



# Factors Influencing Diagenesis and Reservoir Quality in Potential Lithium-Enriched Brine Reservoirs of the Northeastern Texas Smackover Formation

Robert G. Loucks

*Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin,  
P.O. Box X, Austin, Texas 78713–8924, U.S.A.*

## ABSTRACT

Forecasting reservoir quality is a significant risk factor when hydrocarbons or lithium-enriched brines are being produced from the Smackover reservoirs in northeastern Texas. Reservoir quality in Smackover carbonates depends on lithofacies and diagenesis. While lithofacies mapping is consistent and well-defined through wireline-log correlations, understanding the complex effects of diagenesis is much more difficult. Dolomitization, essential for creating high-quality reservoirs, varies laterally across the region, leading to differences in reservoir quality. Seepage reflux from overlying Buckner evaporite brines is likely the cause of dolomitization. The best reservoirs are highly dolomitized, mixed-coated-grainstone sections at the top of the Smackover interval, composed of ooids, oncoids, and other microbial-coated grains. These reservoirs exhibit up to 30% porosity and permeability, ranging up to hundreds to thousands of millidarcys, with pore networks consisting primarily of oomoldic and intercrystalline pores. Detailed analysis of two mineralogically contrasting cores from northeastern Texas highlights the influence of diagenetic histories on reservoir quality.

## INTRODUCTION

The Smackover Formation in northeastern Texas (Fig. 1) has been an exploration target for hydrocarbons since the 1940s (Collins, 1971) and is now considered a target for lithium-rich brines (Heaton and Rhymes, 2023). Reservoirs that host these brines can be thought of as continuous reservoirs because no trap is necessary to concentrate the brines. High-quality reservoirs are necessary for ensuring high production rates of brine production, and, in this region, such reservoirs are associated with dolomitized grainstones in the upper Smackover section (e.g., Harwood and Fontana, 1983; this paper).

This study provides insights into the controls of diagenesis and reservoir quality in potential lithium-brine reservoirs in the Smackover Formation. Specific objectives include

- (1) describing general lithofacies in studied cores,
- (2) defining pore types and their origins,
- (3) discussing effects of mineralogy on pore types and reservoir quality, and
- (4) demonstrating range of reservoir quality encountered in the study area.

Addressing these objectives were found to provide insights into reservoir quality that will aid in an understanding of the production of hydrocarbons and lithium-rich brines from the Smackover Formation in northeastern Texas.

## DATA AND METHODS

To define pore types and diagenesis, two mineralogically contrasting cores from the Smackover Formation in northeastern Texas were analyzed. The Sun Oil No. 1 Price (API# 42223304150000) core in Hopkins County is dolostone dominant, whereas the Shell No. 1 Mary O Ahern (API# 42067000230000) core in Cass County is limestone dominant (Fig. 2). Thin sections were examined for texture, fabric, allochems, mineralogy, pore types, and diagenetic features. These thin sections were also impregnated with blue-dyed epoxy to emphasize macropores and with blue-fluorescent dye to emphasize micropores. A part of each thin section was stained with alizarin-red dye to differentiate calcite from dolomite (Friedman, 1959). Relative amounts of dolomite versus limestone in the No. 1 Price core were estimated from thin sections by testing with 10% HCl acid. In addition, relative amounts of dolomite versus calcite were estimated in the No. 1 Ahern core using X-ray fluorescence analysis (XRF).

## REGIONAL GEOLOGICAL SETTING

Upper Jurassic Smackover strata were deposited in a ramp setting within a restricted basin (Iturralde-Vinent, 2006) that ex-

