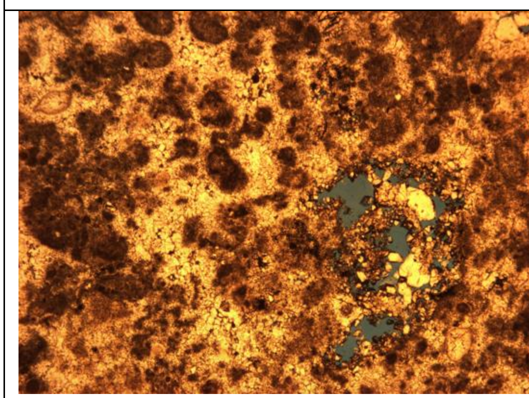
Depth: 11303.8 ft



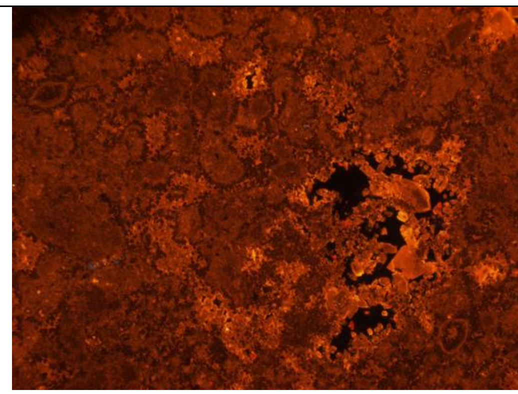
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

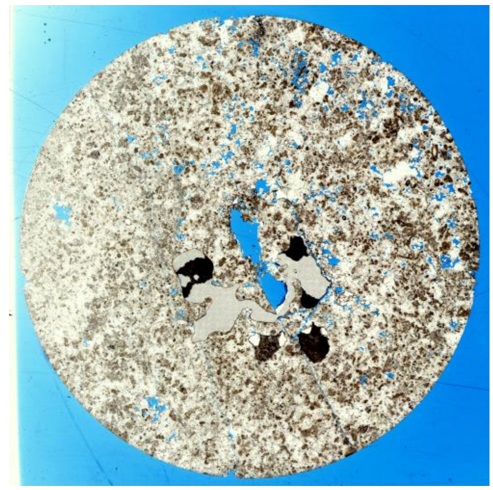
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones).. The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Mosaic calcite cement filling the center of the pores, presenting orange-yellow luminescence.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: orange-yellow – light brown – orange-yellow luminescence. Some crystals do not present zonation, and have light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in a very small amount.

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11304.2 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolite). Very low dolomitization. Anhedral very fine dolomite crystals occur as a replacing / cementation phase. Presence of open microfractures.

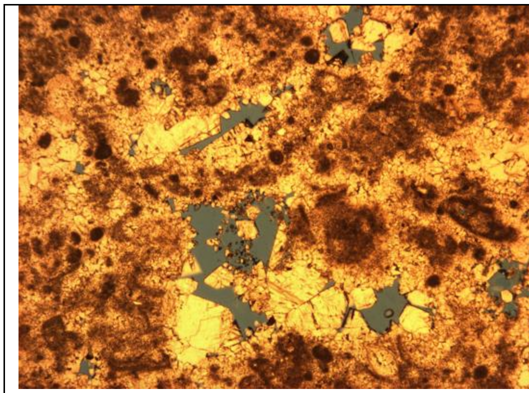
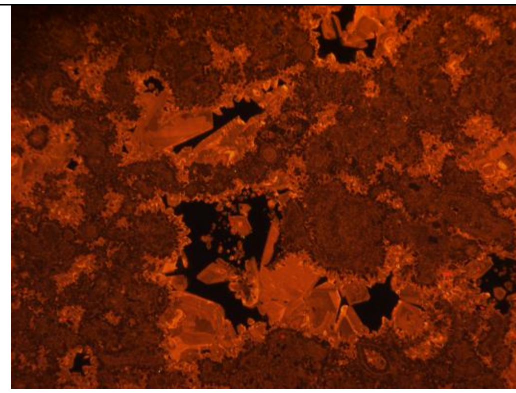
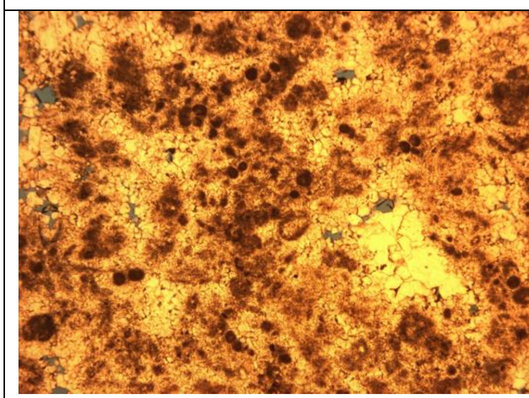
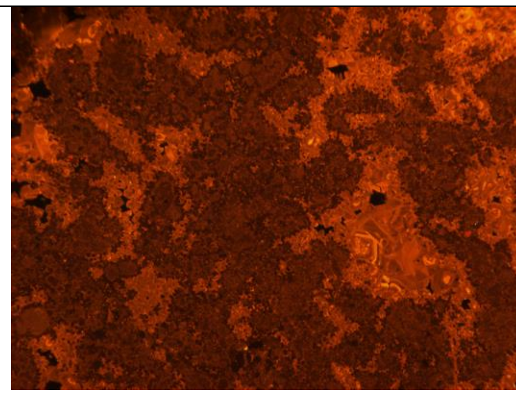
Pore type: Vuggy, and some intercrystalline porosity.

Porosity (image analysis): 7%

Petrophysical analysis:
Porosity – 9%
Permeability – 0.271 md

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11304.2 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

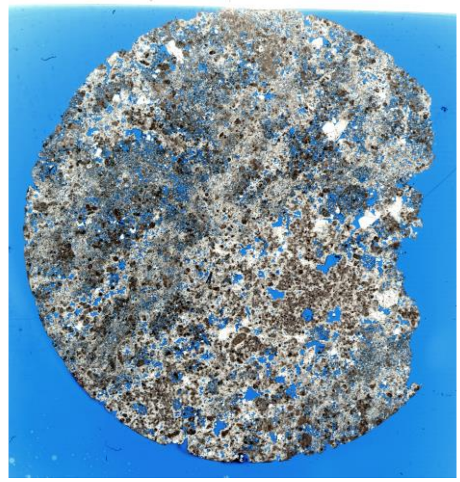
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Blocky calcite cement, zoned (2 to 4 zones). The zones present the following order: dark-brown – light brown – orange-yellow – light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in a very small amount.

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11314.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, and blocky calcite cement. Moderate to high dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase.

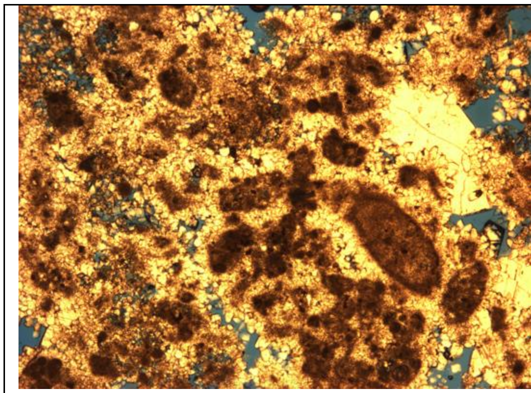
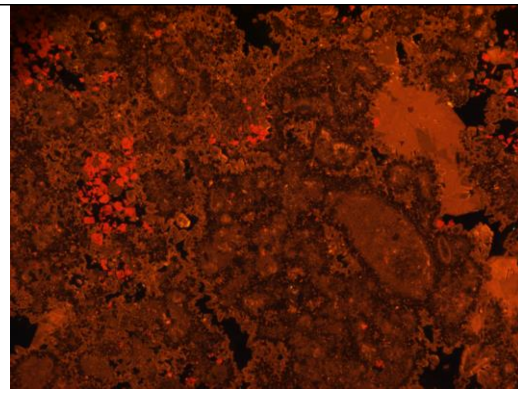
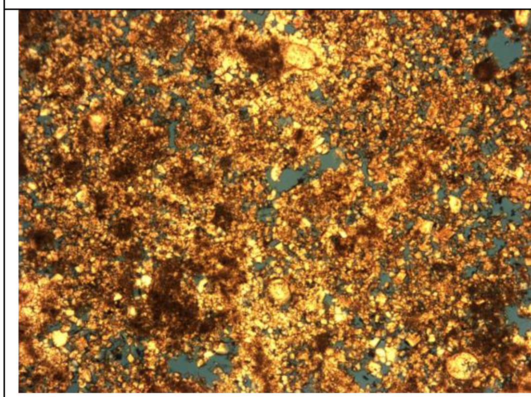
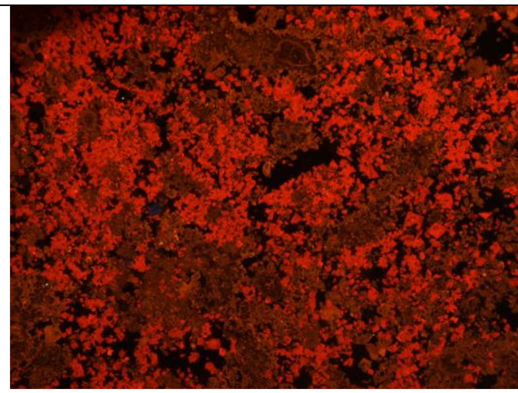
Pore type: Vuggy, intercrystalline, and some intergranular.

Porosity (image analysis): 22%

Petrophysical analysis:
Porosity – 15%
Permeability – 7.07 md

Little Cedar Creek Field **Well: 9** **Permit: 14112**

Depth: 11314.4 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

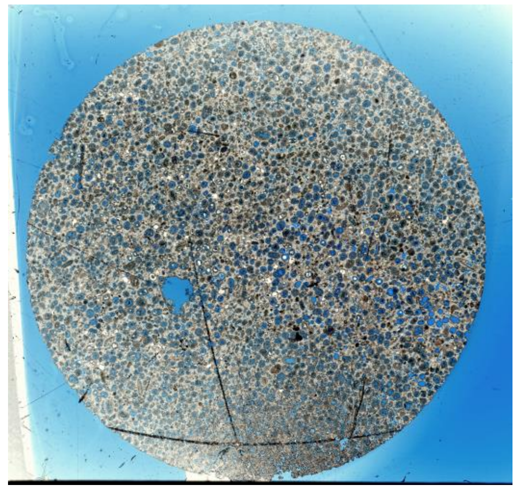
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 4 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has orange-yellow luminescence, the third zone has light brown luminescence and the fourth zone (edge) has orange-yellow luminescence. The presence of 2 zones is more common.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: dark-brown – orange-yellow – light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 10** **Permit: 14114**

Depth: 11288.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone. Fine to medium sand size oolites, some coarse sand size grapestones, green algae, and mollusk fragments. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, and mosaic calcite cement, rare blocky calcite and anhydrite cement, oolite dissolution, no compaction features.

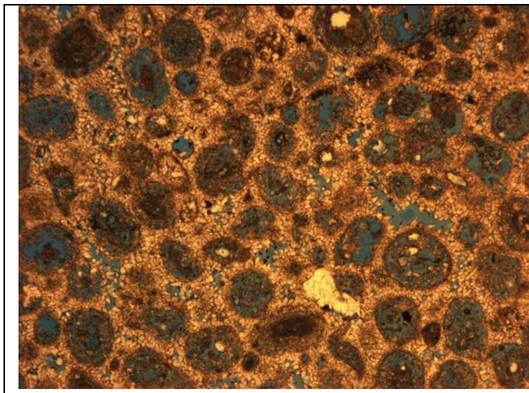
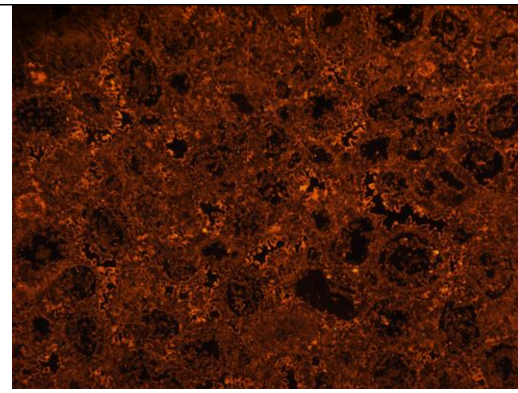
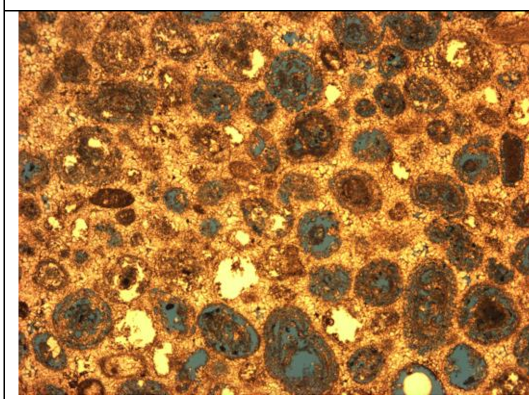
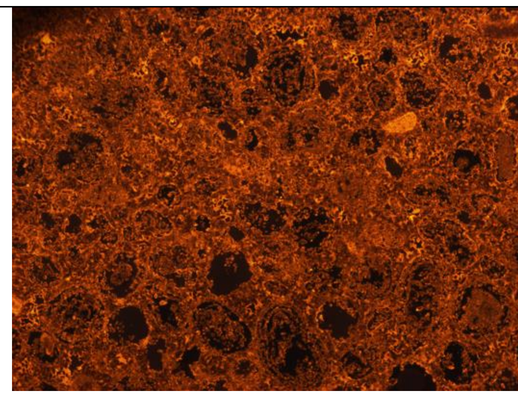
Pore type: Moldic, vuggy, intragranular, intergranular and intercrystalline.

Porosity (image analysis): 26%

Petrophysical analysis:
Porosity – 27%
Permeability – 1.49 md

Little Cedar Creek Field **Well: 10** **Permit: 14114**

Depth: 11288.4 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

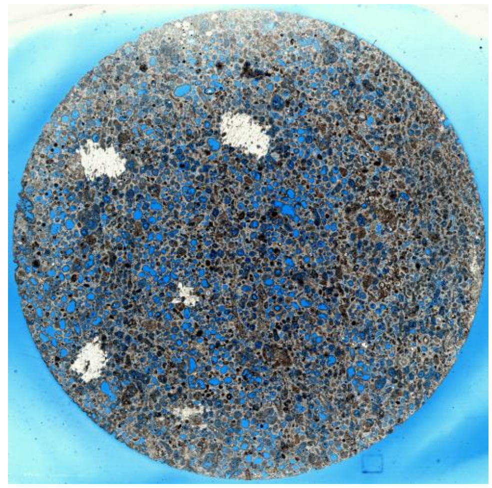
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first luminescent zone occurs.

Little Cedar Creek Field **Well: 10** **Permit: 14114**

Depth: 11293.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to coarse sand oolitic grainstone.

Description: Oolitic grainstone. Fine to coarse (some coarse) sand size oolites, some oncolites. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, mosaic calcite cement, oolite dissolution, anhydrite crystals replacing grain and cement, no compaction features.

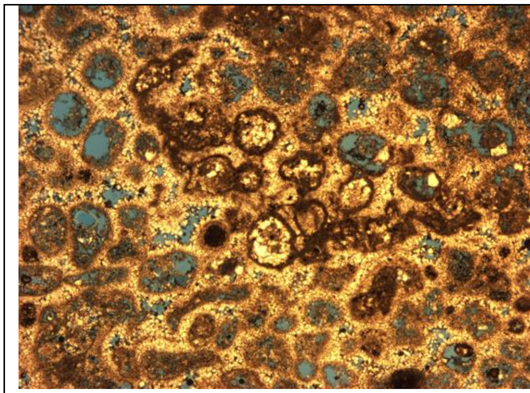
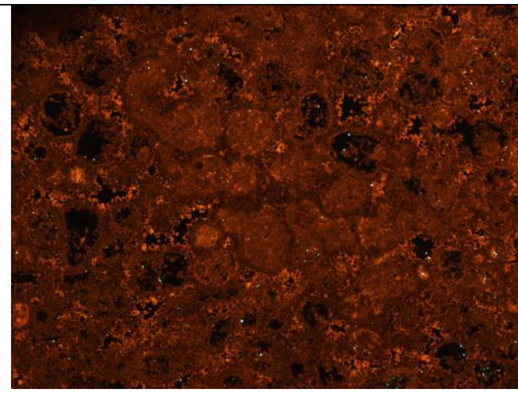
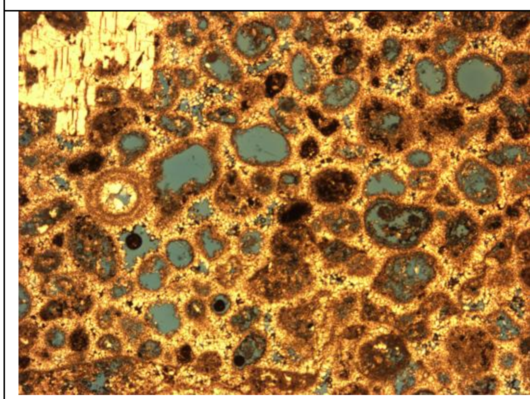
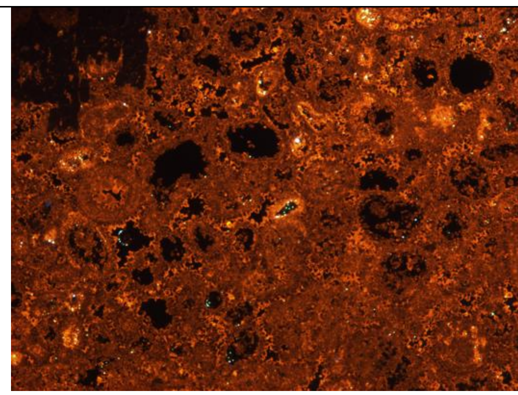
Pore type: Moldic, intergranular, intragranular, and intercrystalline.

Porosity (image analysis) : 30%

Petrophysical analysis:
Porosity – 31%
Permeability – 1.01 md

Little Cedar Creek Field **Well: 10** **Permit: 14114**

Depth: 11293.6 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

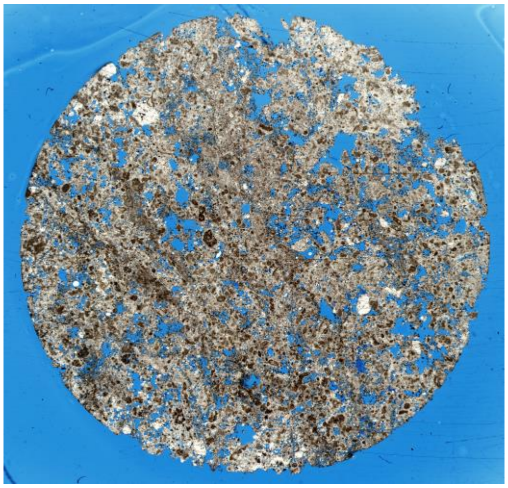
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.

Little Cedar Creek Field **Well: 10** **Permit: 14114**

Depth: 11330.2 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Fine to medium biotite grains occur. The bioclasts are ostracods (with sintaxial calcite cement),and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Very low dolomitization. Anhedral very fine dolomite crystals occur as a replacing / cementation phase. Some open discontinuous microfractures.

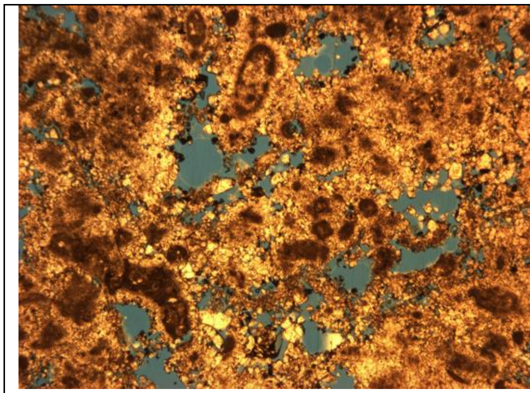
Pore type: Vuggy, intergranular, and intercrystalline.

Porosity (image analysis): 22%

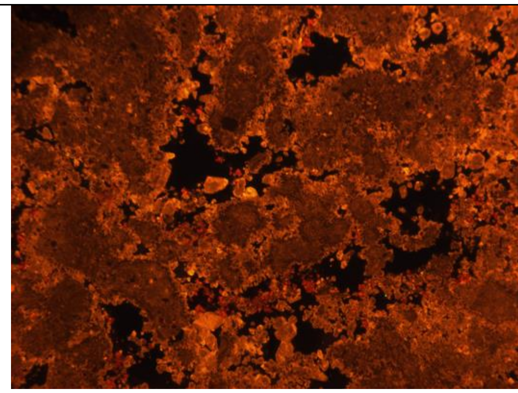
Petrophysical analysis:
Porosity – 20%
Permeability – 465 md

Little Cedar Creek Field **Well: 10** **Permit: 14114**

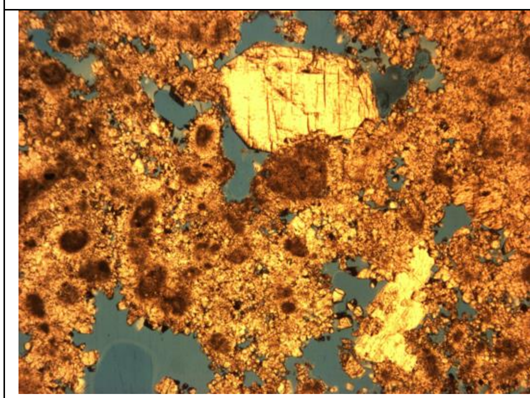
Depth: 11330.2 ft



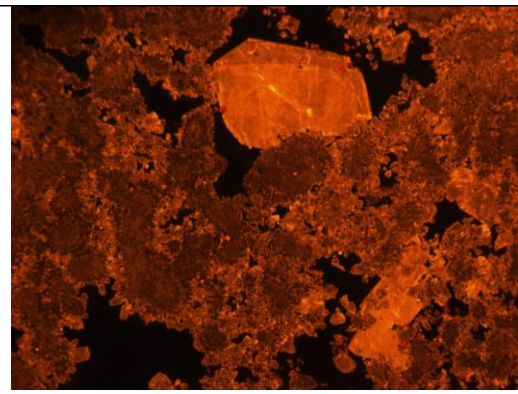
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



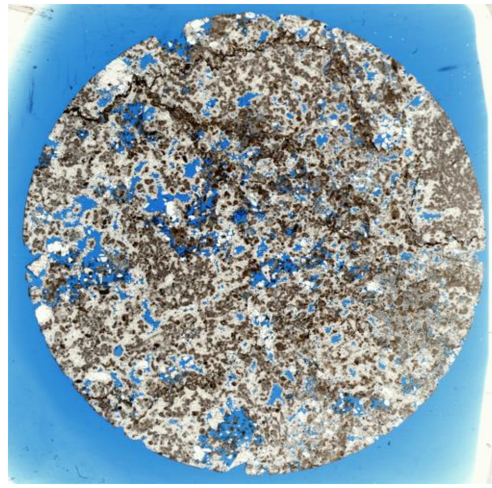
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in a very small amount.

Little Cedar Creek Field **Well: 10** **Permit: 14114**

Depth: 11335.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement),and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Very low dolomitization. Anhedral very fine dolomite crystals occur as a replacing / cementation phase. Some open discontinuous microfractures. Chemical compaction (stylolites).

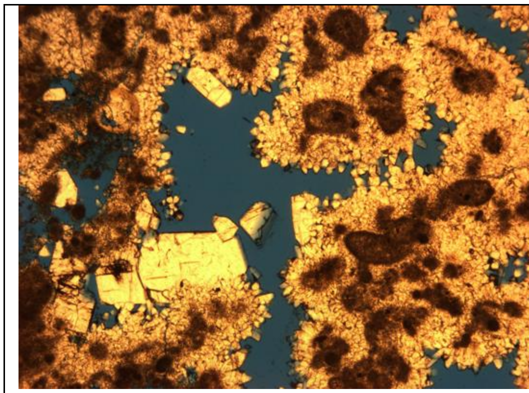
Pore type: Vuggy, and some intercrystalline.

Porosity (image analysis) : 13%

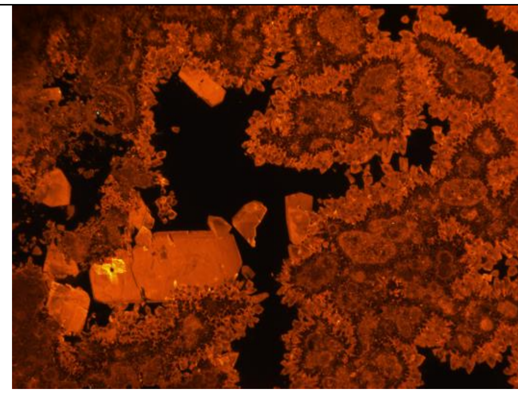
Petrophysical analysis:
Porosity – 15%
Permeability – 52.4 md

Little Cedar Creek Field **Well: 10** **Permit: 14114**

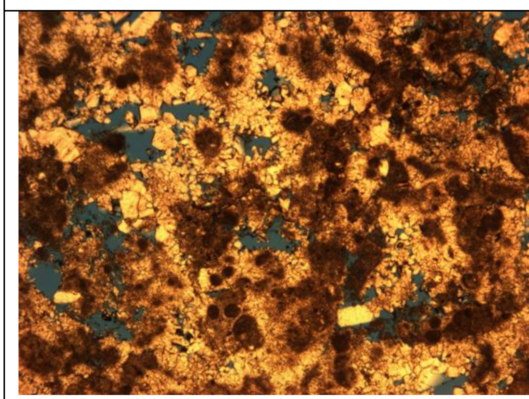
Depth: 11335.9 ft



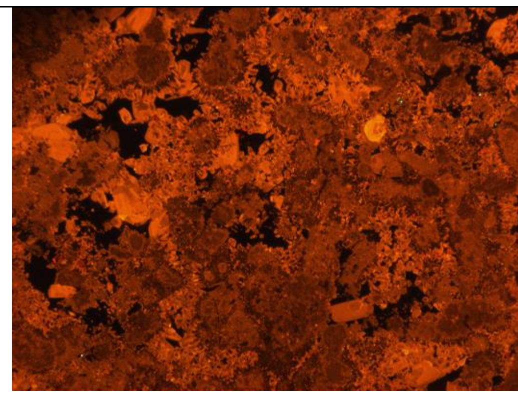
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

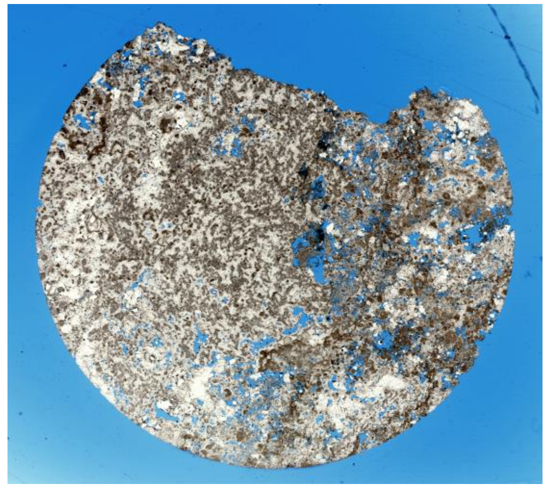
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Mosaic calcite cement filling the center of the pores, presenting orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: orange-yellow – light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite represents less than 1% of the rock.

Little Cedar Creek Field **Well: 10** **Permit: 14114**

Depth: 11338.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand quartz and biotite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and green algae. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Low dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Some open discontinuous microfractures. Chemical compaction (stylolites).

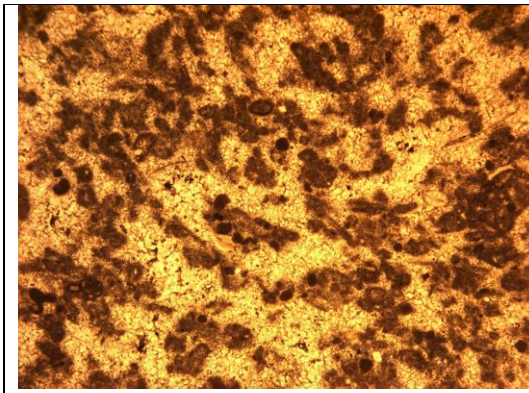
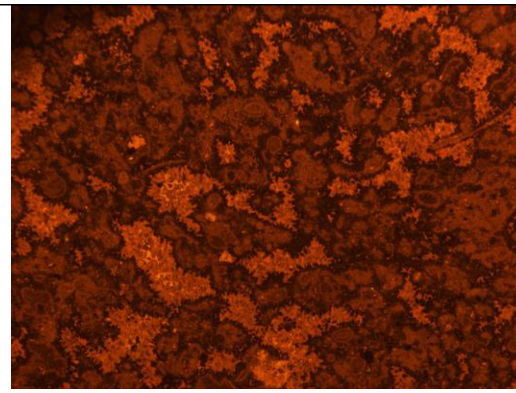
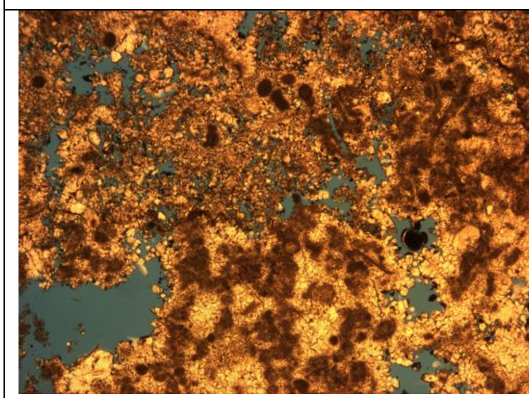
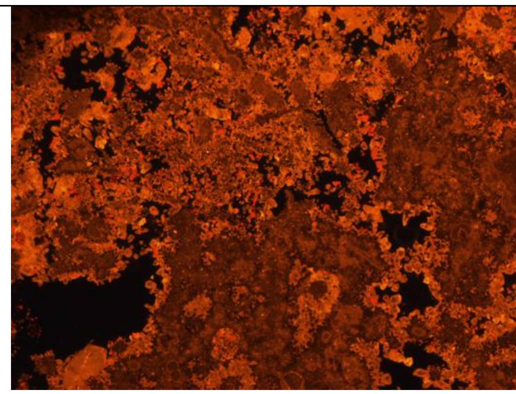
Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 9%

Petrophysical analysis:
Porosity – 9 %
Permeability – 0.046 md

Little Cedar Creek Field **Well: 10** **Permit: 14114**

Depth: 11338.8 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

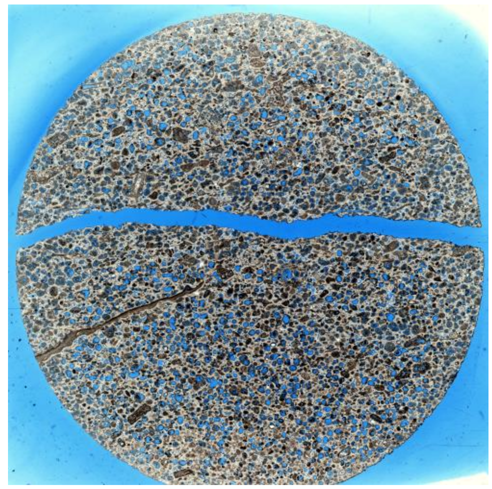
Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (4 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has dark brown luminescence, the third zone has light brown luminescence and the fourth zone (edge) has orange-yellow luminescence.
Mosaic calcite cement filling the center of the pores, presenting orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite represents less than 1% of the rock.

Little Cedar Creek Field **Well: 11** **Permit: 14301-B**

Depth: 11252.7 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone. Fine to medium sand size oolites, some coarse sand size grapestones, green algae, and mollusk fragments. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, mosaic calcite cement, rare blocky calcite cement, oolite dissolution, no compaction features.

Pore type: Moldic, intragranular, intergranular, and intercrystalline.

Porosity (image analysis) : 24%

Petrophysical analysis:
Porosity – 25%
Permeability – 0.21 md

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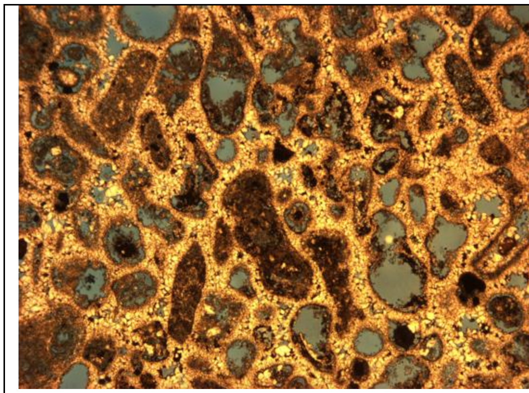
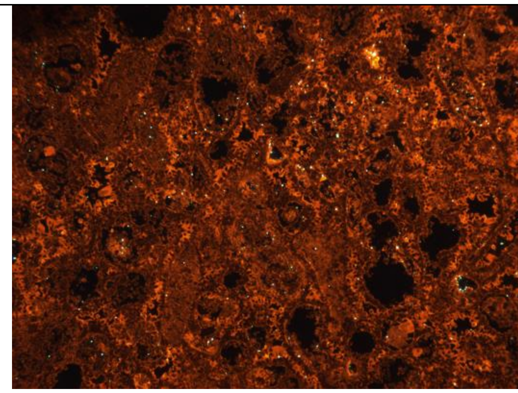
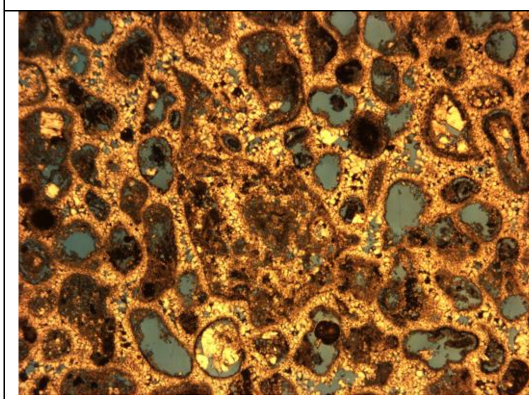
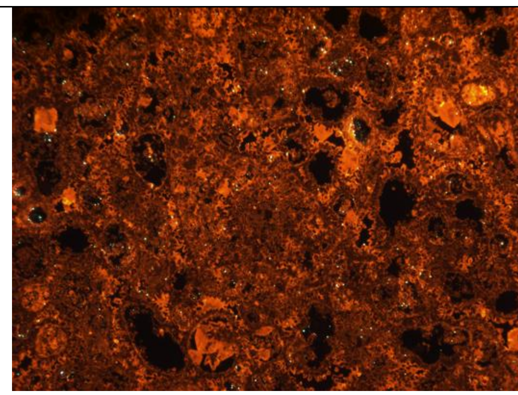
Little Cedar Creek Field **Well: 11** **Permit: 14301-B**

Depth: 11252.7 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.

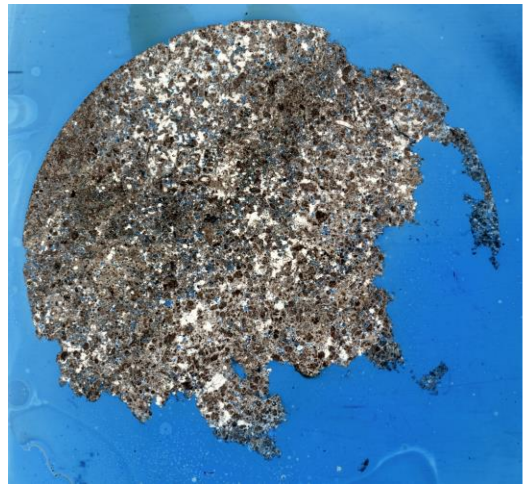
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence. It occurs in the intergranular and moldic porosity.

Little Cedar Creek Field **Well: 11** **Permit: 14301-B**

Depth: 11272.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and green algae. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Very low dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase.

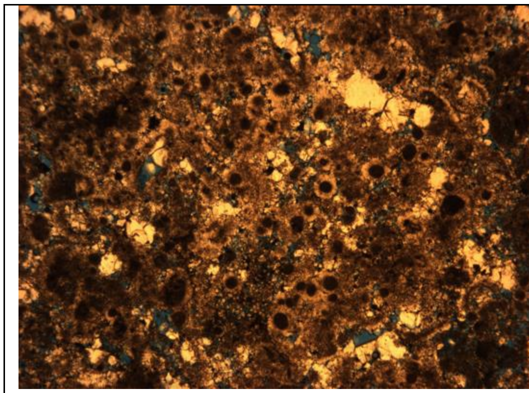
Pore type: intergranular, intercrystalline, and rare vuggy.

Porosity (image analysis): 7%

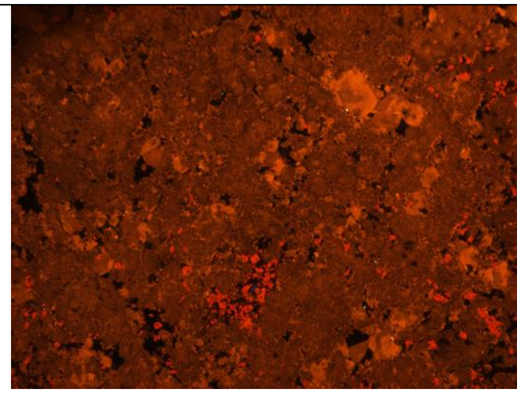
Petrophysical analysis:
Porosity – 7%
Permeability – 0.021 md

Little Cedar Creek Field **Well: 11** **Permit: 14301-B**

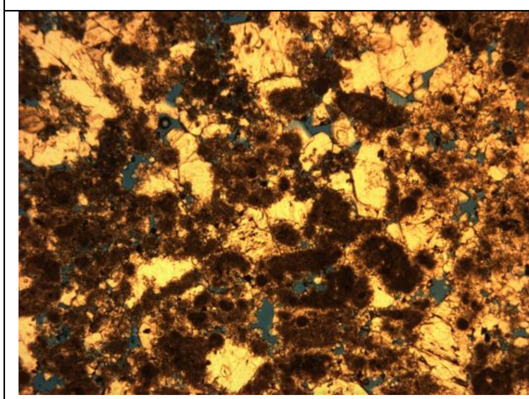
Depth: 11272.6 ft



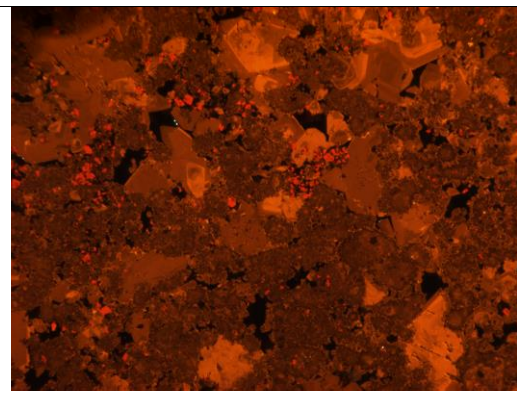
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

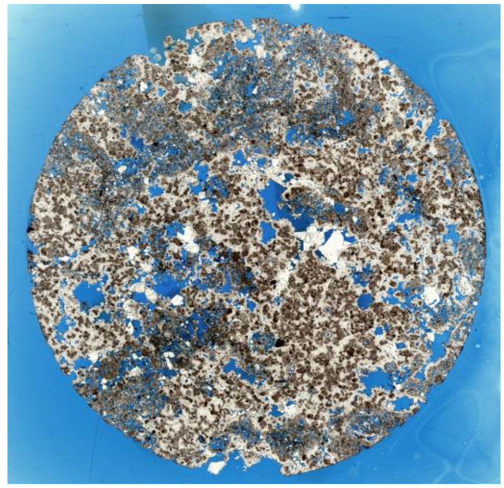
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Mosaic calcite cement filling the center of the pores, presenting orange-yellow luminescence.
Blocky calcite cement, zoned (2 to 4 zones). The zones present the following order: light brown – orange-yellow – light brown – dark brown luminescence. Some crystals are not zoned, and present light brown or orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.

Little Cedar Creek Field **Well: 11** **Permit: 14301-B**

Depth: 11278.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Fine to medium quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement),and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Low dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Some open discontinuous microfractures.

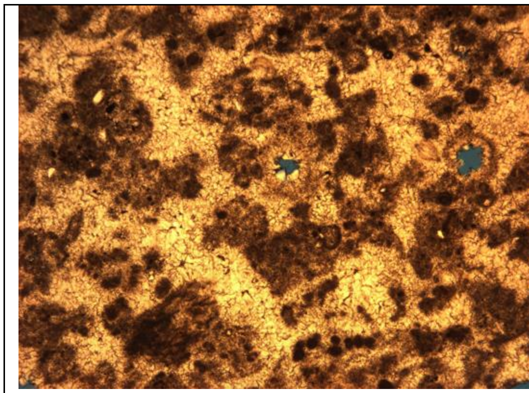
Pore type: Vuggy, and intercrystalline.

Porosity (image analysis) : 20%

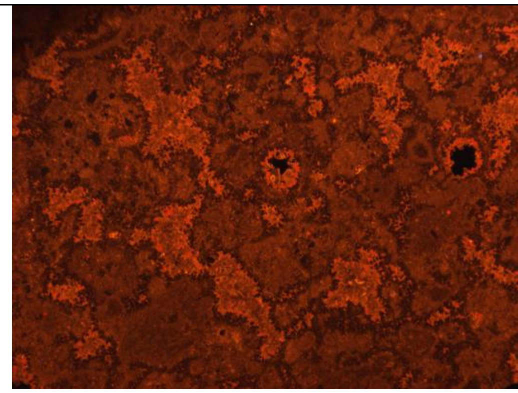
Petrophysical analysis:
Porosity – 19%
Permeability – 362 md

Little Cedar Creek Field **Well: 11** **Permit: 14301-B**

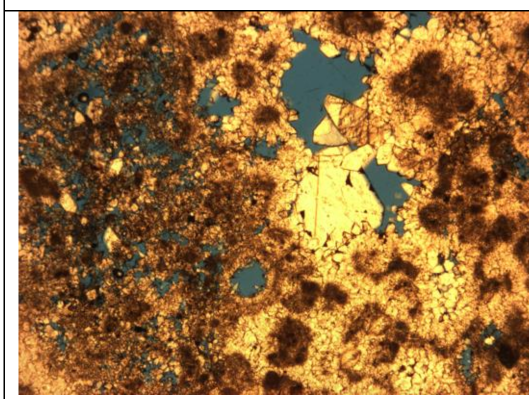
Depth: 11278.4 ft



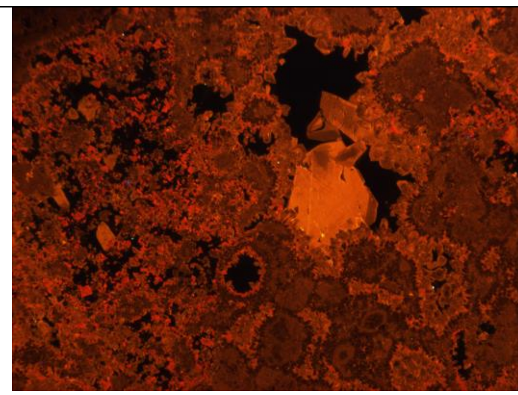
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

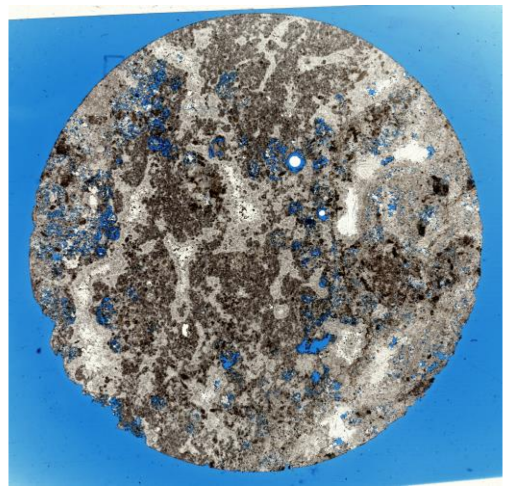
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. It evolves to drusy / mosaic cement to the center of the pores.
Blocky calcite cement, zoned (2 to 4 zones). The zones present the following order: light to dark brown – orange-yellow – dark brown – light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It replaces mainly the first drusy calcite fringe cement.

Little Cedar Creek Field **Well: 11** **Permit: 14301-B**

Depth: 11291.9 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Fine to medium biotite grains occur. The bioclasts are ostracods (with sintaxial calcite cement),and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and anhydrite cement. Very low dolomitization. Subhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Rare open discontinuous microfracture.

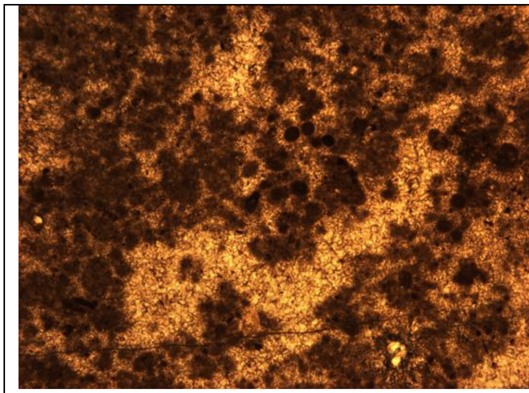
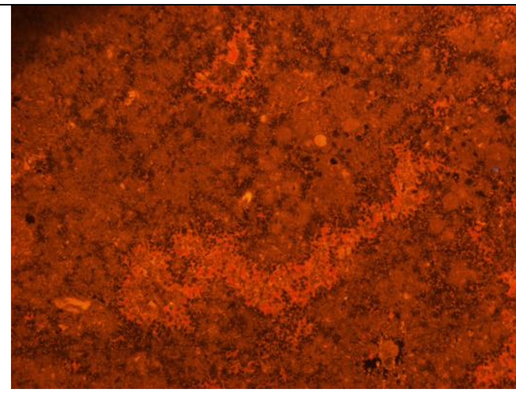
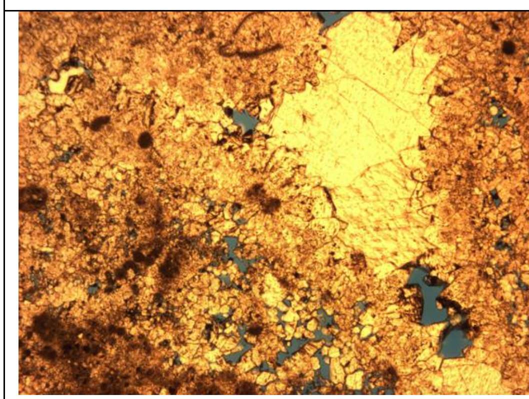
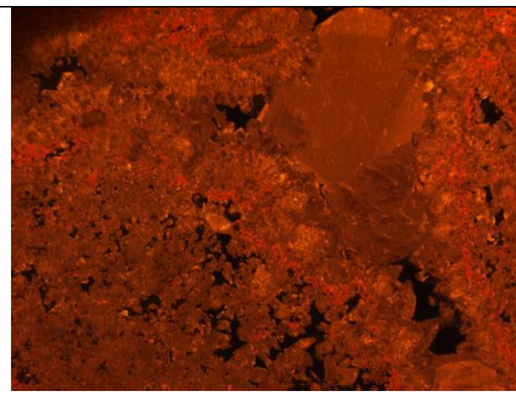
Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 8%

Petrophysical analysis:
Porosity – 12%
Permeability – 2.24 md

Little Cedar Creek Field **Well: 11** **Permit: 14301-B**

Depth: 11291.9 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

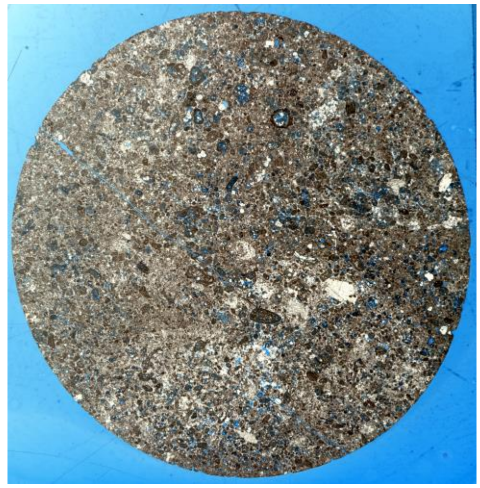
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone (edge) has light brown luminescence. It evolves to mosaic cement to the center of the pores.
Blocky calcite cement, zoned (2 to 4 zones). The zones present the following order: light brown – orange-yellow – light brown – orange-yellow luminescence. Some crystals present several sub-zones of luminescence.
Subhedral to anhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It replaces mainly the drusy calcite fringe cement.

Little Cedar Creek Field **Well: 12** **Permit: 14309**

Depth: 11324.5 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Very fine to very coarse peloidal-skeletal grainstone.

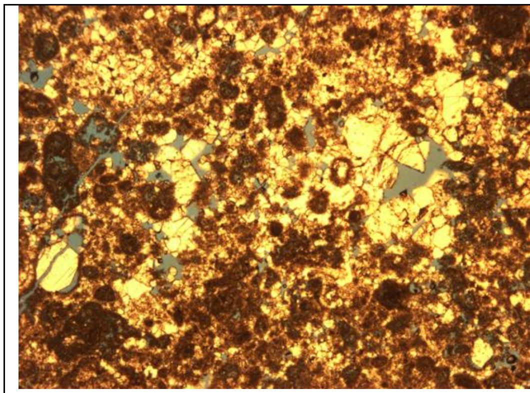
Description: Peloidal-skeletal grainstone. Very fine to fine sand size peloids, coarse to very coarse sand size green algae fragments. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, mosaic calcite cement, blocky calcite cement, anhydrite as cement and replacing phase, no compaction features. Discontinuous open microfractures.

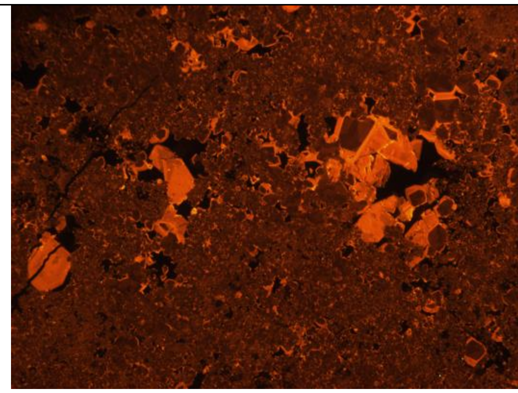
Pore type: Intergranular and intragranular.

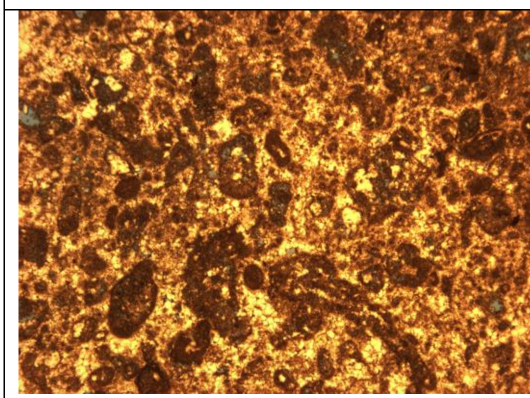
Porosity (image analysis): 8%

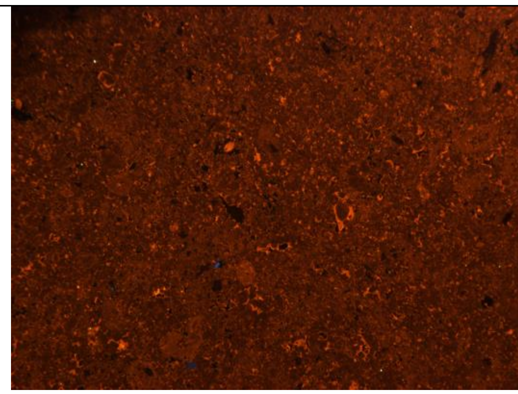
Little Cedar Creek Field **Well: 12** **Permit: 14309**

Depth: 11324.5 ft


Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm


Cathodoluminesce image – same field of the picture on the left side


Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

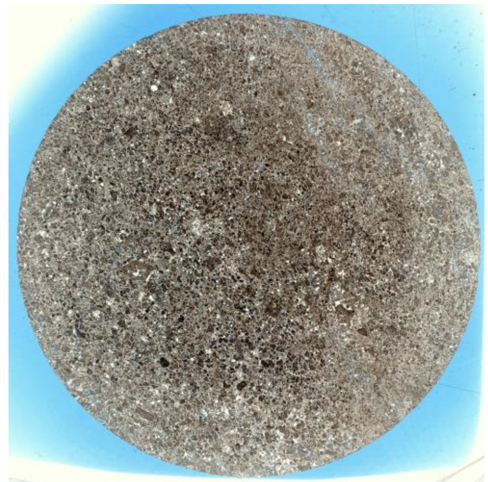
Bladed to drusy calcite fringe cement rimming the grains, presenting light brown to orange-yellow luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark brown– light brown – orange-yellow luminescence. Some crystals are not zoned, and present light brown or orange-yellow luminescence.

Little Cedar Creek Field **Well: 12** **Permit: 14309**

Depth: 11326 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Very fine to very coarse sand peloidal-skeletal grainstone.

Description: Peloidal-skeletal grainstone. Very fine to fine sand size peloids, coarse to very coarse sand size green algae and echinoid fragments, some benthic foraminifera. Some very fine sand quartz and muscovite grains. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, mosaic calcite cement, blocky calcite cement, no mechanical compaction features. Chemical compaction (stylolites). Discontinuous open microfractures.

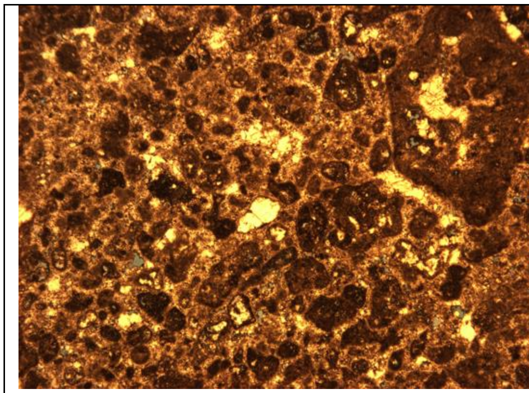
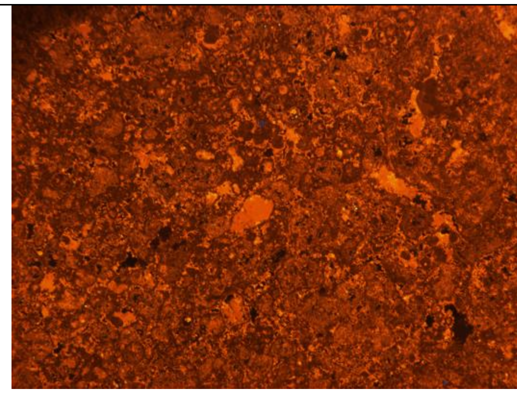
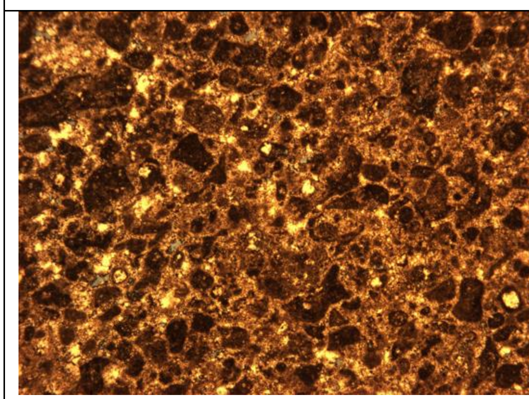
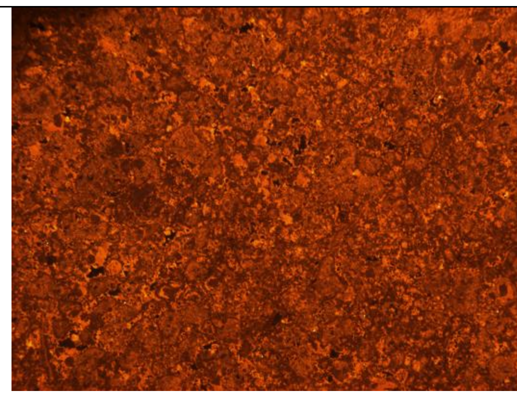
Pore type: Intragranular and intergranular.

Porosity (image analysis) : 2%

Petrophysical analysis:
Porosity – 12%
Permeability – 0.016 md

Little Cedar Creek Field **Well: 12** **Permit: 14309**

Depth: 11326 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

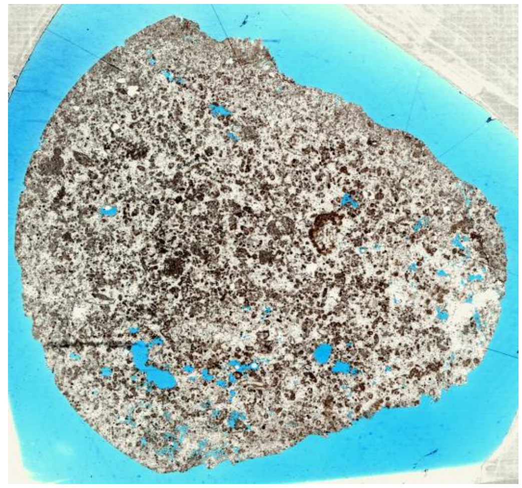
Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2zones). The first zone (inner part of the crystal) is light to dark brown, the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark brown– light brown – orange-yellow luminescence. Some crystals are not zoned, and present light brown or orange-yellow luminescence.

Little Cedar Creek Field **Well: 12** **Permit: 14309**

Depth: 11350 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
</table>

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine quartz grains occur. The bioclasts are ostracods and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Calcite cementation is very intense. Very low dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Some open microfractures.

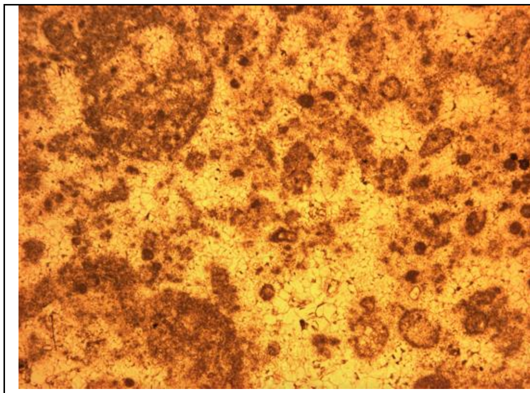
Pore type: Vuggy and some intercrystalline.

Porosity (image analysis): 3%

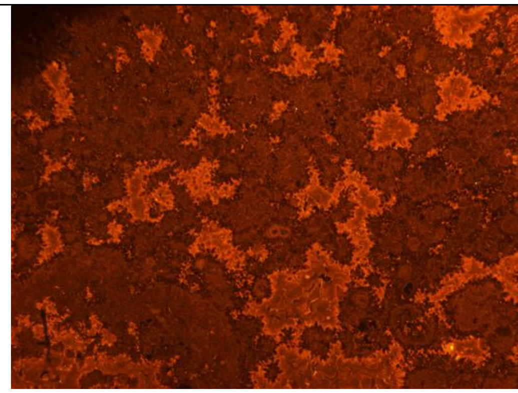
Petrophysical analysis:
Porosity – 14%
Permeability – 32.3 md

Little Cedar Creek Field **Well: 12** **Permit: 14309**

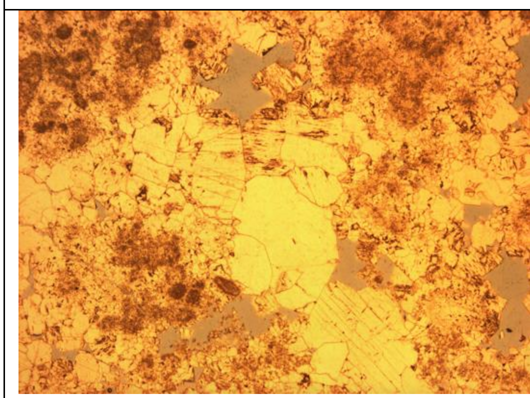
Depth: 11350 ft



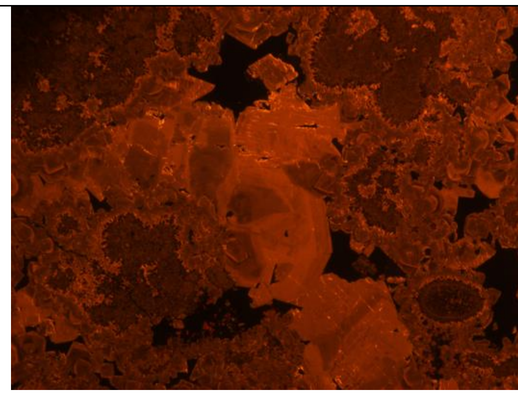
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

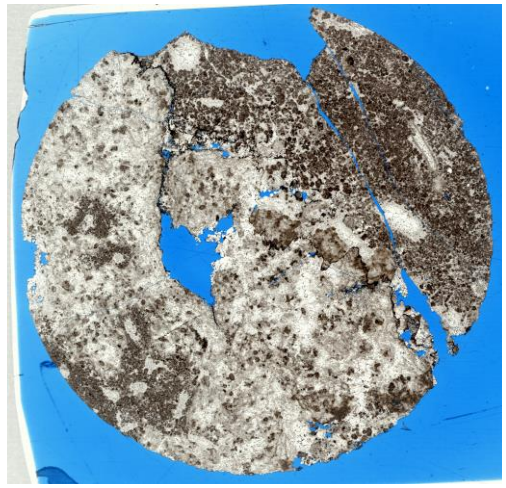
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) dark brown to nonluminescent, the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, presenting light brown luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark to light brown –orange-yellow – light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

Little Cedar Creek Field **Well: 12** **Permit: 14309**

Depth: 11361 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

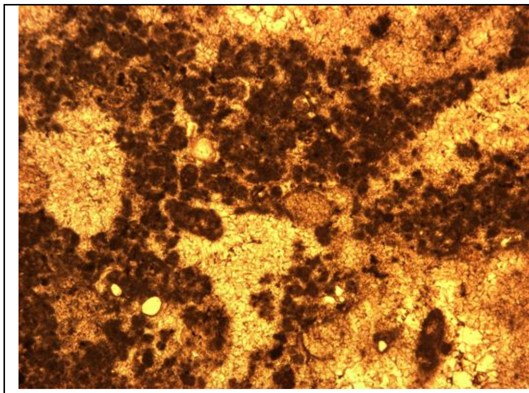
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine quartz and muscovite grains occur. The bioclasts are ostracods and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Calcite cementation and recrystallization are intense. Very low dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Some open microfractures. Chemical compaction (stylolites).

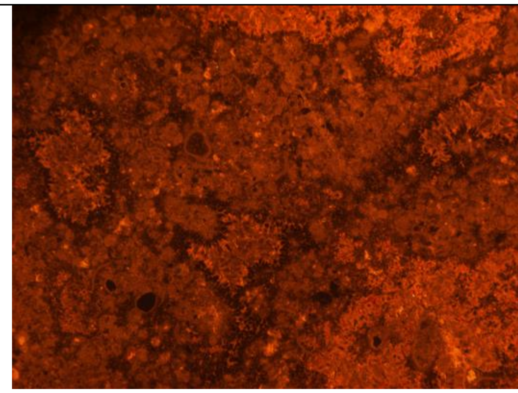
Pore type: Vuggy, some intercrystalline and intragranular porosity.

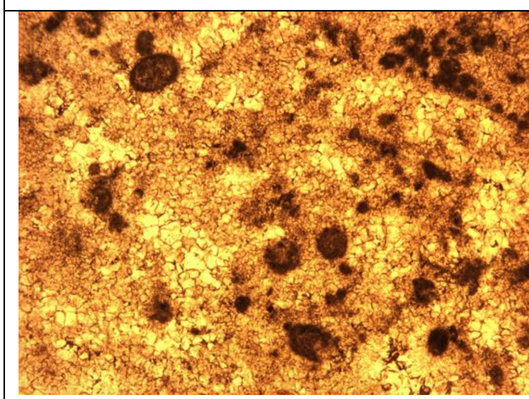
Porosity (image analysis): 5%

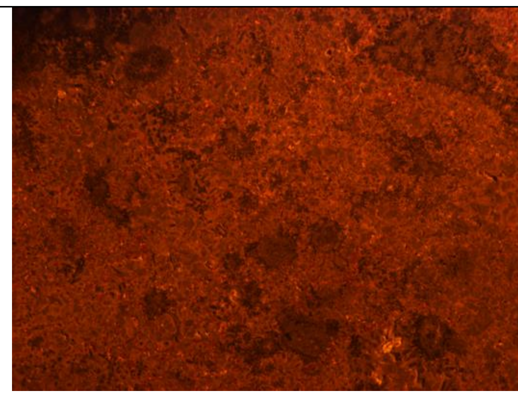
Little Cedar Creek Field **Well: 12** **Permit: 14309**

Depth: 11361 ft


Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm


Cathodoluminesce image – same field of the picture on the left side


Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

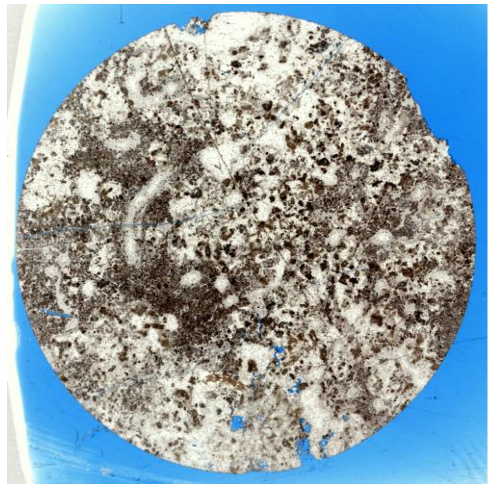
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) dark brown to nonluminescent, the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, presenting light brown luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark to light brown –orange-yellow – light brown luminescence. Some blocky calcite crystals present several subzones of luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

Little Cedar Creek Field **Well: 12** **Permit: 14309**

Depth: 11370 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine quartz grains occur. The bioclasts are ostracods, benthic foraminifera (with sintaxial calcite cement), and echinoid. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe and drusy calcite cement rimming grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Calcite cementation is intense. Some recrystallization occur. Very low dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Some open microfractures.

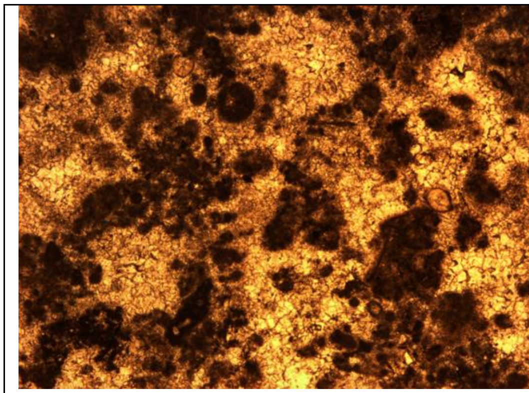
Pore type: Vuggy, and some intercrystalline.

Porosity (image analysis): 1%

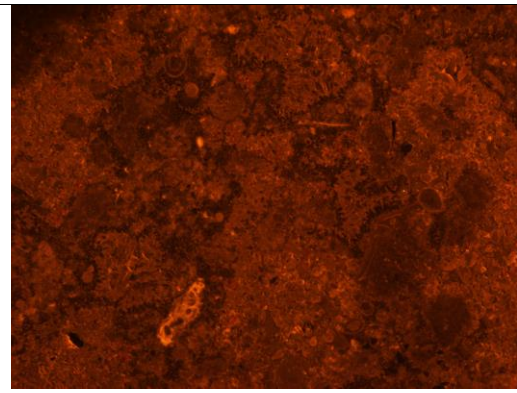
Petrophysical analysis:
Porosity – 5%
Permeability – 0.021 md

Little Cedar Creek Field **Well: 12** **Permit: 14309**

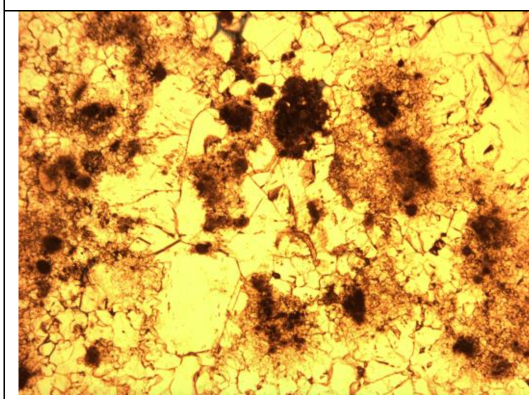
Depth: 11370 ft



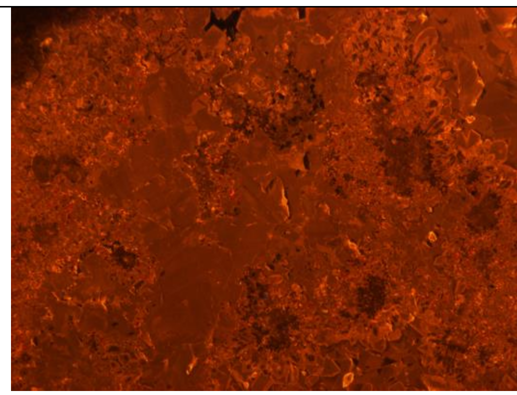
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

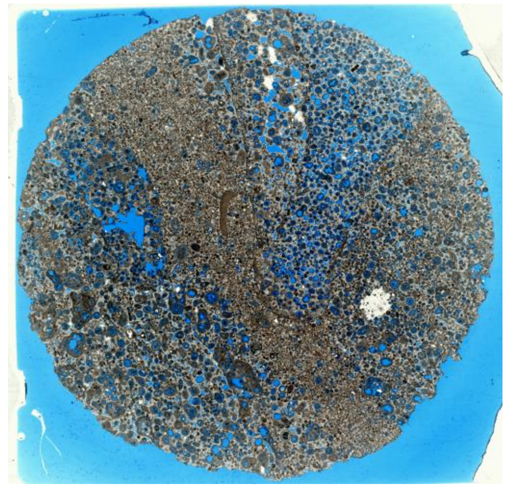
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) dark brown to nonluminescent, the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, presenting light brown luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

Little Cedar Creek Field **Well: 13** **Permit: 14325**

Depth: 11043.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Bimodal oolitic-peloidal grainstone.

Description: Oolitic-peloidal grainstone. Fine to coarse sand size oolites, some very coarse sand to gravel size grapestones, oncolites and green algae fragments. Very fine to fine sand size peloids. Oolites and peloids are concentrated in distinct portions of the rock (there is an irregular layer of peloids). Diagenesis: Bladed to drusy calcite fringe cement rimming grains, and mosaic calcite cement, rare blocky calcite and anhydrite cement and replacement, oolite dissolution, no mechanical compaction features. Chemical compaction (stylolites).

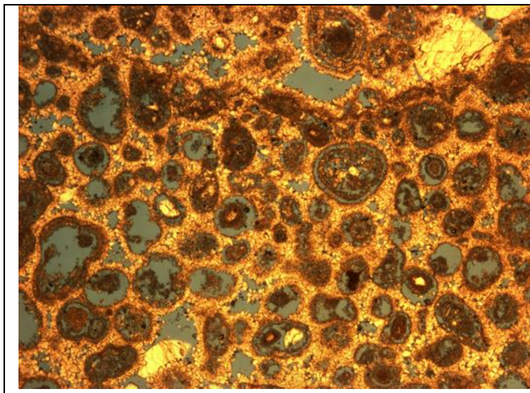
Pore type: Intragranular, moldic, vuggy, intergranular, and some intercrystalline.

