THE MISSISSIPPIAN LEADVILLE LIMESTONE EXPLORATION PLAY, UTAH AND COLORADO – EXPLORATION TECHNIQUES AND STUDIES FOR INDEPENDENTS

(Contract No. DE-FC26-03NT15424)

DELIVERABLE 1-3A
CATALOG OF LEADVILLE POROSITY TYPES AND DIAGENESIS: LISBON FIELD, SAN JUAN COUNTY, UTAH

Submitted by

Utah Geological Survey
Salt Lake City, Utah 84114
2006

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INTRODUCTION

The Mississippian Leadville Limestone has produced over 53 million barrels (bbls) (8.4 million m^3) of oil from six fields in the northern Paradox Basin region, referred to as the Paradox fold and fault belt, of Utah and Colorado. All of these fields are currently operated by small, independent producers. There have been no new discoveries since the early 1960s, and only independent producers continue to explore for Leadville oil targets in the region, 85 percent of which is under the stewardship of the federal government. This environmentally sensitive, 7500-square-mile (19,400 km^2) area is relatively unexplored with only about 100 exploratory wells that penetrated the Leadville (less than one well per township), and thus the potential for new discoveries remains great.

The overall goals of this study are to (1) develop and demonstrate techniques and exploration methods never tried on the Leadville Limestone, (2) target areas for exploration, (3) increase deliverability from new and old Leadville fields through detailed reservoir characterization, (4) reduce exploration costs and risk especially in environmentally sensitive areas, and (5) add new oil discoveries and reserves. These goals are designed to assist the independent producers and explorers who have limited financial and personnel resources.

Exploring for the Leadville Limestone is high risk, with less than a 10 percent chance of success based on the drilling history of the region. Prospect definition requires expensive, three-dimensional (3D) seismic acquisition, often in environmentally sensitive areas. These facts make exploring difficult for independents that have limited funds available to try new, unproven techniques that might increase the chance of successfully discovering oil. We believe that one or more of the project activities will reduce the risk taken by an independent producer in looking for Leadville oil, not only in exploring but in trying new techniques.

Another problem in exploring for oil in the Leadville Limestone is the lack of published or publicly available geologic and reservoir information, such as regional facies maps, complete reservoir characterization studies, surface geochemical surveys, regional hydrodynamic pressure regime maps, and oil show data and migration interpretations. Acquiring this information or producing these studies would save funds and work effort, which independents simply do not possess or normally have available only for drilling. The technology, maps, and studies generated from this project will help independents to identify or eliminate areas and exploration targets prior to spending significant financial resources on seismic data acquisition and environmental litigation, and therefore increase the chance of successfully finding new accumulations of Leadville oil.

GEOLOGIC SETTING

Paradox Basin Overview

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado, with a small portion in northeastern Arizona and northwestern New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast-trending, evaporitic basin that predominately developed during the Pennsylvanian. The basin can generally be divided into three areas: the Paradox fold and fault belt in the north, the Blanding sub-basin in the south-southwest, and the Aneth platform in southeasternmost Utah (figure 1). The Mississippian Leadville Limestone is

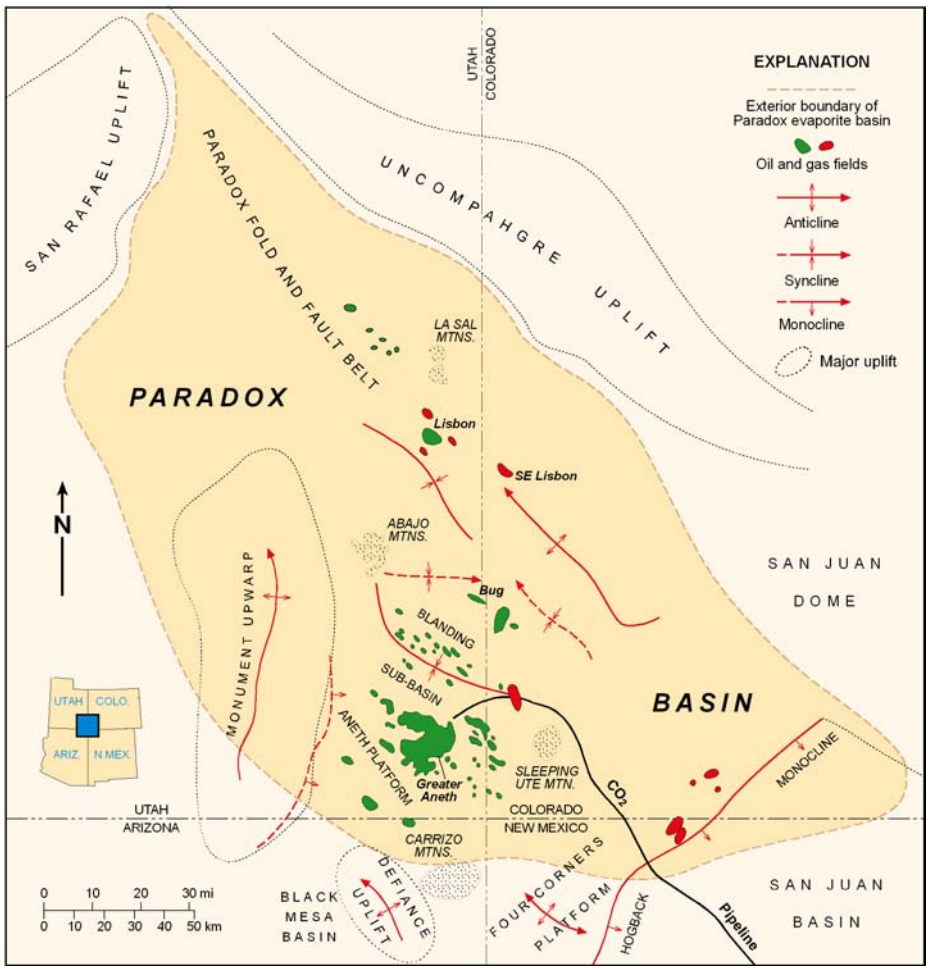


Figure 1. Oil and gas fields in the Paradox Basin of Utah, Arizona, and Colorado.

one of two major oil and gas reservoirs in the Paradox Basin, the other being the Pennsylvanian Paradox Formation (figure 2). Most Leadville production is from the Paradox fold and fault belt (figure 3).

The most obvious structural features in the basin are the spectacular anticlines that extend for miles in the northwesterly trending fold and fault belt. The events that caused these and many other structural features to form began in the Proterozoic, when movement initiated on high-angle basement faults and fractures 1700 to 1600 Ma (Stevenson and Baars, 1987). During Cambrian through Mississippian time, this region, as well as most of eastern Utah, was the site of typical, thin, marine deposition on the craton while thick deposits accumulated in the miogeocline to the west (Hintze, 1993). However, major changes occurred beginning in the Pennsylvanian. A series of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The southwestern flank of the

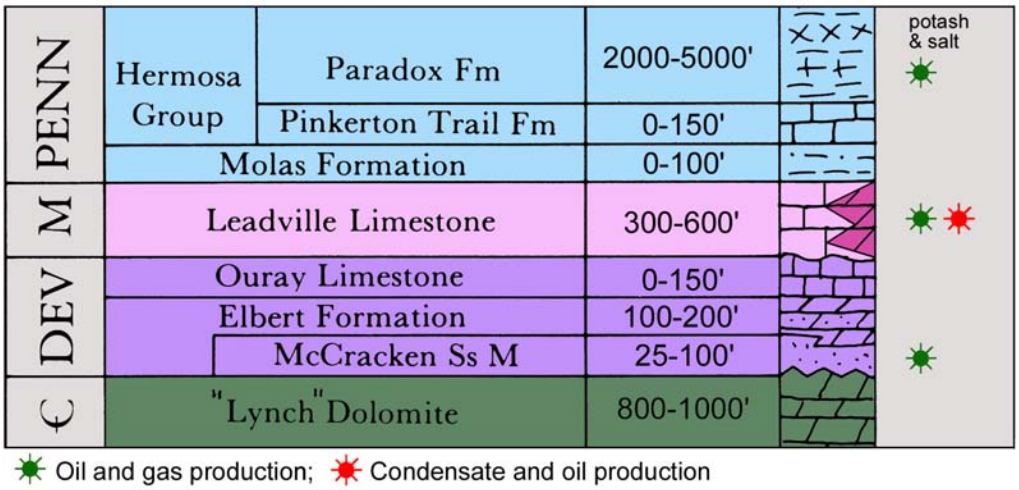


Figure 2. Stratigraphic column of a portion of the Paleozoic section determined from subsurface well data in the Paradox fold and fault belt, Grand and San Juan Counties, Utah (modified from Hintze, 1993).

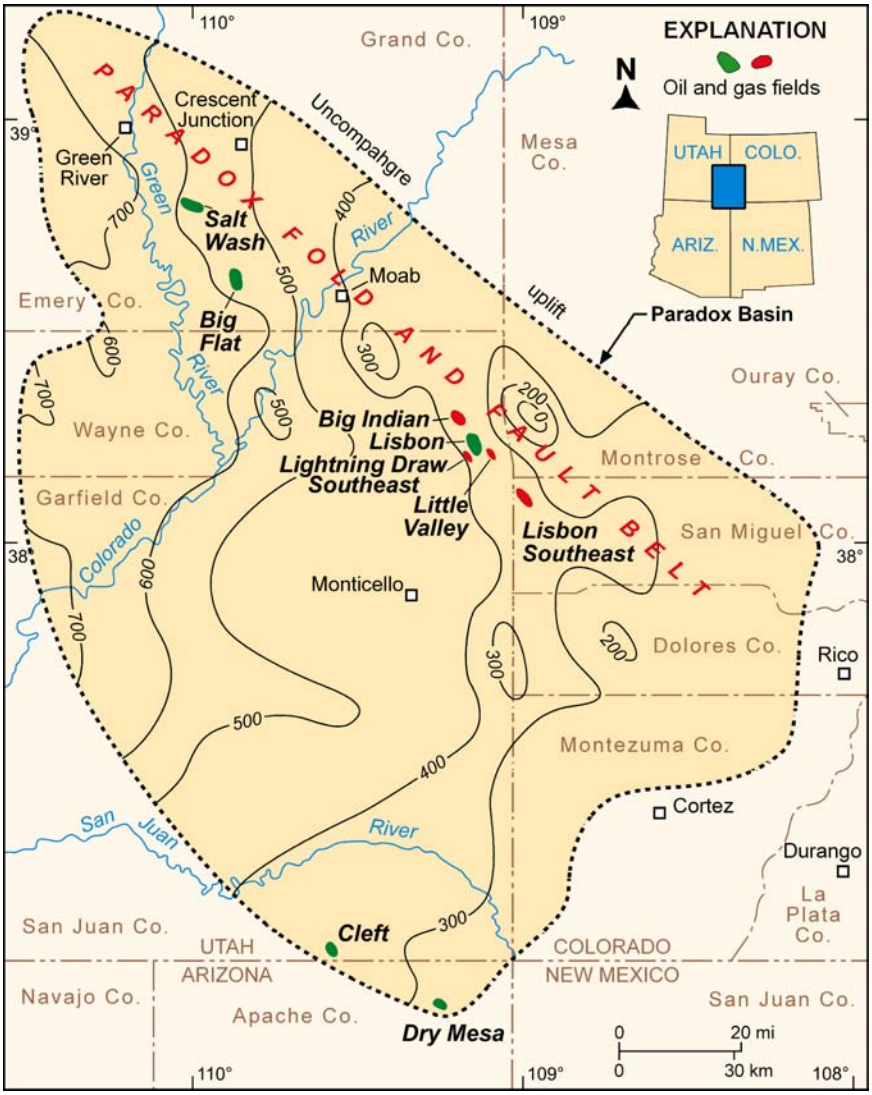


Figure 3. Location of fields that produce from the Mississippian Leadville Limestone, Utah, Arizona, and Colorado. Thickness of the Leadville is shown; contour interval is 100 feet (modified from Parker and Roberts, 1963).

Uncompahgre Highlands (uplift) is bounded by a large, basement-involved, high-angle, reverse fault identified from seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest – the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993).

The Paradox Basin is surrounded by other uplifts and basins, which formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1). The Paradox fold and fault belt was created during the Tertiary and Quaternary by a combination of (1) reactivation of basement normal faults, (2) salt flowage, dissolution and collapse, and (3) regional uplift (Doelling, 2000).

Most oil and gas produced from the Leadville Limestone is found in basement-involved, northwest-trending structural traps with closure on both anticlines and faults (figure 4). Lisbon, Big Indian, Little Valley, and Lisbon Southeast fields (figure 3) are sharply folded anticlines that close against the Lisbon fault zone. Salt Wash and Big Flat fields (figure 3), northwest of the Lisbon area, are unfaulted, east-west- and north-south-trending anticlines, respectively.

Regional Leadville Facies

The Mississippian (late Kinderhookian through Osagean to early Meramecian time) Leadville Limestone is a shallow, open-marine, carbonate-shelf deposit (figure 5). The western part of the Paradox fold and fault belt includes a regional, reflux-dolomitized, interior bank facies containing Waulsortian mounds (Welsh and Bissell, 1979). During Late Mississippian time, the entire carbonate platform in southeastern Utah and southwestern Colorado was subjected to subaerial erosion resulting in formation of a lateritic regolith (Welsh and Bissell, 1979). This regolith and associated carbonate dissolution is an important factor in Leadville reservoir potential (figure 6). Solution breccia and karstified surfaces are common, including possible local development of cavernous zones (Fouret, 1982, 1996).

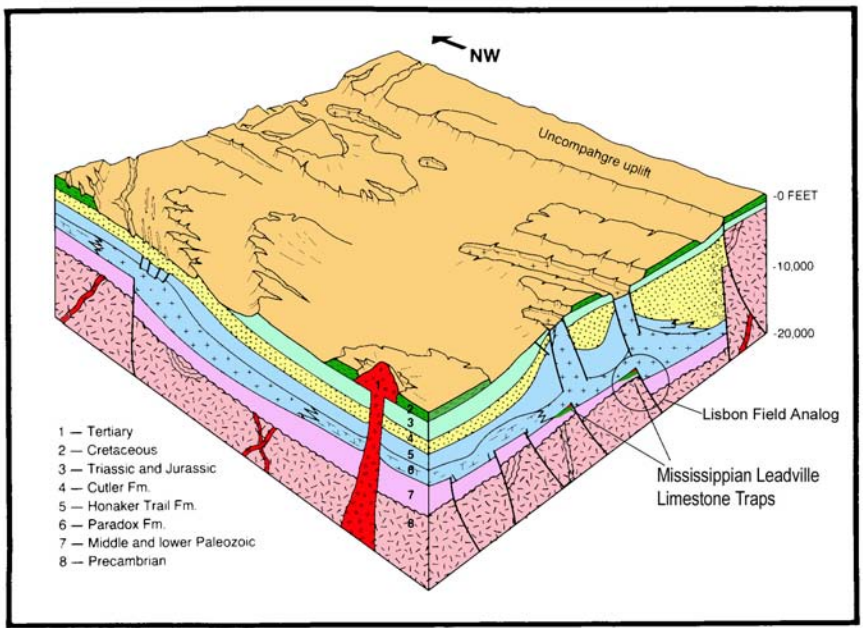


Figure 4. Schematic block diagram of the Paradox Basin displaying basement-involved structural trapping mechanisms for the Leadville Limestone fields (modified from Petroleum Information, 1984; original drawing by J.A. Fallin).

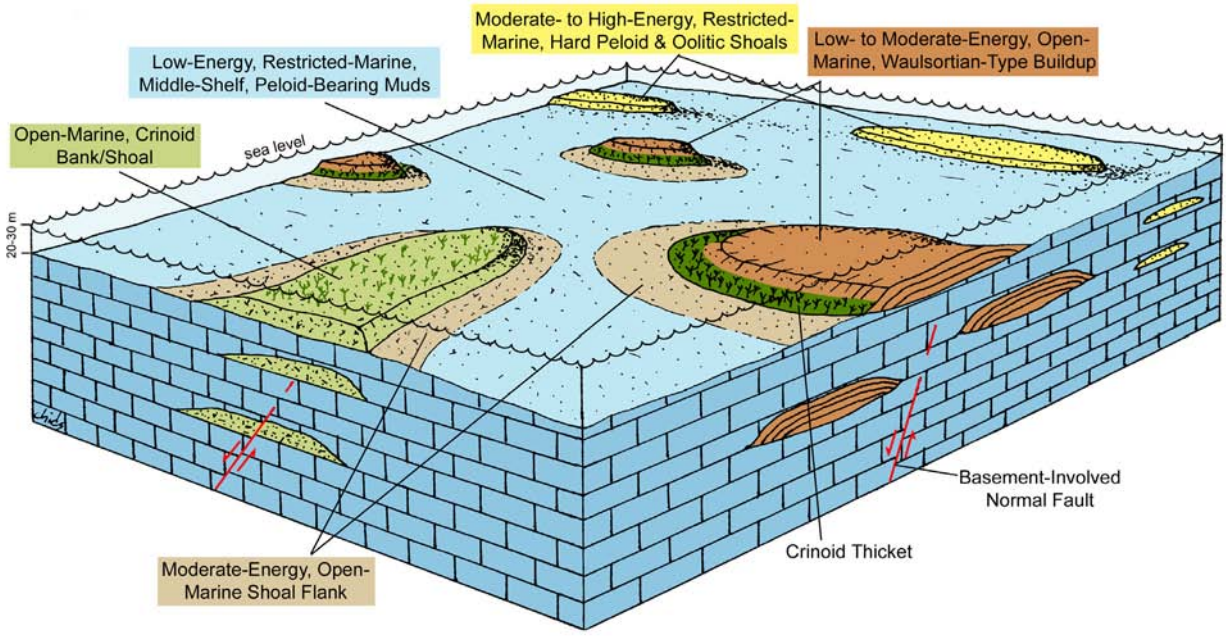


Figure 5. Block diagram displaying major depositional facies, as determined from core, for the Leadville Limestone, Lisbon field, San Juan County, Utah.

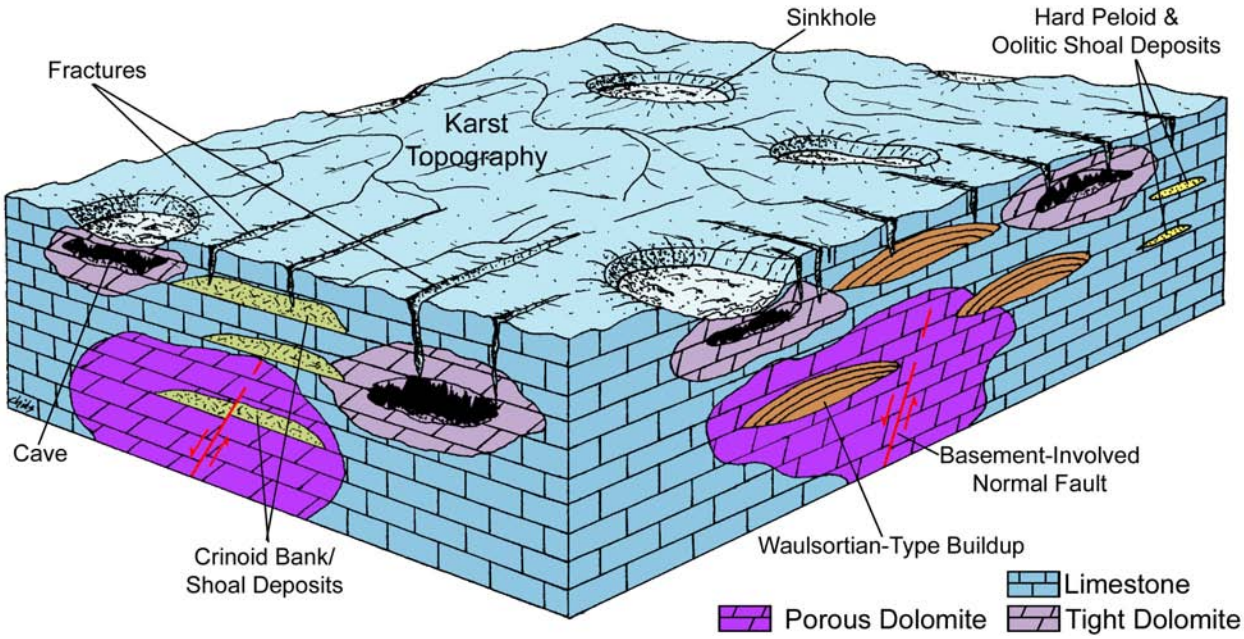


Figure 6. Block diagram displaying post-Leadville karst and fracture overprint.

The Leadville Limestone thins from more than 700 feet (230 m) in the northwest corner of the Paradox Basin to less than 200 feet (60 m) in the southeast corner (Morgan, 1993) (figure 3). Thinning is a result of both depositional onlap onto the Mississippian cratonic shelf and erosion. The Leadville is overlain by the Pennsylvanian Molas Formation and underlain by the Devonian Ouray Limestone (figure 2).

Periodic movement along northwest-trending faults affected deposition of the Leadville Limestone. Crinoid banks or mounds, the primary reservoir facies (figure 5), accumulated in shallow-water environments on upthrown fault blocks or other paleotopographic highs. In areas of greatest paleorelief, the Leadville is completely missing as a result of non-deposition or subsequent erosion (Baars, 1966).

The Leadville Limestone is divided into two members separated by an intraformational disconformity. The dolomitic lower member is composed of mudstone, wackestone, packstone, and grainstone deposited in shallow-marine, subtidal, supratidal, and intertidal environments (Fouret, 1982, 1996). Fossils include crinoids, fenestrate bryozoans, and brachiopods. Locally, mud-supported boundstone creates buildups or mud mounds (Waulsortian facies), involving growth of "algae" (Wilson, 1975; Ahr, 1989; Fouret, 1982, 1996). The upper member is composed of mudstone, packstone, grainstones (limestone and dolomite), and terrigenous clastics also deposited in subtidal, supratidal, and intertidal environments (Fouret, 1982, 1996). Fossils include crinoids and rugose coral. Reservoir rocks are crinoid-bearing packstone (Baars, 1966).

LISBON CASE-STUDY FIELD, SAN JUAN COUNTY, UTAH

Introduction and Field Synopsis

Lisbon field, San Juan County, Utah (figure 3) accounts for most of the Leadville oil production in the Paradox Basin. A wealth of Lisbon core, petrographic, and other data is available to the UGS. The reservoir characteristics, particularly diagenetic overprinting and history, and Leadville facies can be applied regionally to other fields and exploration trends in the Paradox Basin. Therefore, we selected Lisbon as the major case-study field for the Leadville Limestone project. This evaluation included data collection and thin section analysis which catalogued Leadville porosity types and diagenesis as summarized in this report.

The Lisbon trap is an elongate, asymmetric, northwest-trending anticline, with nearly 2000 feet (600 m) of structural closure and bounded on the northeast flank by a major, basement-involved normal fault with over 2500 feet (760 m) of displacement (Smith and Prather, 1981) (figure 7). Several minor, northeast-trending normal faults divide the Lisbon Leadville reservoir into segments.

Producing units in Lisbon field contain dolomitized crinoidal/skeletal grainstone, packstone, and wackestone fabrics. Diagenesis includes fracturing, autobrecciation, karst development, hydrothermal dolomite, and bitumen plugging. The net reservoir thickness is 225 feet (69 m) over a 5120-acre (2100 ha) area (Clark, 1978; Smouse, 1993). Reservoir quality is greatly improved by natural fracture systems associated with the Paradox fold and fault belt. Porosity averages 6 percent in intercrystalline and moldic networks enhanced by fractures; permeability averages 22 millidarcies (mD). The drive mechanism is an expanding gas cap and gravity drainage; water saturation is 39 percent (Clark, 1978; Smouse, 1993). The bottom-hole temperature ranges from 133 to 189ºF (56-87ºC).

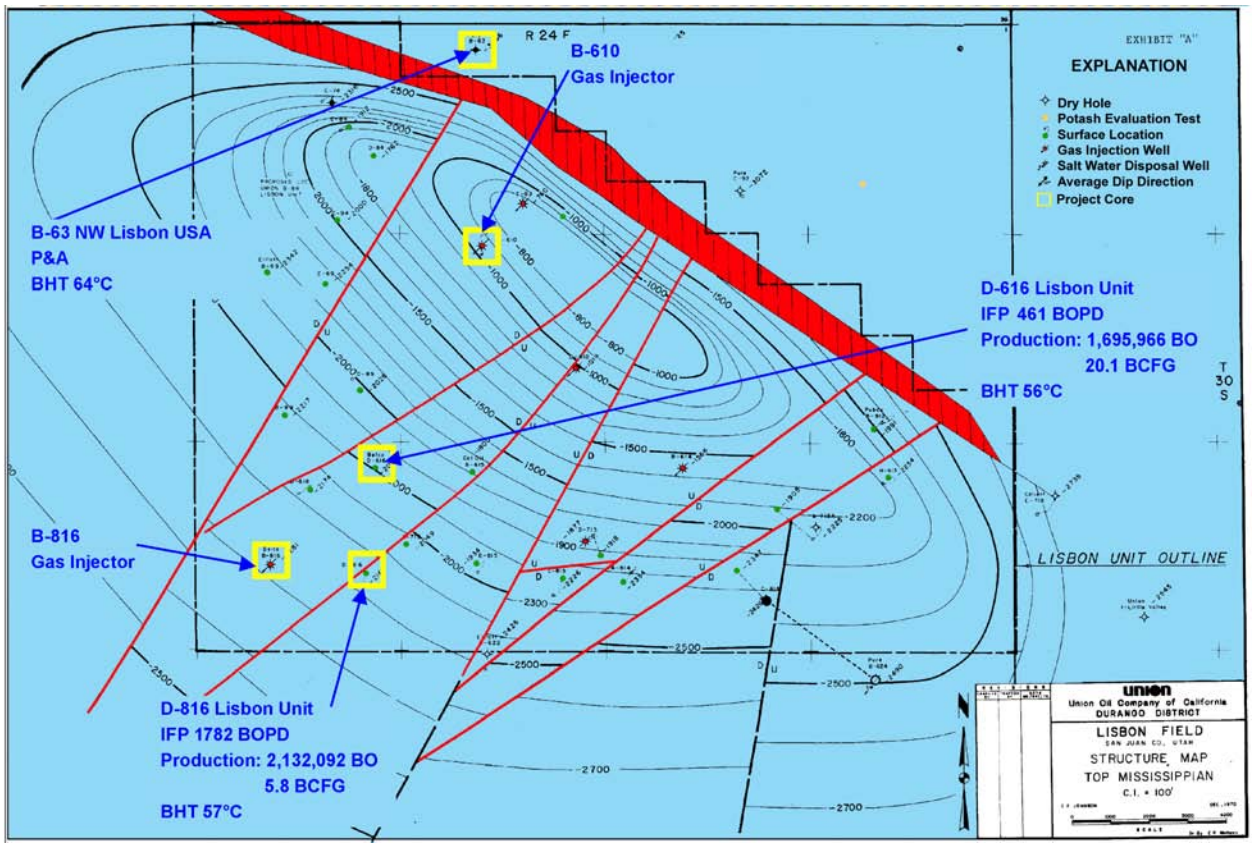


Figure 7. Top of structure of the Leadville Limestone, Lisbon field, San Juan County, Utah (modified from C.F. Johnson, Union Oil Company of California files, 1970; courtesy of Tom Brown, Inc.). Also displayed are wells from which cores were described in this study.

Lisbon field was discovered in 1960 with the completion of the Pure Oil Company No. 1 NW Lisbon USA well, NE1/4NW1/4 section 10, T. 30 S., R. 24 E., SLBL&M (figure 7), with an initial flowing potential of 179 bbls of oil per day (BOPD) (28 m^3) and 4376 thousand cubic feet of gas per day (124 MCMPD). The original reservoir field pressure was 2982 pounds per square inch (psi [20,560 kPa]) (Clark, 1978). There are currently 22 producing (or shut-in wells), 11 abandoned producers, five injection wells (four gas injection wells and one water/gas injection well), and four dry holes in the field. Cumulative production as of March 31, 2006, was 51,145,231 bbls of oil (8,132,092 m^3), 785.4 billion cubic feet of gas (BCFG) (22.2 BCMG) (cycled gas), and 50,073,622 bbls of water (7,961,706 m^3) (Utah Division of Oil, Gas and Mining, 2006). Gas that was re-injected into the crest of the structure to control pressure decline is now being produced.

Three factors create reservoir heterogeneity within productive zones: (1) variations in carbonate fabrics and facies, (2) diagenesis (including karstification), and (3) fracturing. The extent of these factors and how they are combined affect the degree to which they create barriers to fluid flow.