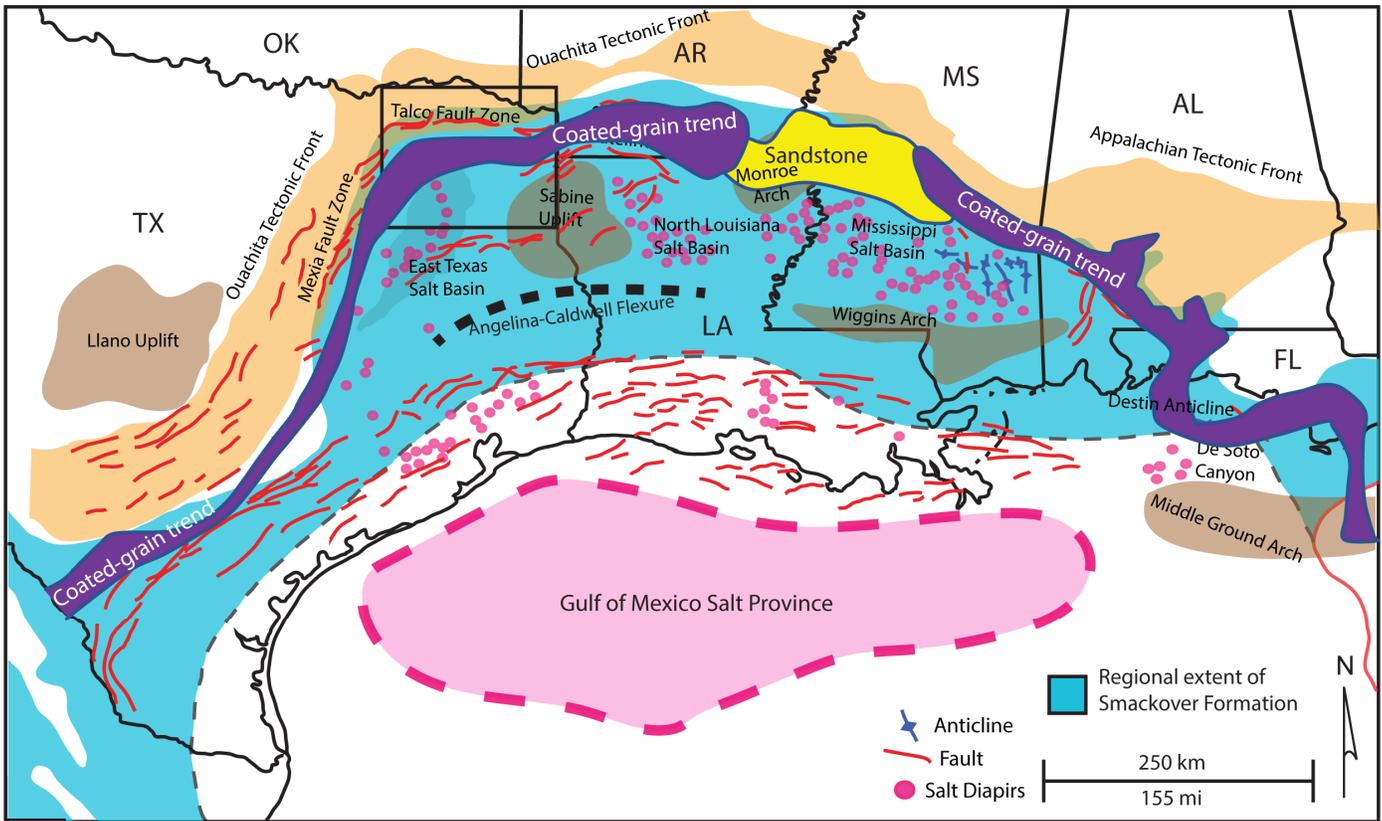
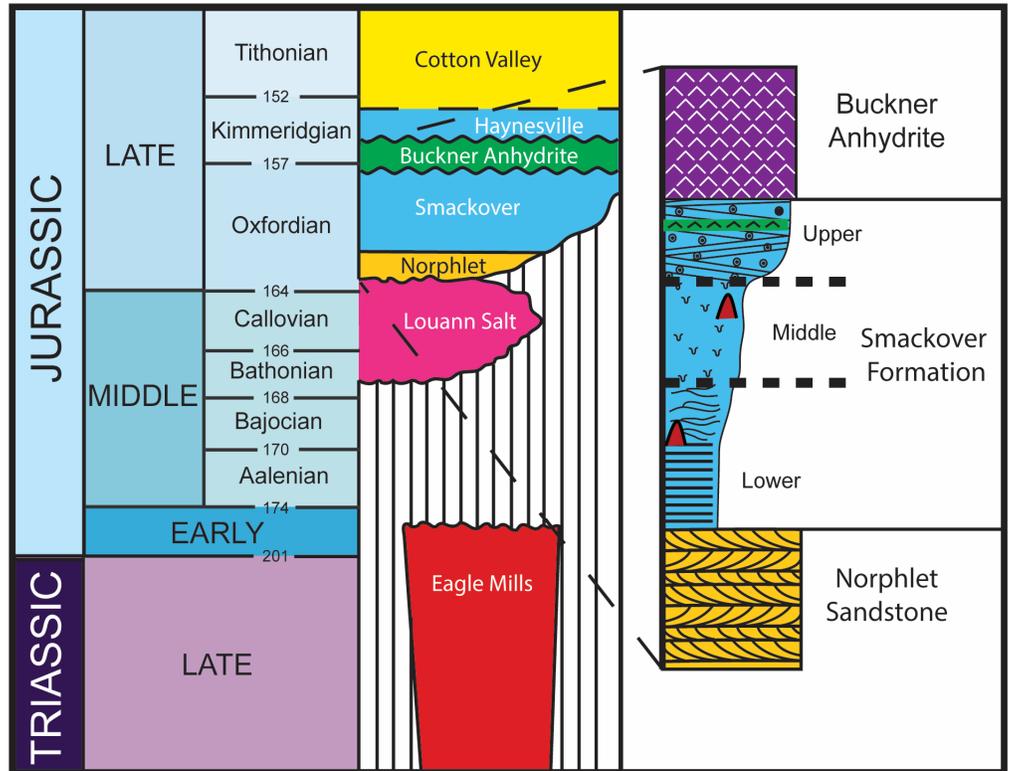


Figure 1. Regional map and stratigraphic column. Figures adapted from Schemper et al. (2022). (A) Geologic map showing structural and geomorphic features along northern Gulf of Mexico. Smackover mixed-coated-grain trend indicated. (B) Stratigraphic column of Triassic and Jurassic strata for northeastern Texas, including lithostratigraphic section. Green-purple chevron pattern = evaporites and red mounds = thrombolites.