Porosity (image analysis): 26%

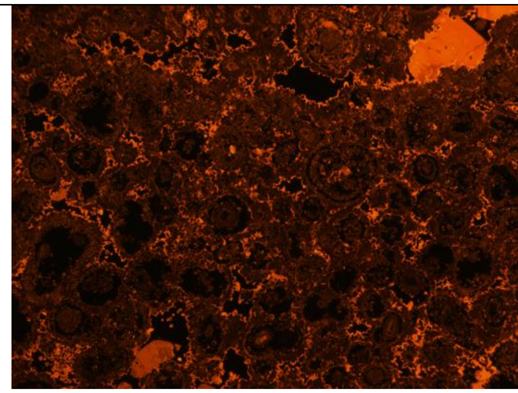
Petrophysical analysis:
Porosity – 24%
Permeability – 0.85 md

Little Cedar Creek Field **Well: 13** **Permit: 14325**

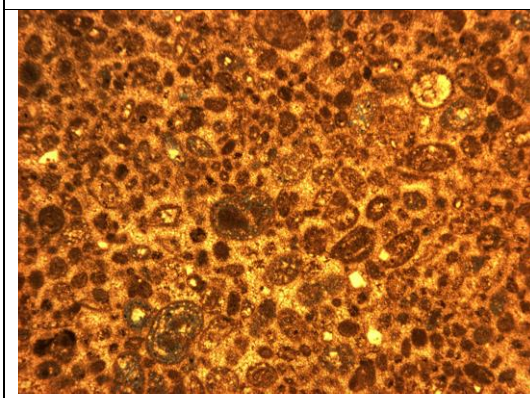
Depth: 11043.8 ft



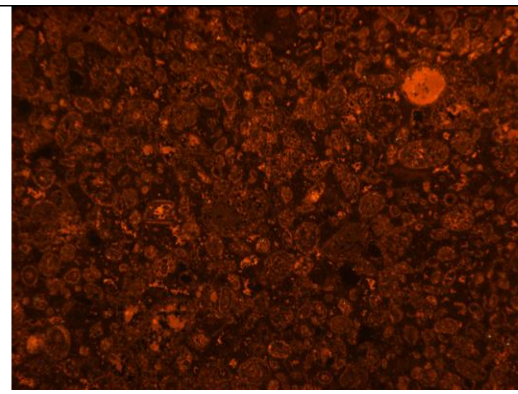
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

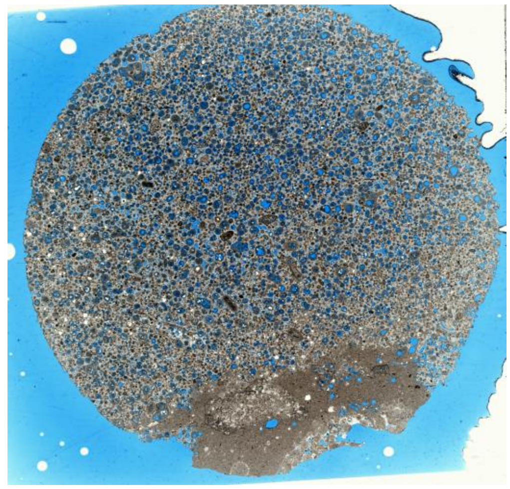


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence. Some crystals are unzoned, and present orange-yellow luminescence.

Little Cedar Creek Field **Well: 13** **Permit: 14325**

Depth: 11046.7 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Oolitic grainstone. Contact with bioturbated peloidal mudstone.

Description: Oolitic grainstone. Fine to medium sand size oolites, very fine peloids, some very coarse sand size grapestones and mollusk fragments. Some silt quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, mosaic calcite cement, rare quartz cement, oolite dissolution, no compaction features.

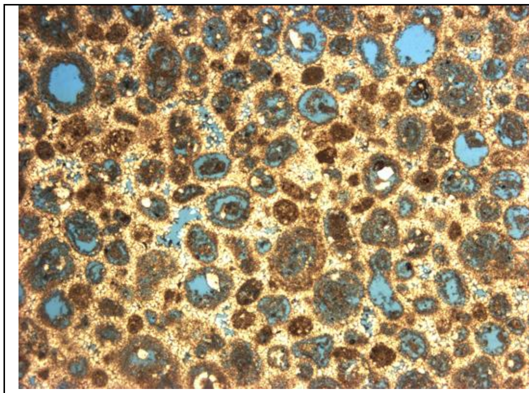
Pore type: Intragranular, moldic, intergranular, and some intercrystalline.

Porosity (image analysis) : 25%

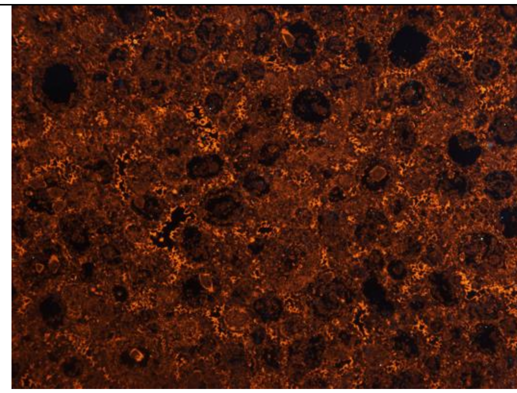
Petrophysical analysis:
Porosity – 20%
Permeability – 0.427 md

Little Cedar Creek Field **Well: 13** **Permit: 14325**

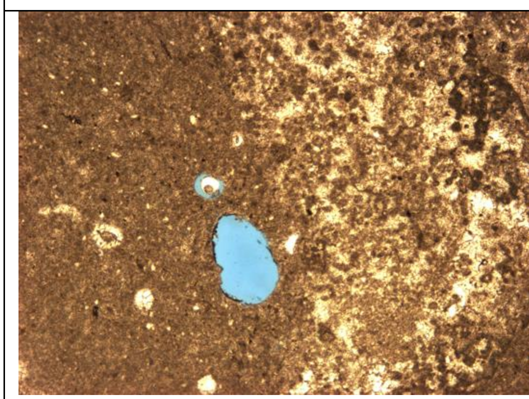
Depth: 11046.7 ft



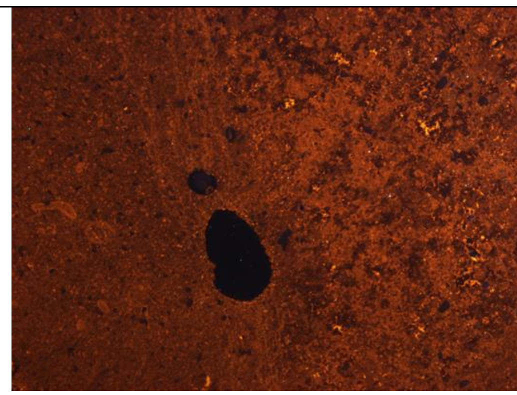
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

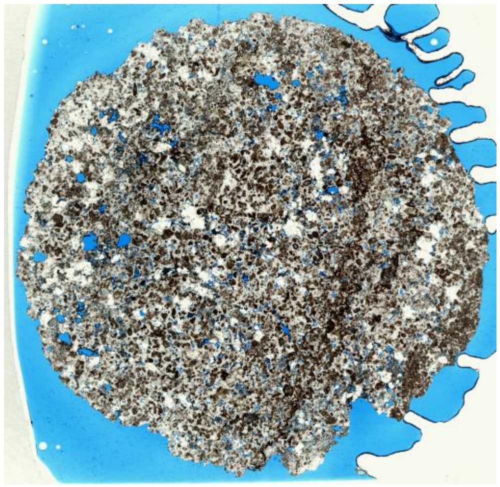


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.

Little Cedar Creek Field **Well: 13** **Permit: 14325**

Depth: 11071.6 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

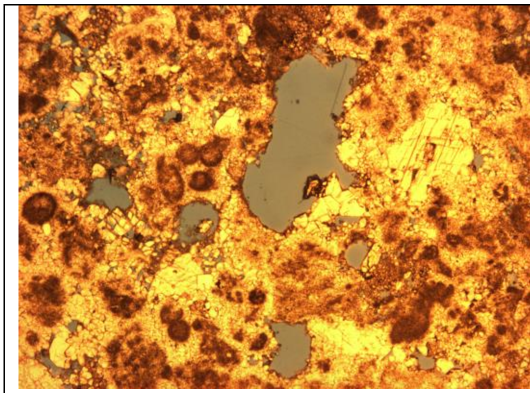
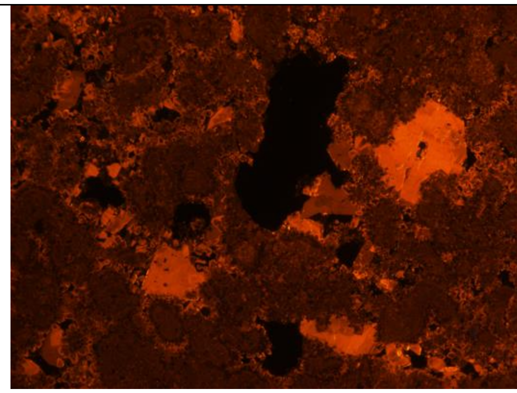
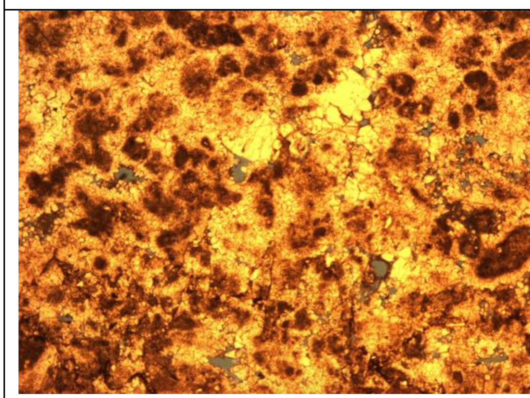
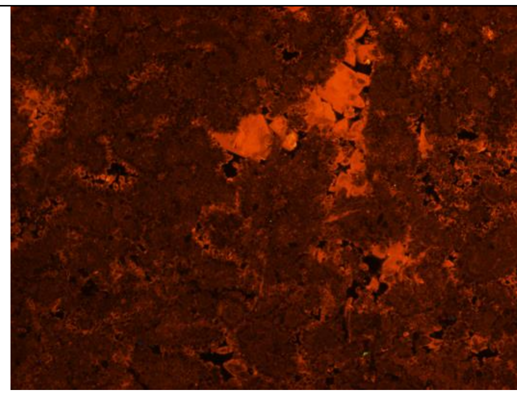
Description: Peloidal thrombolite, with some bioclasts. Very fine to fine quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement),and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolite). Several microfractures occur.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 10%

Little Cedar Creek Field **Well: 13** **Permit: 14325**

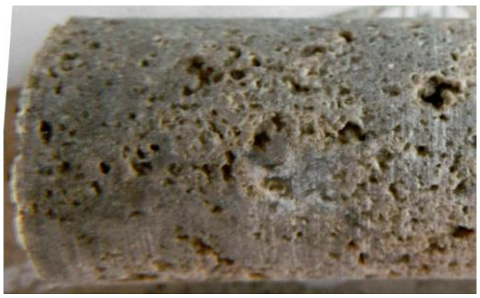
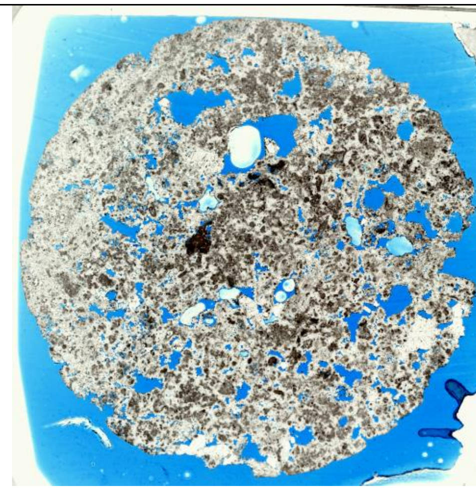
Depth: 11071.6 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 zones). The zones present the following order: orange-yellow – dark brown luminescence.

Little Cedar Creek Field **Well: 13** **Permit: 14325**

Depth: 11084.4 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Fine to medium quartz and biotite grains occur. The bioclasts are ostracods (with sintaxial calcite cement),and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Intense calcite cementation.

Pore type: Vuggy and some intercrystalline.

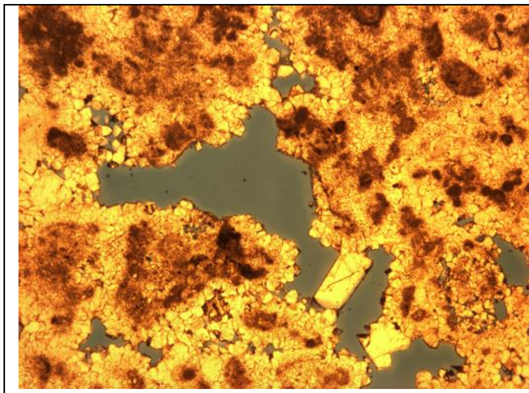
Porosity (image analysis): 17%

Petrophysical analysis:
Porosity – 13%
Permeability – 109 md

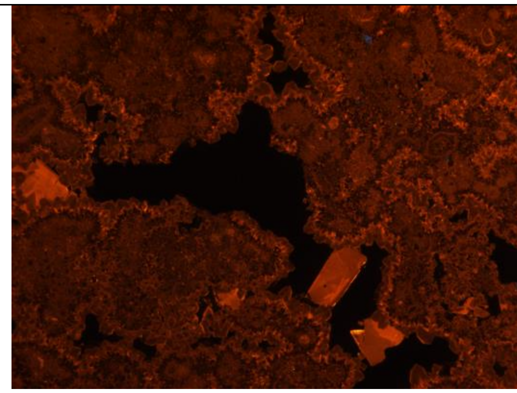
</td>
</tr>
</table>

Little Cedar Creek Field **Well: 13** **Permit: 14325**

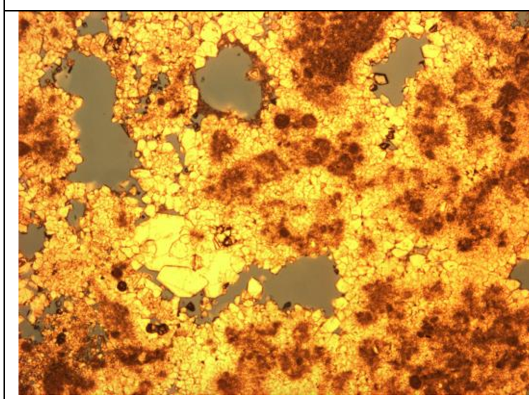
Depth: 11084.4 ft



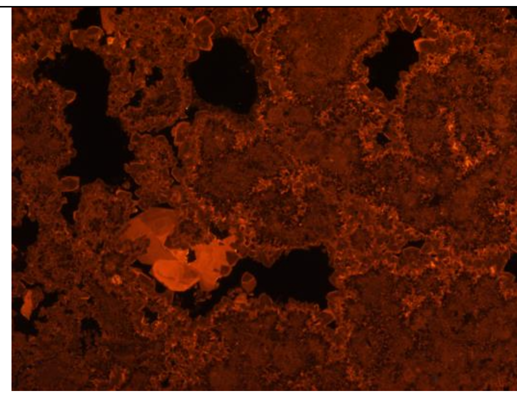
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

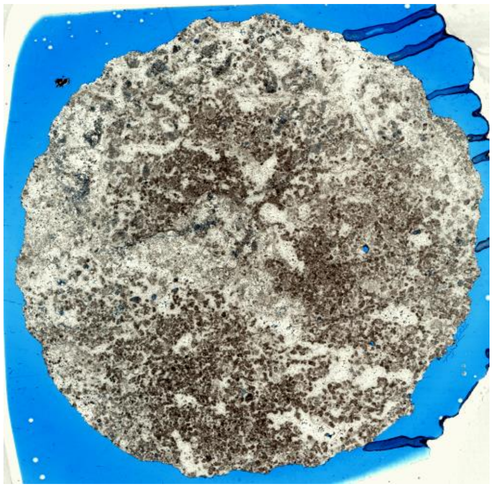
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 to 5 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence, the third zone has orange-yellow luminescence, the fourth zone has light to dark brown luminescence, and the fifth zone has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 zones). The zones present the following order: orange-yellow – light brown luminescence.

Little Cedar Creek Field | **Well: 13** | **Permit: 14325**

Depth: 11093.2 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

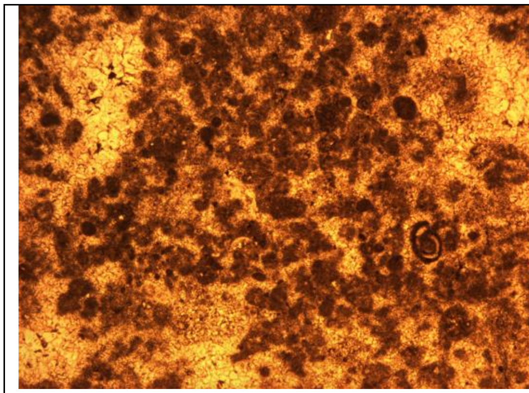
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement),and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Intense calcite cementation and some recrystallization. Some microfractures occur.

Pore type: Intragranular, some intercrystalline.

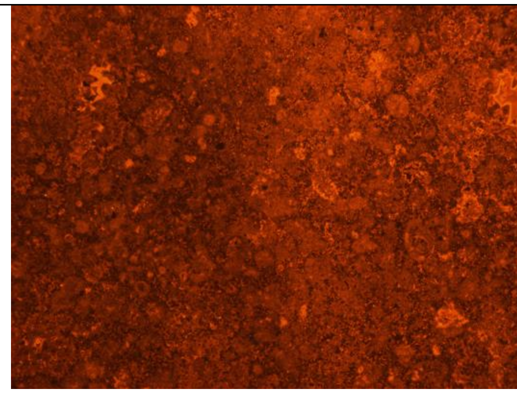
Porosity (image analysis): 1%

Little Cedar Creek Field **Well: 13** **Permit: 14325**

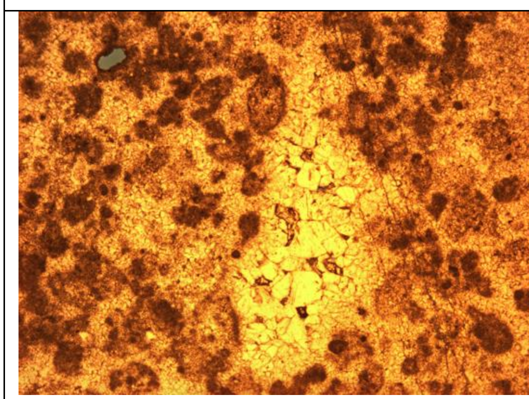
Depth: 11093.2 ft



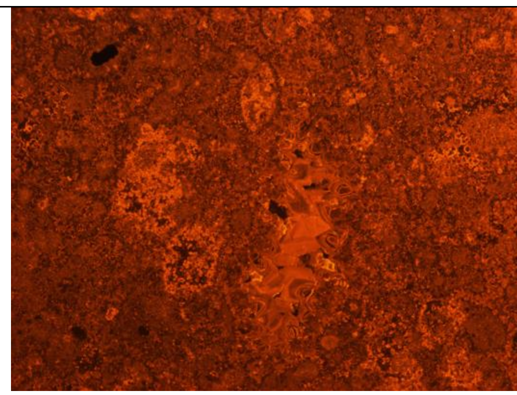
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, presenting dark brown to nonluminescence.
Mosaic calcite cement, zoned (5 zones). The zones present the following order: dark brown – nonlumiescent – light brown – dark brown – orange-yellow. Some variations occur.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark brown – light brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 13** **Permit: 14325**

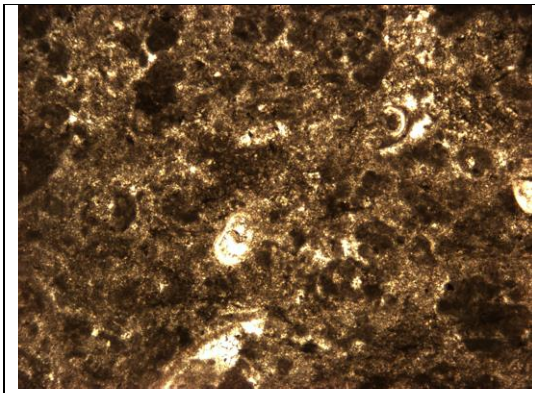
Depth: 11096 ft

<table>
<tr>
<td>
Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">Lithology: Very fine sand peloidal packstone to grainstone.

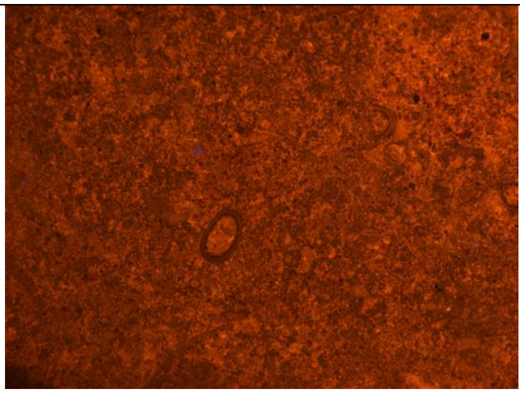
Description: Peloidal packstone to grainstone, with some bioclasts. Very fine to fine sand size peloids. Bioclasts are benthic foraminifera, ostracods, and mollusks. Silt to very fine sand size quartz and muscovite grains. Diagenesis: very fine mosaic calcite cement and blocky calcite cement. Some recrystallization occur. Chemical compaction (solution seams). No visible porosity.</td>
</tr>
</table>

Little Cedar Creek Field **Well: 13** **Permit: 14325**

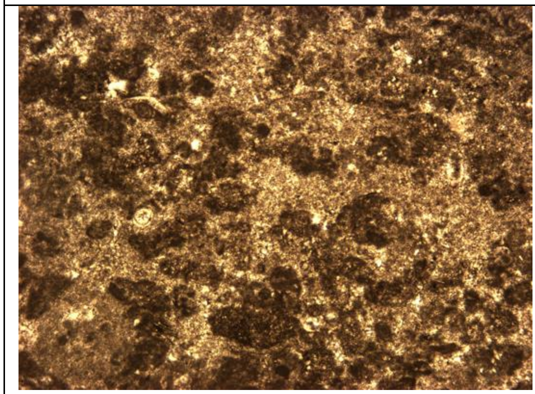
Depth: 11096 ft



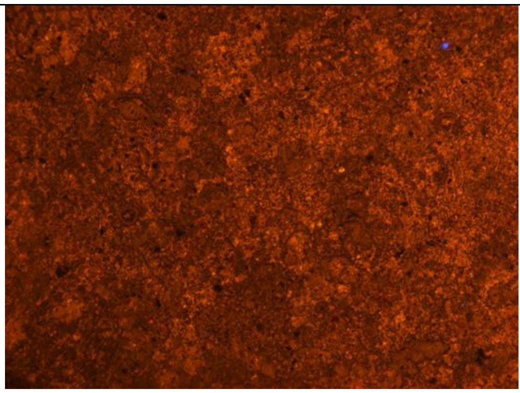
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Mosaic calcite cement, presenting light brown to orange-yellow luminescence.
Blocky calcite cement, presenting orange-yellow luminescence.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

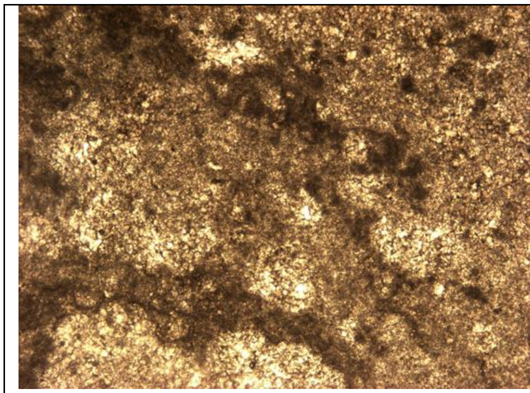
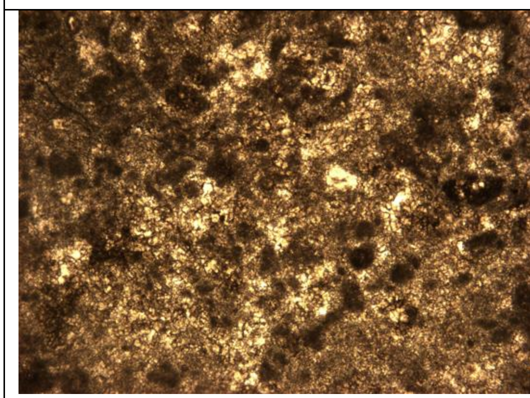
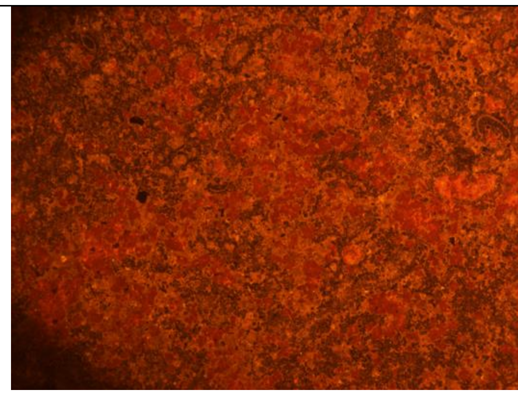
Little Cedar Creek Field **Well: 13** **Permit: 14325**

Depth: 11111 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section
Lithology: Peloidal packstone to grainstone. **Description:** Peloidal packstone to grainstone. Very fine to fine sand size peloids. Silt to very fine sand size quartz and muscovite grains. Diagenesis: very fine mosaic calcite cement and blocky calcite cement. Some recrystallization occur. Moderate dolomitization. Euhedral to anhedral dolomite crystals as replacing or cementing phase. Chemical compaction (solution seams). No visible porosity. Open microfractures.	

Little Cedar Creek Field **Well: 13** **Permit: 14325**

Depth: 11111 ft

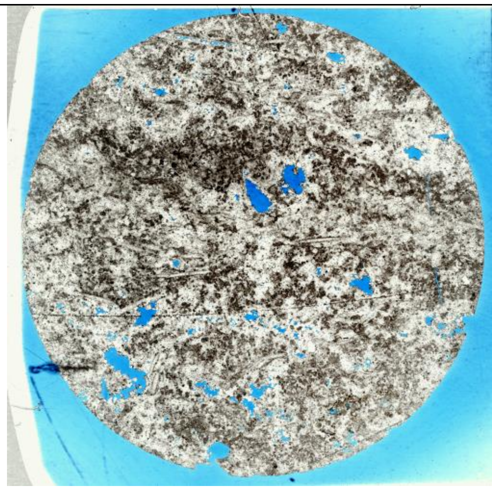
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Mosaic calcite cement, presenting light brown to orange-yellow luminescence.
Blocky calcite cement, presenting orange-yellow to light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.</td></tr>
</table>

Little Cedar Creek Field **Well: 14** **Permit: 14545**

Depth: 11314.7 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine quartz and biotite grains occur. The bioclasts are green algae, and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Intense calcite cementation and some recrystallization.

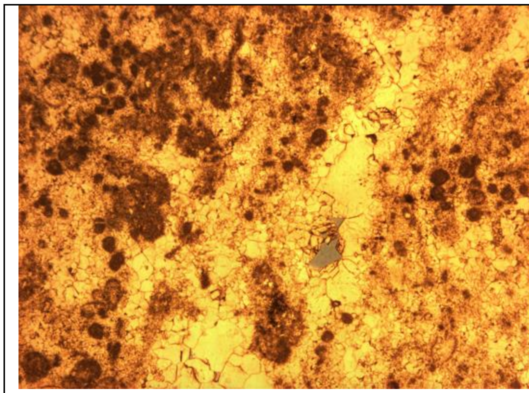
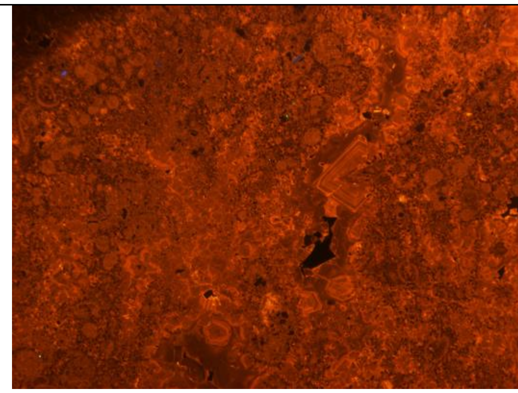
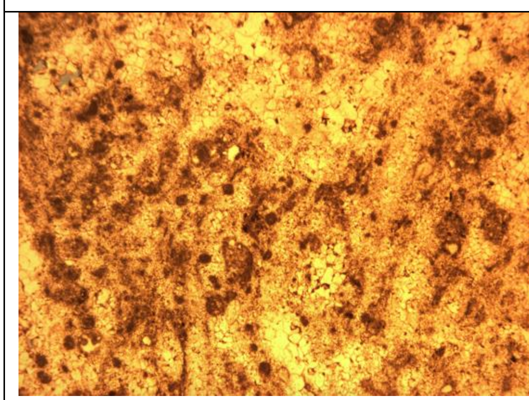
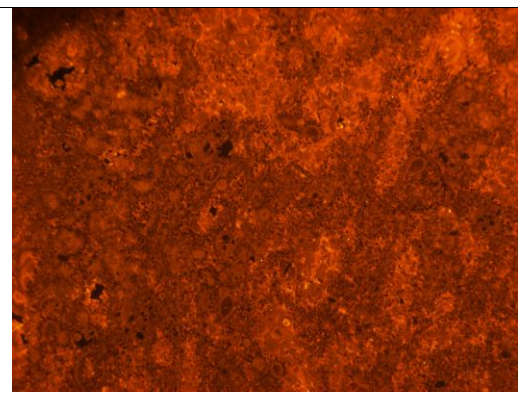
Pore type: Vuggy, some moldic and intercrystalline.

Porosity (image analysis): 4%

Petrophysical analysis:
Porosity – 7%
Permeability – 0.046 md

Little Cedar Creek Field **Well: 14** **Permit: 14545**

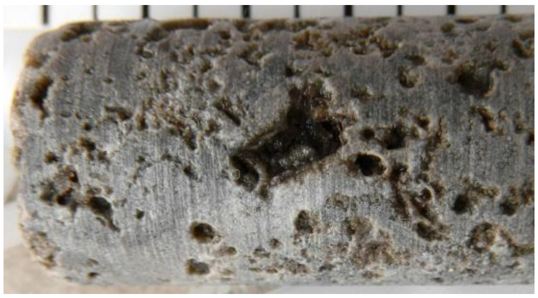
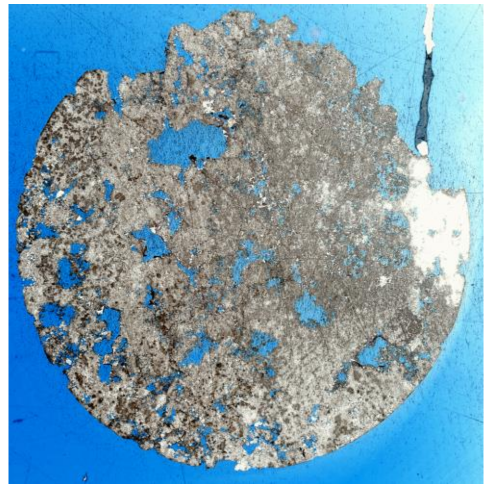
Depth: 11314.7 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Mosaic calcite cement, presenting light brown to orange-yellow luminescence.
Blocky calcite cement, zoned (5 zones). The zones present the following order: light brown – dark brown - orange-yellow luminescence – dark brown – orange-yellow. Some crystals present several subzones of luminescence.

Little Cedar Creek Field **Well: 14** **Permit: 14545**

Depth: 11321.7 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement),and rare benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Intense calcite cementation and some recrystallization. Some microfractures occur. Chemical compaction (stylolites). Intense late dissolution.

Pore type: Vuggy and intercrystalline.

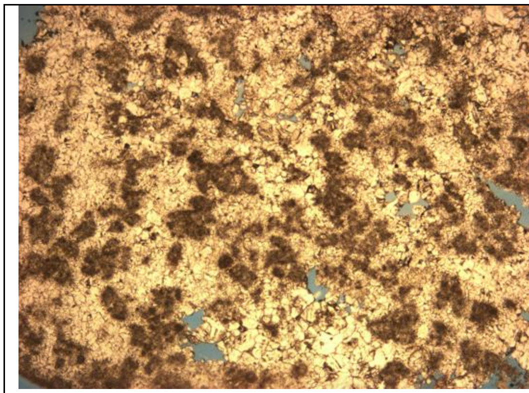
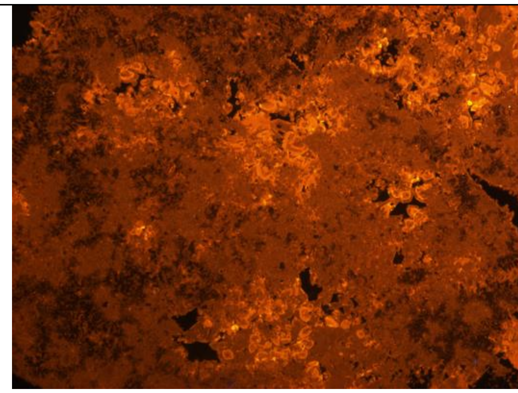
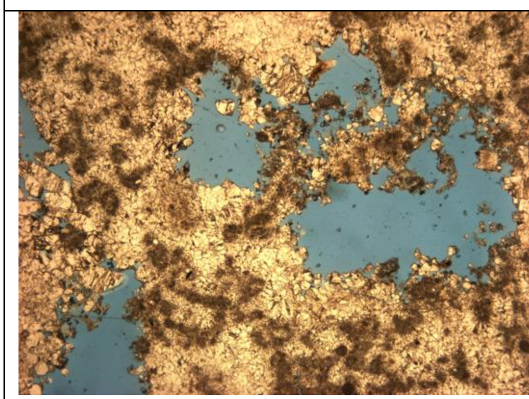
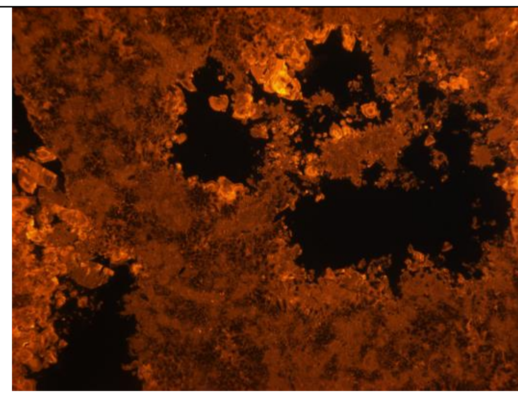
Porosity (image analysis): 19%

Petrophysical analysis:
Porosity – 14%
Permeability – 9.5 md

</td>
</tr>
</table>

Little Cedar Creek Field **Well: 14** **Permit: 14545**

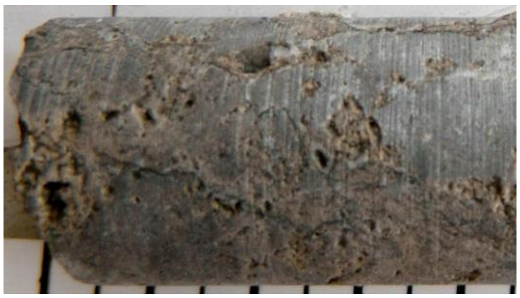
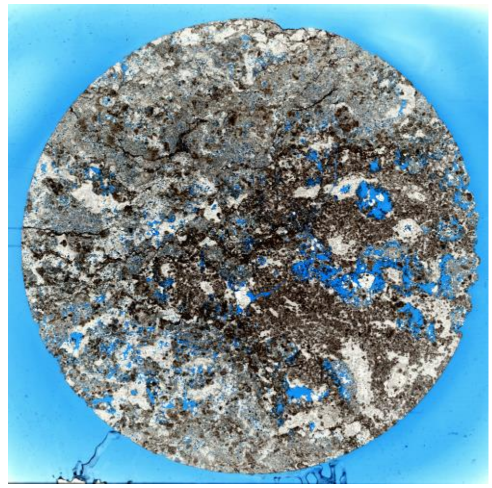
Depth: 11321.7 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (3 zones). The zones present the following order: light brown – orange-yellow – light brown luminescence.

Little Cedar Creek Field **Well: 14** **Permit: 14545**

Depth: 11323.2 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
</table>

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to very fine quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Intense calcite cementation and recrystallization. Chemical compaction (stylolites). Some discontinuous open microfractures occur.

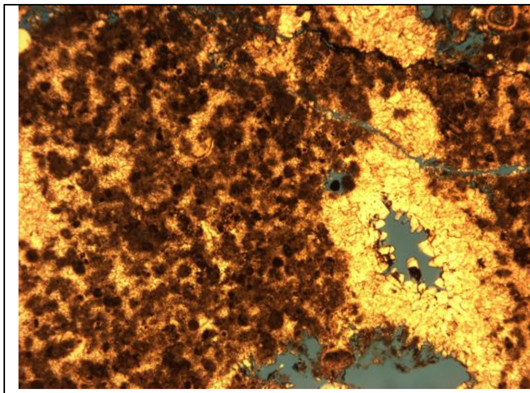
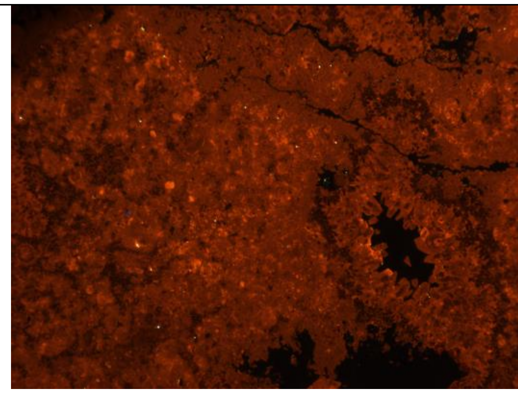
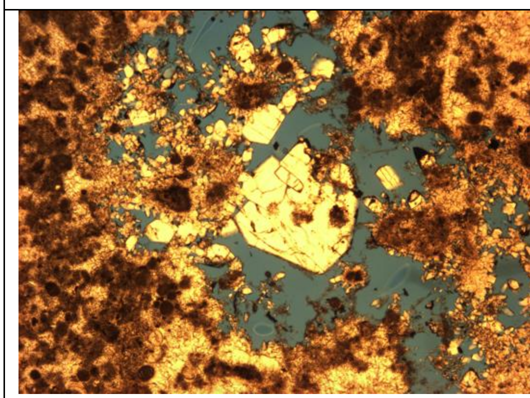
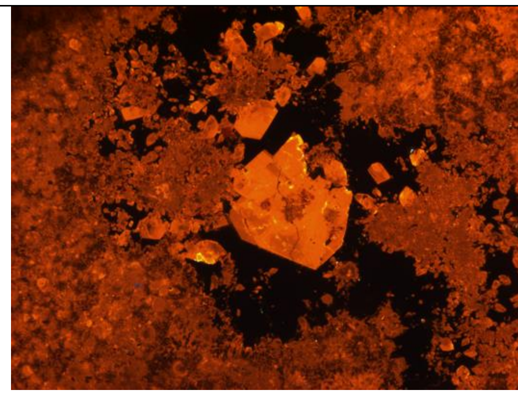
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 15%

Petrophysical analysis:
Porosity – 9%
Permeability – 0.758 md

Little Cedar Creek Field **Well: 14** **Permit: 14545**

Depth: 11323.2 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

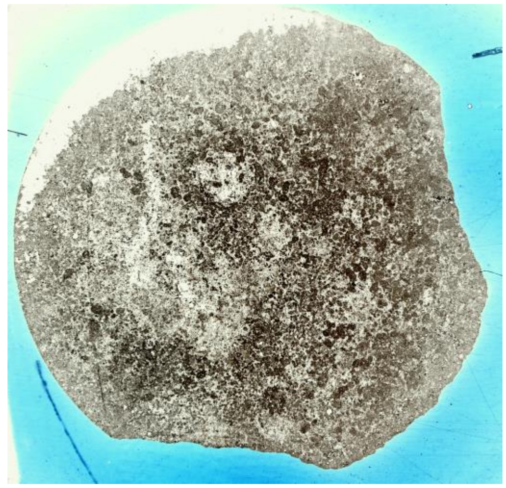
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence. Some crystals are not zoned, and present orange-yellow luminescence.
Recrystallization – small portions of the rock presents recrystallization, losing the original texture.

Little Cedar Creek Field **Well: 14** **Permit: 14545**

Depth: 11332.2 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite. Silt to fine quartz, muscovite and biotite grains occur mainly inside peloids. Very fine to medium sand peloids. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Intense calcite cementation and recrystallization.

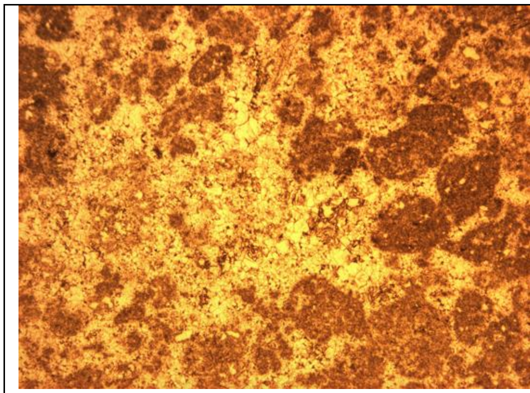
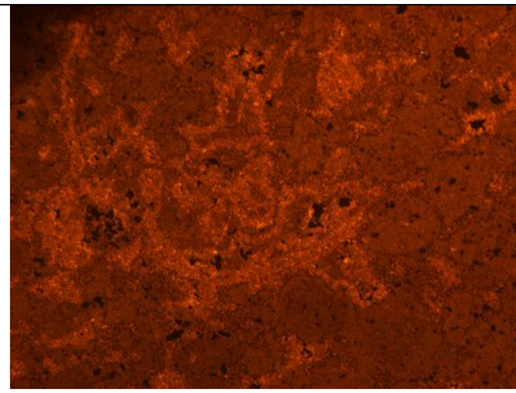
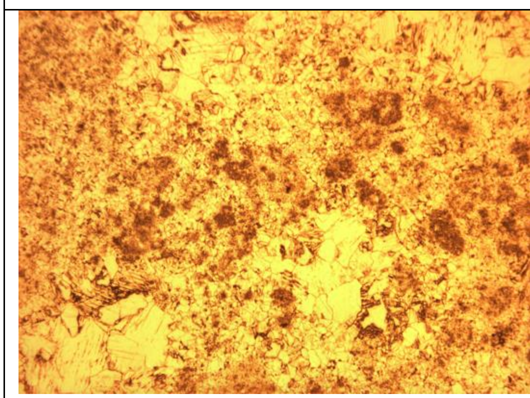
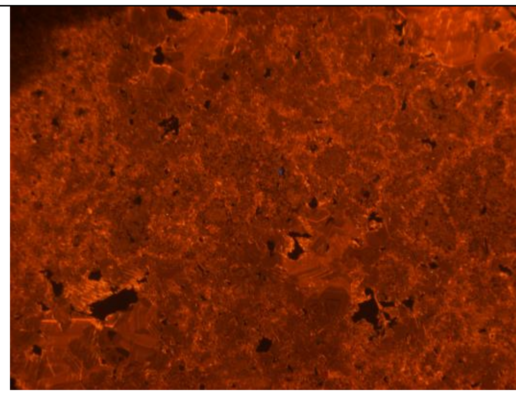
Pore type: No visible porosity.

Porosity (image analysis): no porosity

Petrophysical analysis:
Porosity – 2%
Permeability - < 0.0001 md

Little Cedar Creek Field **Well: 14** **Permit: 14545**

Depth: 11332.2 ft

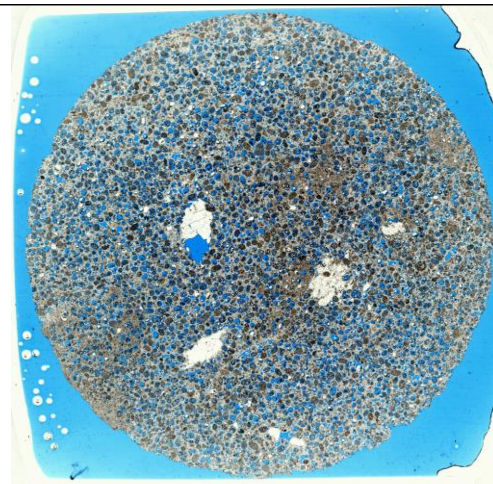
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence. Some crystals present several subzones of luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

Depth: 11255.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to medium sand oolitic grainstone.

Description: Oolitic grainstone, fine to medium sand size, with some bioclasts. Bioclasts are benthic foraminifera and ostracods. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, blocky calcite cement, oolite dissolution, anhydrite crystals replacing grain and cement, no compaction features.

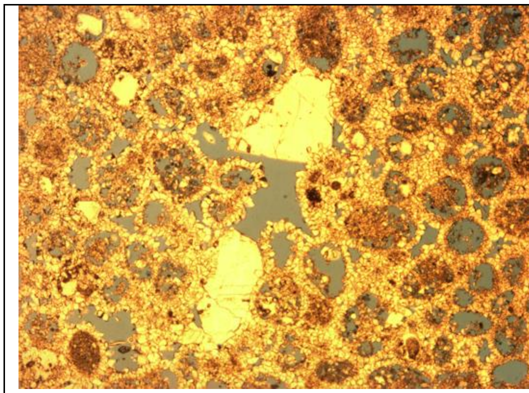
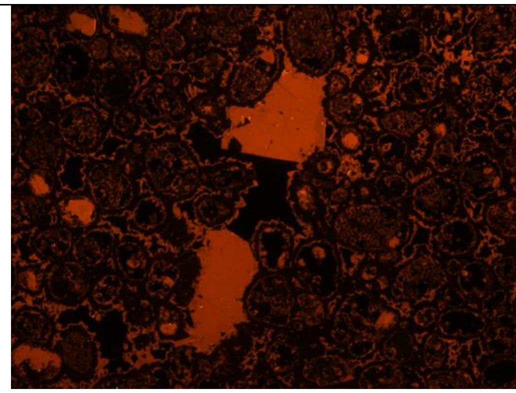
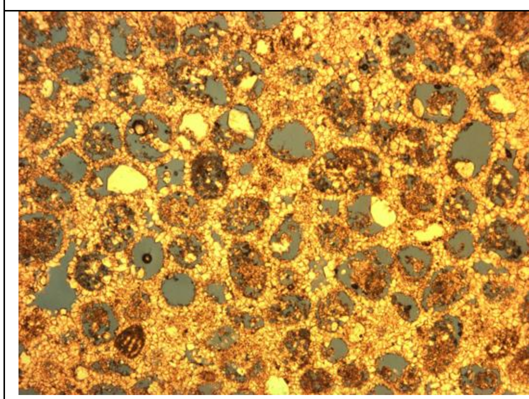
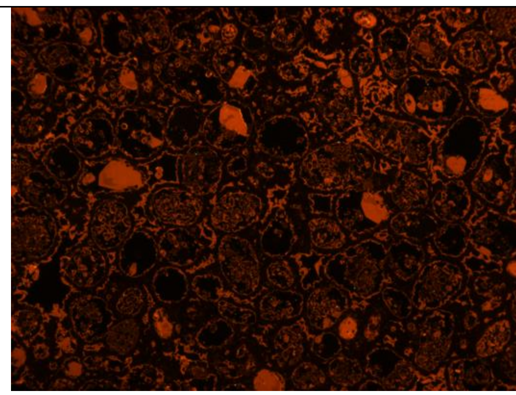
Pore type: Moldic, intragranular, intergranular, and rare vuggy.

Porosity (image analysis): 29%

Petrophysical analysis:
Porosity – 24%
Permeability – 2.25 md

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

Depth: 11255.4 ft

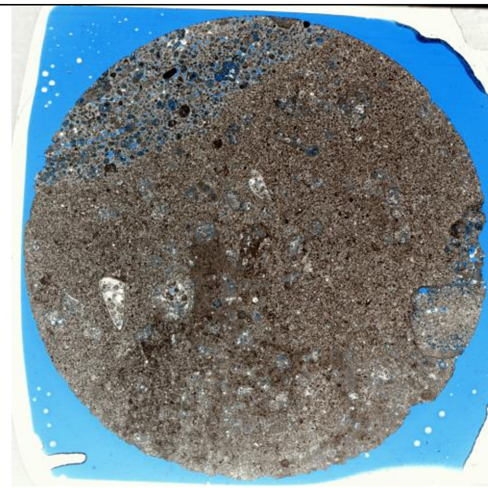
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence. Some crystals are not zoned, and present orange-yellow luminescence. The blocky calcite cement occurs in the intergranular and in the moldic porosity.</td></tr>
</table>

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

Depth: 11266.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloid-skeletal grainstone / oncoid-peloidal grainstone

Description: Peloidal-skeletal grainstone. Very fine to fine sand size peloids. The skeletal fragments are: green algae, benthic foraminifera, and mollusks. Diagenesis: Bladed to drusy calcite fringe cement rimming grains and blocky calcite cement. No compaction features. Open microfractures. This microfacies is in contact with an oncoid-peloidal grainstone. Oncolites medium to coarse sand size. Very fine to fine sand size peloids.

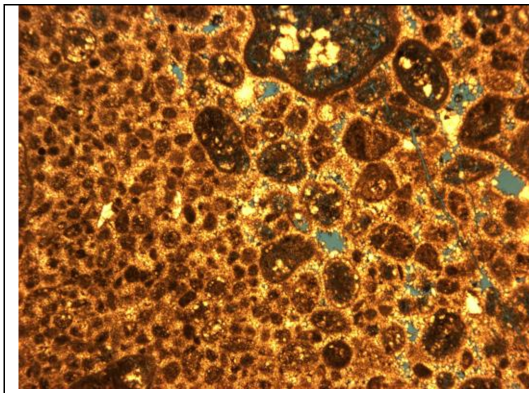
Pore type: Intragranular, intercrystalline and rare vuggy porosity. Intragranular, moldic and intergranular porosity occur in the oncoid-peloid grainstone portion.

Porosity (image analysis): 3%

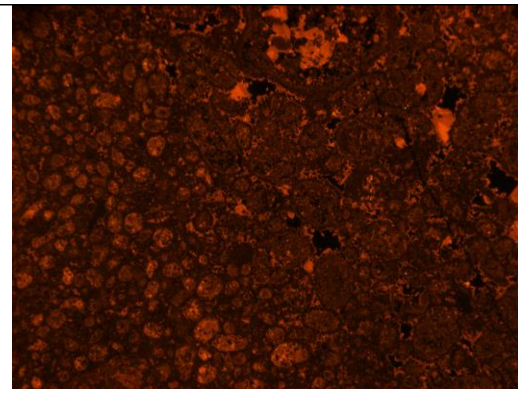
Petrophysical analysis:
Porosity – 12%
Permeability – 0.51 md

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

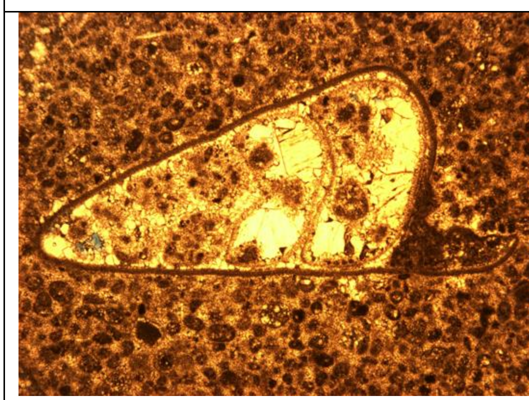
Depth: 11266.5 ft



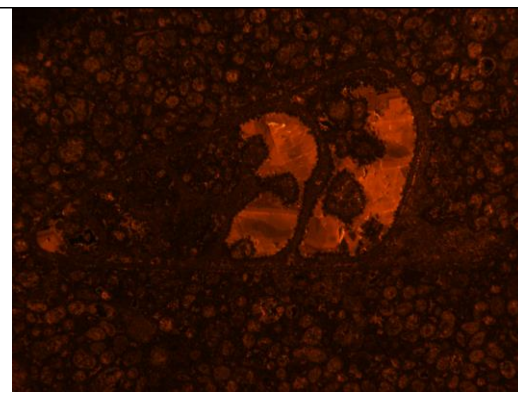
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

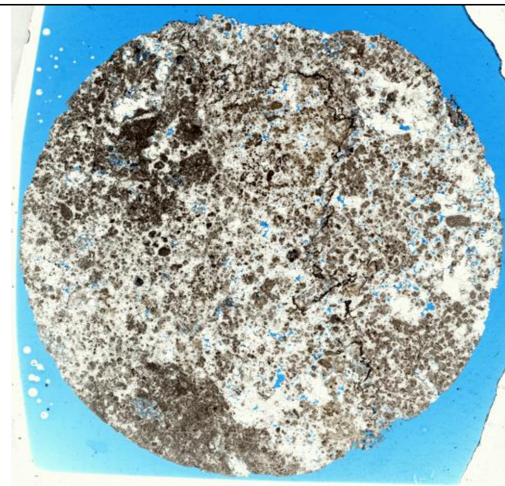
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark brown – orange-yellow – light brown luminescence.

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

Depth: 11291.9 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and biotita grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, significant amount of blocky calcite cement, and some anhydrite cement. Chemical compaction (stylolite).

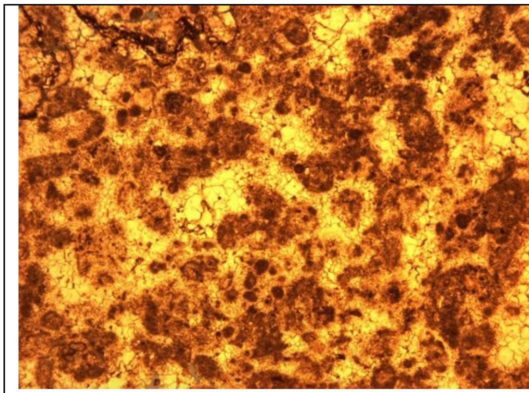
Pore type: Intergranular, intercrystalline and vuggy.

Porosity (image analysis) : 2%

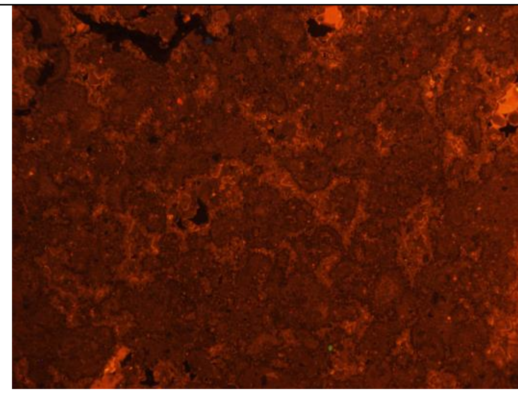
Petrophysical analysis:
Porosity – 4%
Permeability – 0.015 md

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

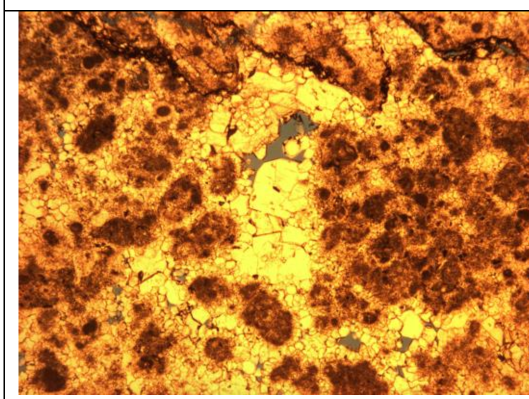
Depth: 11291.9 ft



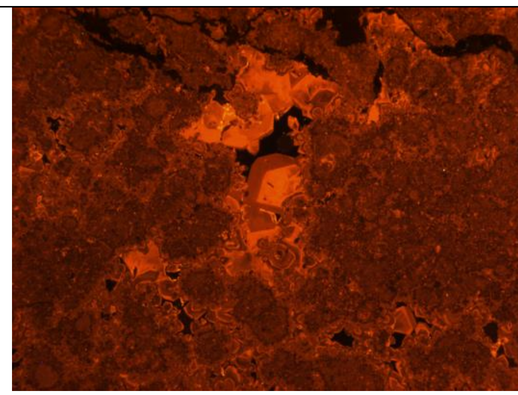
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.

Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence and the second zone (edge) has orange-yellow luminescence.

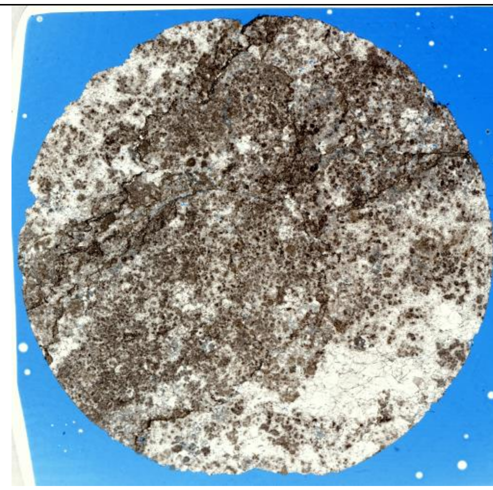
Mosaic calcite cement, zoned (2 zones): light to dark brown – orange-yellow luminescente.

Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: light brown – orange-yellow – dark brown.

Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

Depth: 11299.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and significant amount of blocky calcite cement. Chemical compaction (stylolite).

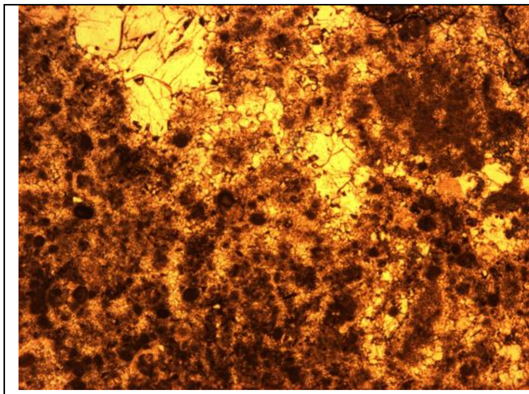
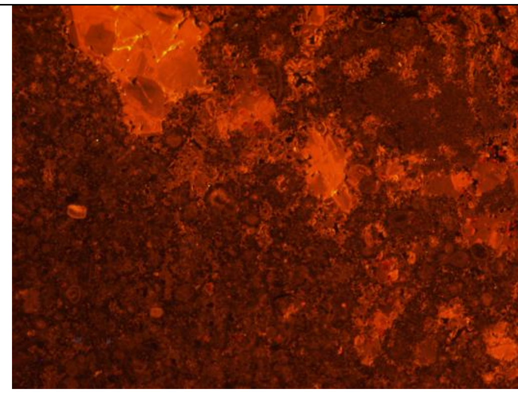
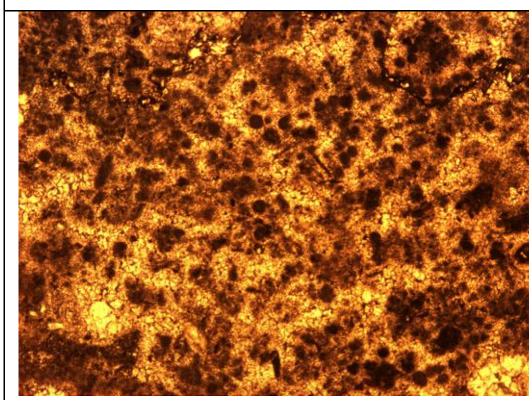
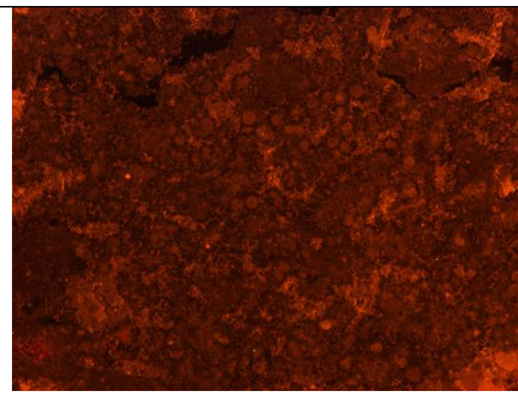
Pore type: Intercrystalline.

Porosity (image analysis): 1%

Petrophysical analysis:
Porosity – 4%
Permeability – 0.01 md

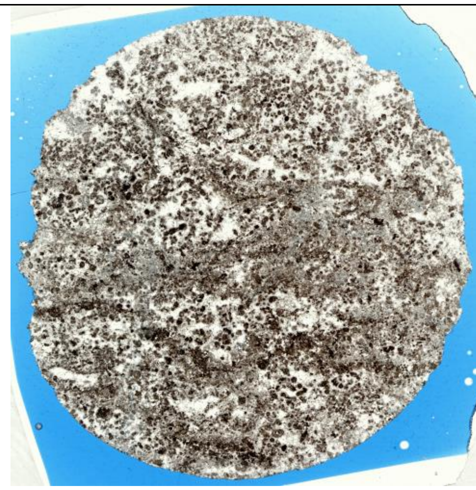
Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

Depth: 11299.9 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescence and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: light brown – orange-yellow – dark brown.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.</td></tr>
</table>

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

Depth: 11302.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and significant amount of blocky calcite cement. Chemical compaction (stylolite). Low dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase.

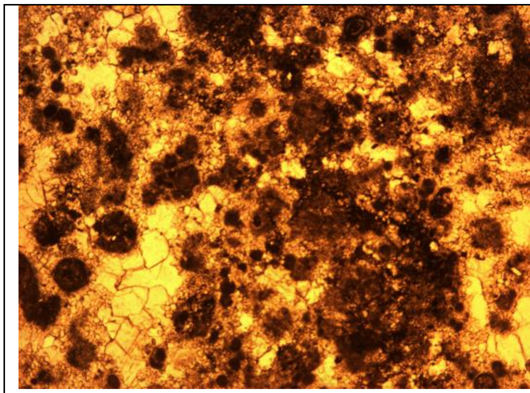
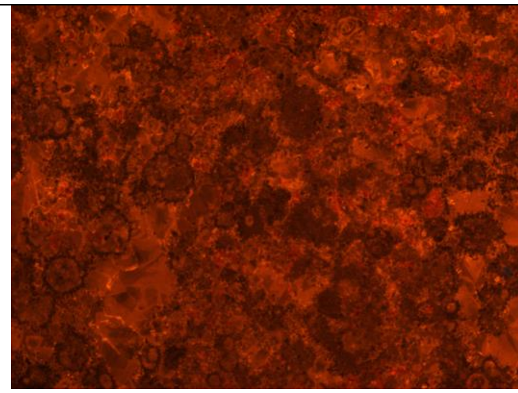
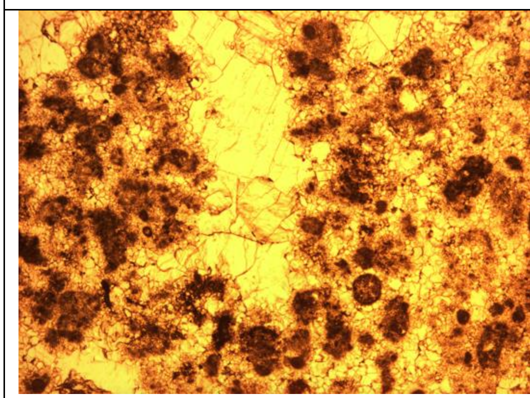
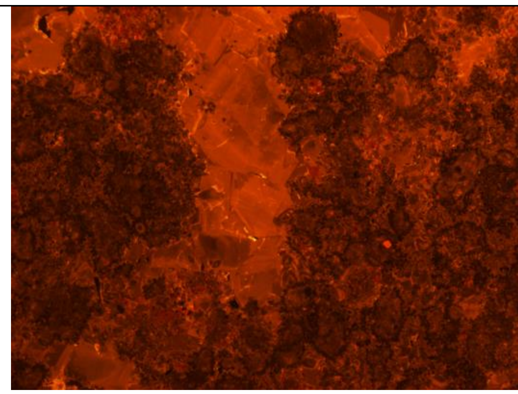
Pore type: Intercrystalline.

Porosity (image analysis): 1%

Petrophysical analysis:
Porosity – 3%
Permeability – 0.001 md

Little Cedar Creek Field **Well: 15** **Permit: 14646-B**

Depth: 11302.9 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

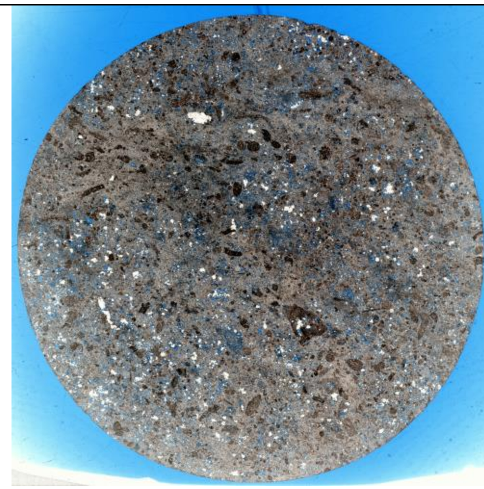
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: light brown – orange-yellow – dark to light brown.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

Little Cedar Creek Field **Well: 16** **Permit: 14652-B**

Depth: 11546.9 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Skeletal-peloidal grainstone.

Description: Skeletal-peloidal grainstone. Very fine to fine sand size peloids, fine to very coarse sand size skeletal fragments: green algae and ostracods. Rare fine sand quartz grains. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, blocky calcite cement. No compaction features.

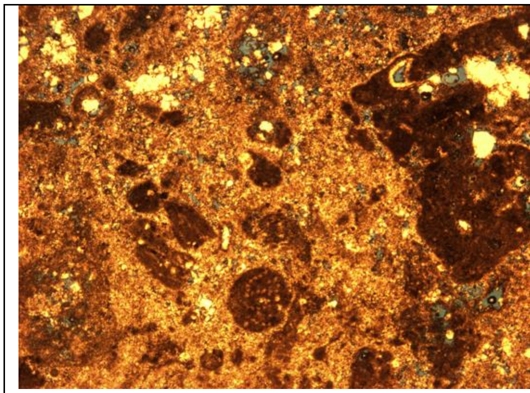
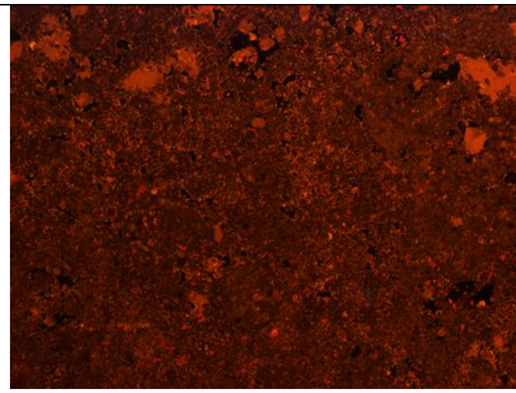
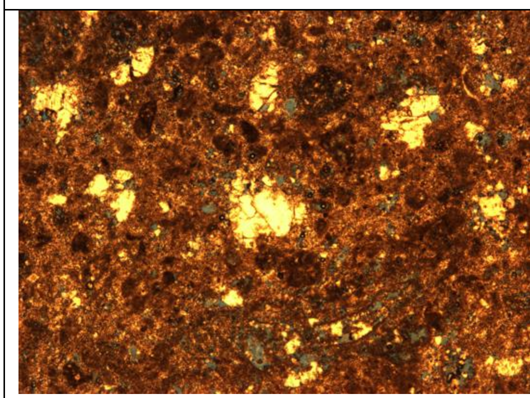
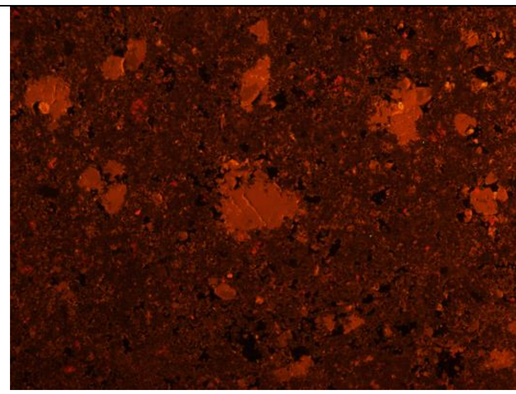
Pore type: Intergranular, intercrystalline, and some intragranular porosity.

Porosity (image analysis) : 10%

Petrophysical analysis:
Porosity – 15%
Permeability – 1.02 md

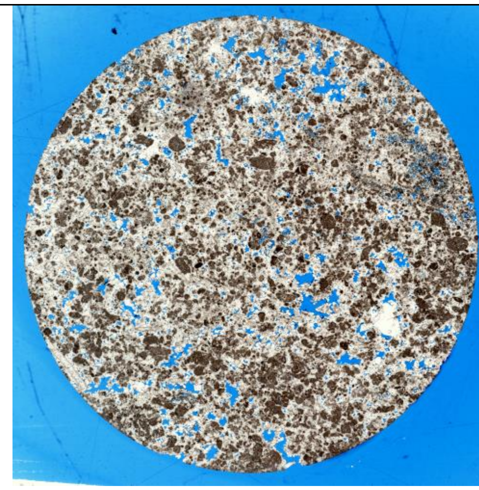
Little Cedar Creek Field **Well: 16** **Permit: 14652-B**

Depth: 11546.9 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light to dark brown – orange-yellow luminescence. Some crystals are not zoned, and present orange-yellow luminescence.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.</td></tr>
</table>

Little Cedar Creek Field **Well: 16** **Permit: 14652-B**

Depth: 11583.1 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are green algae, ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and some anhydrite cement. Low to moderate dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase.