Data Collection and Compilation

Geophysical well logs, cores and cuttings, reservoir data, various reservoir maps, and other information from Lisbon field development wells were collected by the UGS. Well locations, formation tops, production data, completion tests, basic core analysis, porosity and permeability data, and other data were compiled and entered in a database developed by the UGS. This database, INTEGRAL, is a geologic-information database that links a diverse set of geologic data to records using MS Access™. The database is designed so that geological information, such as lithology, petrophysical analyses, or depositional environment, can be exported to software programs to produce cross sections, strip logs, lithofacies maps, various graphs, and other types of presentations. The database containing information on the geological reservoir characterization case study as well as later regional correlations will be available at the UGS's Leadville Limestone project Web site at the conclusion of the project.

DIAGENETIC ANALYSIS

Techniques

The diagenetic fabrics and porosity types found in the various hydrocarbon-bearing rocks of Lisbon field can be indicators of reservoir flow capacity, storage capacity, and untested potential. In order to determine the diagenetic histories of the various Leadville rock fabrics, including both reservoir and non-reservoir, 82 thin sections of representative samples were selected from the conventional cores for petrographic description and possible geochemical analysis (table 1 and Appendix). Carbonate fabrics were again determined according to Dunham's (1962) and Embry and Klovan's (1971) classification schemes. Pores and pore systems were described using Choquette and Pray's (1970) classification (figure 8). Each thin section was photographed with additional close-up photos of (1) typical preserved primary and secondary pore types, (2) cements, (3) sedimentary structures, (4) fractures, and (5) where present, pore-plugging anhydrite and halite.

Typical geochemical and petrographic techniques that may be later employed include (1) epifluorescence and cathodoluminescence petrography for the sequence of diagenesis, (2) stable carbon and oxygen isotope analysis of diagenetic components such as cementing minerals and different generations of dolomites, (3) strontium isotopes for tracing the origin of

Table 1. List of well conventional slabbed core examined and described from the Leadville Limestone, Lisbon field, San Juan County, Utah.*

Well	Location	API No.	Core Interval (feet)	Thin Sections
Lisbon D-816	NE SE 16, T. 30 S., R. 24 E.	43-037-16253	8417-8450	15
Lisbon D-616	C NE NE 16, T. 30 S., R. 24 E.	43-037-15049	8300-9110	13
NW Lisbon B-63	NE NW 3, T. 30 S., R. 24 E.	43-037-11339	9934-10,005	14
Lisbon B-816	NE SW 16, T. 30 S., R. 24 E.	43-037-16244	8463-8697	22
Lisbon B-610	NE NW 10, T. 30 S., R. 24 E.	43-037-16469	7590-8001.5	18

*Repository: Utah Core Research Center.

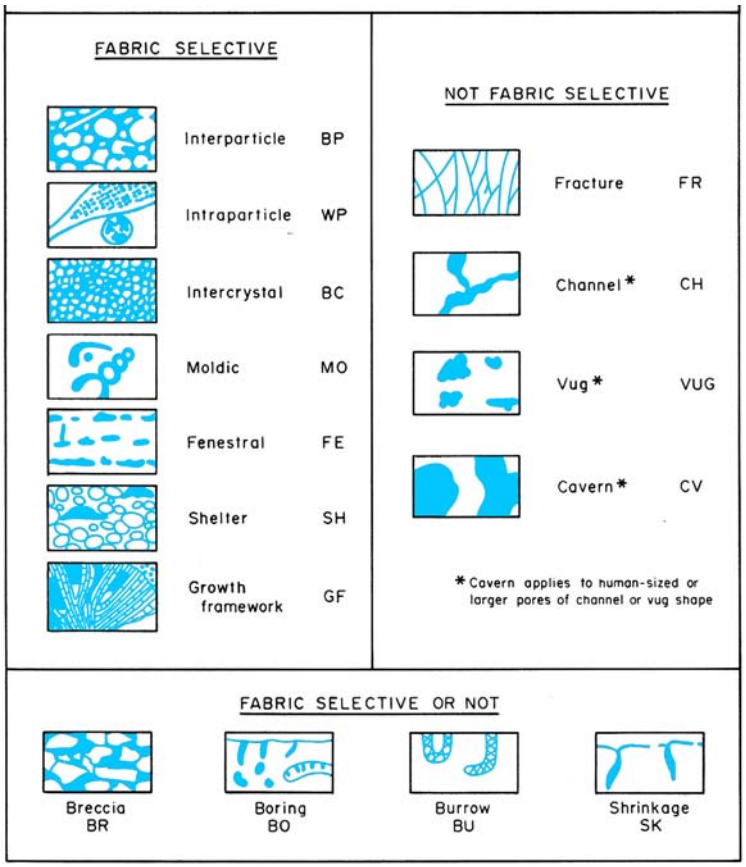


Figure 8. Classification of pores and pore systems in carbonate rocks (Choquette and Pray, 1970).

fluids responsible for different diagenetic events, (4) scanning electron microscope analysis of various dolomites to determine reservoir quality of the dolomites as a function of diagenetic history, (5) fluid inclusion evaluation to determine the temperatures of secondary dolomite formation and the salinity of the original brines, and (6) analysis of the bitumen plugging pore throats.

Reservoir diagenetic fabrics and porosity types of these carbonate buildups were analyzed to (1) determine the sequence of diagenetic events, (2) predict facies patterns, and (3) provide data input for reservoir modeling studies. Diagenetic characterization focused on reservoir heterogeneity, quality, and compartmentalization within the field. All depositional, diagenetic, and porosity information will be combined with the production history in order to analyze the potential for the Leadville Limestone regionally.

Results

An ideal diagenetic sequence based on our analysis of Leadville thin sections from Lisbon field is presented in figure 9. The early diagenetic history of the Leadville sediments, including some early dolomitization and leaching of skeletal grains, resulted in low-porosity and/or low-permeablility rocks. Most of the porosity and permeability associated with hydrocarbon production was developed during deeper subsurface dolomitization and dissolution. Some of these important subsurface processes are shown with the purple bars in figure 9 and are discussed below generally in the order in which they occur.

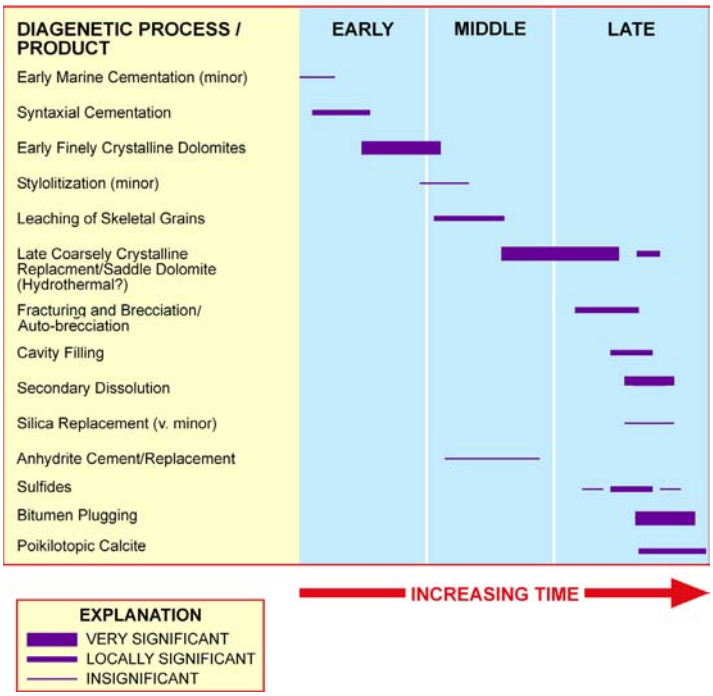


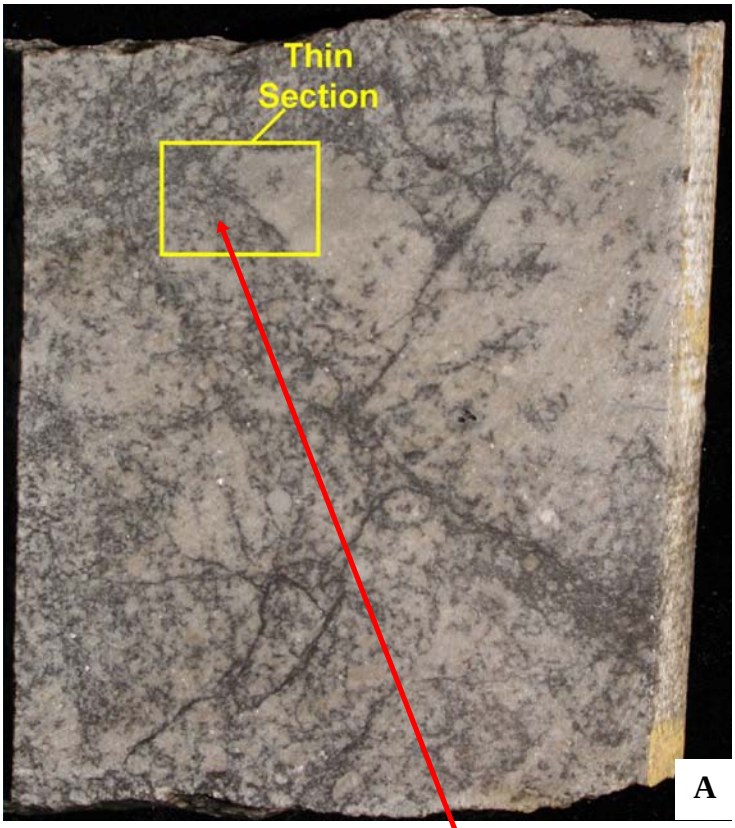
Figure 9. Ideal diagenetic sequence through time based on thin section analysis, Leadville Limestone, Lisbon field.

Syntaxial Cement

Syntaxial cementation is an early diagentic event (figure 9). This type of cementation is found exclusively as overgrowths on echinoderms (figure 10), in this case dominantly crinoids deposited in banks or shoals of the open-marine facies. Crinoid ossicles often appear to be "floating" in cement with little evidence of compaction. If extensive syntaxial cementation has occurred, the result will be a significant reduction of porosity. However, from the thin sections evaluated, it appears that this diagenetic process has been relatively minor.

Dolomitization and Porosity Development

Two basic types of dolomite have been seen within the cores (figure 11A). The first type consists of "stratigraphic" dolomites that preserve original depositional grains and textures. Very fine (<5 μ), interlocking dolomite crystals with no intercrystalline pore spaces are the norm (figure 11B). Commonly, this type of dolomite can be correlated across the field in several relatively thin intervals. The second type of dolomite is a much coarser (>100 μ), later replacement of all types of limestone and earlier "stratigraphic" dolomites (figure 11C). Crosscutting relationships with carbonate bedding and variable dolomite thickness across the field are common. Petrographically, the coarse, second dolomite type consists of crystals with thick, cloudy, inclusion-rich cores and thin, clear overgrowths with planar crystal terminations. Commonly, these coarser dolomites show saddle dolomite characteristics of curved crystal shape (figure 12) and sweeping extinction under cross-polarized lighting. Predating or concomitant with saddle dolomite formation, are pervasive leaching and dissolution episodes that crosscut the carbonate host rocks, and result in late vugs, as well as extensive microporosity. Pyrobitumen appears to coat most intercrystalline dolomite, as well as dissolution pores associated with the second type of dolomite. Most reservoir rocks within Lisbon field appear to be associated with the second, late type of dolomitization and associated leaching events.



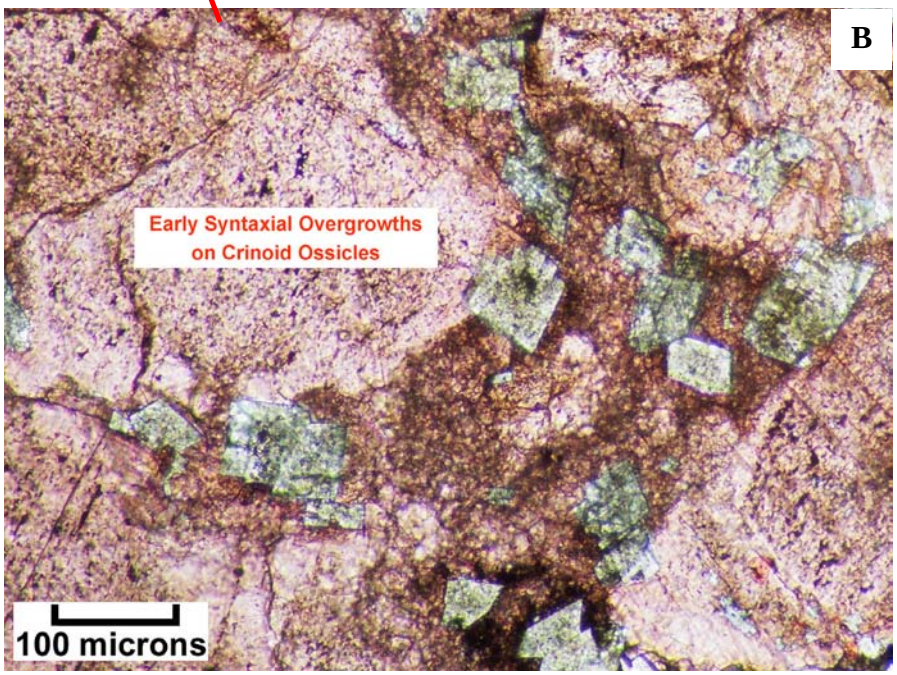


Figure 10. (A) Conventional core slab showing partially dolomitized crinoidal/grainstone packstone. (B) Representative photomicrograph (plane light) from the core in A, showing early syntaxial overgrowths on crinoid ossicles. Crinoids appear cloudy due to inclusions of organic matter. Lisbon No. D-816 well (figure 7), 8435 feet, porosity = 7.5 percent, permeability = 0.03 mD.

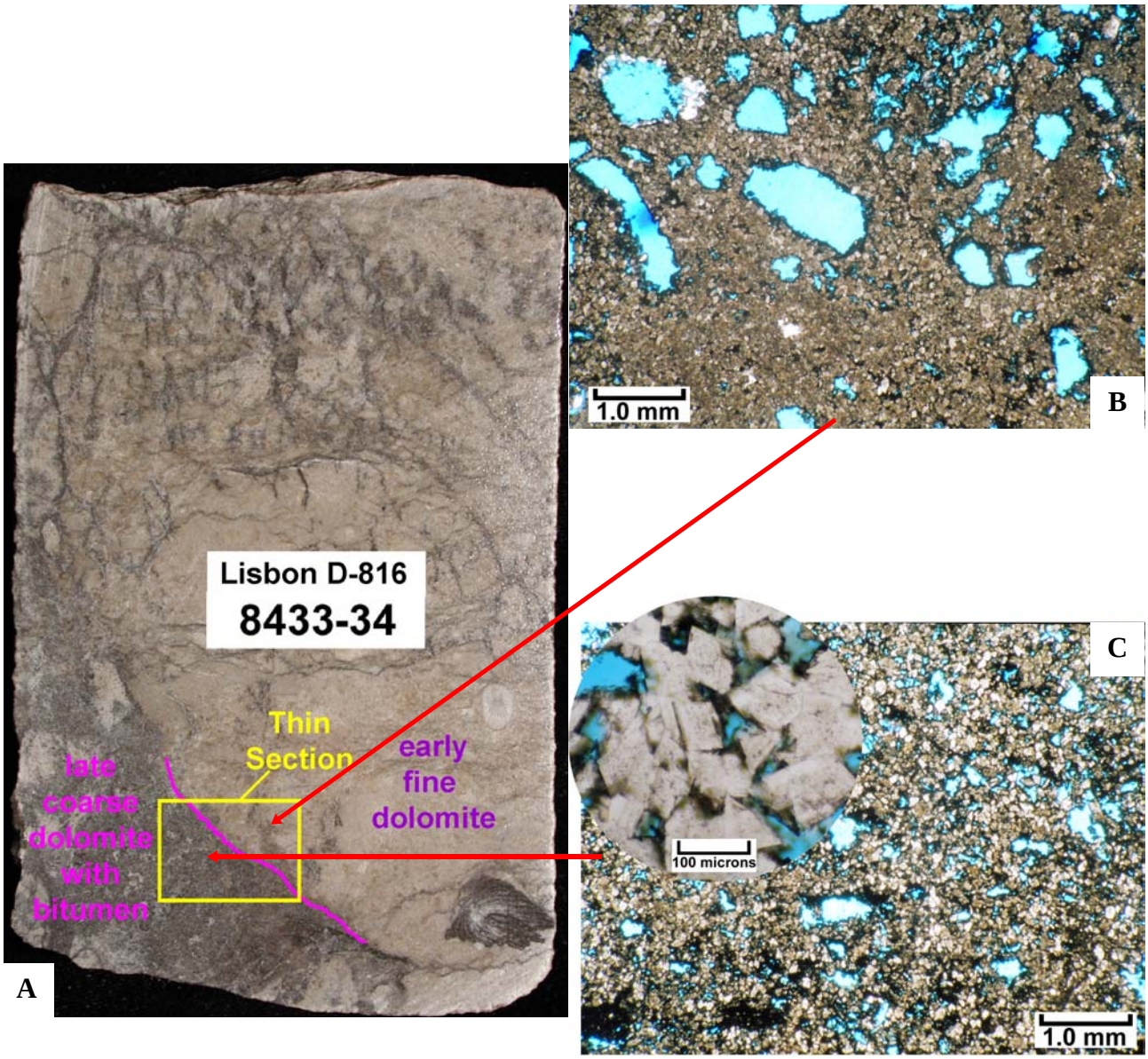


Figure 11. *(A) Conventional core slab showing tight, fabric selective, very fine early dolomite as well as porous, coarser late dolomite. Most of the late dolomite crystal faces are coated with films of pyrobitumen. Hence, most of the areas of crosscutting coarser dolomites are black in this view. Note the position of the thin section which captures the contact between low-permeability early dolomite (upper right part of the thin section box) and high-permeability late, "black dolomite" (lower left). (B) Representative photomicrograph (plane light) of the tight, finely crystalline dolomite with isolated grain molds. Most of this fabric selective dolomite formed early in the diagenetic history of the skeletal/peloid sediment. (C) Representative photomicrograph (plane light) of the coarser, replacement dolomite (both euhedral rhombs and a few "saddle" overgrowths [close-up view in inset]). The black (opaque) areas are the result of pyrobitumen films and minor sulfide precipitation. Lisbon No. D-816 well (figure 7), 8433 feet, porosity = 2 percent, permeability <0.1 mD.*

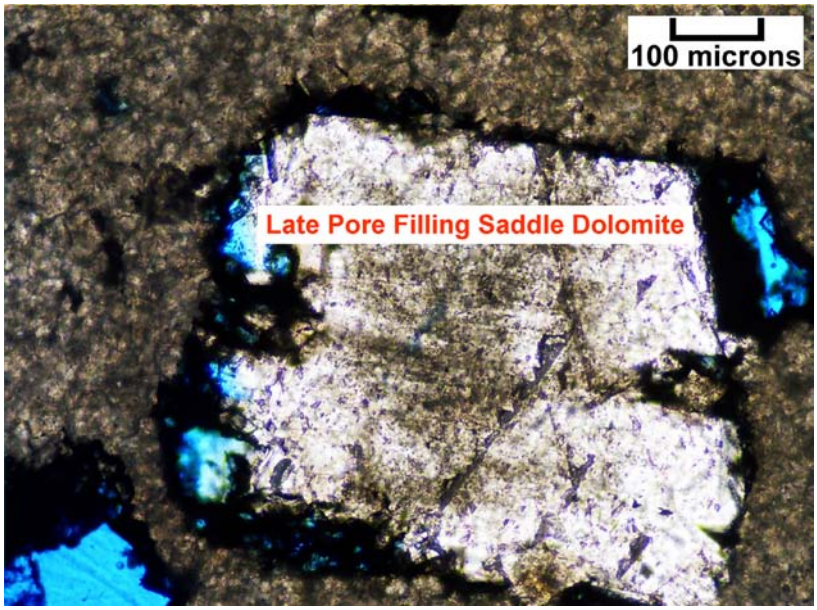


Figure 12. Thin section photomicrograph (plane light) showing a saddle dolomite cement that is filling a large pore (either a grain mold or small vug). The dolomite cement has been surrounded by a coating of pyrobitumen (in black). It appears that this late dolomite cement has been partially dissolved or corroded around its margins after the bitumen coating. Lisbon No. D-816 well (figure 7), 8421 feet, porosity = 8.3 percent, permeability = 34 mD.

Later dolomitization, saddle dolomite, and dolomite cement precipitation may have occurred at progressively higher temperatures, that is, hydothermal dolomite. Hydrothermal events can improve reservoir quality by increasing porosity through dolomitiztion, leaching, development of microporosity, and natural fracturing (forming breccia) kept open with various minerals (Smith, 2004). Hydrothermal dolomite precipitates under temperature and pressure conditions greater than the ambient temperature and pressure of the host limestone (Davies, 2004). The result can be the formation of large, diagenetic-type hydrocarbon traps. Further geochemical analysis is planned to confirm the presence of hydrothermal dolomite in the Leadille Limestone at Lisbon field and the reservoir potential it would imply for the Paradox Basin.

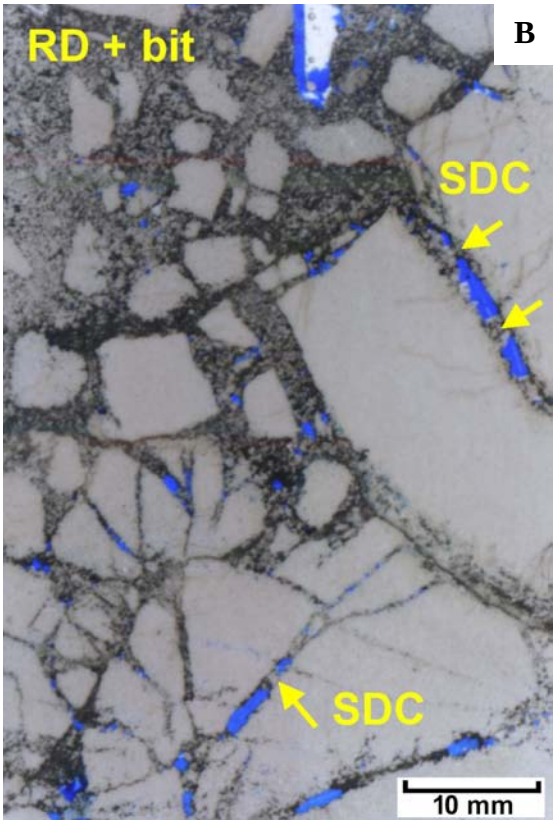
Post-Burial Brecciation

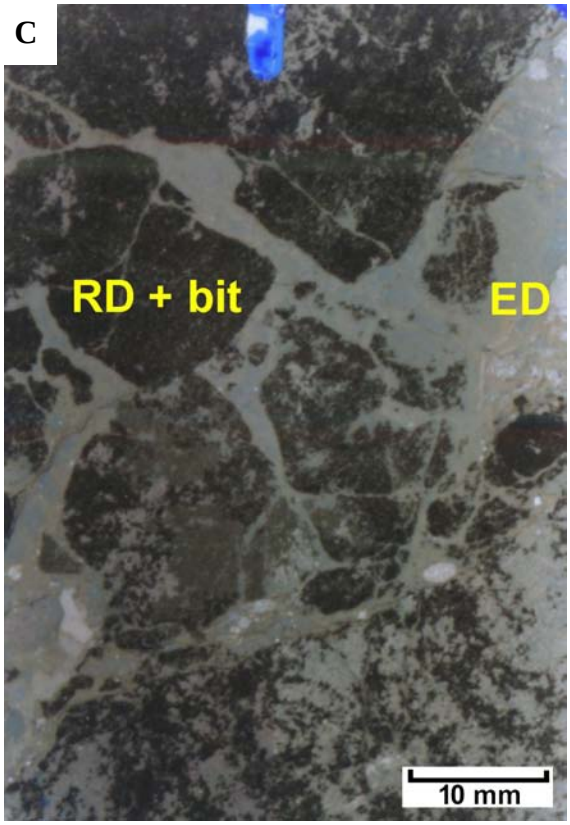
Fracturing and brecciation are quite common within Lisbon field (figure 13 through 15). However, brecciation is most commonly caused by hydrofracturing, creating an explosive-looking, pulverized rock. The result yields an "autobreccia" as opposed to a collapse breccia. Clasts within an autobreccia have basically remained in place and moved very little. Dolomite clasts are commonly surrounded by solution-enlarged fractures partially filled with coarse rhombic and saddle dolomites that are coated with pyrobitumen. Areas between clasts can exhibit very good intercrystalline porosity or microporosity, or they may be filled by low-porosity saddle dolomite cement. Intense bitumen plugging is concurrent or takes place shortly after brecciation. "Reike," or stair-step fractures, are occasionally present, reflecting shear and the explosive fluid expulsion from the buildup of pore pressure.

Karst-Related Processes

Sediment-filled cavities are relatively common throughout the upper third of the Leadville in Lisbon field (figure 16). These cavities or cracks were related to karstification of the exposed Leadville (figure 6). Infilling of the cavities by detrital carbonate and siliciclastic

Figure 13. (A) Conventional core slab showing a dolomite "autobreccia" in which the clasts have moved very little. The black material surrounding the in-place clasts is composed of porous late dolomite coated with pyrobitumen. (B) Entire thin section overview from the core in A, showing low-porosity, white dolomite clasts surrounded by solution-enlarged fractures partially filled with coarse rhombic (RD) and saddle dolomites that are coated with pyrobitumen (bit). These black areas between the clasts exhibit very good intercystalline porosity. The open fracture segments (in blue) between clasts are bridged by coarse, saddle dolomite cements (SDC). (C) Entire thin section overview from the core in A, of black, porous, dolomite clasts surrounded in this case by coarse, low-porosity saddle dolomites. These white dolomites were probably early dolomite (ED) filling space between possible "hydrofactured" replacement dolomites. The black porous dolomites are mostly rhombic (planar) dolomites (RD) coated with thin films of pyrobitumen (bit). Lisbon NW USA No. B-63 well (figure 7), 9938.3 feet, porosity = 6.4 percent, permeability = 54 mD.