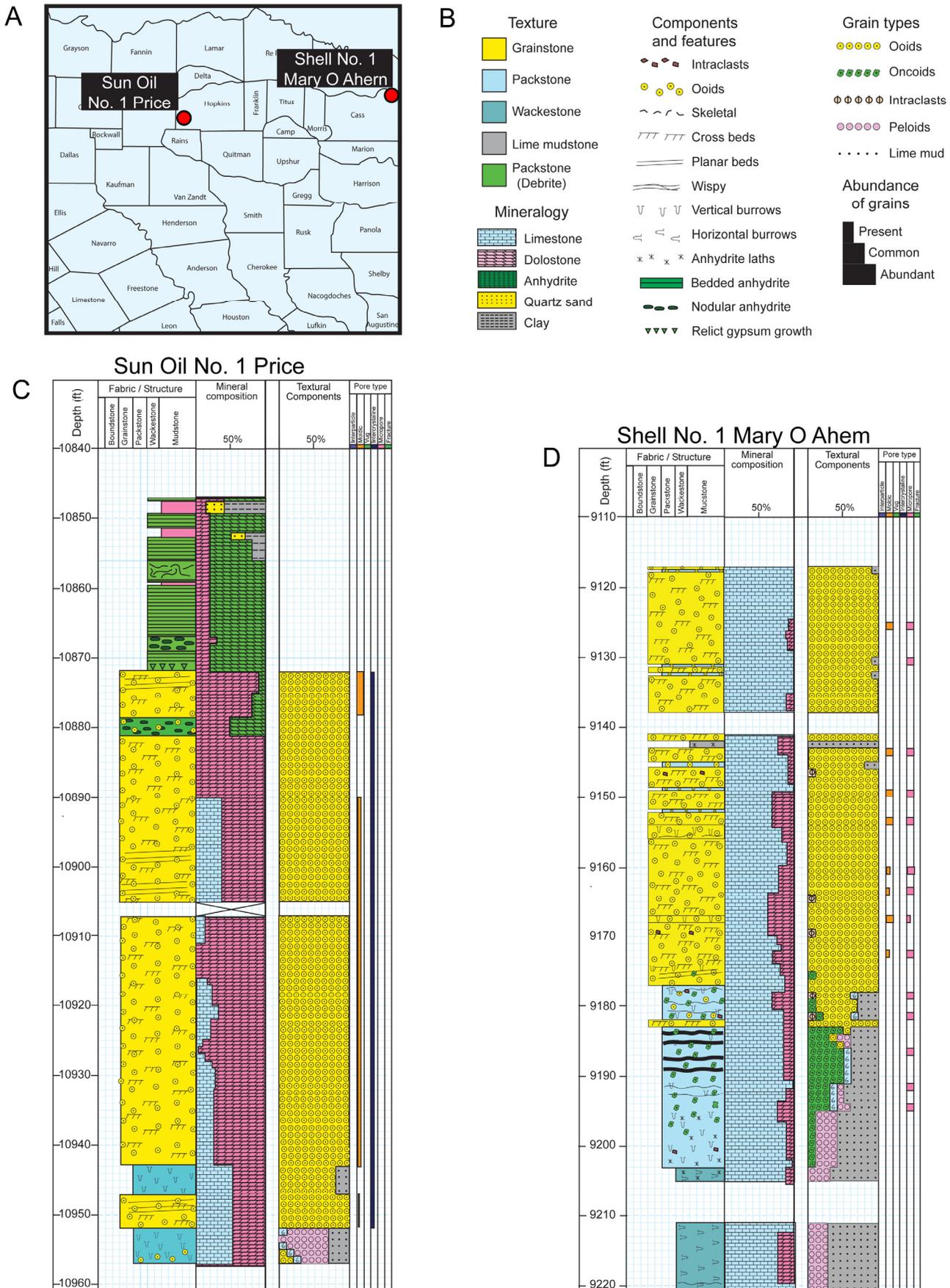


Figure 2. Cores used in investigation. (A) Map showing locations of two cores analyzed. (B) Core legend. (C) Sun Oil No. 1 Price, Hopkins County, Texas. Section predominantly dolostone, with high-quality reservoir sections. (D) Shell No. 1 Mary O Ahern, Cass County, Texas. Section predominantly limestone, with lower-quality reservoir sections.

tended from Florida to Mexico (e.g., Budd and Loucks, 1981) (Fig. 1A). This basin is characterized by an upward-shoaling, tripartite stratigraphic section (Fig. 1B). The lower section is composed of dark, laminated mudstones containing microbial mats; the middle section is composed of peloidal wackestones, packstones, and some thrombolites; and the upper section is composed of ooid and ooid packstones, transitioning into ooid grainstones (Fig. 1B). In some cores, evaporite sections or evaporite-related, collapsed breccia are present.

The Smackover is composed of stacked, higher-order sequences, as opposed to a continuous depositional sequence (Handford and Baria, 2007). The Buckner Evaporite, a separate, lower-order sequence situated above Smackover strata, most likely contributed dolomitizing brines, leading to Smackover dolomitization through seepage-reflux processes.

### SMACKOVER LITHOFACIES

Smackover carbonates were deposited in an arid climate on a ramp that deepened into the restricted, early Gulf of Mexico (e.g., Budd and Loucks, 1981). Figure 3, a diagrammatic model of the Smackover ramp, modified from Budd and Loucks (1981) and Schemper et al. (2022), illustrates the depositional settings and lithofacies. The distal outer ramp consists of argillaceous, laminated lime mudstones interbedded with debrites formed under anoxic, bottom-water and sediment conditions. Dark microbial mats characterize the laminae (e.g., Budd and Loucks, 1981; Moore, 1984), and the proximal outer ramp is dominated by peloidal, horizontally burrowed mudstones and wackestones, with some interbedded debrites. Horizontal burrows indicate environmental stress during deposition. The distal middle ramp comprises burrowed peloidal mudstones and wackestones with vertical burrows, reflecting a less stressed environment. Thrombolites are

generally found in this section. The proximal, middle ramp is similar but contains more oncoids and some packstones. The distal inner ramp transitions to lithofacies containing abundant oncoids, packstones, and some thrombolites and ooids transported from the proximal inner ramp. This lithofacies is heavily burrowed. The proximal inner ramp features high-energy grainstones deposited in a strandplain system, with lagoonal and supratidal/sabkha mudstones and evaporites landward in lower-energy, more restricted settings. Overall, energy levels and less restrictive, depositional conditions increase up the ramp, peaking in the high-energy, strandplain-barrier system. Environments landward of the strandplain-barrier system become progressively more restricted and lower energy.

The Shell No. 1 Mary O Ahern and Sun Oil No. 1 Price wells both cored the upper section of the Smackover Formation (Figs. 2C and 2D), revealing lithofacies of the inner-ramp environments. In the distal inner ramp, cores exhibit vertically burrowed peloidal and oncolitic packstones (Figs. 4C, 4E, 5C, and 5E), ooids being present in upper intervals of the packstones. The proximal inner ramp is characterized by ooid-rich grains and some intraclasts (Figs. 4A, 4B, 4D, 5A, 5B, and 5D). A brecciated zone near the top of the interval in the No. 1 Price well is interpreted as evaporite-related breccia (Fig. 2C). Additionally, the top of this core includes the basal Buckner Evaporite. No. 1 Price well core is notably more dolomitized than No. 1 Ahern core (Figs. 2C and 2D).