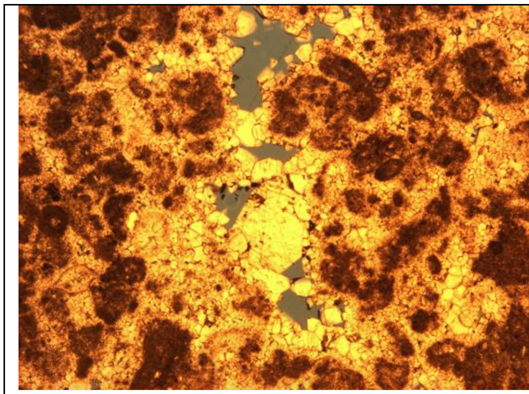
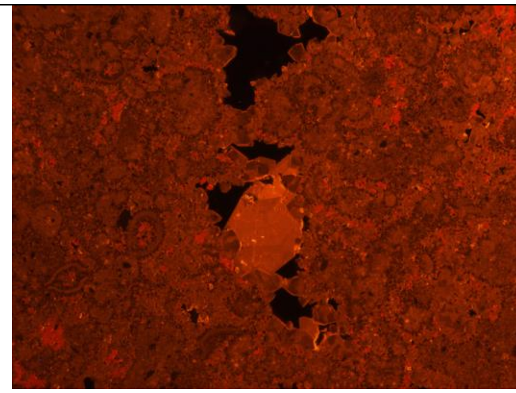
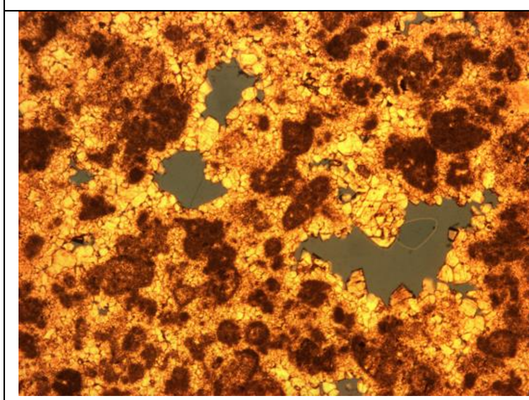
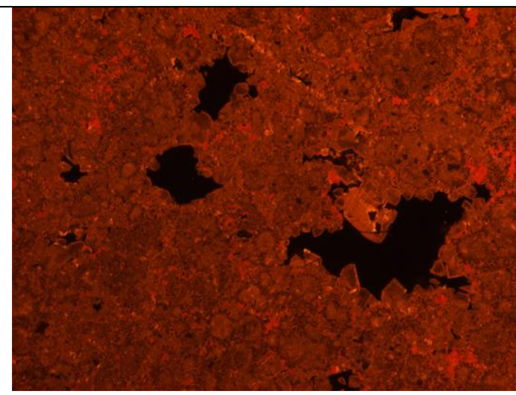
Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 8%

Petrophysical analysis:
Porosity – 8%
Permeability - < 0.0001 md

Little Cedar Creek Field **Well: 16** **Permit: 14652-B**

Depth: 11583.1 ft

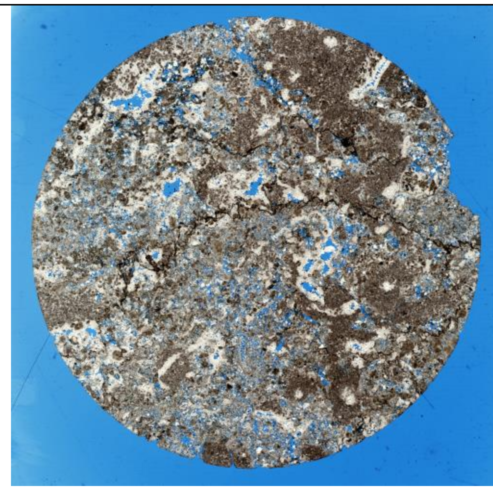
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light to dark brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 16** **Permit: 14652-B**

Depth: 11587.7 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

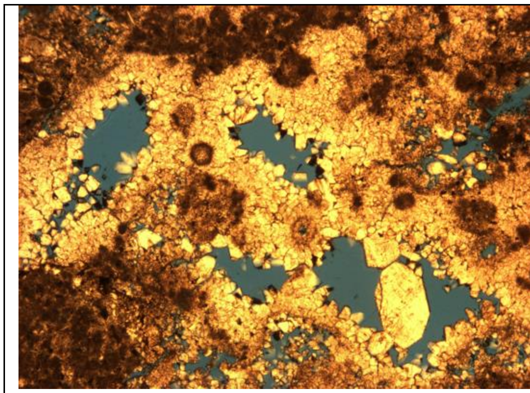
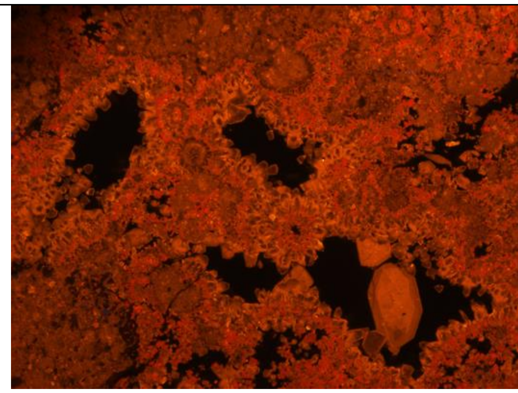
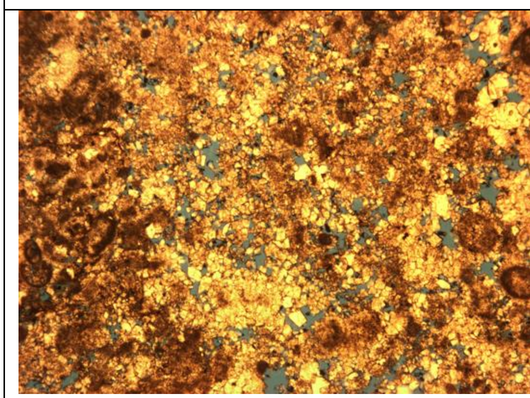
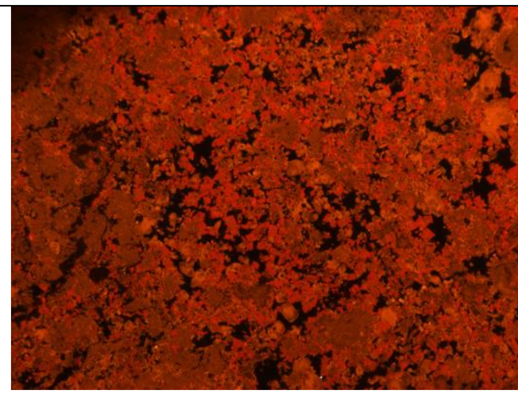
Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Moderate to high dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Chemical compaction (stylolite).

Pore type: Intercrystalline and vuggy.

Porosity (image analysis) : 10%

Little Cedar Creek Field **Well: 16** **Permit: 14652-B**

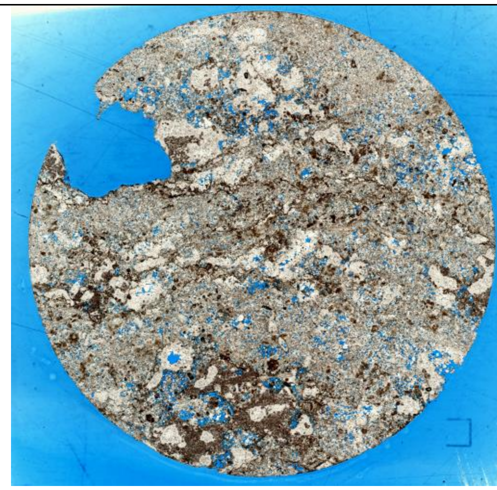
Depth: 11587.7 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 to 4 zones): light brown – orange-yellow – light brown – orange-yellow luminescente.
Blocky calcite cement, zoned (2 zones). The zones present the following order: orange-yellow – light brown.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 16** **Permit: 14652-B**

Depth: 11589.3 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods and benthic foraminifera. Peloid clusters are common. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Moderate dolomitization. Euhedral to anhedral very fine dolomite crystals occur as a replacing / cementation phase. Moderate to high calcite recrystallization. Chemical compaction (stylolites and solution seams). Late dissolution.

Pore type: Intercrystalline and vuggy.

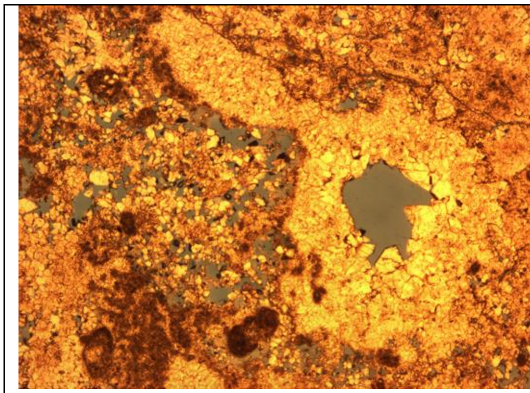
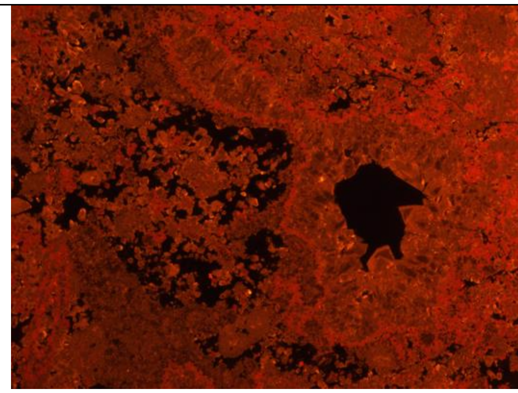
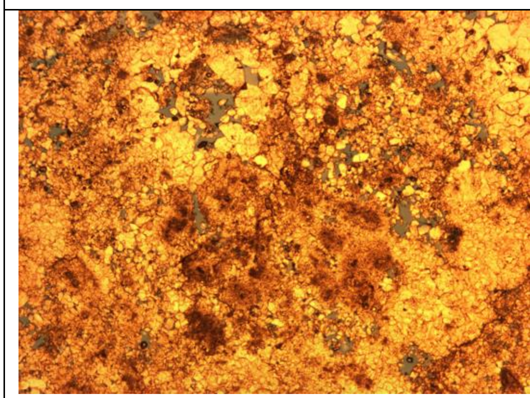
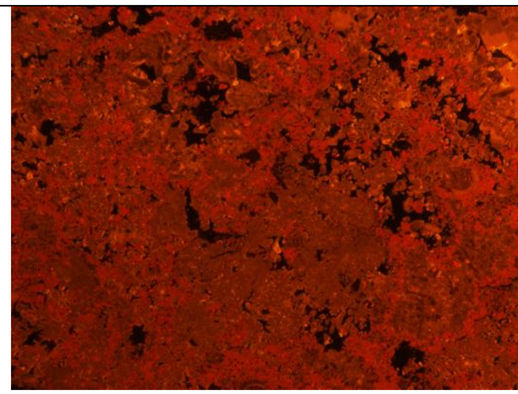
Porosity (image analysis) : 13%

Petrophysical analysis:
Porosity – 10%
Permeability – 3.92 md

</td>
</tr>
</table>

Little Cedar Creek Field **Well: 16** **Permit: 14652-B**

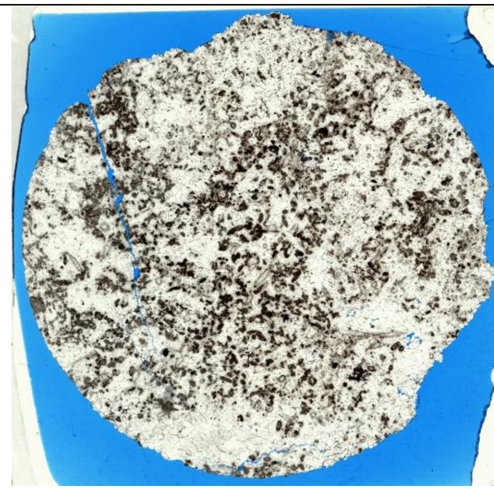
Depth: 11589.3 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown or nonluminescent and the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 to 4 zones): light brown – orange-yellow – light brown – orange-yellow luminescente.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. The dolomite replaces preferentially the drusy calcite cement.</td></tr>
</table>

Little Cedar Creek Field **Well: 17** **Permit: 14965**

Depth: 11256.3 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement.

Pore type: Intercrystalline, microfractures and vuggy.

Porosity (image analysis) : 1%

</td>
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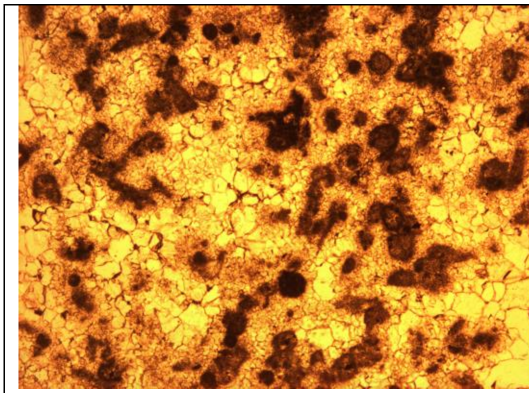
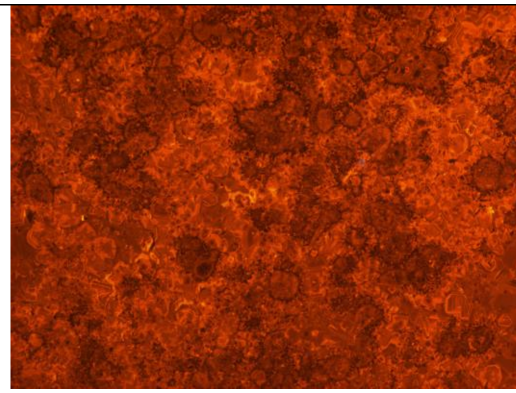
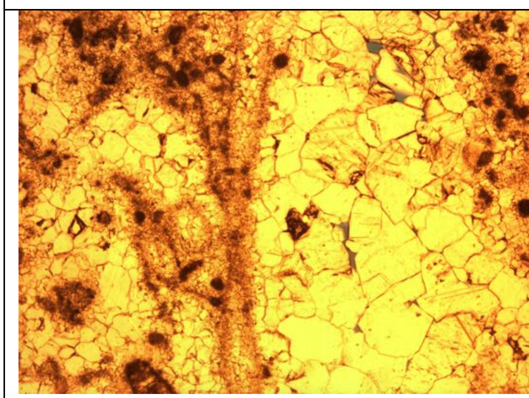
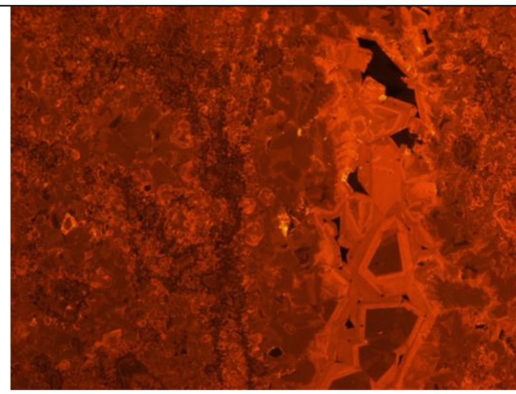
</table>

Little Cedar Creek Field **Well: 17** **Permit: 14965**

Depth: 11256.3 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

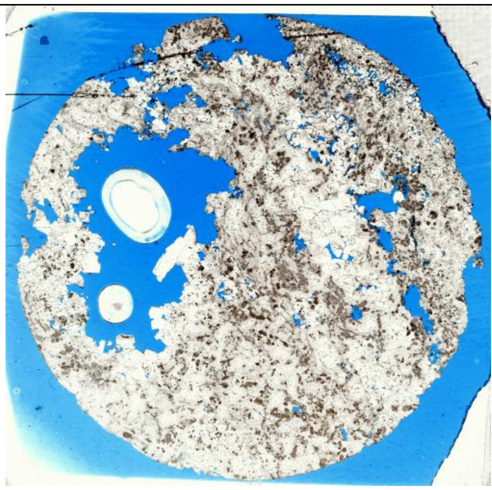
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence and the second zone (edge) has light brown to orange-yellow luminescence.
Mosaic calcite cement, zoned (2 to 3 zones): dark brown – light brown – orange yellow luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark brown - orange-yellow – light brown luminescence.

Little Cedar Creek Field **Well: 17** **Permit: 14965**

Depth: 11259.6 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Silt size quartz grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Late dissolution.

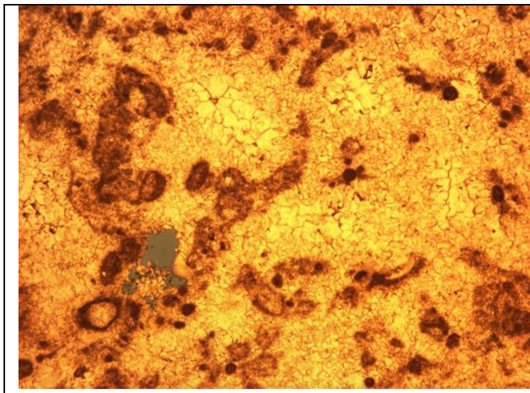
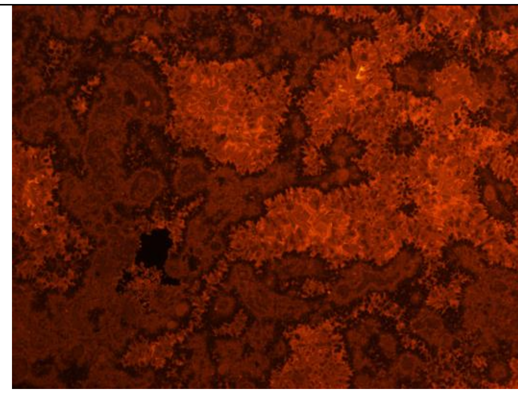
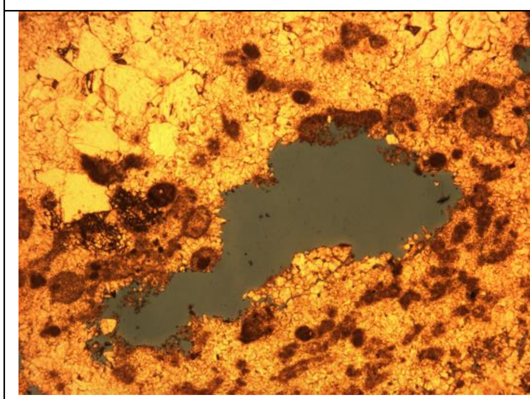
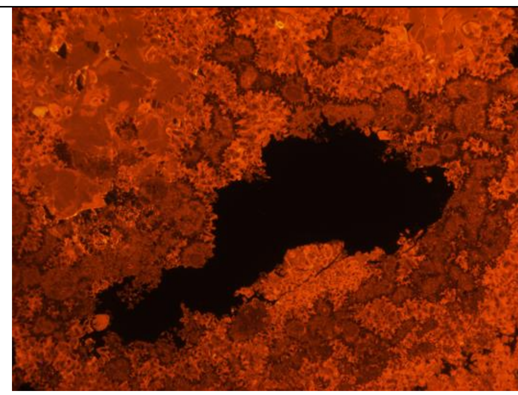
Pore type: Vuggy, intercrystalline

Porosity (image analysis) : 24%

Petrophysical analysis:
Porosity – 6%
Permeability – 1.99 md

Little Cedar Creek Field **Well: 17** **Permit: 14965**

Depth: 11259.6 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

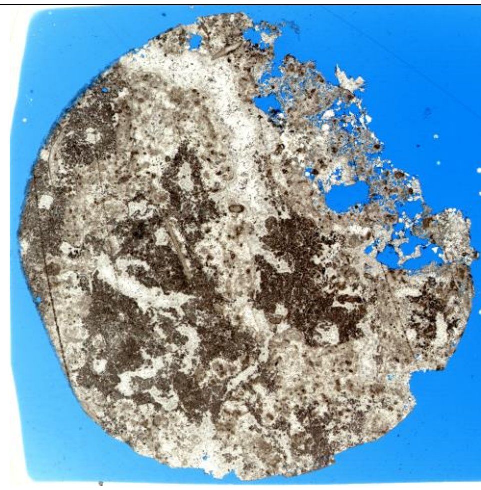
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 to 4 zones): dark to light brown– orange-yellow – light brown – orange-yellow luminescence. Some subzones occur.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark brown – light brown – orange-yellow luminescence. Several subzones occur.

Little Cedar Creek Field **Well: 17** **Permit: 14965**

Depth: 11268.1 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera, ostracods (with sintaxial calcite cement), and green algae (?). Peloid clusters are abundant. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Some portions with late dissolution and fine calcite cement crystals with intercrystalline porosity between them.

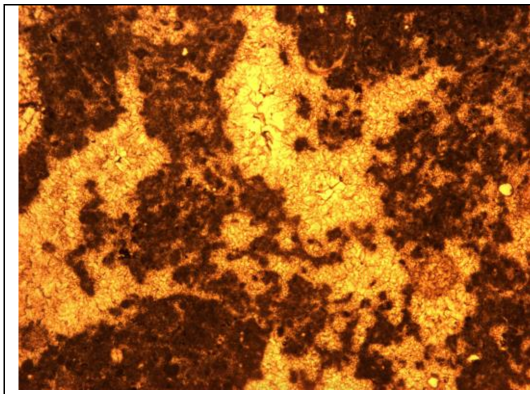
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 4%

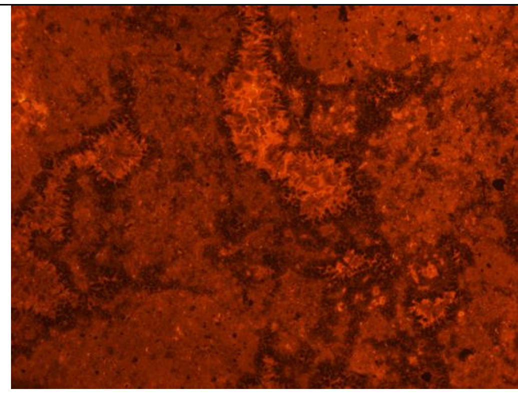
Petrophysical analysis:
Porosity – 5%
Permeability – 0.006 md

Little Cedar Creek Field **Well: 17** **Permit: 14965**

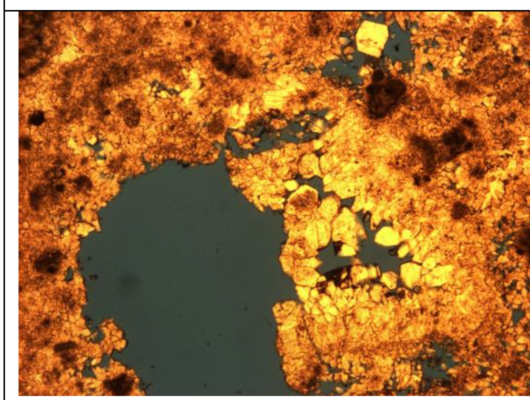
Depth: 11268.1 ft



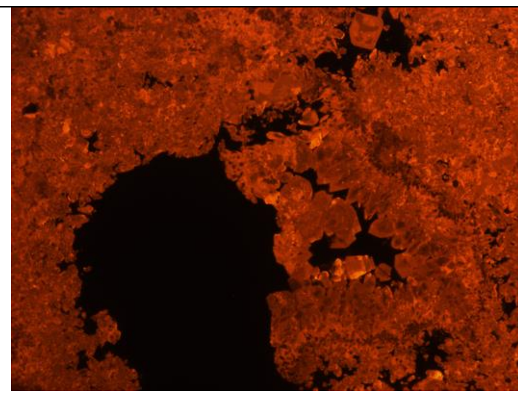
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

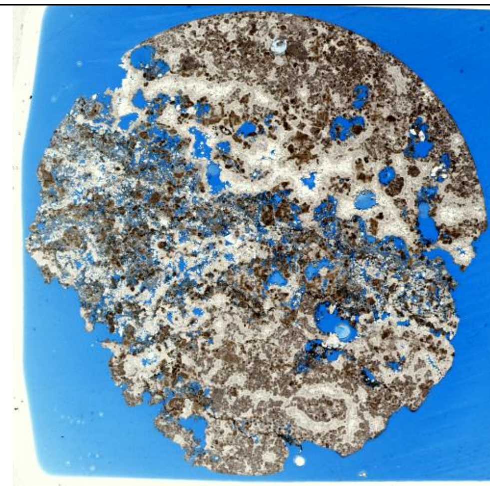
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown– orange-yellow luminescence.

Little Cedar Creek Field **Well: 17** **Permit: 14965**

Depth: 11271.1 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

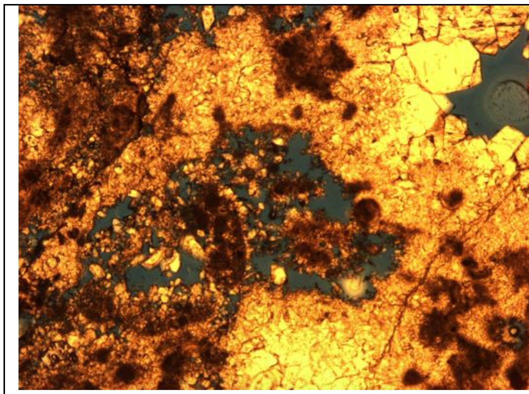
Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement) and benthic foraminifera. Peloid clusters are abundant. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Some portions with late dissolution and fine calcite cement crystals with intercrystalline porosity between them.

Pore type: Vuggy and intercrystalline.

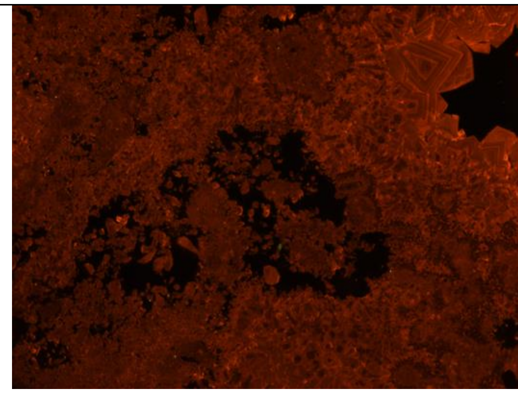
Porosity (image analysis) : 16%

Little Cedar Creek Field **Well: 17** **Permit: 14965**

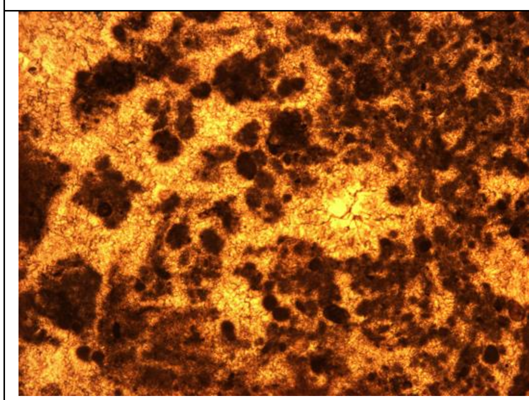
Depth: 11271.1 ft



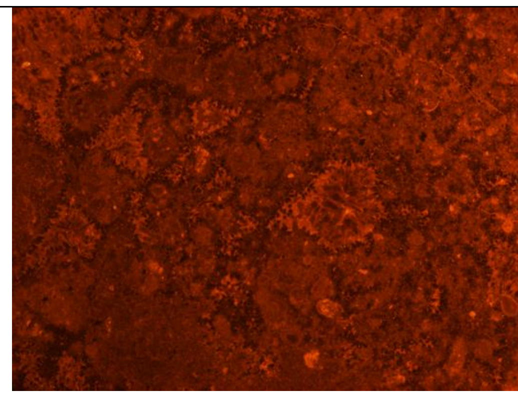
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has light brown to orange-yellow luminescence.
Mosaic calcite cement, zoned (2 to 6 zones): light brown – orange-yellow – light brown – orange-yellow – light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (6 zones). The zones present the following order: dark to light brown – orange-yellow – light brown – orange-yellow – light brown – orange-yellow luminescence. Several subzones occur.

Little Cedar Creek Field **Well: 17** **Permit: 14965**

Depth: 11283.8 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite intensely recrystallized. Diagenesis: mosaic calcite and blocky calcite cement. Chemical compaction (stylolites). Late dissolution.

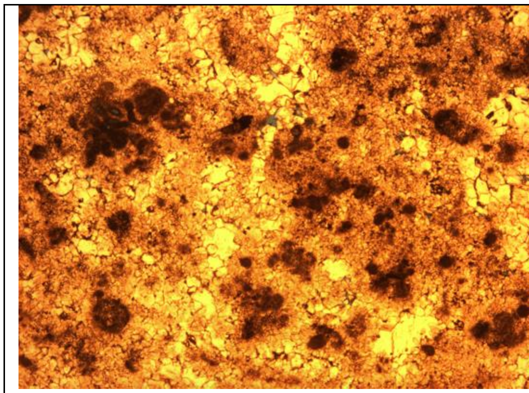
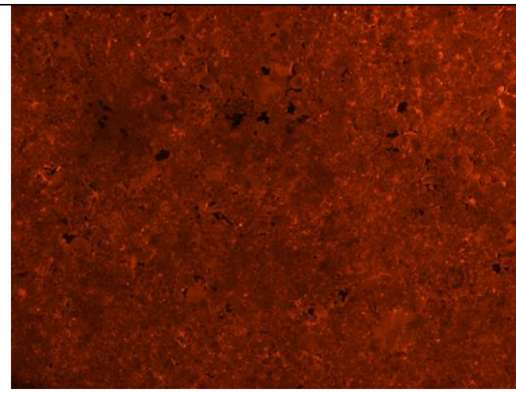
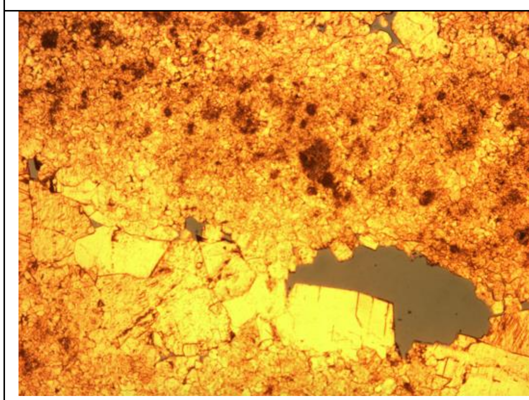
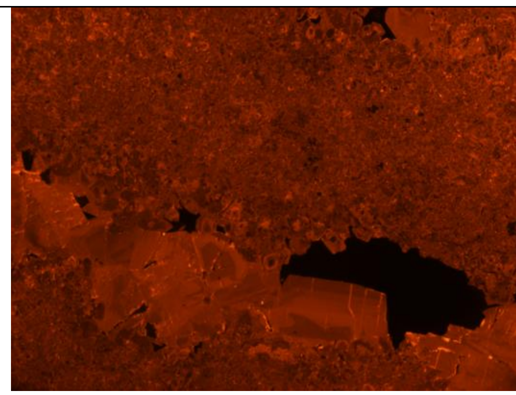
Pore type: Intercrystalline and vuggy.

Porosity (image analysis) : 1%

Petrophysical analysis:
Porosity – 3%
Permeability – 0.016 md

Little Cedar Creek Field **Well: 17** **Permit: 14965**

Depth: 11283.8 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

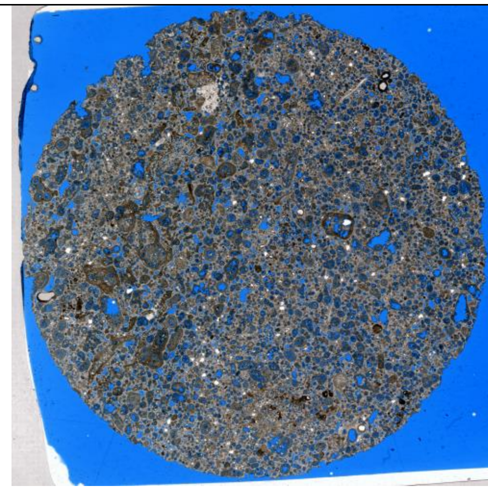
Cathodoluminescence image analysis:
Mosaic calcite cement, presenting light brown luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark to light brown – orange-yellow – light brown.

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11121.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Oolitic grainstone.

Description: Oolitic grainstone, with grapestones. Fine to medium sand size oolites, and coarse to very coarse sand grapestones. Some echinoid fragments occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, some blocky calcite cement, oolite dissolution, no compaction features.

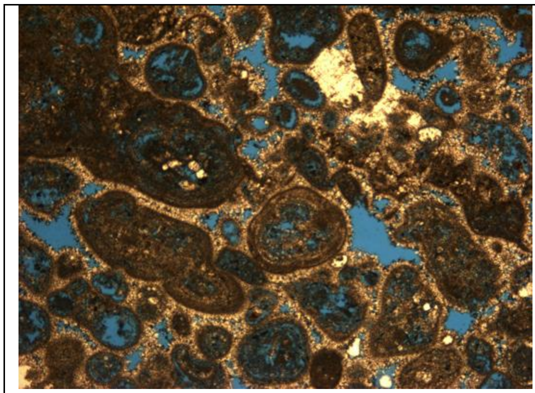
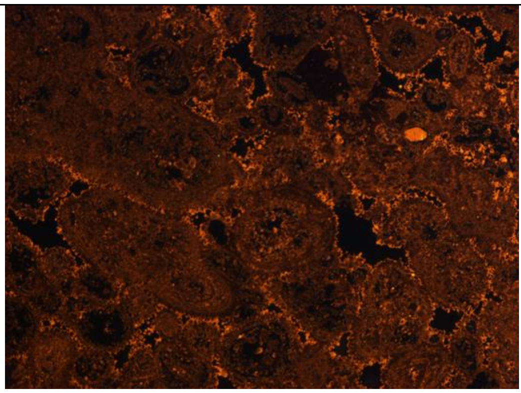
Pore type: Moldic, intergranular and intragranular.

Porosity (image analysis) : 27%

Petrophysical analysis:
Porosity – 26%
Permeability – 18.7 md

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11121.6 ft

<table>
<tr>
<td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td>
<td>
Cathodoluminesce image – same field of the picture on the left side</td>
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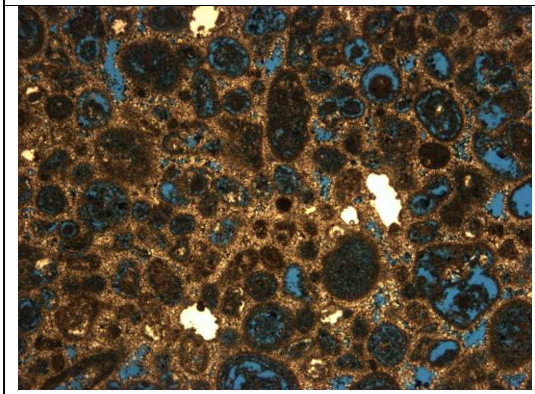
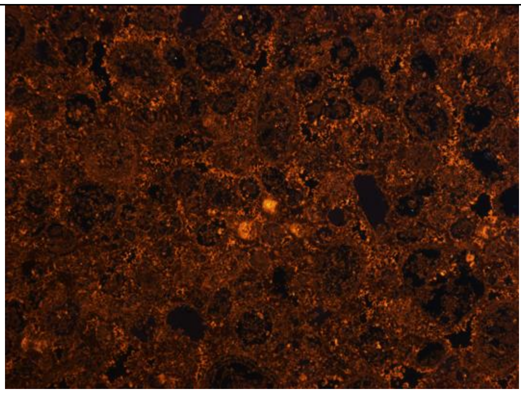
<td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td>
<td>
Cathodoluminesce image – same field of the picture on the left side</td>
</tr>
<tr>
<td colspan="2">Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs. It also occurs in some moldic porosity, growing from the border to the center.
Blocky calcite cement, unzoned, presenting light orange-yellow luminescence.</td>
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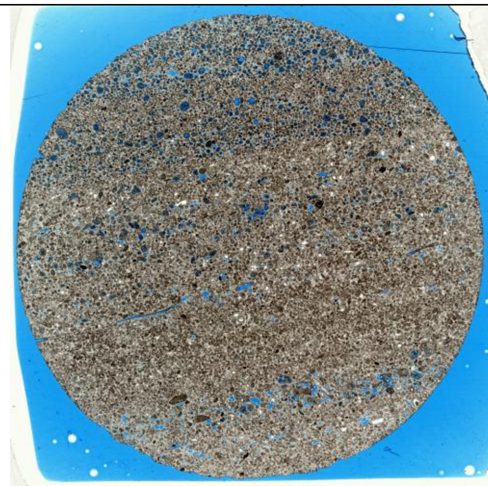
</table>

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11125.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal grainstone.

Description: Peloidal grainstone, with some oolites, grapestones and bioclasts. Very fine to fine sand size peloids, fine to medium sand size oolites and grapestones. Bioclasts are green algae and benthic foraminifera. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, oolite dissolution, no compaction features.

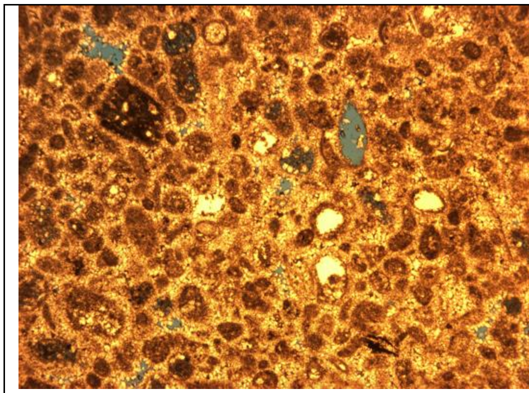
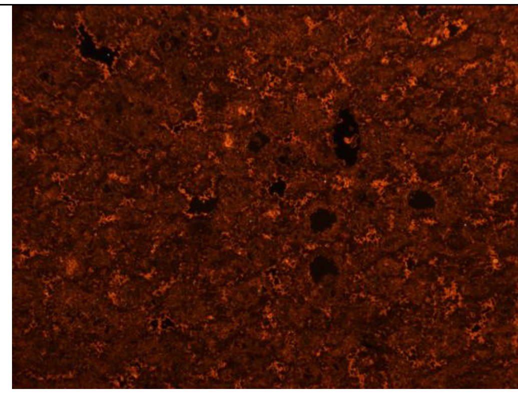
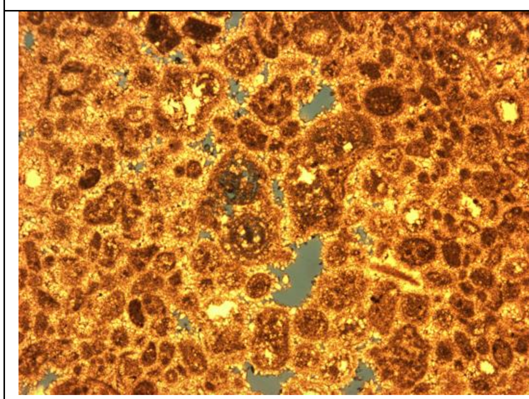
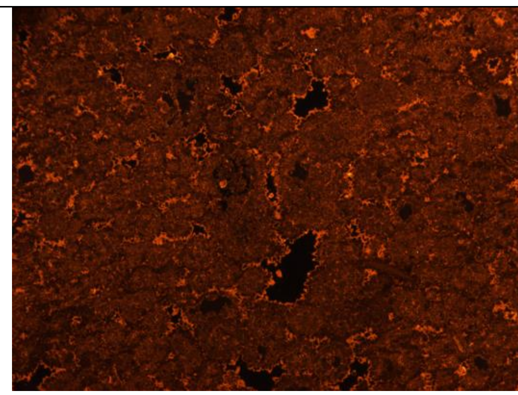
Pore type: Intragranular, moldic, and intergranular.

Porosity (image analysis) : 5%

Petrophysical analysis:
Porosity – 10%
Permeability – 0.044 md

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11125.5 ft

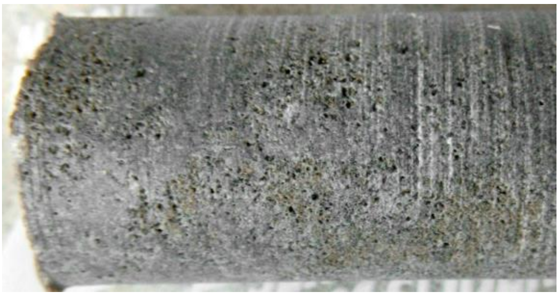
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11144.9 ft

Plug – 2.15 cm (diameter)



Macroscopic photo

Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Silt size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, and blocky calcite cement. Locally late dissolution.

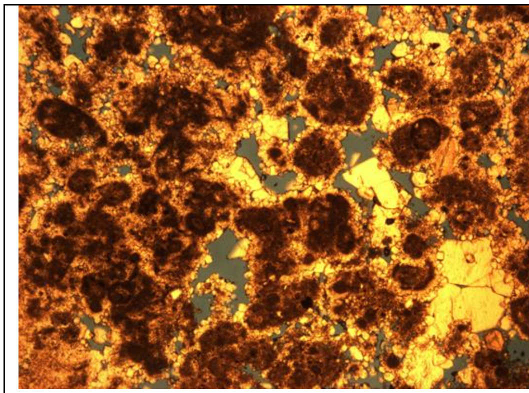
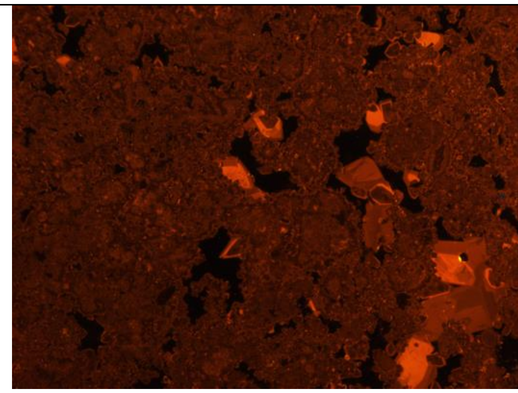
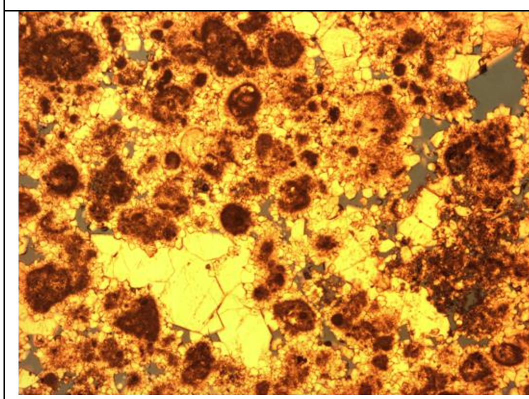
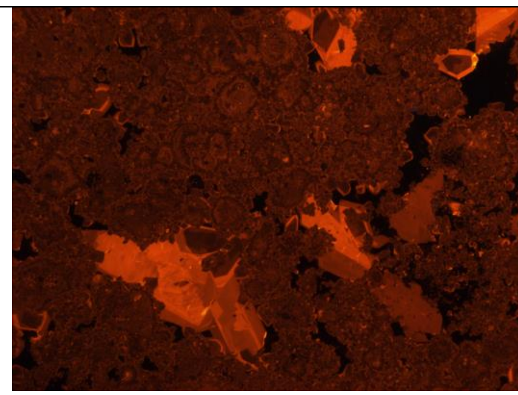
Pore type: Intergranular and vuggy.

Porosity (image analysis) : 11%

Petrophysical analysis:
Porosity – 9%
Permeability – 0.158 md

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11144.9 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

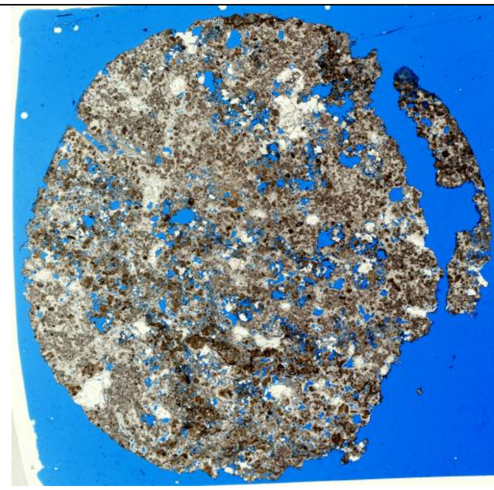
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has light brown luminescence.
Blocky calcite cement, zoned (5 zones). The zones present the following order: very dark brown – dark brown – light brown – orange-yellow – light brown luminescence.

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11152 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Rare silt size quartz. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolites). Late dissolution.

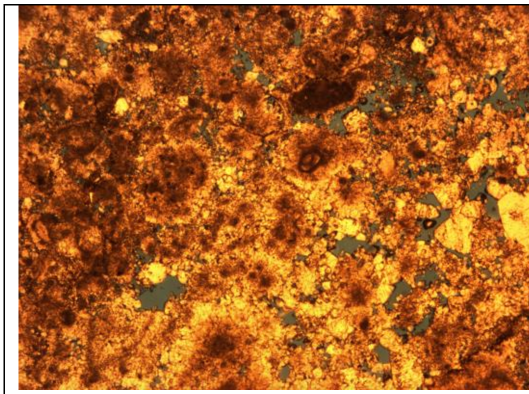
Pore type: Vuggy and intergranular.

Porosity (image analysis) : 13%

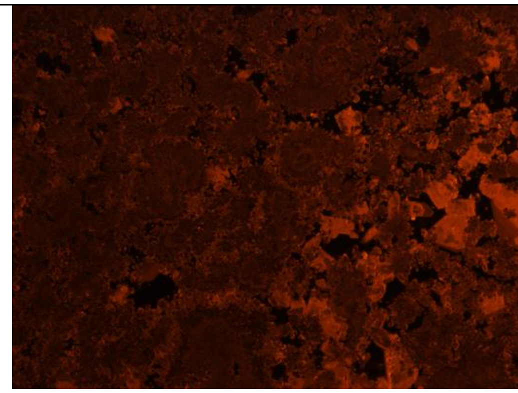
Petrophysical analysis:
Porosity – 13%
Permeability – 26.6 md

Little Cedar Creek Field **Well: 18** **Permit: 15000**

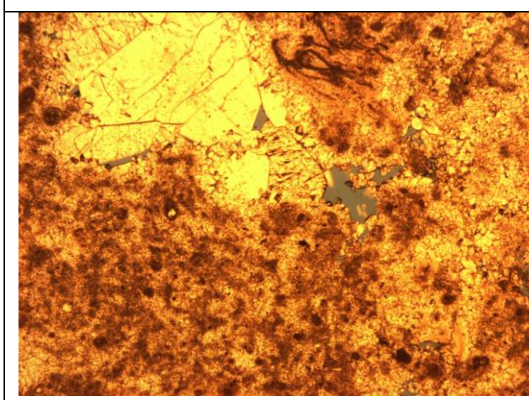
Depth: 11152 ft



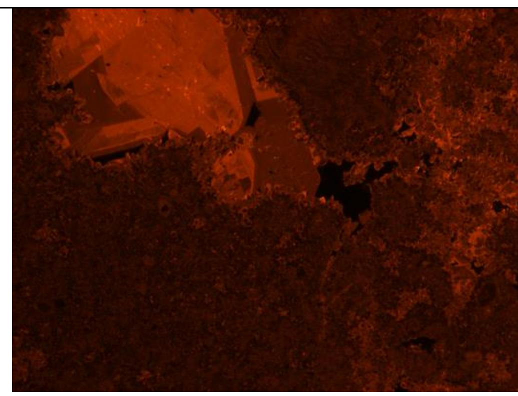
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



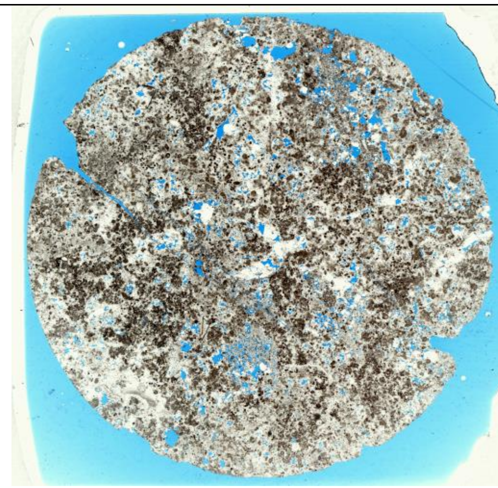
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 to 4 zones): dark brown – orange-yellow – light brown – orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 zones). The zones present the following order: orange-yellow –light brown luminescence.

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11163.6 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Very fine to fine size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Late dissolution.

Pore type: Vuggy, intergranular, intercrystalline, and microfractures.

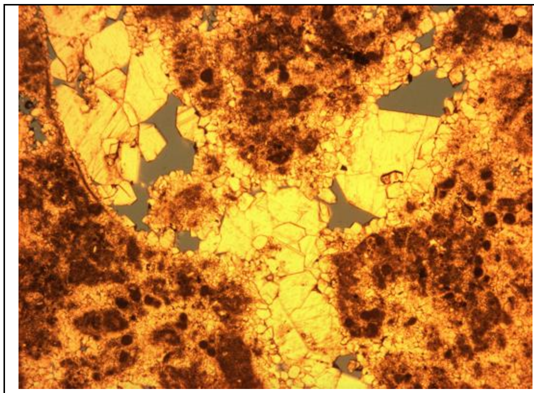
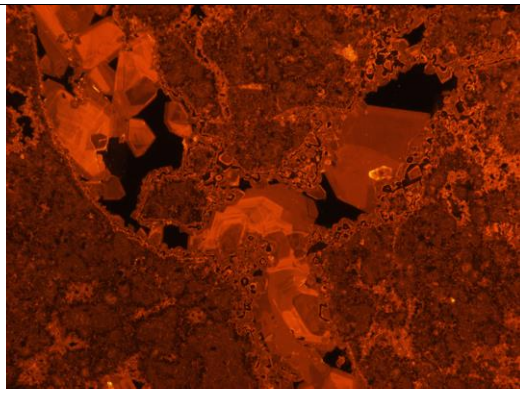
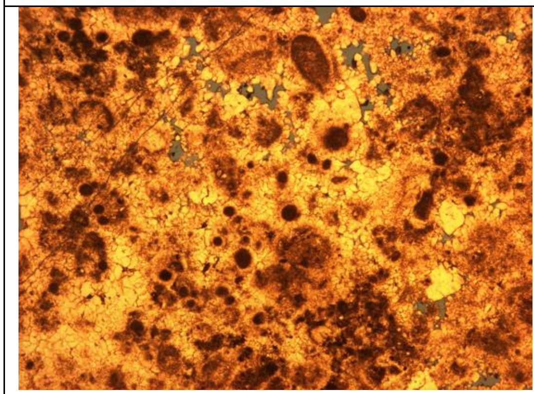
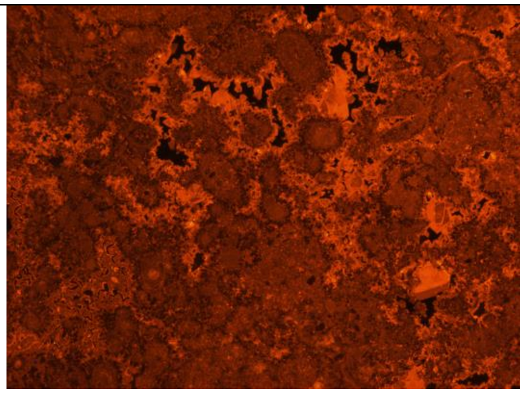
Porosity (image analysis) : 7%

Petrophysical analysis:
Porosity – 7%
Permeability – 0.654 md

</td>
</tr>
</table>

Little Cedar Creek Field **Well: 18** **Permit: 15000**

Depth: 11163.6 ft

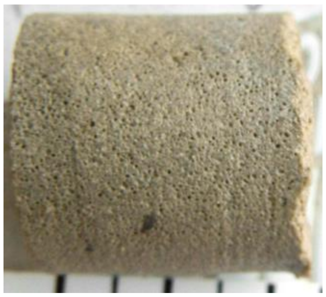
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Botryoidal calcite cement, occurring as a crust covering the surface of some pores, zoned (3 zones): nonluminescent – orange-yellow – light brown luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: light brown – orange-yellow – light brown luminescence. Several subzones occur.

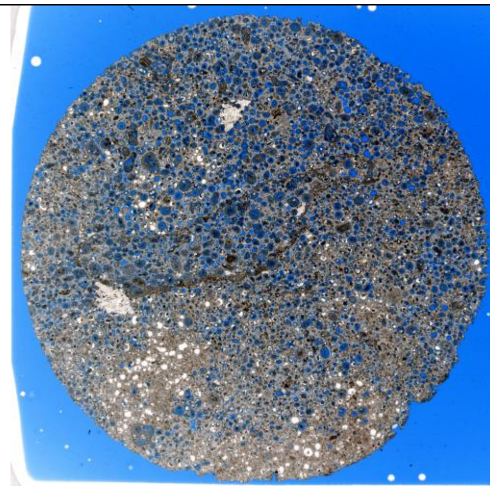
Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11129.2 ft

Plug – 2.15 cm (diameter)



Macroscopic photo



Scanned thin section

Lithology: Oolitic graintone.

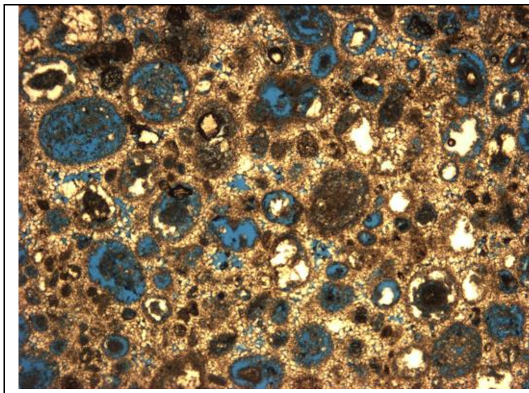
Description: Oolitic grainstone, bioturbated. Fine to medium sand size oolites, rare coarse sand size oolites and grapestones. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, some blocky calcite cement, anhydrite occur as patches (replacing grains and calcite cements, and also cementing pore space), oolite dissolution, no compaction features.

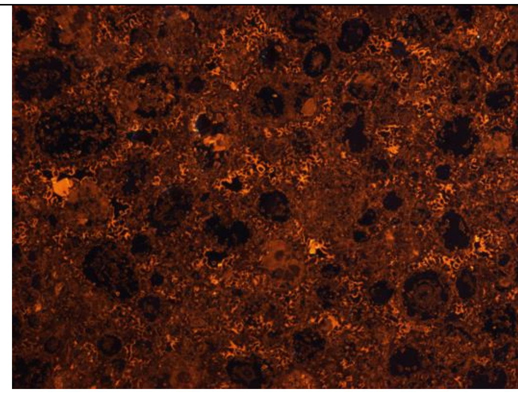
Pore type: Moldic, intragranular, and intergranular.

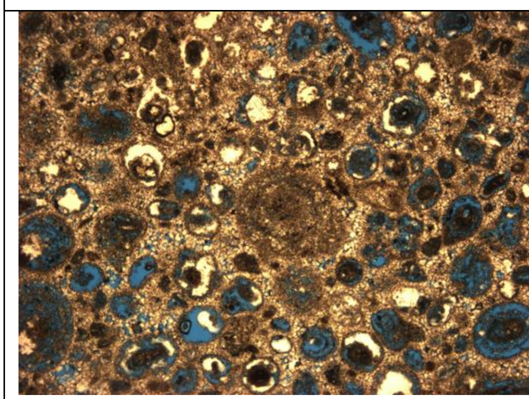
Porosity (image analysis) : 24%

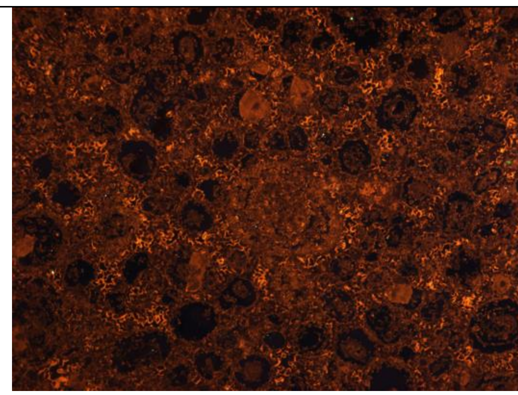
Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11129.2 ft


Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm


Cathodoluminesce image – same field of the picture on the left side


Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm


Cathodoluminesce image – same field of the picture on the left side

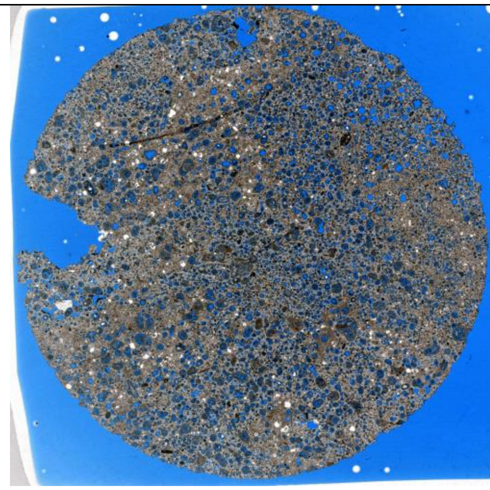
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, presenting light brown or orange-yellow luminescence. It occurs in intergranular and moldic porosity.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11132.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Oolitic grainstone.

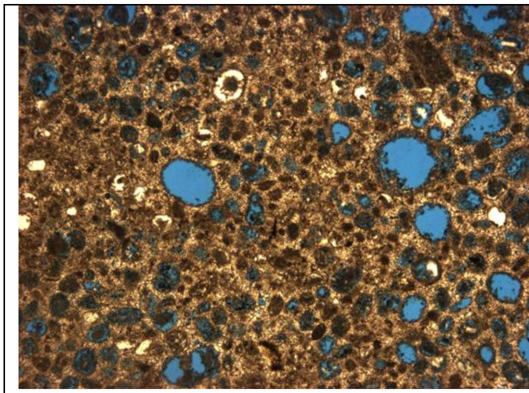
Description: Oolitic grainstone, with some peloids and grapestones. Fine to medium sand size oolites, some coarse sand size grapestones and very fine sand size peloids. Very fine to fine sand size quartz and muscovite grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, some blocky calcite cement, oolite dissolution, no compaction features.

Pore type: Moldic, intragranular, and intergranular.

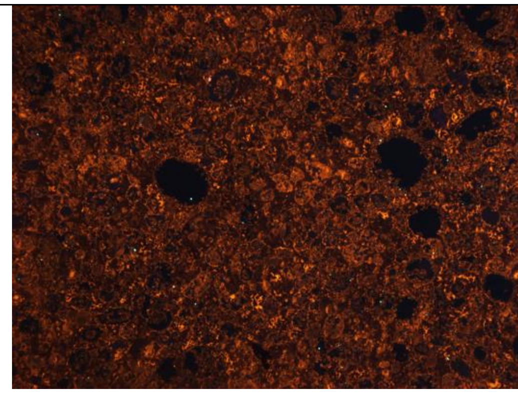
Porosity (image analysis) : 24%

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

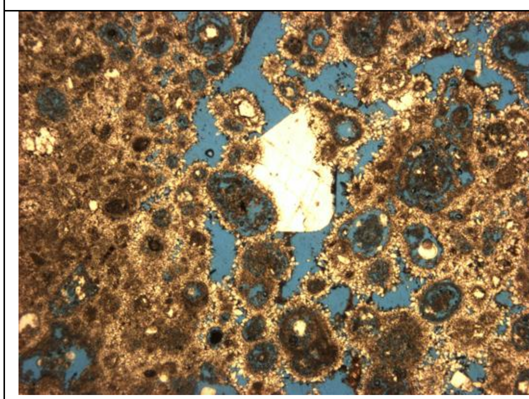
Depth: 11132.5 ft



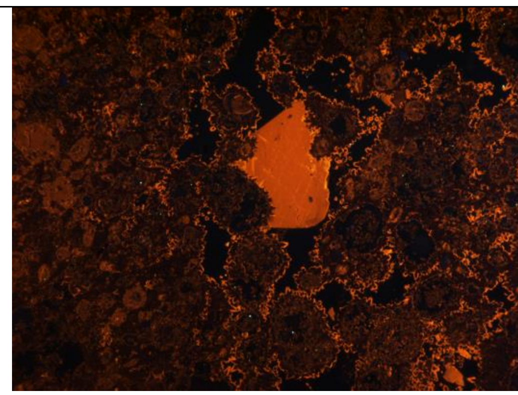
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

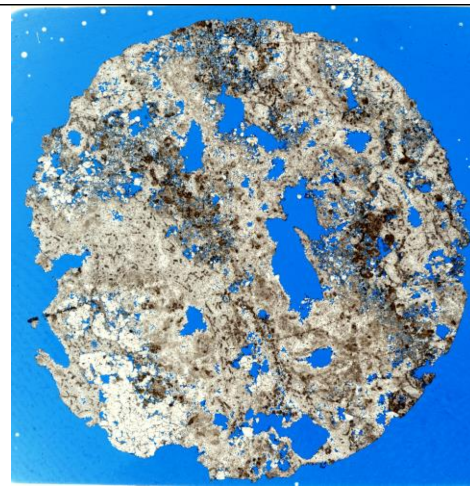
Cathodoluminescence image analysis:

Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.

Blocky calcite cement, zoned (2 zones): dark brown – orange-yellow luminescence. The unzoned crystals present orange-yellow luminescence.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11168.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

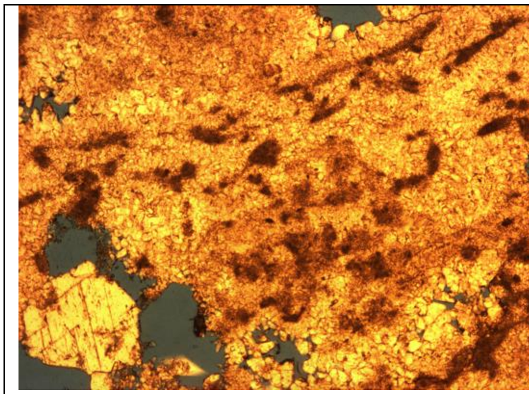
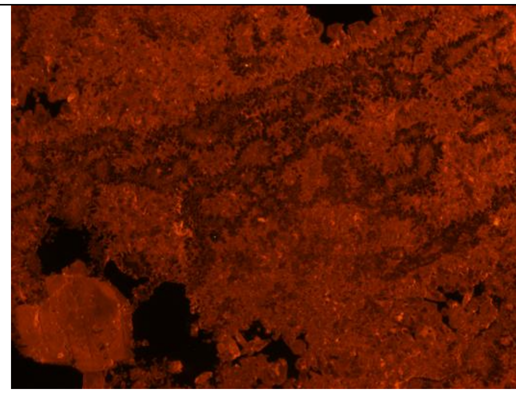
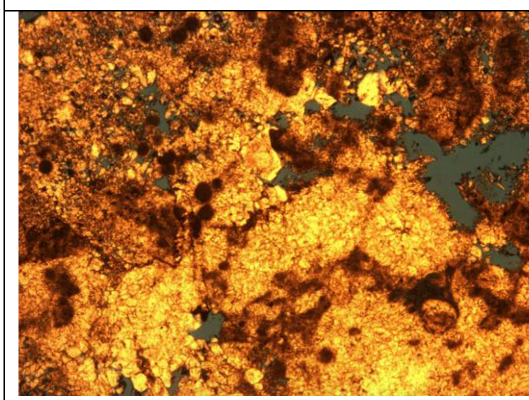
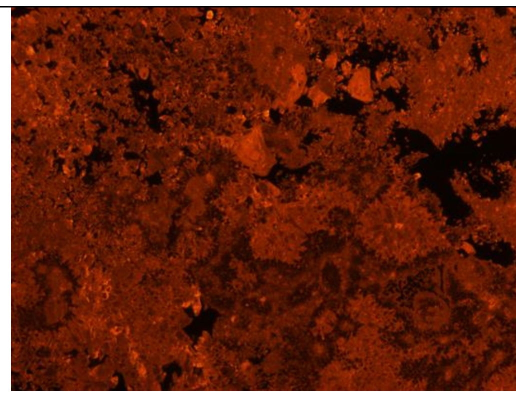
Description: Peloidal thrombolite, with bioclasts. The rock is partially recrystallized. Silt size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Elongated and filamentous features / grains are observed. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains, mosaic calcite cement, and blocky calcite cement. Locally late dissolution.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 18%

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11168.9 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, presenting dark brown luminescence.
Mosaic calcite cement, presenting orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11171.4 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

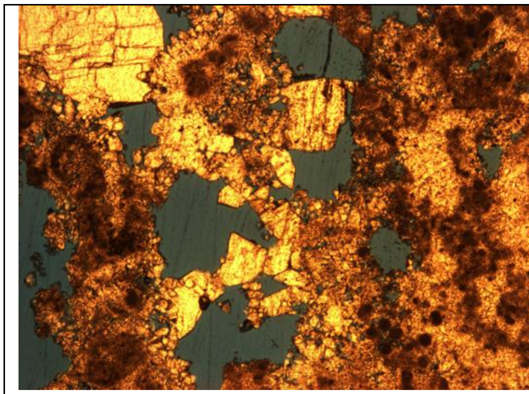
Description: Peloidal thrombolite, with bioclasts. Part of the rock is recrystallized. Silt size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Late dissolution.

Pore type: Vuggy and intercrystalline.

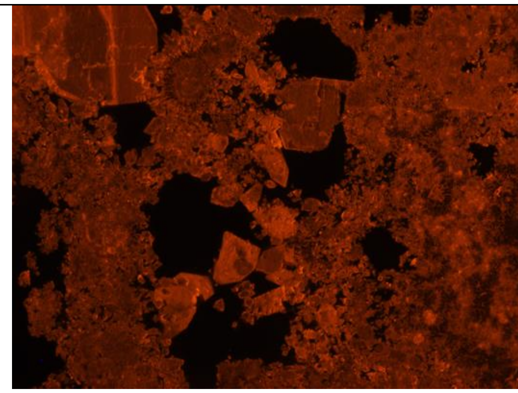
Porosity (image analysis) : 18%

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

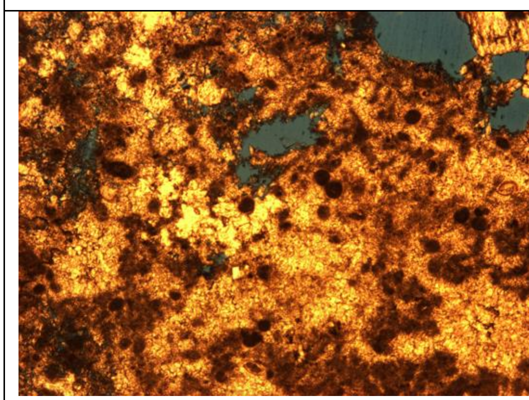
Depth: 11171.4 ft



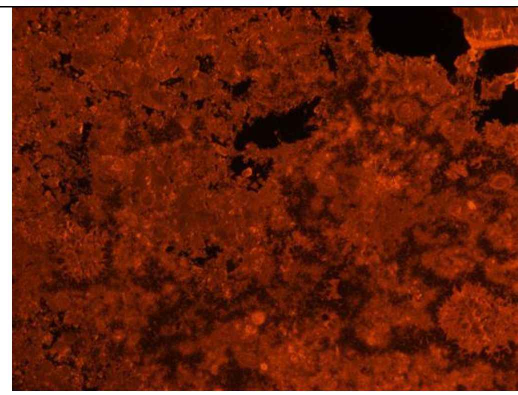
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.

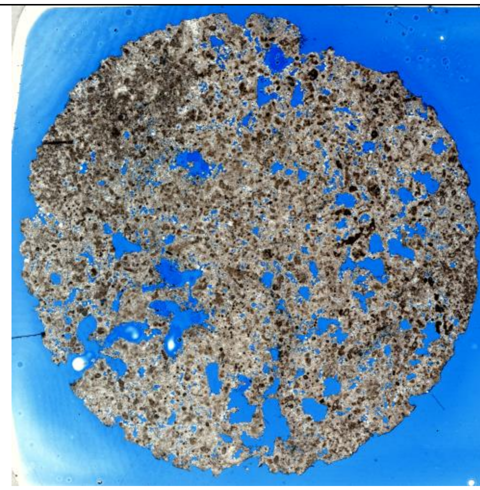
Drusy calcite fringe cement rimming the grains, zoned (2 zones): dark brown – light brown to orange-yellow.

Mosaic calcite cement, presenting light brown to orange-yellow luminescence.

Blocky calcite cement, zoned (2 or 3 zones). The zones present the following order: dark brown – light brown luminescence, and light-brown – orange-yellow – light brown luminescence.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11173.5 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

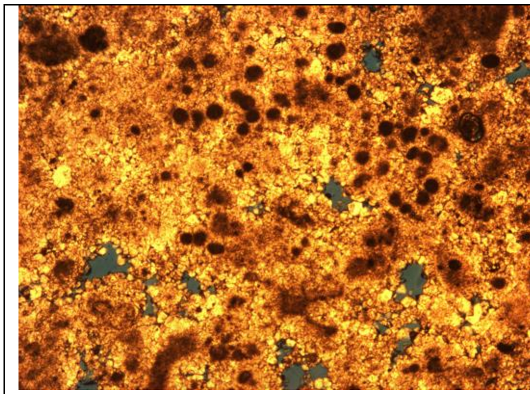
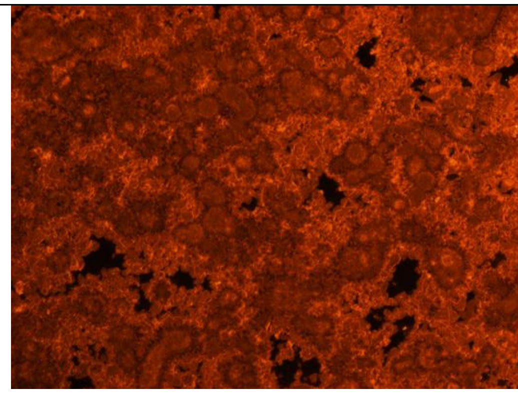
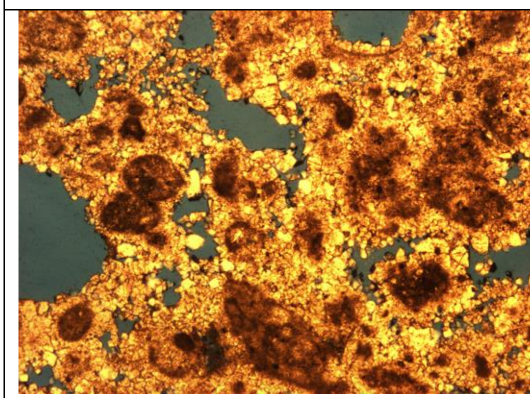
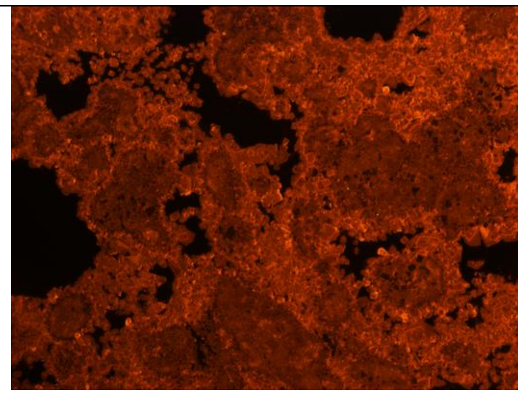
Description: Peloidal thrombolite, with bioclasts. Some round features with hollow center occur, possibly originated by algae or bacteria. Silt size grains are observed. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Late dissolution.

Pore type: Vuggy and intergranular.

Porosity (image analysis) : 19%

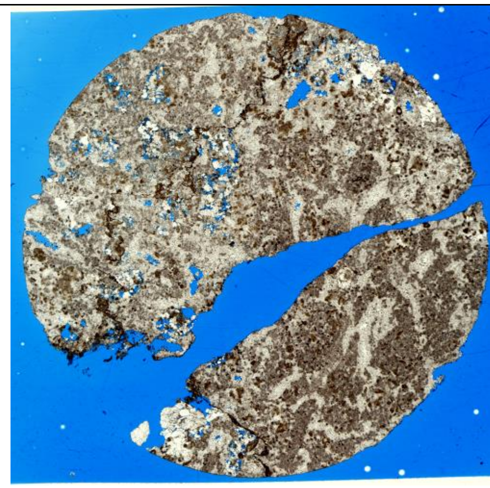
Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11173.5 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (3 zones): light brown – orange-yellow – light brown luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11177.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

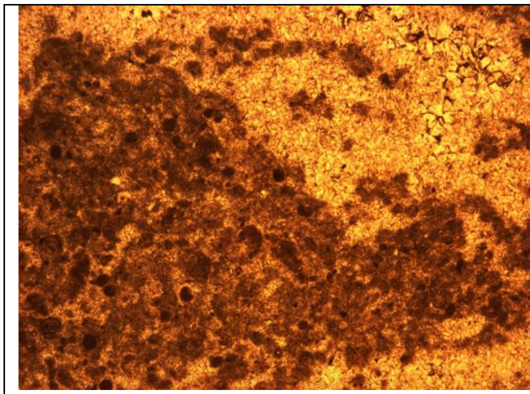
Description: Peloidal thrombolite, with bioclasts. Silt size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are abundant. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Chemical compaction (stylolites). Locally late dissolution.

Pore type: Vuggy and intercrystalline.