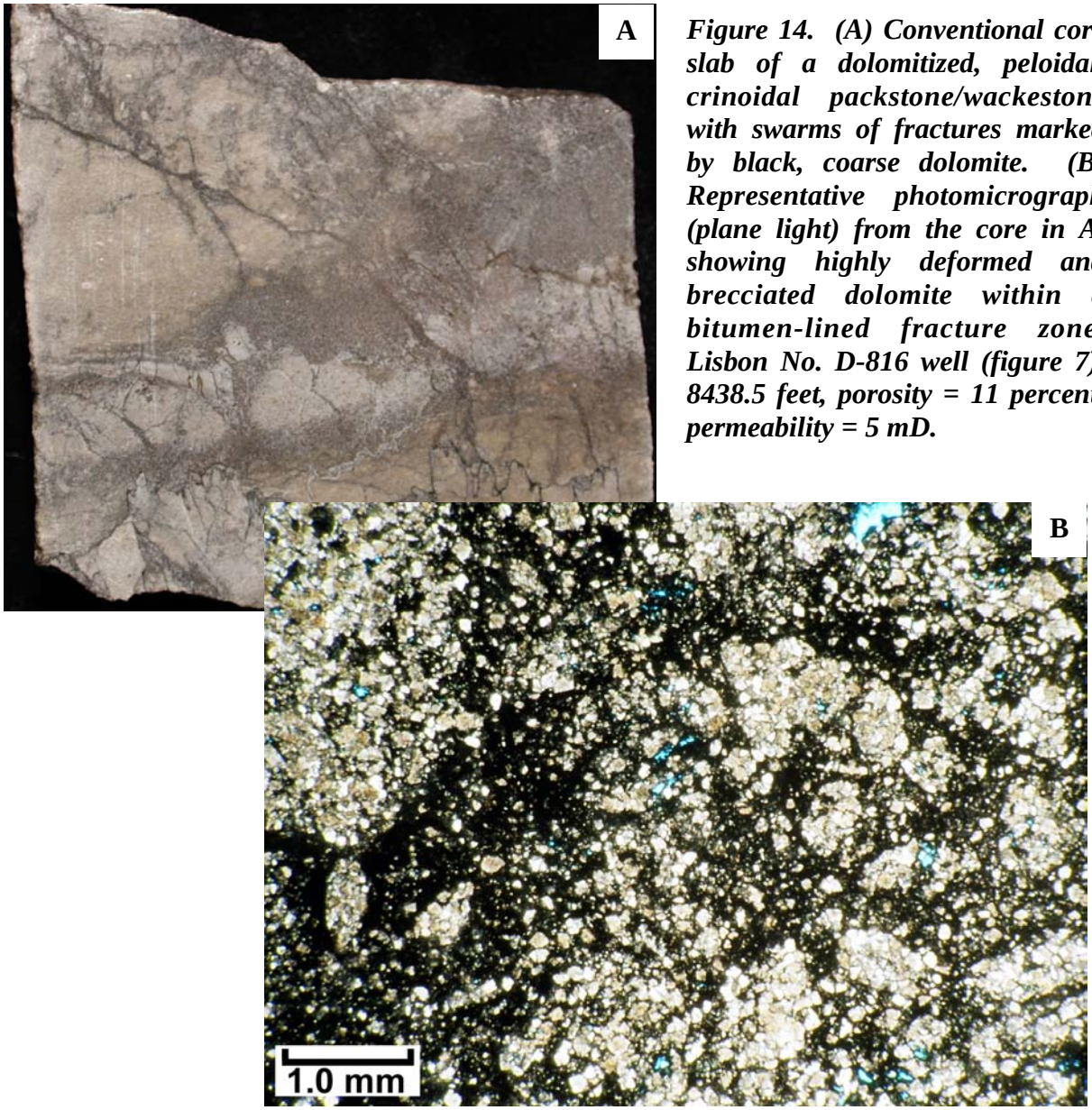
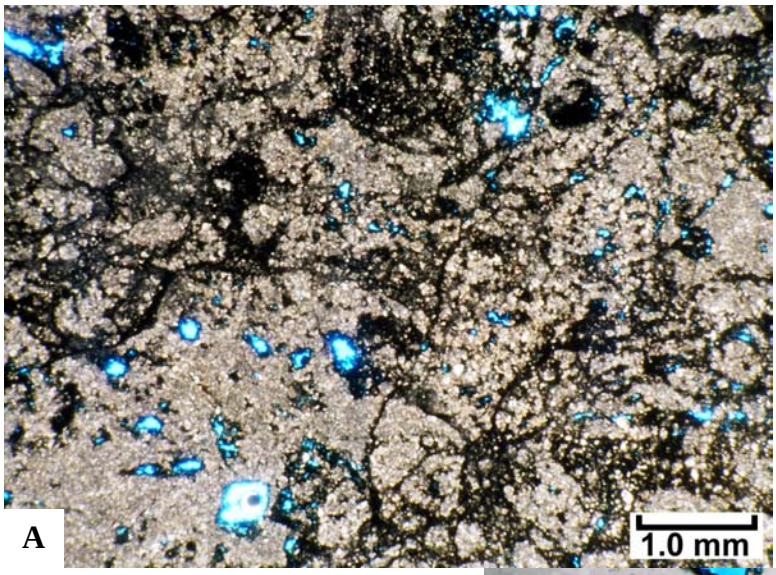


Figure 14. (A) Conventional core slab of a dolomitized, peloidal/ crinoidal packstone/wackestone with swarms of fractures marked by black, coarse dolomite. (B) Representative photomicrograph (plane light) from the core in A, showing highly deformed and brecciated dolomite within a bitumen-lined fracture zone. Lisbon No. D-816 well (figure 7), 8438.5 feet, porosity = 11 percent, permeability = 5 mD.

sediments occurred before the deposition of the Pennsylvanian Molas Formation. The contact between the transported material and the country rock can be sharp, irregular, and corroded with small associated mud-filled fractures. The transported material consists of poorly sorted detrital quartz grains (silt size), chert fragments, carbonate clasts, clay, and a few clasts of mud balls (desiccated and cracked). The carbonate muds infilling the karst cavities are largely dolomitized (a later diagenetic process), very finely crystalline, and non-porous. The infilling some times displays a crude layering in places.

Other karst features observed in Leadville thin sections include the presence of "root hair" – thin, sinuous cracks filled with dolomitized mud. Clasts also may have a coating of clay. Both of these features are evidence of a possible, nearby soil zone.



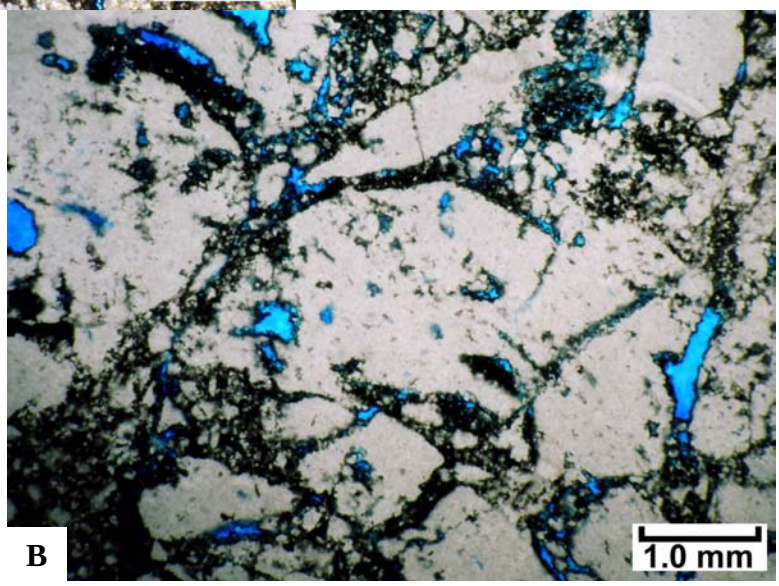


Figure 15. (A) Representative photomicrograph (plane light), showing another example of intensely brecciated dolomite within a bitumen-lined fracture zone. (B) Representative photomicrograph (plane light), showing large autoclasts and bitumen in an intensely brecciated dolomite. Lisbon No. D-816 well (figure 7), 8423 feet, porosity = 10.5 percent, permeability = 47 mD.

Anhydrite and Sulfides

Dissolution pores (molds) and pore throats are in places plugged or bridged by lathes of late anhydrite cement (figure 17). In the photomicrographs studied, complete plugging of porosity was rare and the overall presence of anhydrite cement and replacement was relatively insignificant for the Leadville Limestone in the Lisbon reservoir rocks.

Possible sulfide minerals are observed in several Leadville thin sections (figure 18). They appear as small, angular, brassy crystals. They tend to line moldic pores or form on, and between, rhombic dolomite crystals. These minerals may be associated with hydrothermal fluids responsible for the coarse saddle dolomites. They may also be related to copper mineralization found a few miles to the east at the Lisbon Valley copper mine. The copper deposit includes fracture filling and disseminated copper sulfides (chalcocite, bornite, and covellite) replacing dead oil and pyrite (J.P. Thorson, Summo Minerals, verbal communication, September 20, 1996). The exact nature and composition of the sulfide minerals at Lisbon field is unknown and will be examined in closer detail with the scanning electron microscope later in the reservoir characterization.

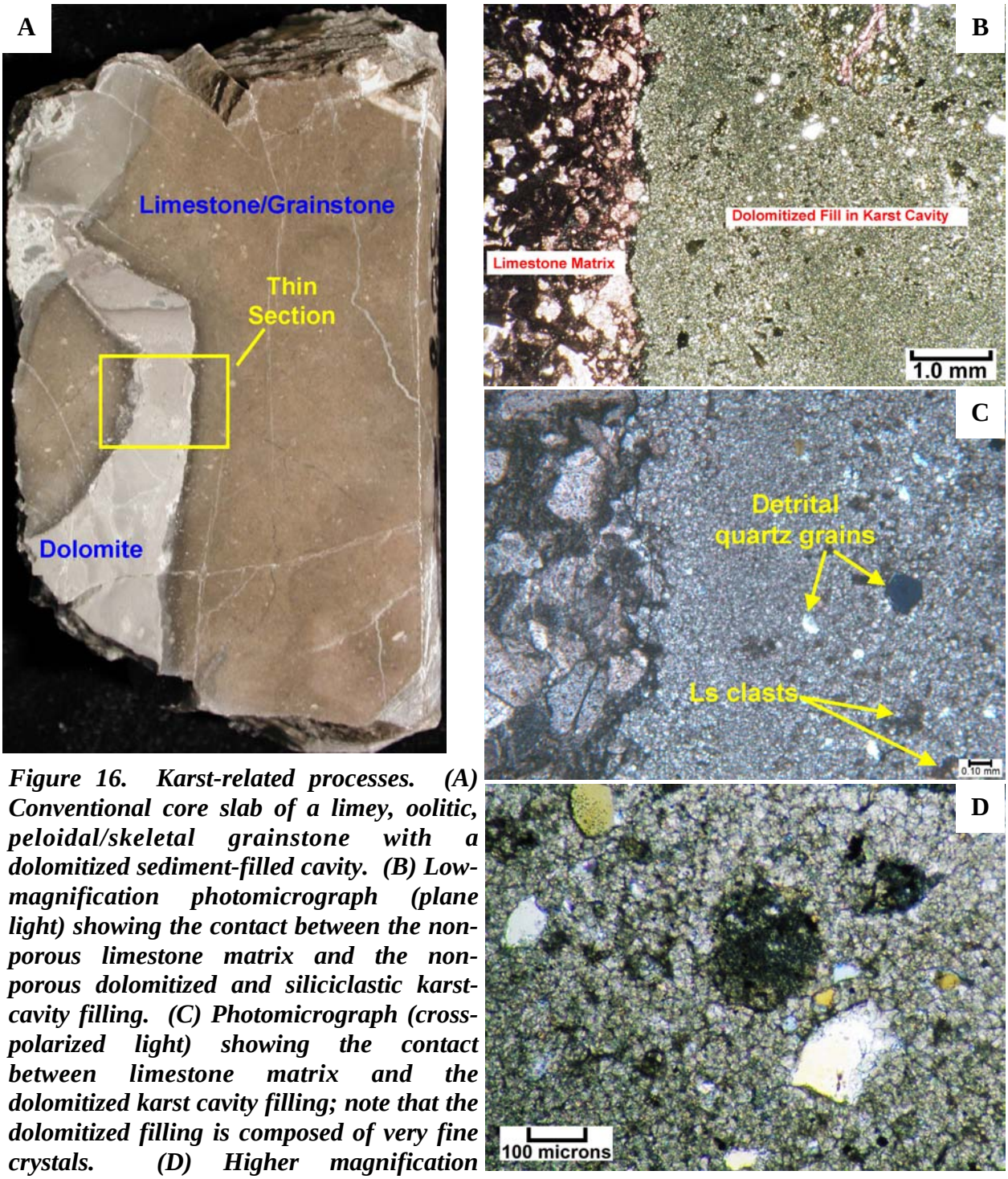


Figure 16. Karst-related processes. (A) Conventional core slab of a limey, oolitic, peloidal/skeletal grainstone with a dolomitized sediment-filled cavity. (B) Low-magnification photomicrograph (plane light) showing the contact between the non-porous limestone matrix and the non-porous dolomitized and siliciclastic karst-cavity filling. (C) Photomicrograph (cross-polarized light) showing the contact between limestone matrix and the dolomitized karst cavity filling; note that the dolomitized filling is composed of very fine crystals. (D) Higher magnification photomicrograph (plane light) of detrital quartz grains (white) and small carbonate clasts (dark gray) within the tight, dolomitized mud filling the karst cavity. Lisbon No. D-616 well (figure 7), 8308-8309 feet, porosity = 1.2 percent, permeability = 11.1 mD.

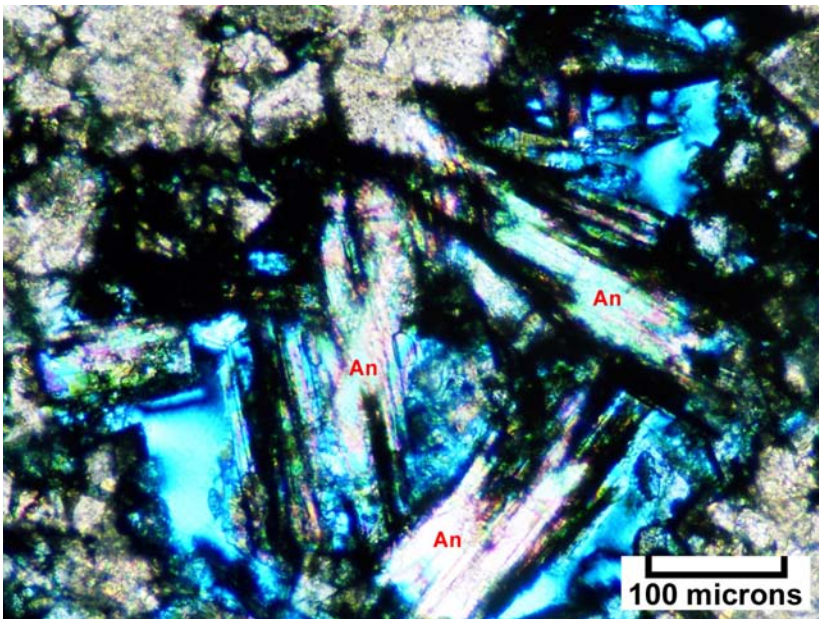


Figure 17. Representative photomicrograph (cross-polarized light) showing lathes of late anhydrite cement (An, in the pastel colors) filling a dissolution pore. The unfilled portions of the pore are seen in the blue areas. Lisbon No. D-816 well (figure 7), 8426-8431 feet, porosity = 11.1 percent, permeability = 15 mD.

Late Macrocalcite

Macrocalcite, also referred to as poikilotopic calcite, is viewed as late, large, slow-growing crystals (figure 19), and although not extensive in the Leadville at Lisbon field, its presence provides some significant insight into the diagenetic history of these rocks. The example shown in figure 19 shows an autobreccia that retains small amounts of early, finely crystalline (tight) dolomite replaced by "mini-saddles" and medium crystalline (euhedral) dolomite. Early during this sample's history, it had intercrystalline porosity that was enhanced by dissolution to form additional pores. Subsequently, the pores were partially filled with coarsely crystalline saddle dolomite and bitumen. Finally, the remaining solution-enlarged pores were occluded by poikilotopic calcite. Poikilotopic calcite may have formed as oil-field water rose, following the gas/condensate cap.

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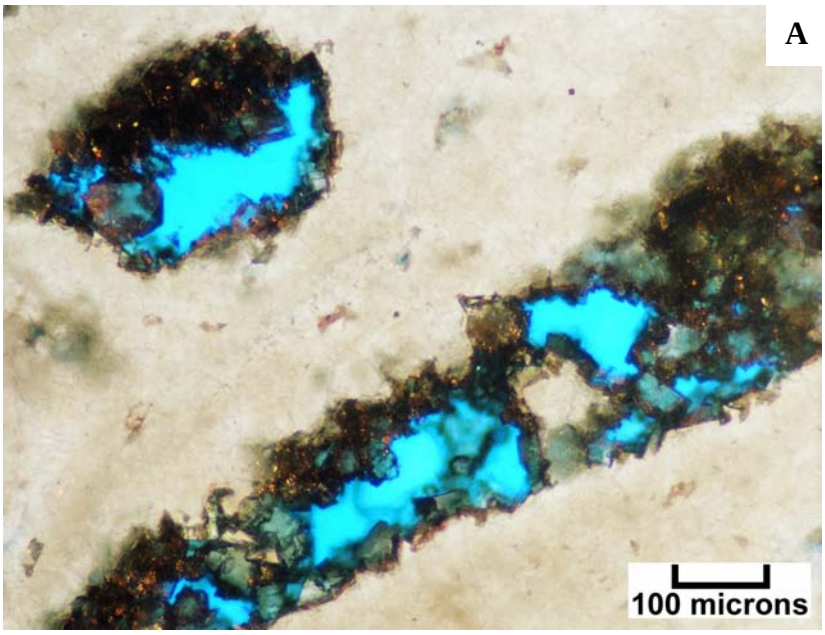
Core and petrophysical data were provided by Tom Brown, Inc. (now Encana Corp.). James Parker of the Utah Geological Survey (UGS) drafted figures and Cheryl Gustin, UGS, formatted the manuscript. This report was reviewed by David Tabet and Robert Ressetar of the UGS.



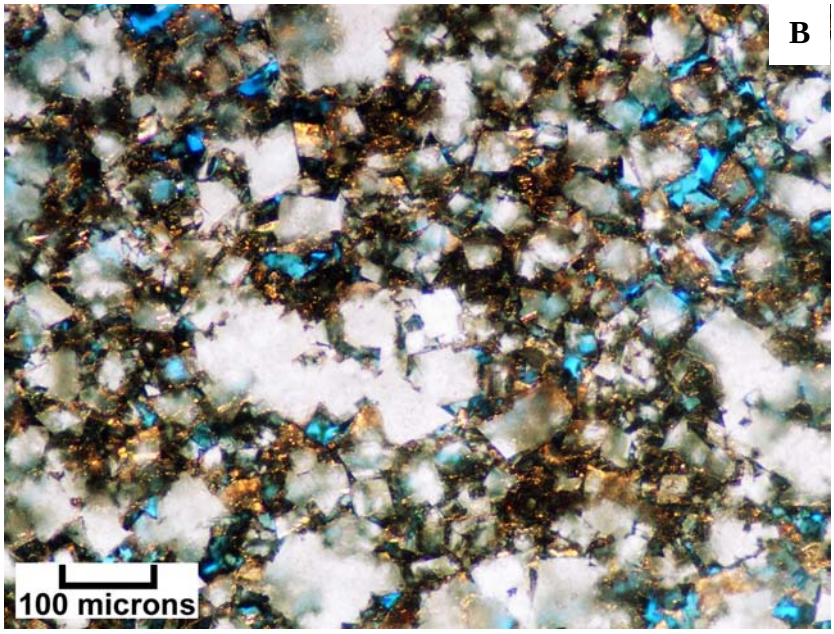


Figure 18. Possible sulfide mineralization within the Leadvlle Limestone at Lisbon field. (A) Photomicrograph ("white card" and reflected light) showing moldic pore lined with black pyrobitumen and possible sulfide minerals (small brassy crystals). Lisbon No. D-816 well (figure 5), 8444-8445 feet, porosity = 6.6 percent, permeability = 7 mD. (B) Photomicrograph ("white card" and reflected light) showing black pyrobitumen and sulfide minerals on and between rhombic dolomite crystals (in white and light gray). Lisbon No. D-816 well (figure 7), 8446-8447 feet, porosity = 13 percent, permeability = 59 mD.

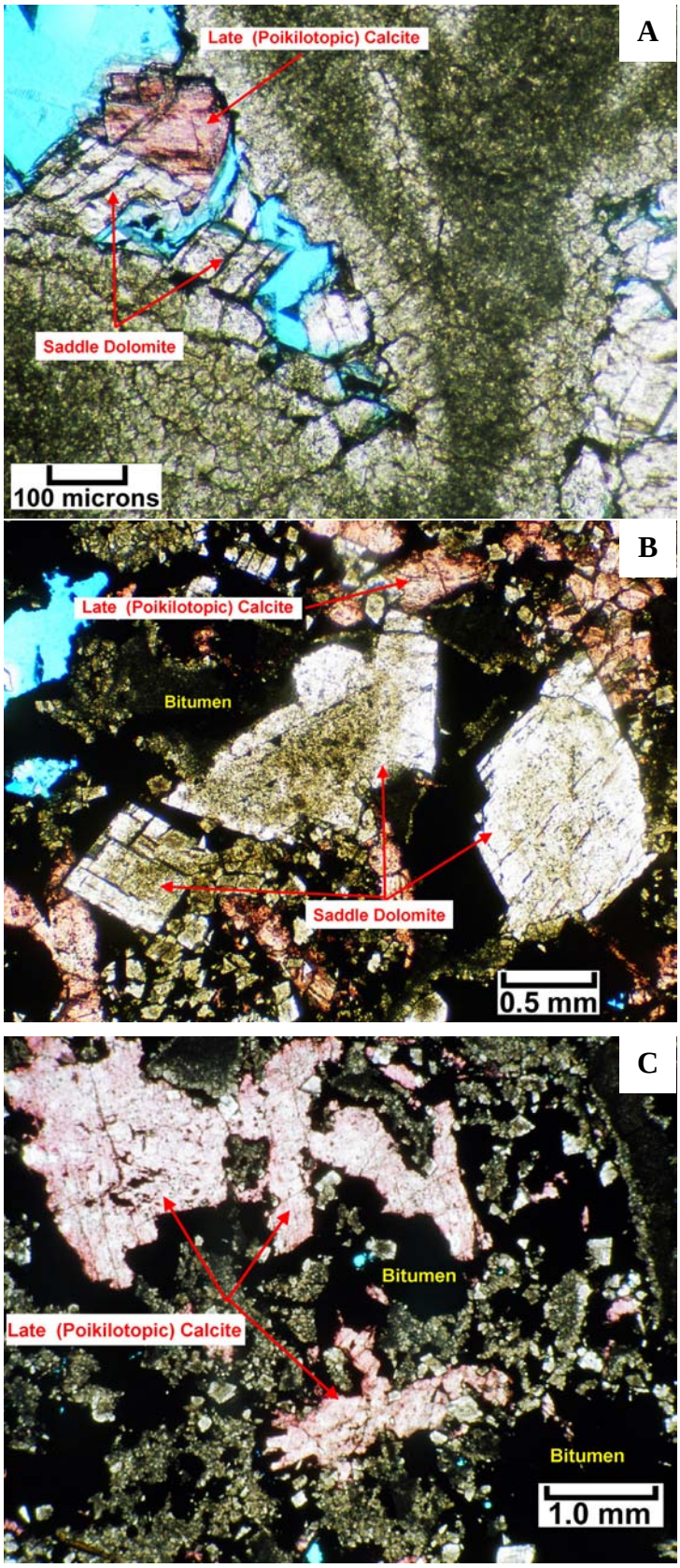


Figure 19. (A) Photomicrograph (plane light) showing saddle dolomite crystals and a single late macrocalcite crystal (stained red) filling a portion of a large dissolution pore (blue) in a finely crystalline dolomite matrix. Northwest Lisbon No. B-63 well (figure 5), 9991.8 feet, porosity = 6.2 percent, permeability = 0.3 mD. (B) Photomicrograph (plane light) showing coarse rhombic and saddle replacement dolomite that displays cloudy cores and clear rims. Dissolution pores are filled with pyrobitumen (black) and late macrocalcite (stained red). An additional episode of dissolution can be seen as the open (blue) pores that appear to post-date most of the pyrobitumen emplacement. (C) Dissolution pores filled completely with bitumen (black) and late macrocalcite (stained red) that resemble saddle dolomite molds. B and C from Northwest Lisbon No. B-63 well (figure 7), 10,004-10,005 feet, porosity = 14.4 percent, permeability = 1.9 mD.

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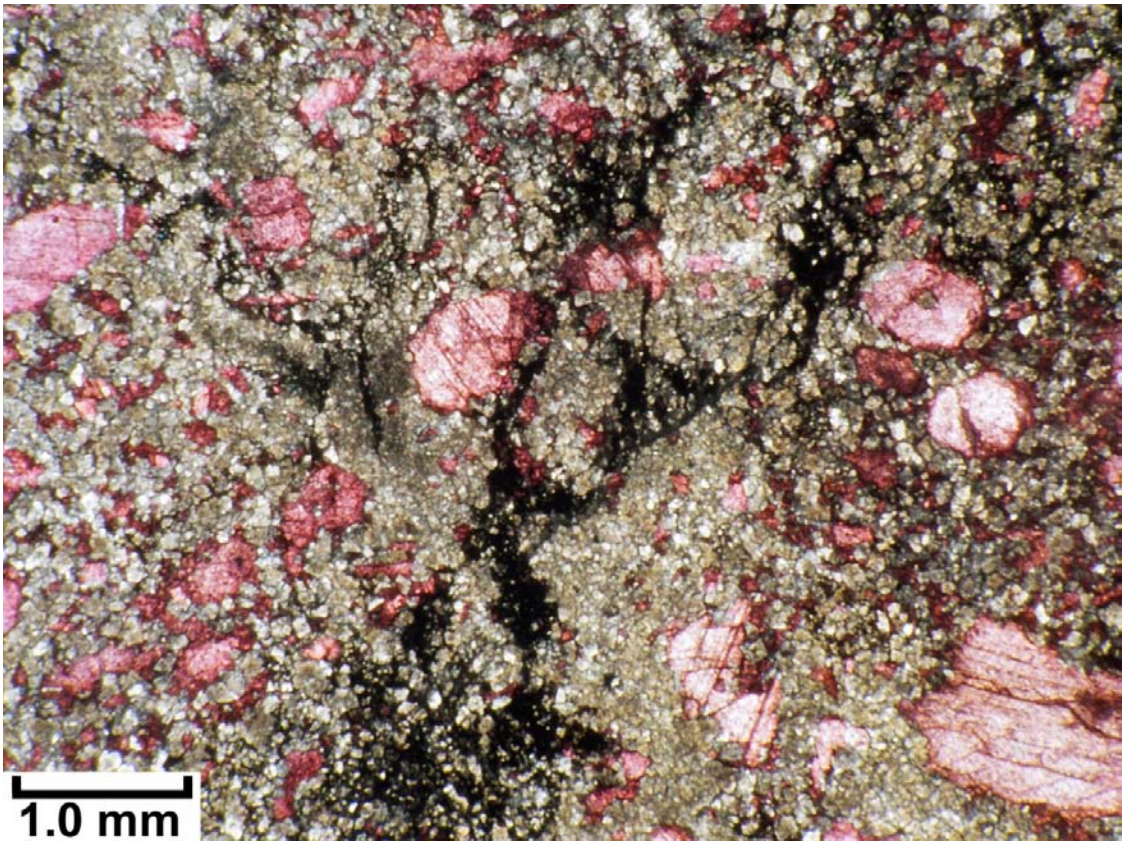
APPENDIX

THIN SECTION PHOTOMICROGRAPHS AND DESCRIPTIONS: LISBON FIELD, SAN JUAN COUNTY, UTAH

LISBON NO. D-816
NE1/4 SE1/4, Section 16, T. 30 S., R. 24 E.

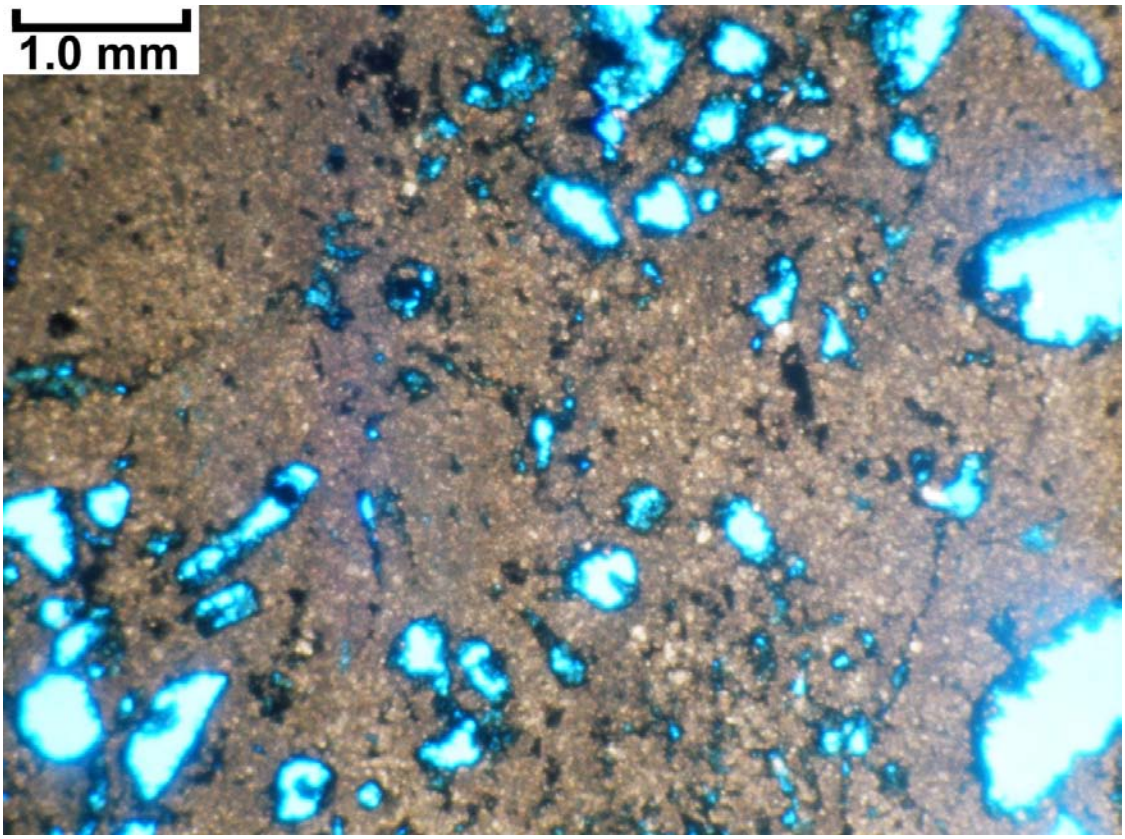
8419 ft.