### REVIEW OF PORE NETWORKS AND ASSOCIATED DIAGENESIS

For an understanding of pore development, preservation, and destruction, a grasp of the concept of diagenesis is essential. Figure 6 illustrates the key diagenetic processes observed in the

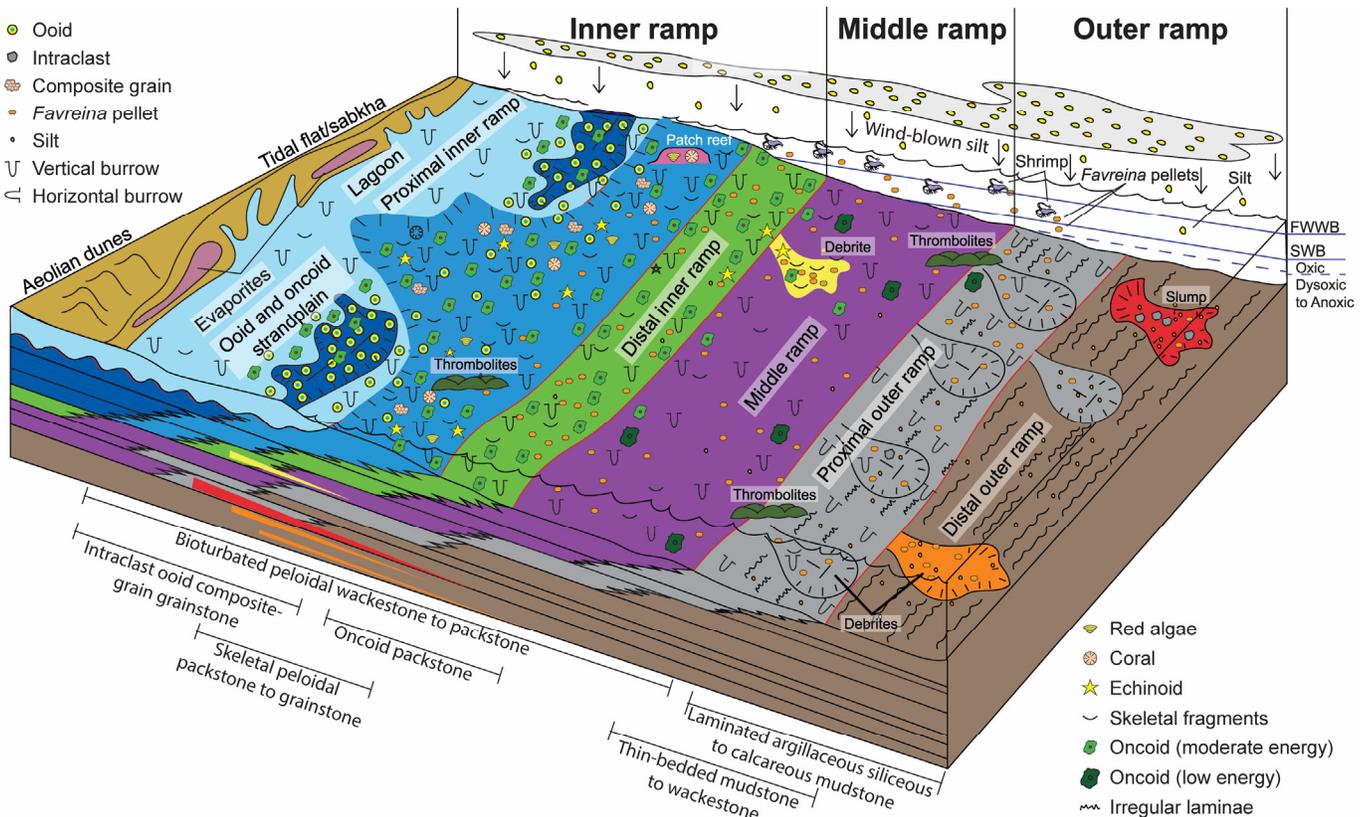
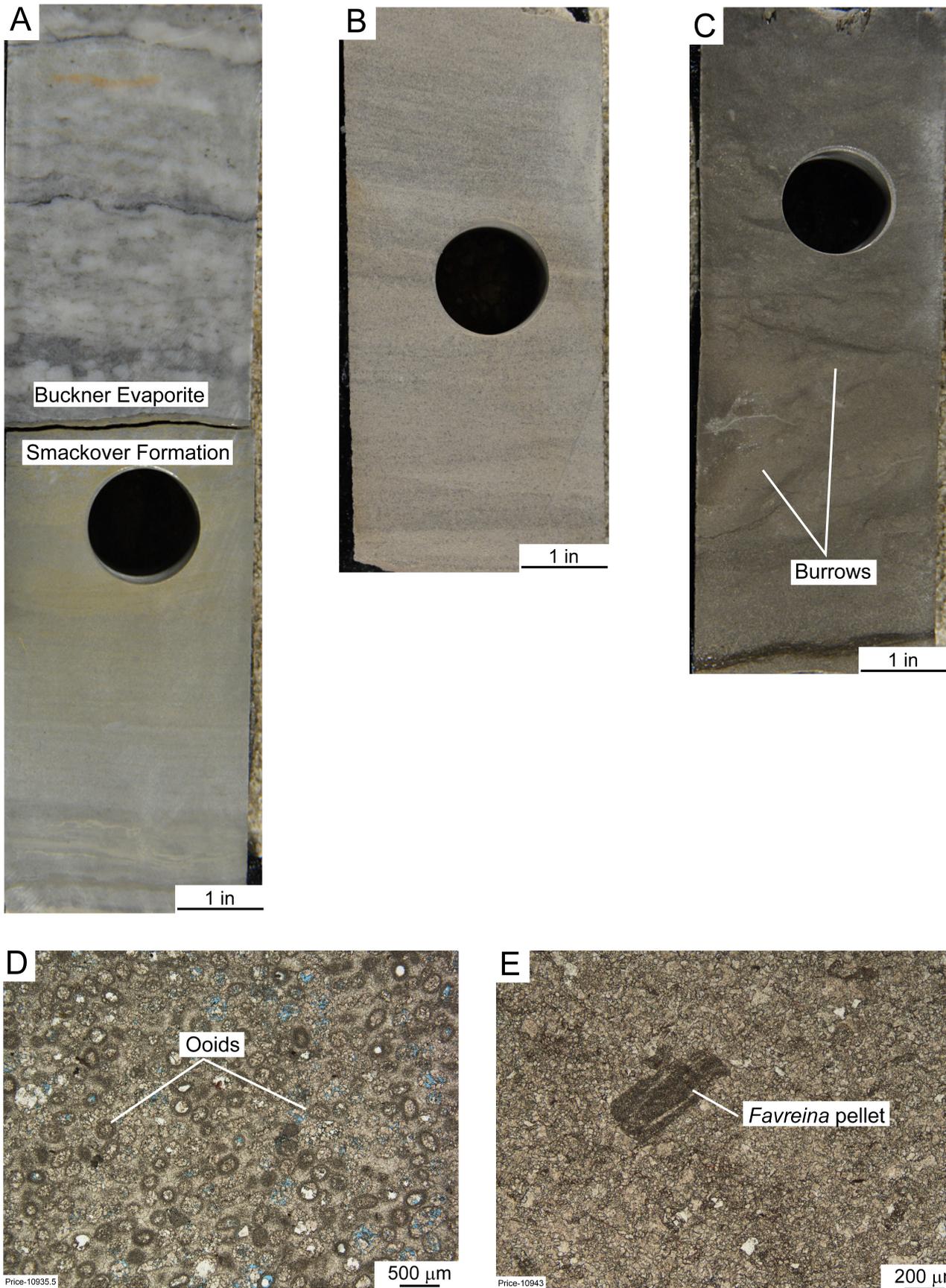
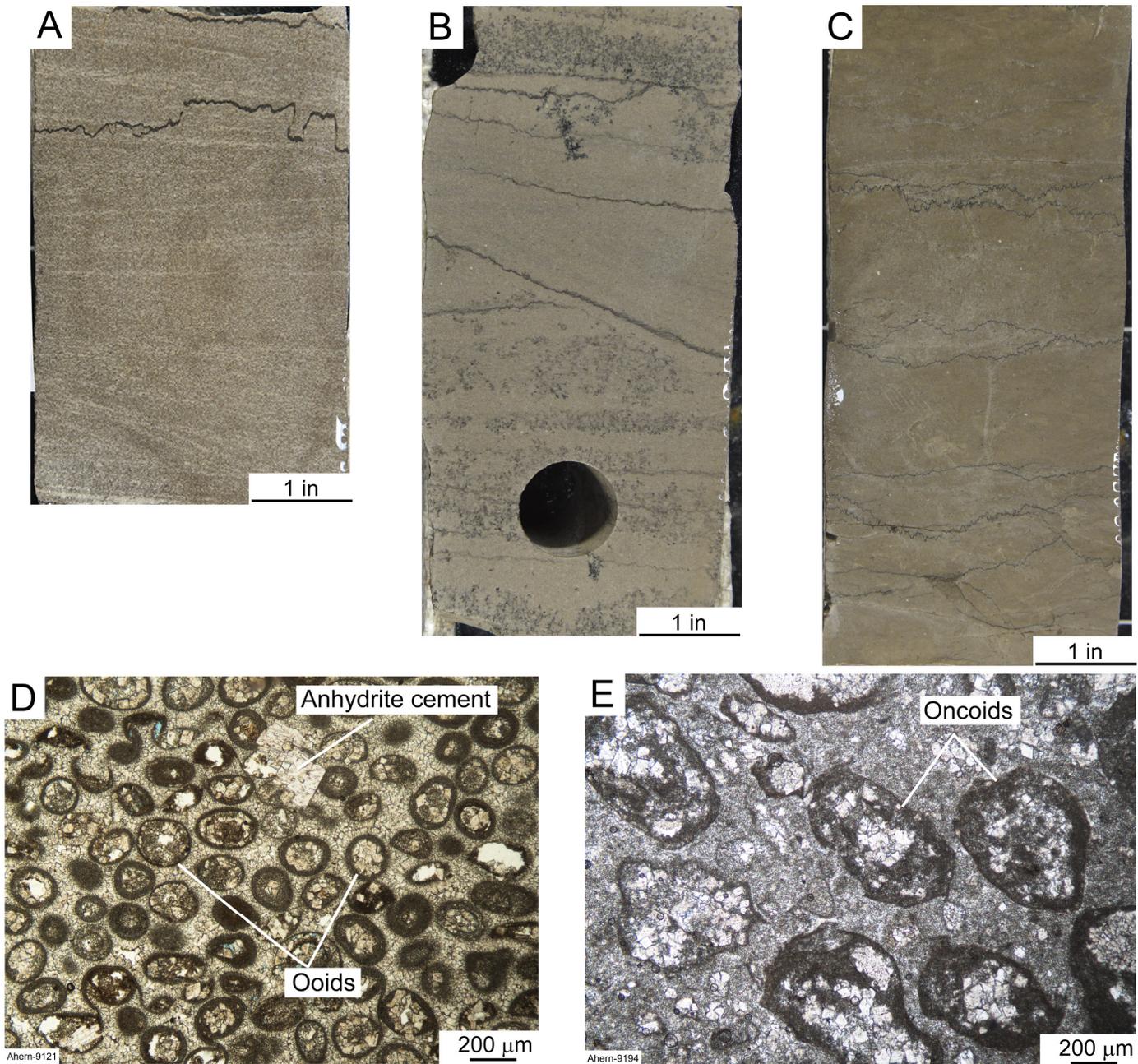


Figure 3. Schematic depositional ramp model for Smackover Formation in northeastern Texas (modified after Budd and Loucks [1981] and Schemper et al. [2022]).