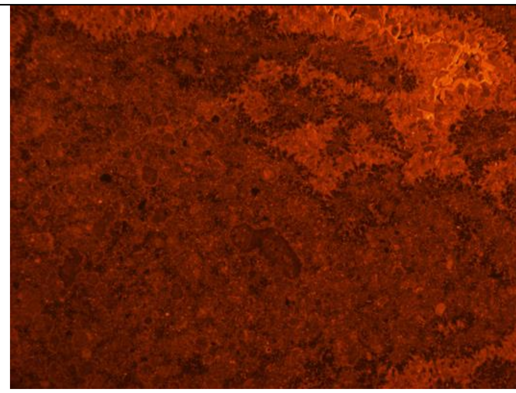
Porosity (image analysis): 5%

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

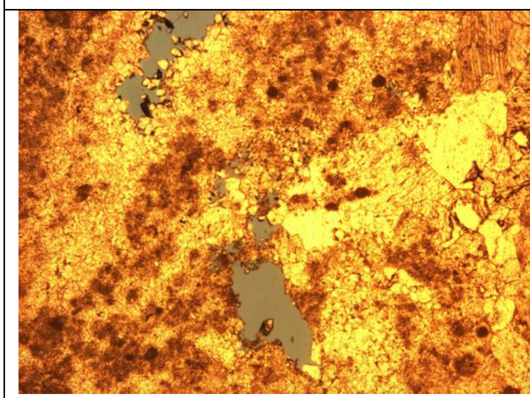
Depth: 11177.9 ft



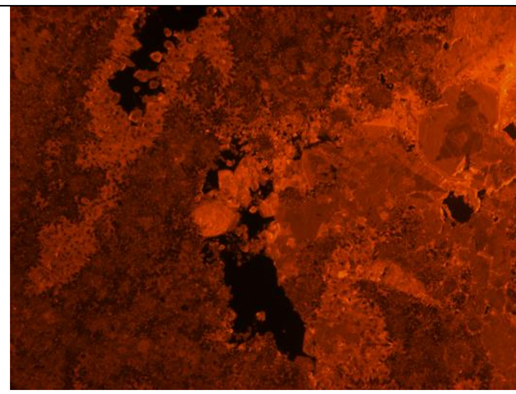
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

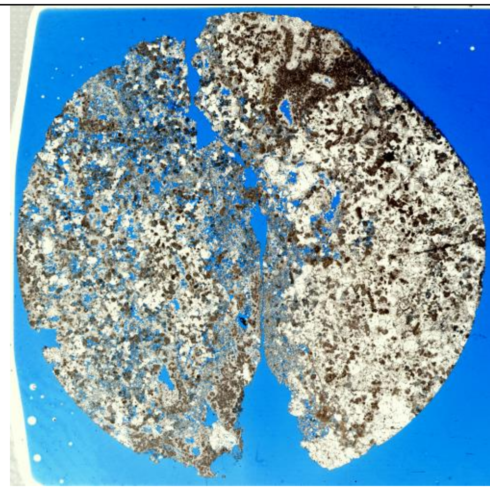


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): dark brown - light brown luminescence.
Blocky calcite cement, zoned (2 to 3 zones): dark brown – light brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11184.5 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

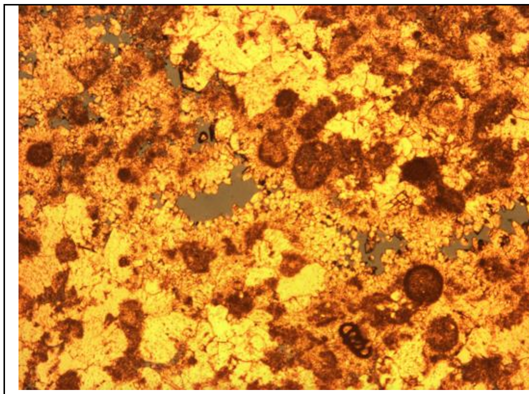
Description: Peloidal thrombolite, with bioclasts. Part of the rock is recrystallized. Silt size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, and blocky calcite cement. Locally late dissolution. Late dissolution, and fine calcite cement crystals with intercrystalline pore space between them.

Pore type: Vuggy and intercrystalline.

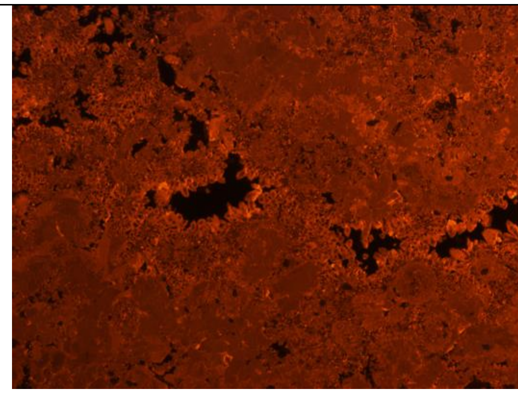
Porosity (image analysis) : 18%

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

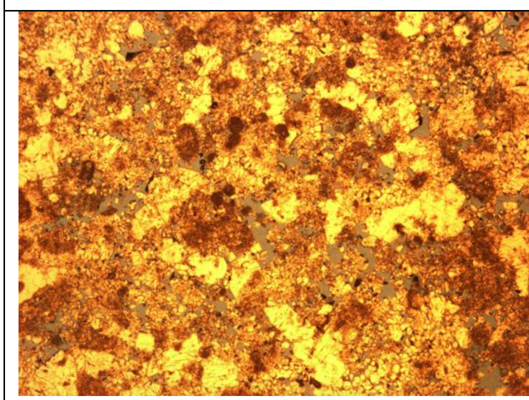
Depth: 11184.5 ft



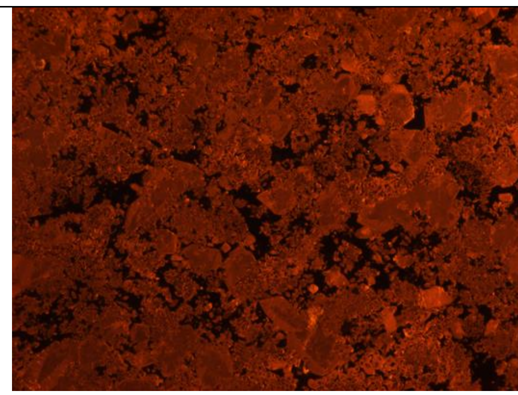
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

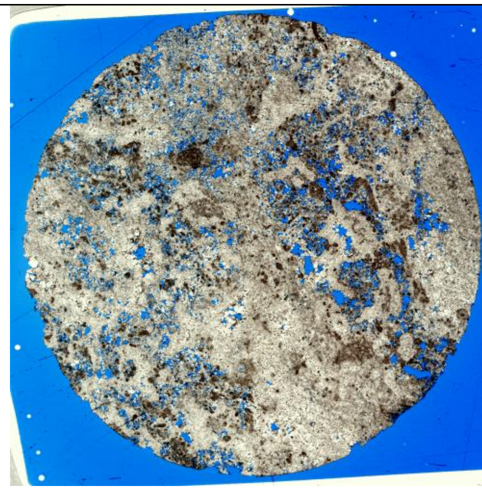
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has orange-yellow luminescence.

Blocky calcite cement, zoned (2 to 3 zones): dark brown – light brown – orange-yellow luminescence. Several nonzoned crystals present light brown luminescence.

Recrystallization of calcite occur locally, presenting light brown luminescence.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11192.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

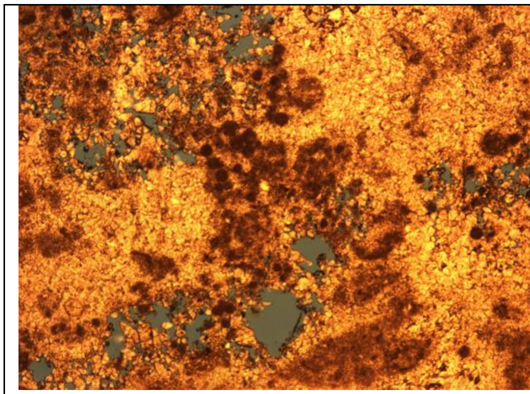
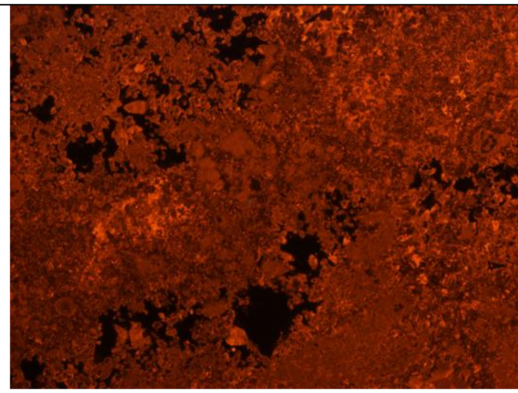
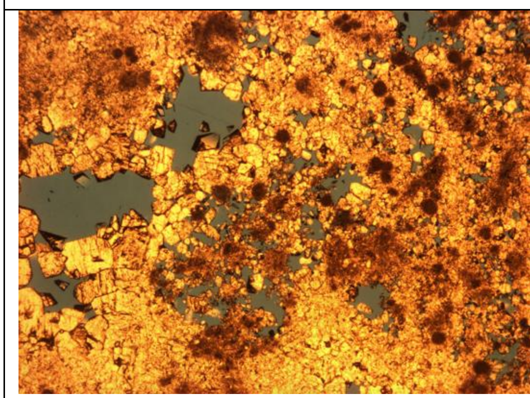
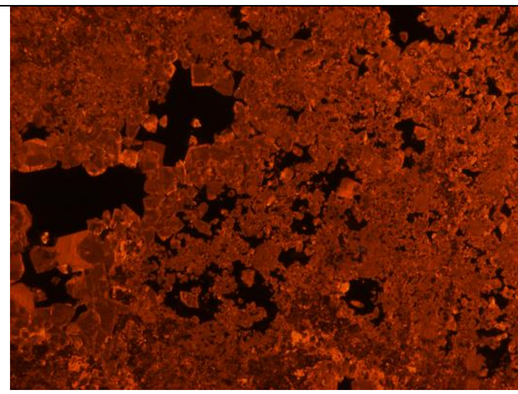
Description: Peloidal thrombolite. Part of the rock is recrystallized. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, and blocky calcite cement. Locally late dissolution. Fine calcite crystals with intercrystalline porosity between them.

Pore type: Intercrystalline and vuggy.

Porosity (image analysis) : 11%

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11192.9 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Mosaic calcite cement, zoned (2 zones): dark brown - light brown luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Recrystallization – some portions of the rock is recrystallized, and the original texture is lost. The recrystallized calcite present light brown luminescence.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11195.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo

Scanned thin section

Lithology: Peloidal thrombolite.

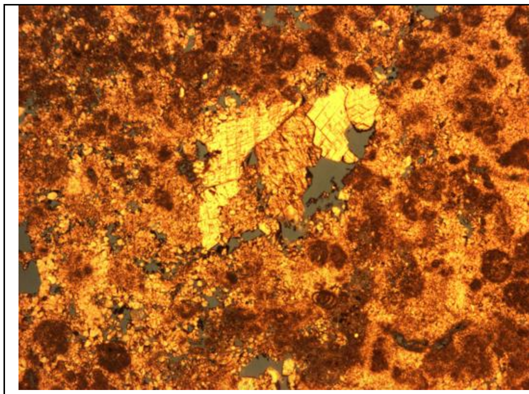
Description: Peloidal thrombolite, with bioclasts. Part of the rock is recrystallized. Silt size quartz grains occur. The bioclasts are benthic foraminifera and rare mollusk (?). Peloid clusters are common. Diagenesis: mosaic calcite cement, and blocky calcite cement. Locally late dissolution. Fine calcite cement crystals with intercrystalline porosity between them.

Pore type: Intercrystalline and vuggy.

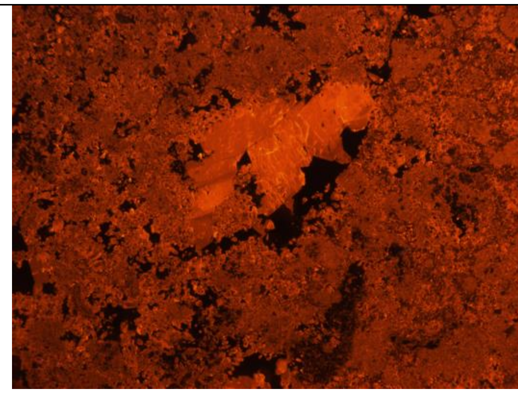
Porosity (image analysis) : 12%

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

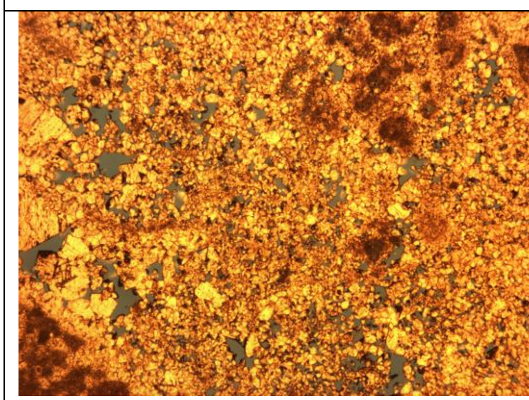
Depth: 11195.5 ft



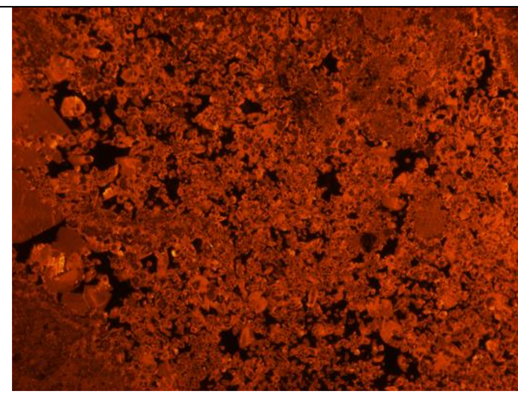
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

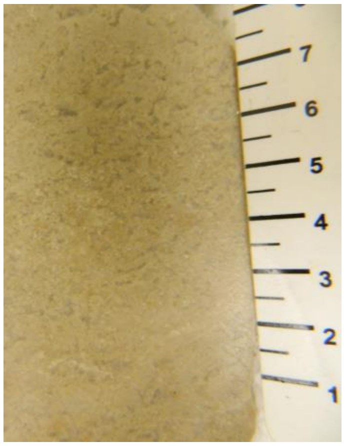


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Mosaic calcite cement, zoned (2 to 4 zones): light brown – dark brown – light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): orange-yellow – light brown luminescence. Some subzones occur.
Recrystallization – some portions of the rock is recrystallized, and the original texture is lost. The recrystallize calcite present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11198.3 ft



Macroscopic photo

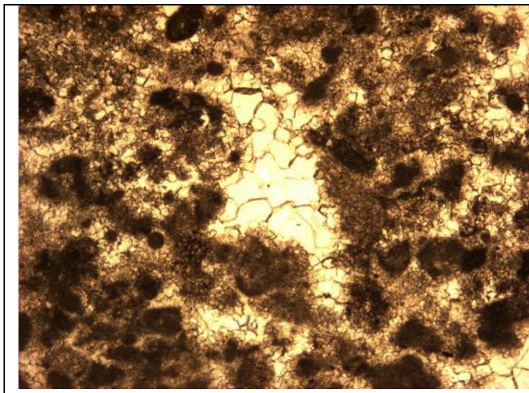

Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Silt size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: mosaic calcite cement, and blocky calcite cement. Low dolomitization. Very fine dolomite crystals occur as replacing mineral and cement (?).

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11198.3 ft

<table>
<tr><td>
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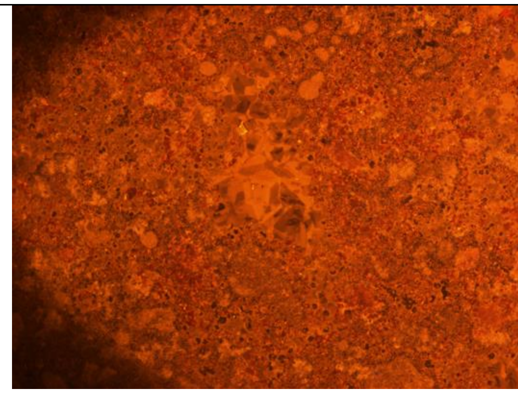
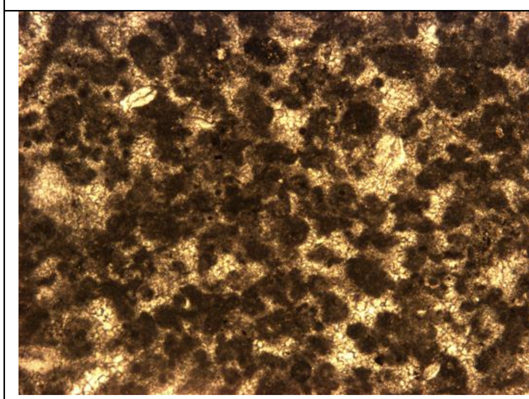
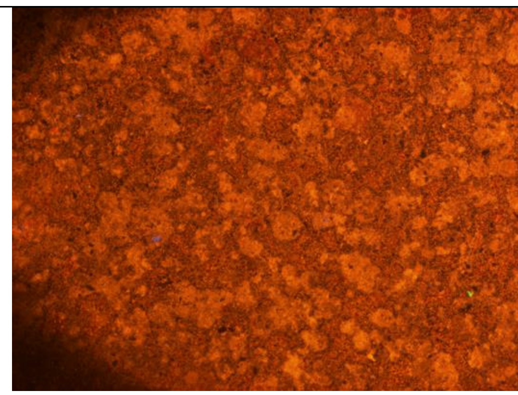
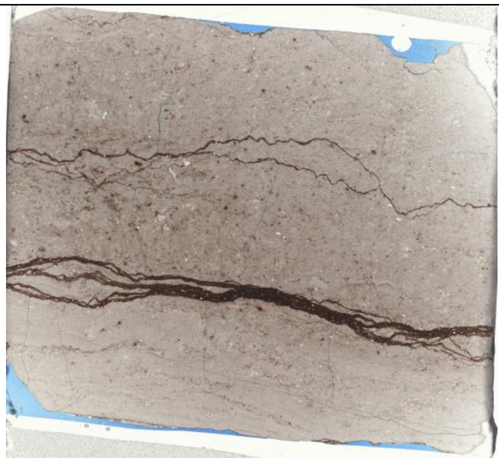
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (3 zones): dark brown – light brown – orange-yellow luminescence. In some crystals several subzones occur.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite occurs in a very small amount.</td></tr>
</table>

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11218.4 ft

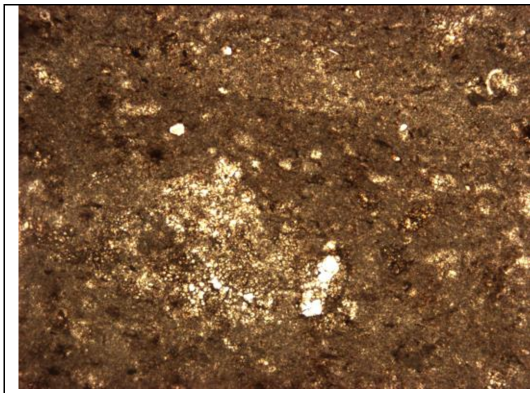
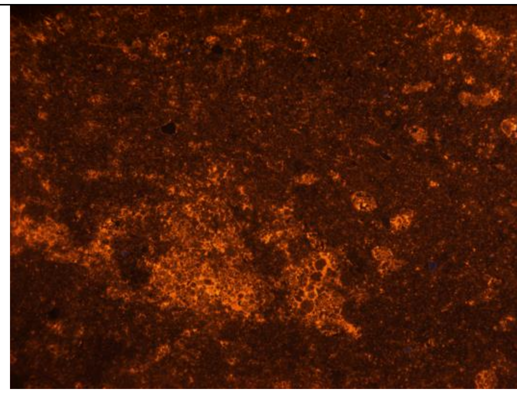
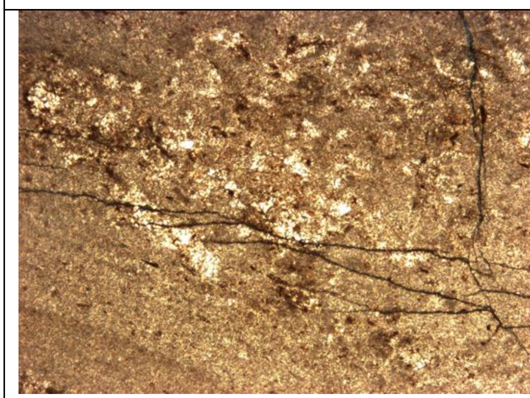
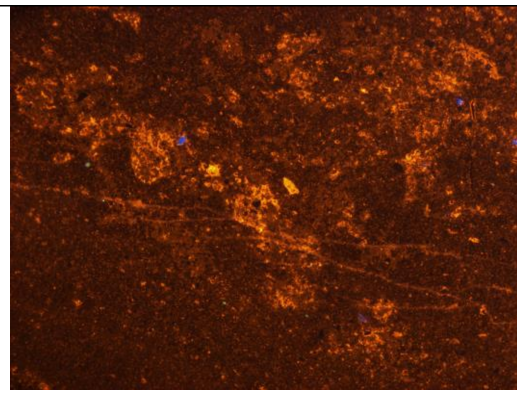
 Macroscopic photo	 Scanned thin section

Lithology: Mudstone.

Description: Mudstone, with silt to fine sand quartz grains and rare bioclasts (ostracods?). Stylolites are very common. Mosaic calcite cement occurs locally. A weak lamination is observed. Closed microfractures.

Little Cedar Creek Field **Well: 19** **Permit: 15159-B**

Depth: 11218.4 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Blocky calcite cement, zoned (2 zones): dark brown – orange-yellow luminescence.
Microfractures – microfractures are highlighted in the cathodoluminescence image, presenting orange-yellow luminescence.

Little Cedar Creek Field **Well: 20** **Permit: 15165**

Depth: 11502.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo

Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts and cylindrical tubular structures. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera, ostracods, and echinoid (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, and blocky calcite cement. Late dissolution. Chemical compaction (stylolites).

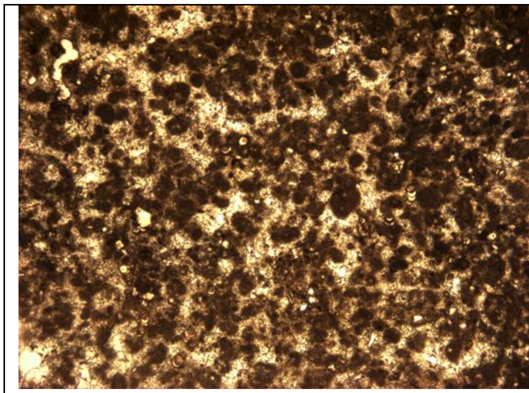
Pore type: Intercrystalline and intragranular.

Porosity (image analysis) : 2%

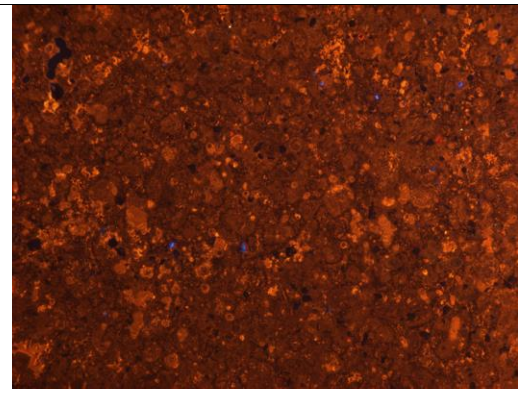
Petrophysical analysis:
Porosity – 2%
Permeability – 0.004 md

Little Cedar Creek Field **Well: 20** **Permit: 15165**

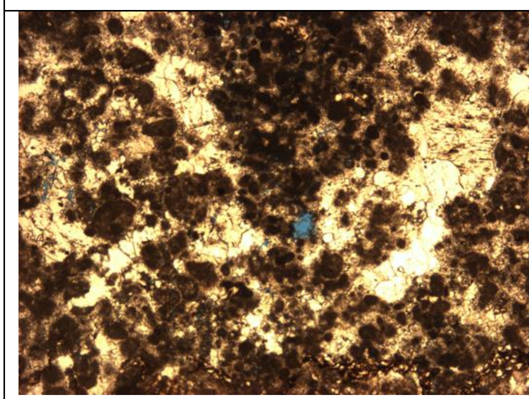
Depth: 11502.4 ft



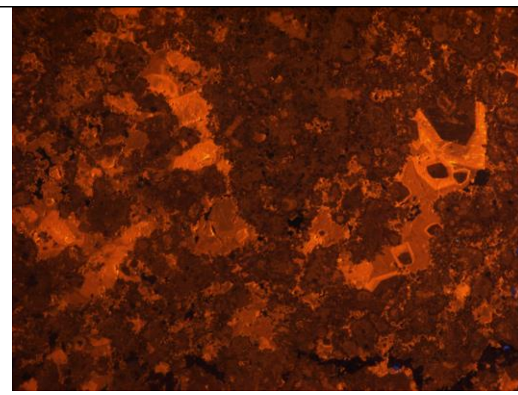
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

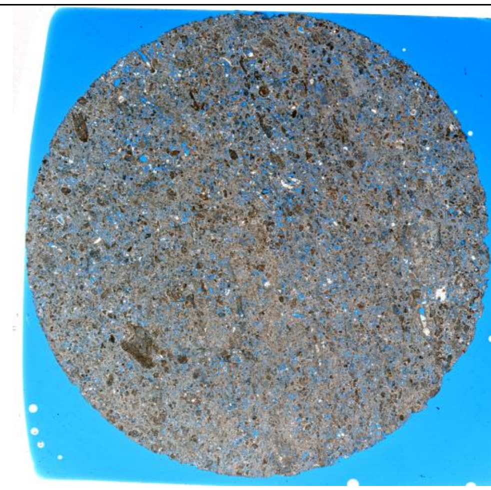
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones): dark brown– orange-yellow to light brown luminescence.
Blocky calcite cement, zoned (3 zones): dark brown – orange-yellow – light brown luminescence.

Little Cedar Creek Field **Well: 20** **Permit: 15165**

Depth: 11519.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal grainstone.

Description: Peloidal grainstone, with bioclasts. Very fine to fine sand size peloids, medium to coarse sand to gravel size bioclast fragments. Bioclasts are: green algae, ostracods, benthic foraminifera, and rare mollusk (?). Silt to very fine sand size quartz and muscovite grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, some blocky calcite cement.

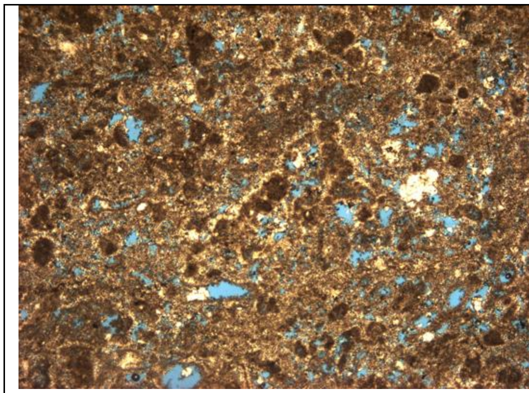
Pore type: Intergranular and intragranular.

Porosity (image analysis) : 20%

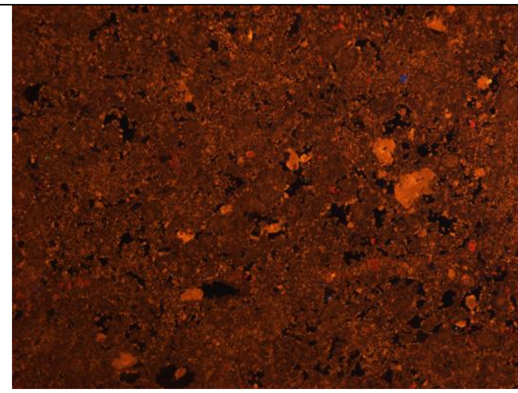
Petrophysical analysis:
Porosity – 17%
Permeability – 2.08 md

Little Cedar Creek Field **Well: 20** **Permit: 15165**

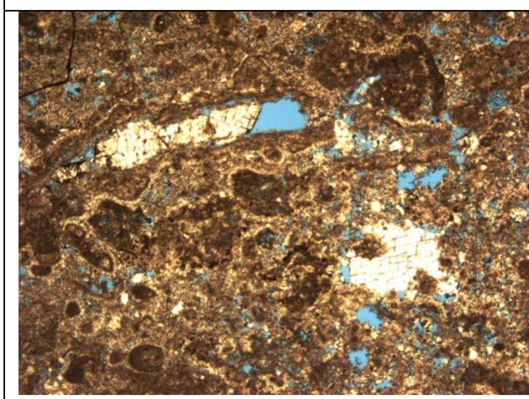
Depth: 11519.5 ft



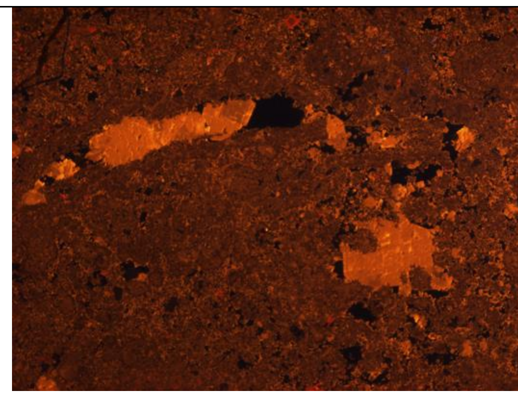
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

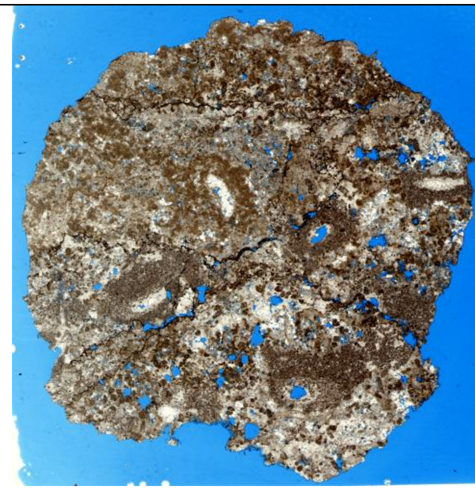
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, presenting orange-yellow luminescence, generally nonzoned, but locally presents 2 zones: light brown – orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite represents less than 1% of the rock.

Little Cedar Creek Field **Well: 20** **Permit: 15165**

Depth: 11549 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Silt size quartz grains occur. Part of the rock is recrystallized.The bioclasts are benthic foraminifera, ostracods and green algae (?). Peloid clusters are abundant. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains, mosaic calcite cement, and blocky calcite cement. Very fine dolomite crystals represent less than 1% of the rock. Chemical compaction (stylolites). Late dissolution.

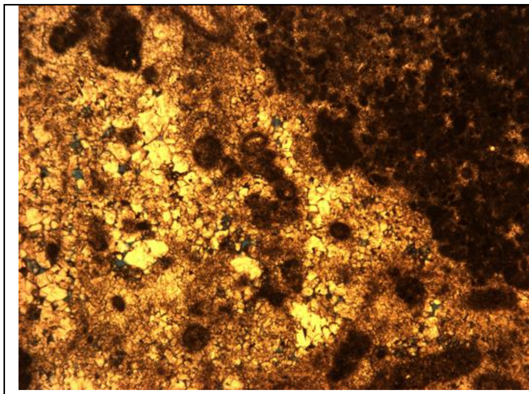
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 7%

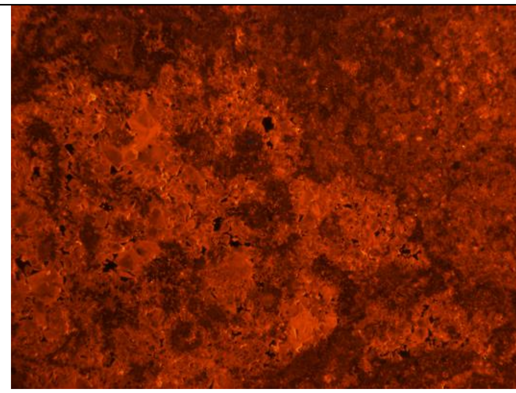
Petrophysical analysis:
Porosity – 7%
Permeability – 0.059 md

Little Cedar Creek Field **Well: 20** **Permit: 15165**

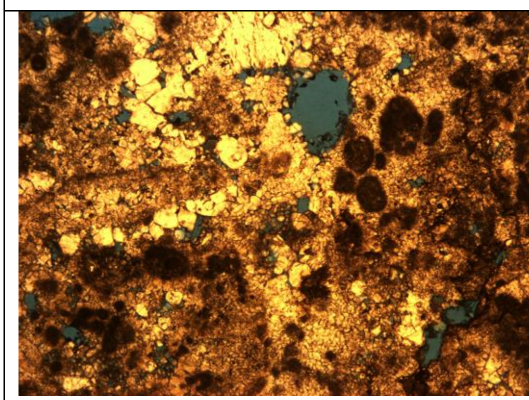
Depth: 11549 ft



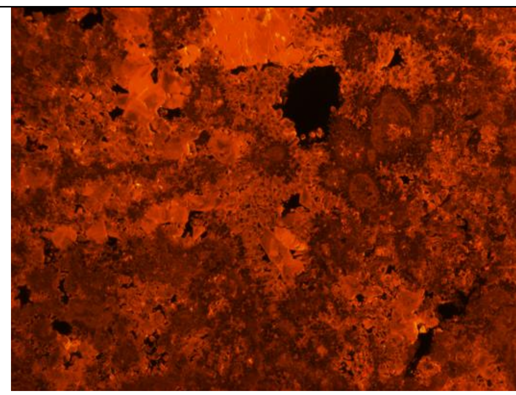
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.

Drusy calcite fringe cement rimming the grains, zoned (2 to 3 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone has light brown luminescence and the third zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first or first and second zones occur.

Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.

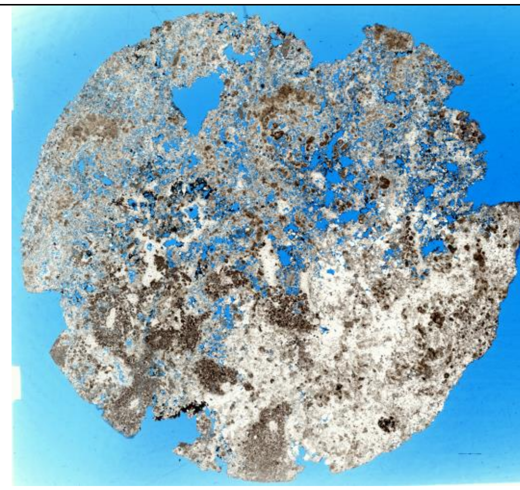
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence. The unzoned crystals present orange-yellow luminescence.

Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. The dolomite represents less than 1% of the rock.

Little Cedar Creek Field **Well: 20** **Permit: 15165**

Depth: 11554.6 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
</table>

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts (benthic foraminifera). The rock is partially recrystallized. Silt to fine sand size quartz and muscovite grains occur. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains, mosaic calcite cement, and blocky calcite cement. Very fine dolomite crystals represent less than 1% of the rock. Locally late dissolution. Fine calcite cement crystals with intercrystalline pores between them.

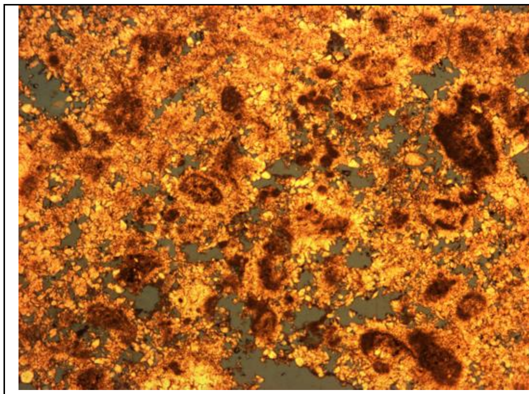
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 18%

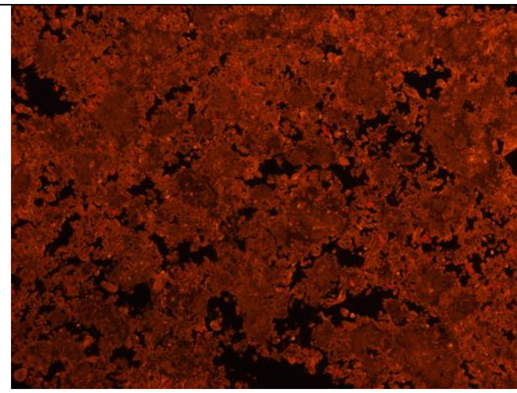
Petrophysical analysis:
Porosity – 19%
Permeability – 159 md

Little Cedar Creek Field **Well: 20** **Permit: 15165**

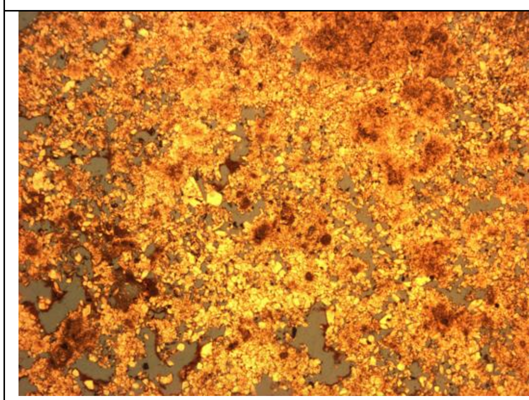
Depth: 11554.6 ft



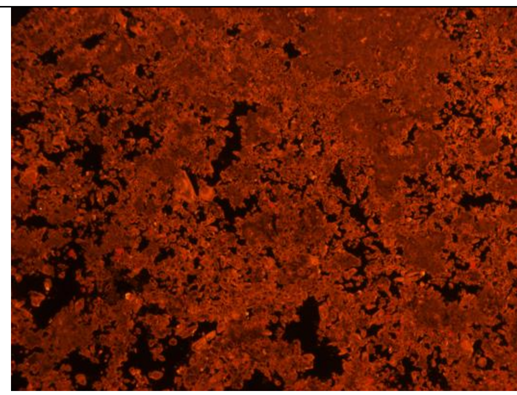
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

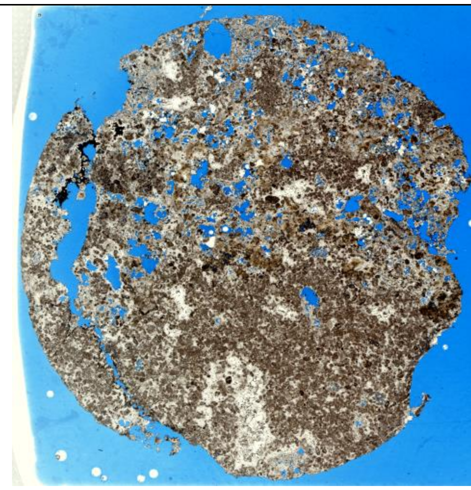
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent, occurs locally.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone (edge) has light brown luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Mosaic calcite cement, zoned (3 zones): dark brown – orange-yellow – light brown luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. The dolomite represents less than 1% of the rock.
Recrystallization – part of the rock is recrystallized, and lost the original texture. The recrystallized calcite present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 20** **Permit: 15165**

Depth: 11577.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Silt to fine sand size quartz and muscovite grains occur. Bioclasts are: benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains, mosaic calcite cement, and blocky calcite cement. Low to moderate dolomitization. Very fine anhedral to euhedral dolomite crystals. Late dissolution.

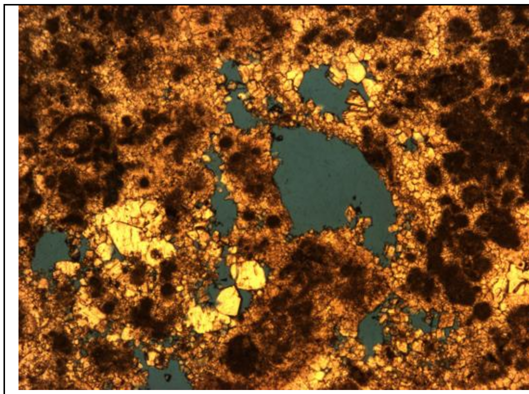
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 11%

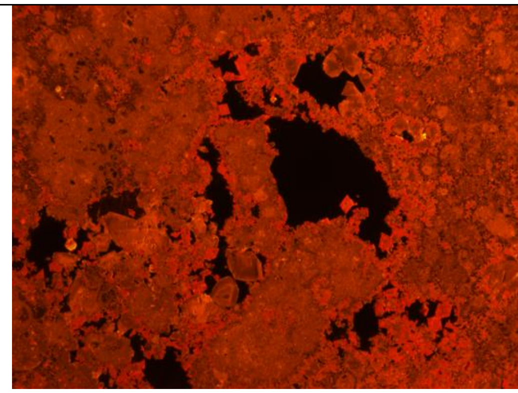
Petrophysical analysis:
Porosity – 11%
Permeability – 10.7 md

Little Cedar Creek Field **Well: 20** **Permit: 15165**

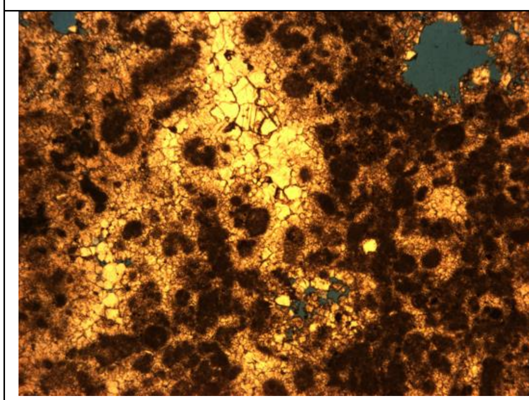
Depth: 11577.5 ft



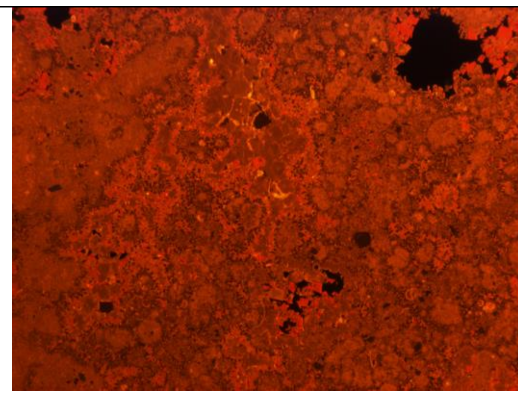
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

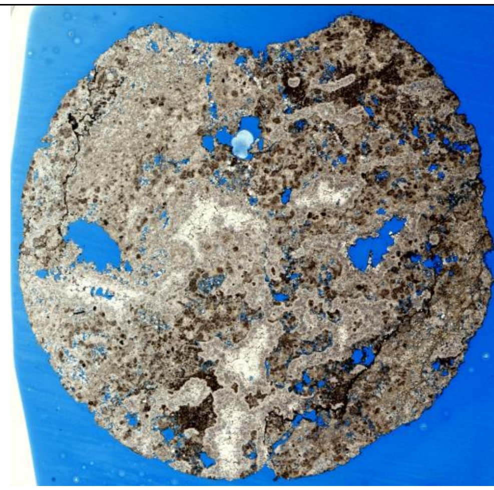
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone (edge) has light brown luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals commonly do not present zonation and have red luminescence, but locally it presents 2 or 3 zones: red – dark red – light red. Dolomite replaces preferentially the first cementation phase.

Little Cedar Creek Field **Well: 20** **Permit: 15165**

Depth: 11582.2 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. The rock is partially recrystallized. Silt to fine sand size quartz grains occur. Bioclasts are: benthic foraminifera and ostracods. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains, mosaic calcite cement, and blocky calcite cement. Low dolomitization. Very fine anhedral to euhedral dolomite crystals. Chemical compaction (stylolites). Late dissolution.

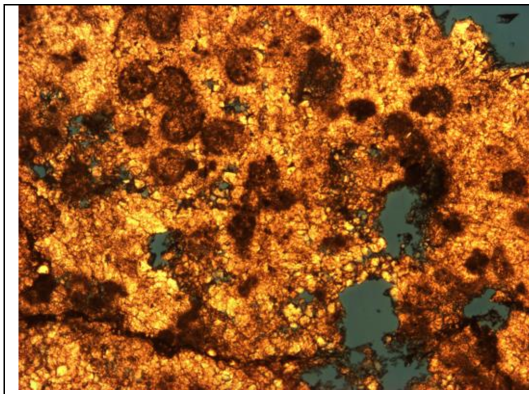
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 10%

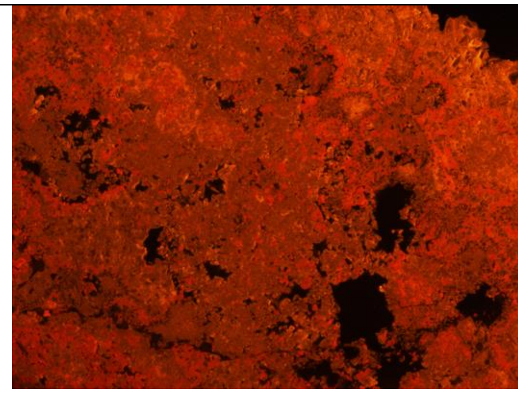
Petrophysical analysis:
Porosity – 9%
Permeability – 4.82 md

Little Cedar Creek Field **Well: 20** **Permit: 15165**

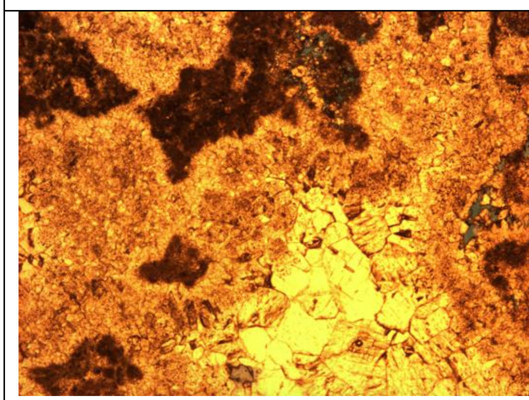
Depth: 11582.2 ft



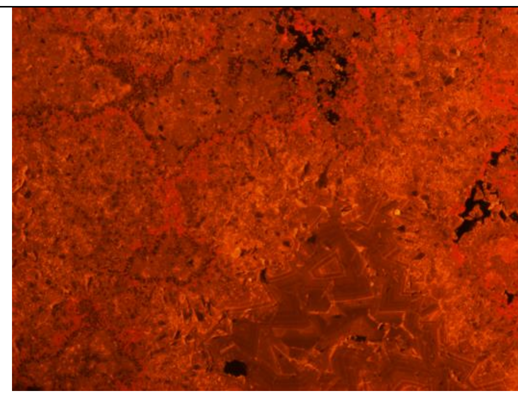
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

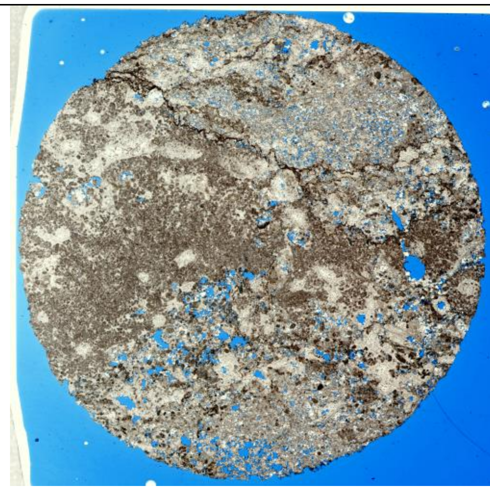
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent, occurs locally.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, the second zone (edge) has light brown luminescence.
Mosaic calcite cement, presenting light brown luminescence.
Blocky calcite cement, zoned (4 zones): light brown – orange-yellow – dark brown – light brown luminescence. Some subzones occur.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. Dolomite replaces preferentially the drusy calcite cement, but also occurs in patches and replacing gastropod shell.

Little Cedar Creek Field **Well: 20** **Permit: 15165**

Depth: 11586.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with bioclasts. Silt to fine sand size quartz and muscovite grains occur. Bioclasts are: benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains, mosaic calcite cement, and blocky calcite cement. Moderate dolomitization. Very fine anhedral to euhedral dolomite crystals. Chemical compaction (stylolites). Late dissolution.

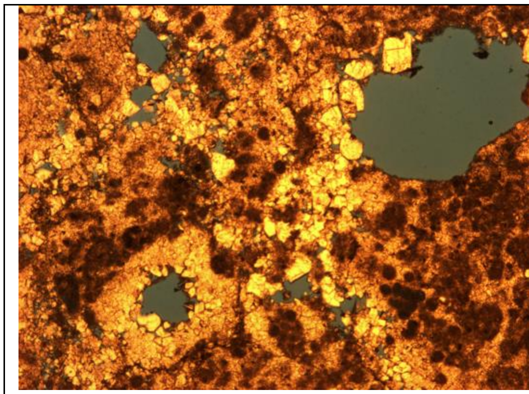
Pore type: Vuggy and intercrystalline.

Porosity (image analysis) : 6%

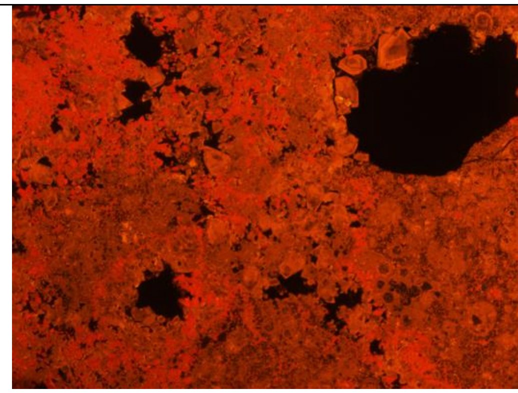
Petrophysical analysis:
Porosity – 9%
Permeability – 4.82 md

Little Cedar Creek Field **Well: 20** **Permit: 15165**

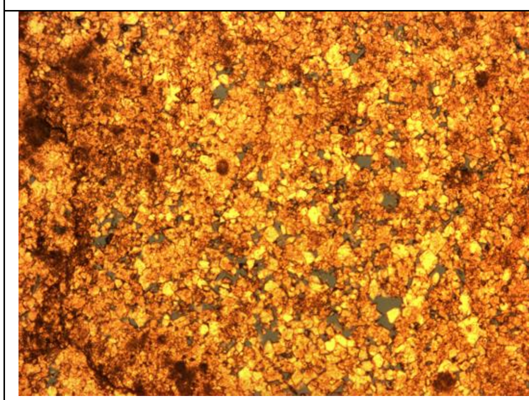
Depth: 11586.5 ft



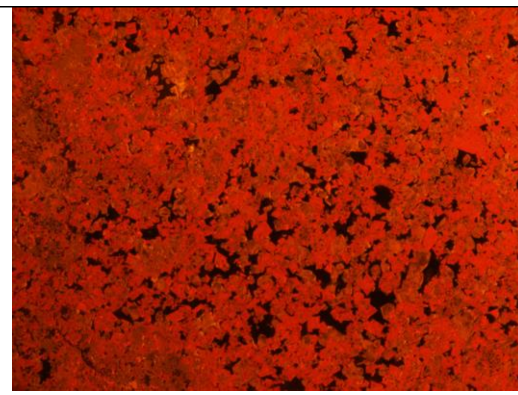
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

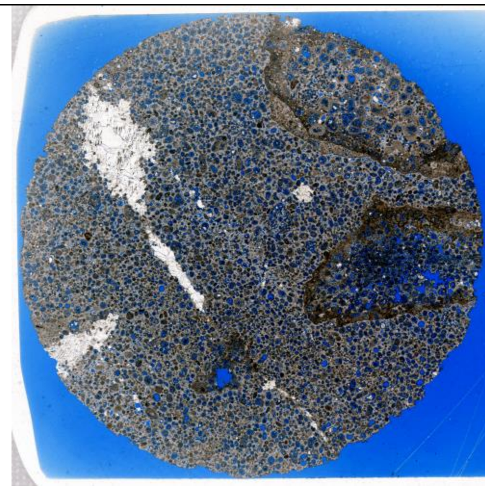


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent, occurs locally.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has light brown luminescence. In places where the grains are very close together, only the first or first and second zones occur.
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Blocky calcite cement, zoned (4 zones): dark to light brown – orange-yellow - light brown – orange-yellow luminescence. Some subzones occur.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase.. The dolomite crystals generally do not present zonation and have red luminescence, but locally it presents 2 or 3 zones: red – dark red – light red. Dolomite replaces preferentially the first cementation phase.

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11218.2 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Fine to medium sand ooilitic-peloidal grainstone, bioturbated.

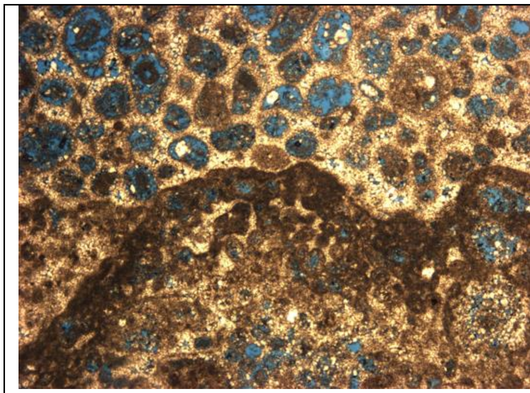
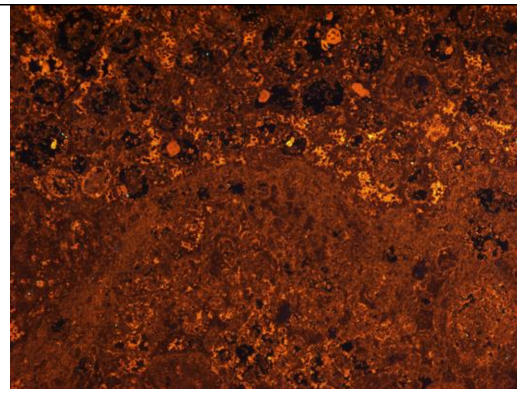
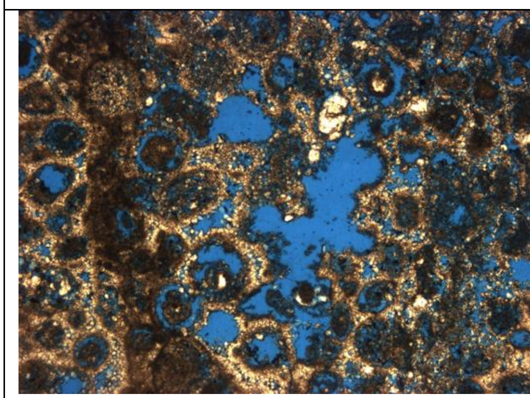
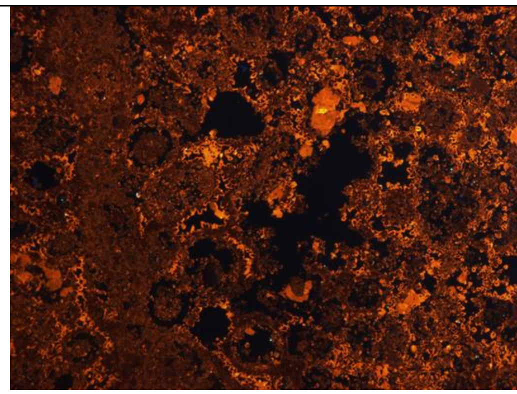
Description: Oolitic-peloidal grainstone, fine to medium sand size, with some coarse sand size oolites and grapestones, bioturbated. Some very fine to fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement, anhydrite as a replacing phase, oolite dissolution, cemented fracture, no compaction features.

Pore type: Intragranular, moldic, intergranular, and some vugs.

Porosity (image analysis) : 28%

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11218.2 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Blocky calcite cement, zoned (2 zones). The zones present the following order: orange-yellow – light brown luminescence. Some crystals are unzoned, and present light brown or orange-yellow luminescence. The blocky calcite cement occurs in the intergranular and in the moldic porosity.</td></tr>
</table>

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11223.3 ft

Plug – 2.15 cm (diameter)

Macroscopic photo

Scanned thin section

Lithology: Fine to coarse sand oolitic-oncolitic grainstone.

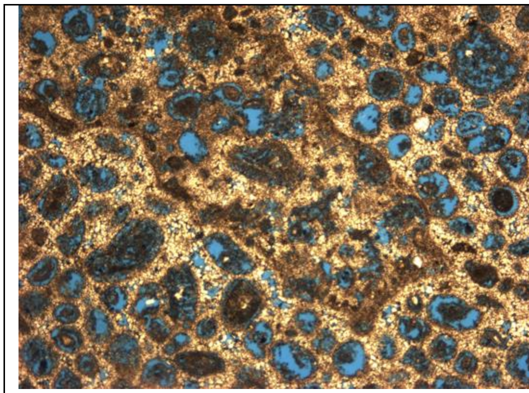
Description: Oolitic-oncolitic grainstone, fine to coarse sand size, locally bioturbated. Some very fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, rare blocky calcite cement, rare anhydrite as a replacing phase, oolite dissolution, some elongated grains due compaction.

Pore type: Moldic, intragranular, rare intergranular and vuggy.

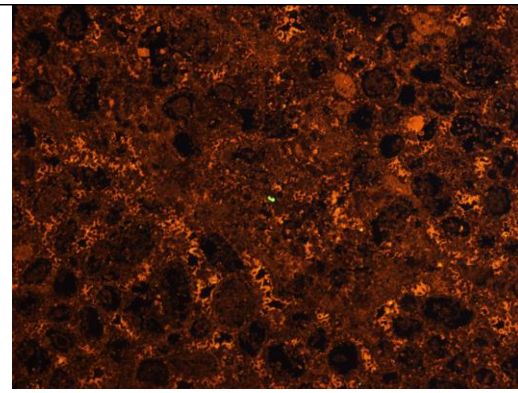
Porosity (image analysis) : 34%

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

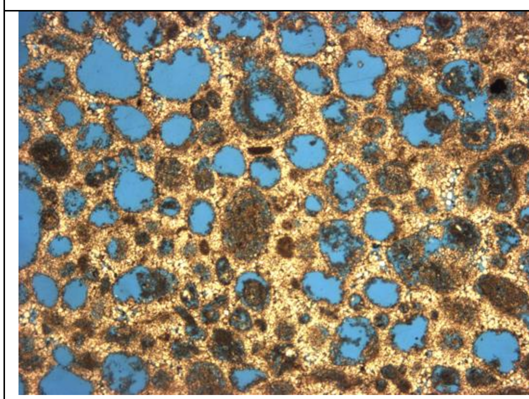
Depth: 11223.3 ft



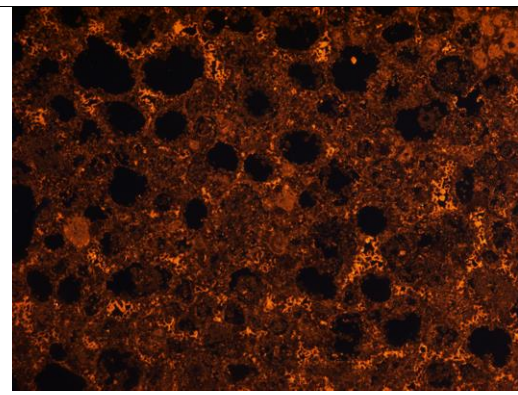
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

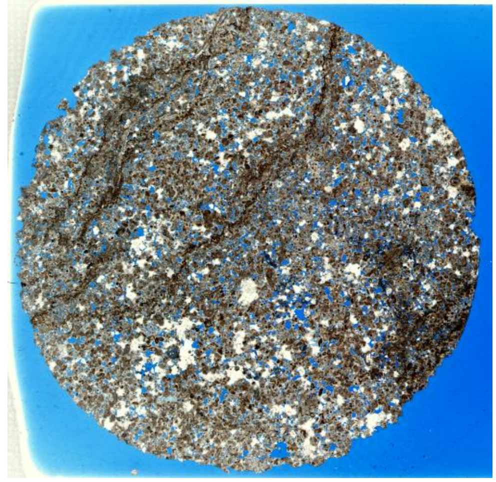
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence. In places where the grains are very close together, only the first zone occurs.
Rare **blocky calcite** cement, presenting orange-yellow luminescence. It occurs inside moldic pores.

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11249.3 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

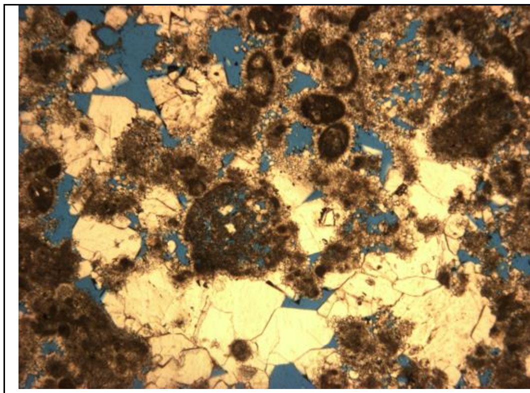
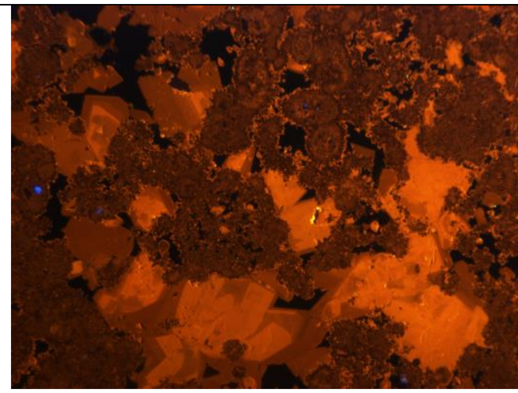
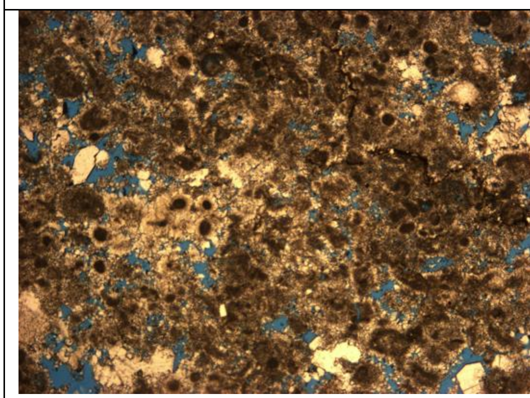
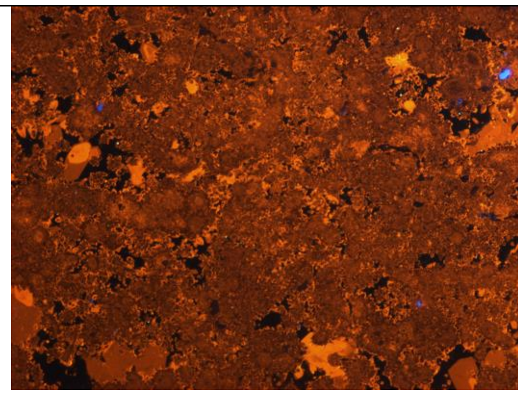
Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , blocky calcite cement, and rare anhydrite cement. Stylolites occur. Some primary growth framework vugs enlarged by dissolution.

Pore type: Intergranular, vuggy, and some intragranular.

Porosity (image analysis): 18%

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11249.3 ft

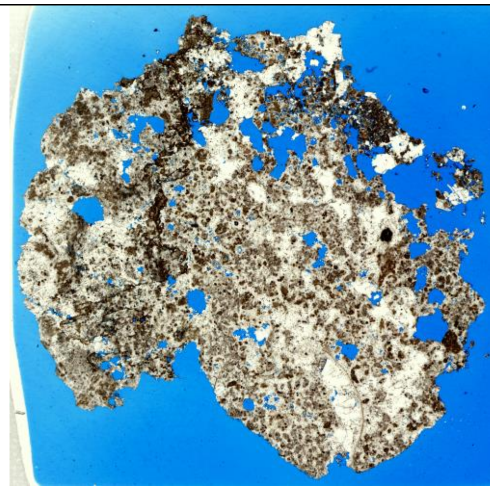
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: light to dark brown – orange-yellow – light brown. Unzoned crystals present light brown or orange-yellow luminescence.

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11261.3 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and rare gastropod. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , mosaic calcite cement, blocky calcite cement, some anhydrite cement. Stylolites occur. Primary growth framework vugs enlarged by dissolution.

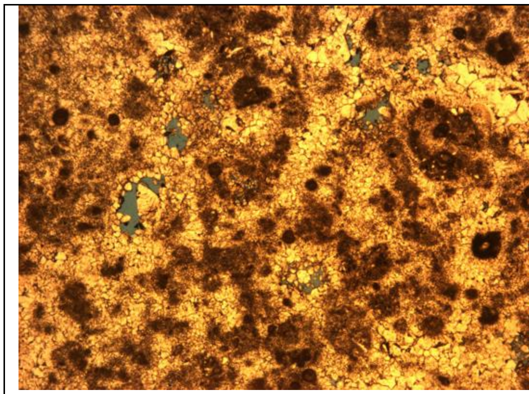
Pore type: Vuggy.

Porosity (image analysis): 18%

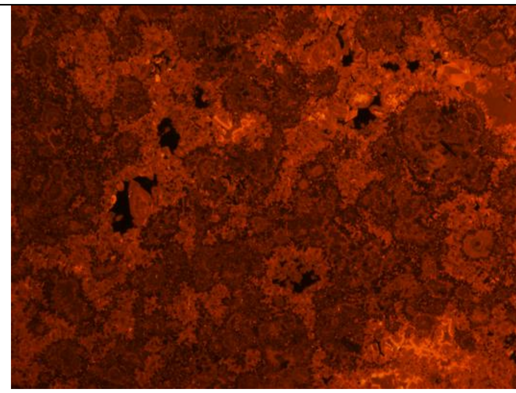
</td>
</tr>
</table>

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

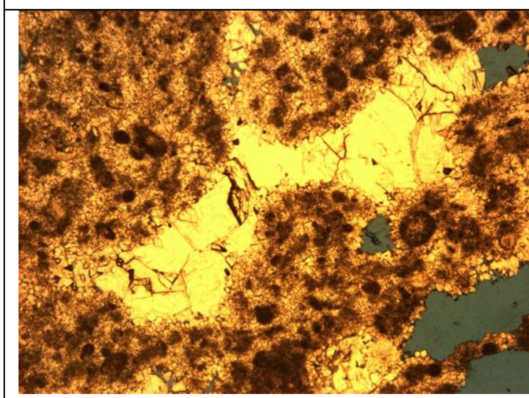
Depth: 11261.3 ft



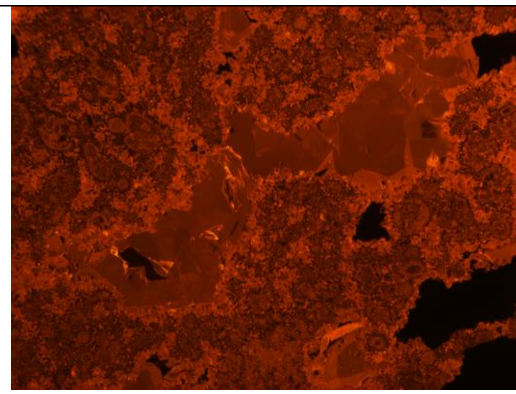
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



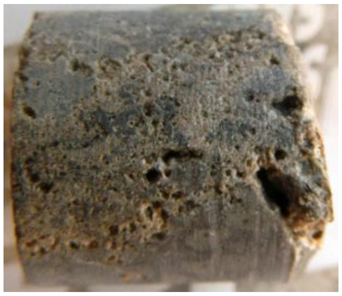
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence and the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 to 3 zones). The zones present the following order: dark brown – light brown – orange-yellow luminescence.

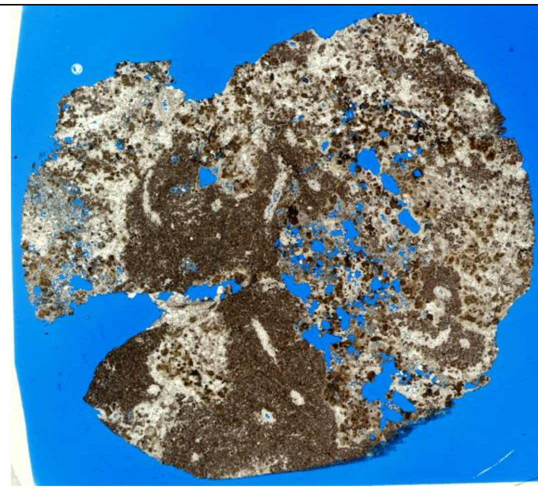
Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11267.2 ft

Plug – 2.15 cm (diameter)



Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

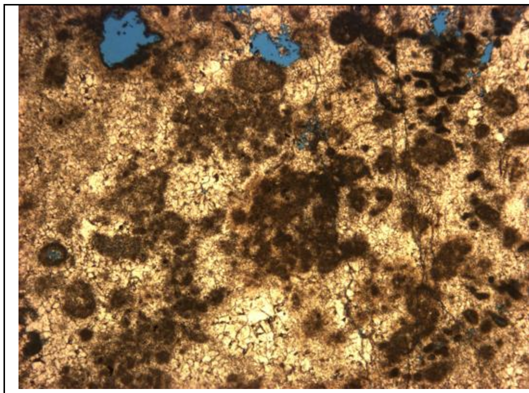
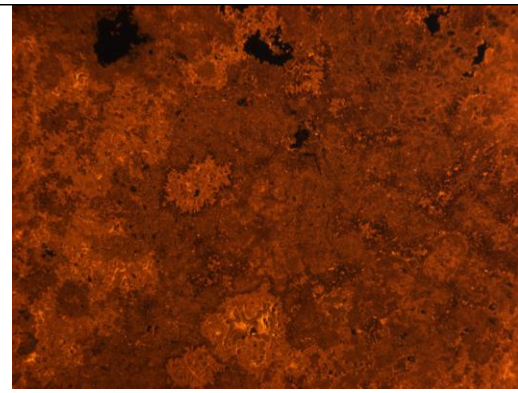
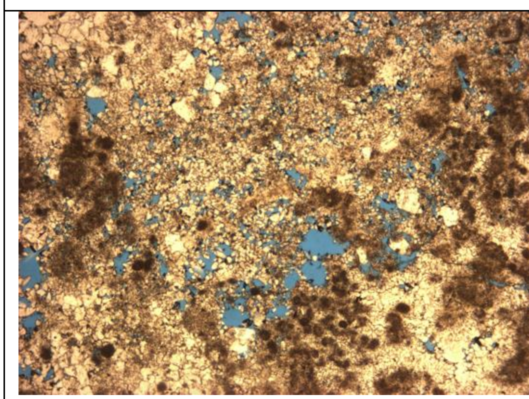
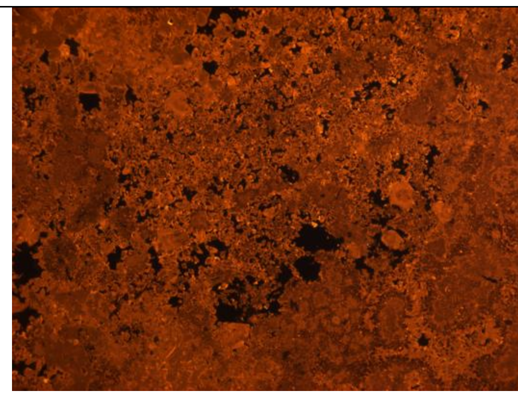
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Part of the rock is composed by densely grouped peloids. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , mosaic calcite cement, blocky calcite cement, rare anhydrite cement. Low calcite recrystallization. Primary growth framework vugs enlarged by dissolution.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 13%

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11267.2 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

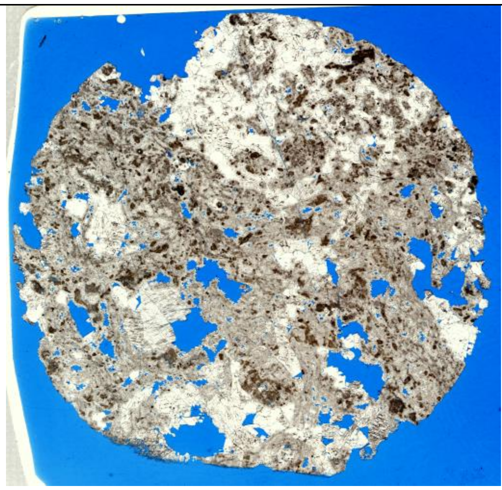
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence and the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: dark brown – light brown luminescence.
Recrystallization – some portions of the rock are recrystallized, and the original texture of the rock is lost. The recrystallized calcite present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11270 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

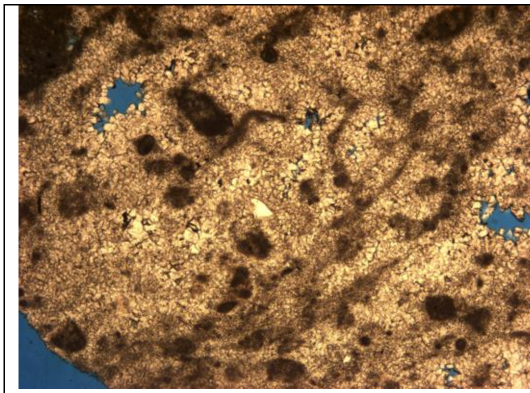
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Some filamentous features occur. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , mosaic calcite cement, blocky calcite cement, some anhydrite cement. Fractures occur. Primary growth framework vugs present enlargement by dissolution.