Plug	oriented; ∅ 1.9%, K< 0.1 mD
Description:	calcareous dolomite, originally crinoidal/peloidal grainstone/ packstone; calcite (30%) dolomite (70%) with undolomitized remnants of crinoids, bryozoans, and peloids. Dolomite is very fine to medium crystalline, fractures with pyrobitumen plugging; no BC; poorly sorted dolomite crystals from finely sorted to euhedral rhombs; no saddle dolomite; open marine.
Diagenetic Events:	1) deposition; 2) carbonate cement as syntaxial overgrowths; 3) replacement dolomite not under burial conditions (replacing crinoid ossicles and large skeletal grains); 4) fracturing; 5) pyrobitumen. No bleaching.
Pore Types:	tight, none



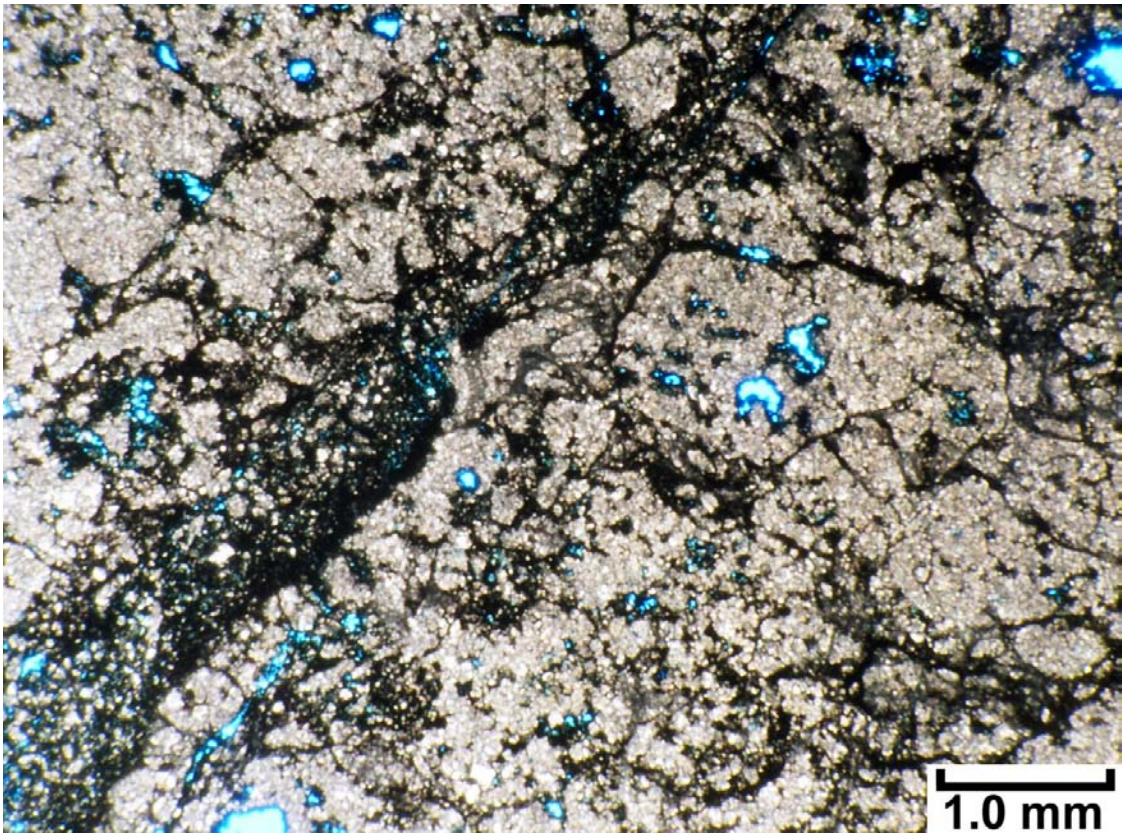
8421 ft.

Plug:	no orientation; ∅ 8.3%, K = 34 mD
Description:	dolomite (100%), crinoidal/(soft) peloidal wackestone; uniform massive type dolomitic matrix with molds and some BC; crinoids leached; ghost of peloids; micro-fractures; no bitumen.
Diagenetic Events:	1) complete replacement of matrix by uniformally anhedral, finely crystalline dolomite, some burial overprint on finely crystalline dolomite; 2) leaching of undolomitized fossils and matrix; 3) some late saddle dolomites cement filling molds (not enough to effect reservoir quality); 4) micro-fractures; 5) trace of bitumen.
Pore Types:	Mo, BC, and FR



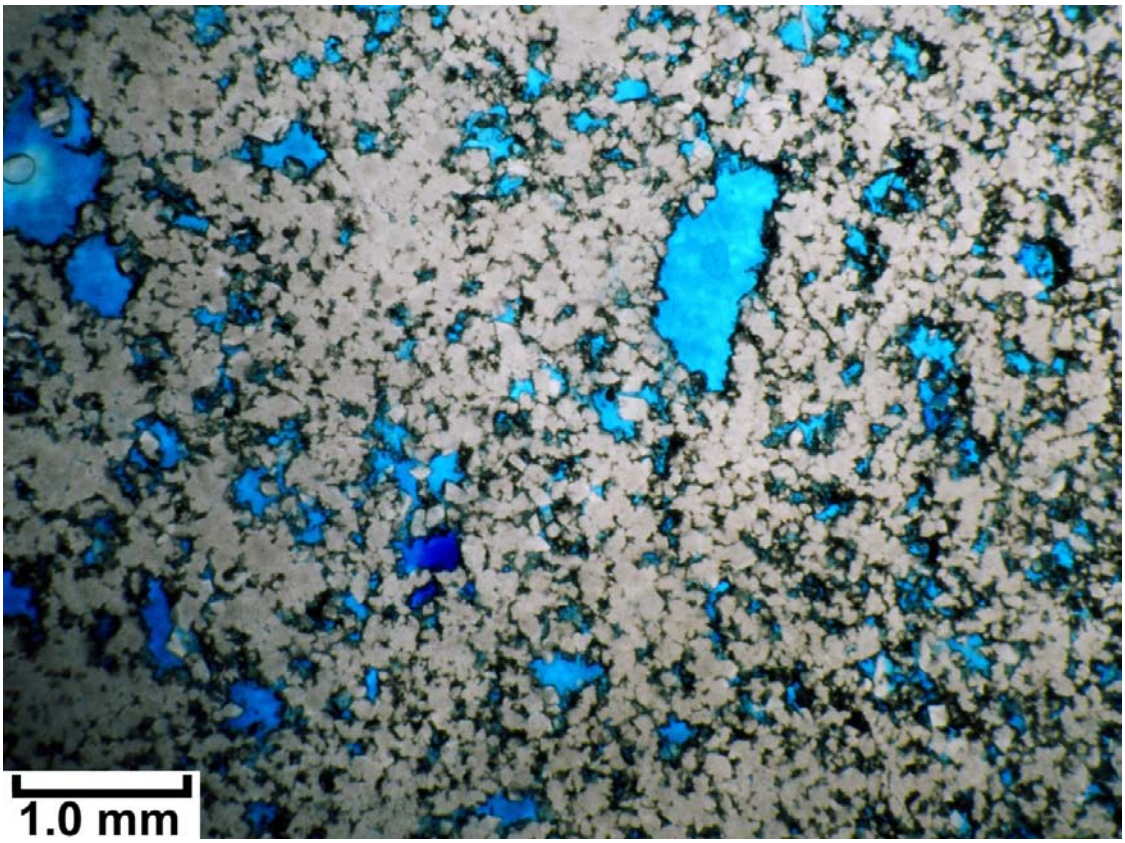
8423 ft.

Plug:	no orientation; ∅ 10.5%, K = 47 mD
Description:	dolomite (100%), peloidal/crinoidal wackestone; completely dolomitized; leached out undolomitized grains and matrix with hydro fracture overprint; intense bitumen-filled fractures (fracture breccia) but in place, not solution collapse breccia (in-place clasts).
Diagenetic Events:	1) complete replacement of matrix by dolomite; 2) leaching of dolomitized grains and matrix; 3) recrystallization and saddle dolomite (coarsely crystalline dolomite = hydrothermal overprint resulting in increased permeability and porosity); 4) concurrent or later in-place, intense fracturing with bitumen.
Pore Types:	early BC, Mo, late BC, FR



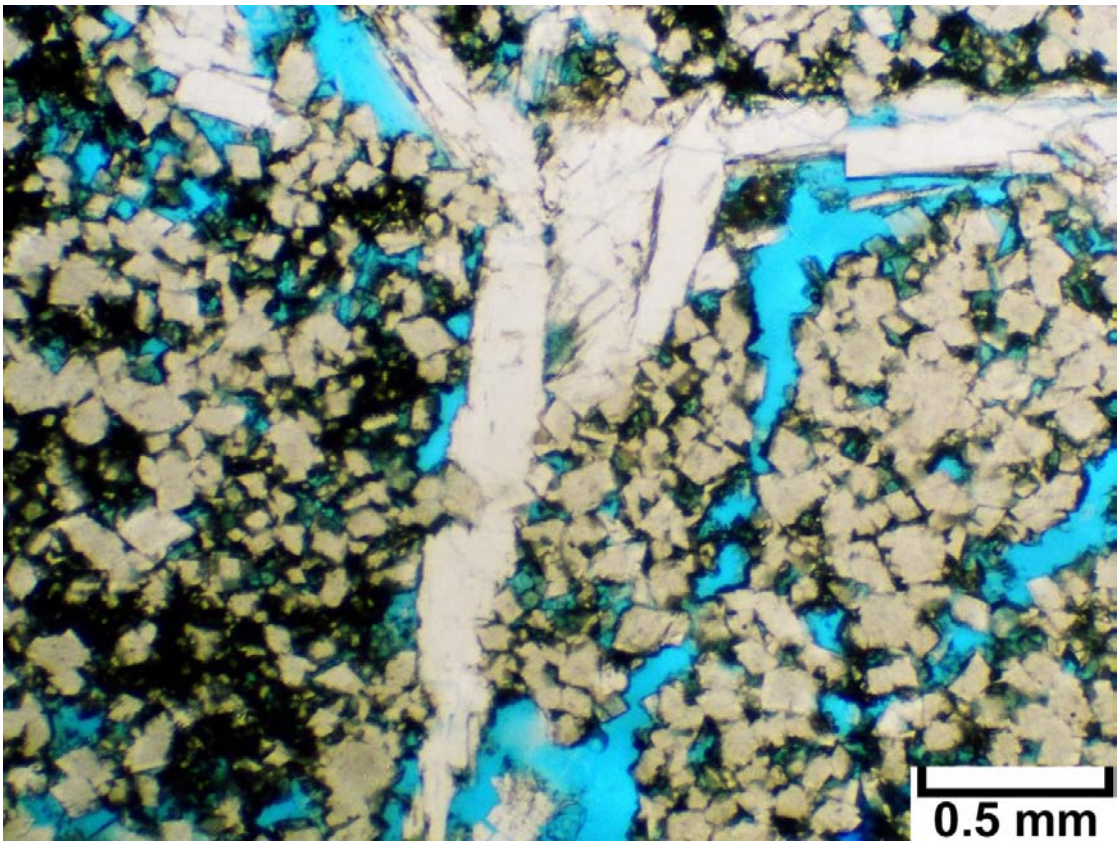
8426-8431? ft.

Plug:	no orientation; ∅ 11.1%, K = 15 mD
Description:	dolomite (100%), crinoidal/peloidal wackestone; relict crinoid molds, relict pellets; higher BC; coarsely crystalline; bitumen bearing; dark syngenetic dolomite preserving original fabrics; light crystals, curved crystals increase BC, some microfractures.
Diagenetic Events:	1) complete replacement of pellet muds; 2) leaching of undolomitized carbonate grains; 3) replacement by coarse dolomite crystals (saddle); 4) fracturing concurrent with breccia; 5) some anhydrite in molds; 6) bitumen emplacement in the BC and Mo.
Pore Types:	Mo, BC (greater in percent and larger in size)



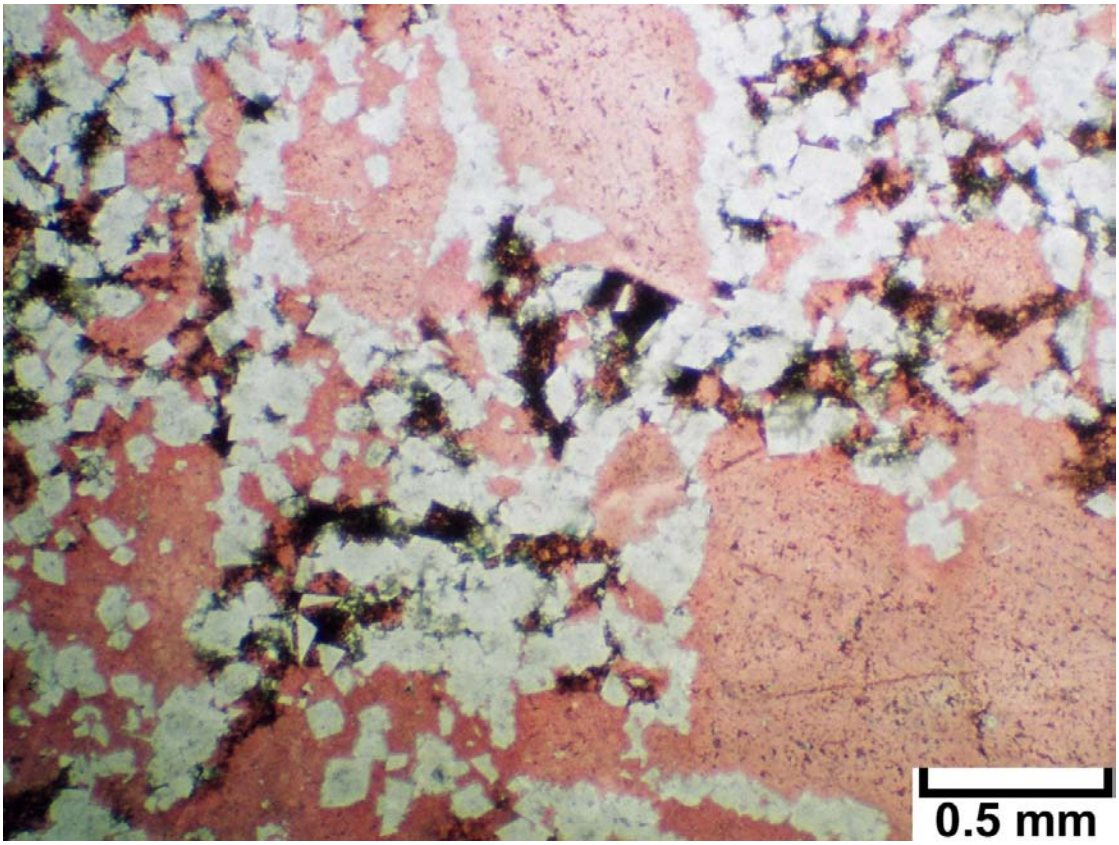
8433 ft.

Plug:	oriented; ∅ 2%, K = <0.1 mD; note – permeability and porosity not representative of core
Description:	dolomite (100%), crinoidal/peloidal wackestone; type; early aphanitic dark crystal matrix; probable crinoid molds with some anhydrite lathes in molds; and later coarsely crystalline dolomite with good porosity but with anhydrite and bitumen in Mo and BC (bitumen lining porosity). Photos show cross-cutting dolomite porosity within early (low permeability and porosity) versus late (high permeability and porosity) dolomite.
Diagenetic Events:	same as the 8426-31 foot sample but more cross-cutting of fabrics and bitumen in coarse BC. Possibly anhydrite pre-dates dolomite where dolomite is observed growing into anhydrite.
Pore Types:	BC, Mo



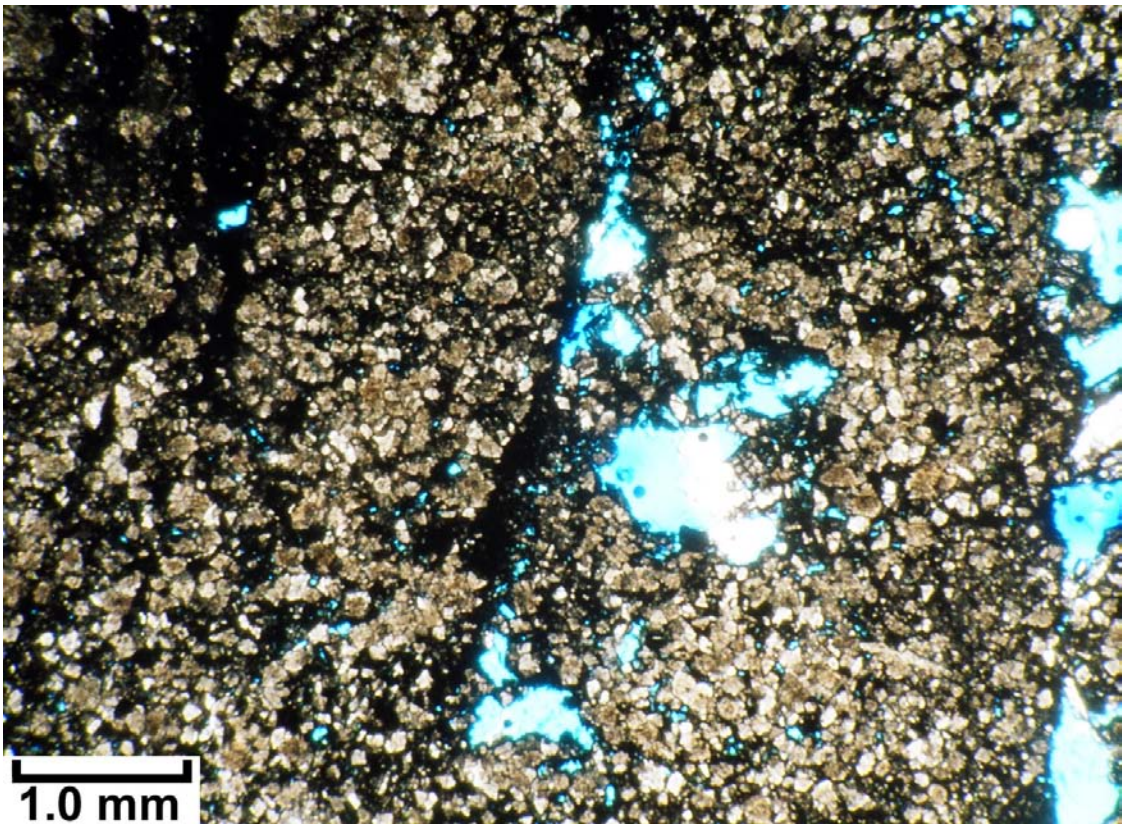
8435 ft.

Plug:	oriented; ∅ 7.5%, K = 0.03 mD
Description:	partially dolomitized limestone; crinoidal grainstone/packstone; syntaxial cement overgrowths on crinoids floating in cement (no compaction); through-going cleavage; some fine-grained crystalline dolomites; crinoids are cloudy due to inclusions of organic matter.
Diagenetic Events:	1) syntaxial cement; 2) minor dolomitization; 3) minor saddle dolomite; 4) minor bitumen.
Pore Types:	no visual porosity



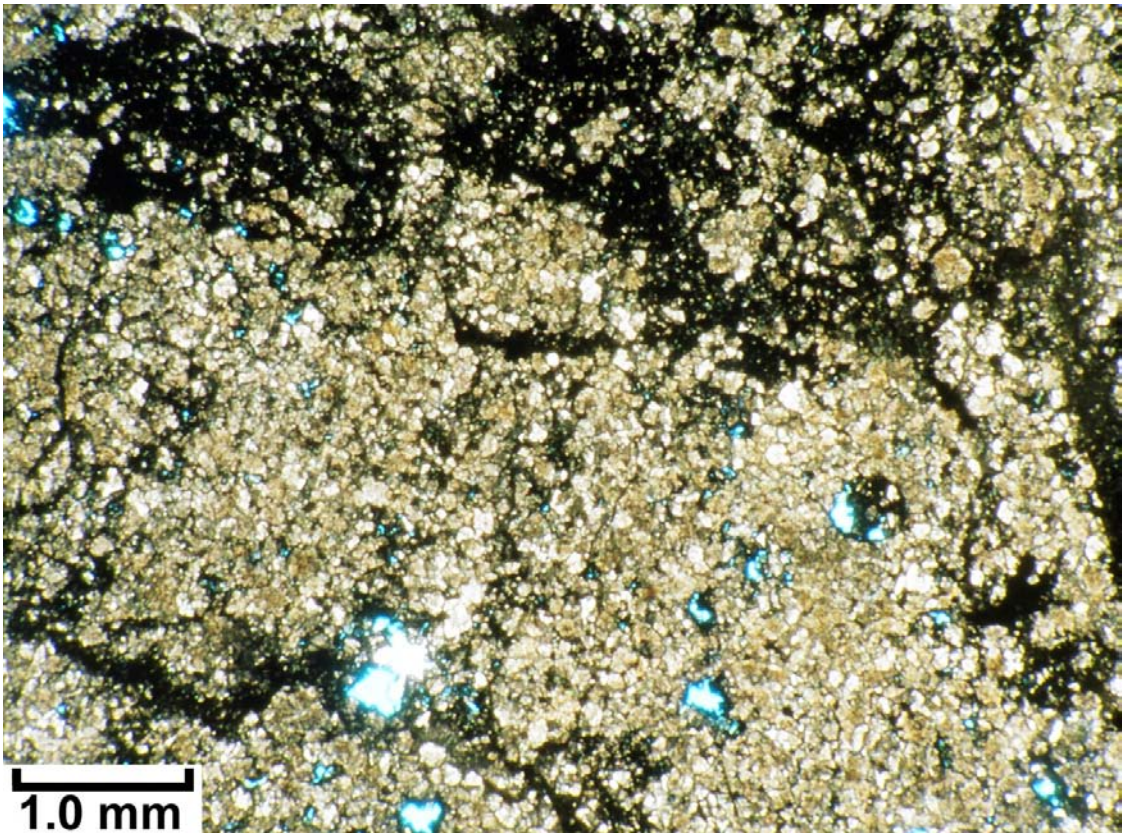
8435.8 ft.

Plug:	oriented; ∅ 7.5%, K = 0.03 mD
Description:	dolomite (100%), peloidal crinoidal packstone/wackestone; solution-enlarged molds; some fracturing lined with bitumen (linear solution enlarged pores possibly representing a second later stage of dissolution); hard pellets or coated grains.
Diagenetic Events:	1) early dolomitization; 2) leaching of undolomitized skeletal grains (crinoids); 3) late coarse crystalline dolomite; 4) fracturing; 5) late stage dissolution; 6) bitumen and minor sulfides.
Pore Types:	Mo, CH, BC, FR



8438.6 ft.

Plug:	oriented; ∅ 11%, K = 5 mD
Description:	same as sample 8435.8 feet but highly fractured/deformed/ brecciated with pyro-bitumen lining; in-place “islands” in breccia that is hydrofracturing – explosive-looking, pulverized rock; bitumen-filled fractures contain large dolomite rhombs; tight matrix outside of fracturing.
Diagenetic Events:	same as sample 8435.8 feet with intense fracturing and brecciation after first-stage dolomitization; later-stage dolomitization associated with fracturing.
Pore Types:	BC, Mo, CH, FR



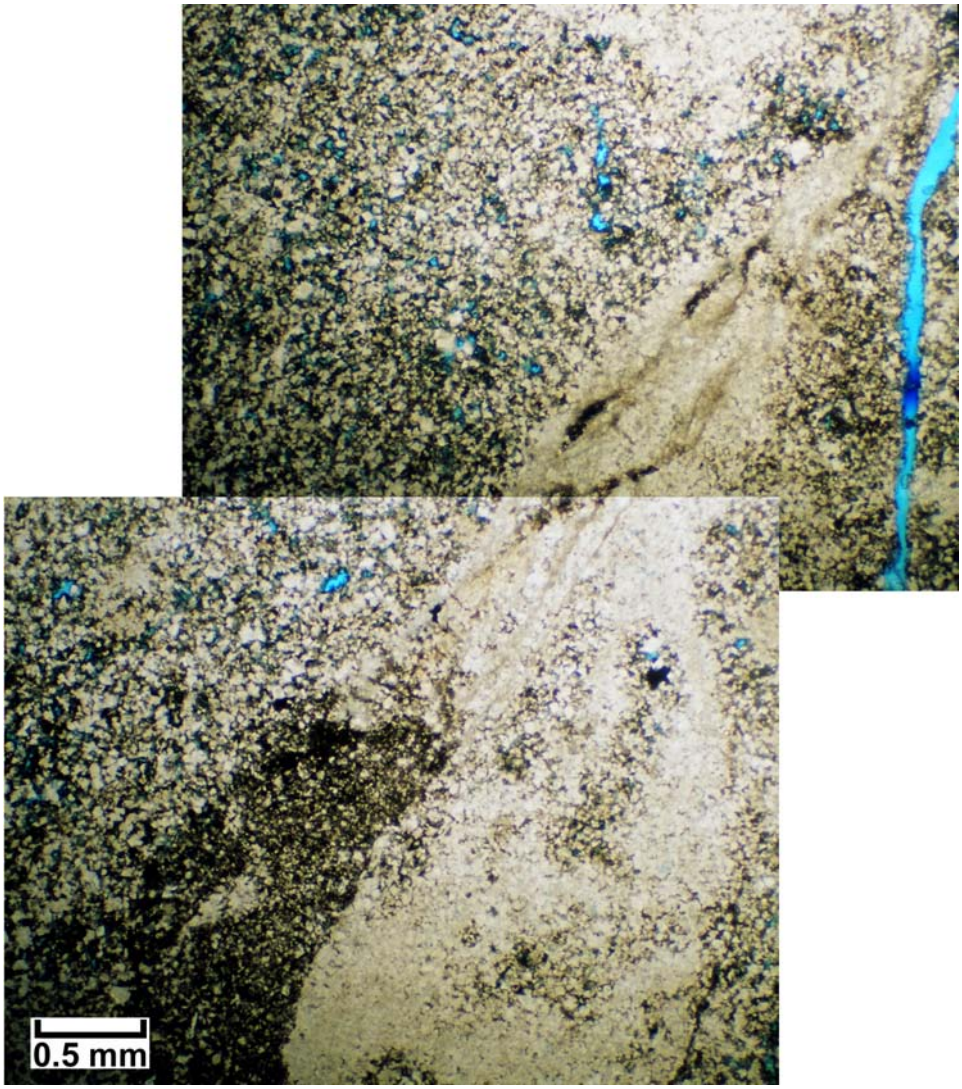
8439-40 ft.

Plug: oriented; ∅ 11.1%, K = 5 mD

Description: dolomite (100%), peloidal? wackestone/mudstone with BC (replacement saddle dolomite leads to BC); rare molds; some fractures; “Reike” or stair step fractures – reflection of explosive fluid expulsion (build up of pore pressure); bitumen; zebra dolomite; curvi-linear, tight finely crystalline areas (tight aphanitic dolomite with no bitumen) surrounded by coarser saddle dolomite.