**Figure 4.** Lithofacies examples from Sun Oil No. 1 Price core. (A) Contact between Smackover Formation below and Buckner Evaporite above. Smackover section exhibits plane bedding, whereas Buckner section shows bedded anhydrite nodules. Core slab at 10,854 ft (3308.3 m). (B) Cross-bedded ooid grainstone. Core slab at 10,903.3 ft (3323.3 m). (C) Burrowed packstone. Core slab at 10,843 ft (3304.9 m). (D) Ooid grainstone with oomoldic pores. Thin section at 10,935.5 ft (3333.1 m). (E) Peloidal packstone with *Favreina* pellets. Thin section at 10,943 ft (3335.4 m).



**Figure 5.** Lithofacies examples from Shell No. 1 Mary O Ahern core. (A) Cross-bedded ooid grainstone. Core slab at 9124 ft (2781.0 m). (B) Cross-bedded ooid grainstone with dark patches of diagenetic alteration. Core slab at 9157 ft (2791.1 m). (C) Burrowed packstone. Core slab at 9,125.8 ft (2,781.5 m). (D) Ooid grainstone with anhydrite-replacement cement. Thin section at 9121 ft (2780.1 m). (E) Oncoid packstone. Thin section at 9194 ft (2802 m).

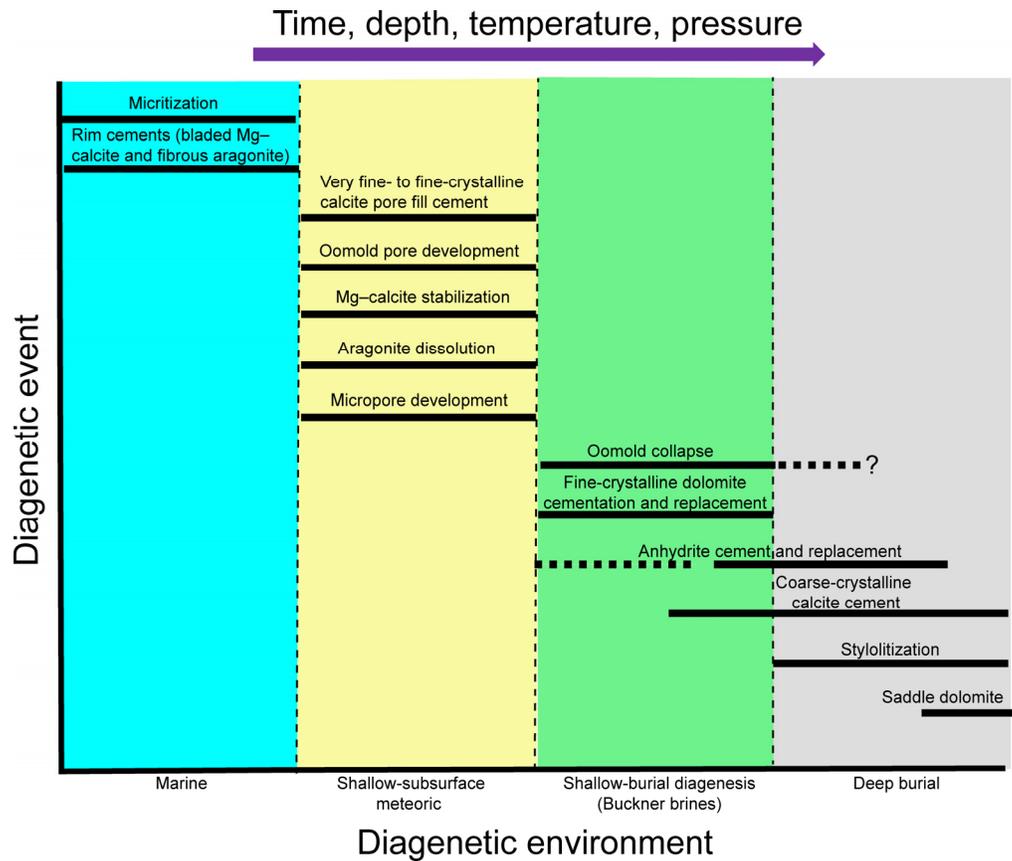
northeastern Texas Smackover Formation and highlights the major diagenetic features, along with the diagenetic environments in which they formed. Primary diagenetic features that influence reservoir quality include (1) rim cement (bladed Mg–calcite and fibrous aragonite); (2) very fine- to fine-equant, pore-filling calcite cement; (3) oomoldic pore development from the dissolution of aragonite ooids; (4) micropore formation in former Mg–calcite micrite envelopes; and (5) passive to aggressive dolomitization.

Rim cement (Fig. 7A) played an important role in preventing the compaction of grains, thereby preserving interparticle pores (Moore, 1984). Fine- to very fine-equant, pore-filling calcite cement formed in primary interparticle pores and secondary-dissolution, skeletal moldic pores (Fig. 7A). These cements were

a major factor in oomoldic pore occlusion and subsequent porosity loss. The dissolution of aragonite ooids led to development of oomoldic pores (Figs. 7A, 7B, 8A, and 8B), which created abundant porosity in ooid grainstones. However, they contributed little to permeability unless these pores were connected to the primary pore network. Stabilization of Mg–calcite grains generally resulted in a mesh of microrhombic crystalline calcite with numerous micropores (Figs. 7A–7D) (Loucks et al., 2013; Loucks, 2024). Micropores contribute to overall porosity but have minimal impact on permeability.

Extent of dolomitization has a significant effect on reservoir quality. In passive dolomitization, dolomite precipitates only in available pore space (Figs. 7A and 7B). In aggressive dolomitiza-

**Figure 6. Paragenetic sequence showing diagenetic events versus diagenetic environments.**



tion, dolomite not only fills existing pores but also replaces the precursor limestone, creating new pores. In cases of very aggressive dolomitization, the original texture and fabric of the rock may become nearly unrecognizable (Figs. 8A–8D).