Pore type: Vuggy and fracture.

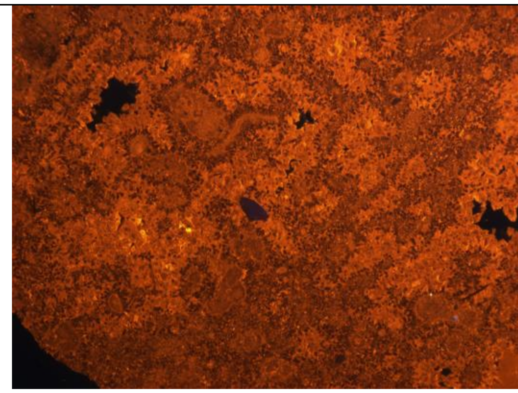
Porosity (image analysis): 8%

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

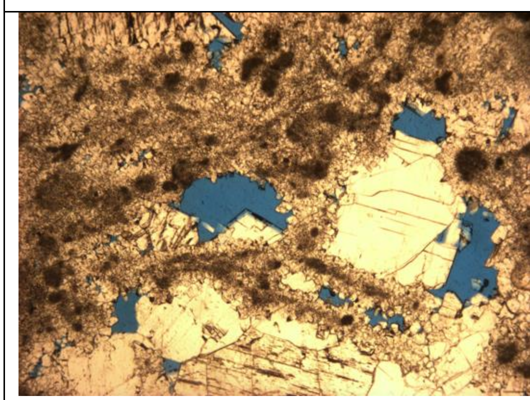
Depth: 11270 ft



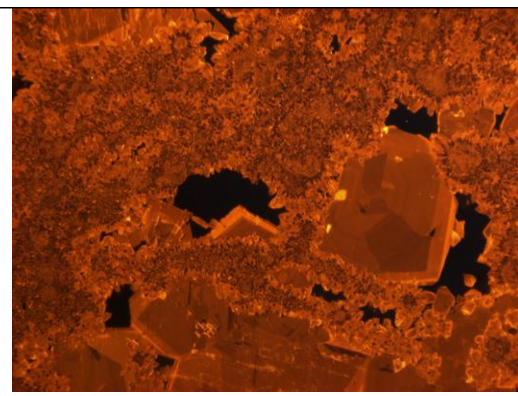
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Fibrous calcite fringe cement rimming the grains, nonluminescent.

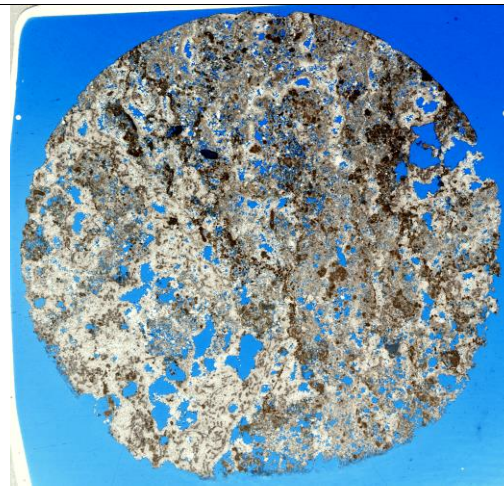
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence and the second zone (edge) has light brown luminescence.

Mosaic calcite cement, zoned (4 zones): orange-yellow – light brown – orange yellow – light brown luminescence.

Blocky calcite cement, zoned (3 zones). The zones present the following order: dark to light brown – light brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11279.5 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

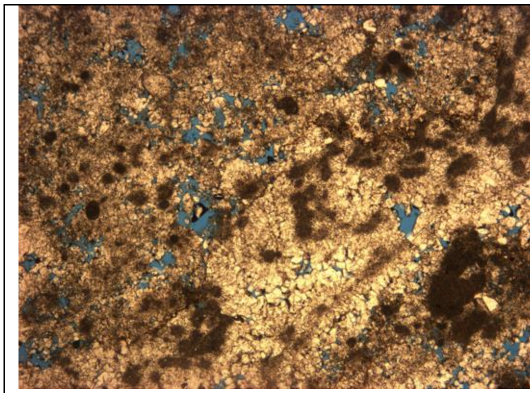
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement), and benthic foraminifera. Some filamentous features occur. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , mosaic calcite cement, and some blocky calcite cement. Moderate recrystallization. Solution seams occur. Primary growth framework vugs present enlargement by dissolution.

Pore type: Vuggy and intercrystalline.

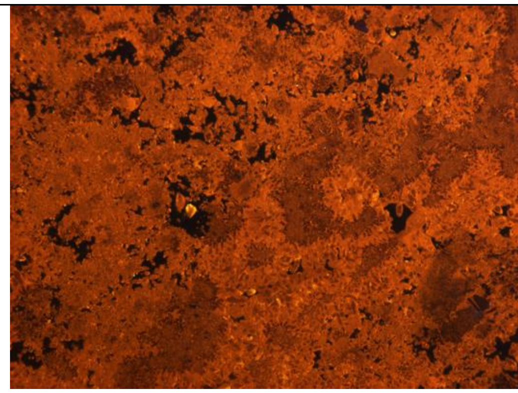
Porosity (image analysis): 18%

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

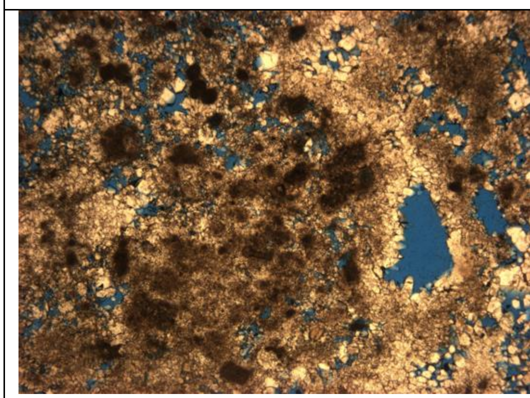
Depth: 11279.5 ft



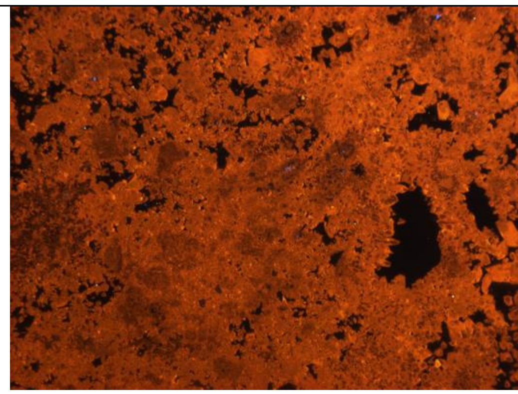
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



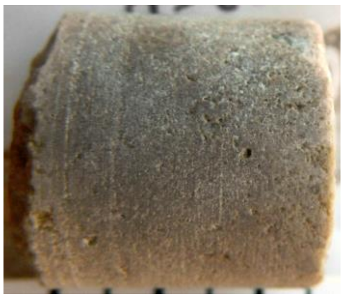
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent, occurs locally.
Drusy calcite fringe cement rimming the grains, presenting dark brown luminescence.
Mosaic calcite cement, zoned (2 zones): dark brown – orange-yellow luminescence.
Recrystallization – some portions of the rock are recrystallized, and the original texture of the rock is lost. The recrystallized calcite presents orange-yellow luminescence.

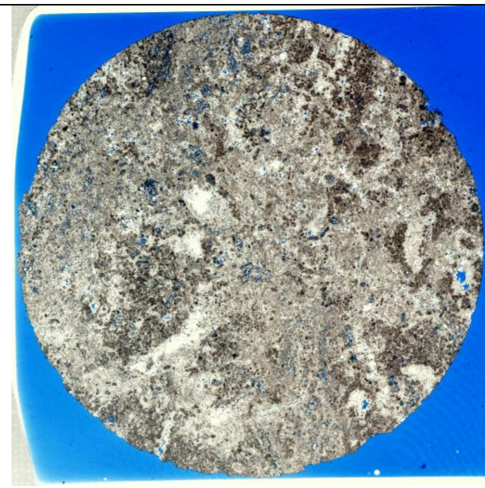
Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11291.8 ft

Plug – 2.15 cm (diameter)



Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

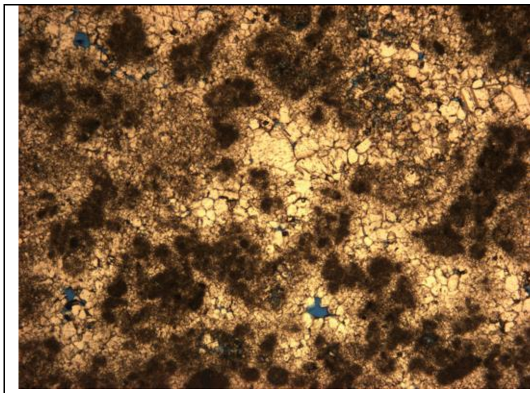
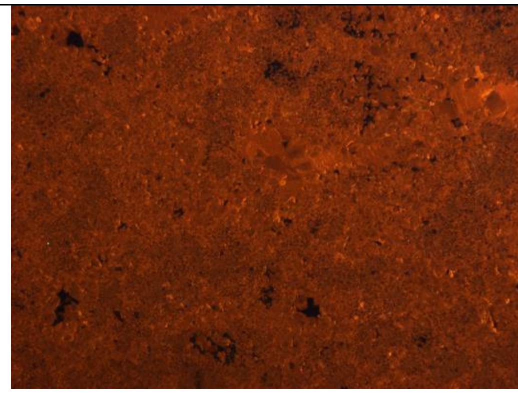
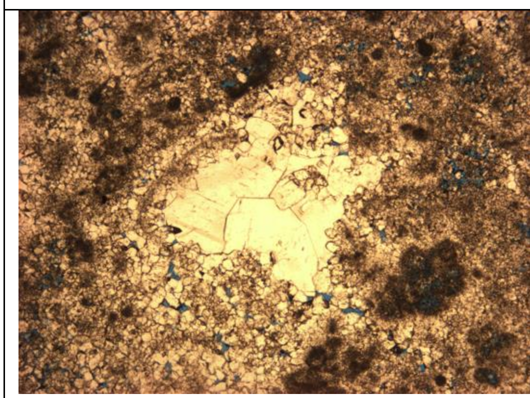
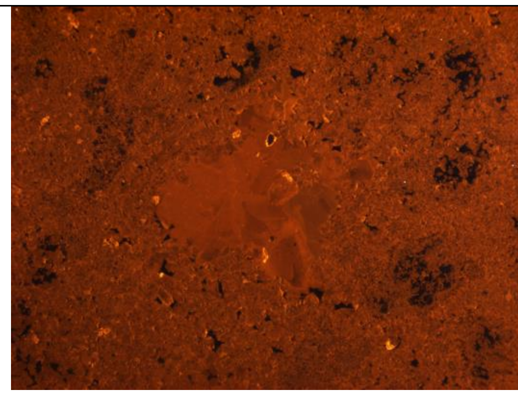
Description: Peloidal thrombolite, with some bioclasts. Silt to very fine sand size quartz and muscovite grains occur. The bioclasts are ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: mosaic calcite cement, blocky calcite cement, some anhydrite cement. Intense cementation and recrystallization.

Pore type: Intercrystalline and vuggy.

Porosity (image analysis): 8%

Little Cedar Creek Field **Well: 21** **Permit: 15263-B**

Depth: 11291.8 ft

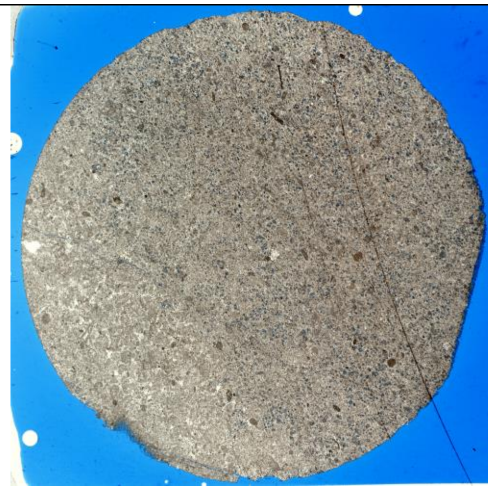
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Mosaic calcite cement, presenting light brown luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – light brown luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11109.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Very fine to fine peloidal grainstone.

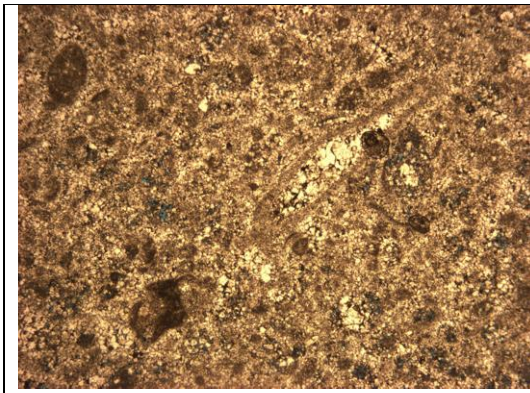
Description: Peloidal grainstone, fine to medium sand size, with some fine to medium sand size skeletal fragments. Some very fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, blocky calcite cement, rare anhydrite as a replacing phase, no compaction features. Intense cementation.

Pore type: Intercrystalline.

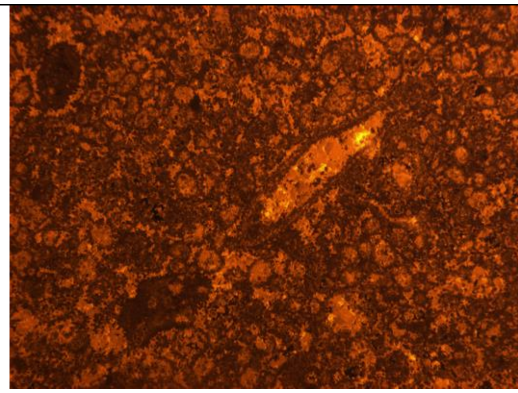
Porosity (image analysis): 2%

Little Cedar Creek Field **Well: 22** **Permit: 15357**

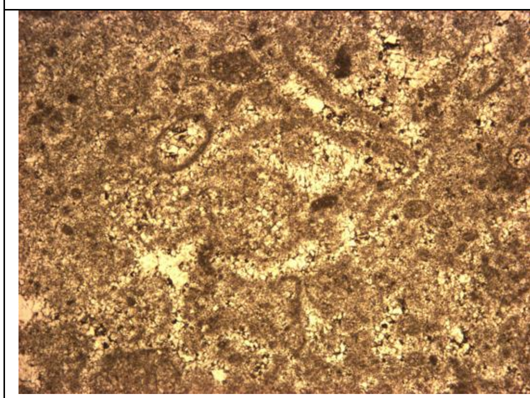
Depth: 11109.6 ft



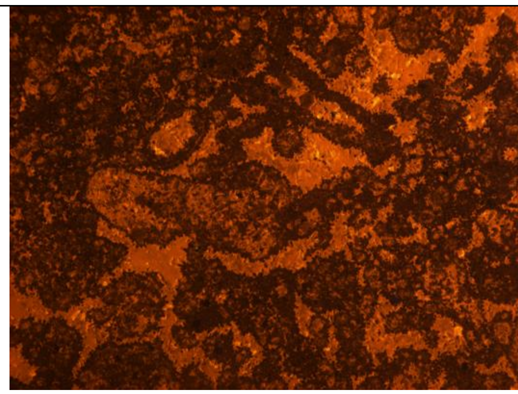
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

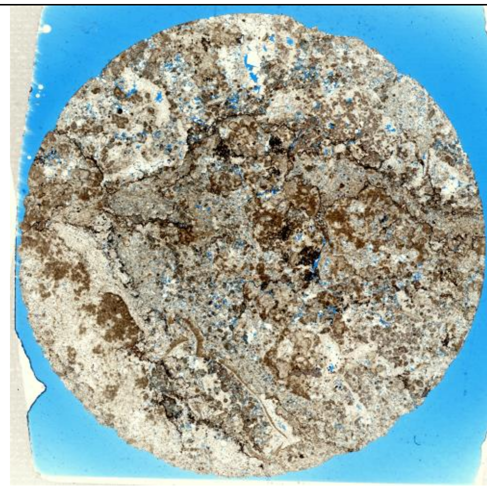
Cathodoluminescence image analysis:
Bladded to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) is dark brown to nonluminescent, and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, presenting orange-yellow luminescence. Locally zoned (2 zones): dark brown – orange-yellow. Some subzones occur.

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11153.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

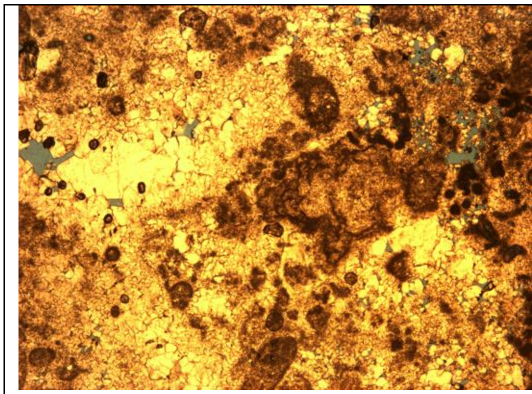
Description: Peloidal thrombolite, with some bioclasts. Some silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera, ostracods (with sintaxial calcite cement), and green algae(?). Some filamentous and branching features occur. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters , blocky calcite cement, and rare anhydrite cement. Stylolites occur. Low to moderate recrystallization. Some late dissolution.

Pore type: Intercrystalline and vuggy.

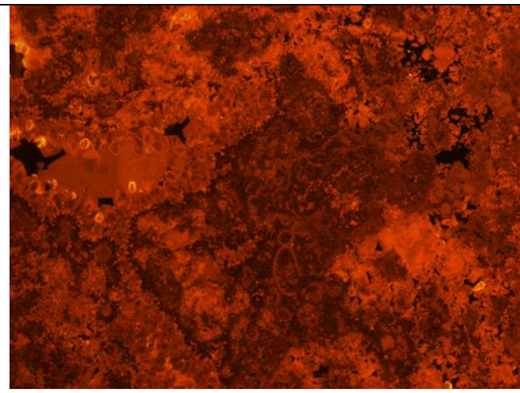
Porosity (image analysis): 5%

Little Cedar Creek Field **Well: 22** **Permit: 15357**

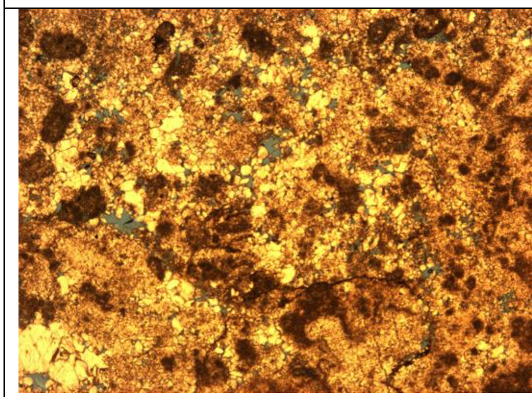
Depth: 11153.6 ft



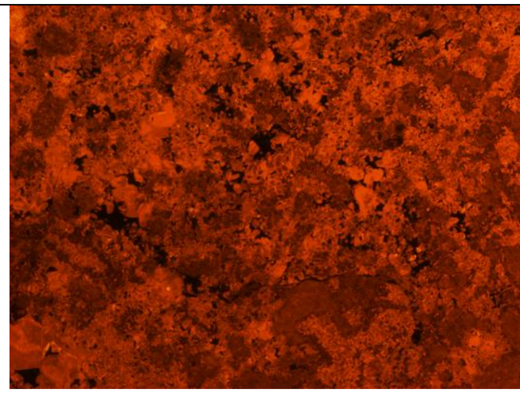
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

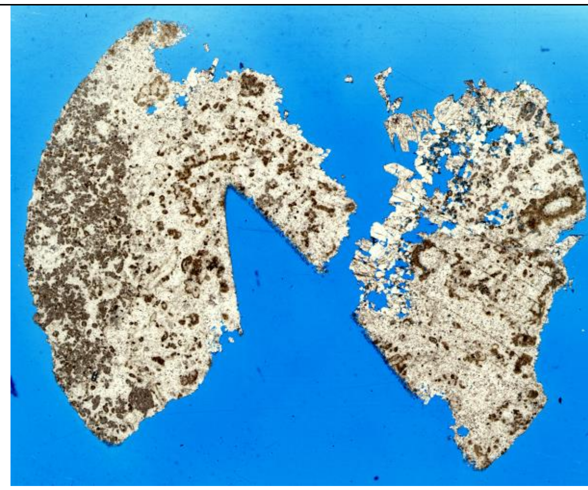


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone has dark to light brown luminescence and the third zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): dark brown – orange-yellow luminescence.
Blocky calcite cement, zoned (3 zones). The zones present the following order: light to dark brown – orange-yellow – light brown. Unzoned crystals present light brown or orange-yellow luminescence.

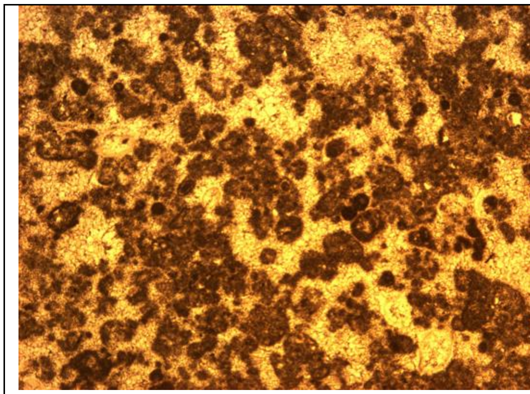
Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11158.6 ft

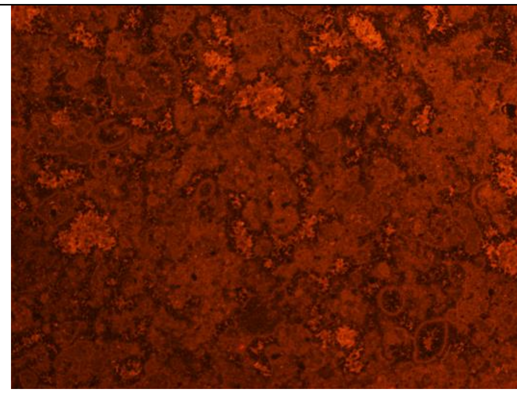
Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section
Lithology: Peloidal thrombolite. **Description:** Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Some filamentous features. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, blocky calcite cement, and some anhydrite cement. Some late dissolution. **Pore type:** Vuggy and intercrystalline. **Porosity (image analysis):** 12%	

Little Cedar Creek Field **Well: 22** **Permit: 15357**

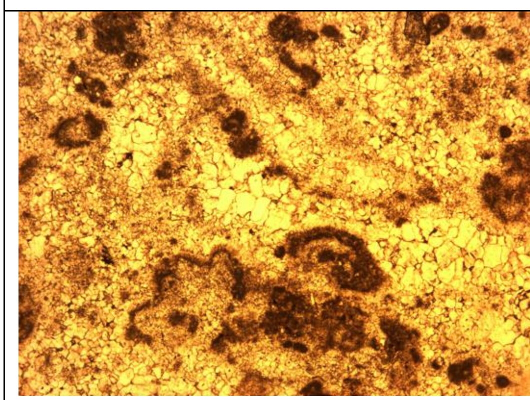
Depth: 11158.6 ft



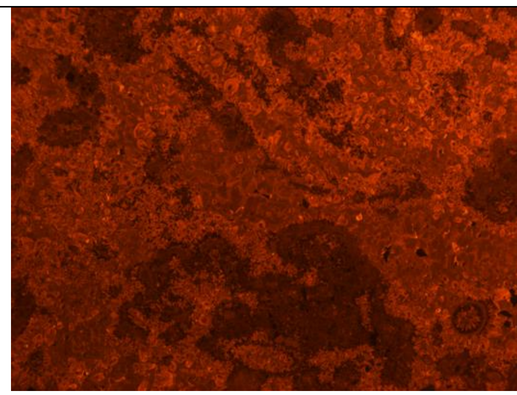
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

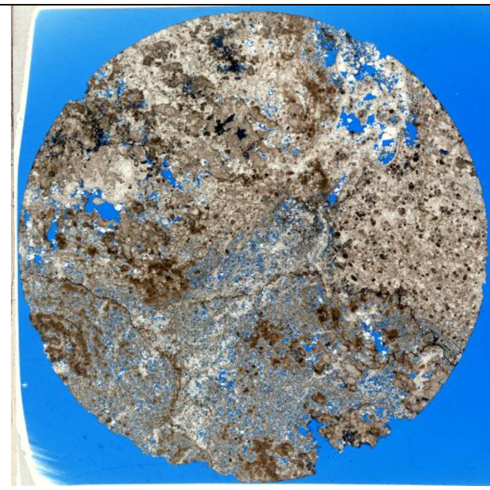
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone has dark to light brown luminescence and the third zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence.

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11161 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

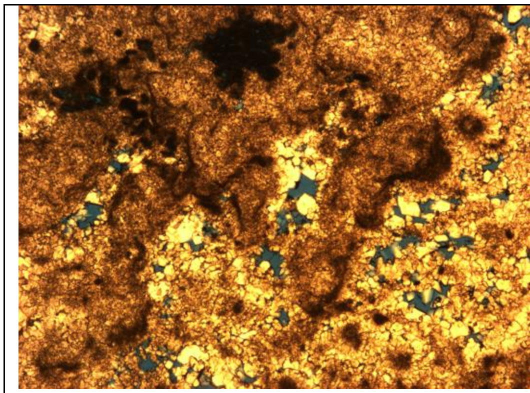
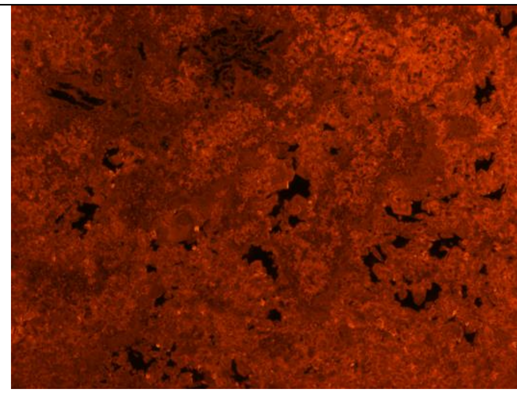
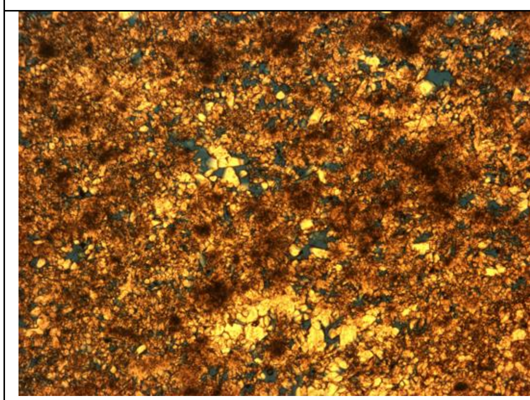
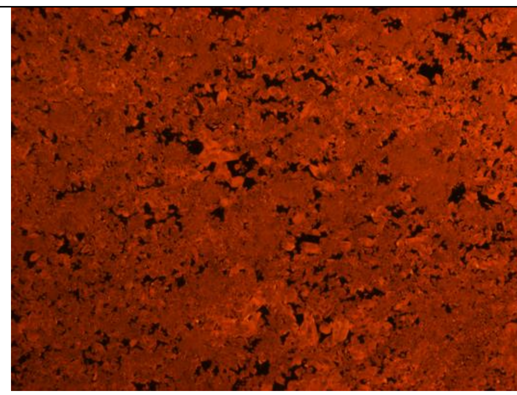
Description: Peloidal thrombolite, with rare bioclasts. Rare silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Some filamentous features occur. Peloid clusters are common. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, rare blocky calcite cement, and rare anhydrite cement. Stylolites occur. Some primary growth framework vugs enlarged by dissolution. Moderate to high recrystallization.

Pore type: Intercrystalline and vuggy.

Porosity (image analysis): 10%

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11161 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

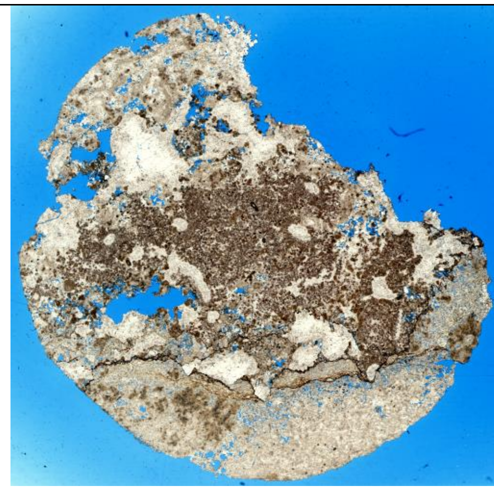
Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light dark brown – orange-yellow luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, possibly resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11165 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

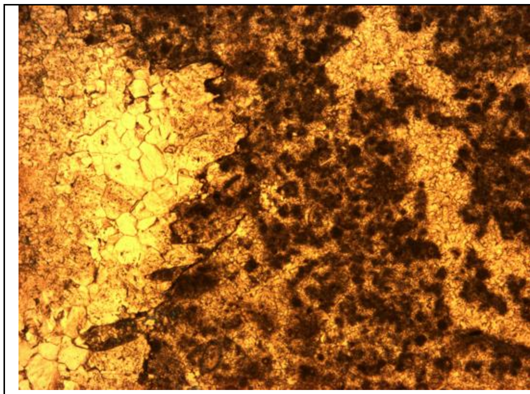
Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, blocky calcite cement, and rare anhydrite cement. Stylolites occur. Some primary growth framework vugs enlarged by dissolution. Moderate to high recrystallization. Fractures occur.

Pore type: Vuggy and intercrystalline.

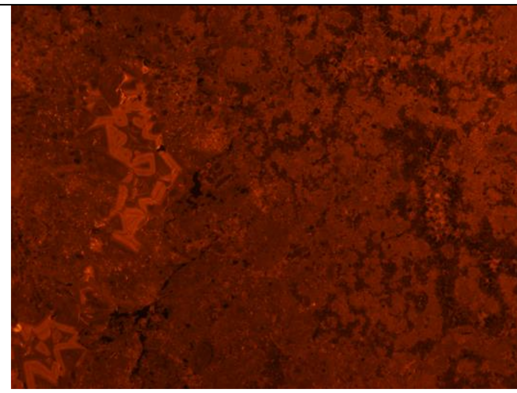
Porosity (image analysis): 7%

Little Cedar Creek Field **Well: 22** **Permit: 15357**

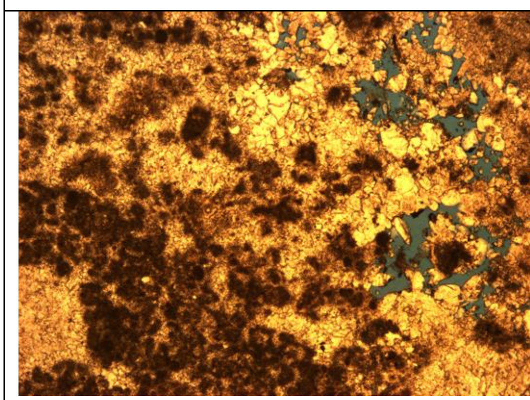
Depth: 11165 ft



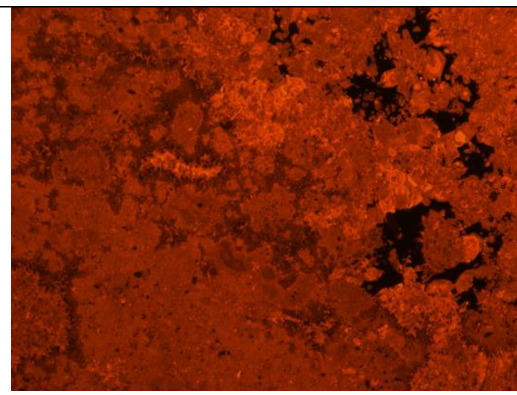
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

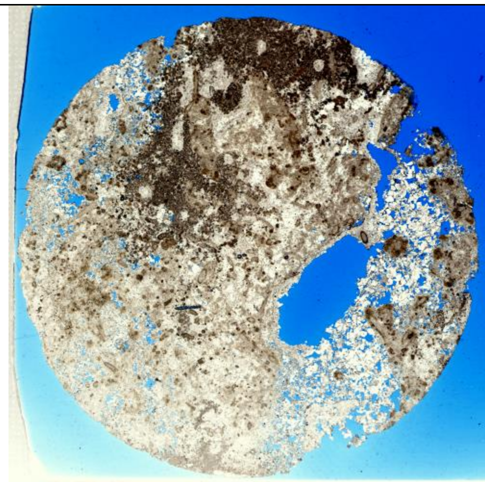
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grain clusters, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (3 zones): light brown – orange-yellow – light brown luminescence.
Blocky calcite cement, zoned (5 zones). The zones present the following order: dark brown – orange-yellow – light brown – orange-yellow – dark brown luminescence.

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11168 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

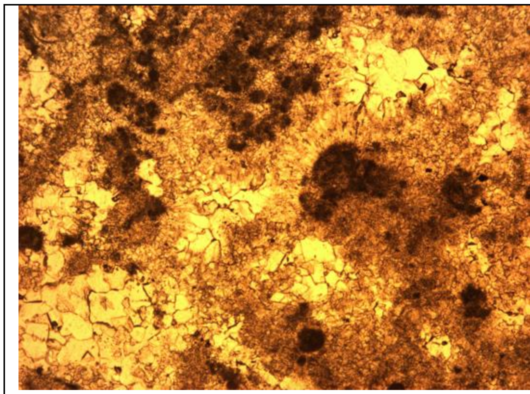
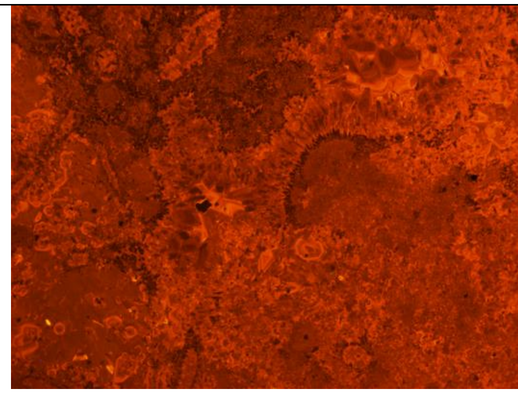
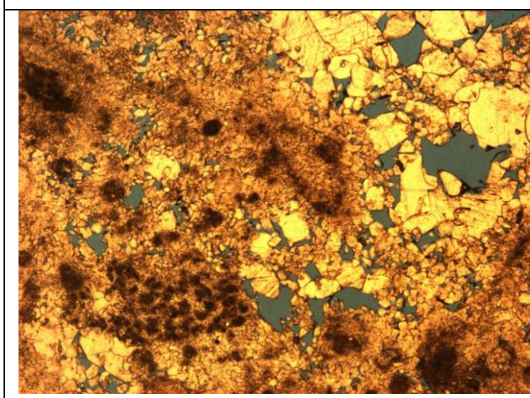
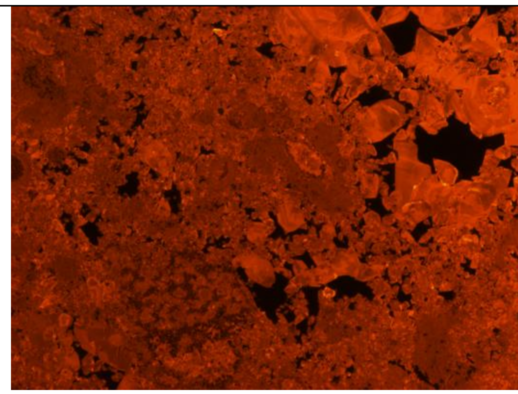
Description: Peloidal thrombolite, with some bioclasts. Some silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Parts of the rock present denser amout of peloids. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, blocky calcite cement, and rare anhydrite cement. Rare discontinuous stylolites occur. Late dissolution occurs. Low to moderate recrystallization.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 13%

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11168 ft

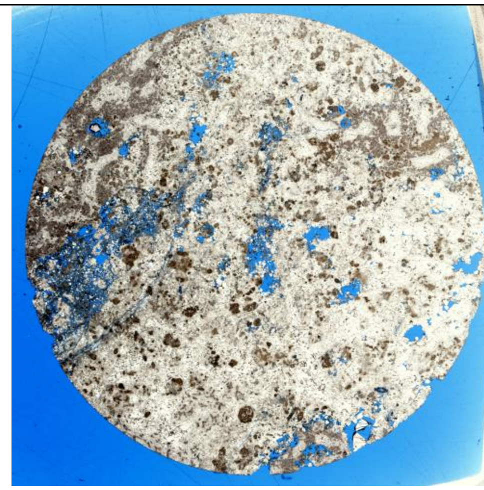
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) has orange-yellow luminescence, the second zone has dark brown luminescence and the third zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (3 zones): dark brown – light brown – orange-yellow luminescence. Some subzones occur.
Blocky calcite cement has irregular zones. The zones observed present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11171.8 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
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<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Some silt to very fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, blocky calcite cement, and rare anhydrite cement. Stylolites and fractures occur. Late dissolution. Intense cementation.

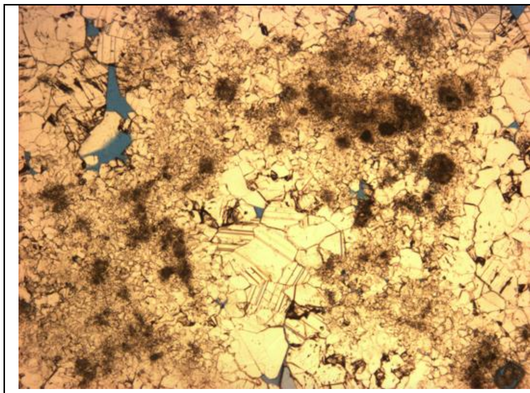
Pore type: Vuggy, intercralline, and fractures.

Porosity (image analysis): 7%

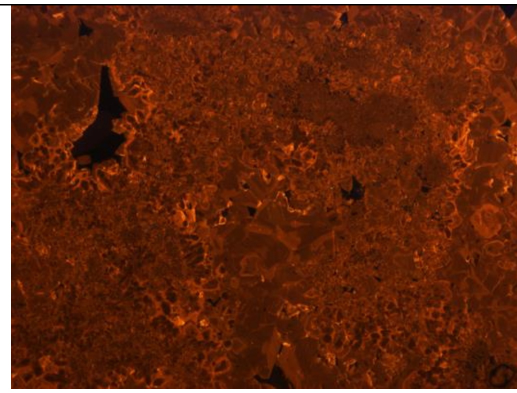
</td>
</tr>
</table>

Little Cedar Creek Field **Well: 22** **Permit: 15357**

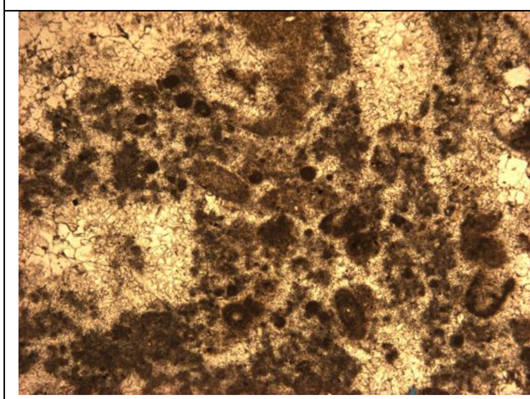
Depth: 11171.8 ft



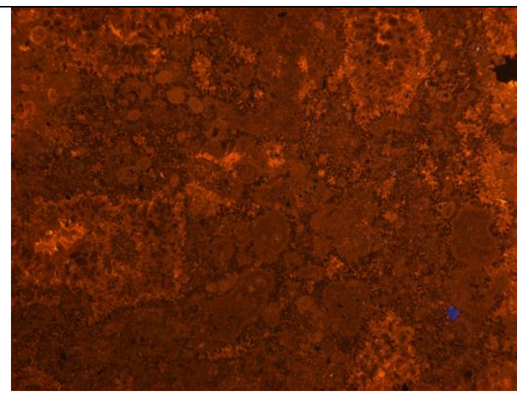
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

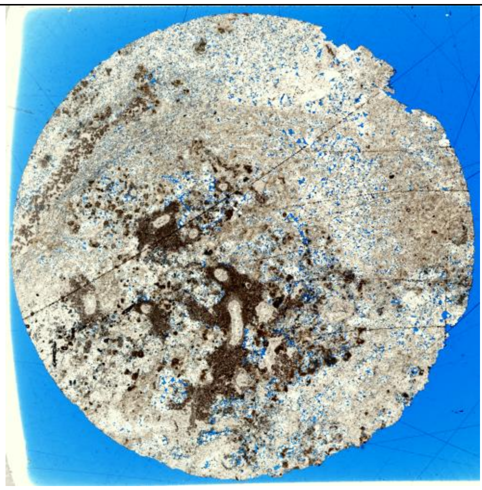


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grain clusters, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): dark to light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: dark brown – light brown.

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11186.5 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

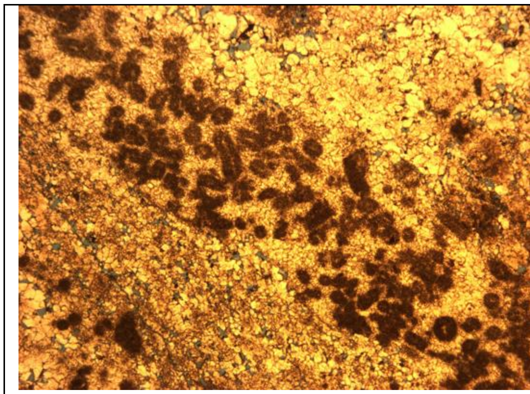
Description: Peloidal thrombolite, with some bioclasts. Rare silt to fine sand size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, blocky calcite cement, and some anhydrite cement. Rare dolomite. Moderate to high recrystallization and cementation.

Pore type: Intercrystalline and vuggy.

Porosity (image analysis): 9%

Little Cedar Creek Field **Well: 22** **Permit: 15357**

Depth: 11186.5 ft

<table>
<tr><td>
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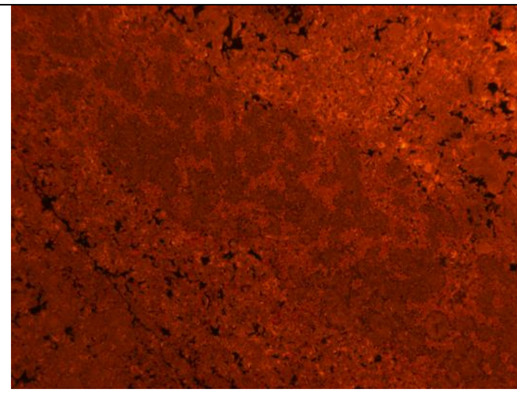
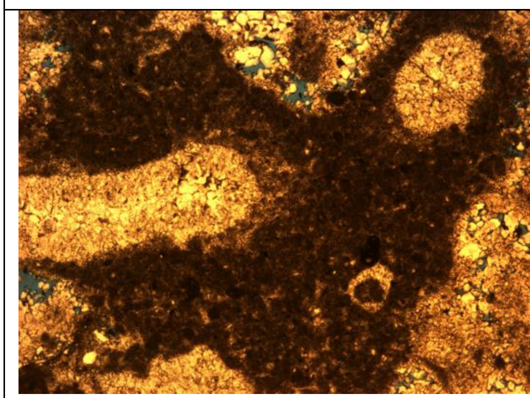
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
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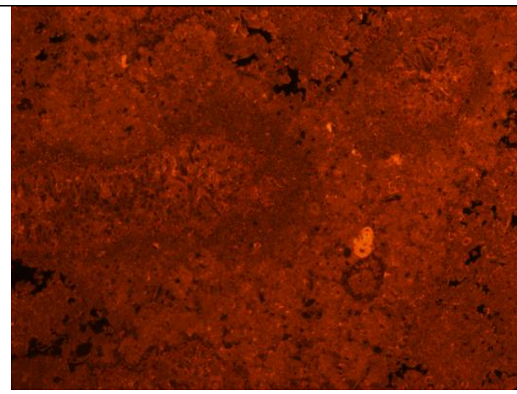
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, presenting light brown luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.</td></tr>
</table>

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11005.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo

Scanned thin section

Lithology: fine to medium oolitic grainstone, bioturbated.

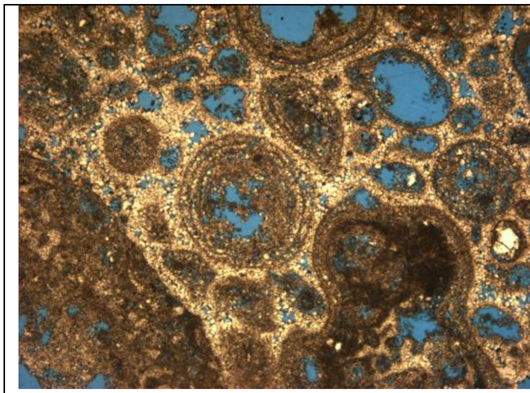
Description: Oolitic grainstone, fine to medium sand size, with some coarse to very coarse sand size oolites and grapestones, bioturbated. Some very fine to fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement, rare anhydrite as a replacing phase, oolite dissolution, no compaction features.

Pore type: Moldic, intragranular, and intergranular.

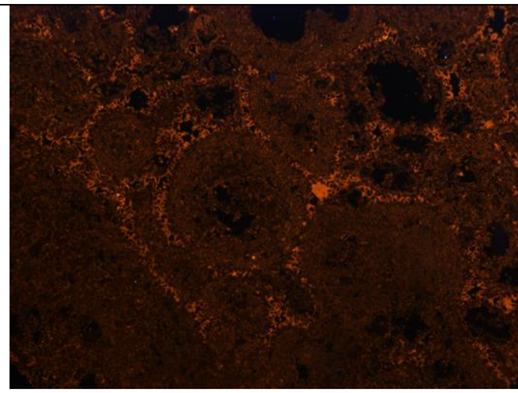
Porosity (image analysis): 29%

Little Cedar Creek Field **Well: 23** **Permit: 15413**

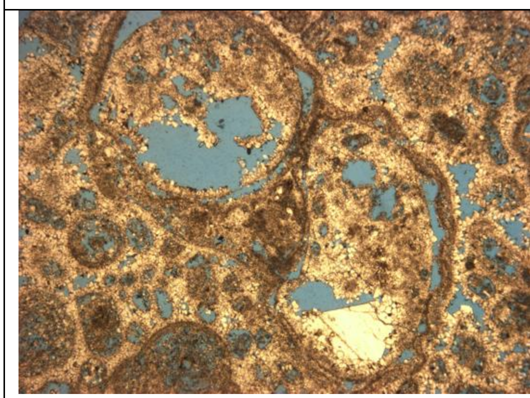
Depth: 11005.8 ft



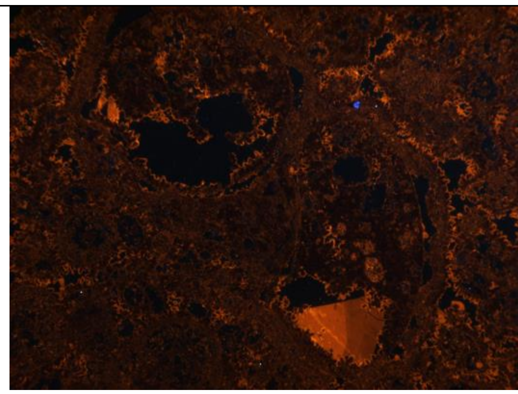
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence. Locally it occurs inside intraskeletal porosity, growing from the border to the center.
Very fine to fine mosaic calcite cement, light to dark brown luminescence.
Blocky calcite cement, zoned (2 zones). The zones present the following order: light brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11012.3 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Fine to medium oolitic grainstone.

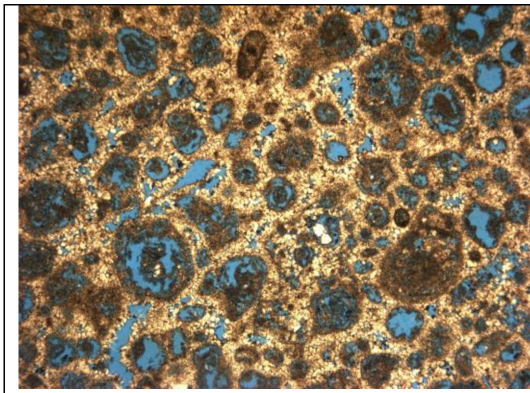
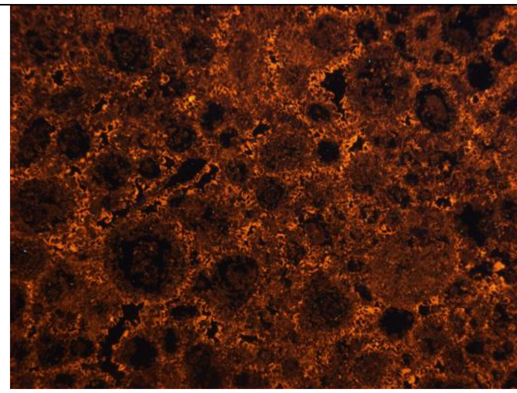
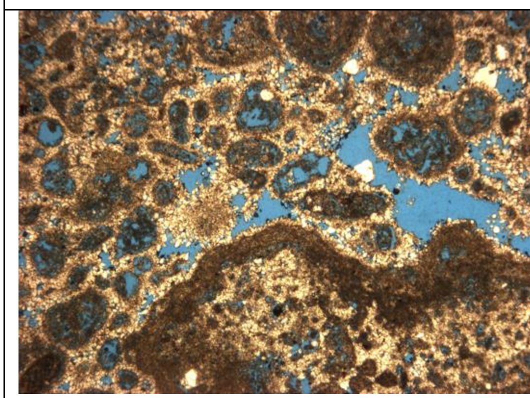
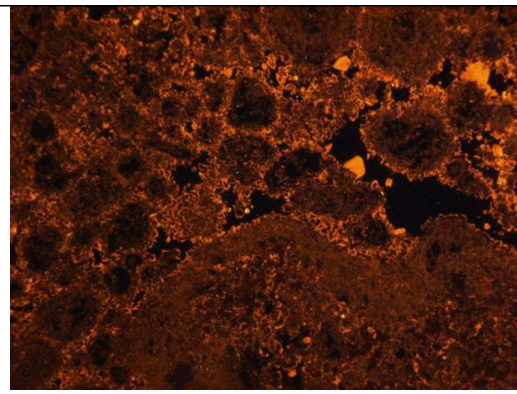
Description: Oolitic grainstone, fine to medium sand size, with some coarse sand size oolites and grapestones, locally bioturbated. Some very fine to fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, blocky calcite cement, and rare anhydrite as a replacing phase, oolite dissolution, no compaction features.

Pore type: Moldic, intragranular, and intergranular.

Porosity (image analysis): 32%

Little Cedar Creek Field **Well: 23** **Permit: 15413**

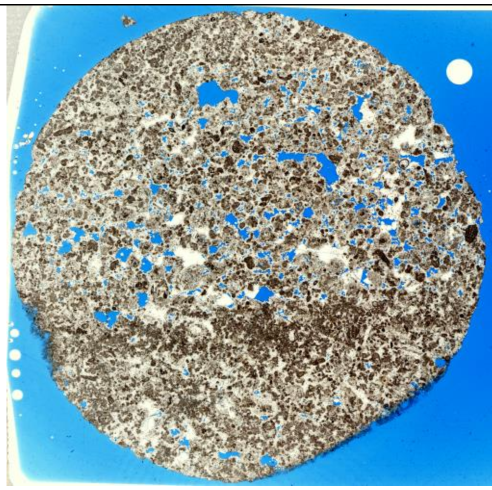
Depth: 11012.3 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.
Blocky calcite cement, presenting orange-yellow luminescence.

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11044.8 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and rare anhydrite cement. Some primary growth framework vugs enlarged by dissolution.

Pore type: Vuggy.

Porosity (image analysis): 8%

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11044.8 ft

<table>
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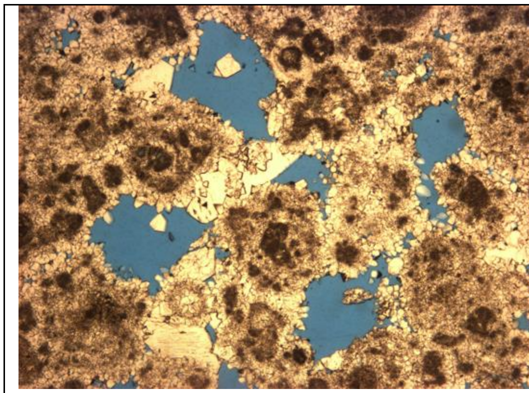
<td>
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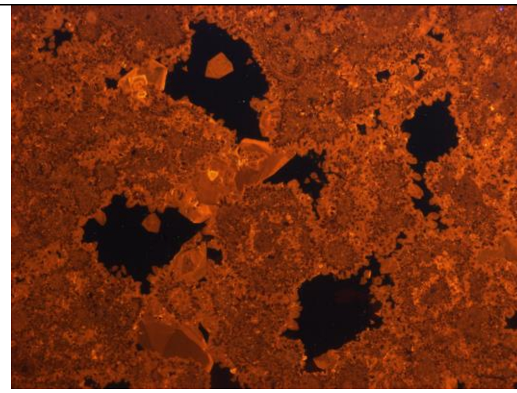
Full horizontal axis = 3.5 mm</td>
<td>
Cathodoluminesce image – same field of the picture on the left side</td>
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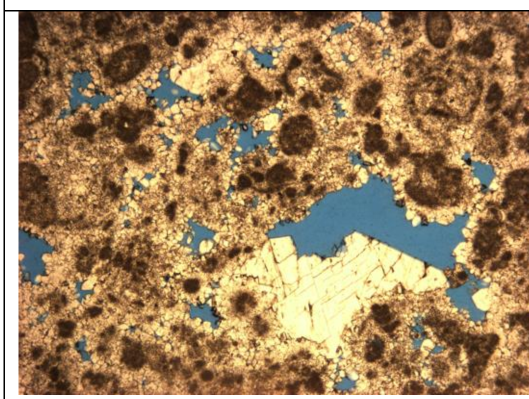
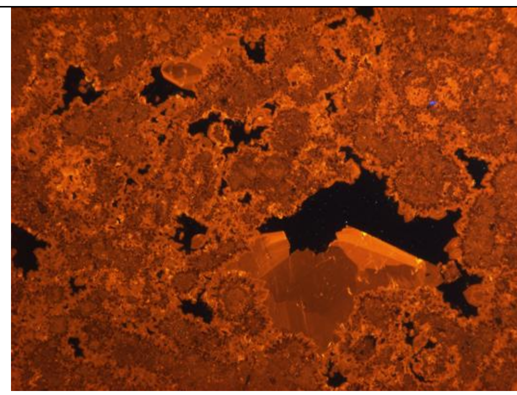
<td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td>
<td>
Cathodoluminesce image – same field of the picture on the left side</td>
</tr>
<tr>
<td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) has light brown luminescence, the second zone has orange-yellow luminescence and the third zone (edge) has light brown luminescence.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, zoned (3 zones). The zones present the following order: dark to light brown – orange-yellow – light orange-yellow. Unzoned crystals present light brown or orange-yellow luminescence.</td>
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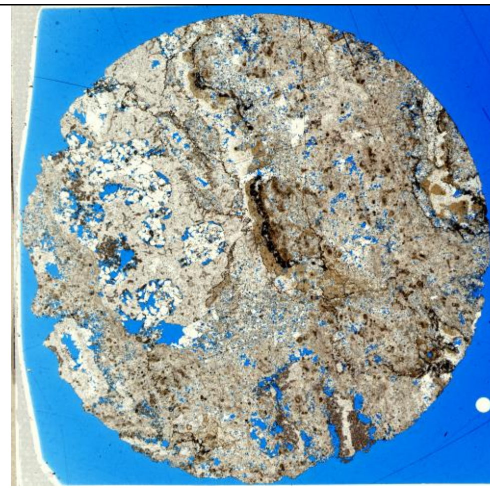
</table>

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11054.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

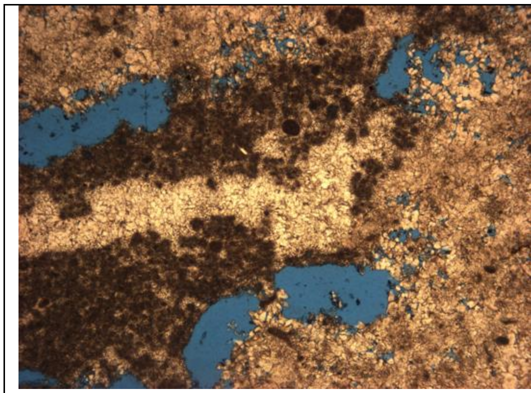
Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and some anhydrite cement. Stylolites occur. Moderate to high recrystallization and cementation. Late dissolution.

Pore type: Vuggy and intercrystalline.

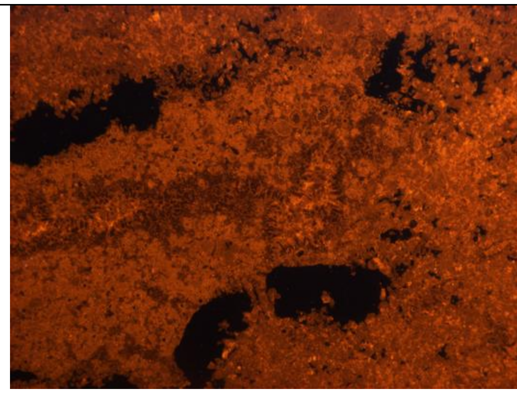
Porosity (image analysis): 12%

Little Cedar Creek Field **Well: 23** **Permit: 15413**

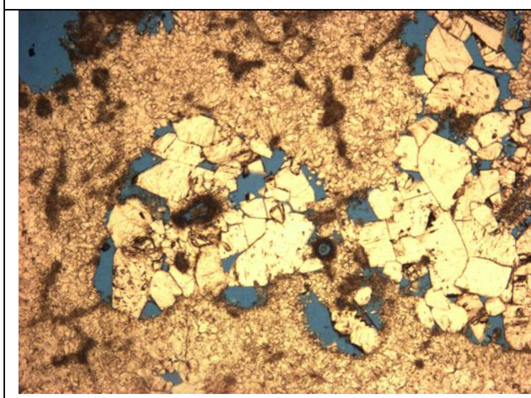
Depth: 11054.6 ft



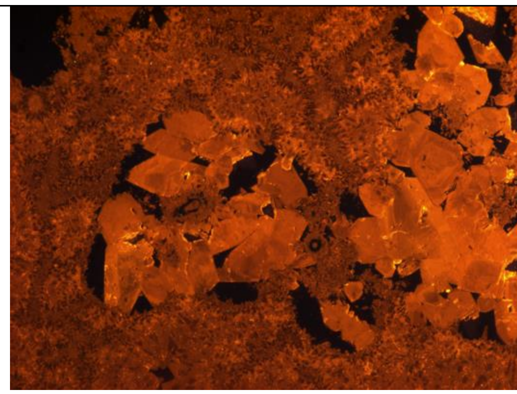
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

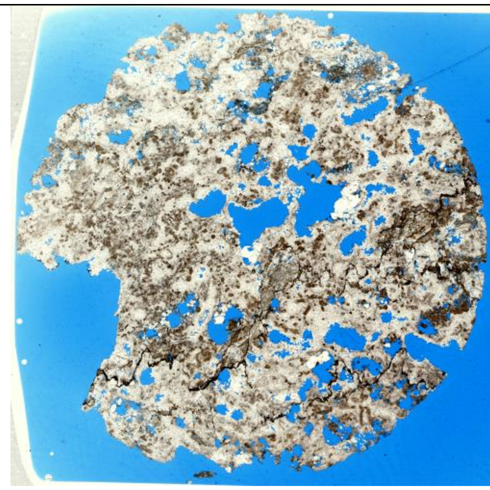
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, light brown to orange-yellow luminescent.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, presenting irregular zonation. It presents light brown to orange-yellow luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, possibly resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11061.5 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

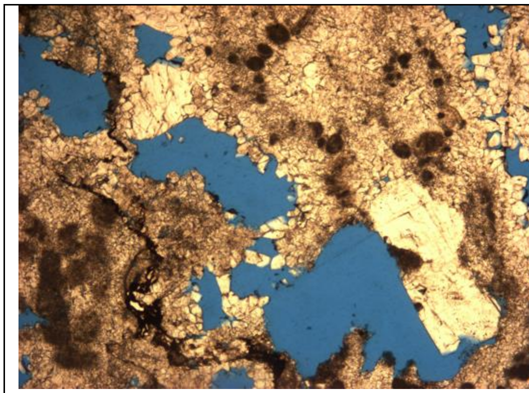
Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and some anhydrite cement. Stylolites occur. Late dissolution. Local recrystallization.

Pore type: Vuggy and intercrystalline.

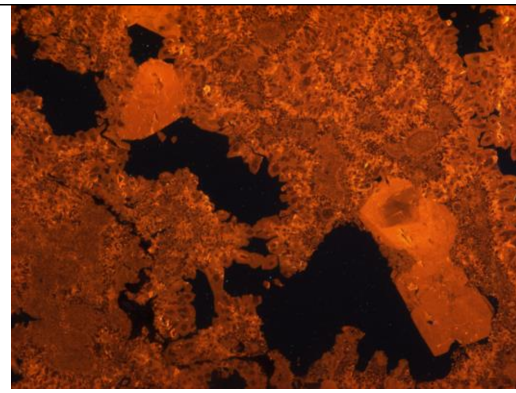
Porosity (image analysis): 19%

Little Cedar Creek Field **Well: 23** **Permit: 15413**

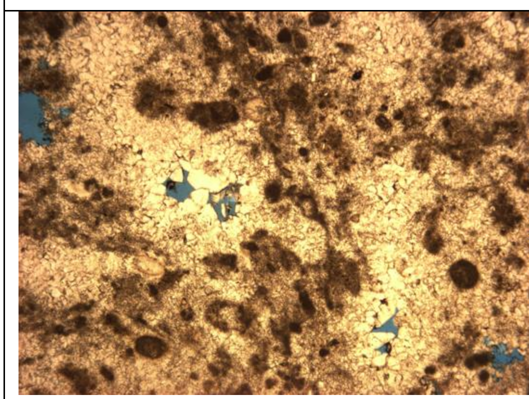
Depth: 11061.5 ft



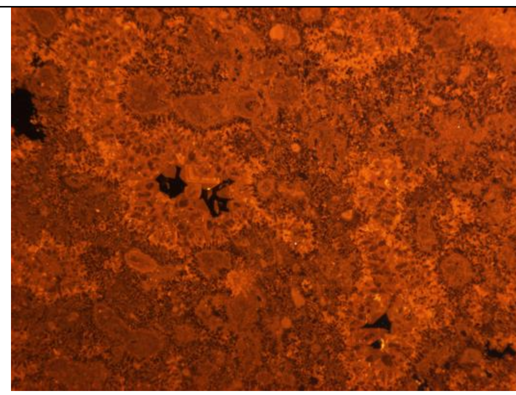
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

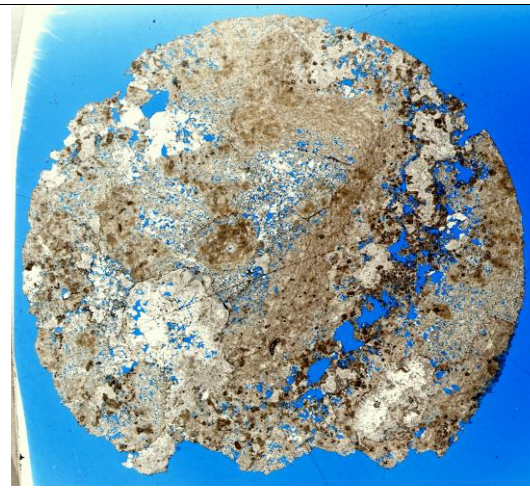
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, presenting 3 zones: orange-yellow – dark brown – light brown luminescence.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, presenting irregular zonation. It presents light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11063 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

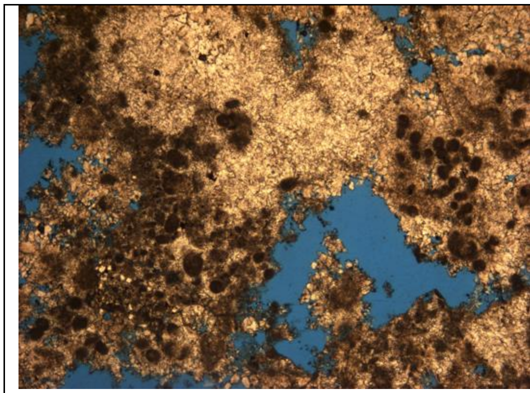
Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and some anhydrite cement. Stylolites occur. Moderate to high recrystallization and cementation. Late dissolution.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 13%

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11063 ft

<table>
<tr><td>
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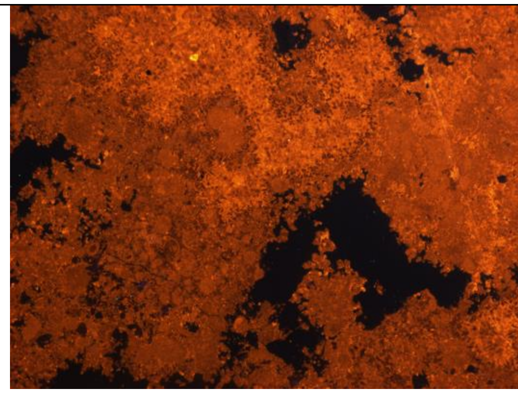
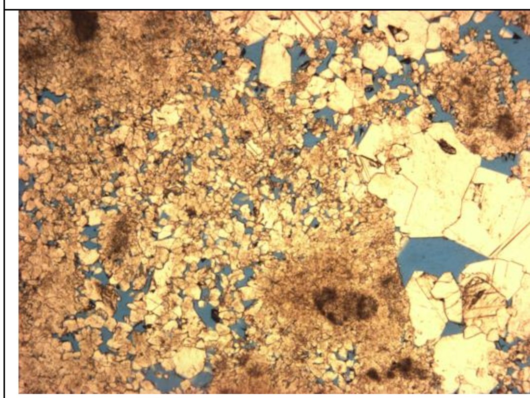
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
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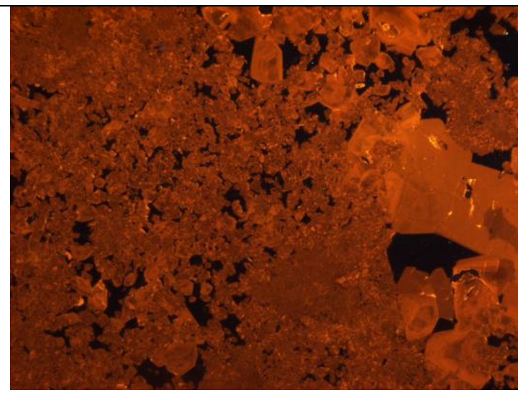
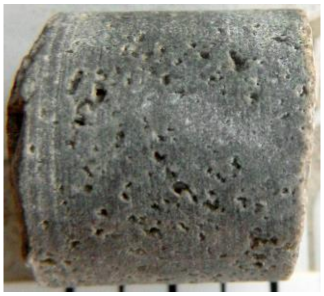
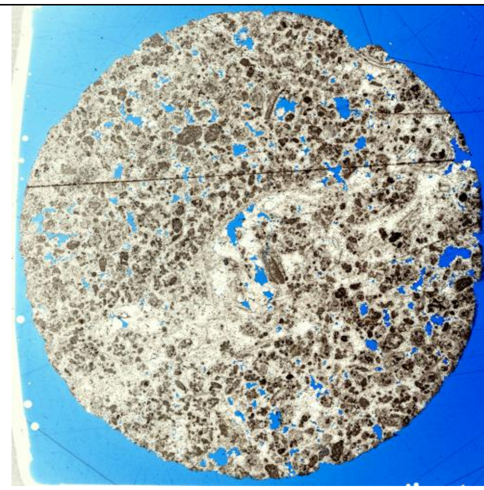
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, light brown to orange-yellow luminescent.
Mosaic calcite cement, light brown to orange-yellow luminescence.
Blocky calcite cement, presenting irregular zonation. It presents dark brown, light brown and orange-yellow luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, possibly resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11066.7 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

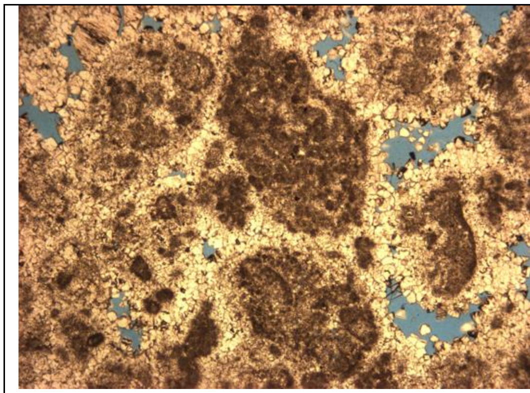
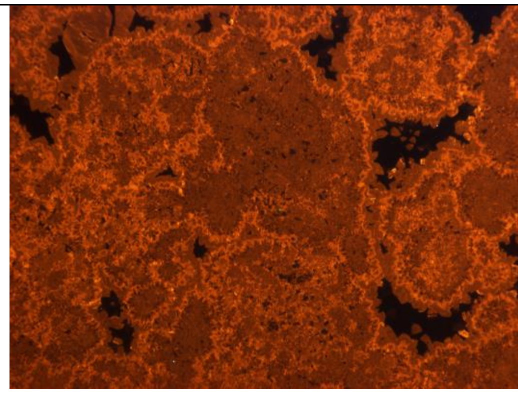
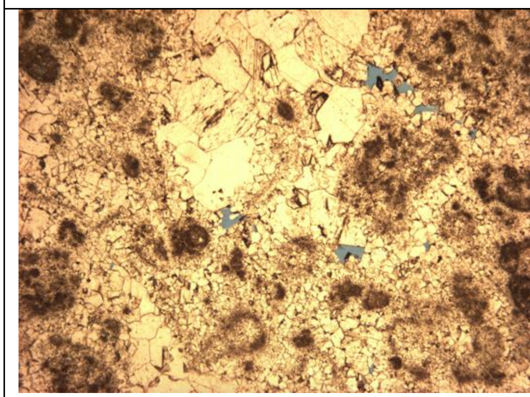
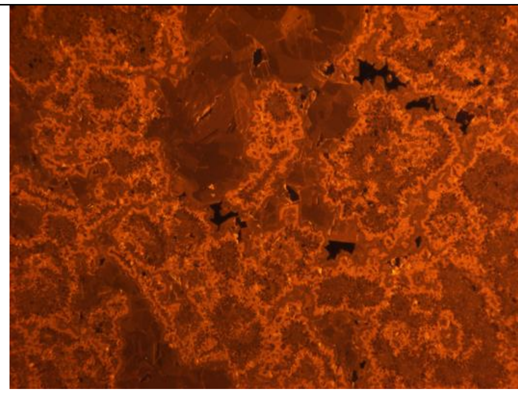
Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera and rare gastropods (?). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and some anhydrite cement.

Pore type: Vuggy.