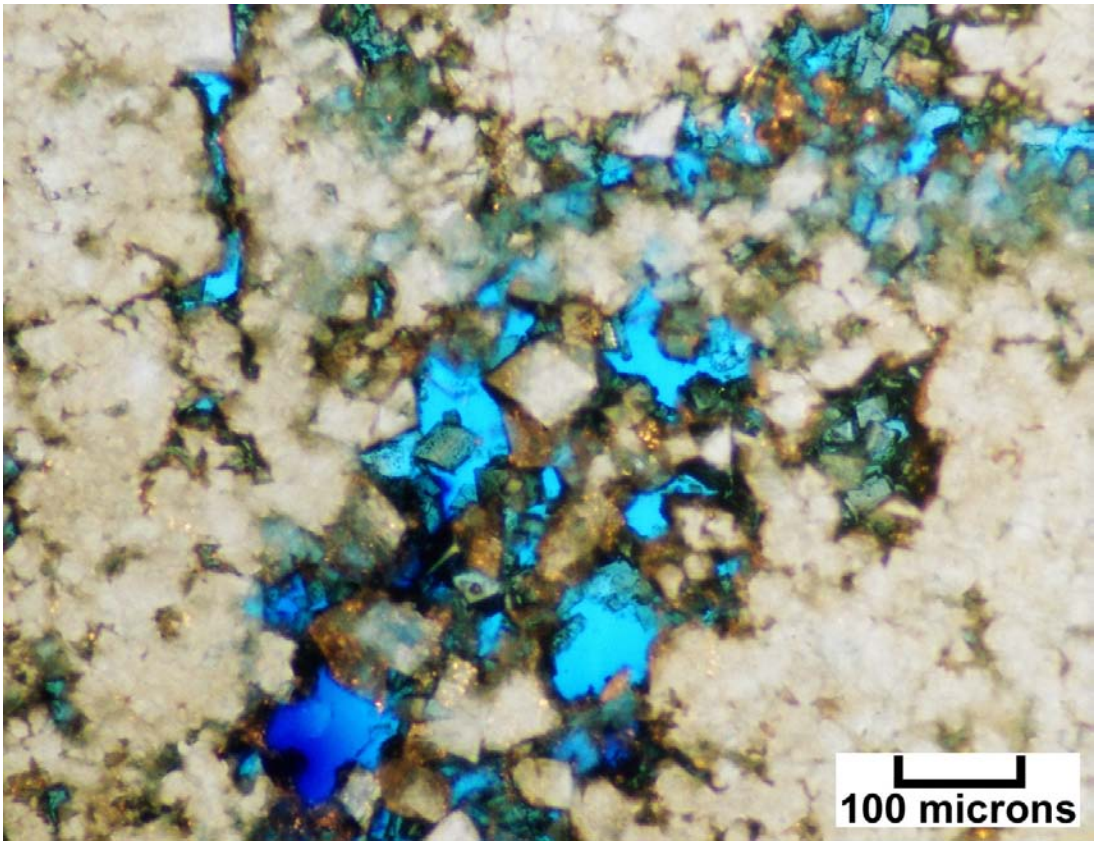
Diagenetic Events: 1) early dolomitization; 2) coarser rhombic dolomite with good BC; 3) fracturing; 4) bitumen plugging.

Pore Types: BC, Mo, CH



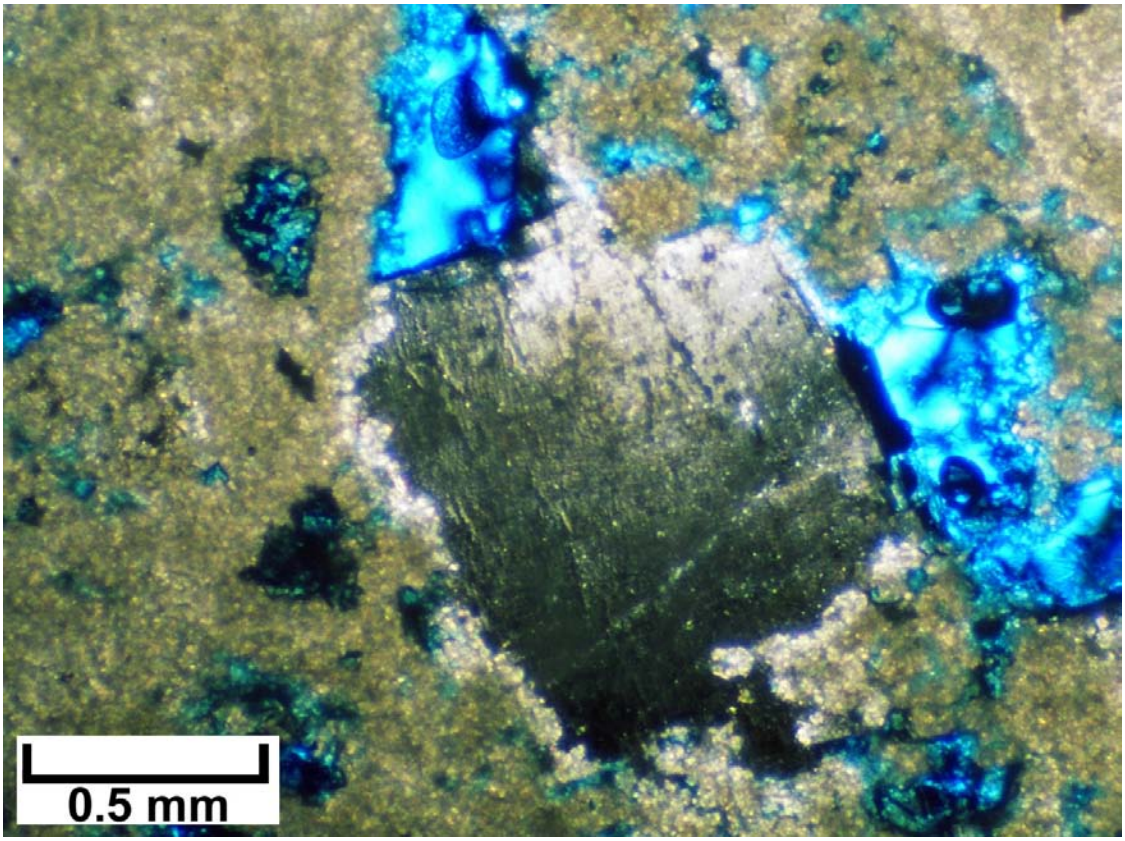
8442-43 ft.

Plug:	oriented; ∅ 8.6%, K = 1 mD
Description:	dolomite (100%), peloidal sparse crinoidal packstone; late dolomite replaced by sulfides (pyrite or chalcopyrite); a few microfractures and solution molds; all pore types are lined with bitumen and possible sulfide minerals.
Diagenetic Events:	1) some early dolomitization; 2) leaching; 3) second dolomite overprint; 4) sulfides; 5) bitumen.
Pore Types:	BC, rare Mo, some FR



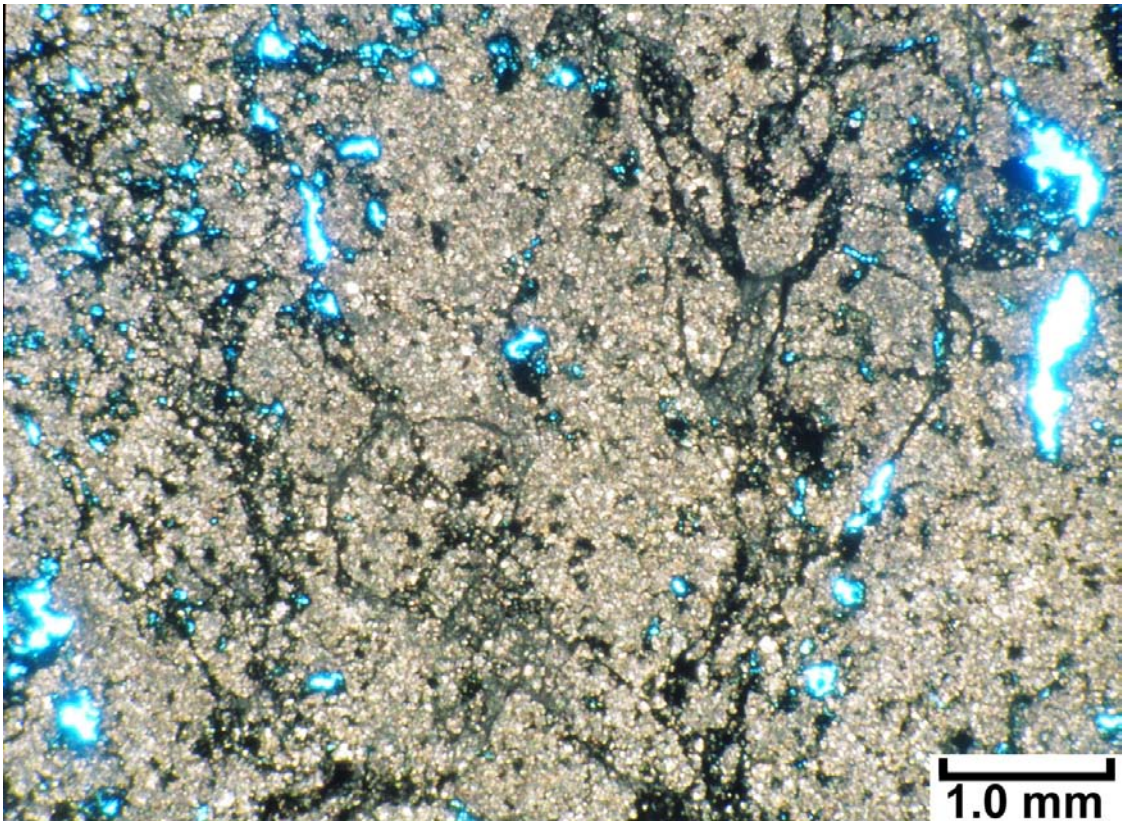
8444-45 ft.

Plug:	oriented; ∅ 6.6%, K = 7 mD
Description:	dolomite (100%), preserved peloids and crinoids packstone/ wackestone; mostly grains; moldic porosity from medium-sized crinoids; very little BC; tight, finely crystalline dolomite; saddle dolomites with sulfides and bitumen ? (opaque in some molds); no mini-saddle dolomites; trace of bitumen.
Diagenetic Events:	1) early dolomitization; 2) leaching; 3) minor late pore filling saddle dolomites (large), also called pearlspar; 4) sulfide filling.
Pore Types:	Mo only



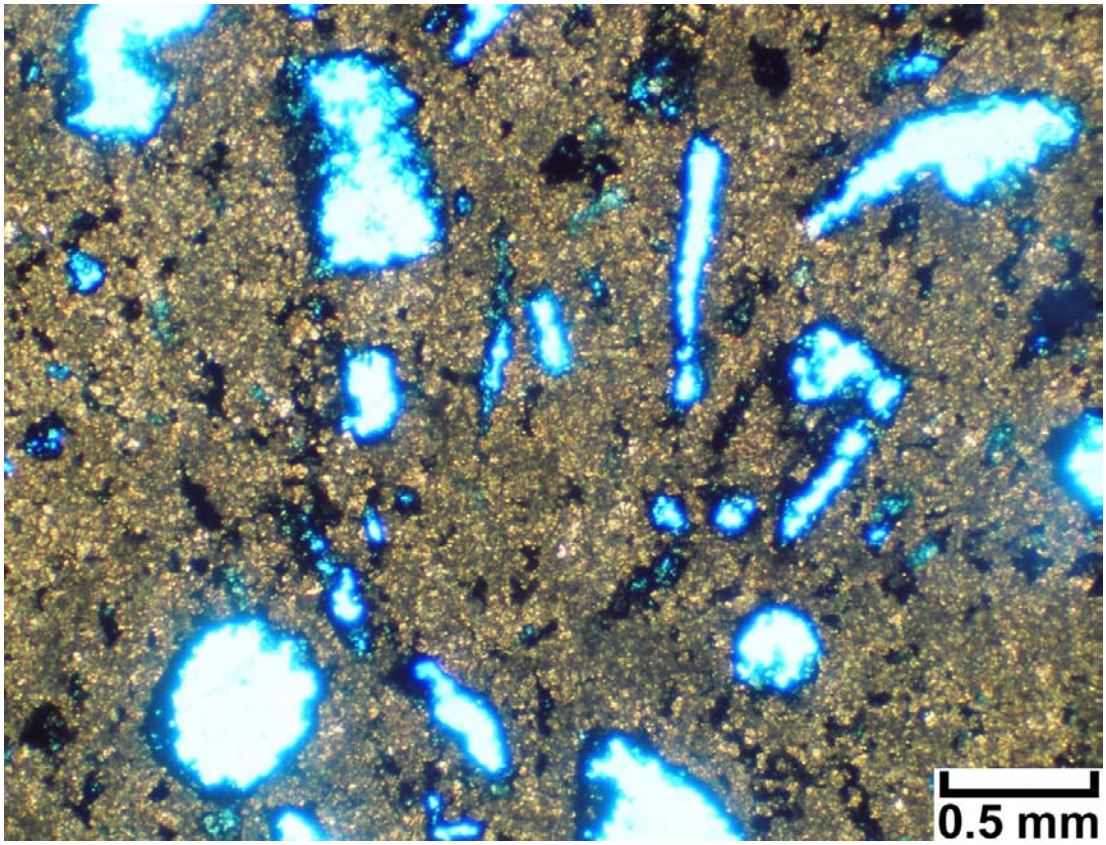
8446-47 ft.

Plug:	oriented; ∅ 13%, K = 29 mD
Description:	dolomite (100%), crinoidal/peloidal packstone wackestone; mixture of early tight dolomite and late coarse dolomite associated with BC; abundant bitumen with BC; extensive microfracturing (some open, some closed by bitumen); associated brecciation of tight, early dolomite and some pulverized rock matrix (explosive, shattered tight matrix dolomite); that is, autobrecciation.
Diagenetic Events:	1) early dolomitization; 2) leaching of skeletal grains; 3) late small saddle/replacement dolomite; 4) fracturing/brecciation; 5) bitumen.
Pore Types:	BC, some occasional Mo, FR, CH



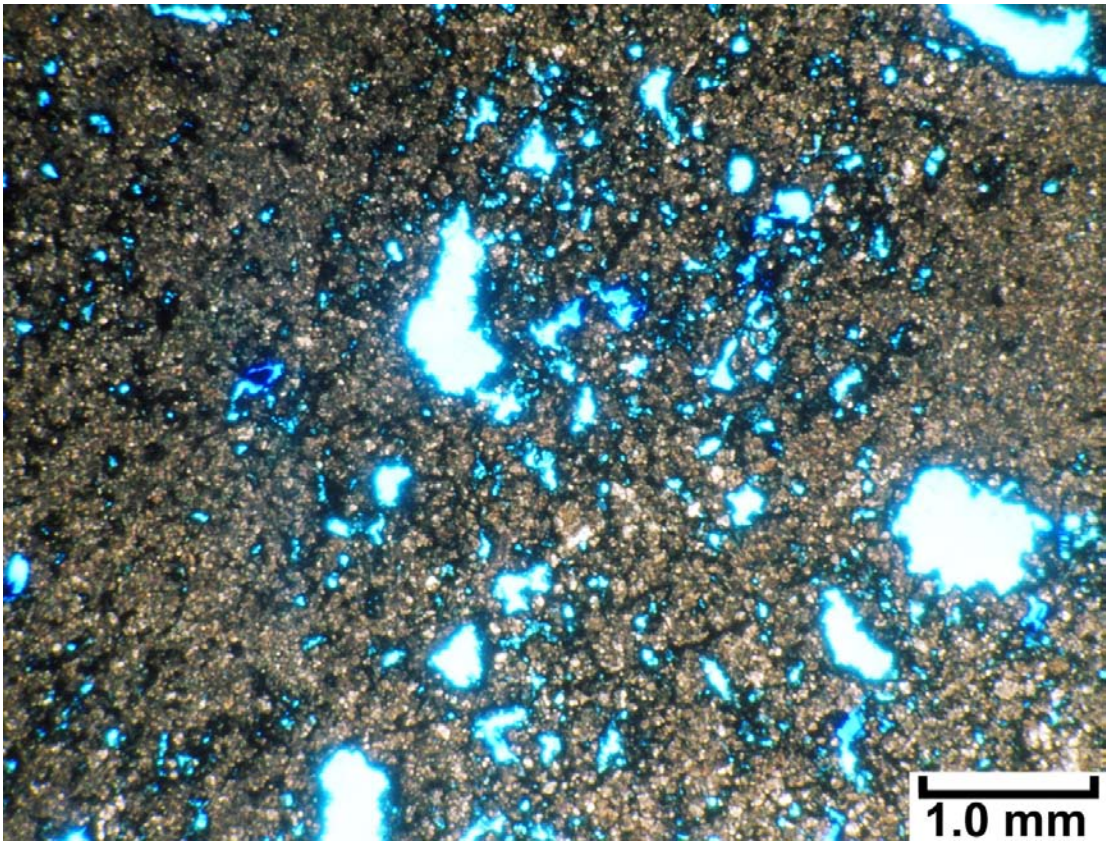
8447-48 ft.

Plug:	no orientation; ∅ 9.9%, K = 6.6 mD
Description:	dolomite (100%), fossiliferous; peloidal wackestone with Mo and relatively little BC; traces of bitumen lining molds; molds poorly sorted ranging from small dissolved microfossils to large crinoids and rugose corals; dominated by early fine-grained, tight dolomite matrix.
Diagenetic Events:	1) early dolomitization; 2) leaching; 3) minor bitumen.
Pore Types:	Mo, minor BC



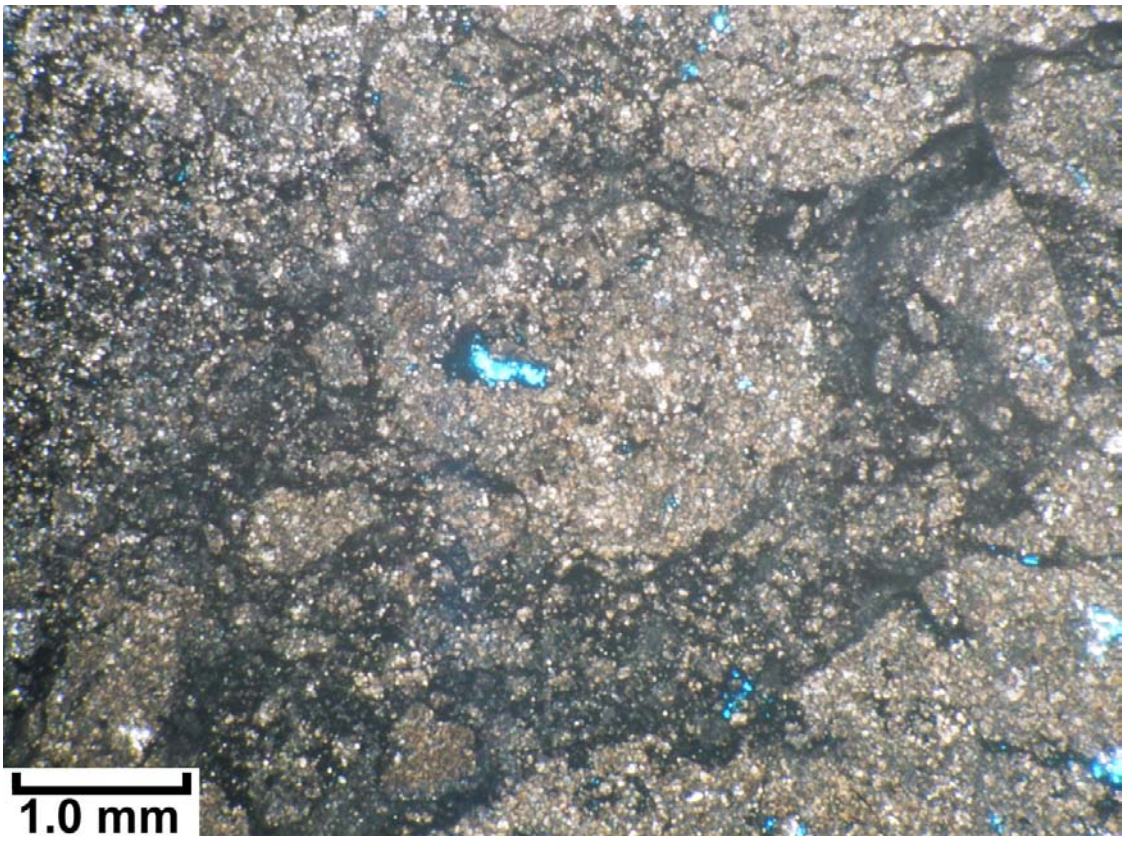
8448-49 ft.

Plug:	oriented; ∅ 7%, K = 6.1 mD
Description:	dolomite (100%), peloidal/skeletal wackestone; most visual porosity is poorly sorted molds; microfossils to medium-grained crinoids and rugose corals; tight, early dolomite matrix; some fractures and smaller molds have bitumen; minor late dolomite starting incipient BC (opens up to give permeability).
Diagenetic Events:	1) early dolomitization; 2) leaching; 3) minor late dolomitization; 4) saddle dolomite cement; 5) fracturing; 6) bitumen.
Pore Types:	Mo, incipient BC, FR



8449-50 ft.

Plug:	no orientation; ∅ 7.3%, K = 0.41 mD
Description:	dolomite (100%), peloidal/skeletal wackestone; highly fractured and brecciated auto brecciation (clasts in-place or slightly rotated).
Diagenetic Events:	1) early dolomitization; 2) leaching; 3) fracturing; 4) secondary dissolution; 5) bitumen.
Pore Types:	Mo, CH, FR – no permeability



LISBON NO. D-616
C NE1/4 NE1/4, Section 16, T. 30 S., R. 24 E.

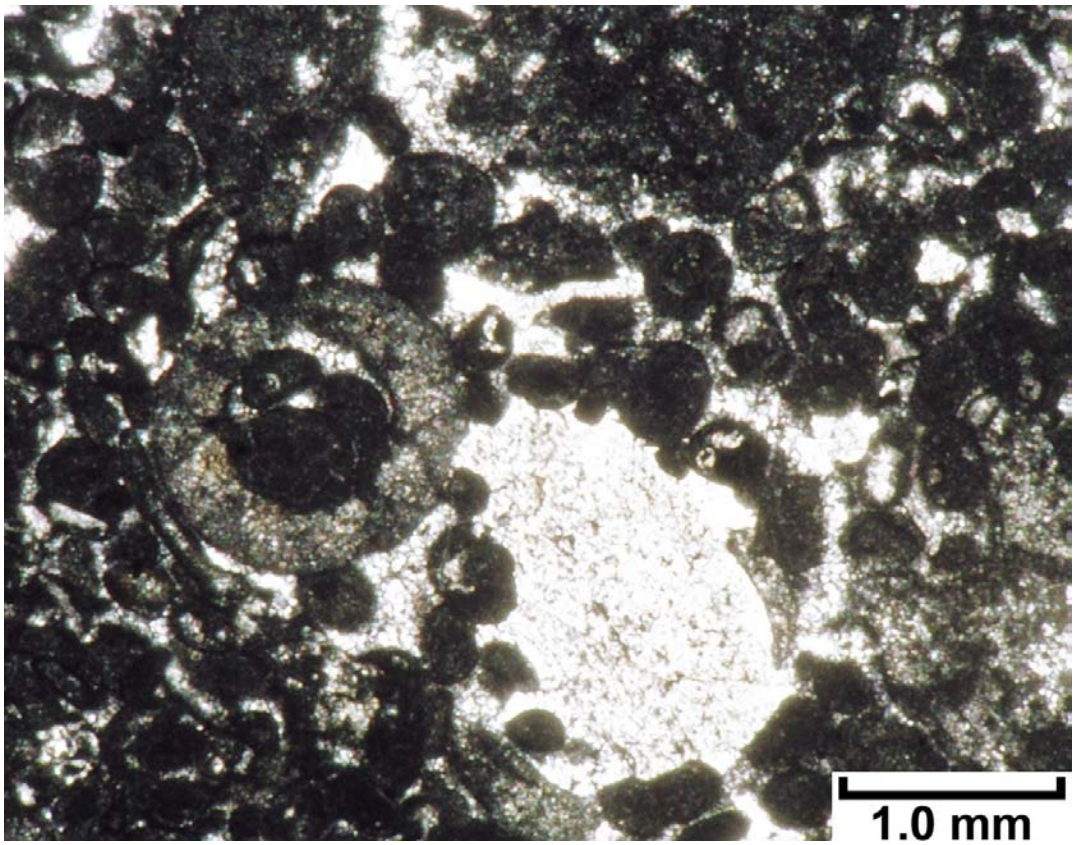
8308-09 ft.

Plug: ∅ 1.2%, K = 11.1 mD

Description: limestone (100%), oolitic, peloidal, skeletal grainstone; fossils include crinoids, brachiopod fragments, and forams (indothyroid); coated grains and hard pellets showing pressure solution against grains = compaction; filled opening – filled with transported material, that is karst filling with a sharp contact between a pipe of fine crystalline, tight dolomite containing poorly sorted detrital quartz grains, chert fragments, and transported carbonate clasts exhibiting crude layering. The filling shows early dolomitization but after lithification of the grainstone matrix; solution pits along wall filled with sediment.

Diagenetic Events: 1) early marine fibrous isopachous cement; 2) compaction; 3) syntaxial cement and lithification of grainstone; 4) fracturing; 5) solution enlargement of fractures; 6) filling fractures with sediments; 7) dolomitization of the sediment fill without dolomitizing the rock matrix.

Pore Types: FR



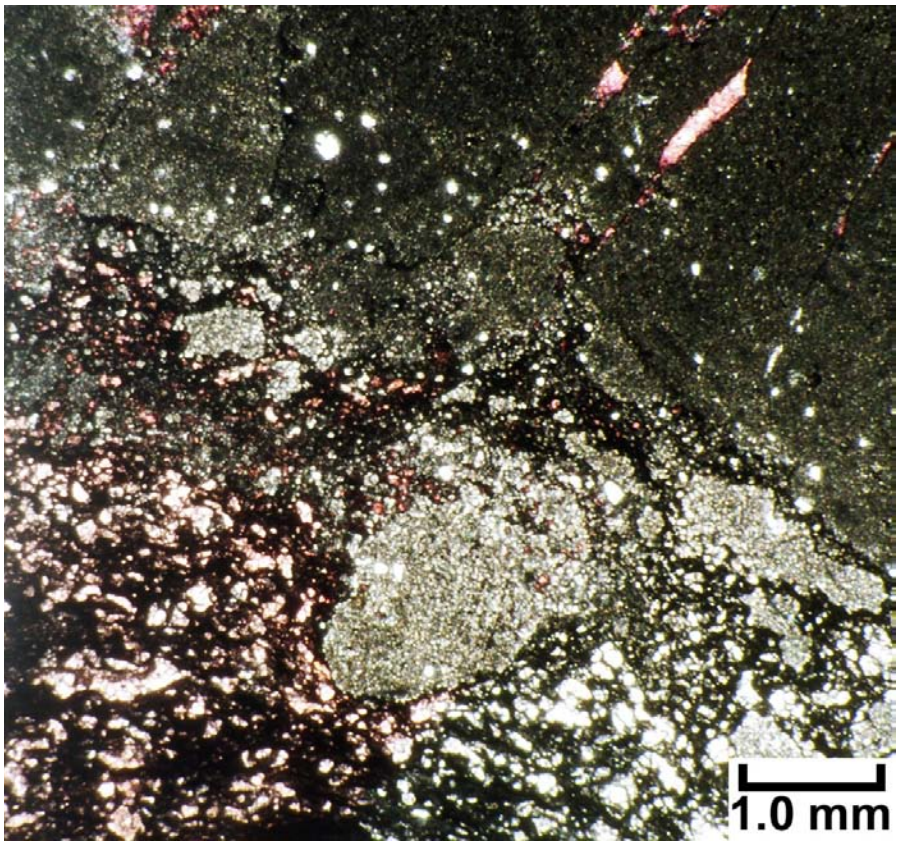
8316-17 ft.

Plug: ∅ 2.8%, K = 2.1 mD

Description: country rock – limestone (100%), recrystallized (calcite spar) fossils including forams and brachiopods in a peloid (soft pellet) mud; wackestone; infilling – mostly dolomite with detrital quartz; clasts of mud balls (desiccated and cracked); poorly sorted; brecciated; transported material; contact with country rock is irregular, sharp, and corroded; filled fractures and some disseminated pyrite.