Some pore types and networks within the northeastern Texas Smackover strata are products of calcite/aragonite/Mg–calcite meteoric diagenesis, whereas others result from dolomitization, with some pore networks being influenced by both processes (Figs. 7 and 8). Dolograins exhibit the highest reservoir quality, ranging from fair to excellent (Fig. 9). Also, some lime wackestones, packstones, and grainstones, as well as dolowackestones and dolopackstones, show poor to fair reservoir quality. Most lime and dolowackestones to dolopackstones, however, exhibit poor reservoir quality (i.e., tight).

### Limestone Examples

#### Oomoldic and Micropore Network in a Lime Grainstone

Oomoldic pores can be isolated by fine-bladed and fine-equant calcite cement in ooid lime grainstone (Figs. 7A and 7B) and are the result of the dissolution of aragonitic ooids. The fine-equant calcite fills interparticle pores, whereas the former Mg–calcite micrite rims surrounding the dissolved ooid cortices contain micropores. Because cementation of interparticle pores effectively isolates oomoldic and micropores, the pore network exhibits moderate porosity but low permeability (porosity = 13.4% and permeability = 0.077 md).

#### Micropores in a Lime Packstone

Micropores are commonly found in the coatings of ooids and oncoids. In Figures 7C and 7D, a peloidal ooid/oncoid lime packstone displays that the coatings of ooids/oncoids are mi-

croporous. Since the associated peloids lack micropores, microporous ooid/oncoid grains do not create an effective connected pore system. Each microporous region is isolated from adjacent porous regions (Fig. 7D). This type of pore network has low porosity and very low permeability (porosity = 7.9% and permeability = 0.079 md).

#### Partly Occluded Oomoldic Pores and Fine-Allochem Pores in Limestone

In certain lime wackestones and lime packstones (Figs. 7E and 7F), dissolution of ooids and fine allochems within a micrite matrix has resulted in a pore network having moderate porosity and low permeability (porosity = 12.9% and permeability = 0.206 md). This type of limestone pore network is relatively uncommon.