Porosity (image analysis): 4%

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11066.7 ft

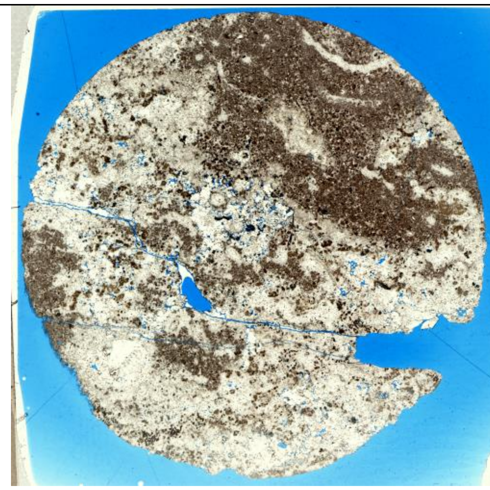
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grain clusters, nonluminescent.
Drusy calcite fringe cement rimming the grains, presenting 2 zones: orange-yellow – light brown luminescence.
Mosaic calcite cement, light brown luminescent.
Blocky calcite cement, presenting irregular zonation. It presents dark brown to light brown luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11080.3 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

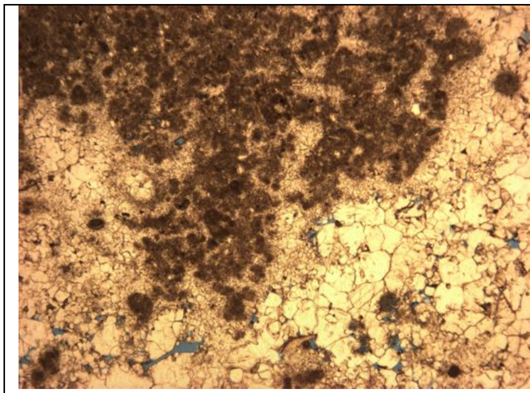
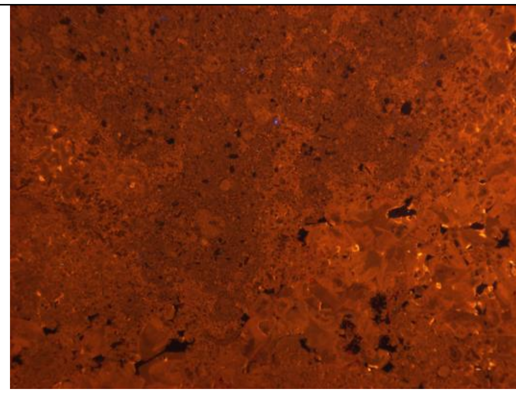
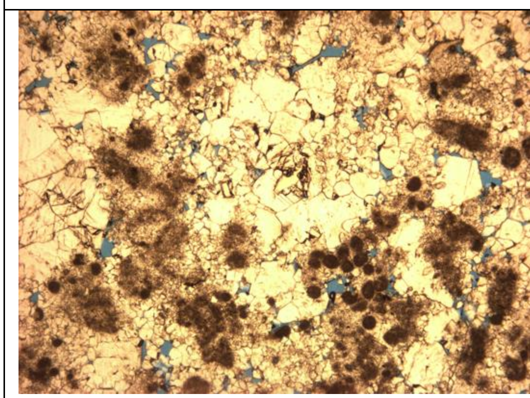
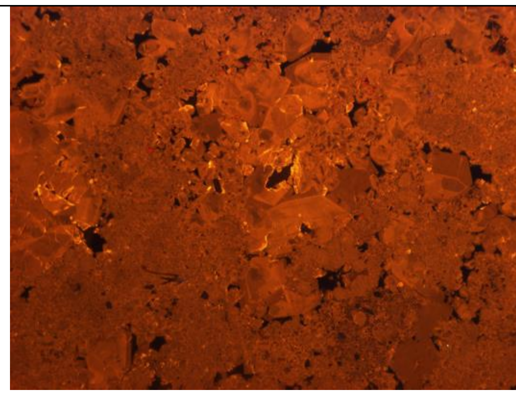
Description: Peloidal thrombolite, with some bioclasts. Some silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera. Part of the rock is composed by very densely clustered peloids. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and some anhydrite cement. Fractures occur. Moderate to high recrystallization and cementation. Rare dolomite.

Pore type: Intercrystalline, vuggy, and fracture.

Porosity (image analysis): 6%

Little Cedar Creek Field **Well: 23** **Permit: 15413**

Depth: 11080.3 ft

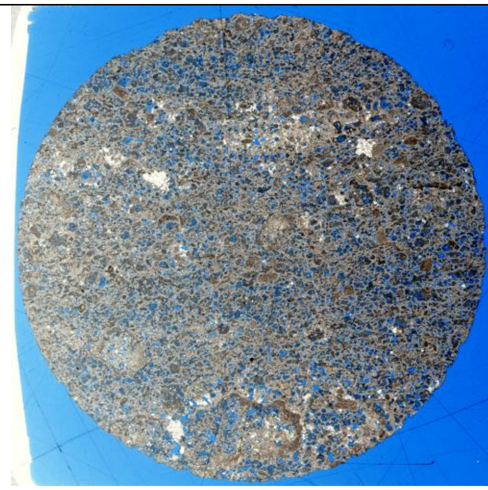
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, light brown to orange-yellow luminescent.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, presenting irregular zonation. It presents light brown to orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

Little Cedar Creek Field **Well: 24** **Permit: 15418**

Depth: 11079.6 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">Lithology: Fine to medium sand peloidal-oolitic grainstone

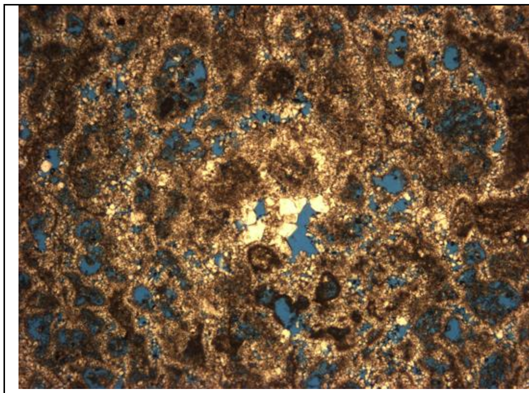
Description: Peloidal-oolitic grainstone, fine to medium sand size, with some coarse sand intraclasts and skeletal fragements, locally bioturbated. Rare very fine to fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement, anhydrite as a replacing phase, oolite dissolution, some grains elongated by compaction.

Pore type: Intergranular, intragranular, moldic, and rare vuggy.

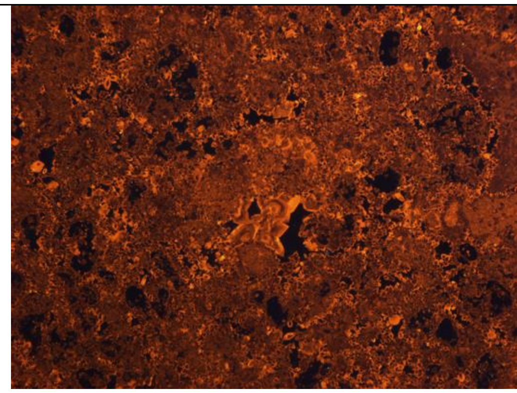
Porosity (image analysis): 15%</td>
</tr>
</table>

Little Cedar Creek Field **Well: 24** **Permit: 15418**

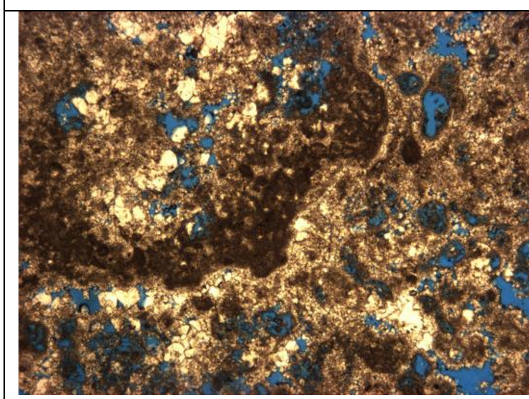
Depth: 11079.6 ft



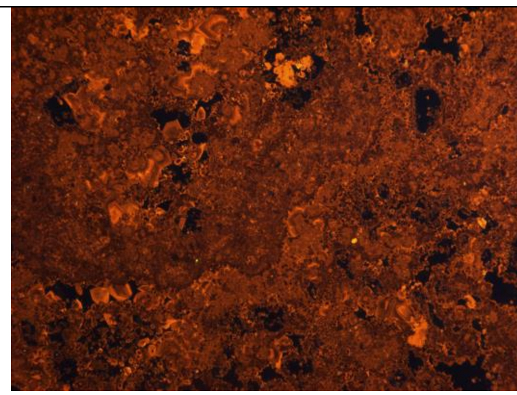
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.
Very fine to fine mosaic calcite cement, light brown luminescent.
Blocky calcite cement, zoned (up to 5 zones). The zones present the following order: light brown – dark brown – orange-yellow – dark to light brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 24** **Permit: 15418**

Depth: 11081 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Very fine to fine peloidal grainstone.

Description: Peloidal grainstone, very fine to fine sand size, with some medium to coarse sand skeletal fragements. Bioclasts are equinoids (with sintaxial calcite cement), benthic foraminifera, and ostracods. Rare very fine to fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement. Intense cementation.

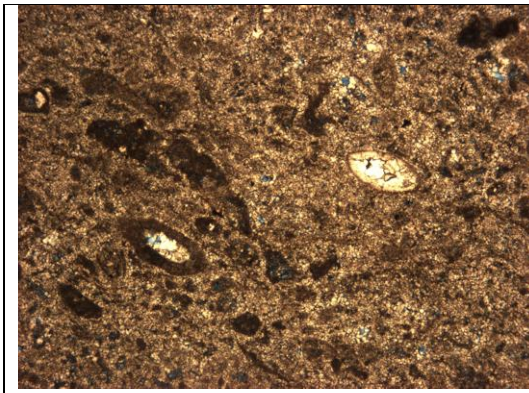
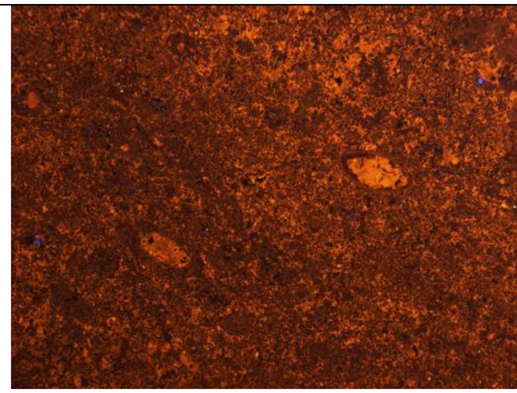
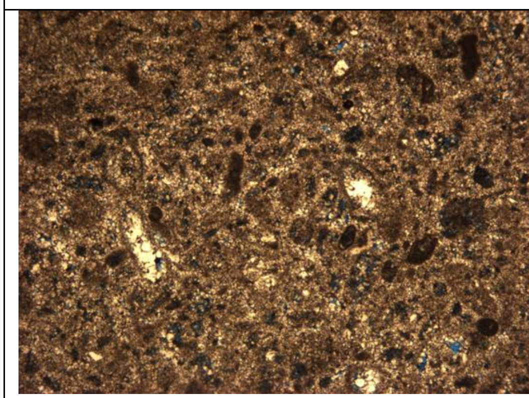
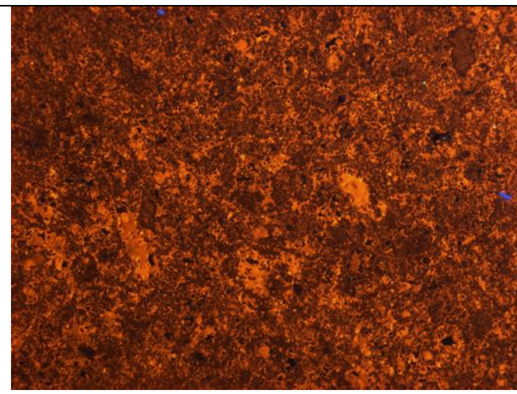
Pore type: Intercrystalline and intragranular.

Porosity (image analysis): 6%

</td>
</tr>
</table>

Little Cedar Creek Field **Well: 24** **Permit: 15418**

Depth: 11081 ft

	
Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	Cathodoluminesce image – same field of the picture on the left side
	
Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	Cathodoluminesce image – same field of the picture on the left side

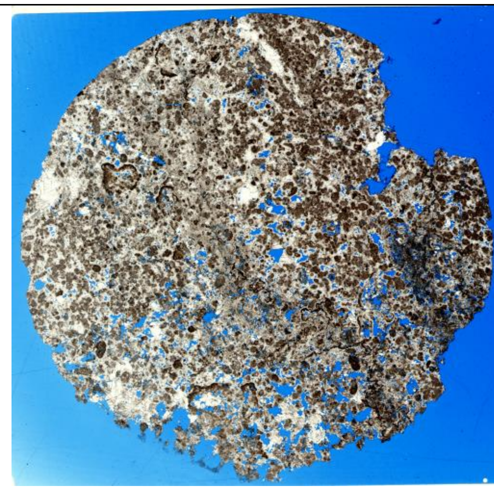
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.
Very fine to fine mosaic calcite cement, light brown to orange-yellow luminescence.
Blocky calcite cement, presenting orange-yellow luminescence.

Little Cedar Creek Field **Well: 24** **Permit: 15418**

Depth: 11132.3 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

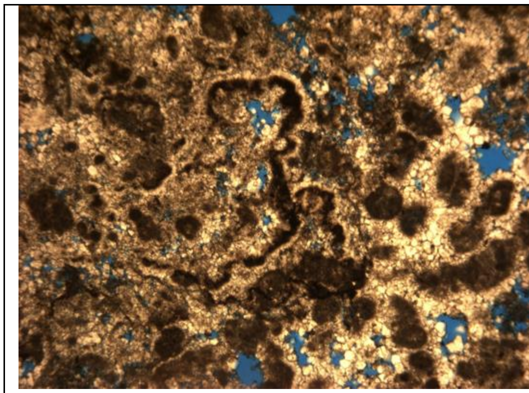
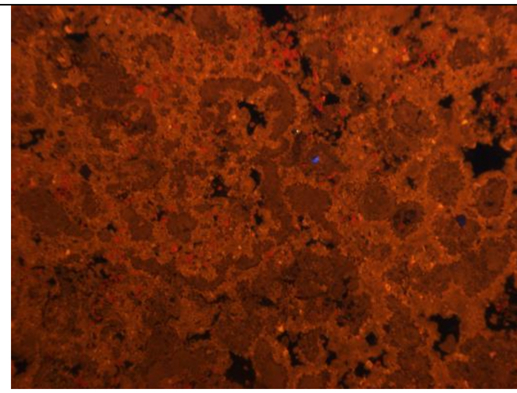
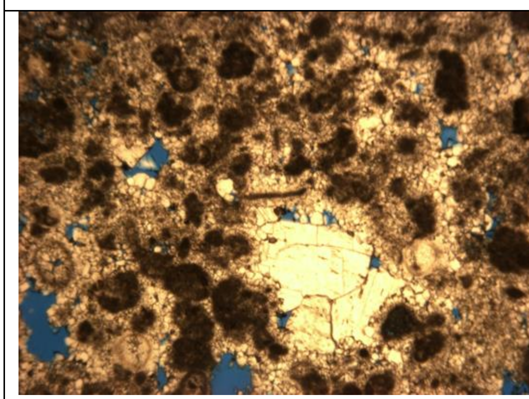
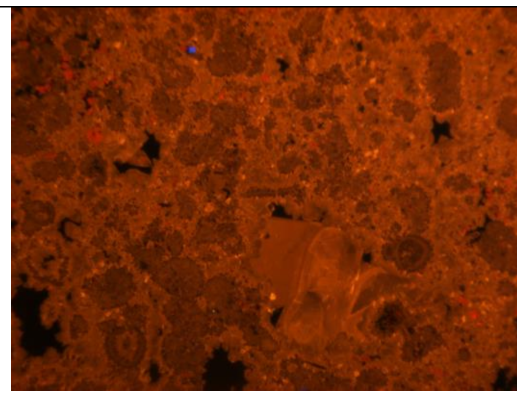
Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Some filamentous features occur. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, and rare anhydrite cement. Fractures and rare stylolite occur. Some primary growth framework vugs enlarged by dissolution. Rare dolomite.

Pore type: Vuggy.

Porosity (image analysis): 14%

Little Cedar Creek Field **Well: 24** **Permit: 15418**

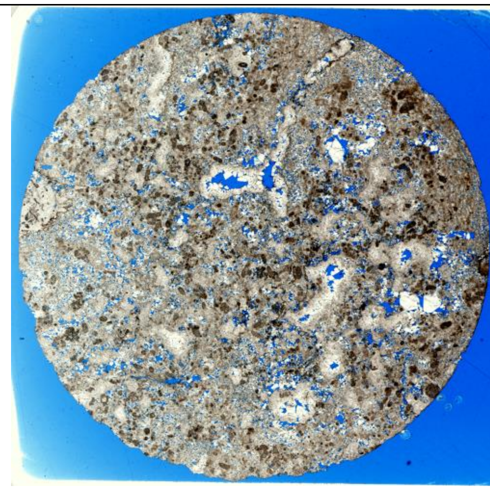
Depth: 11132.3 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, presenting light brown luminescence.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, presenting irregular zonation. It presents dark to light brown and orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

Little Cedar Creek Field **Well: 24** **Permit: 15418**

Depth: 11135.6 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

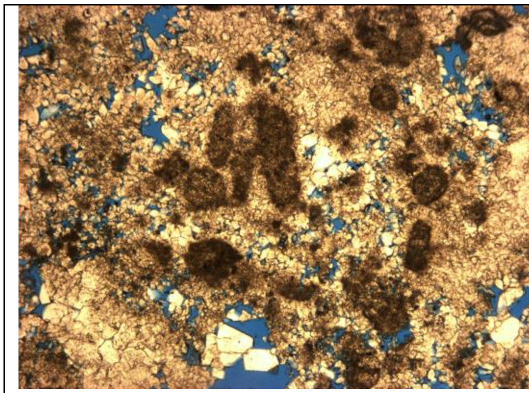
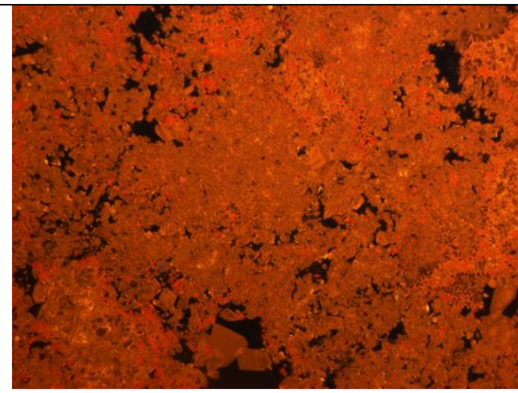
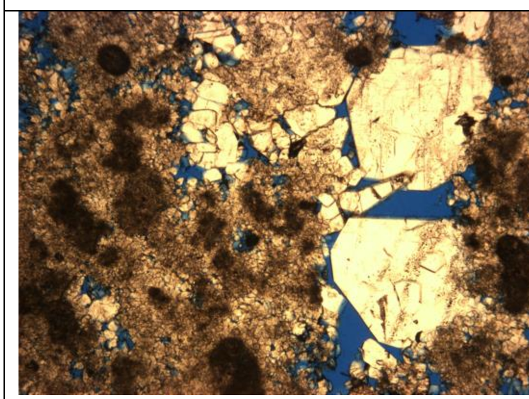
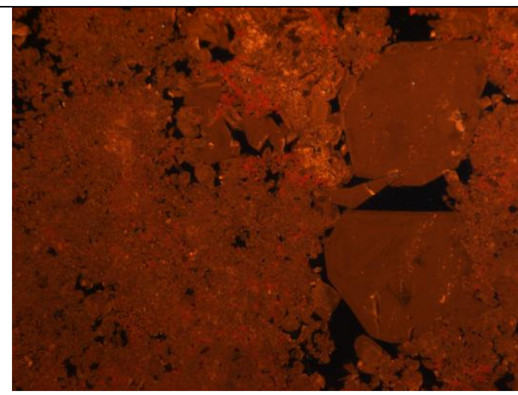
Description: Peloidal thrombolite, with some bioclasts. Rare silt to very fine sand size quartz grains occur. The bioclasts are benthic foraminifera. Peloid clusters are common. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Rare dolomite. Moderate to high recrystallization and calcite cementation.

Pore type: Intercrystalline and vuggy.

Porosity (image analysis): 15%

Little Cedar Creek Field **Well: 24** **Permit: 15418**

Depth: 11135.6 ft

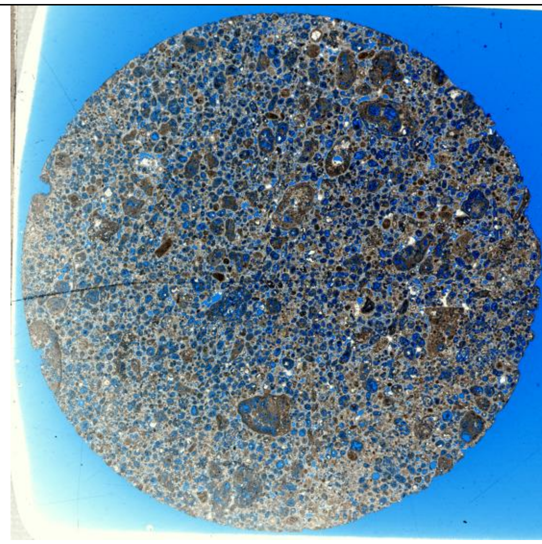
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Mosaic calcite cement, light brown to orange-yellow luminescence.
Blocky calcite cement, presenting light brown luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, possibly resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.
Euhedral to subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. It represents less than 1% of the rock.

Little Cedar Creek Field **Well: 25** **Permit: 15493**

Depth: 10958.5 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Fine to medium oolitic-oncolitic grainstone.

Description: Oolitic-oncolitic grainstone, fine to medium sand size, with some coarse to very coarse sand oncolites, grapestones, and skeletal fragments. Bioclasts are green algae and gastropods (?). Rare very fine to fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement, rare anhydrite cement, oolite dissolution, no compaction features.

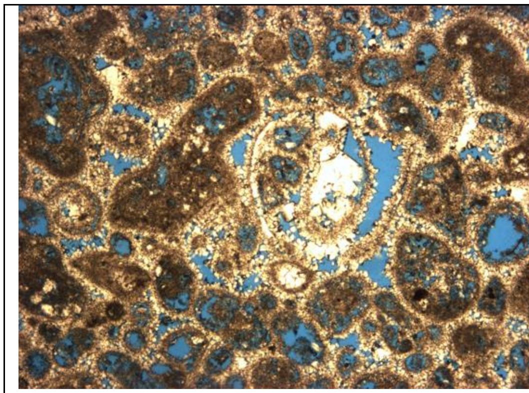
Pore type: Intergranular, intragranular, and moldic.

Porosity (image analysis): 23%

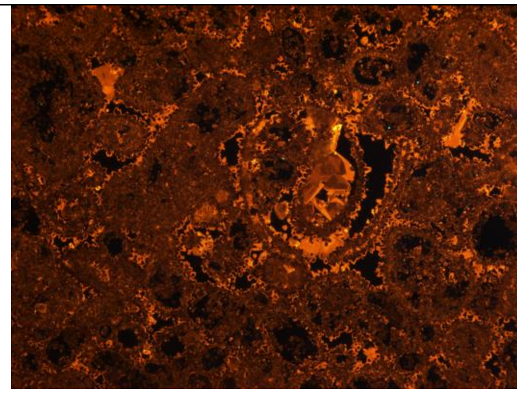
</td>
</tr>
</table>

Little Cedar Creek Field **Well: 25** **Permit: 15493**

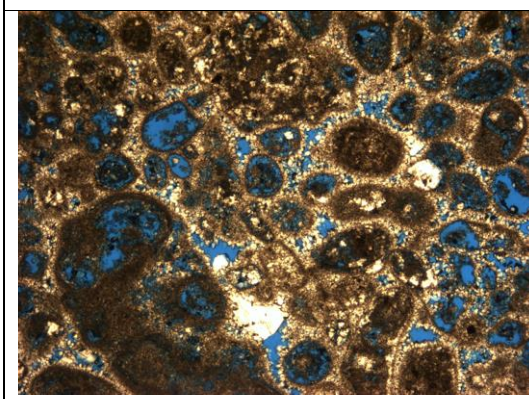
Depth: 10958.5 ft



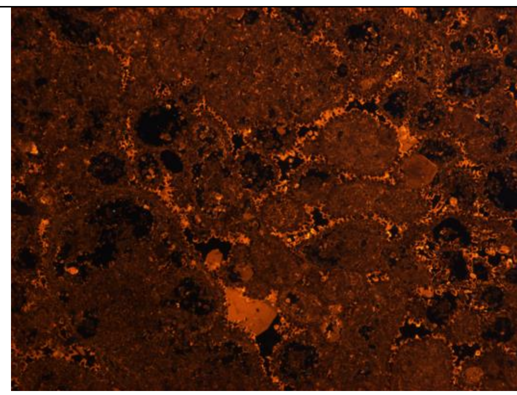
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

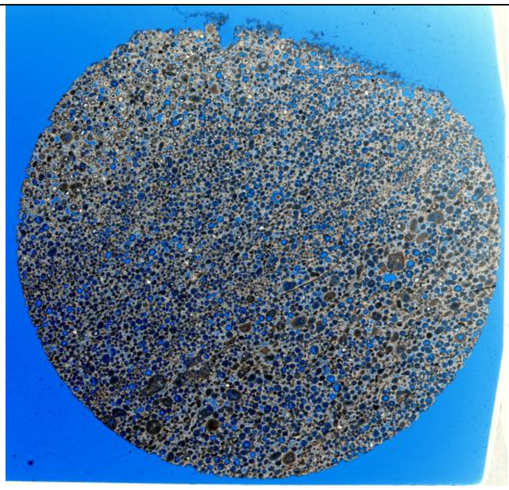
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.

Very fine to fine mosaic calcite cement, light brown luminescent.

Blocky calcite cement, zoned (up to 3 zones). The zones present the following order: light brown – dark brown – orange-yellow.

Little Cedar Creek Field **Well: 25** **Permit: 15493**

Depth: 10966.3 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Fine to medium sand oolitic-oncolitic grainstone.

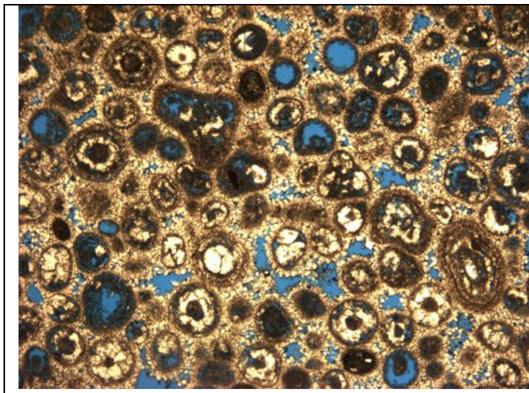
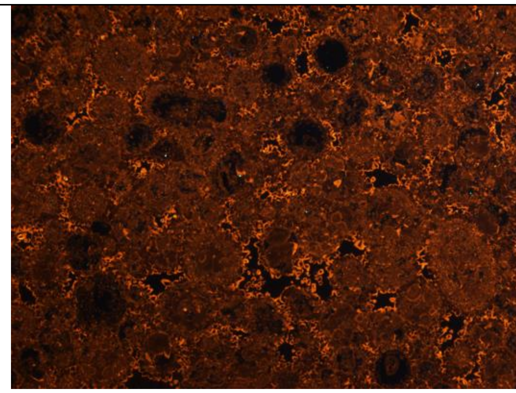
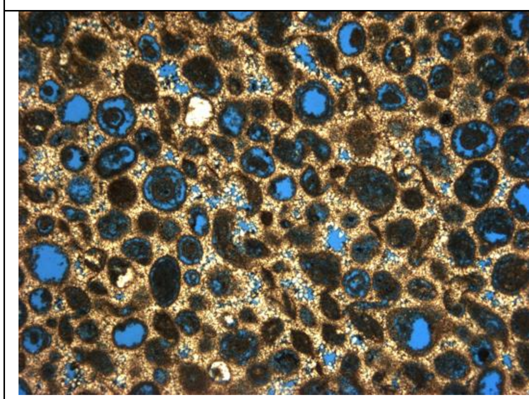
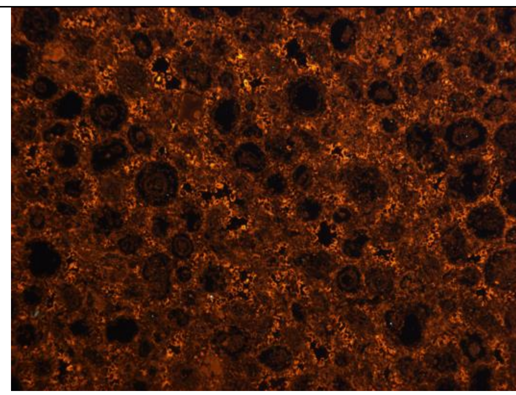
Description: Oolitic-oncolitic grainstone, fine to medium sand size, with some coarse sand oncolites. Rare very fine to fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement, oolite dissolution, no compaction features.

Pore type: Moldic, intragranular, and intergranular.

Porosity (image analysis): 30%

Little Cedar Creek Field **Well: 25** **Permit: 15493**

Depth: 10966.3 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

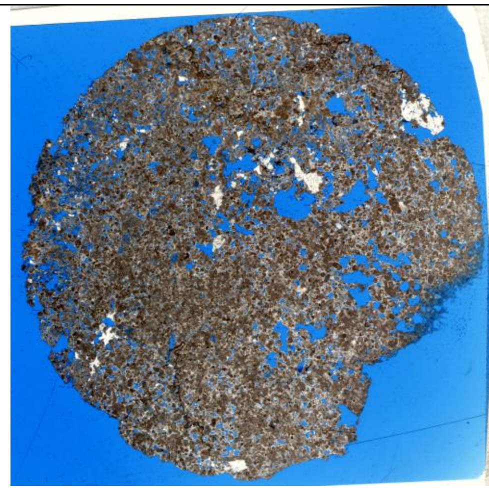
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.
Very fine to fine mosaic calcite cement, light brown luminescent.
Blocky calcite cement, presenting dark brown luminescence. The blocky calcite occurs in moldic porosity.

Little Cedar Creek Field **Well: 25** **Permit: 15493**

Depth: 10996.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

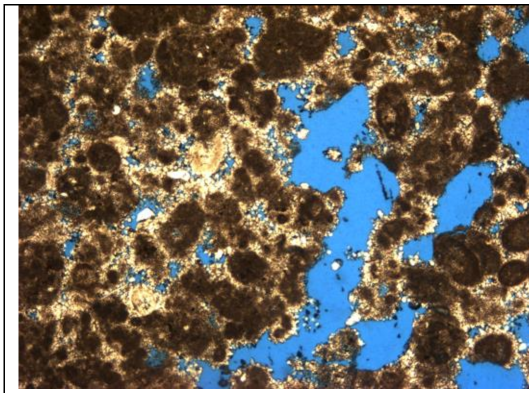
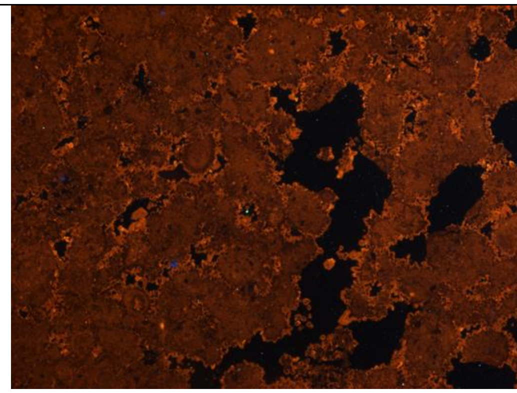
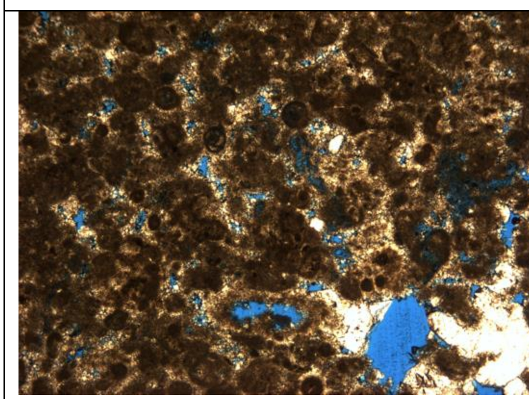
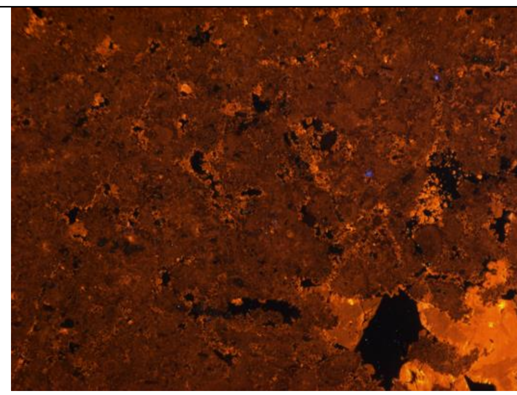
Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Some discontinuous stylolites and fractures occur. Primary growth framework vugs enlarged by dissolution.

Pore type: Vuggy and intergranular.

Porosity (image analysis): 18%

Little Cedar Creek Field **Well: 25** **Permit: 15493**

Depth: 10996.8 ft

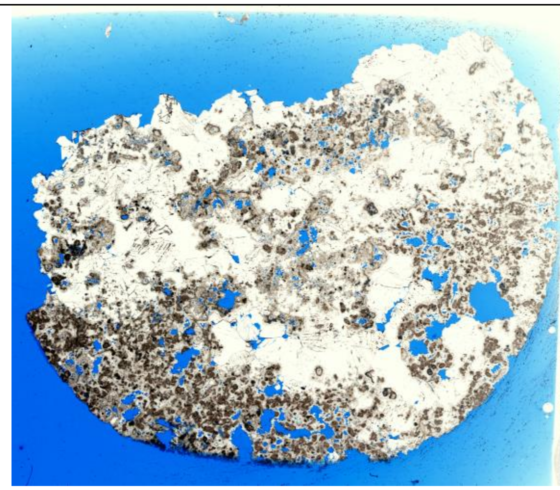
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (up to 4 zones): dark brown to nonluminescent – light brown – orange-yellow – light brown luminescence.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, presenting irregular zonation. It presents dark to light brown and orange-yellow luminescence.

Little Cedar Creek Field **Well: 25** **Permit: 15493**

Depth: 11001ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
</table>

Lithology: Peloidal thrombolite.

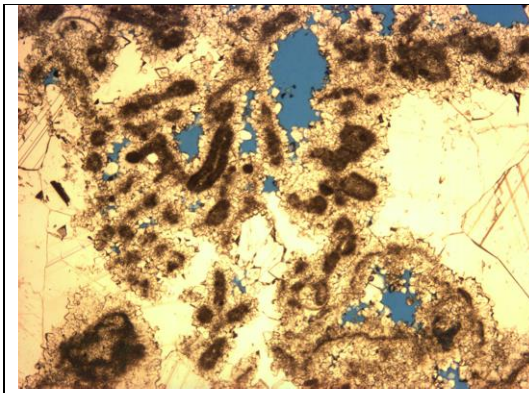
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Some filamentous features. Peloid clusters are common. Diagenesis: fibrous calcite cement rimming grains and peloid clusters, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Primary growth framework vugs enlarged by dissolution. Large amount of blocky calcite cementation.

Pore type: Vuggy.

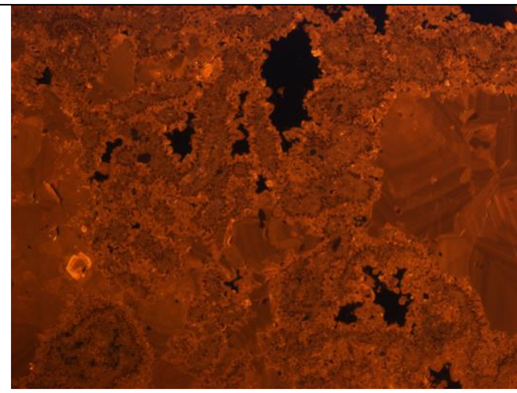
Porosity (image analysis): 7%

Little Cedar Creek Field **Well: 25** **Permit: 15493**

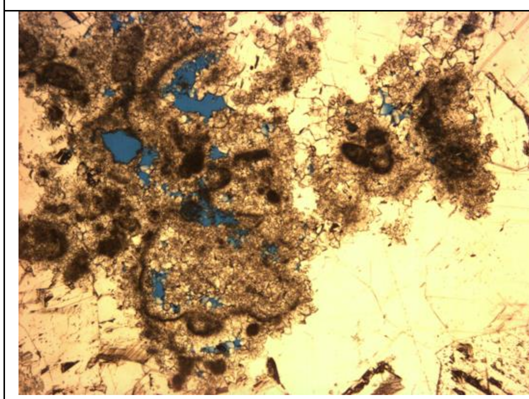
Depth: 11001ft



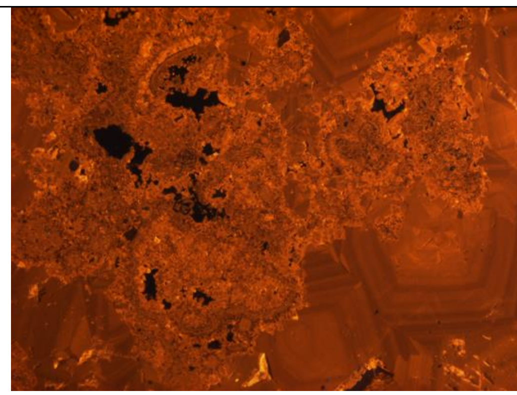
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

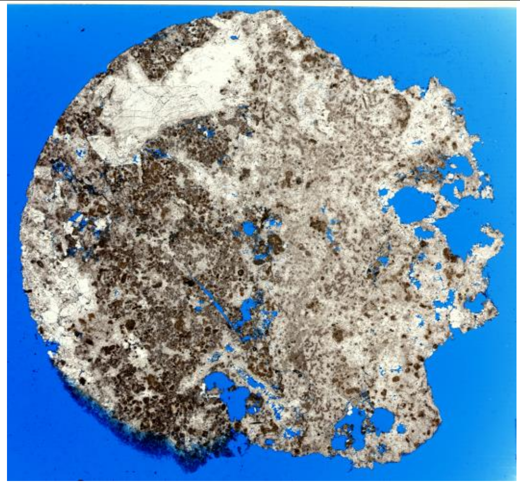
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, presenting light brown luminescence.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, zoned (up to 9 zones). It alternates dark brown and light brown luminescent zones. Some subzones occur.

Little Cedar Creek Field **Well: 25** **Permit: 15493**

Depth: 11011.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

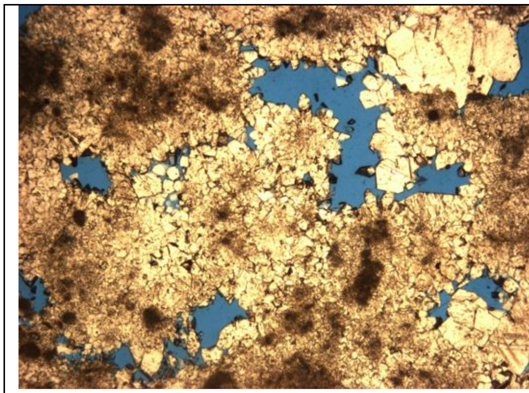
Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz and muscovite grains occur. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Part of the rock present very dense peloid clusters. Some elongated features occur. Diagenesis: fibrous calcite cement rimming peloids and peloid clusters, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Some partially cemented fractures occur. Late dissolution.

Pore type: Vuggy.

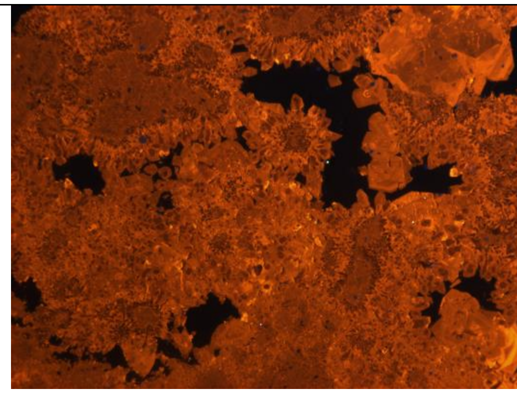
Porosity (image analysis): 7%

Little Cedar Creek Field **Well: 25** **Permit: 15493**

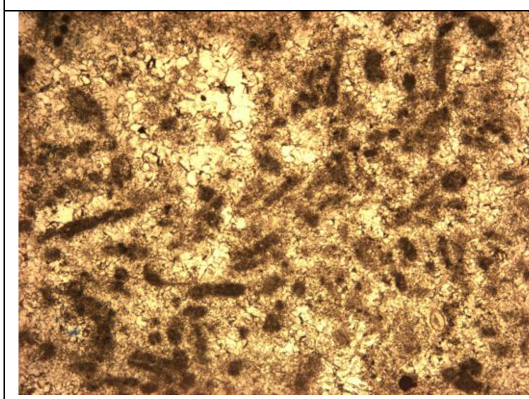
Depth: 11011.4 ft



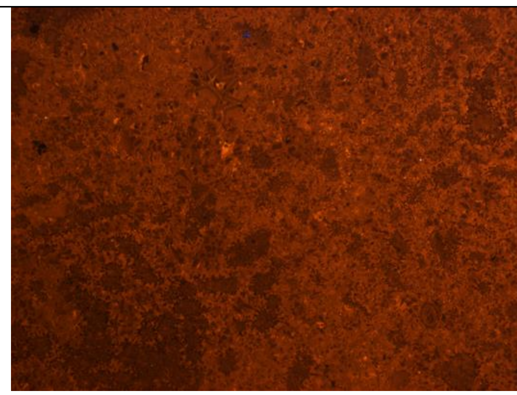
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



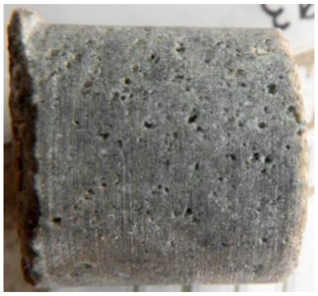
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains zoned (2 zones): dark brown - light brown to orange-yellow luminescence.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, zoned (up to 6 zones): dark brown – light brown – orange-yellow – light brown – orange-yellow – light brown.

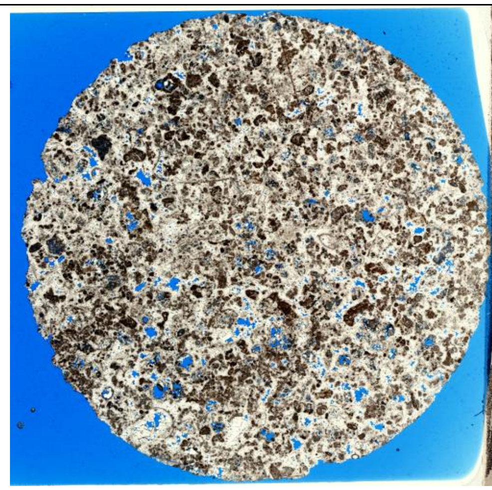
Little Cedar Creek Field **Well: 25** **Permit: 15493**

Depth: 11030.9 ft

Plug – 2.15 cm (diameter)



Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

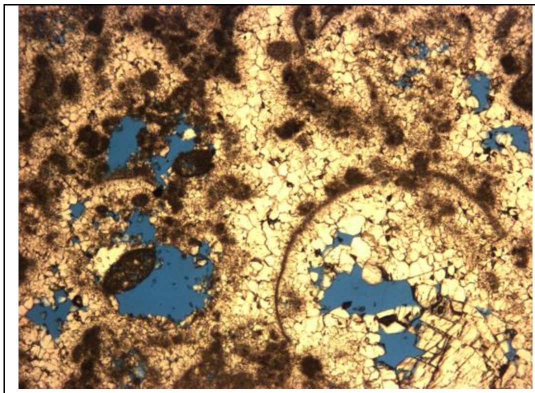
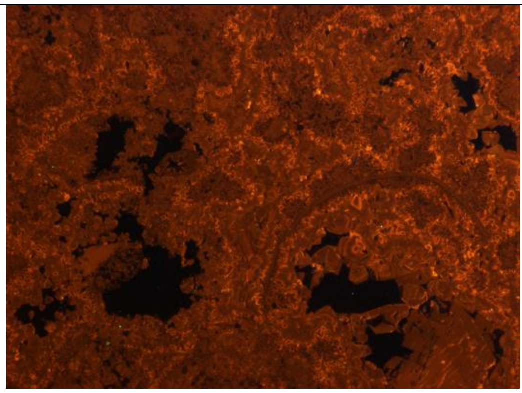
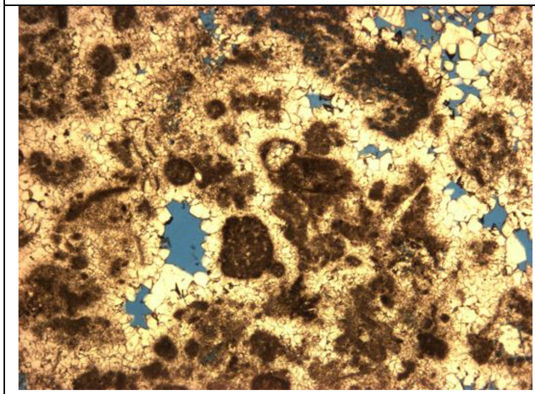
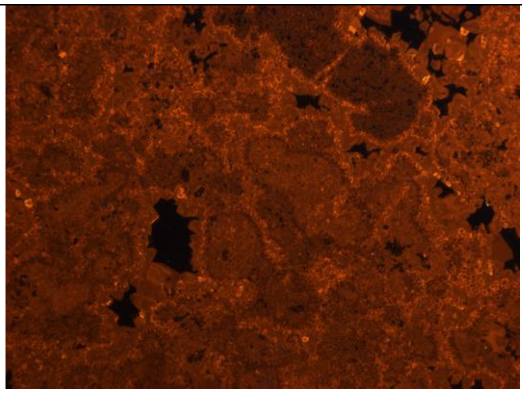
Description: Peloidal thrombolite, with some bioclasts. Silt to fine sand size quartz grains occur. The bioclasts are green algae (?). Peloid clusters are common. Diagenesis: fibrous calcite cement rimming peloids and peloid clusters, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Late dissolution.

Pore type: Vuggy.

Porosity (image analysis): 4%

Little Cedar Creek Field **Well: 25** **Permit: 15493**

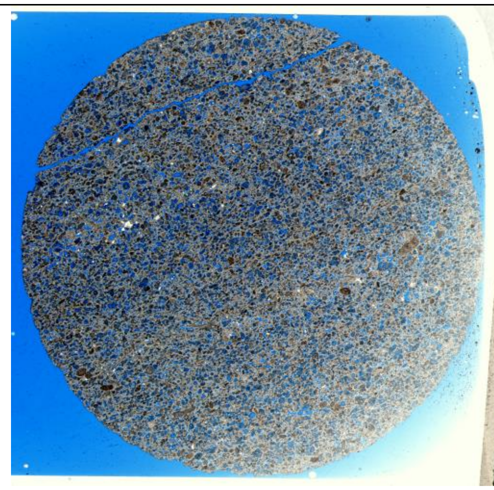
Depth: 11030.9 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones): orange-yellow – light brown luminescence.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, light brown luminescent.

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

Depth: 11102.5 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Very fine to fine peloidal-skeletal grainstone.

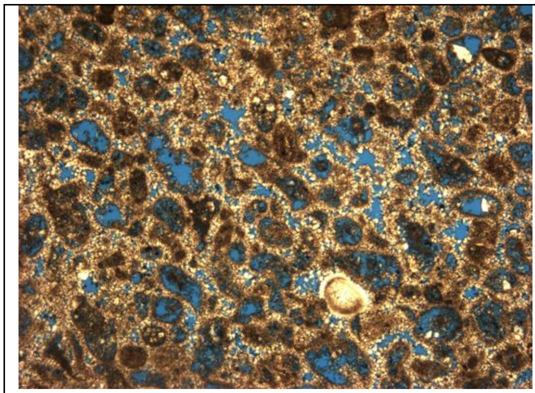
Description: Peloidal-skeletal grainstone, very fine to fine sand size, with some oolites and medium sand size skeletal fragments. Bioclasts are green algae. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement, grains dissolution, no compaction features.

Pore type: Intragranular, moldic, and intergranular.

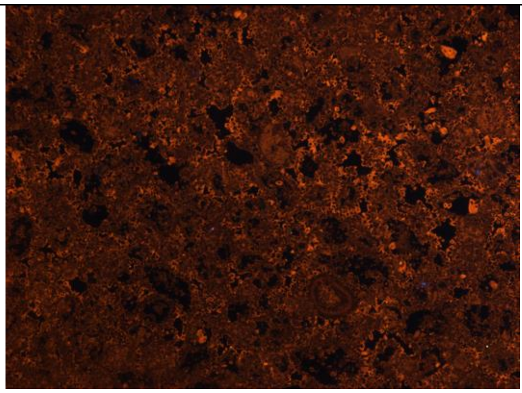
Porosity (image analysis): 28%

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

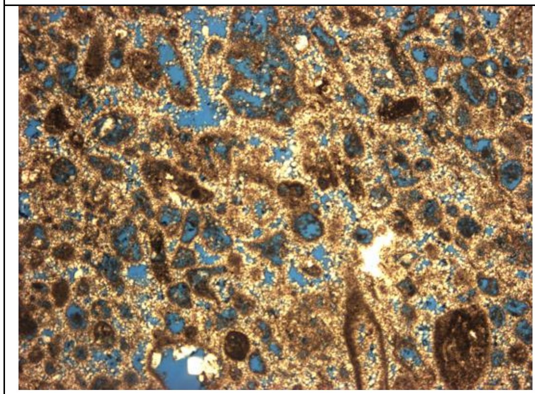
Depth: 11102.5 ft



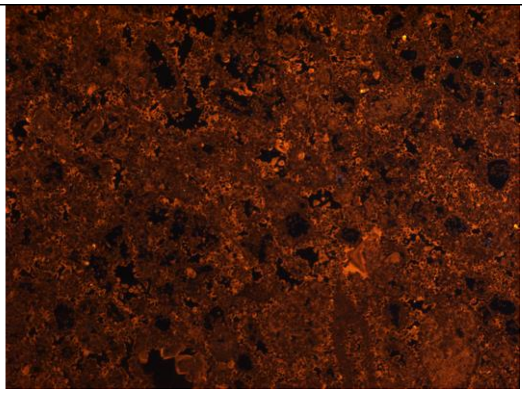
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

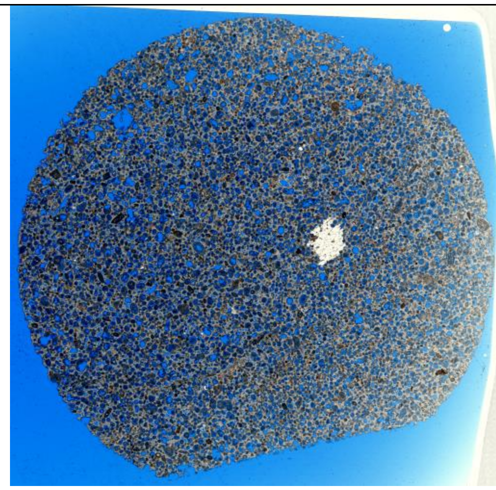
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.
Very fine to fine mosaic calcite cement, light brown luminescent.
Blocky calcite cement, zoned (up to 4 zones): dark brown – light brown – dark brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

Depth: 11108.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to medium sand size oolitic grainstone.

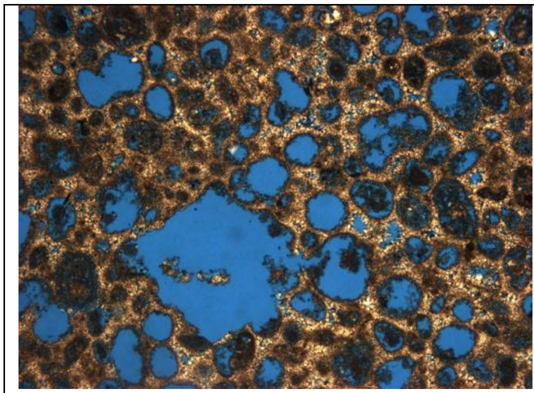
Description: Oolitic grainstone, fine to medium sand size, with some coarse sand size skeletal fragments. Bioclasts are green algae and gastropods (?). Rare very fine to fine quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, fine mosaic calcitic cement, blocky calcite cement, anhydrite as a replacing phase, oolite dissolution, no compaction features.

Pore type: Moldic, intragranular, and vuggy.

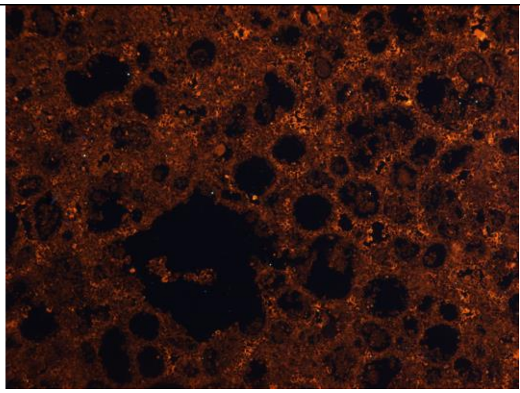
Porosity (image analysis): 33%

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

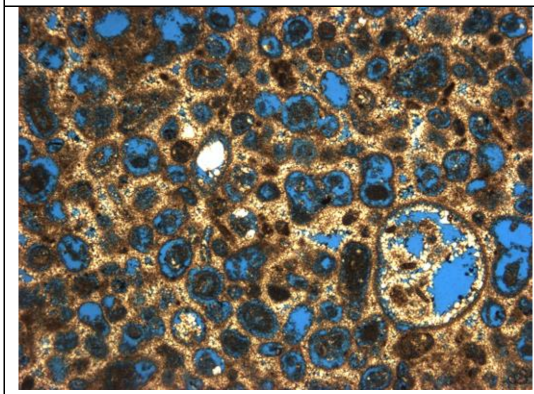
Depth: 11108.5 ft



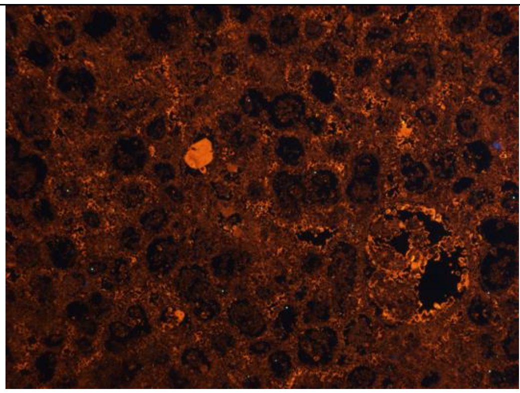
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

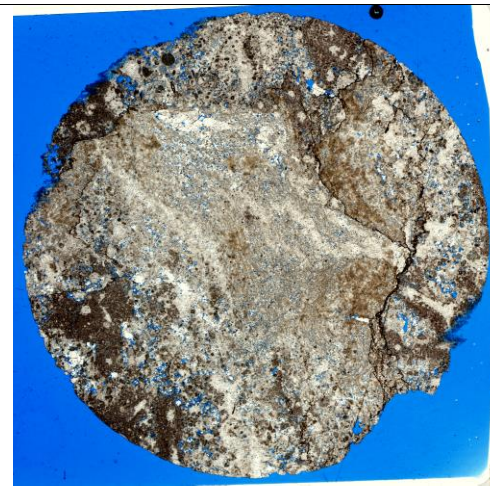


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.
Very fine to fine mosaic calcite cement, light brown luminescent.
Blocky calcite cement, presenting orange-yellow luminescence.

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

Depth: 11165.3 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

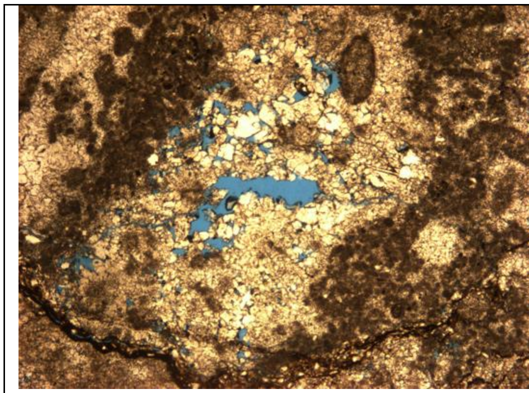
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera. Some parts of the rock present very dense peloid clusters. Diagenesis: fibrous calcite cement rimming grains and peloid clusters, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Rare dolomite. Moderate to high recrystallization and calcite cementation. Stylolites and fractures occur. Late dissolution.

Pore type: Intercrystalline, vuggy, and fractures.

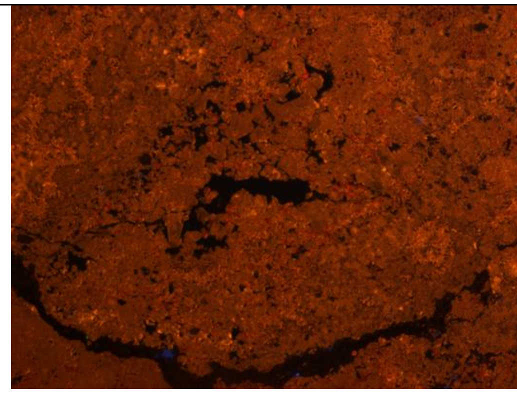
Porosity (image analysis): 4%

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

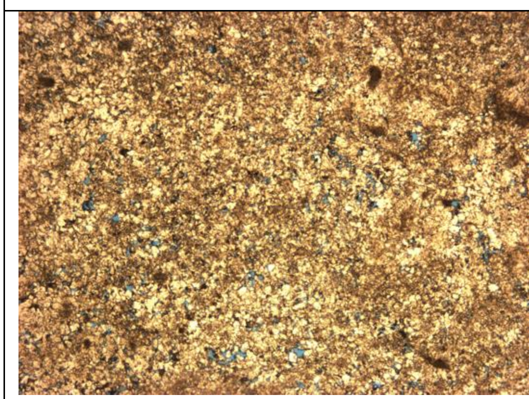
Depth: 11165.3 ft



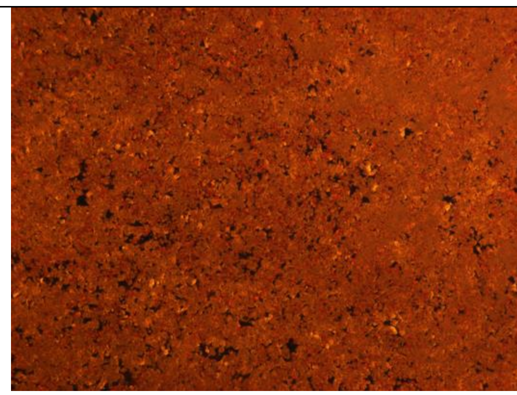
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

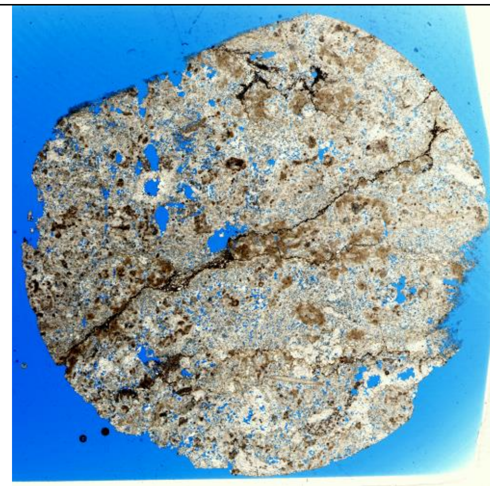


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (3 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone has dark to light brown luminescence and the third zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, possibly resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. The dolomite represents less than 1% of the rock.

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

Depth: 11168.8 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

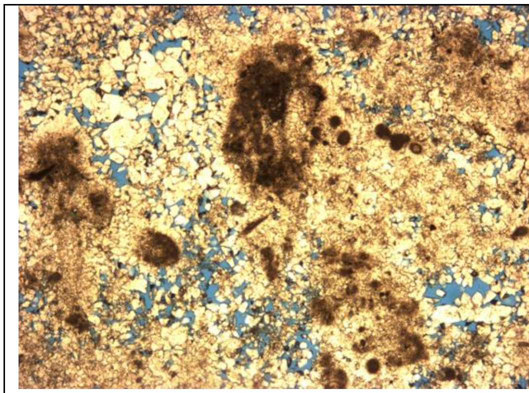
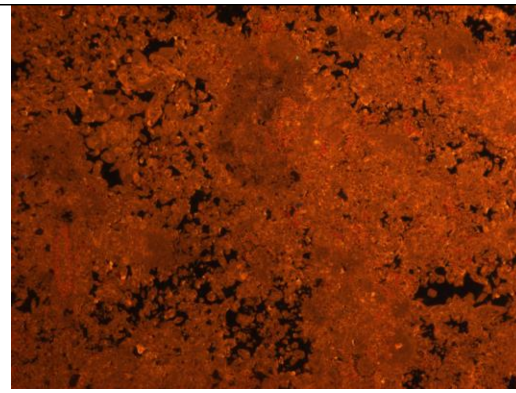
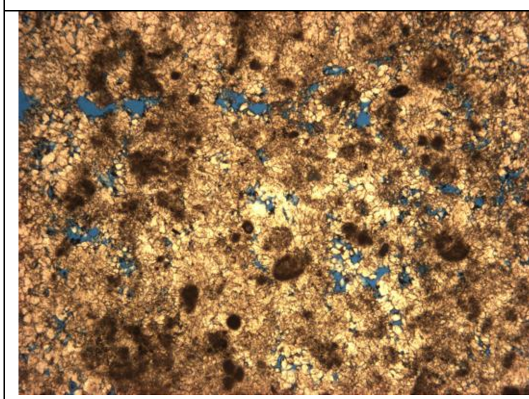
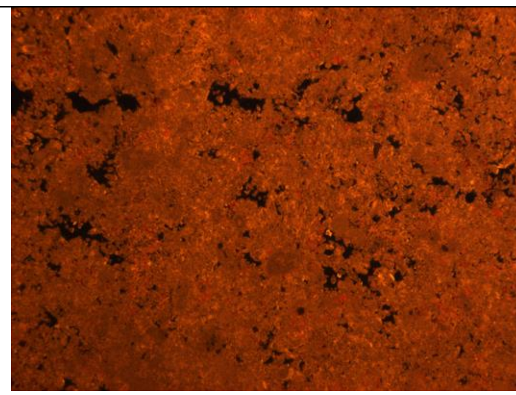
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera, and green algae (?). Some parts of the rock present very dense peloid clusters. Diagenesis: mosaic calcite cement, and blocky calcite cement. Rare dolomite. Moderate to high recrystallization and calcite cementation. Stylolites occur. Late dissolution.

Pore type: Intercrystalline and vuggy.

Porosity (image analysis): 12%

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

Depth: 11168.8 ft

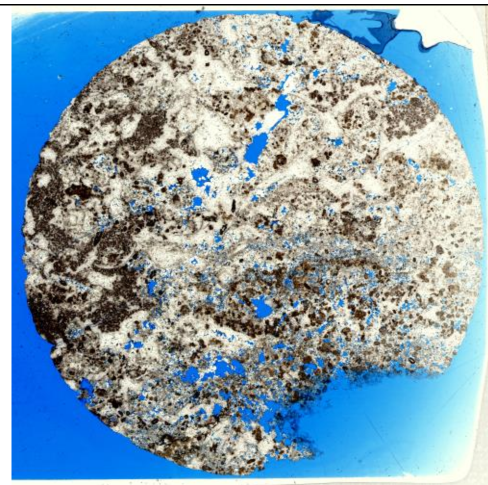
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

Cathodoluminescence image analysis:
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, possibly resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. The dolomite represents less than 1% of the rock.

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

Depth: 11170.3 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)


Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
</table>

Lithology: Peloidal thrombolite.

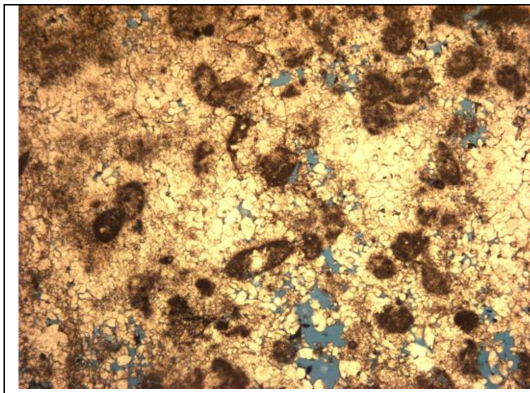
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera, ostracods (with sintaxial cement), and gastropods (?). Some parts of the rock present very dense peloid clusters. Diagenesis: mosaic calcite cement, and blocky calcite cement. Rare dolomite. Moderate to high recrystallization and calcite cementation. Fractures occur. Late dissolution.

Pore type: Vuggy, intercrystalline, and fractures.

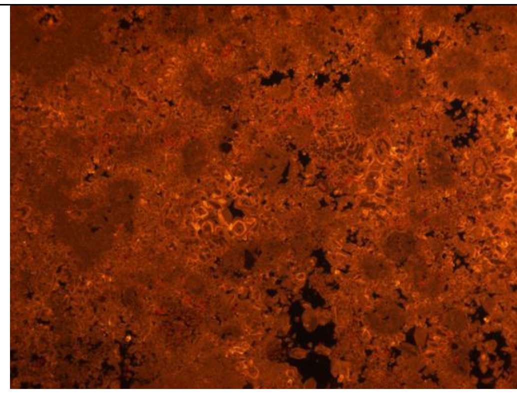
Porosity (image analysis): 6%

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

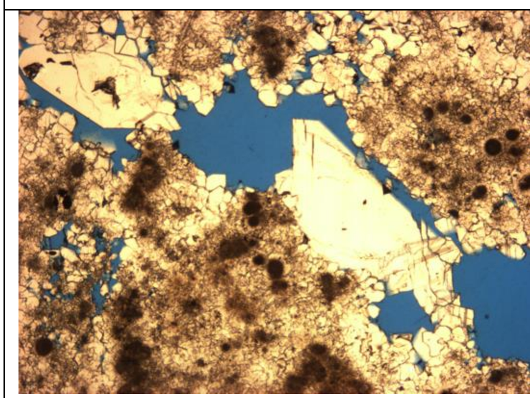
Depth: 11170.3 ft



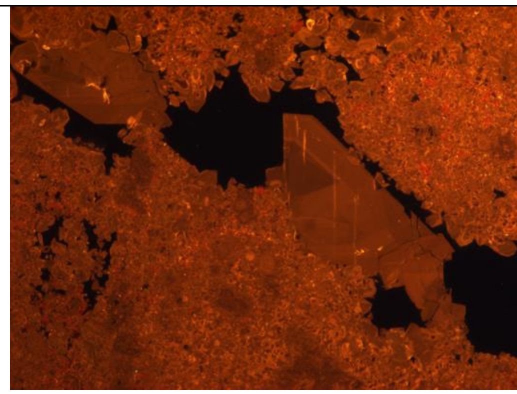
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

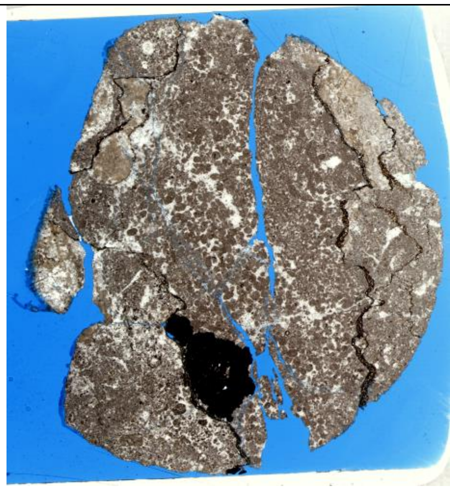


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has light brown luminescence, the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (3 zones): light to dark brown – orange-yellow – light brown luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. The dolomite represents less than 1% of the rock.

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

Depth: 11171.6 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

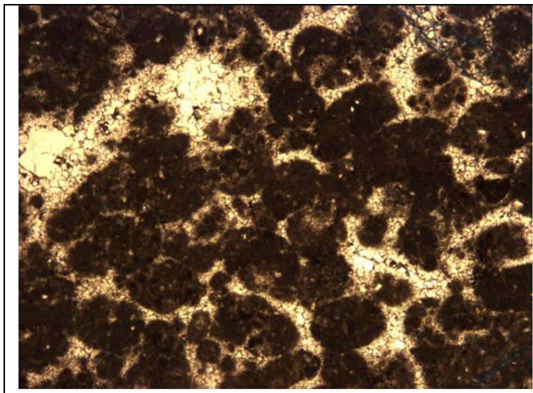
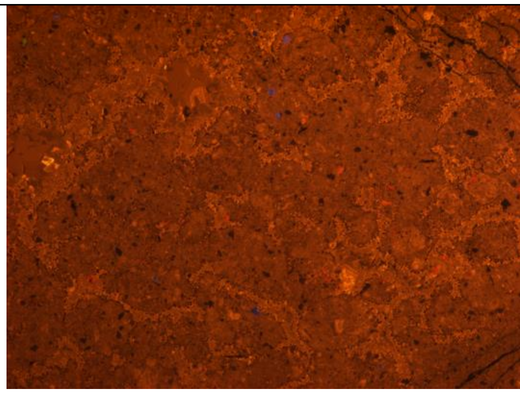
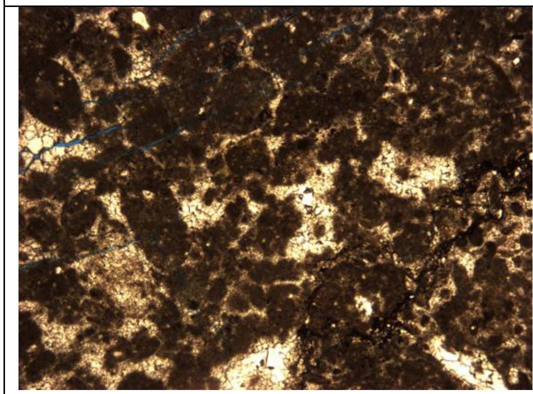
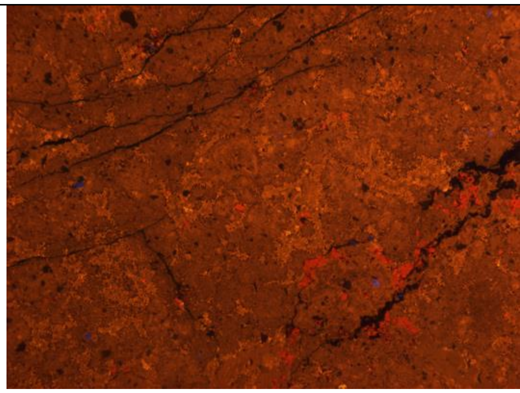
Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera, and green algae (?). Some parts of the rock present very dense peloid clusters. Diagenesis: mosaic calcite cement, and blocky calcite cement. Rare dolomite. Stylolites and pyrite cluster occur. Open fractures cut cemented fractures. Late dissolution.

Pore type: Fractures and vuggy.

Little Cedar Creek Field **Well: 26** **Permit: 15496-B**

Depth: 11171.6 ft

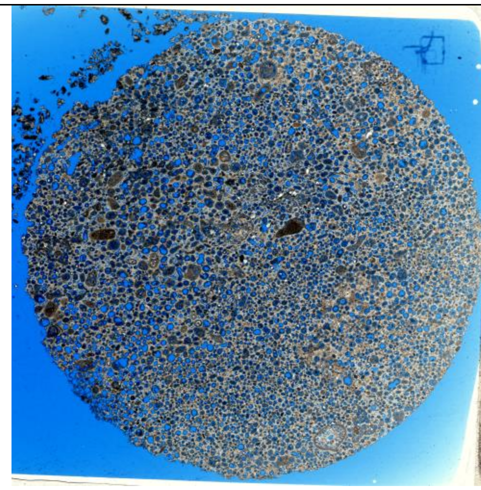
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Blocky calcite cement, presenting light brown luminescence.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence. The dolomite represents less than 1% of the rock.</td></tr>
</table>

Little Cedar Creek Field **Well: 27** **Permit: 15497**

Depth: 10910.3 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to medium sand oolitic-oncolitic grainstone.