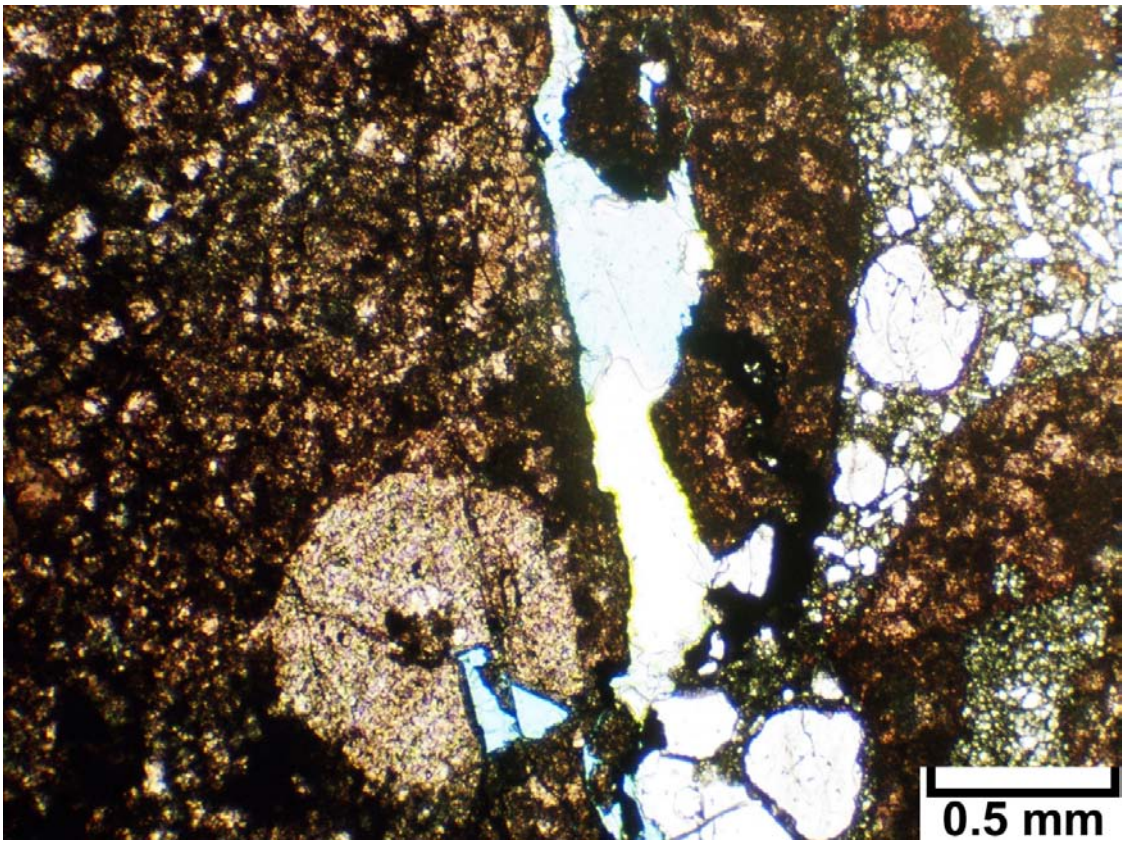
Diagenetic Events: 1) compaction; 2) recrystallization of fossils into spar; 3) stylolites; 4) solution cavities; 5) filling of cavity with sediment; 6) dolomitization of filling; 7) fractures filled with calcite spar; 8) minor fracture-filling with ferroan calcite; 9) late pyrite.

Pore Types: none



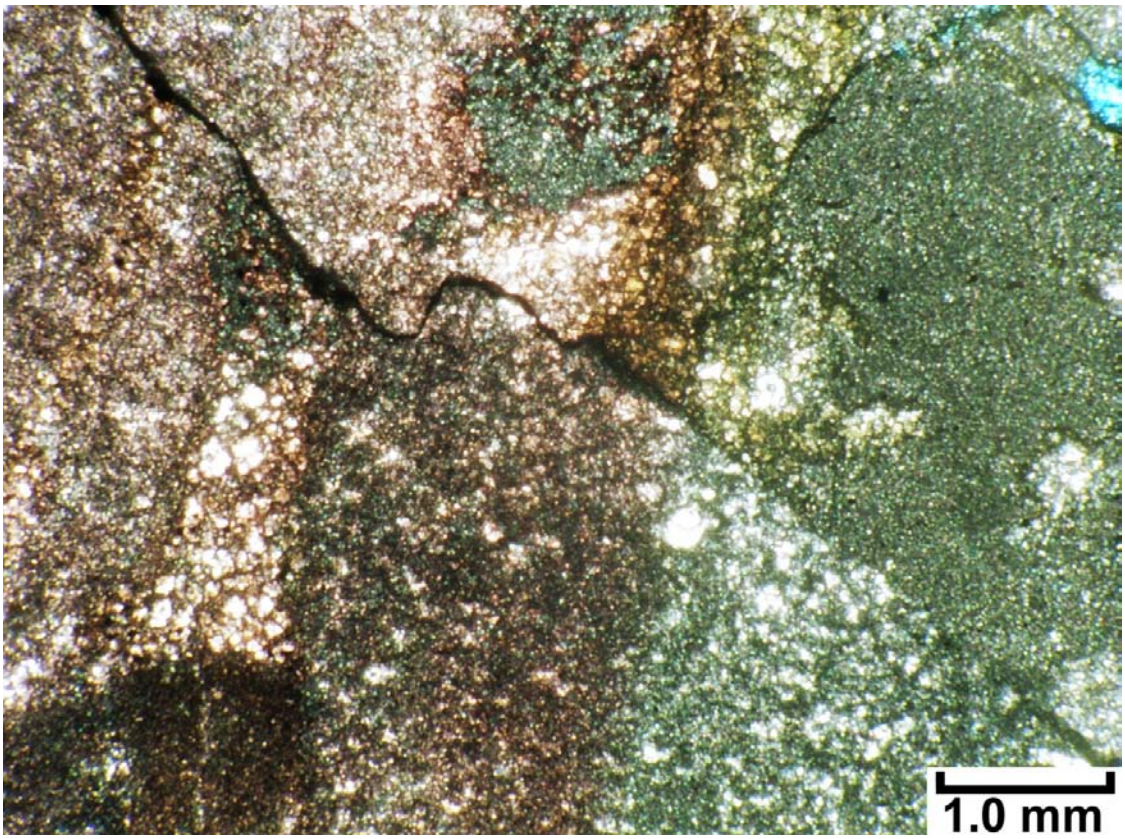
8322-23 ft.

Plug:	∅ 2.7-2.5%, K = 2.5-80.6 (fracture) mD
Description:	limestone (100%) with disseminated pyrite throughout, hard pellet, skeletal (brachiopods and crinoids) packstone/wackestone; neomorphic spar (calcite; dolomite filled karst crack, detrital quartz from the Pennsylvanian Molas Fm.; stylolites).
Diagenetic Events:	1) compaction; 2) stylolitization; 3) neomorphism; 4) crack; 5) infilling; 6) dolomitization; 7) pyrite.
Pore Types:	none



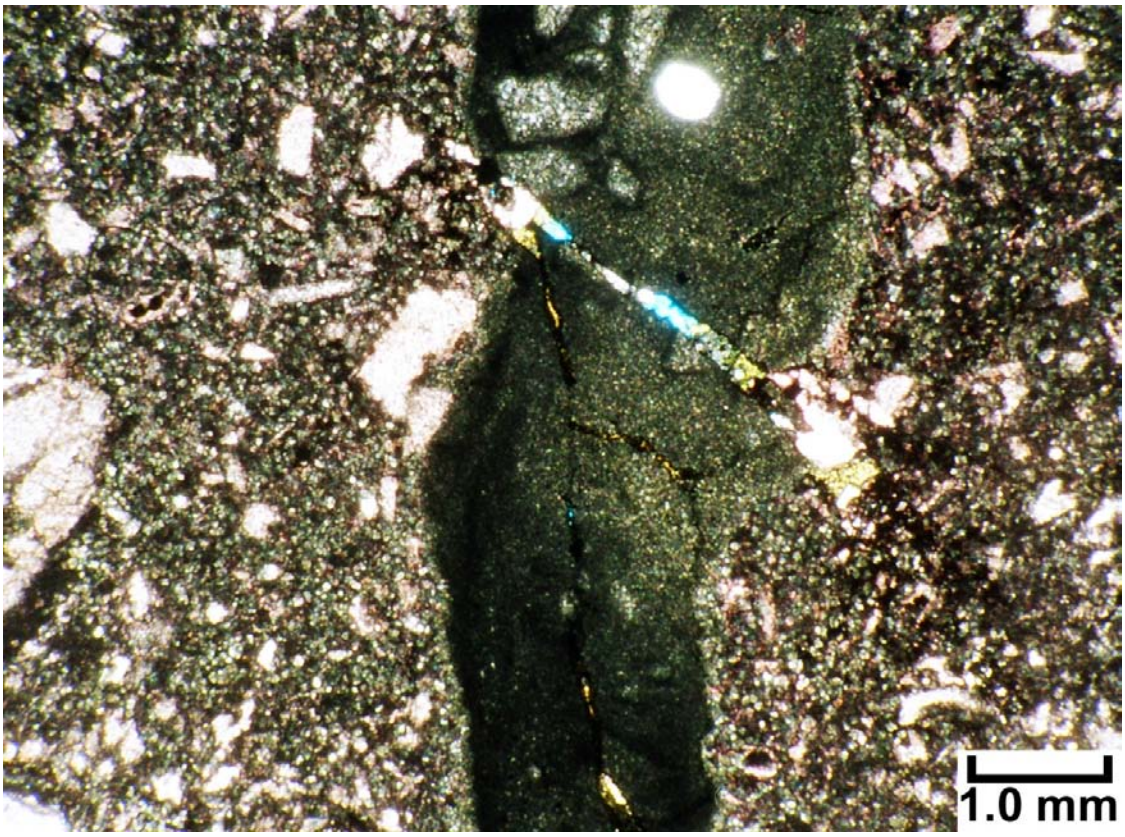
8328-29 ft.

Plug:	∅ 0.4%, K = 0.86 mD
Description:	limestone, skeletal/peloidal wackestone; massive, encrusting, low-relief spongeheads (finger sponges or colonies) surrounded by detrital carbonate sediment; abundant high to medium relief stylolites; some early dolomitization (1%); some disseminated pyrite.
Diagenetic Events:	1) compaction; 2) cementation; 3) minor finely crystalline dolomitization for stylolitization.
Pore Types:	none



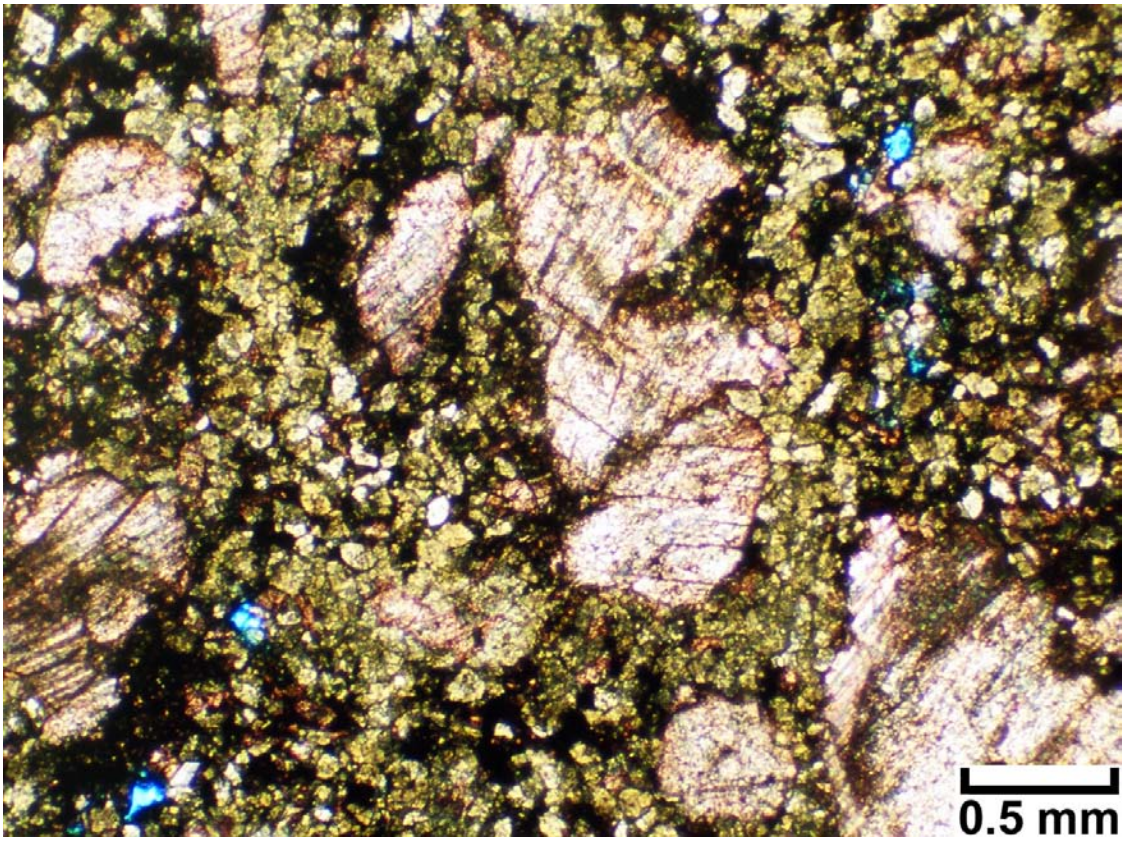
8356-57 ft.

Plug:	no permeability and porosity
Description:	country rock – slightly dolomitic limestone in undisturbed rock, fossilferous, open-marine packstone/wackestone; very diverse fauna – crinoids, brachiopods, and trilobite trash; minor dolomite replacement with trace of bitumen; karst filling – (cavity in fill) – clasts, quartz, mud, clays, root hair (evidence of soil zone) – sinuous or crack filled with dolomitized mud; clay coating on clasts is a soil-zone feature, that is pickup of quartz grains which is evidence of transport and karst; on core appears as dense clay mud; karsting has not yielded reservoir rock.
Diagenetic Events:	1) lithification; 2) exposure and fill; 3) dolomitization of fill; 4) late fractures; 5) dolomite filling in fractures.
Pore Types:	only minor FR



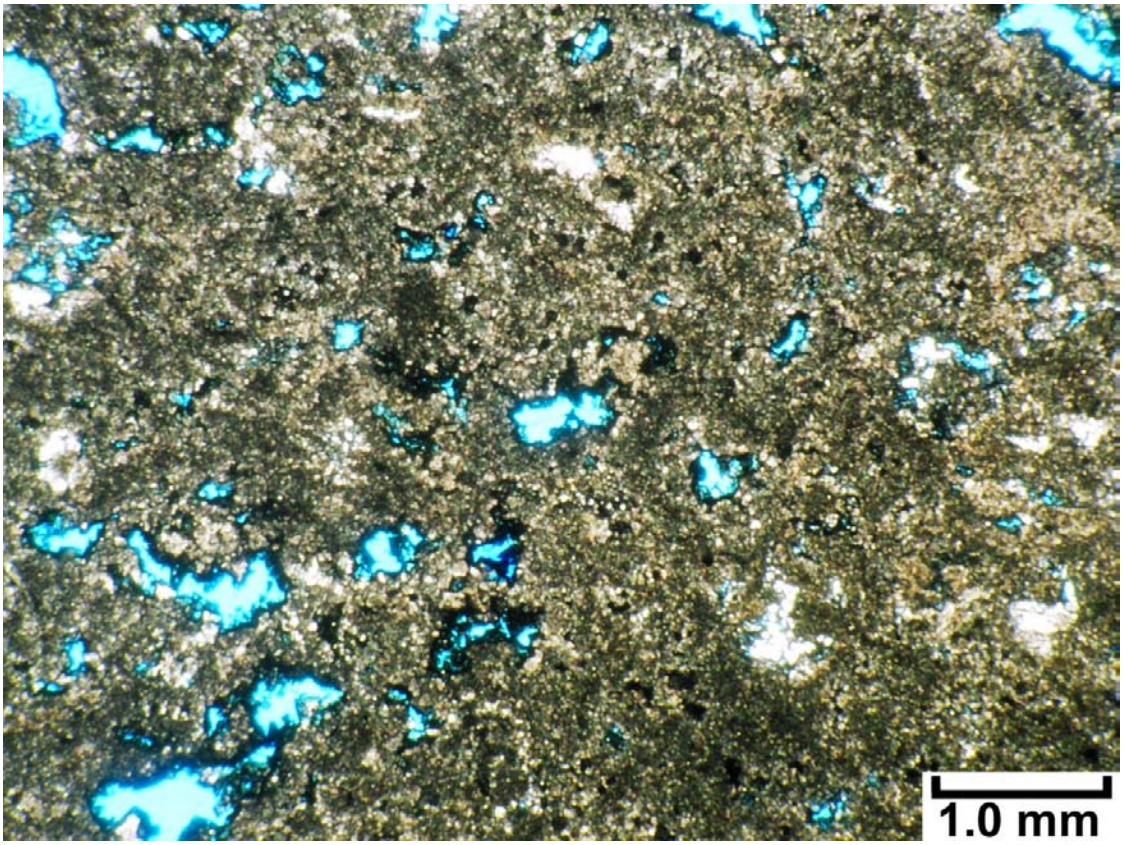
8372-73 ft.

Plug:	no permeability and porosity
Description:	dolomite (50-60%), limestone (40-50%), crinoidal grainstone; crinoids have some syntaxial cement overgrowths; bitumen plugging porosity; dolomite is medium crystalline, euhedral, burial to hydrothermal dolomite (plain to saddle dolomite) yielding BC which was later plugged with bitumen; no Mo, karst filling, or fractures.
Diagenetic Events:	1) compaction; 2) syntaxial cement; 3) burial dolomite; 4) bitumen plugging.
Pore Types:	trace of BC



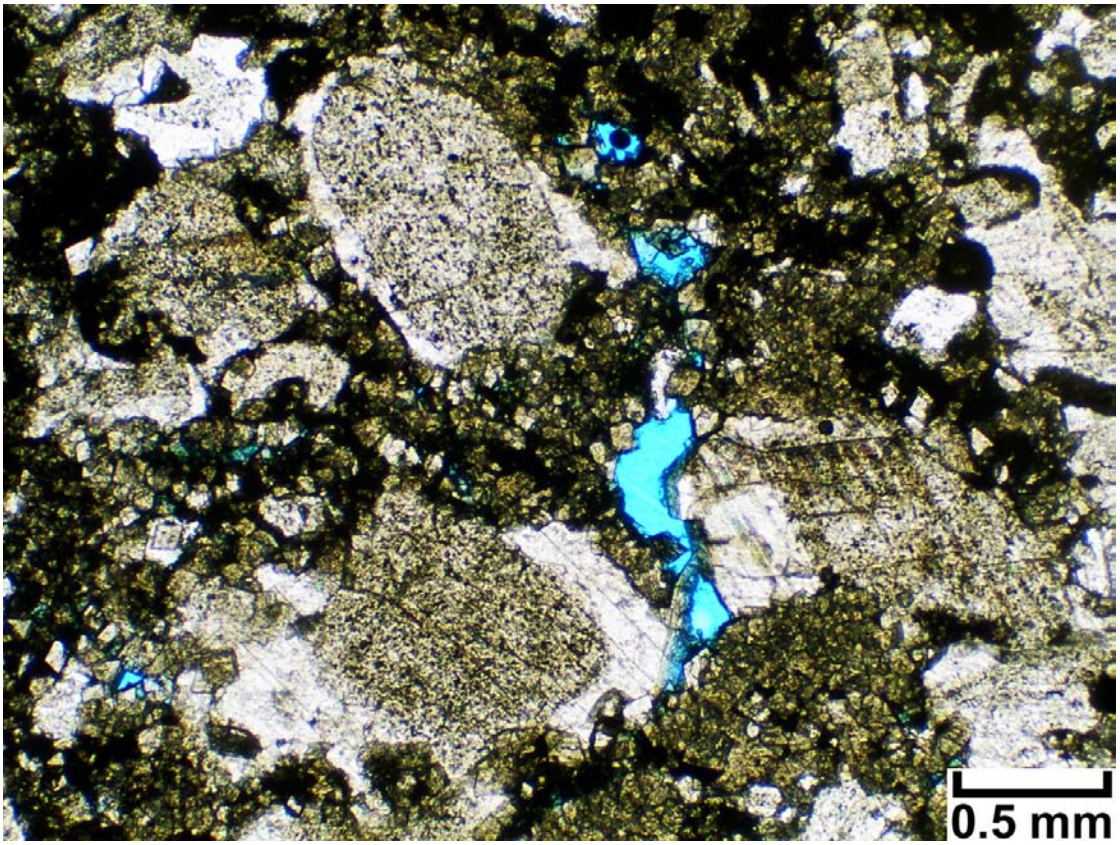
8380-81 ft.

Plug:	no permeability and porosity
Description:	dolomite (100%), skeletal/crinoidal, coated grain/oolitic grainstone/packstone; frequent Mo, occasional bitumen lining molds; a few intraclasts (rip ups) and brachiopods; dolomite appears to be syngenetic, tight, and aphanitic; some early isopachous cement.
Diagenetic Events:	1) early isopachous cement; 2) early dolomite; 3) leaching of crinoids; 4) bitumen.
Pore Types:	Mo



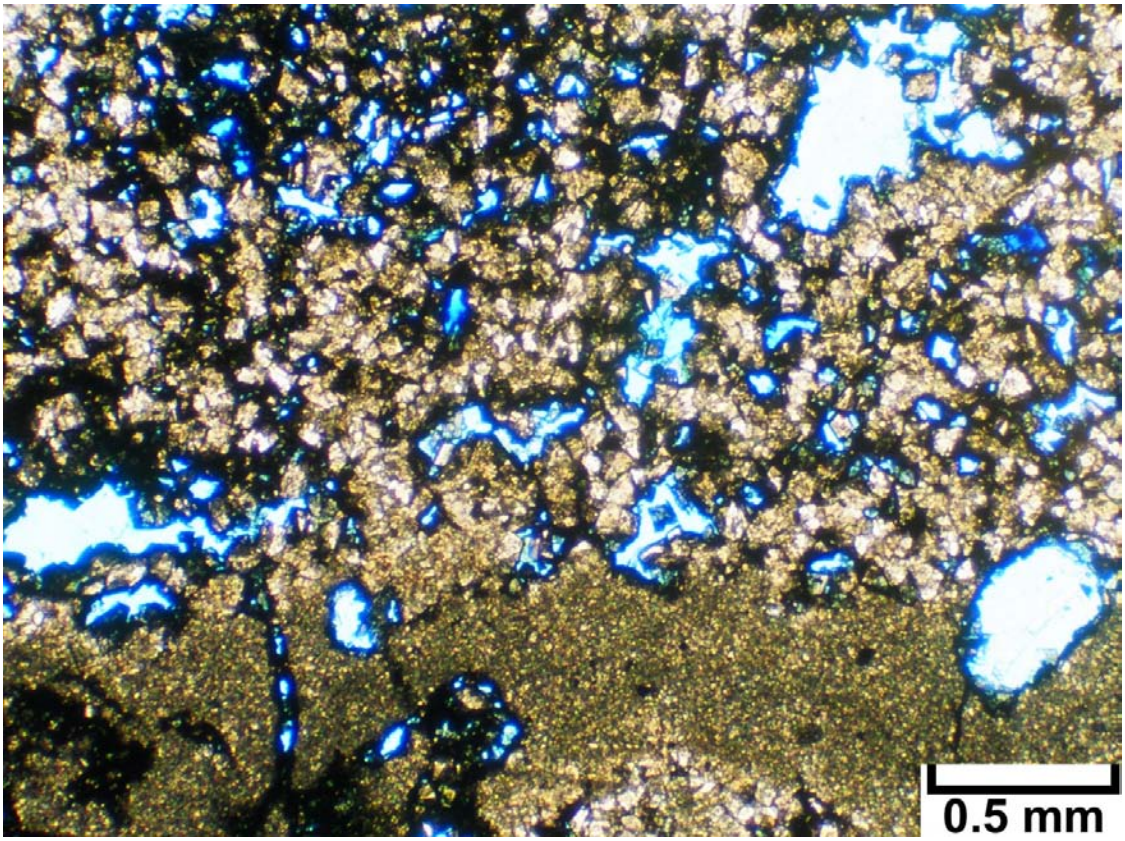
8441 ft.

Plug:	no permeability and porosity
Description:	partially dolomitized (60-85%) limestone, fossiliferous/crinoidal grainstone/packstone; well-formed dolomite crystals with incipient BC and bitumen impregnation; contains remnants of fenestrate bryozoan and brachiopods; shows dolomitization fronts.
Diagenetic Events:	1) syntaxial cement; 2) late dolomitization; 3) bitumen.
Pore Types:	BC (bitumen plugged)



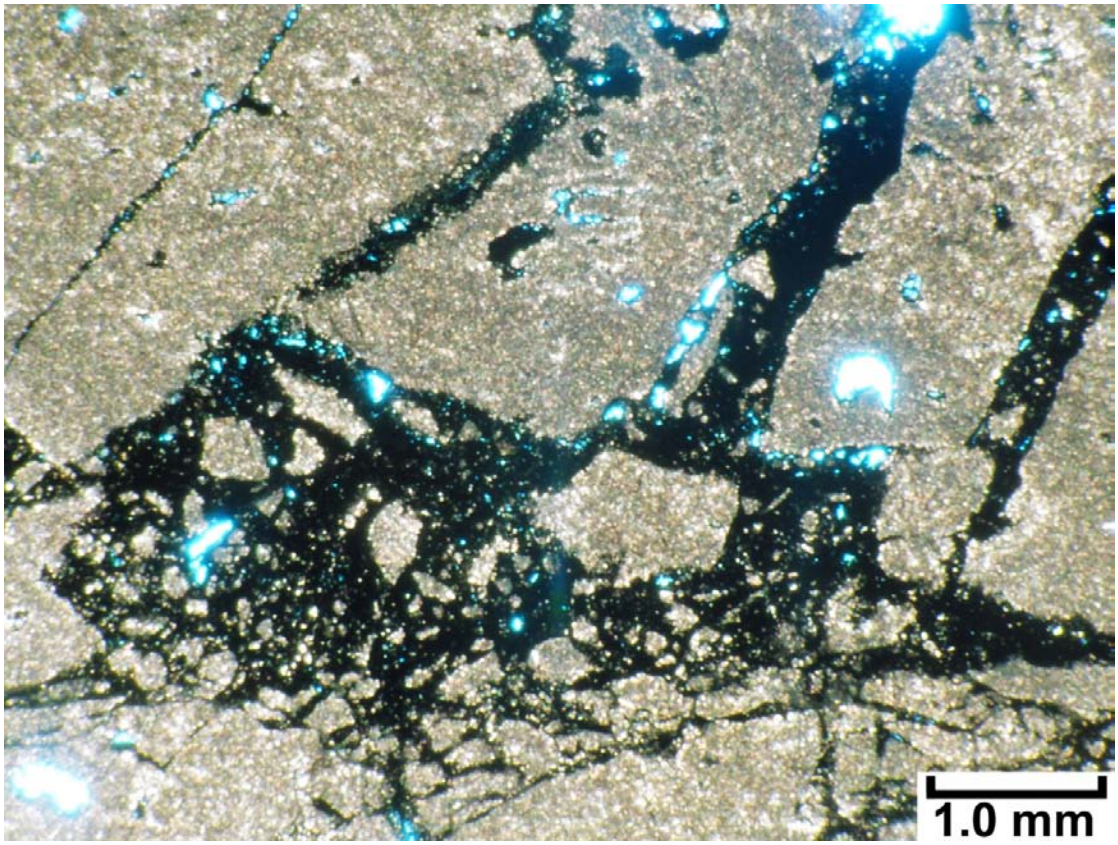
8559 ft.

Plug:	no permeability and porosity
Description:	reservoir – dolomite (100%), crinoidal packstone/wackestone; with moldic porosity; aphanitic tight early dolomite but mostly late slightly hydrothermal medium crystalline, euhedral dolomite; well formed BC, relic molds, fractures, bitumen, and some sulfides.
Diagenetic Events:	1) early dolomitization; 2) leaching; 3) late dolomitization; 4) bitumen and sulfides.
Pore Types:	BC, relic Mo, FR



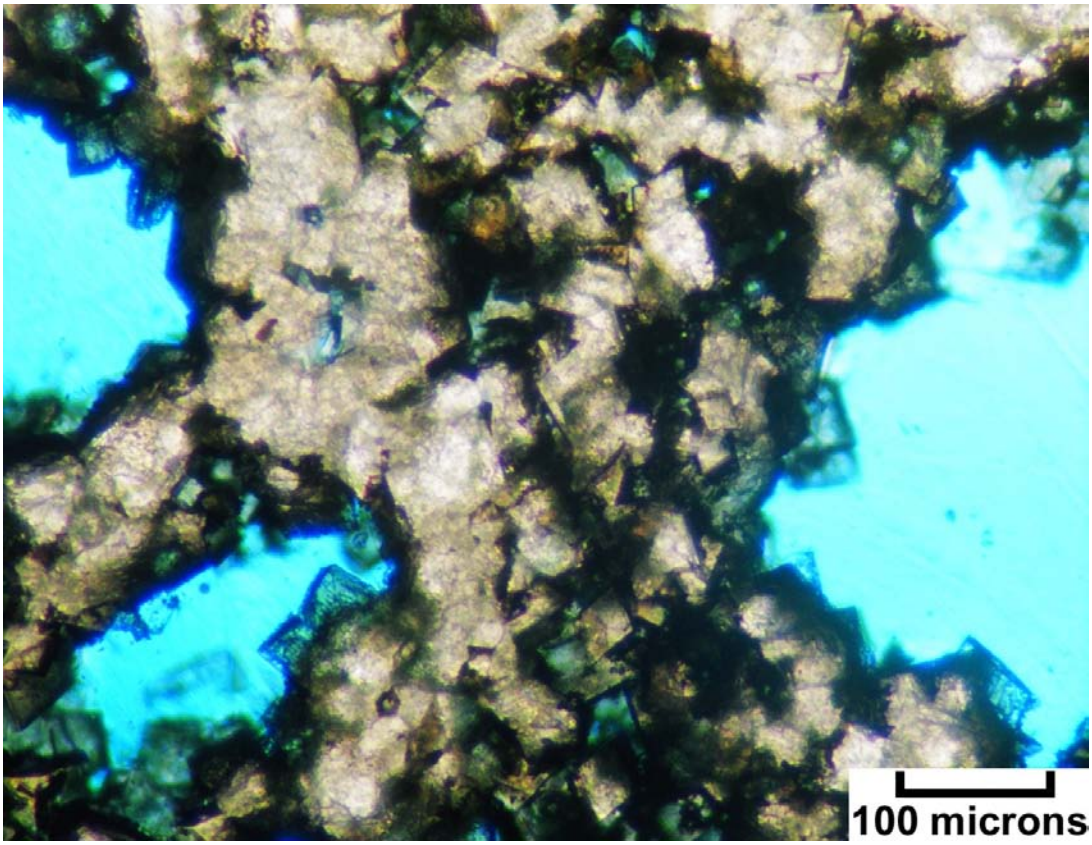
8579 ft.