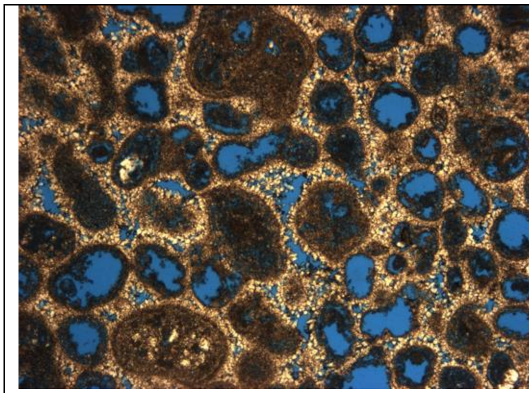
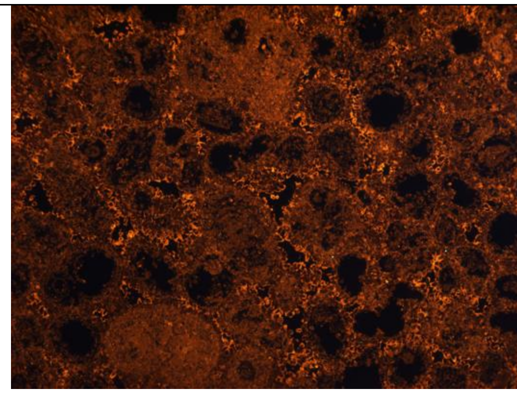
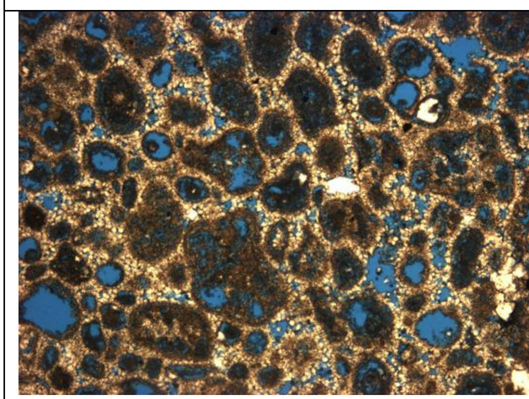
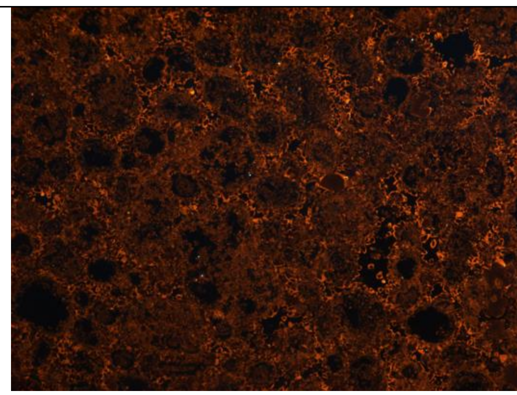
Description: Oolitic-oncolitic grainstone, fine to medium sand size, with some coarse sand size oncolites and skeletal fragments. Bioclasts are benthic foraminifera and echinoid (with sintaxial cement). Some fine sand quartz and muscovite grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, blocky calcite cement, oolite dissolution, no compaction features.

Pore type: Moldic, intragranular, rare intergranular.

Porosity (image analysis): 27%

Little Cedar Creek Field **Well: 27** **Permit: 15497**

Depth: 10910.3 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

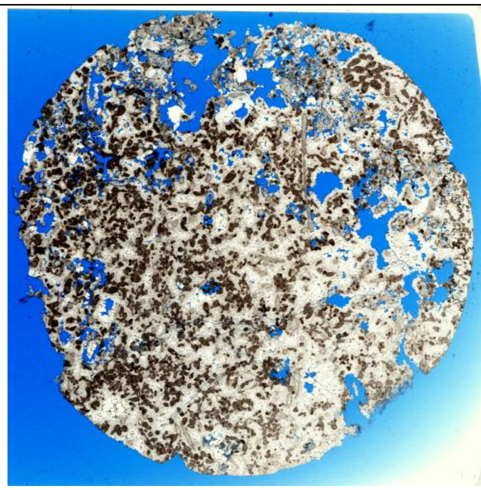
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 27** **Permit: 15497**

Depth: 10954.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

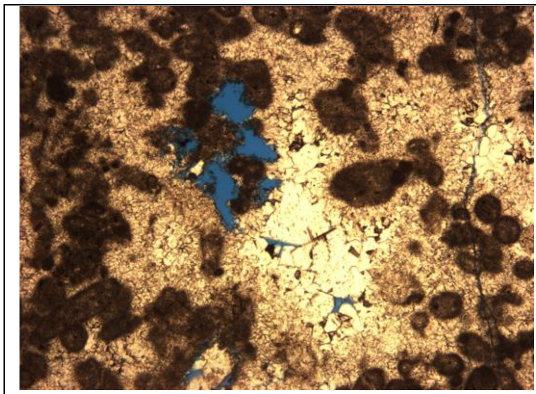
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera, ostracods (with sintaxial cement), green algae (?), and gastropods (?). Some elongated features. Diagenesis: fibrous calcite cement rimming grains, drusy calcite cement rimming grains, mosaic calcite cement, and blocky calcite cement. High calcite cementation. Small discontinuous fractures occur. Late dissolution.

Pore type: Vuggy and fractures.

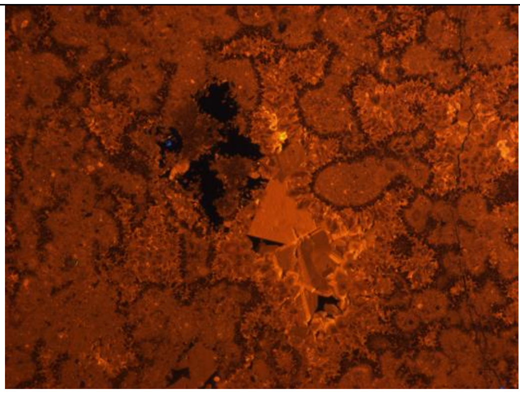
Porosity (image analysis): 13%

Little Cedar Creek Field **Well: 27** **Permit: 15497**

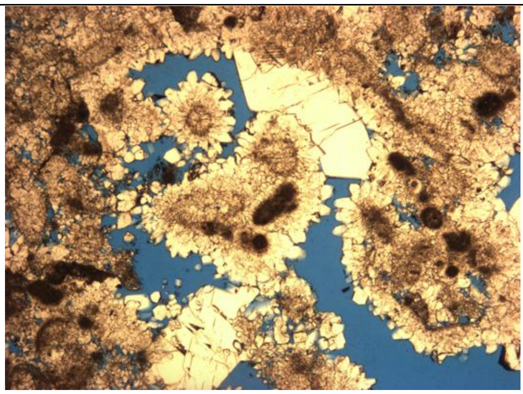
Depth: 10954.8 ft



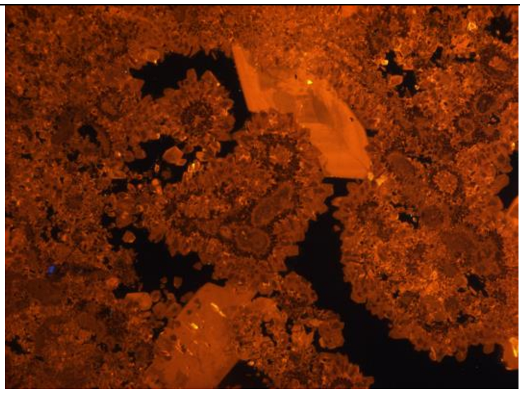
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

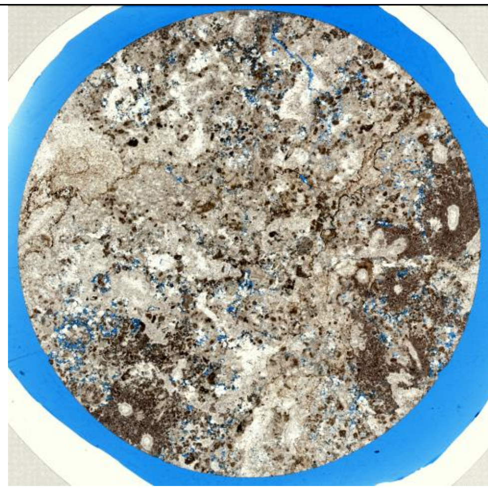
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (3 zones): dark brown – light brown – orange-yellow luminescence. Some crystals are not zoned, presenting orange-yellow luminescence.

Little Cedar Creek Field **Well: 27** **Permit: 15497**

Depth: 10956.3 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloids clusters.

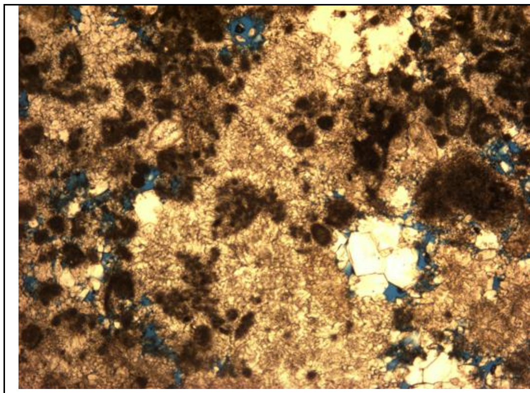
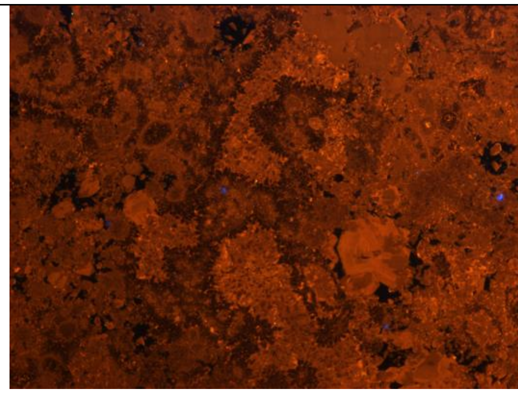
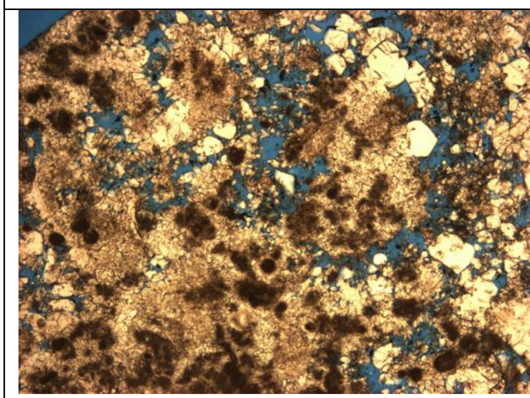
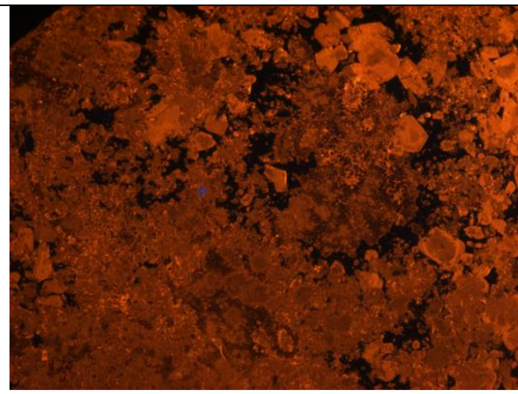
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera, ostracods (with sintaxial cement), green algae (?). Some parts of the rock present very dense peloid clusters. Diagenesis: fibrous calcite cement rimming grains, drusy calcite cement rimming grains, mosaic calcite cement, and blocky calcite cement. Moderate to high calcite recrystallization and cementation. Stylolites occur. Late dissolution.

Pore type: Vuggy, intercrystalline, and channel.

Porosity (image analysis): 3%

Little Cedar Creek Field **Well: 27** **Permit: 15497**

Depth: 10956.3 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

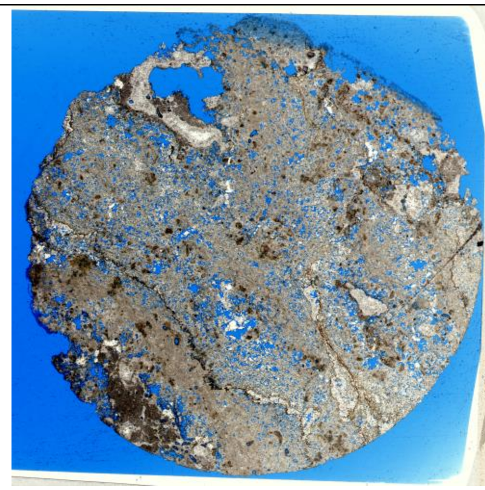
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, nonluminescent, occurs locally.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 27** **Permit: 15497**

Depth: 10960.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

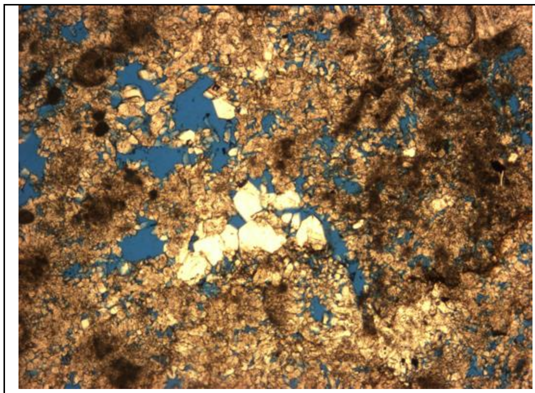
Description: Peloidal thrombolite. Parts of the rock present very dense peloid clusters. Diagenesis: mosaic calcite cement, and blocky calcite cement. High calcite recrystallization and cementation. Stylolites occur. Late dissolution.

Pore type: Intercrystalline and vuggy.

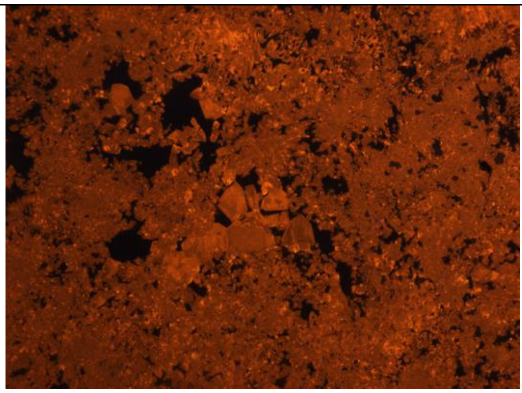
Porosity (image analysis): 14%

Little Cedar Creek Field **Well: 27** **Permit: 15497**

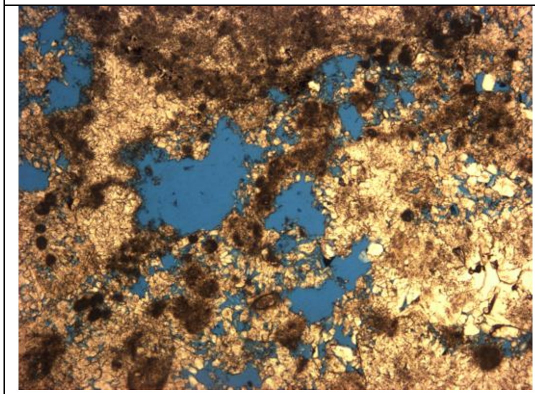
Depth: 10960.5 ft



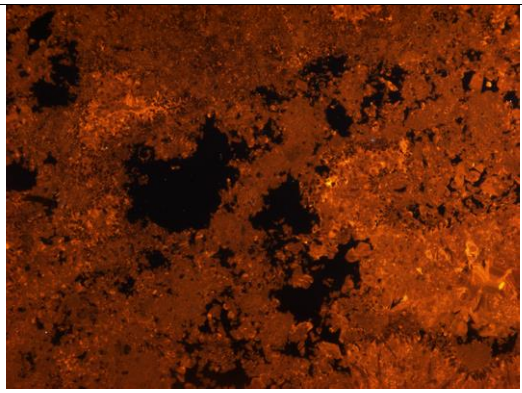
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

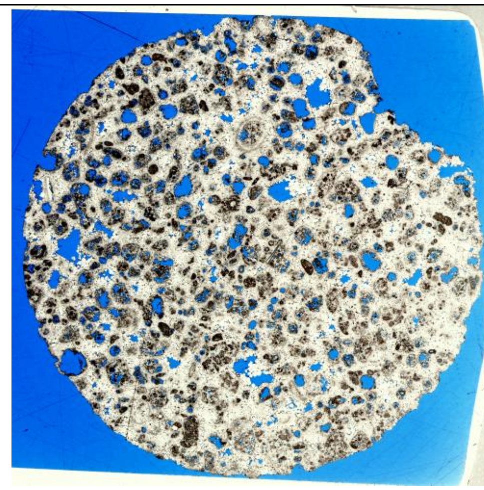
Cathodoluminescence image analysis:
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence and dark brown – light brown luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, possibly resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 27** **Permit: 15497**

Depth: 10979.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to medium sand intraclastic grainstone.

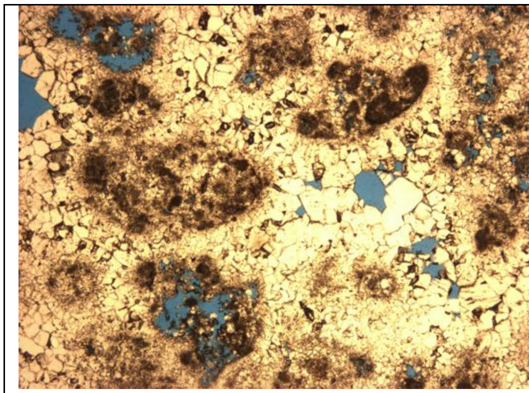
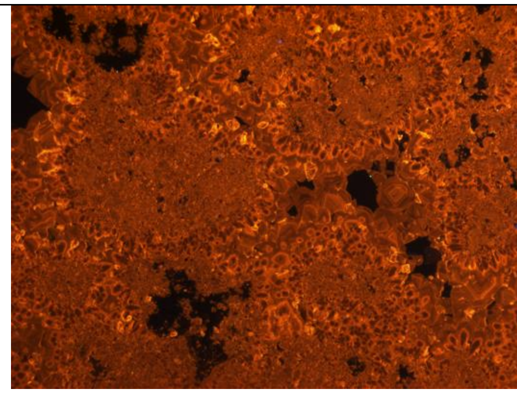
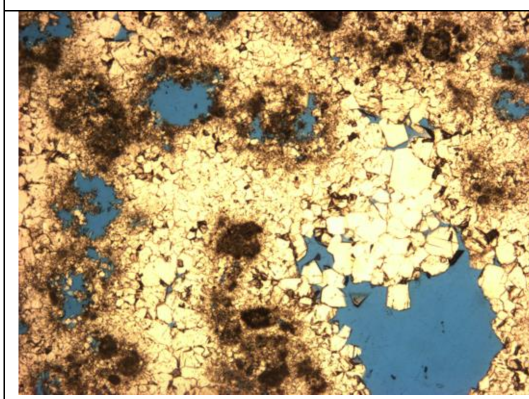
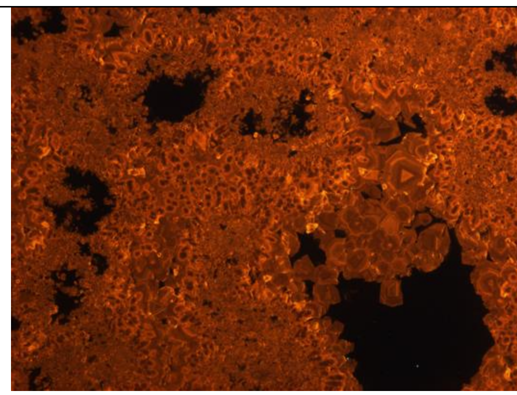
Description: Intraclastic grainstone, fine to medium sand size. Intraclasts are peloidal grainstones / thrombolite (?). Some bioclasts. Diagenesis: drusy calcite cement, and blocky calcite cement. Late dissolution.

Pore type: Moldic, intergranular, and vuggy.

Porosity (image analysis): 11%

Little Cedar Creek Field **Well: 27** **Permit: 15497**

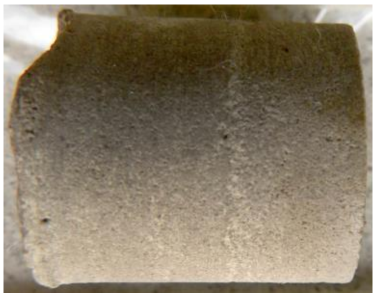
Depth: 10979.5 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (up to 5 zones): dark brown – orange-yellow – light brown – orange yellow – light brown.
Mosaic calcite cement, zoned (up to 6 zones): dark brown – light brown – orange-yellow – light brown – orange-yellow – light brown luminescence. It is common to have 2 zones: dark brown – light brown luminescence.

Little Cedar Creek Field **Well: 28** **Permit: 15731**

Depth: 11180.5 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Very fine to fine sand peloidal grainstone.

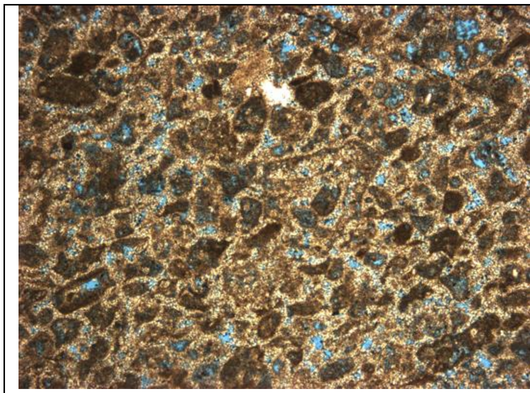
Description: Peloidal grainstone, very fine to fine sand size, with some oolites and medium sand size skeletal fragments. Bioclasts are benthic foraminifera, echinoid (with sintaxial cement), and green algae (?). Some sitl to very fine sand quartz grains occur. Diagenesis: Bladed to drusy calcite fringe cement rimming grains, blocky calcite cement, some late dissolution, no compaction features.

Pore type: Intergranular, intragranular, and moldic.

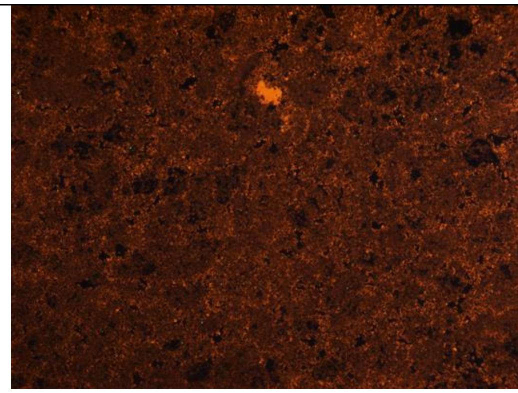
Porosity (image analysis) : 17%

Little Cedar Creek Field **Well: 28** **Permit: 15731**

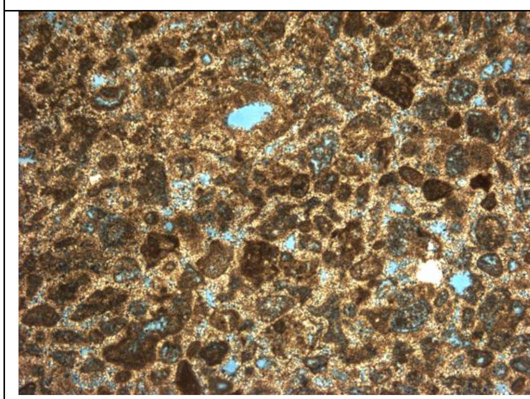
Depth: 11180.5 ft



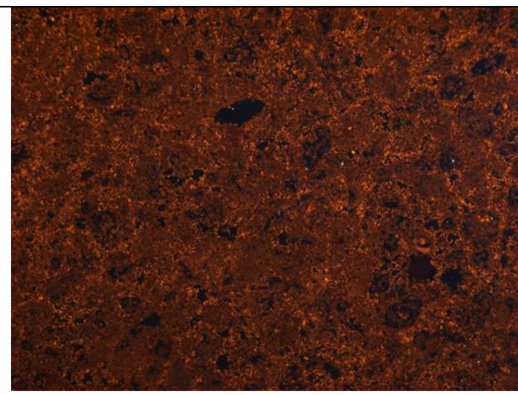
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

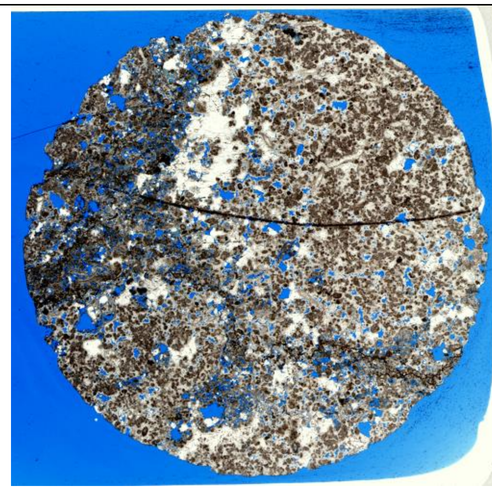
Cathodoluminescence image analysis:
Bladed to drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescent or is nonluminescent, and the second zone (edge) has light orange-yellow luminescence.
Blocky calcite cement, presenting orange-yellow luminescence.

Little Cedar Creek Field **Well: 29** **Permit: 16053**

Depth: 10243 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and rare gastropod. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, some microcrystalline quartz (?) cement. Stylolites occur. Primary growth framework vugs enlarged by dissolution.

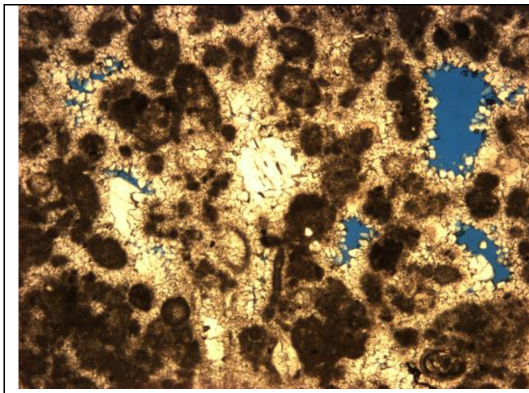
Pore type: Vuggy and intergranular.

Porosity (image analysis): 14%

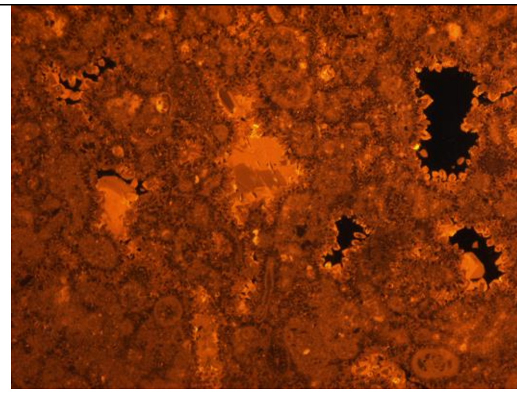
Petrophysical analysis:
Porosity – 12%
Permeability – 6.3 md

Little Cedar Creek Field **Well: 29** **Permit: 16053**

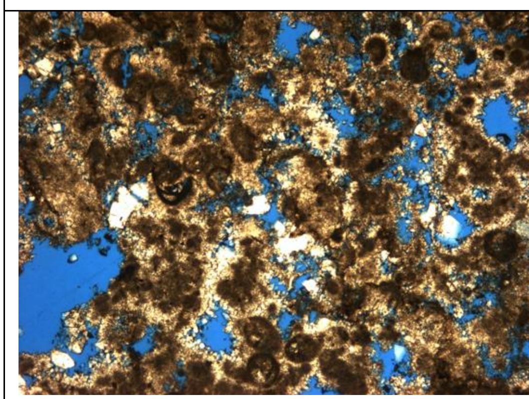
Depth: 10243 ft



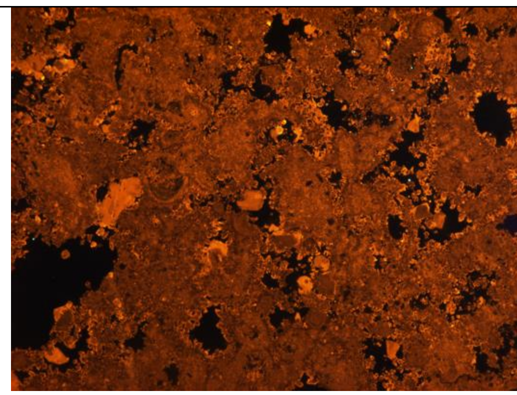
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

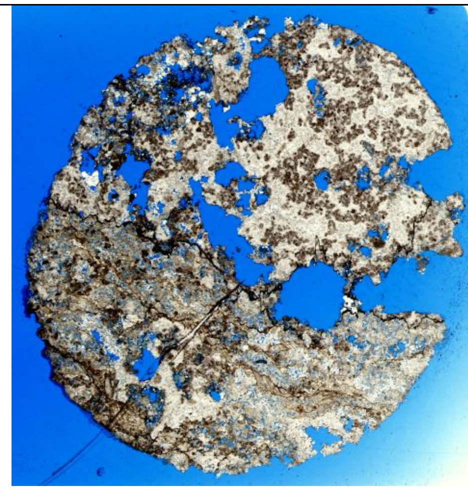
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, dark brown luminescence.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has light brown luminescence, the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): dark to light brown –orange-yellow luminescence and orange-yellow – light brown luminescence.

Little Cedar Creek Field **Well: 29** **Permit: 16053**

Depth: 10249.9 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

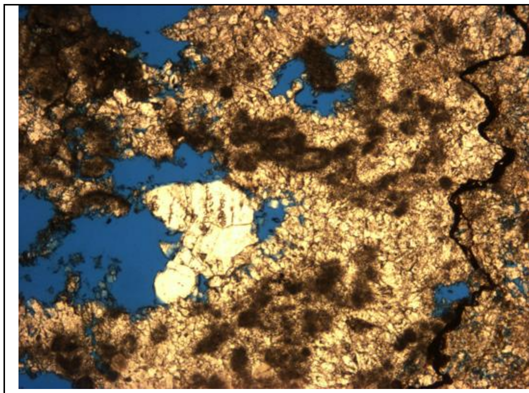
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement) and benthic foraminifera. Peloid clusters are common. Some silt size quartz grains occur. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, blocky calcite cement, some microcrystalline quartz (?) cement. Stylolites occur. Moderate to high calcite recrystallization and cementation. Late dissolution.

Pore type: Vuggy and intercrystalline.

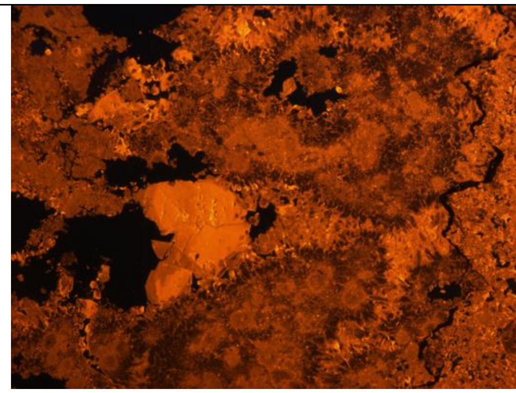
Porosity (image analysis): 25%

Little Cedar Creek Field **Well: 29** **Permit: 16053**

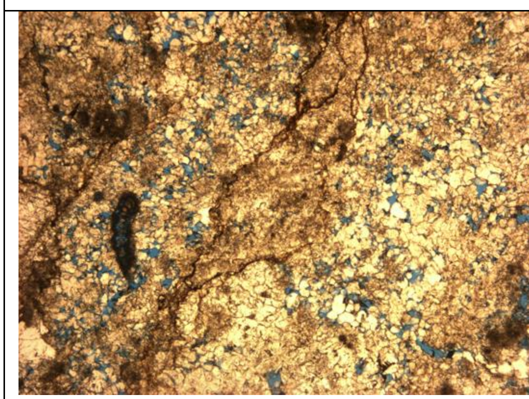
Depth: 10249.9 ft



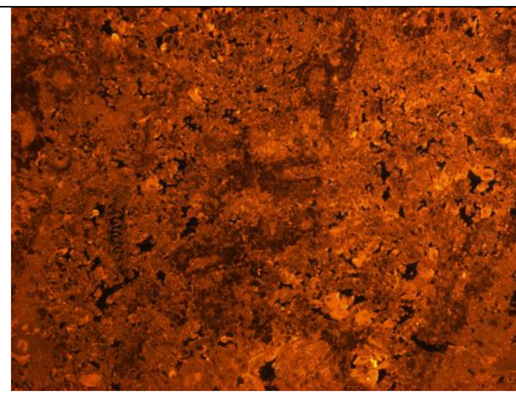
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

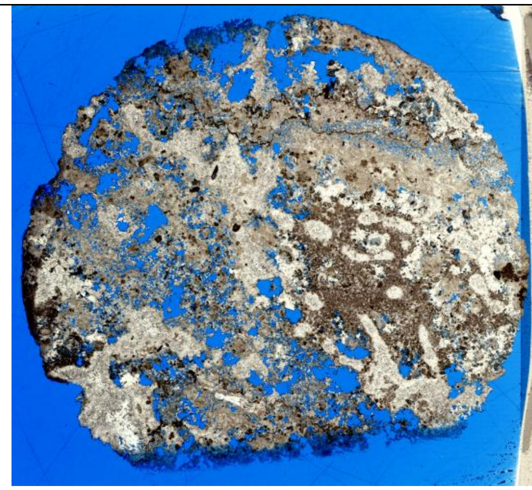
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, dark brown luminescence.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has light brown luminescence, the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): orange-yellow – light brown.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 29** **Permit: 16053**

Depth: 10252.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement) and benthic foraminifera. Some portions of the rock present very dense peloid clusters. Diagenesis: mosaic calcite cement, blocky calcite cement, rare microcrystalline quartz (?) cement. Stylolites occur. Medium to high calcite recrystallization and cementation. Late dissolution.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 15%

Petrophysical analysis:
Porosity – 20%
Permeability – 91.2 md

Little Cedar Creek Field **Well: 29** **Permit: 16053**

Depth: 10252.5 ft

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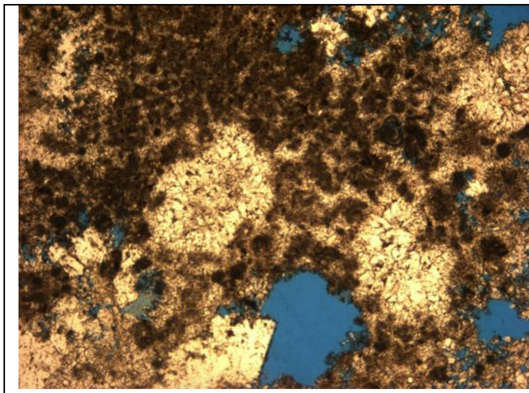
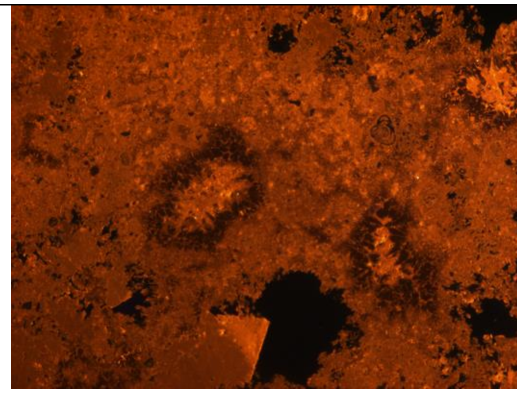
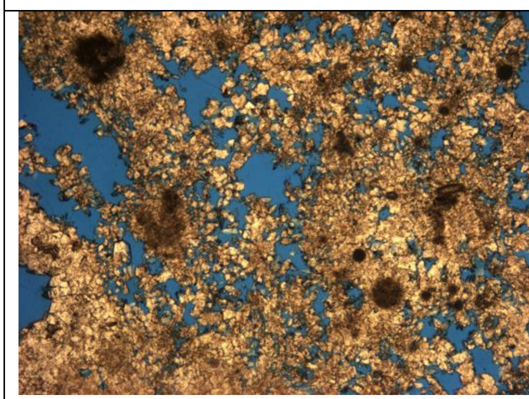
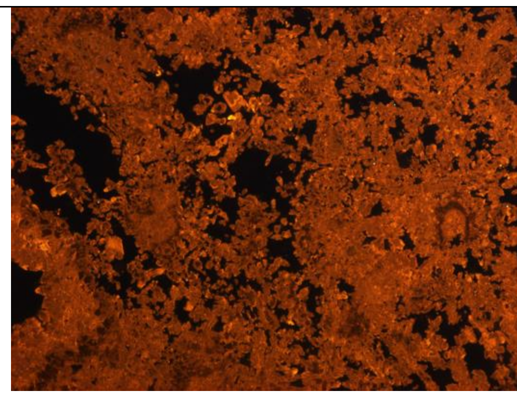
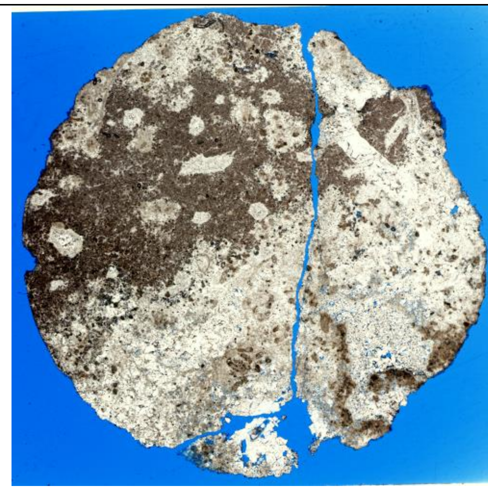
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Mosaic calcite cement, zoned (3 zones): dark brown – light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): orange-yellow – light brown.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 29** **Permit: 16053**

Depth: 10255.1 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement), benthic foraminifera, and rare gastropod. Some portions of the rock present very dense peloid clusters. Diagenesis: mosaic calcite cement, blocky calcite cement. Stylolites and fractures occur. Medium to high calcite recrystallization and cementation. Late dissolution.

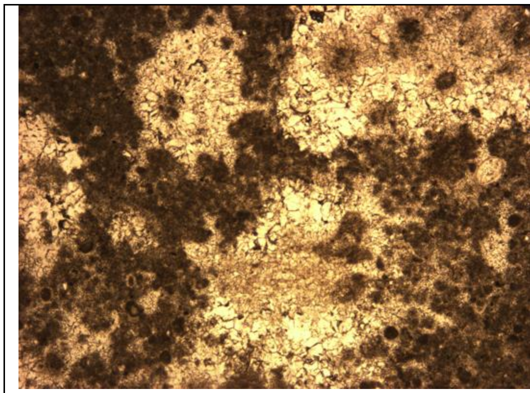
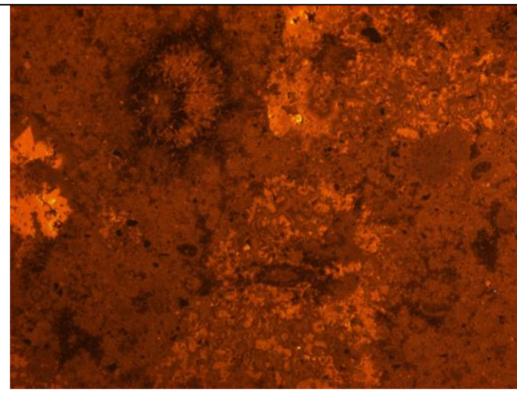
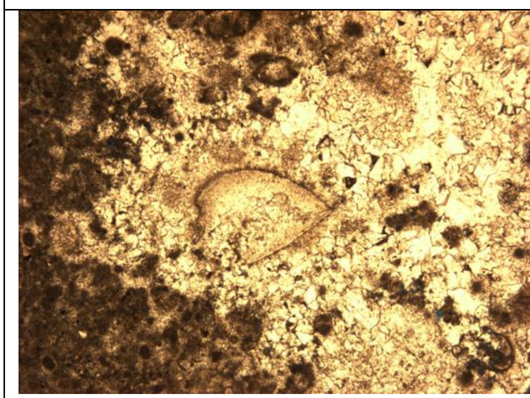
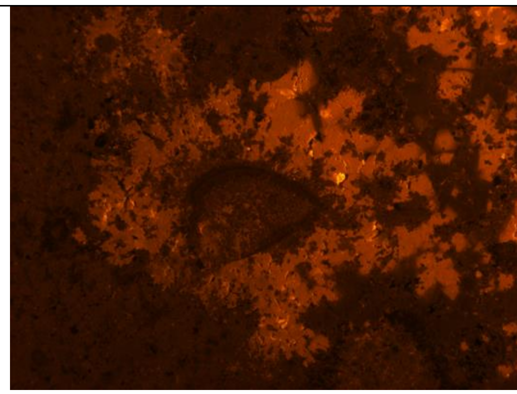
Pore type: Intercrystalline and fracture.

Porosity (image analysis): 1%

Petrophysical analysis:
Porosity – 4%
Permeability – 0.678 md

Little Cedar Creek Field **Well: 29** **Permit: 16053**

Depth: 10255.1 ft

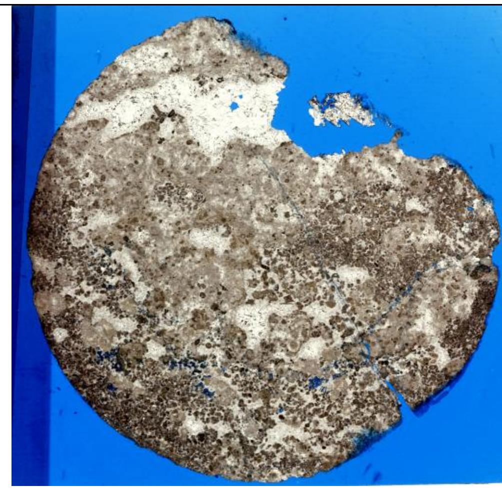
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Mosaic calcite cement, zoned (4 zones): dark brown – orange-yellow – dark brown – light brown luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – orange-yellow luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 29** **Permit: 16053**

Depth: 10258.8 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are ostracods (with sintaxial calcite cement) and benthic foraminifera. Peloid clusters are common. Some elongated features occur. Diagenesis: fibrous calcite cement rimming grains, drusy calcite cement rimming grains, mosaic calcite cement, and blocky calcite cement. Stylolites, cemented fractures and open fractures occur. Medium to high calcite recrystallization and cementation. Late dissolution.

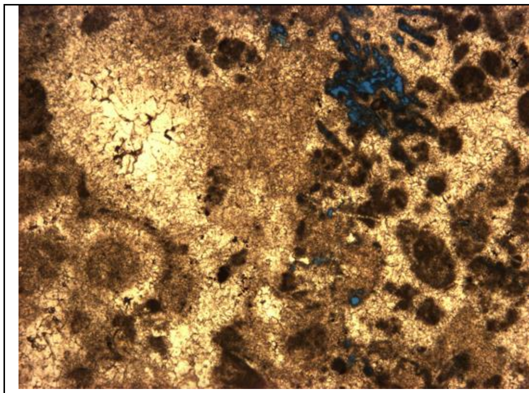
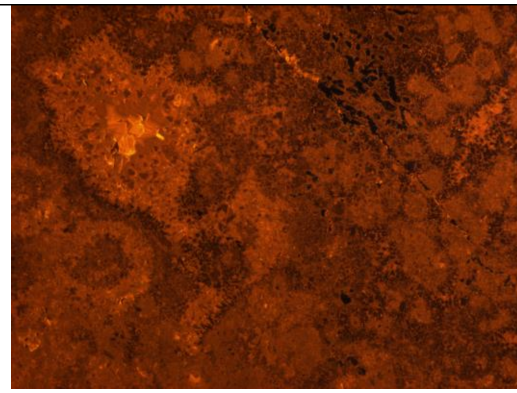
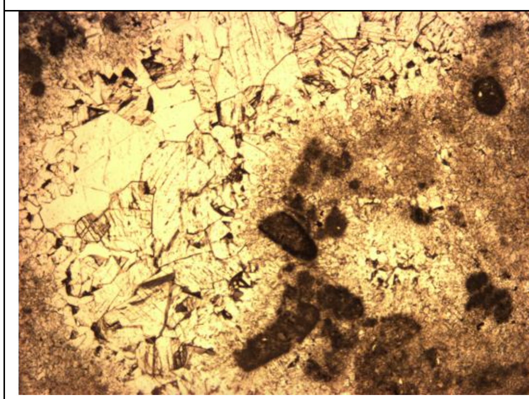
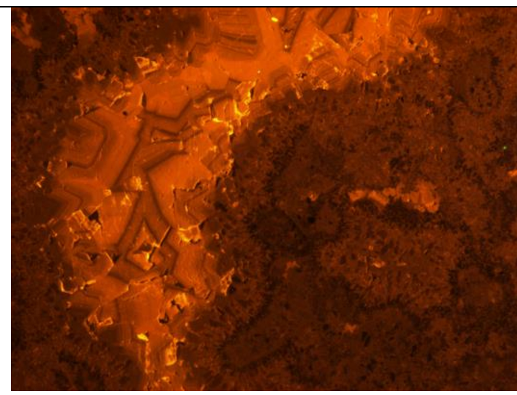
Pore type: Intragranular and fractures.

Porosity (image analysis): 3%

Petrophysical analysis:
Porosity – 3%
Permeability – 0.012 md

Little Cedar Creek Field **Well: 29** **Permit: 16053**

Depth: 10258.8 ft

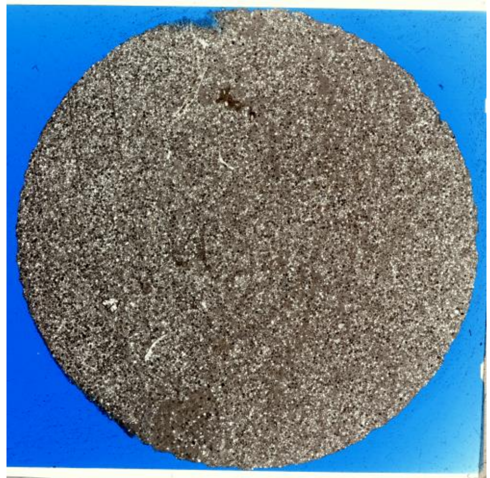
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming the grains, dark brown luminescence.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, the second zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (7 zones): dark brown – light brown – dark brown – light brown – orange-yellow – dark brown – light brown. Some subzones occur.

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10795.2 ft

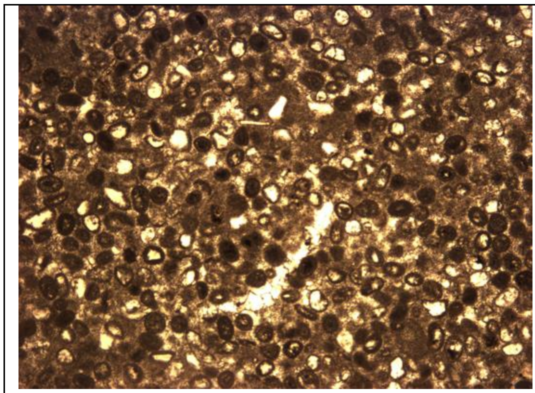
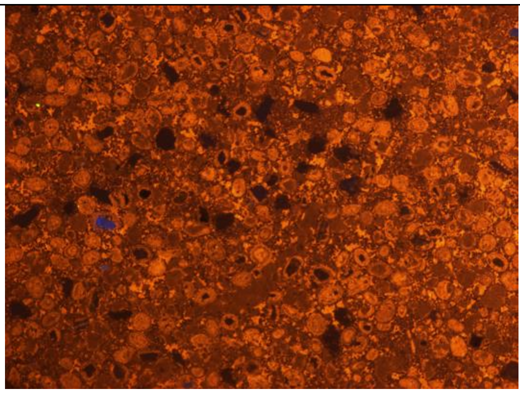
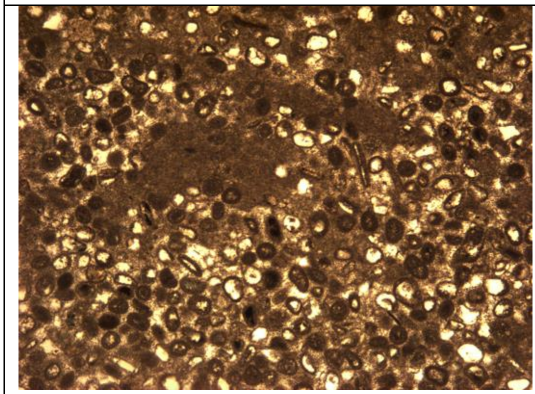
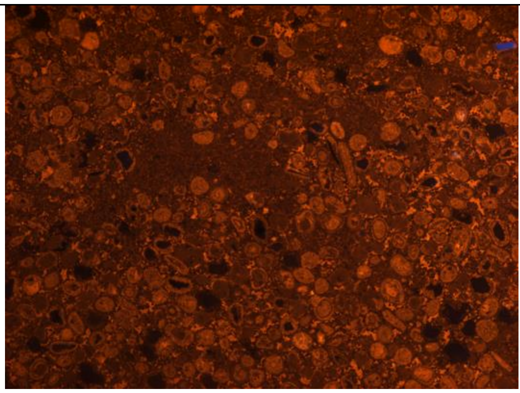
<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">Lithology: Very fine to fine sand oolitic packstone.

Description: Oolitic packstone, very fine to fine sand size, with bioclasts. Bioclasts are echinoids (with sintaxial cement) and gastropods. A high amount of oolites present quartz or feldspar grains as it nucleous. Several oolites present calcite cement as it nucleous. Some fine sand size quartz and muscovite grains occur. Diagenesis: mosaic calcite cement, and blocky calcite cement. Calcite cement occurs between grains and inside oolite grains.</td>
</tr>
</table>

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10795.2 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
Cathodoluminescence image analysis: **Mosaic calcite** cement, orange-yellow luminescent. **Blocky calcite** cement, dark brown luminescent.	

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10833.6 ft

<table>
<tr><td>Plug – 2.15 cm (diameter)

Macroscopic photo</td><td>
Scanned thin section</td></tr>
<tr><td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera. Some portions of the rock present dense peloid clusters. Some silt size quartz grains occur. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Several stylolites occur. Late dissolution.

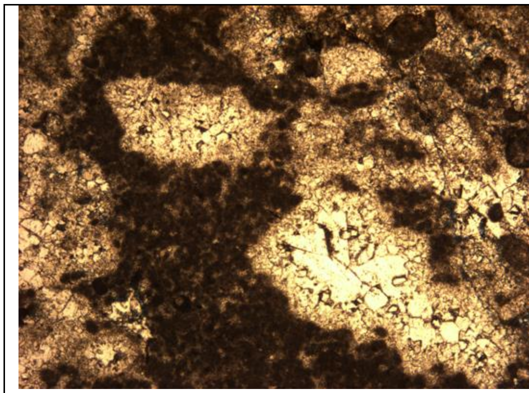
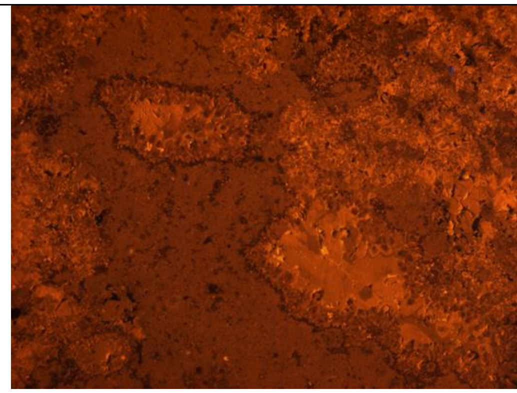
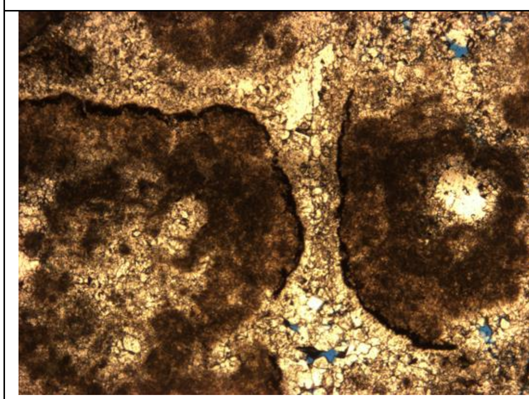
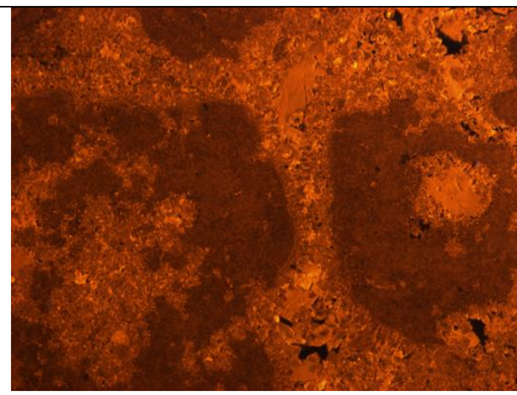
Pore type: Intercrystalline and channel.

Porosity (image analysis): 2%

</td></tr>
</table>

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10833.6 ft

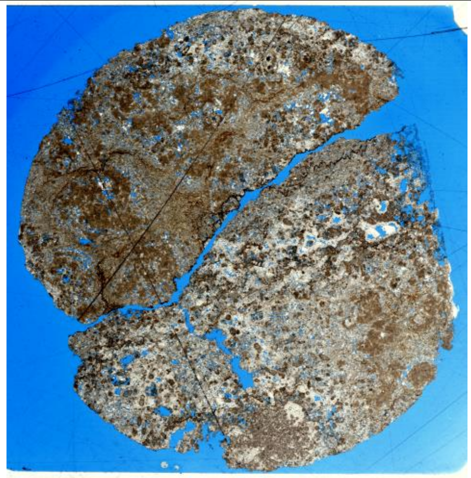
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grain clusters, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence. Some crystals are unzoned, presenting orange-yellow luminescence.

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10839.3 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera. Some portions of the rock present dense peloid clusters. Some filamentous features occur. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, and blocky calcite cement. Stylolites occur. Moderate to high calcite recrystallization and cementation. Late dissolution.

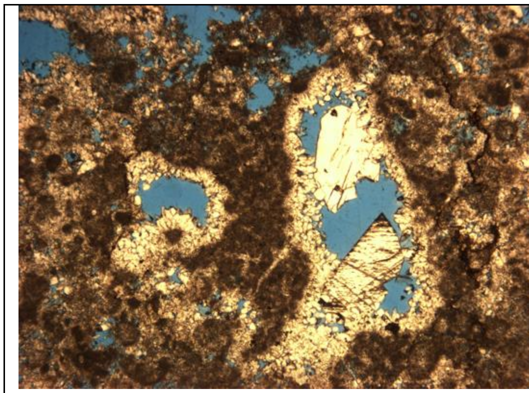
Pore type: Intercrystalline and vuggy.

Porosity (image analysis): 10%

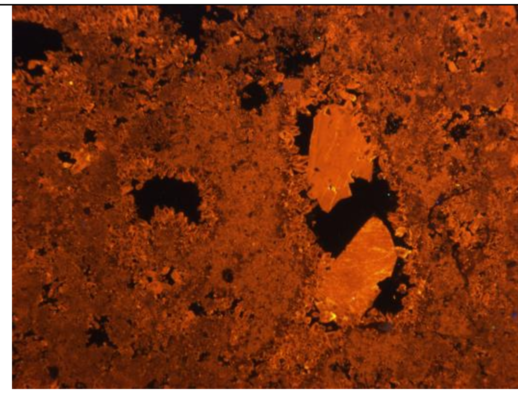
</td>
</tr>
</table>

Little Cedar Creek Field **Well: 30** **Permit: 16115**

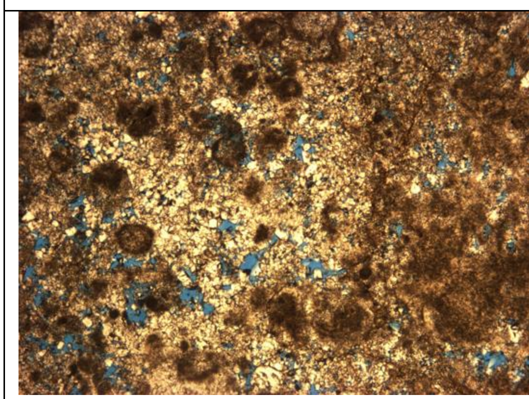
Depth: 10839.3 ft



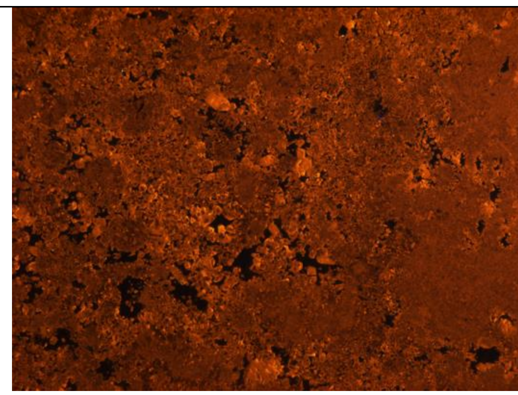
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



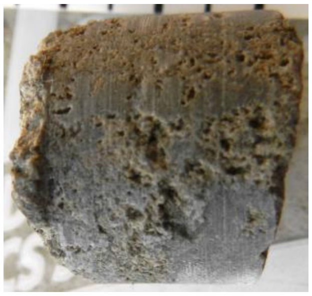
Cathodoluminesce image – same field of the picture on the left side

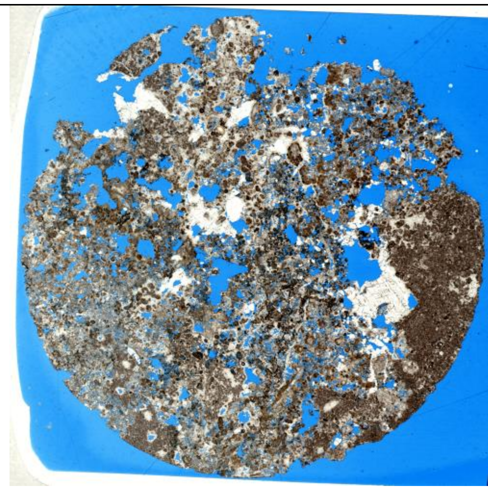
Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, orange-yellow luminescent.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10844.2 ft

Plug – 2.15 cm (diameter)


Macroscopic photo


Scanned thin section

Lithology: Peloidal thrombolite.

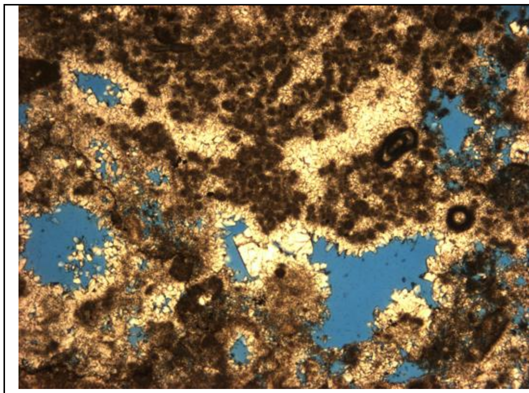
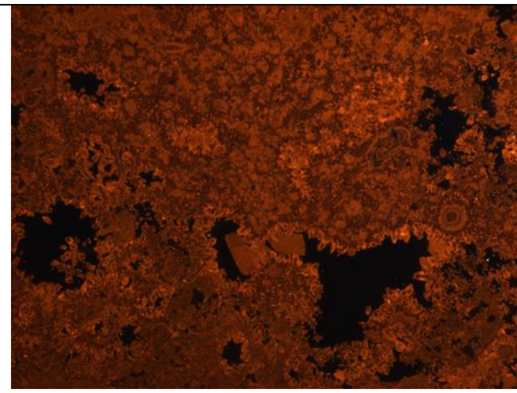
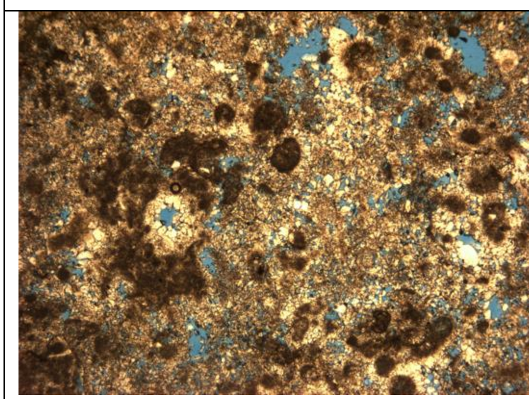
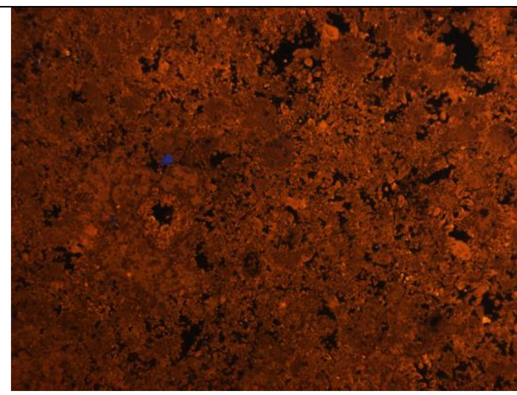
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera and ostracods (with sintaxial cement). Some portions of the rock present dense peloid clusters. Some filamentous features occur. Diagenesis: fibrous calcite cement rimming grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Moderate to low calcite recrystallization and cementation. Late dissolution.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 25%

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10844.2 ft

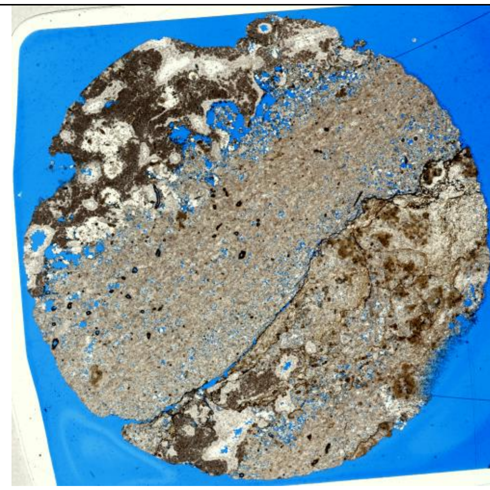
<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
</table>

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grains, dark brown luminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, light brown luminescent.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10852 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">Lithology: Peloidal thrombolite.

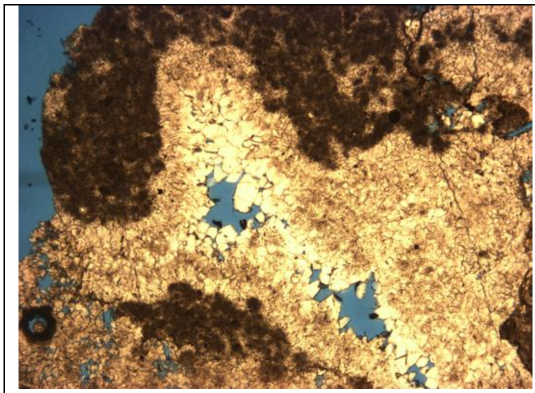
Description: Peloidal thrombolite. Some portions of the rock present dense peloid clusters. Some filamentous features occur. Diagenesis: fibrous calcite cement rimming grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Moderate to high calcite recrystallization and cementation. Stylolites occur. Late dissolution.
.

Pore type: Vuggy and intercrystalline.

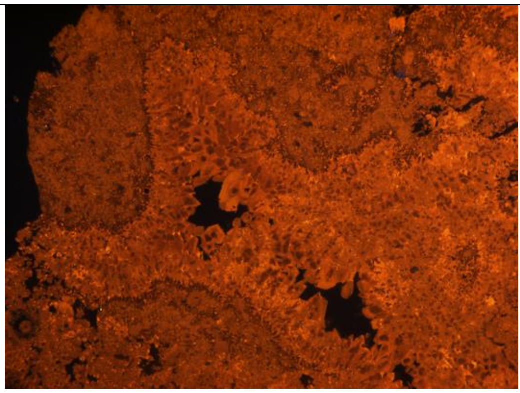
Porosity (image analysis): 7%</td>
</tr>
</table>

Little Cedar Creek Field **Well: 30** **Permit: 16115**

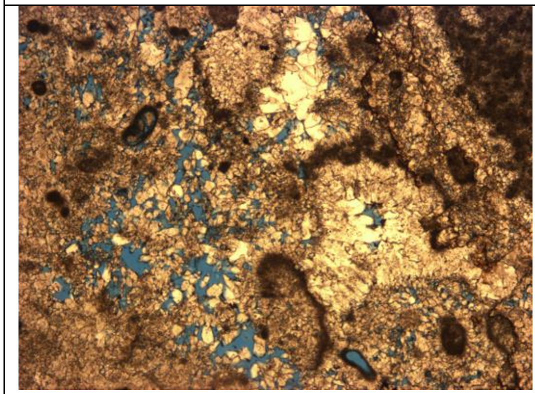
Depth: 10852 ft



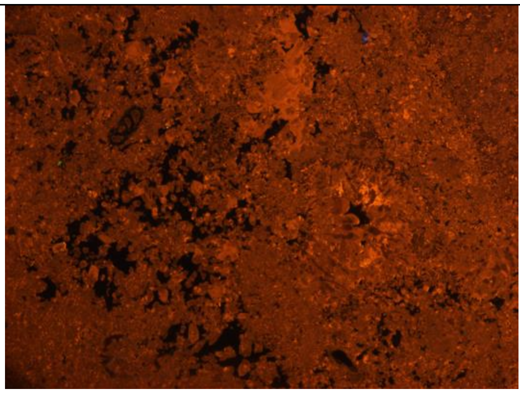
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



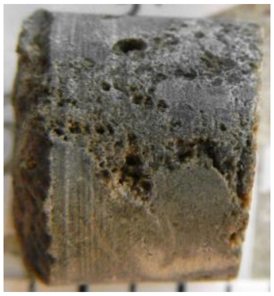
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grain clusters, dark brown luminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence. Some crystals are unzoned, presenting light brown luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

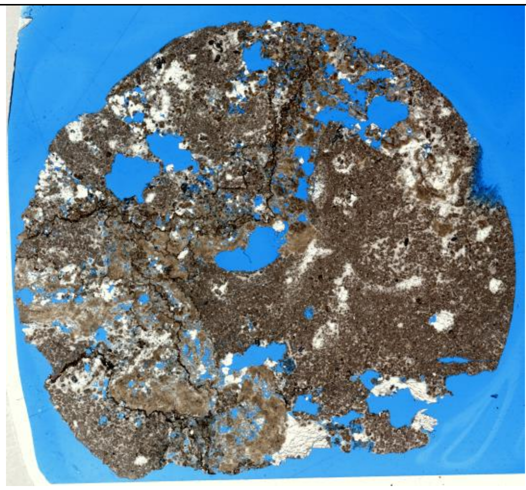
Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10855.8 ft

Plug – 2.15 cm (diameter)



Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

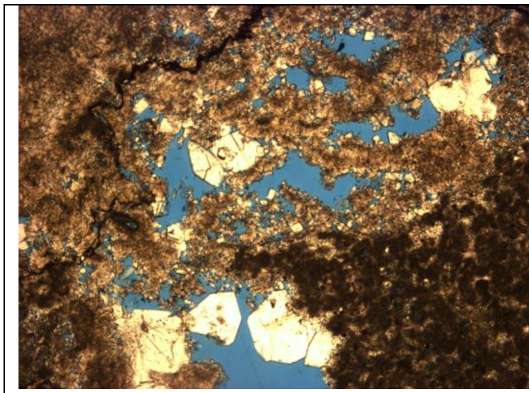
Description: Peloidal thrombolite, with some bioclasts. Bioclasts are benthic foraminifera. Great part of the rock is composed by dense peloid clusters. Some filamentous features occur. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, and blocky calcite cement. Low calcite recrystallization. Stylolites and fractures occur. Late dissolution.

Pore type: Vuggy and intercrystalline.

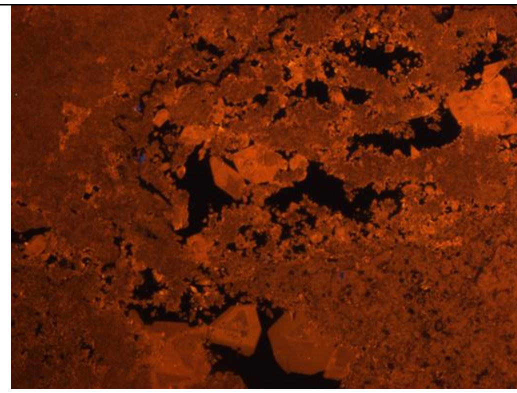
Porosity (image analysis): 14%

Little Cedar Creek Field **Well: 30** **Permit: 16115**

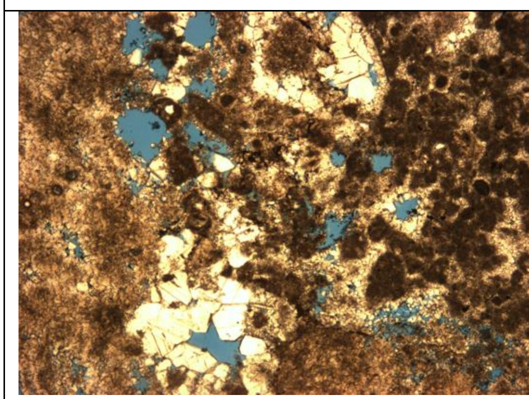
Depth: 10855.8 ft



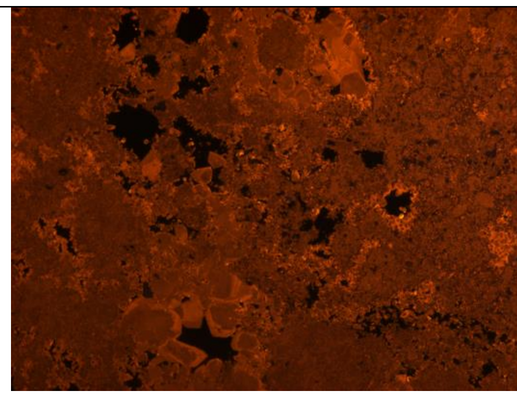
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



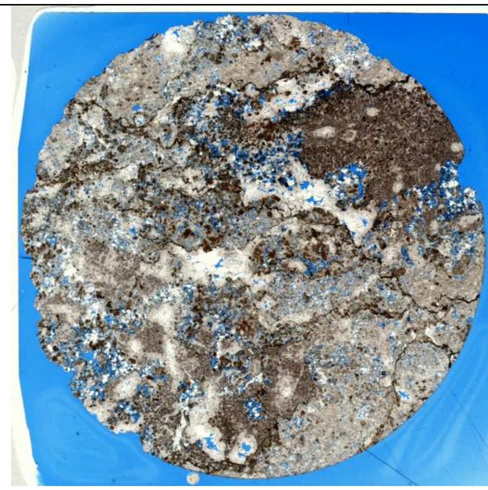
Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – light brown luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10866 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Bioclasts are benthic foraminifera and ostracods (with sintaxial cement). Part of the rock is composed by dense peloid clusters. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, and blocky calcite cement. Moderate to high calcite recrystallization. Stylolites occur. Late dissolution.

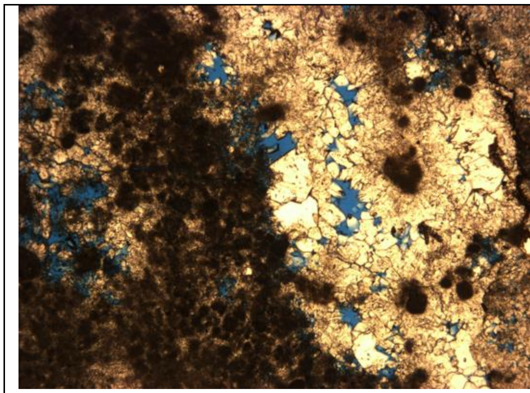
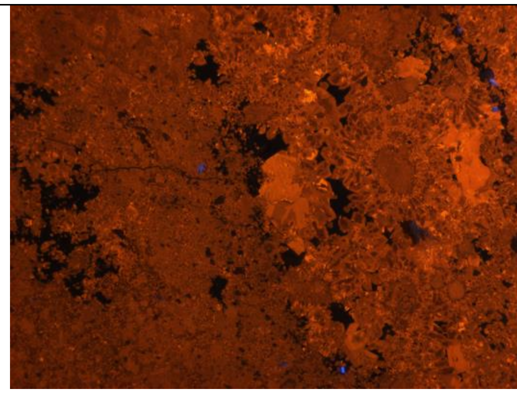
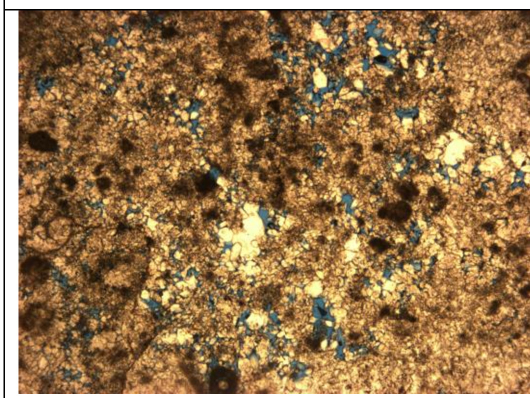
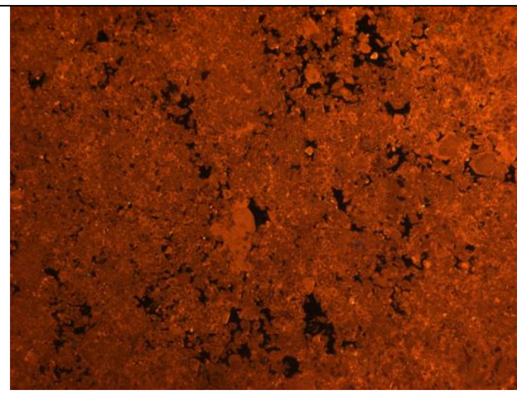
Pore type: Intercrystalline and vuggy.

Porosity (image analysis): 11%

</td>
</tr>
</table>

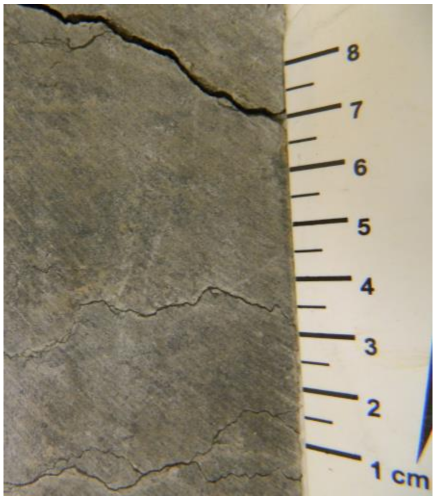
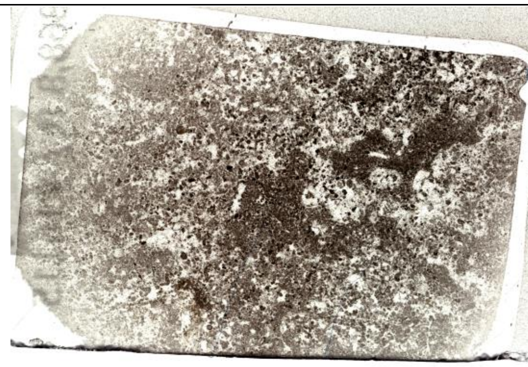
Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10866 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has light brown to orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10868.8 ft

 Macroscopic photo	 Scanned thin section

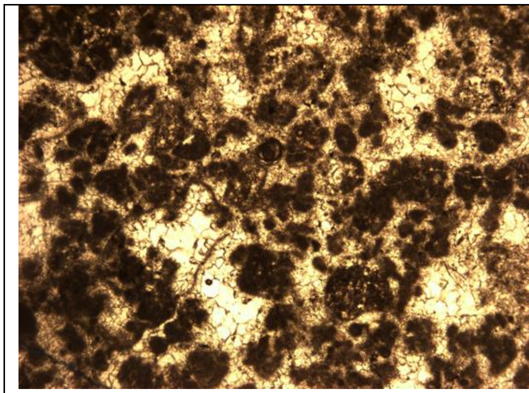
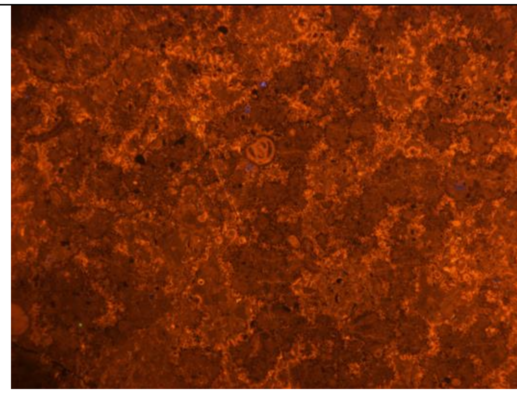
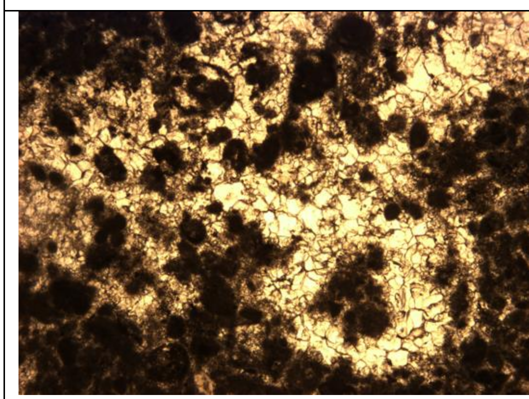
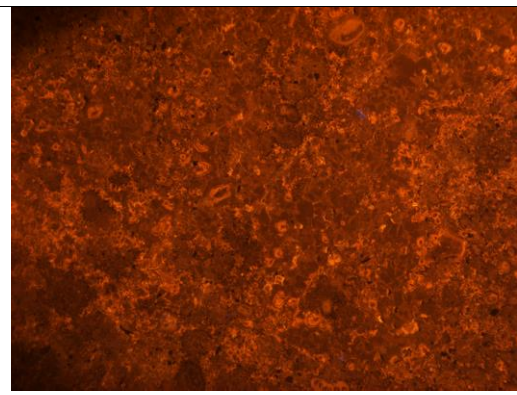
Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Bioclasts are benthic foraminifera and some gastropods (?). Part of the rock is composed by dense peloid clusters. Diagenesis: fibrous calcite cement rimming grains, drusy calcite cement rimming the grains and peloid clusters, and mosaic calcite cement. Low calcite recrystallization. Fractures occur.

Pore type: Fractures.

Little Cedar Creek Field **Well: 30** **Permit: 16115**

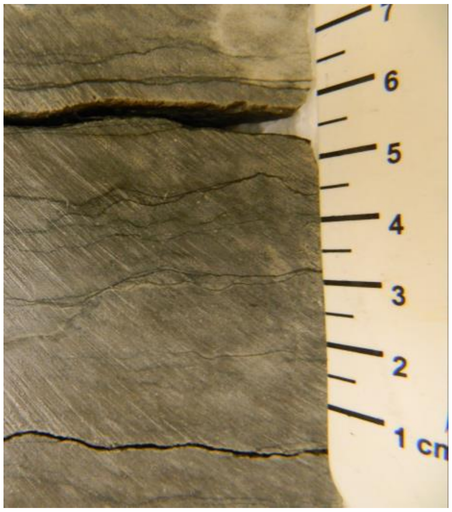
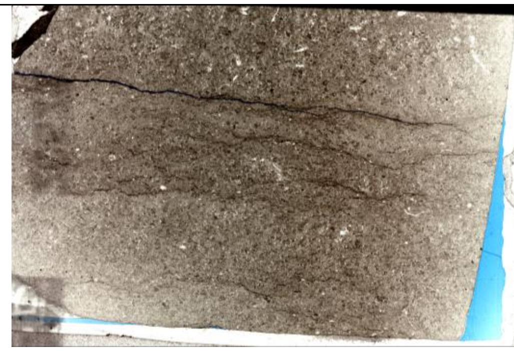
Depth: 10868.8 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grains, dark brown luminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.

Little Cedar Creek Field **Well: 30** **Permit: 16115**

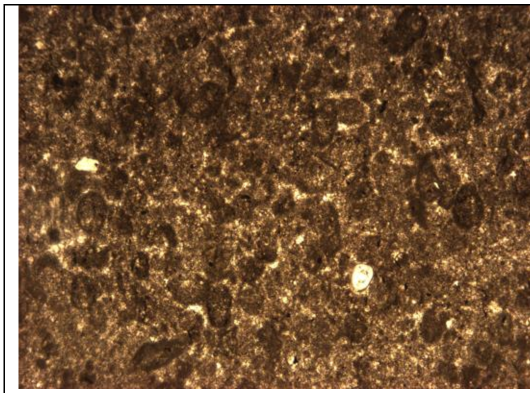
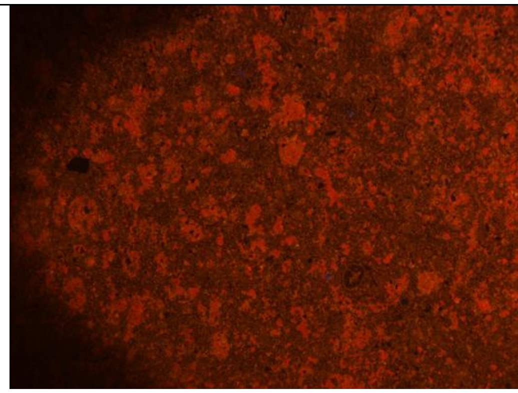
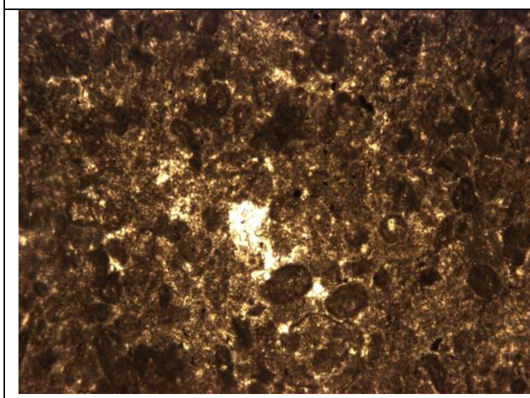
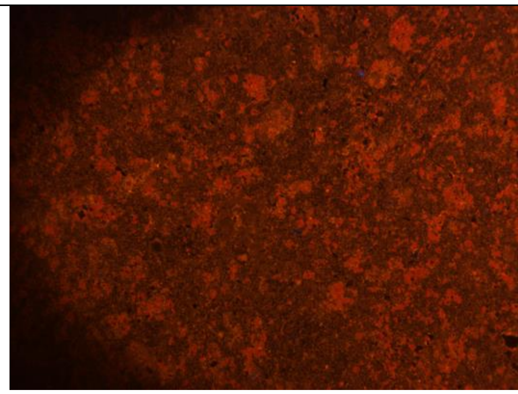
Depth: 10875.9 ft

<table>
<tr>
<td>
Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">Lithology: Peloidal packstone.

Description: Peloidal packstone, with some bioclasts. Bioclasts are echinoids (with sintaxial cement) and arthropods (?). Some silt to very fine sand size quartz grains occur. Diagenesis: blocky calcite cement, low dolomitization. Stylolites occur.</td>
</tr>
</table>

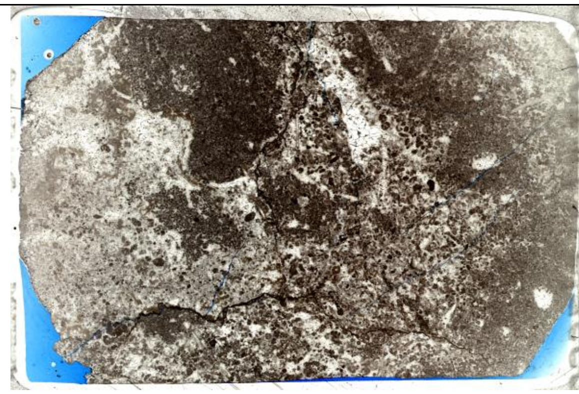
Little Cedar Creek Field **Well: 30** **Permit: 16115**

Depth: 10875.9 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Blocky calcite cement, dark brown luminescent.
Subhedral very fine dolomite crystals occur as a replacing / cementing phase. The dolomite crystals do not present zonation and have red luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10592.5 ft

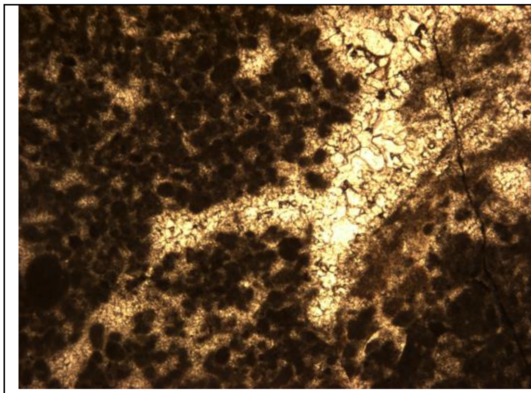
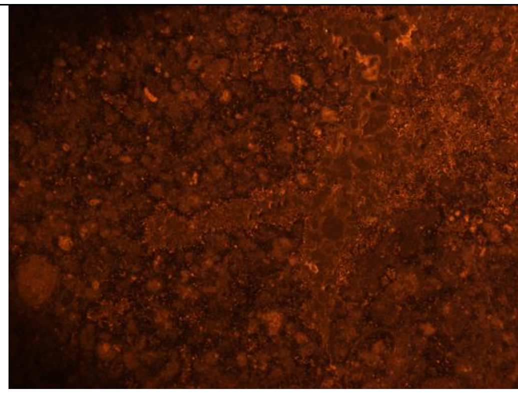
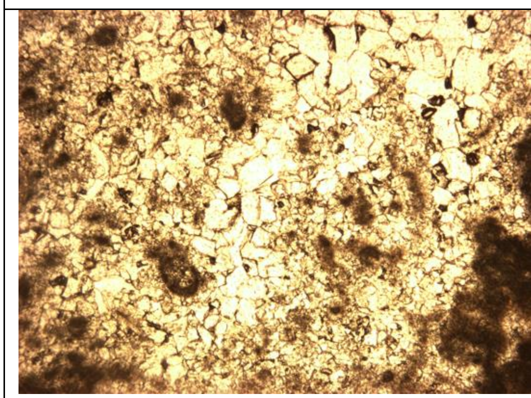
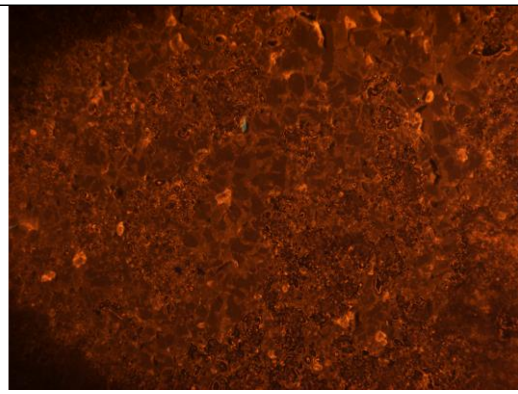
 Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Bioclasts are green alage. Part of the rock is composed by dense peloid clusters. Diagenesis: fibrous calcite cement rimming grains, mosaic calcite cement, and blocky calcite cement. Low calcite recrystallization. Stylolites occur.

Little Cedar Creek Field **Well: 31** **Permit: 16135**

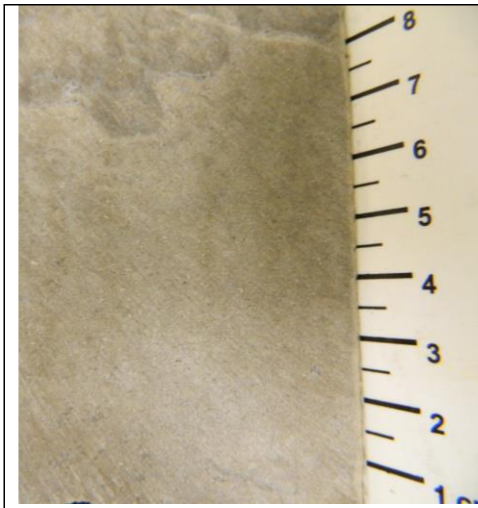
Depth: 10592.5 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

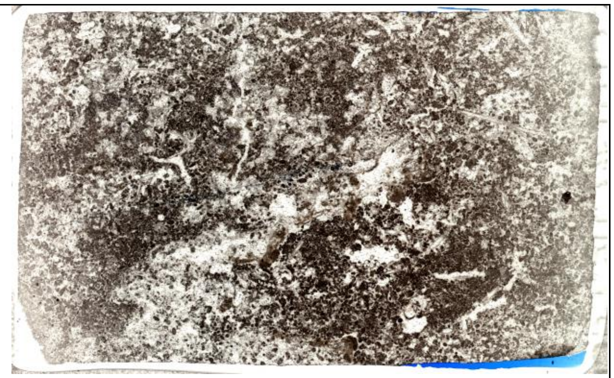
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grain clusters, nonluminescent.
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence.

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10594.9 ft



Macroscopic photo

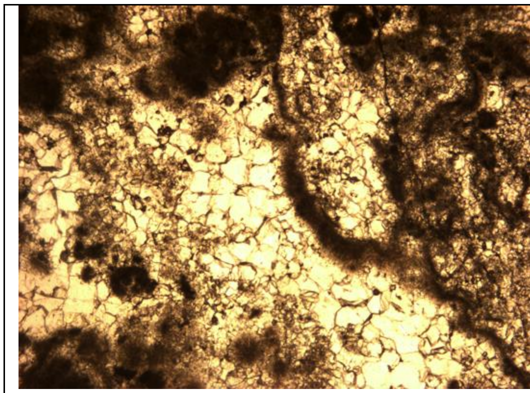
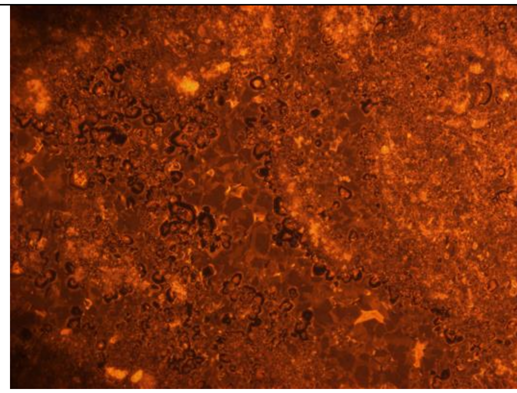
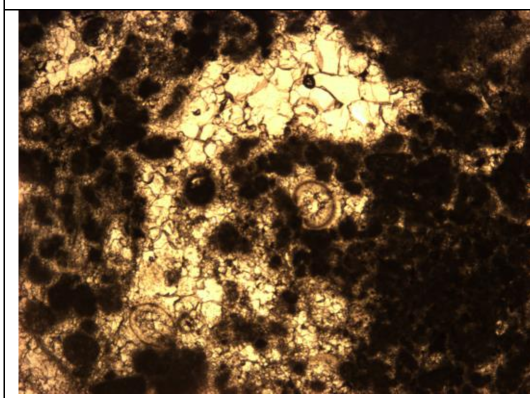
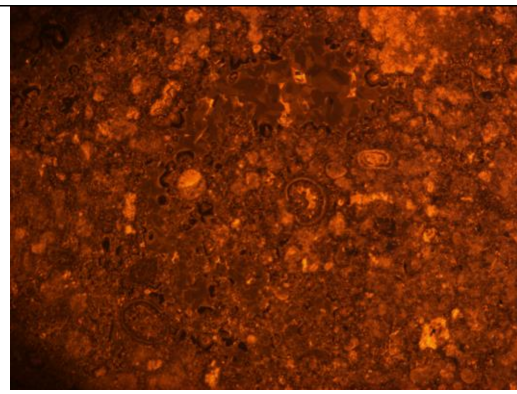

Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. Bioclasts are green algae. Some filamentous features. Part of the rock is composed by dense peloid clusters. Diagenesis: botryoidal calcite cement, mosaic calcite cement, and blocky calcite cement.

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10594.9 ft

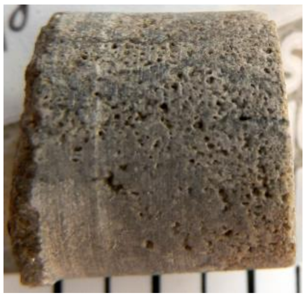
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Botryoidal calcite cement, zoned (3 zones): dark to light brown – orange-yellow – nonluminescent.
Mosaic calcite cement, zoned (3 zones): dark brown – light brown – orange-yellow luminescence.

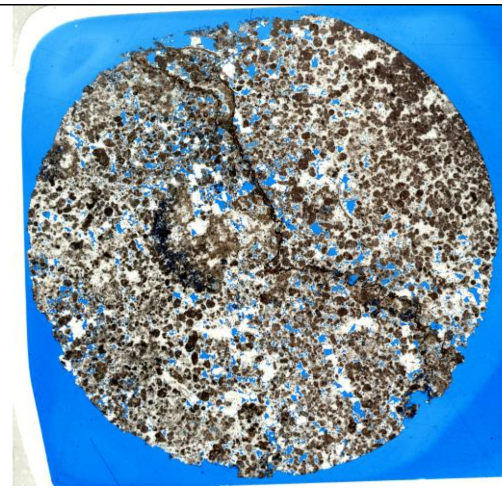
Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10597.2 ft

Plug – 2.15 cm (diameter)



Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

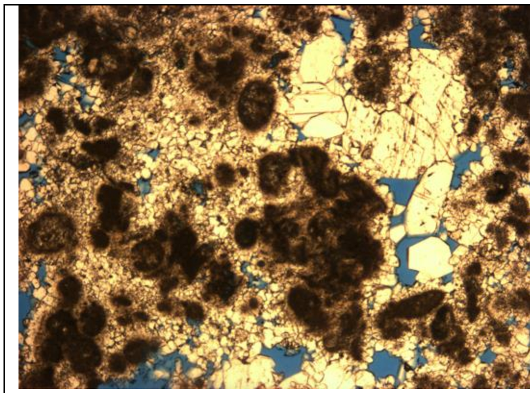
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Rare silt to very fine sand size quartz and muscovite grains occur. Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Stylolites occur.

Pore type: Vuggy and intergranular.

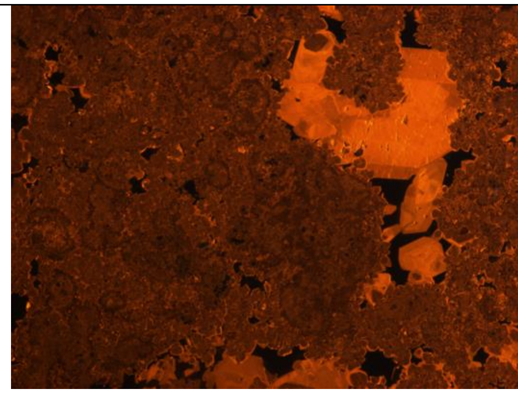
Porosity (image analysis): 9%

Little Cedar Creek Field **Well: 31** **Permit: 16135**

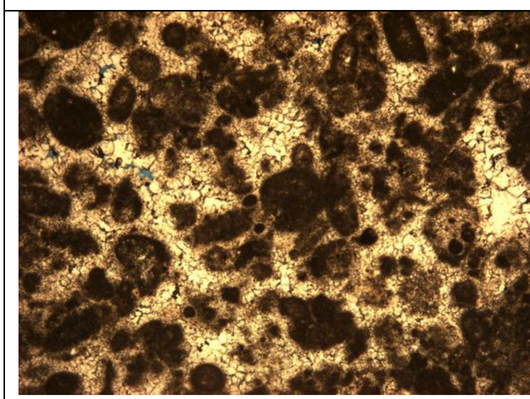
Depth: 10597.2 ft



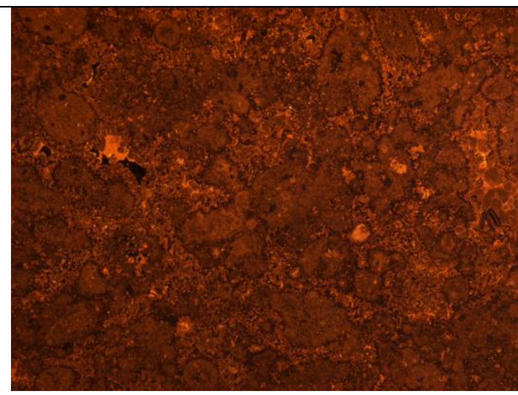
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

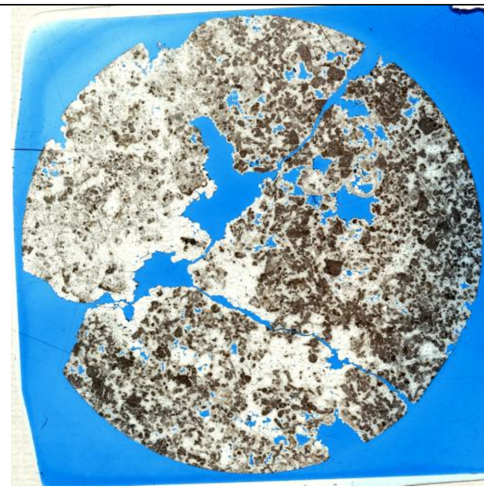
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grain clusters, nonluminescent.
Drusy calcite fringe cement rimming the grains, zoned (3zones). The first zone (inner part of the crystal) has light brown luminescence, the second zone has dark brown luminescence, and the third zone (edge) has light brown luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, with irregular zones, presenting light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10602 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

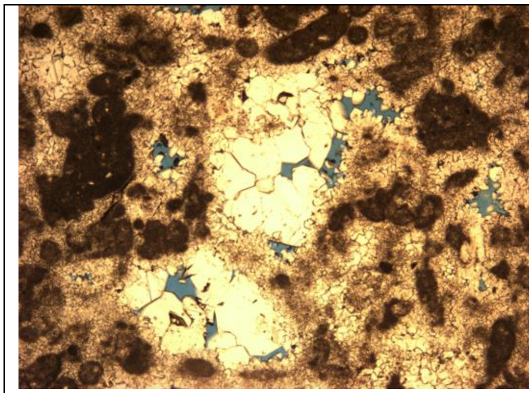
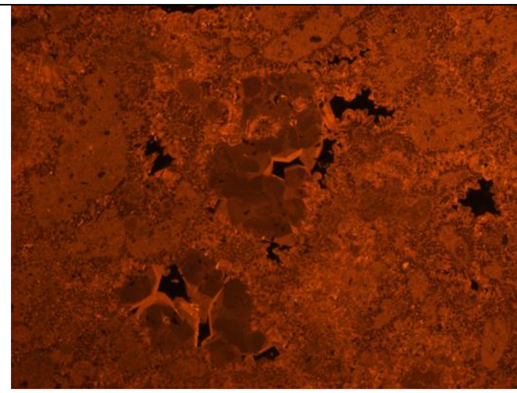
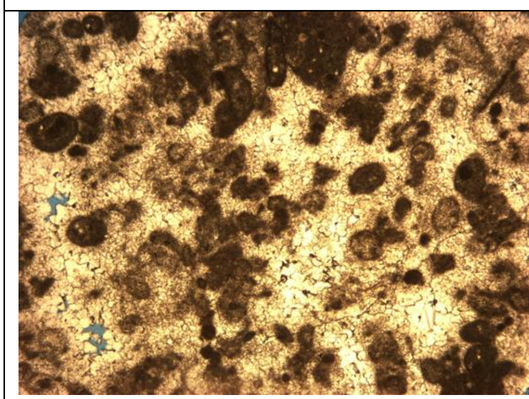
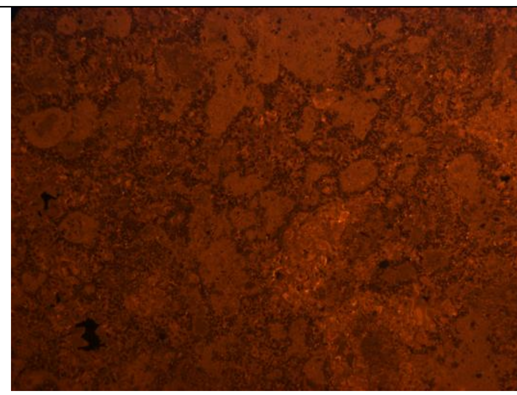
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera, ostracods (with sintaxial calcite cement), echinoids, and gastropods. Peloid clusters are common. Some filamentous features occur. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Fractures occur. Moderate to high calcite recrystallization and cementation. Late dissolution.

Pore type: Vuggy, intercrystalline, and fracture.

Porosity (image analysis): 12%

Little Cedar Creek Field **Well: 31** **Permit: 16135**

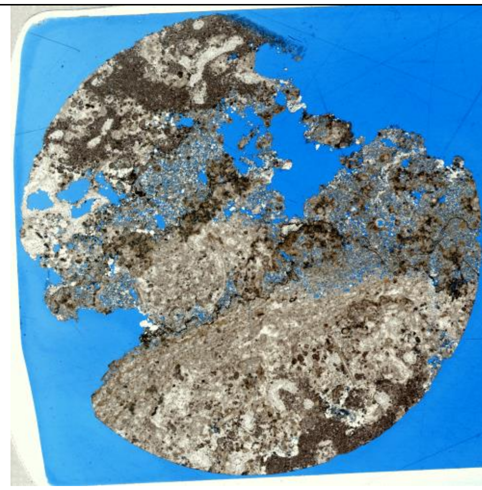
Depth: 10602 ft

<table>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td>
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm</td><td>
Cathodoluminesce image – same field of the picture on the left side</td></tr>
<tr><td colspan="2">Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grain clusters, dark brown luminescent.
Drusy calcite fringe cement rimming the grains, zoned (2zones). The first zone (inner part of the crystal) has dark brown luminescence, and the second zone (edge) has light brown to orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (3 zones): dark brown – light brown – orange-yellow luminescence.</td></tr>
</table>

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10607.6 ft

<table>
<tr>
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
</tr>
<tr>
<td colspan="2">Lithology: Peloidal thrombolite.

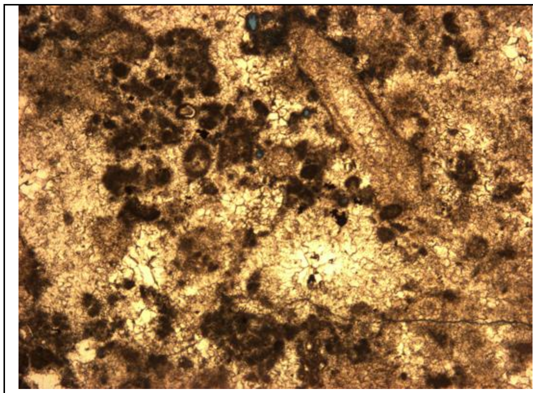
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera, ostracods (with sintaxial calcite cement), and green algae (?). Peloid clusters are common. Some filamentous features occur. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Fractures, stylolites, and pyrite crystals occur. Moderate to high calcite recrystallization and cementation. Late dissolution.

Pore type: Vuggy and intercrystalline.

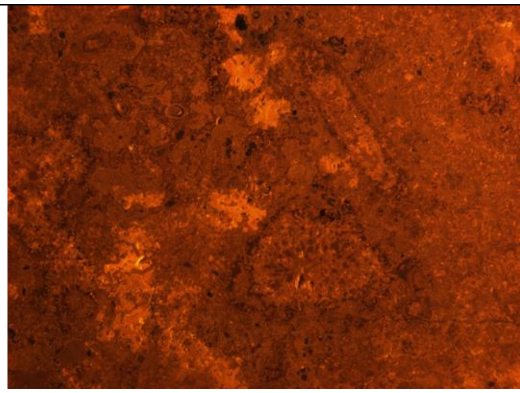
Porosity (image analysis): 20%</td>
</tr>
</table>

Little Cedar Creek Field **Well: 31** **Permit: 16135**

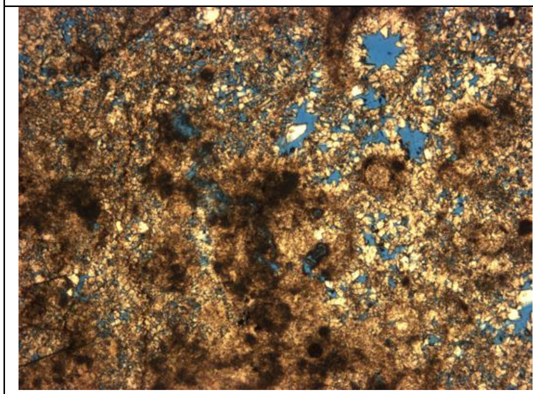
Depth: 10607.6 ft



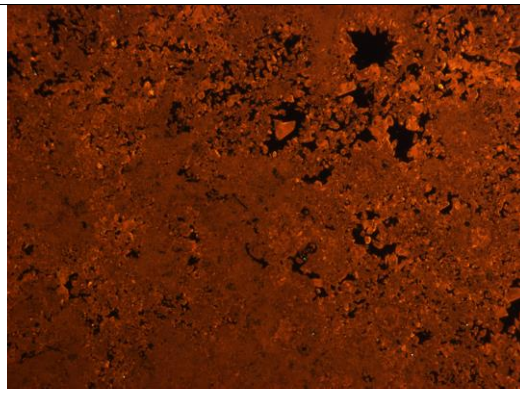
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

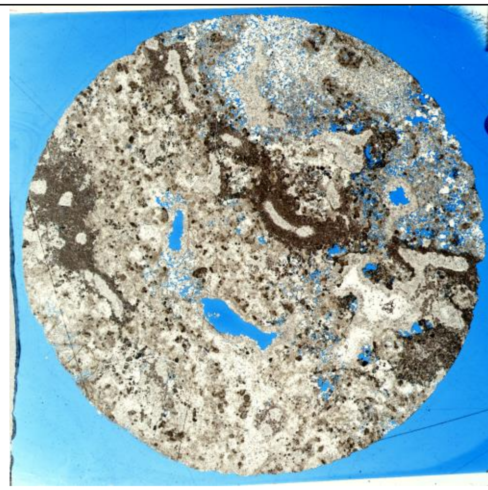


Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grains, dark brown luminescent, occurs locally.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): dark brown – light brown luminescence and locally orange-yellow luminescent.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10608.5 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

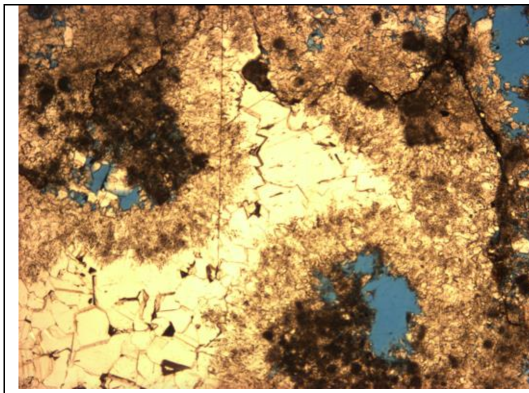
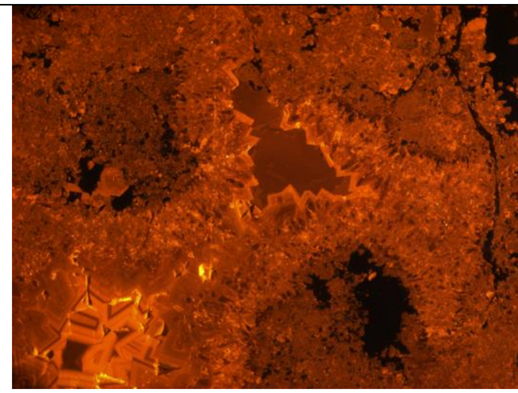
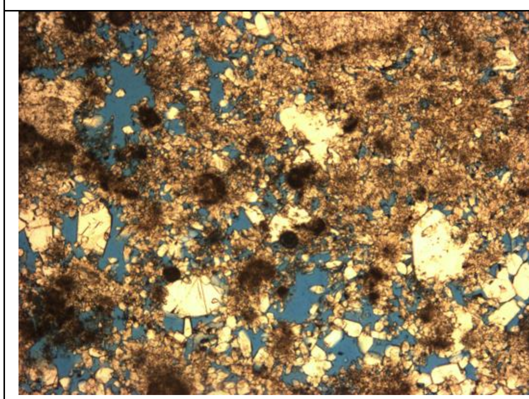
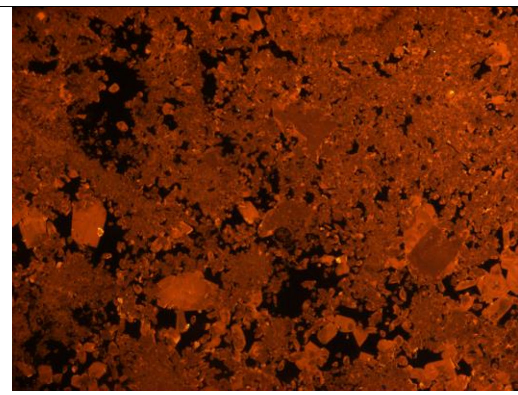
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera. Peloid clusters are common. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Stylolites occur. Moderate to high calcite recrystallization and cementation. Late dissolution.

Pore type: Intercrystalline and vuggy.

Porosity (image analysis): 8%

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10608.5 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

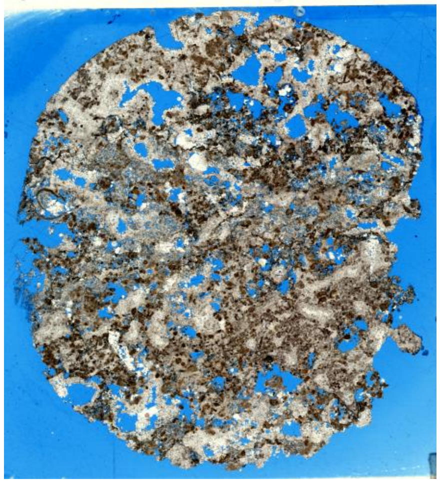
Cathodoluminescence image analysis:
Drusy calcite fringe with irregular zonation, presenting dark brown to orange-yellow luminescence.
Mosaic calcite cement, zoned. It presents at least 5 zones: dark brown – light brown – nonluminescent – orange-yellow – dark brown luminescence.
Blocky calcite cement, dark brown luminescent.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10621.6 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

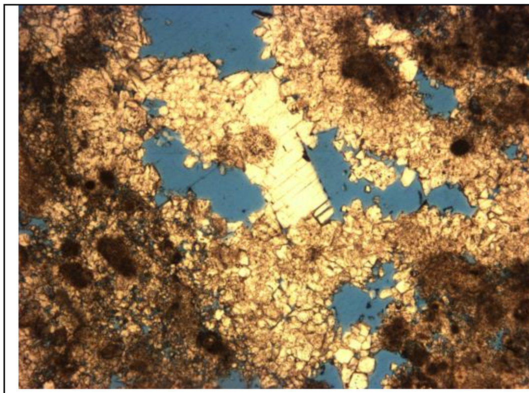
Description: Peloidal thrombolite. Some silt size quartz grains occur. Peloid clusters are common. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Stylolites occur. Moderate to high calcite recrystallization and cementation. Late dissolution.

Pore type: Vuggy and intercrystalline.

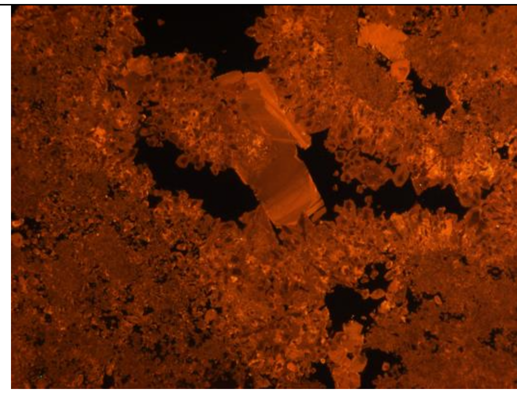
Porosity (image analysis): 18%

Little Cedar Creek Field **Well: 31** **Permit: 16135**

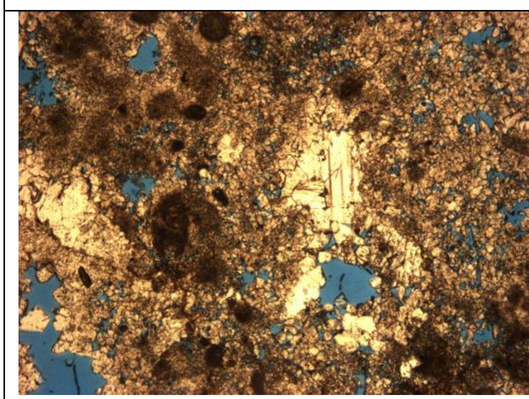
Depth: 10621.6 ft



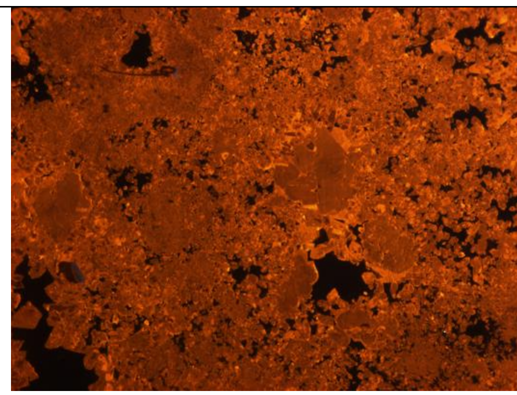
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

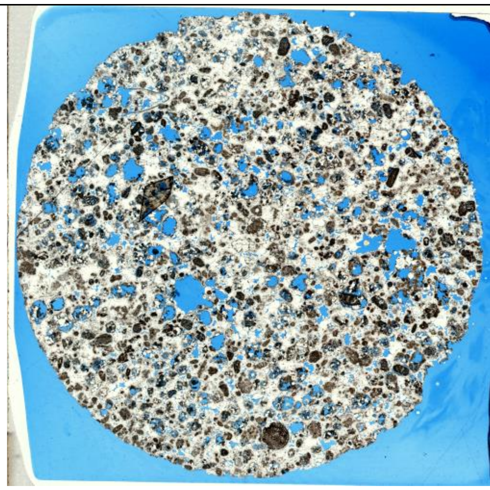
Cathodoluminescence image analysis:
Drusy calcite fringe with irregular zonation, presenting dark brown to orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence. Some subzones occur.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 31** **Permit: 16135**

Depth: 10636 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Fine to medium sand **s**keletal-intraclastic grainstone.

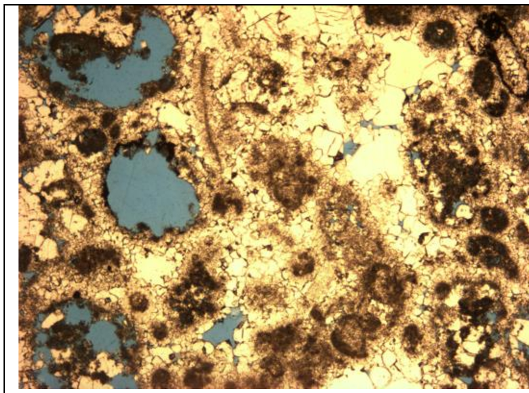
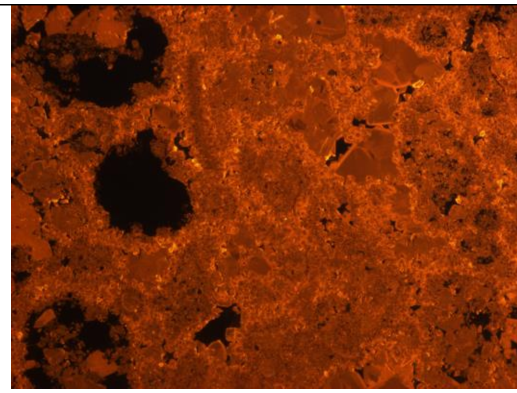
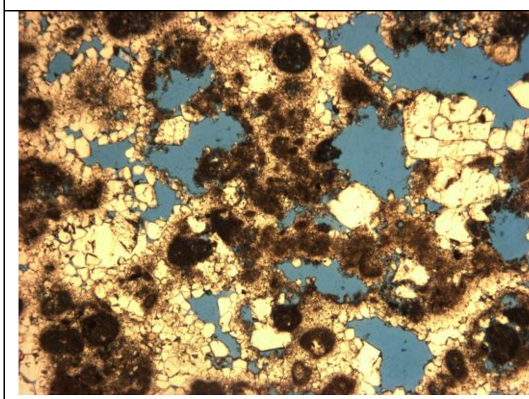
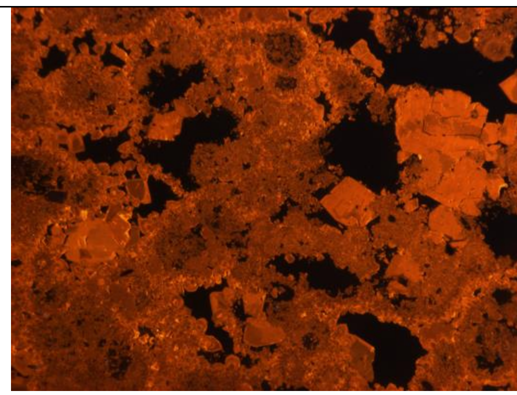
Description: Skeletal-intraclastic grainstone, fine to medium sand size. Skeletal fragments are benthic foraminifera. Intraclasts are peloidal grainstone / thrombolite. Diagenesis: drusy calcite cement rimming grains, and blocky calcite cement. Late dissolution.

Pore type: Moldic, intragranular and intergranular.

Porosity (image analysis): 16%

Little Cedar Creek Field **Well: 31** **Permit: 16135**

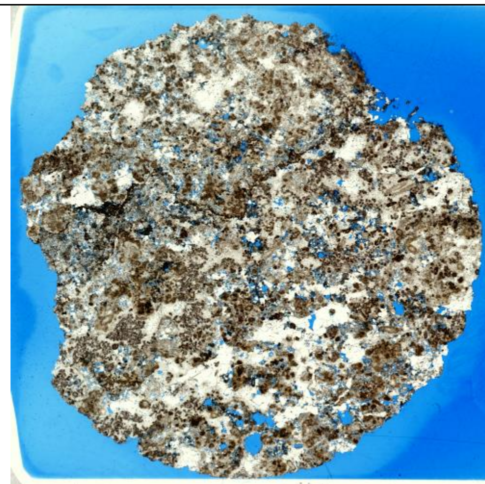
Depth: 10636 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Drusy calcite fringe zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence. Some subzones occur.

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10481.9 ft

Plug – 2.15 cm (diameter)  Macroscopic photo	 Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Some filamentous features occur. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Stylolites occur. Moderate to high calcite recrystallization and cementation. Late dissolution.

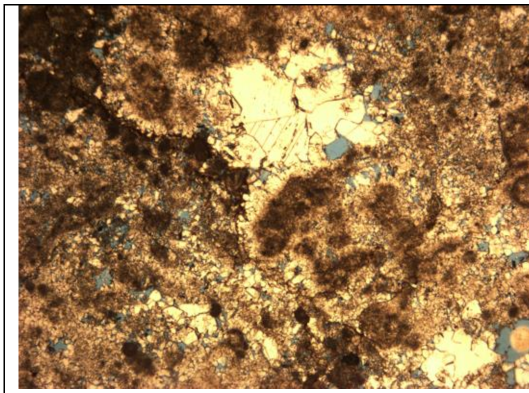
Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 8%

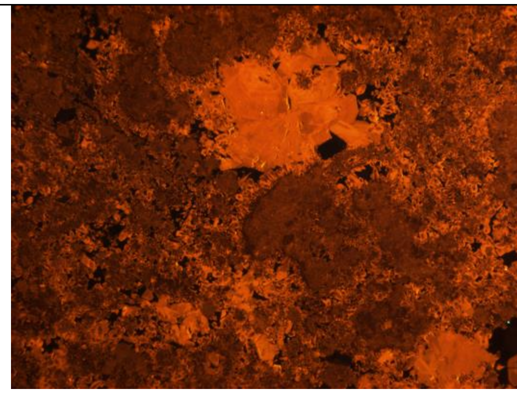
Petrophysical analysis:
Porosity – 6%
Permeability - < 0.001 md

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

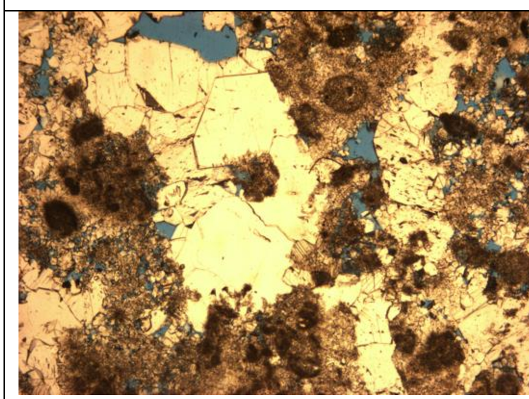
Depth: 10481.9 ft



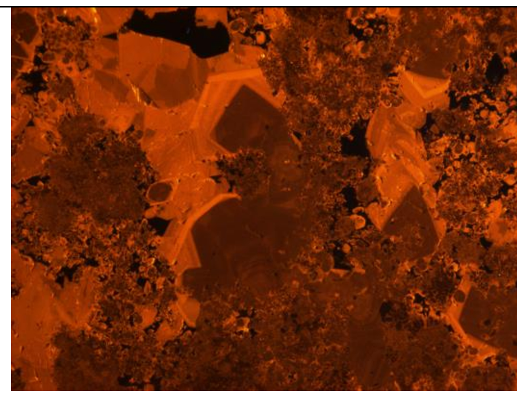
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:

Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence, and the second zone (edge) has orange-yellow luminescence.

Blocky calcite cement, zoned: dark brown – orange-yellow luminescence and dark brown – light brown luminescence. Some subzones occur.

Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10487 ft

<table>
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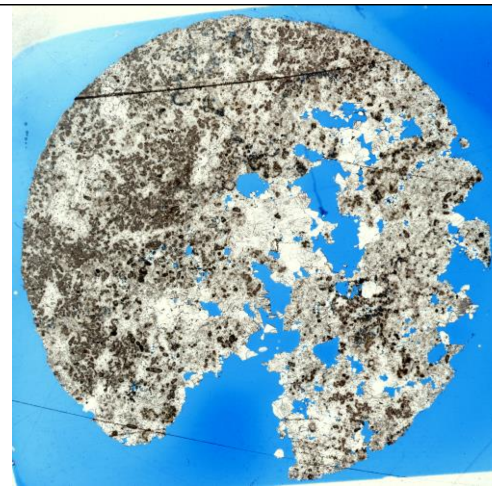
<td>Plug – 2.15 cm (diameter)

Macroscopic photo</td>
<td>
Scanned thin section</td>
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Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Peloid clusters are common. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Moderate to high calcite recrystallization and cementation. Late dissolution.

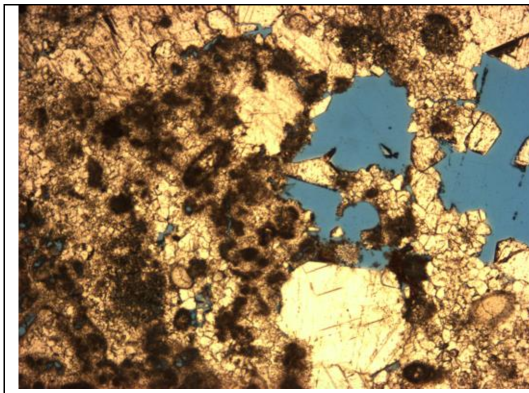
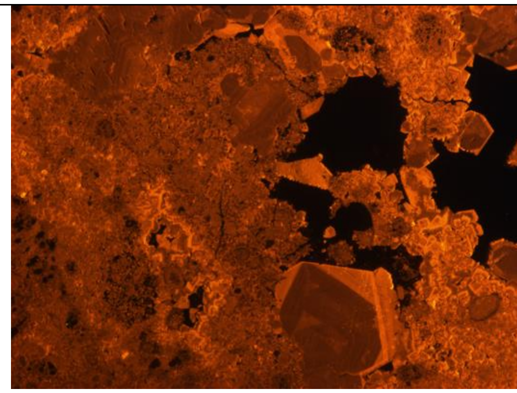
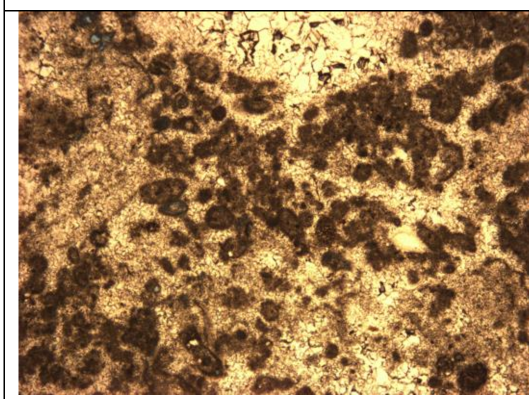
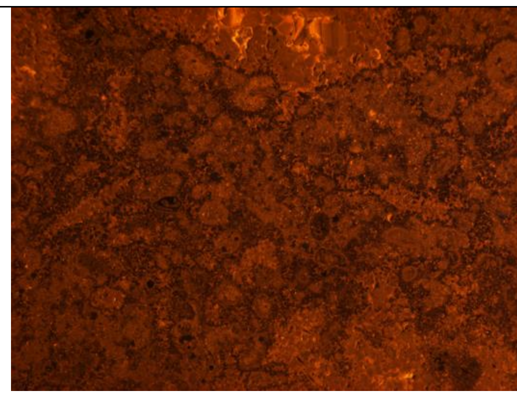
Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 15%

Petrophysical analysis:
Porosity – 9%
Permeability – 0.003 md

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10487 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

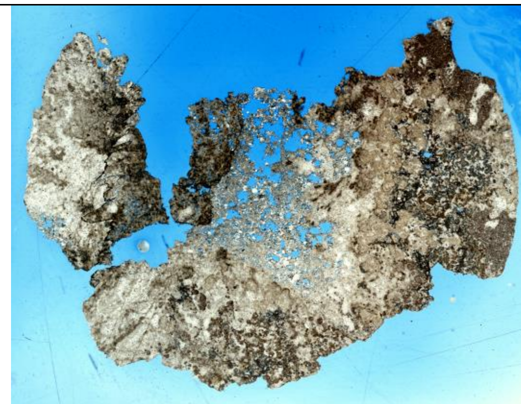
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grains, dark brown luminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): dark brown – orange-yellow luminescence. Some subzones occur.

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10496.5 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

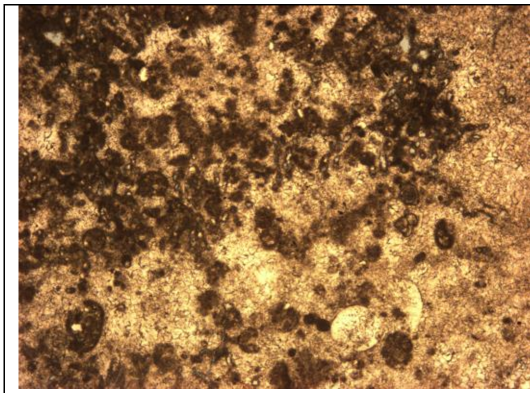
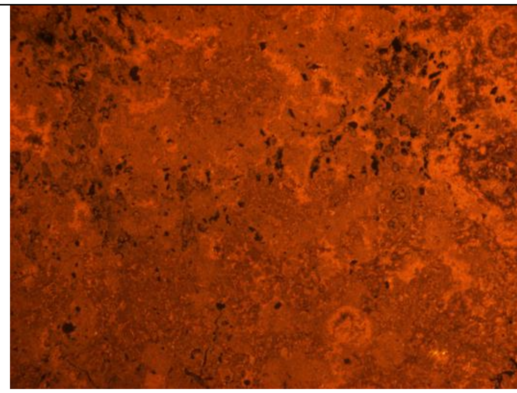
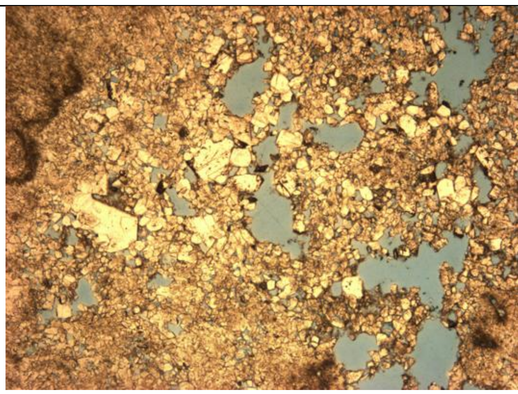
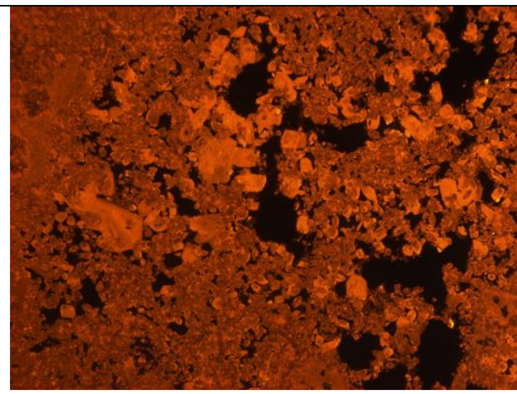
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera and ostracods (with sintaxial calcite cement). Some tubular features with hollow center occur. Peloid clusters are common. Diagenesis: mosaic calcite cement, and blocky calcite cement. Stylolites occur. Moderate to high calcite recrystallization and cementation. Late dissolution.

Pore type: Vuggy, intercrystalline and intragranular.

Porosity (image analysis): 23%

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10496.5 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

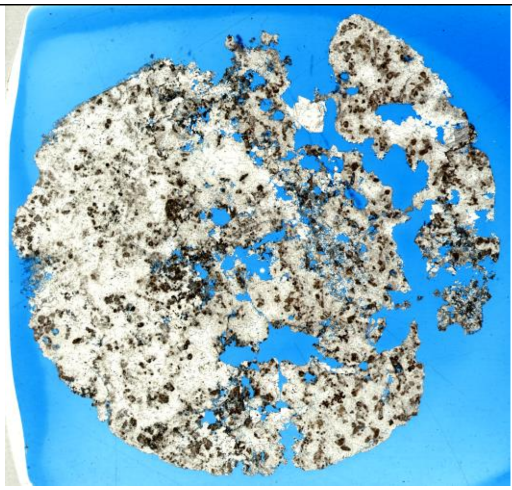
Cathodoluminescence image analysis:
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, orange-yellow luminescent.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10504.4 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

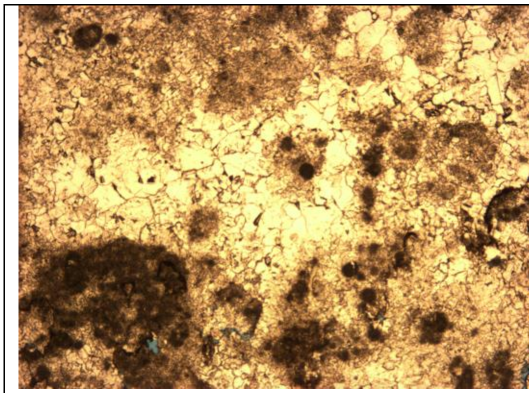
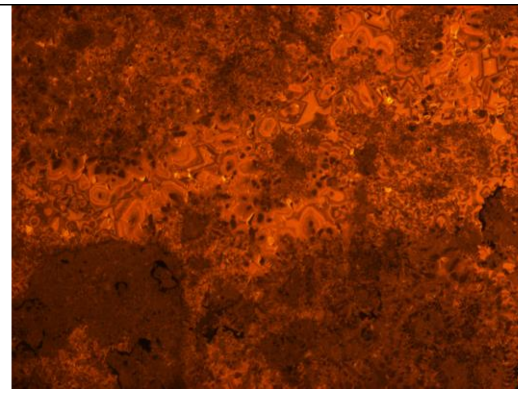
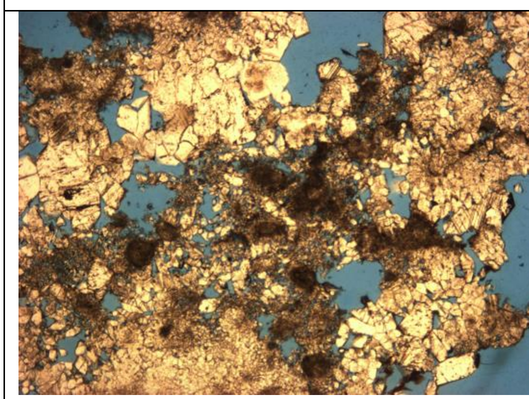
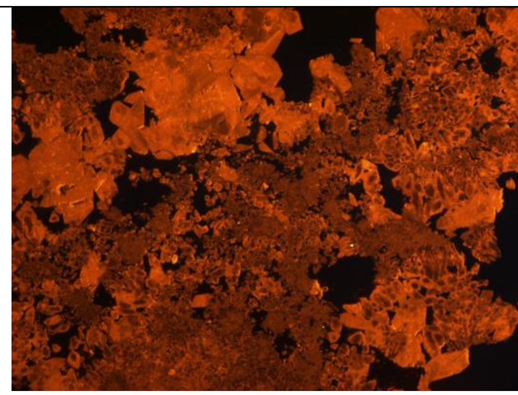
Description: Peloidal thrombolite. Peloid clusters are common. Some filamentous features occur. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Moderate to high calcite recrystallization and cementation. Late dissolution.

Pore type: Vuggy and intercrystalline.

Porosity (image analysis): 23%

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10504.4 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

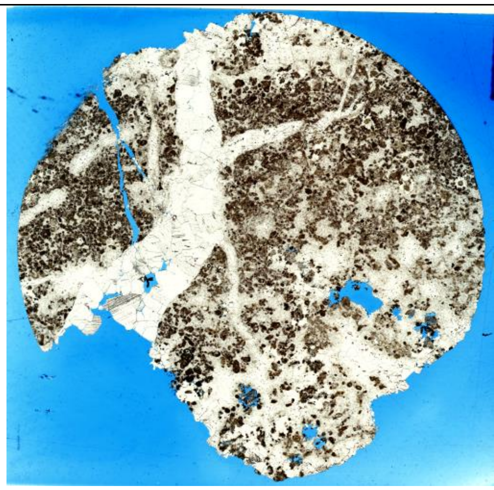
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grains, dark brown luminescent.
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, zoned (7 zones): dark brown – light brown – orange-yellow – light brown – orange yellow – light brown – dark brown luminescence.
Blocky calcite cement, orange-yellow luminescent.
Calcite recrystallization – some portions of the rock present a fine crystalline calcite texture, resulting from recrystallization. The calcite crystals present light brown to orange-yellow luminescence.

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10504.9 ft

Plug – 2.15 cm (diameter)

Macroscopic photo



Scanned thin section

Lithology: Peloidal thrombolite.

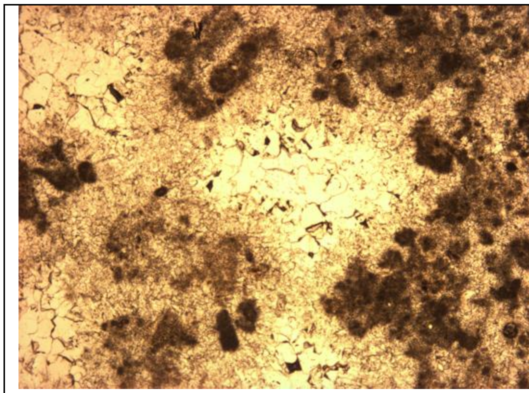
Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera, ostracods (with sintaxial calcite cement). Peloid clusters are common. Silt to very fine sand size quartz and muscovite grains occur. Diagenesis: fibrous calcite cement fringe rimming the grains, drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Open fractures and fractures cemented by calcite occur. Late dissolution.

Pore type: Vuggy and fracture.

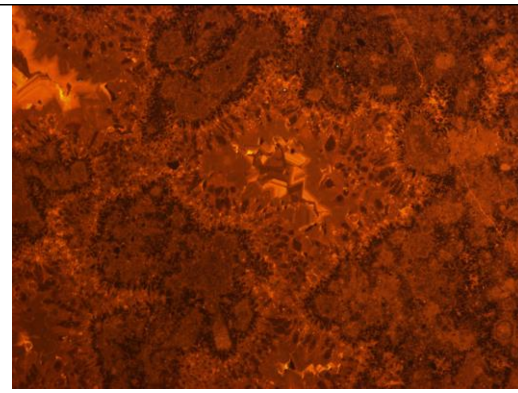
Porosity (image analysis): 5%

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

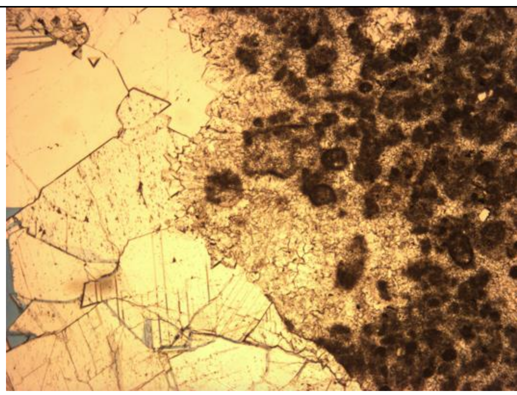
Depth: 10504.9 ft



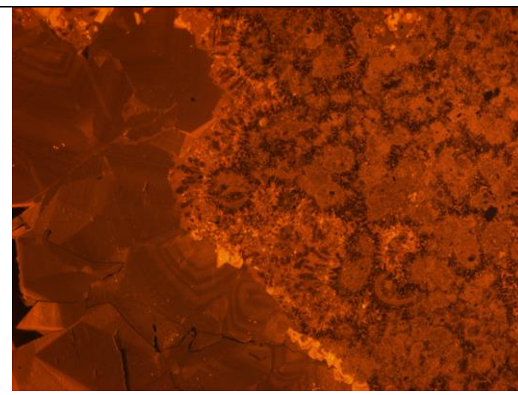
Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm



Cathodoluminesce image – same field of the picture on the left side



Photomicrography / Plane polarized light
Full horizontal axis = 3.5 mm

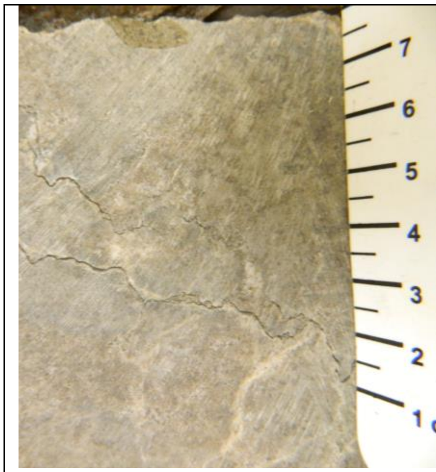


Cathodoluminesce image – same field of the picture on the left side

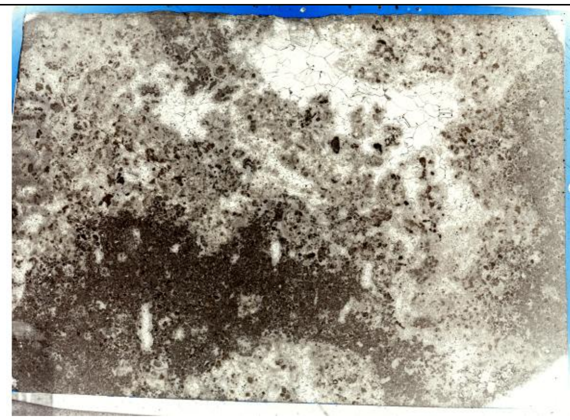
Cathodoluminescence image analysis:
Fibrous calcite fringe cement rimming grains, dark brown luminescent.
Drusy calcite fringe cement rimming the grains, with irregular zonation. It presents light brown to orange-yellow luminescence.
Mosaic calcite cement, zoned (2 zones): dark to light brown – orange-yellow luminescence.
Blocky calcite cement, zoned (2 zones): light brown – orange-yellow luminescence. Several subzones occur.

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10515 ft



Macroscopic photo



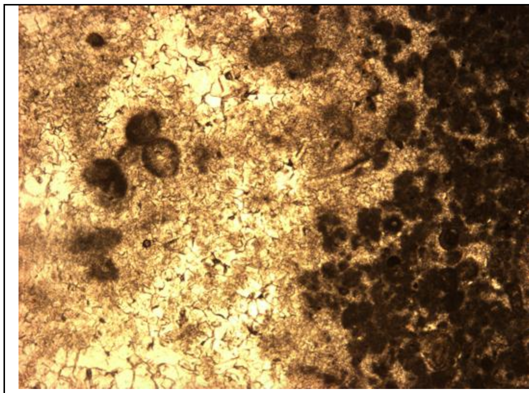
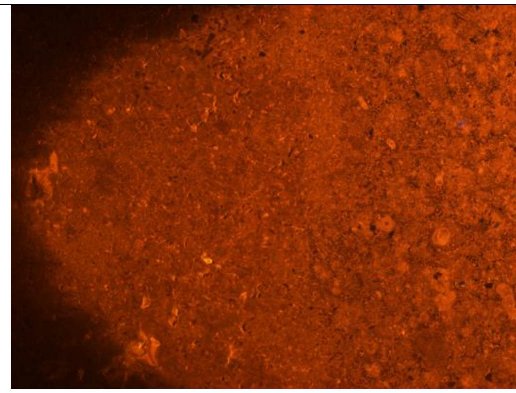
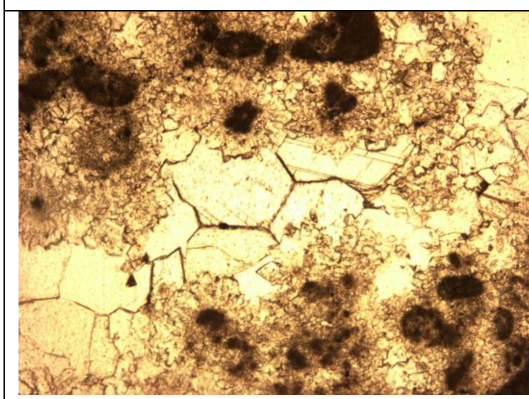
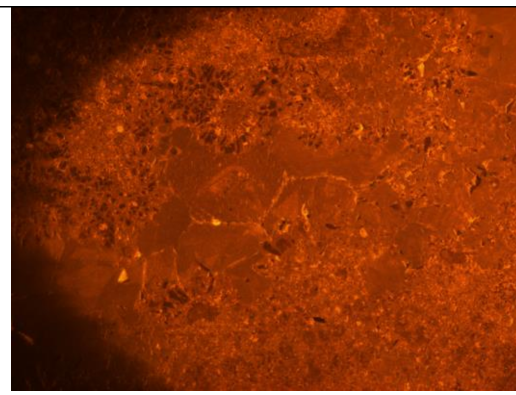
Scanned thin section

Lithology: Peloidal thrombolite.

Description: Peloidal thrombolite, with some bioclasts. The bioclasts are benthic foraminifera. Parts of the rock correspond to very dense peloid clusters. Very fine sand size quartz grains occur. Diagenesis: drusy calcite cement rimming the grains and peloid clusters, mosaic calcite cement, and blocky calcite cement. Large vugs cemented by calcite.

Little Cedar Creek Field **Well: 32** **Permit: 16238-B**

Depth: 10515 ft

 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side
 Photomicrography / Plane polarized light Full horizontal axis = 3.5 mm	 Cathodoluminesce image – same field of the picture on the left side

Cathodoluminescence image analysis:
Drusy calcite fringe cement rimming the grains, zoned (2 zones). The first zone (inner part of the crystal) has dark to light brown luminescence, and the second zone (edge) has orange-yellow luminescence.
Mosaic calcite cement, light brown to orange-yellow luminescent.
Blocky calcite cement, light brown luminescent.