Plug:	no permeability and porosity
Description:	dolomite (100%), peletal/skeltal wackestone; all early, anhedral dolomite (no porosity); early Mo; highly fractured with some fractures lined with bitumen, brecciation with rotated clasts, quartz lining fractures containing overgrowths (silica diagenesis); minor anhydrite needles in pores.
Diagenetic Events:	1) early dolomitization; 2) leaching of undolomitized fossils; 3) fracturing; 4) solution enlargement of fractures; 5) silica lining of fracture margins and replacement of clasts; 6) bitumen.
Pore Types:	Mo, CH, FR



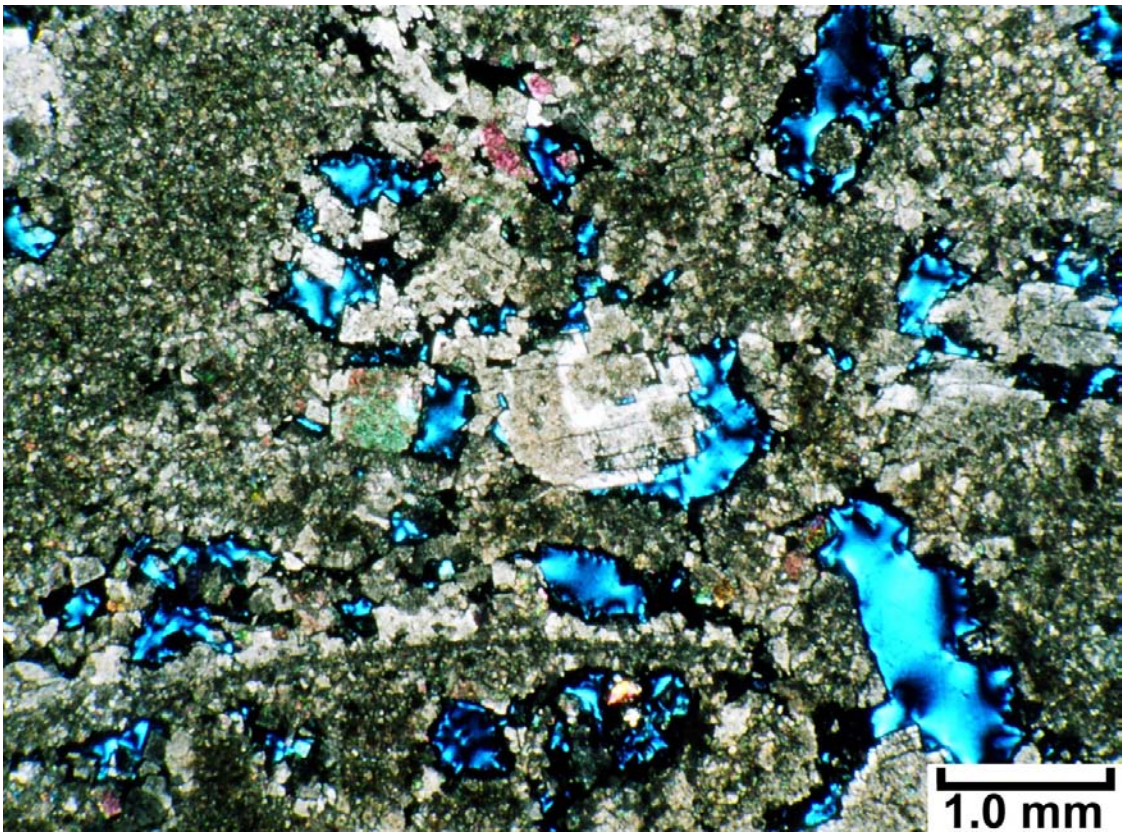
8584 ft.

Plug:	no permeability and porosity
Description:	dolomite (100%), peloidal/skeletal packstone/wackestone; contains skeletal moldic porosity; early syngenetic dolomite but some incipient late dolomite and BC around molds – just starting transition from early to late dolomitization; some bitumen in newly opened BC and lining molds; no fractures or brecciation in matrix; some sulfides.
Diagenetic Events:	1) early dolomitization; 2) leaching; 3) some late dolomitization; 4) bitumen.
Pore Types:	Mo, some BC



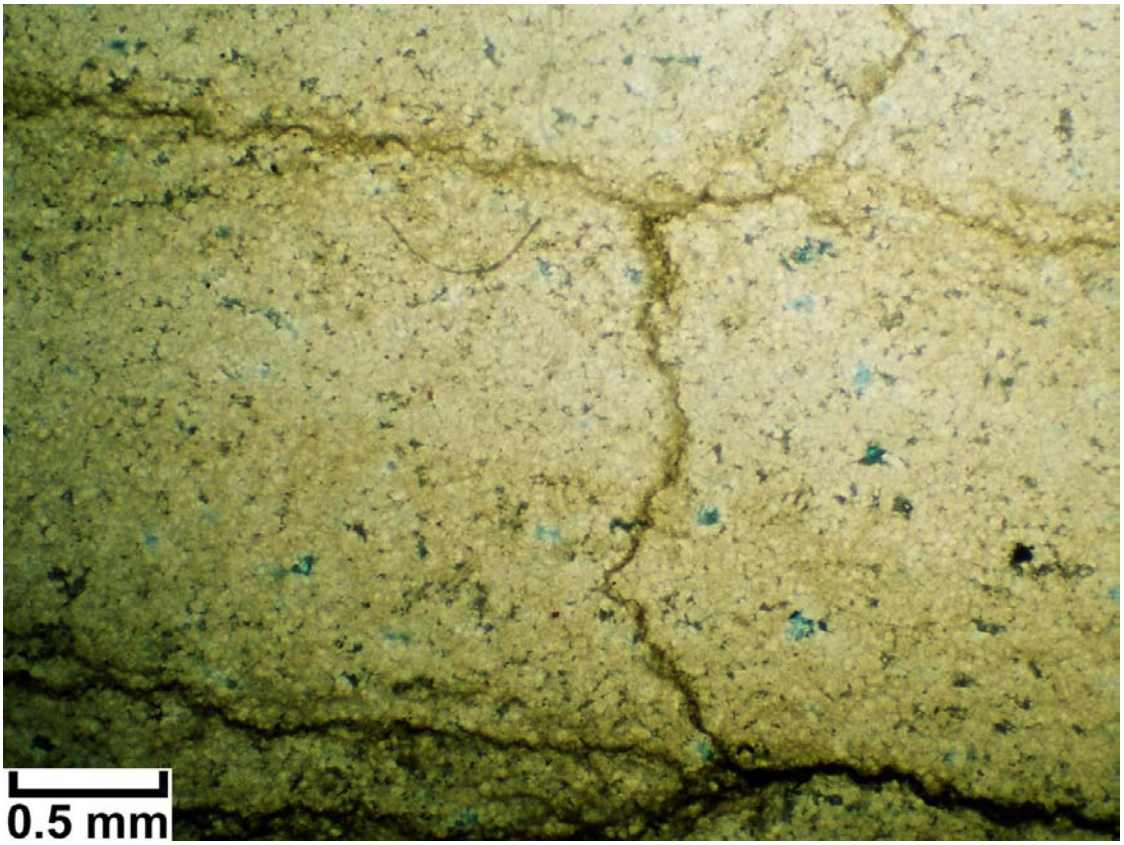
8619 ft.

Plug:	no permeability and porosity
Description:	reservoir – dolomite (100%), crinoidal/hard pellet/fossiliferous grainstone/packstone; some brachiopods; good Mo, some BC, most diagnostic hydrothermal dolomite; very coarse dolomite – saddle dolomite with ghosts of original aphanitic dolomite crystals; late molds (dissolution) of saddle dolomite crystals (mega samples).
Diagenetic Events:	1) early aphanitic type dolomite; 2) leaching of skeletal grains; 3) hydrothermal dolomite; 4) secondary leaching; 5) bitumen.
Pore Types:	Mo, BC, FR



8682 ft.

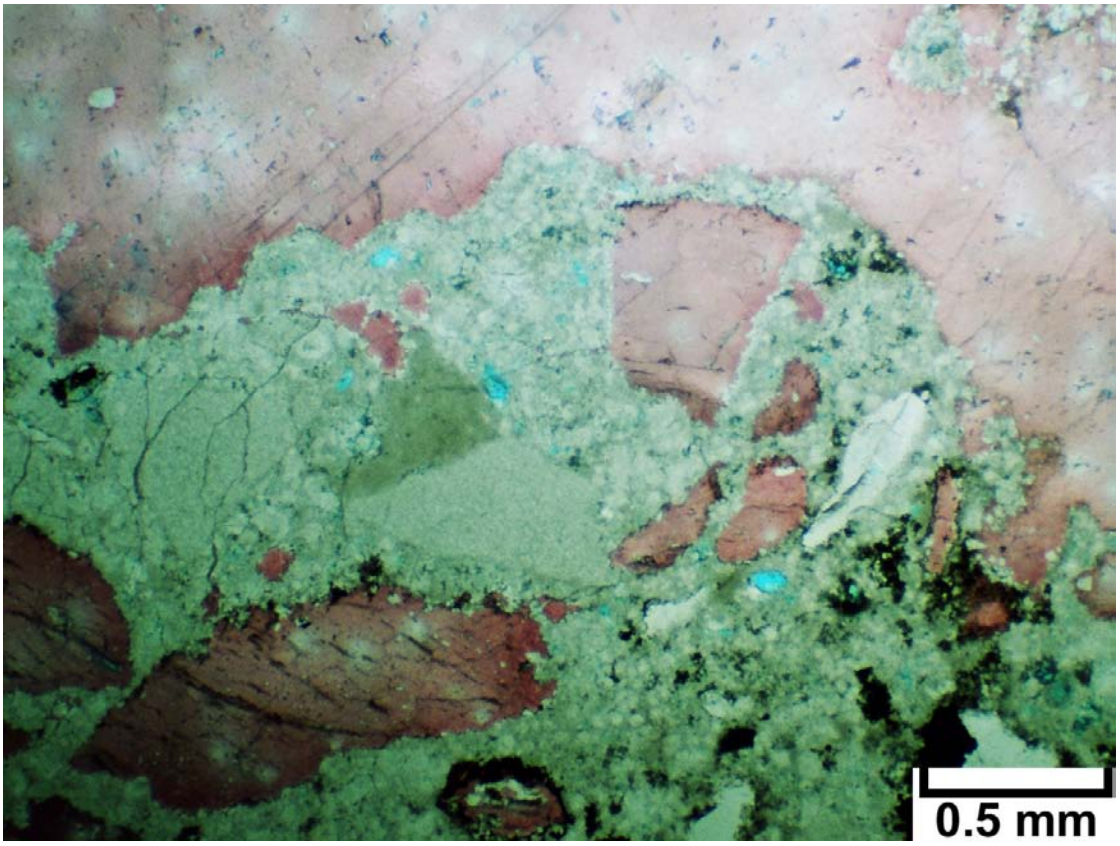
Plug:	no permeability and porosity
Description:	dolomite (100%), soft pellet, muddy, cryptalgal packstone; laminated; aphanitic, syngenetic dolomite – fine BC/small BC yielding false porosity; whispy seam stylolites; flattened pellets due to compaction; a few silt-sized quartz grains (eolian) and trace of fine evaporitic anhydrite; only early dolomitization.
Diagenetic Events:	1) compaction ; 2) syngenetic dolomitization; 3) stylolites.
Pore Types:	micro BC



LISBON PURE NO. C-2 (B-63)
NE1/4 NW1/4, Section 3, T. 30 S., R. 24 E.

9960.6 ft.

Plug:	∅ 4%, K = none
Description:	calcite (60-65%), dolomite (35-40%); brecciated with in-place clast (autobreccia) that retains small amounts of early, finely crystalline (tight) dolomite replaced by mini saddles (euhedral) of medium crystalline dolomite that once had BC, followed by coarsely crystalline saddle dolomite and associated dissolution pores, followed by bitumen plugging of most of the BC and some of the solution-enlarged pores. The remainder of the solution-enlarged pores are largely occluded by coarse, late, slow-growing poikilotopic (big, slow-growing crystals) calcite.
Diagenetic Events:	1) dolomitization; 2) leaching; 3) brecciation; 4) saddle dolomites; 5) poikliotopic late calcite; 6) bitumen plugging.
Pore Types:	Mo, some BC



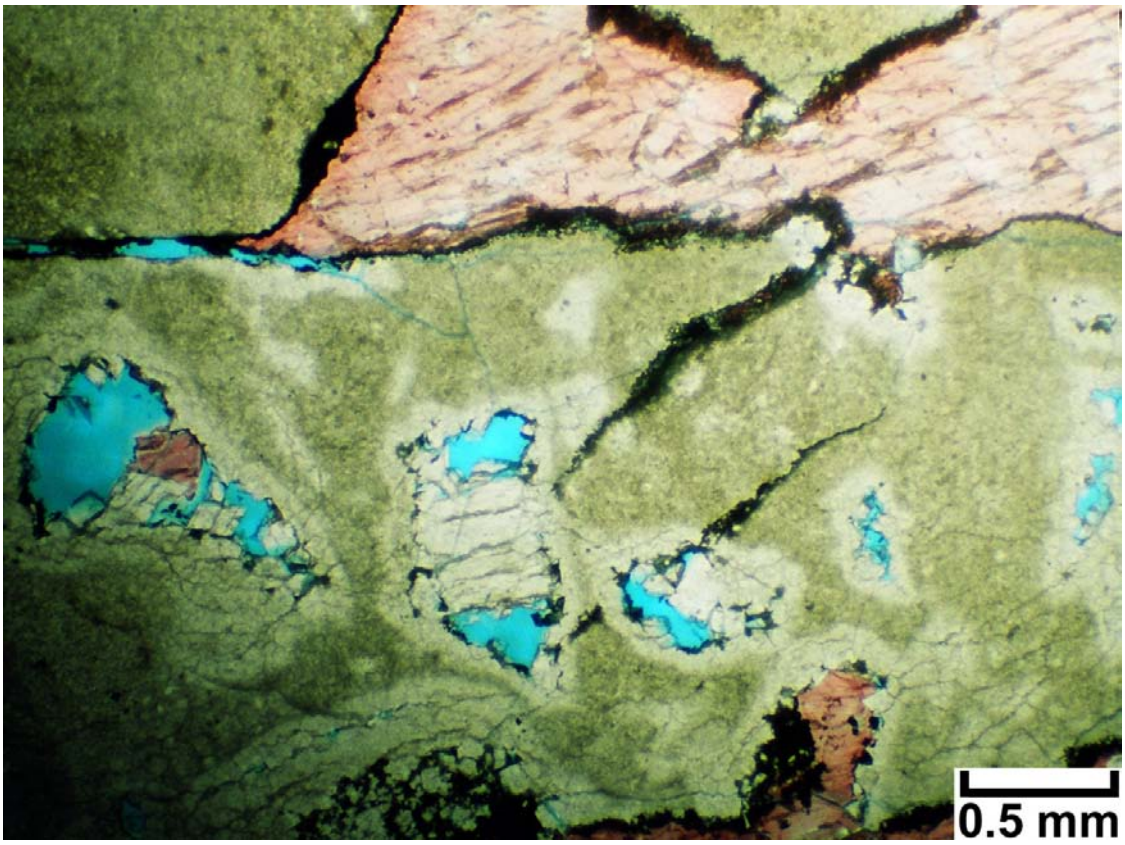
9991.8 ft.

Plug: ∅ 6.2%, K = 0.3 mD

Description: dolomite (60%), calcite (40%); brecciated, with in-place clast (autobreccia) that retains small amounts of early, finely crystalline (tight) dolomite replaced by mini saddles (euhedral) of medium crystalline dolomite that once had BC, followed by coarsely crystalline saddle dolomite and associated dissolution pores, followed by bitumen plugging of most of the BC and some of the solution-enlarged pores. The remainder of the solution-enlarged pores are largely occluded by coarse, late, slow-growing poikilotopic calcite.

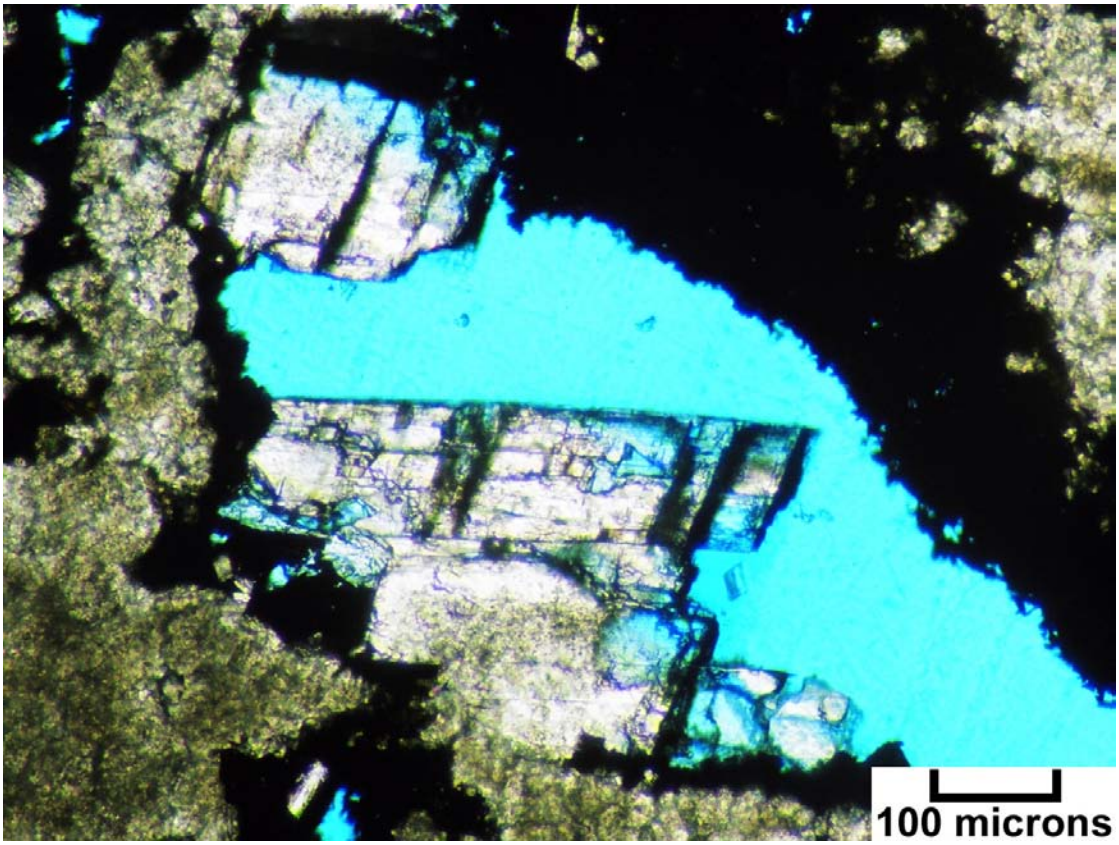
Diagenetic Events: 1) dolomitization; 2) leaching; 3) brecciation; 4) saddle dolomites; 5) poikilotopic late calcite; 6) bitumen plugging.

Pore Types: Mo, some BC



10,001.5 ft.

Plug:	∅ 8.5%, K = 0.7 mD
Description:	dolomite (100%), peloidal/skeletal wackestone; finely to medium crystalline dolomite (tight syngenetic dolomite), containing Mo; molds and modest BC are lined with bitumen, minor saddle dolomite but no late calcite or brecciation.
Diagenetic Events:	1) dolomitization; 2) leaching; 3) brecciation; 4) saddle dolomites; 5) bitumen plugging.
Pore Types:	Mo, some BC



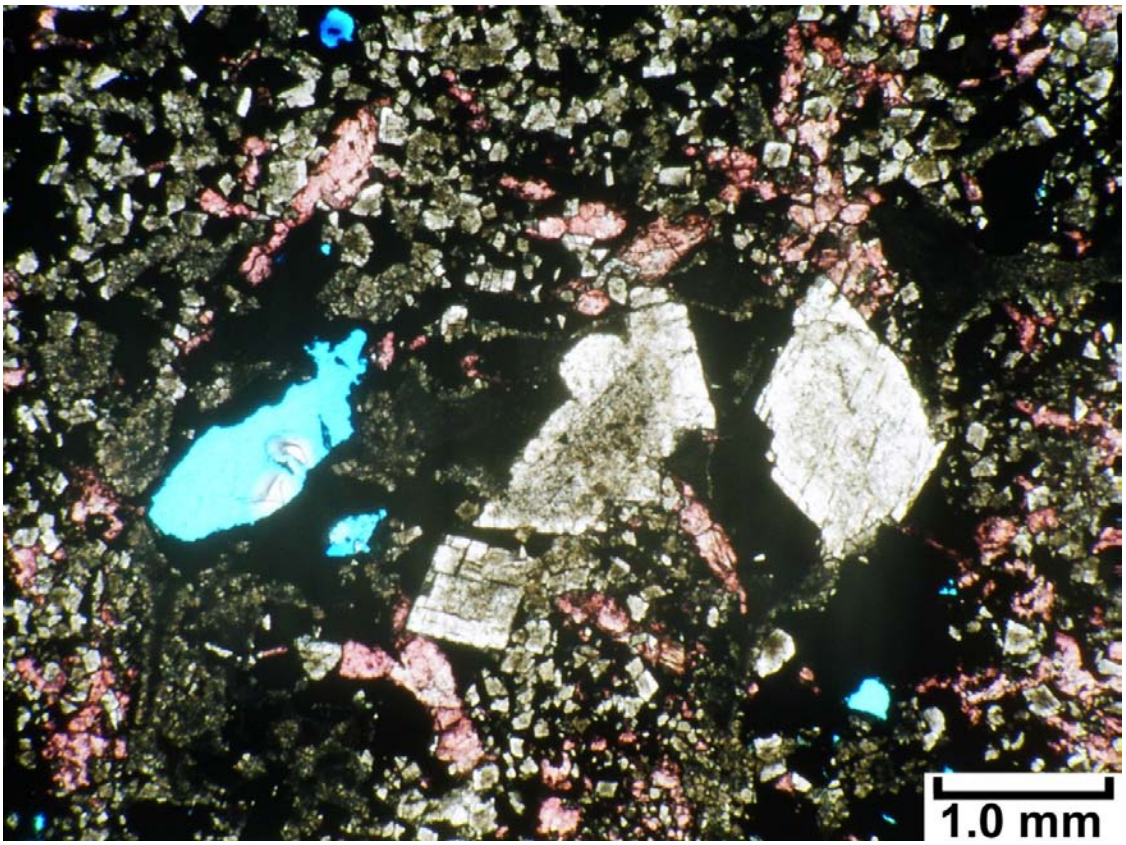
10,004-05 ft.

Plug: ∅ 14.4%, K = 1.9 mD (fractures)

Description: dolomite (60%), calcite (40%); brecciated, with in-place clast (autobreccia) that retains small amounts of early, finely crystalline (tight) dolomite replaced by mini saddles (euhedral) of medium crystalline dolomite that once had BC, followed by coarsely crystalline saddle dolomite and associated dissolution pores, followed by bitumen plugging of most of the BC and some of the solution-enlarged pores. The remainder of the solution-enlarged pores are largely occluded by coarse, late, slow-growing poikilotopic calcite. Similar to late-stage pores seen in the D-616 well at 8619 feet, but then filled with late calcite. Note: oil field water rose following the gas/condensate cap and deposited the calcite. The shape of the pores appears like late-stage dissolution.

Diagenetic Events: 1) dolomitization; 2) leaching; 3) brecciation; 4) saddle dolomites; 5) poikilotopic late calcite; 6) bitumen plugging.

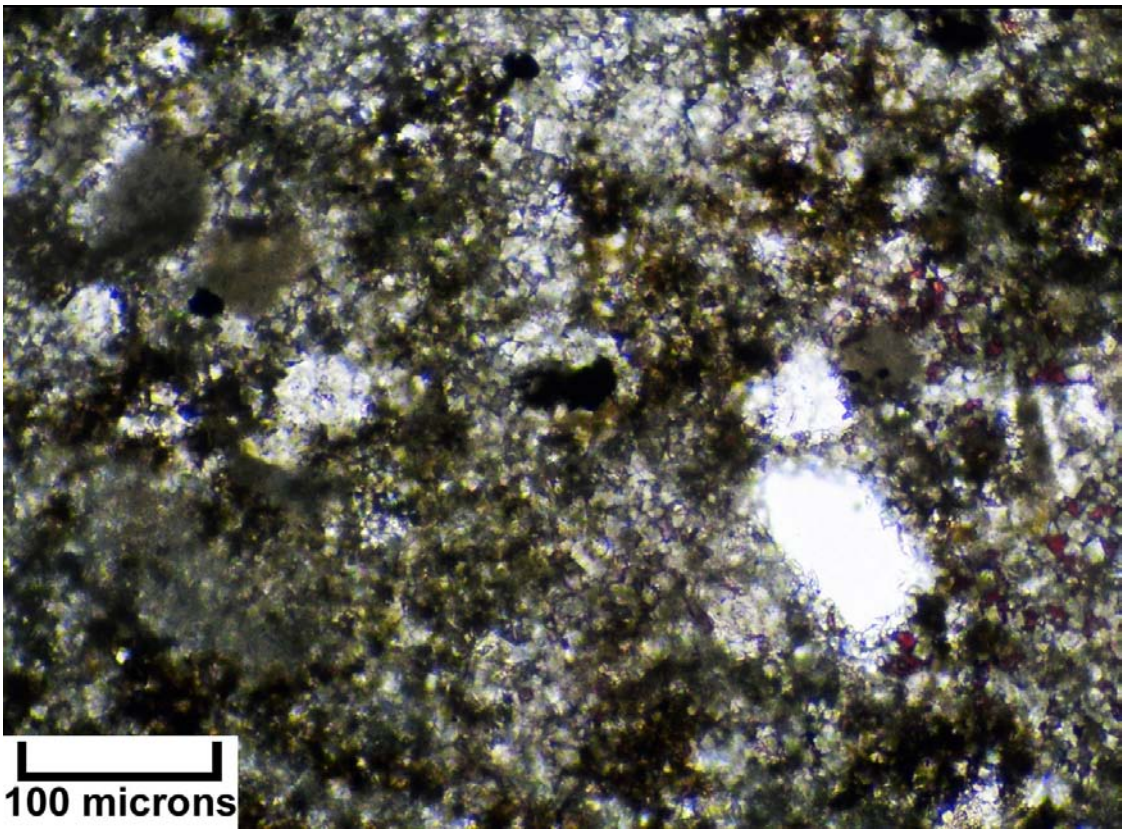
Pore Types: Mo, some BC



LISBON NO. B-816
NE1/4 SW1/4, Section 16, T. 30 S., R. 24 E.

8463.5 ft.

Plug:	∅ 7.9%, K = na
Description:	black dolomite, peloidal packstone/wackestone; finely crystalline, with open microfractures, a few detrital quartz grains (windblown floating with peloids), forams (indothyrids).
Diagenetic Events:	1) early replacement dolomite; 2) minor fracturing; 3) bitumen.
Pore Types:	micro BC



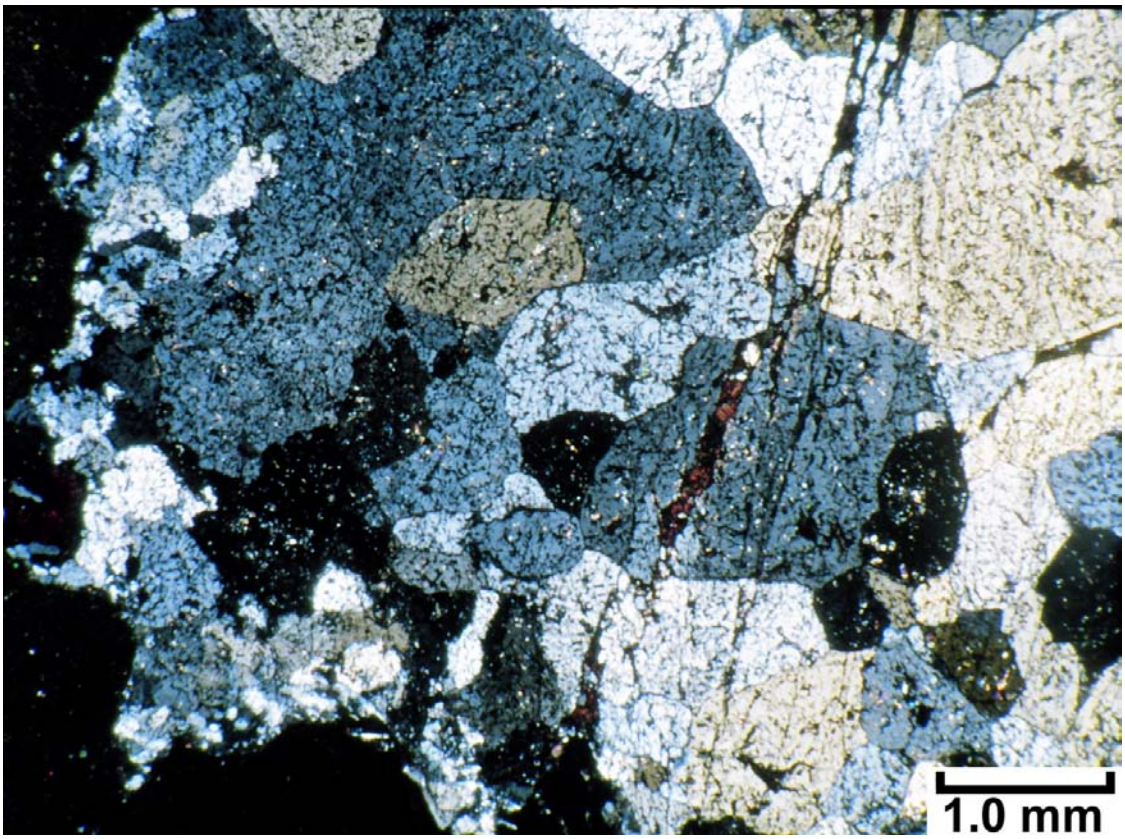
8468 ft.

Plug: ∅ 8.4%, K = 3.2 mD

Description: dolomite, pellet/foram packstone/wackestone.

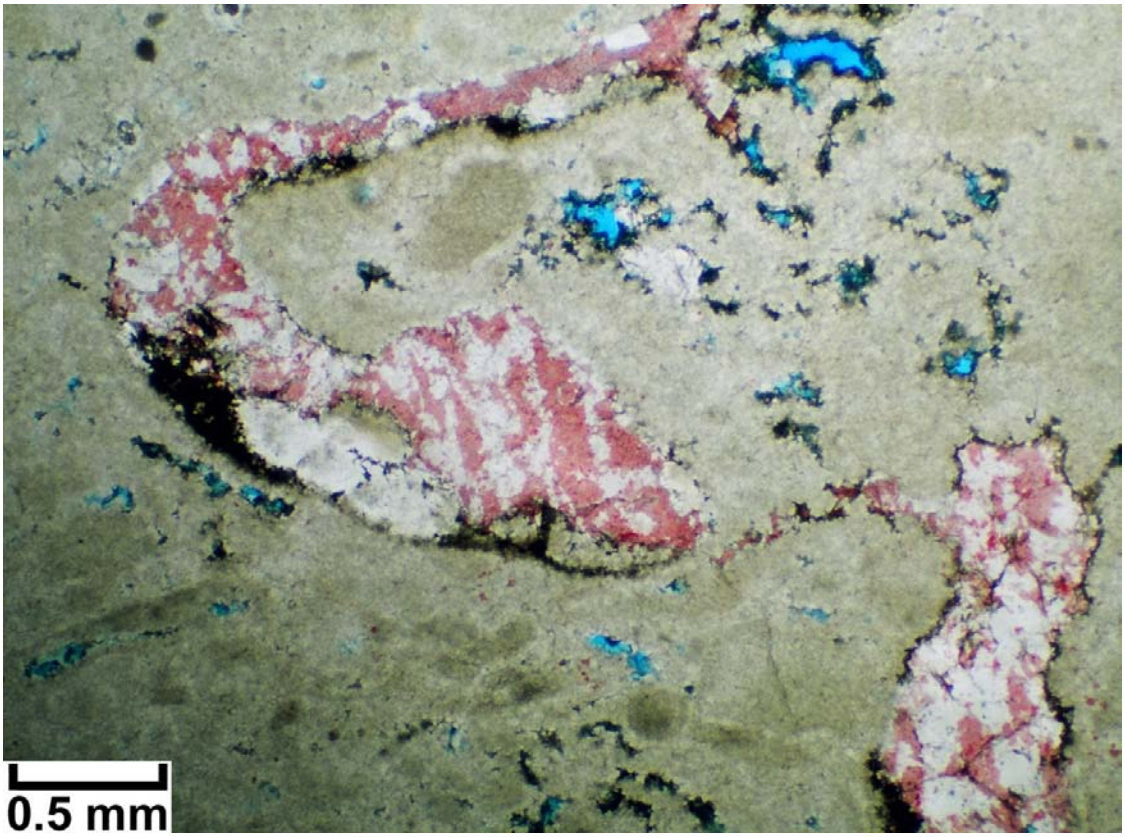
Diagenetic Events: 1) matrix replaced by early syngenetic dolomite preserving the original fabric; 2) late anhedral replacement of finely crystalline dolomite destroying fabric; 3) replacement silica and calcite of dolomite; 4) euhedral etched dolomite and formation of coarse dolomite and associated bitumen and fine sulfides; 5) hydrothermal dolomite (rhombs with curved crystal faces) replacing ground mass; 6) mega quartz and mega calcite of unknown origin.

Pore Types: Mo, BC



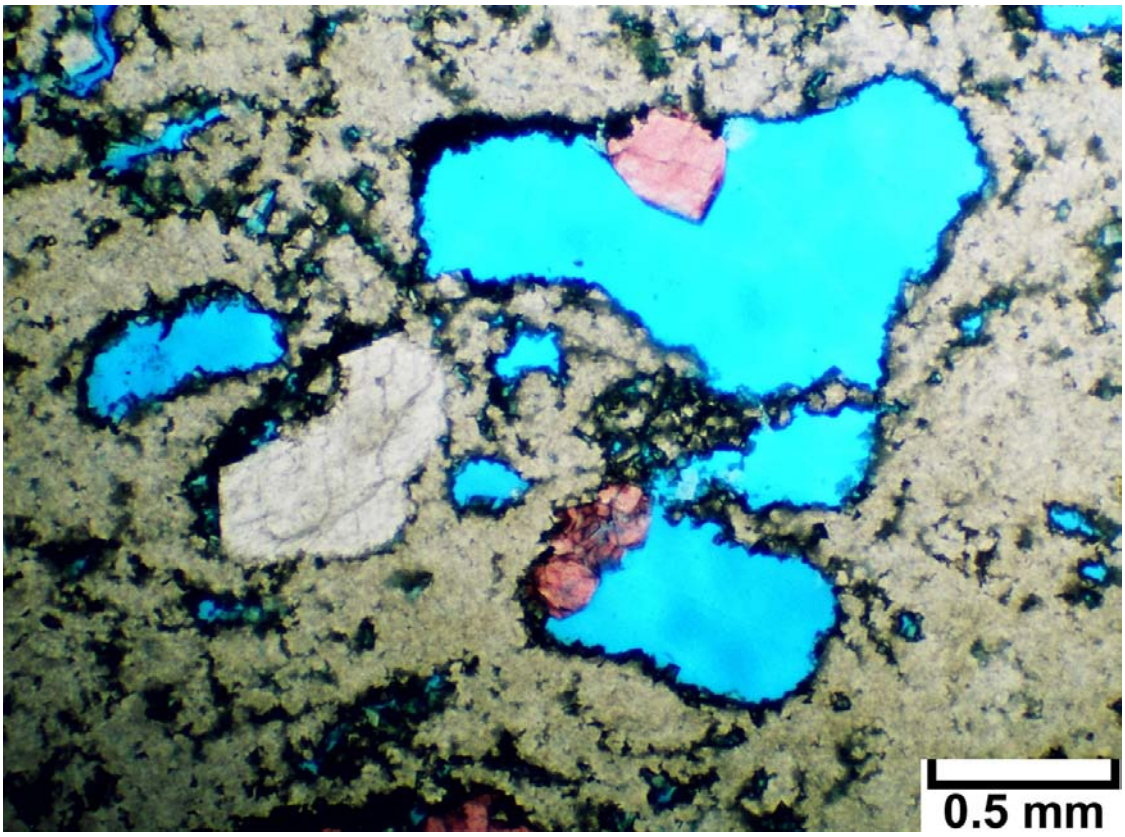
8473.5 ft.

Plug:	∅ 2.3%, K = 17 mD
Description:	dolomite, peloidal wackestone/packstone; indothyroid forams; some open fractures; early anhedral dolomite; etching and leaching; late calcite pore filling; some bitumen in fractures.
Diagenetic Events:	1) matrix diagenesis same as 8468 feet; 2) patch dissolution/ leaching yielding porosity that post dates dolomitization and sylolites; 3) fracturing; 4) bitumen lining and fractures; 5) partial filling of fractures by calcite; 6) replacement by late silica.
Pore Types:	Mo, BC



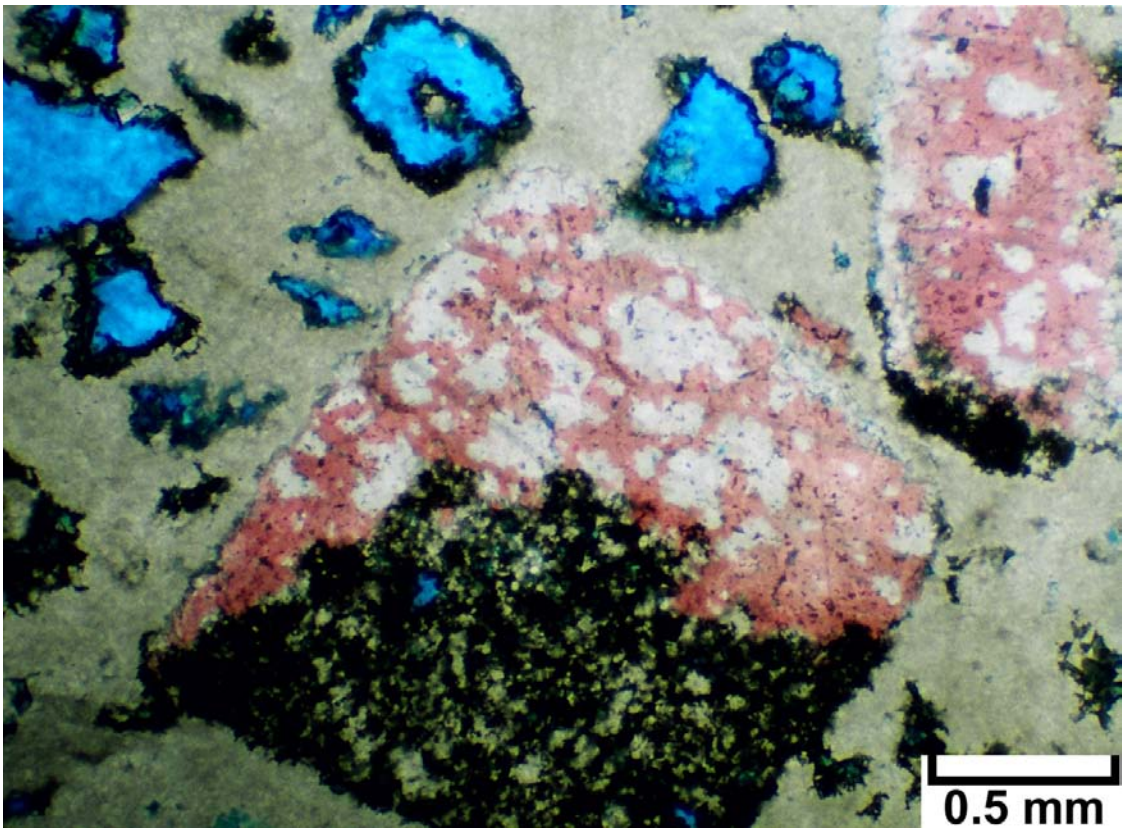
8486 ft.

Plug:	∅ 5.9%, K = 0.2 mD
Description:	dolomite (100%), peloidal/skeletal/ crinoidal grainstone/ packstone; well developed baroque dolomite filling in molds; leached grains; late calcite; bitumen lining.
Diagenetic Events:	1) dolomitization; 2) leaching; 3) saddle dolomite; 4) bitumen; 5) late calcite.
Pore Types:	Mo, BC



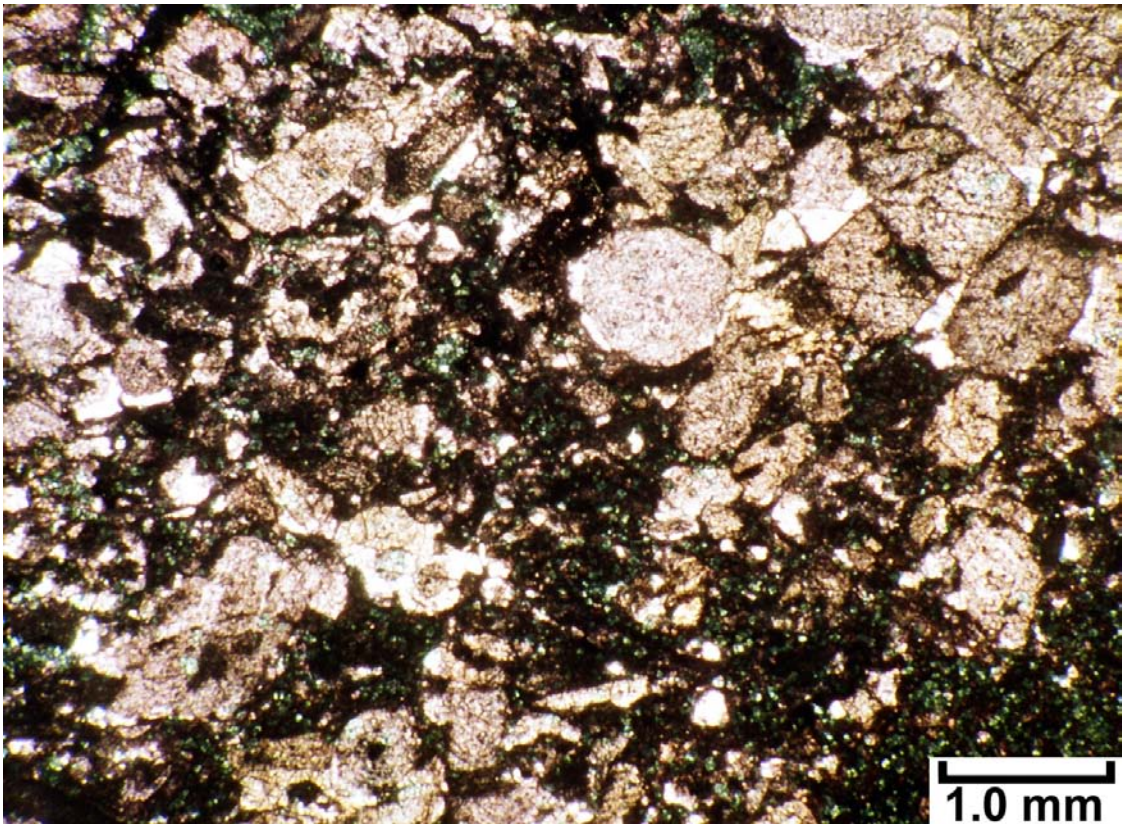
8488 ft.

Plug:	∅ 1.5%, K = 0.5 mD
Description:	same as 8486 feet but no saddle dolomite; some silicification of calcite.
Diagenetic Events:	1) dolomitization; 2) leaching; 3) bitumen; 4) late calcite; 5) silicification.
Pore Types:	Mo, BC



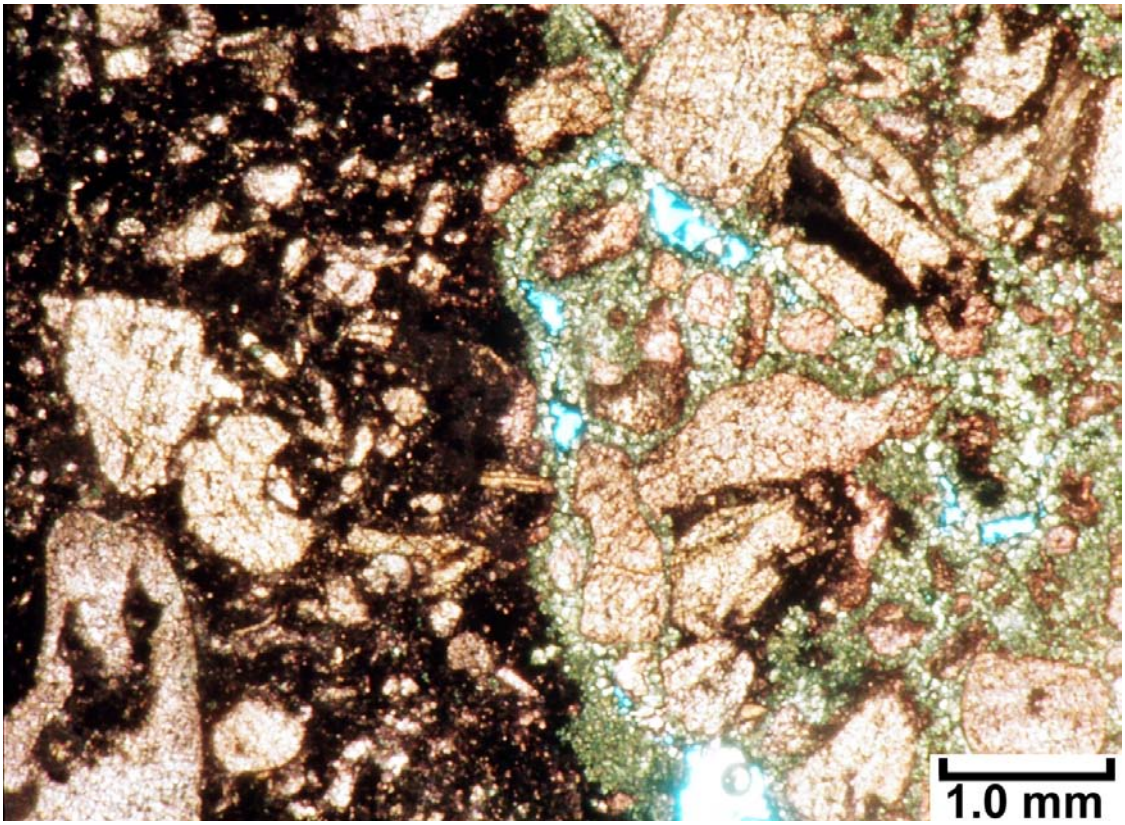
8490.3 ft.

Plug:	∅ 1.7%, K = nd
Description:	limestone (70%), dolomite (30%), crinoidal/skeletal grainstone; good example of a grainstone turned to finely crystalline dolomite or “black shale” or dolomitic mudstone.
Diagenetic Events:	1) compaction; 2) early dolomitization; 3) leaching; 4) late dolomite cement, fracturing, and replacement dolomite; 5) bitumen.
Pore Types:	Mo, FR



8509 ft.

Plug:	oriented; ∅ 3%, K = nd
Description:	limestone, fossiliferous wackestone; crinoids brachiopods; contact between limestone and dolomite fractures lined with coarse dolomite; leached pores filled with dolomite.
Diagenetic Events:	1) compaction; 2) early dolomitization; 3) leaching; 4) late dolomite cement, fracturing, and replacement dolomite; 5) bitumen.
Pore Types:	Mo, FR



LISBON NO. B-610
NE1/4 NW1/4, Section 10, T. 30 N., R. 24 E.

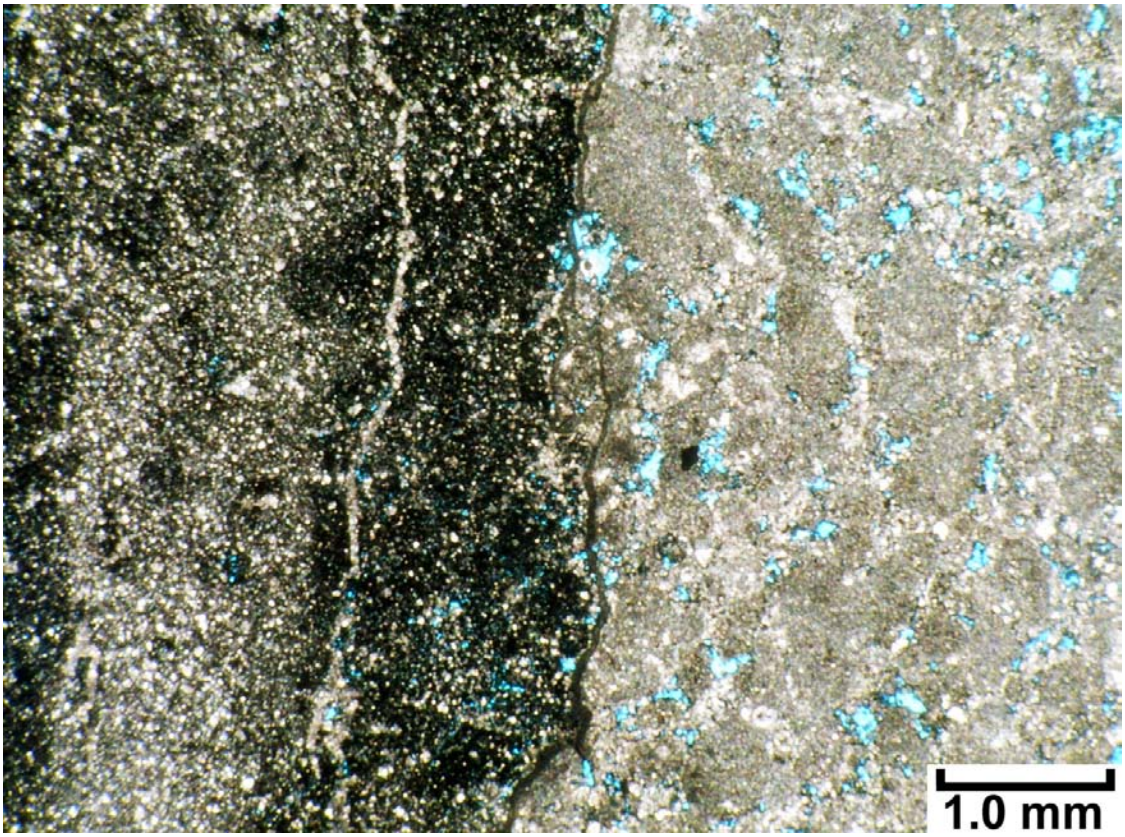
7897 ft.

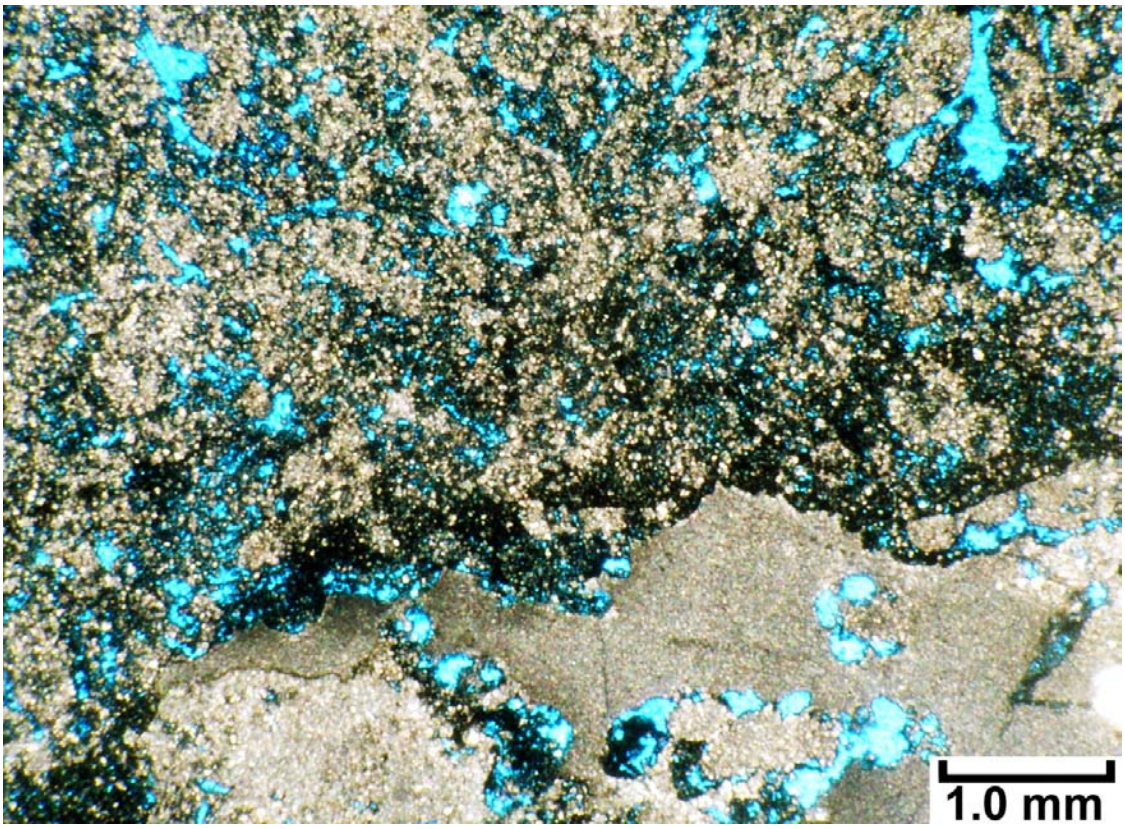
Plug: oriented; ∅ 6.3%, K = 83 mD

Description: 1) light dolomite – peloidal/oolitic? grainstone; early dolomite associated with Mo (not effective permeability and porosity); pores contain some late saddle dolomite, no bitumen; this is a stratigraphic dolomite – correlates from well to well. 2) black dolomite – cross-cutting of black dolomite and well preserved syngenetic dolomite (high permeability and porosity – reservoir); fractures lined with bitumen; micro BC; sharp front; series of cross-cutting fractures with late dolomite replacing early dolomite, relic grains, no infilling of detrital sediment, fractures filled with late dolomite cement.

Diagenetic Events: 1) compaction; 2) early dolomitization; 3) leaching; 4) late dolomite cement, fracturing, and replacement dolomite; 5) bitumen.

Pore Types: Mo, micro BC, some WP



7886 ft.

Plug:	no orientation; ∅ 13.8%, K = 114 mD
Description:	dolomite (100%), peloidal/skeletal grainstone/packstone; sample experienced early fabric-preserving dolomitization (syngenetic), followed by leaching of undolomitized grains; problematical brecciation (auto-brecciation) surrounded by micro fractures; dissolution along micro fractures of early dolomite matrix formed solution-enlarged fractures as well as CH and small vugs; major cross-cutting dissolution event resulted in micro BC; bitumen lining yielded a black dolomite; finely patchy replacement by coarser saddle? dolomite with cloudy cores and clear overgrowths.
Diagenetic Events:	1) compaction; 2) early dolomitization; 3) leaching; 4) brecciation and fracturing; 5) secondary dissolution; 6) saddle dolomite; 7) bitumen.
Pore Types:	Mo, CH, vugs, micro BC, FR (solution enlarged)