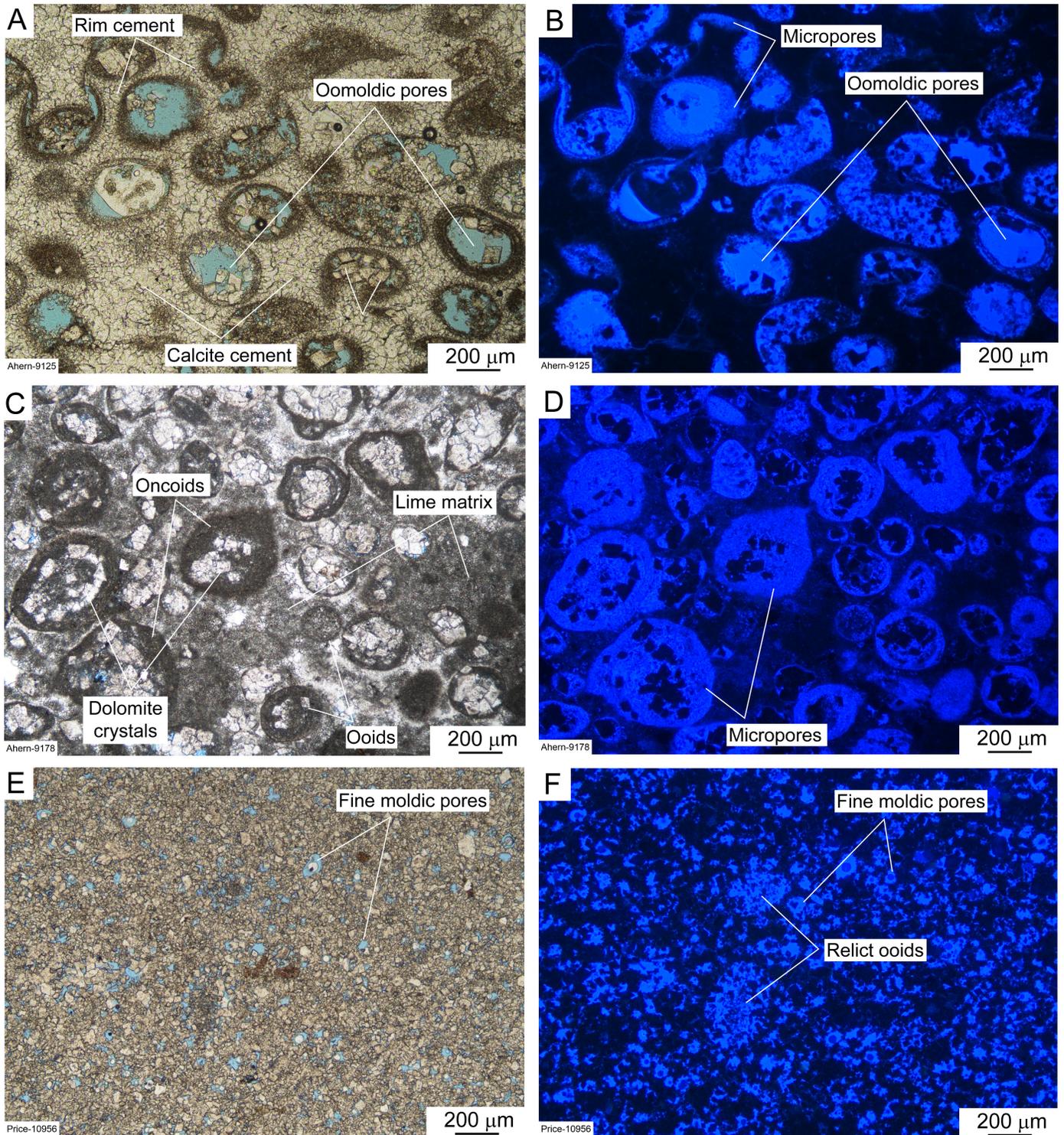
### Dolostone Examples

#### Interparticle and Oomoldic Pores in a Dolograinsone

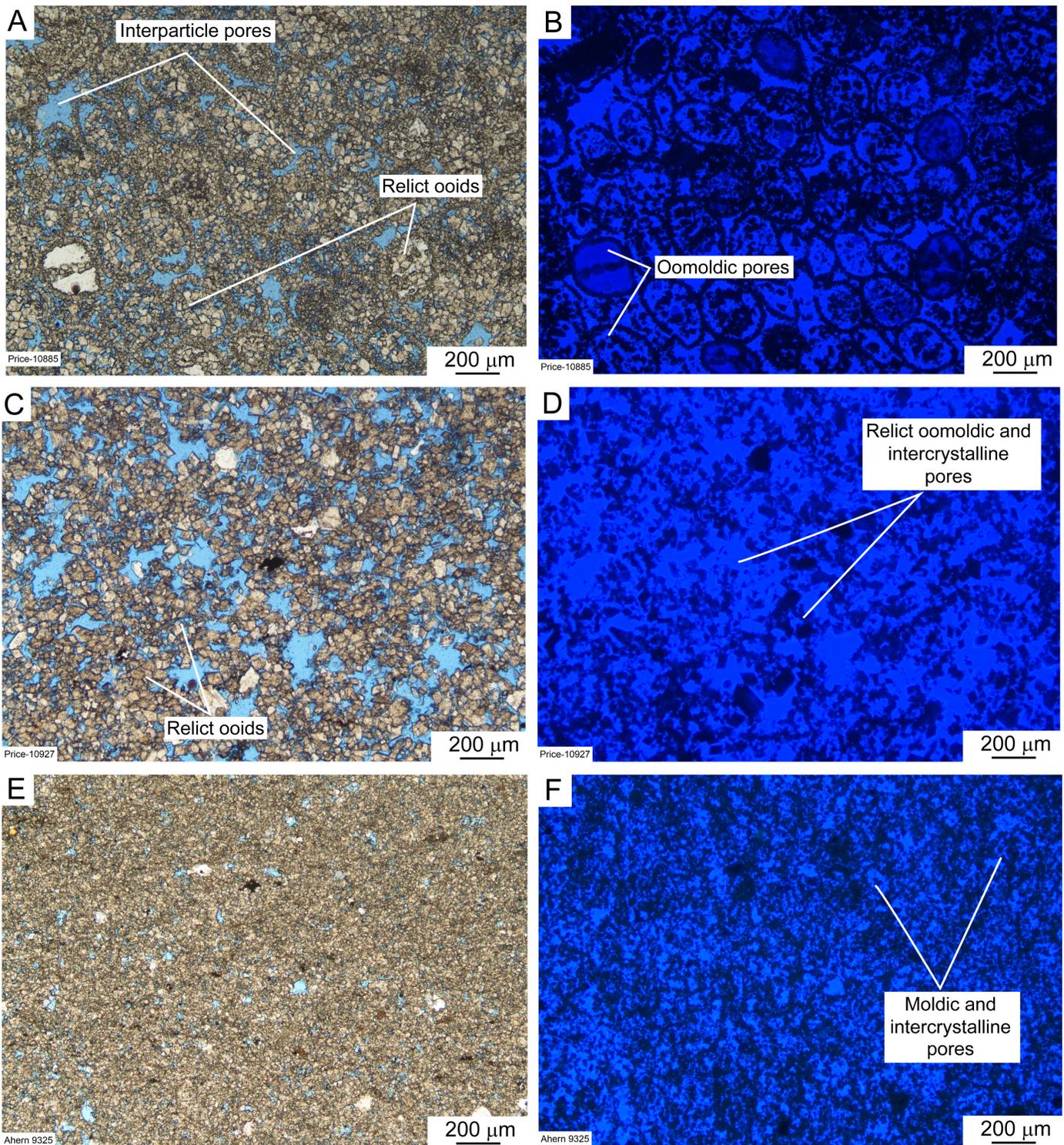
When dolomitization is extensive, the rock can become fully dolomitized while retaining its original fabric. Ooid dolograinsone can have a pore network combining interparticle and oomoldic pores (Figs. 8A and 8B). Many ooid rims are preserved by dolomite rinds (Fig. 8B), which are porous and facilitate connectivity with the interparticle pore system. This combination of pore types results in a dolostone with good porosity and permeability (porosity = 18.4% and permeability = 29.6 md).

#### Intercrystalline and Relict Oomoldic Pores in a Dolograinsone

In cases of highly aggressive dolomitization, original texture and fabric of the limestone can be obscured (Figs. 8C and 8D).



**Figure 7.** Thin-section examples of pore networks in limestones. (A) Oomoldic lime grainstone with interparticle pores filled with fine-crystalline, calcite-bladed cement, followed by fine-crystalline, calcite-equant cement. Porosity = 13.4%; permeability = 0.077 md; and matrix density = 2.73 g/cm<sup>3</sup>. (B) Same as A under cross-polarized light. Blue = pores. Dual pore network of oomoldic and micropores. (C) Ooid/oncoid lime packstone with micropores. Porosity = 7.9%; permeability = 0.079 md; and matrix density = 2.76 g/cm<sup>3</sup>. (D) Same as C under cross-polarized light. Blue = pores. Micropores present in oncoid coating. (E) Ooid/peloidal dolopackstone. Porosity = 12.9%; permeability = 0.206 md; and matrix density = 2.74 g/cm<sup>3</sup>. (F) Same as E under cross-polarized light. Blue = pores. Many of the fine pores are dissolution related.



**Figure 8.** Thin-section examples of pore networks in dolostones. (A) Ooid dolograins showing aggressive dolomitization. Oomoldic and interparticle pores common. Porosity = 18.4%; permeability = 29.6 md; and matrix density = 2.85 g/cm<sup>3</sup>. (B) Same as A under cross-polarized light. Blue = pores. Dolomite rims preserve relict ooids. (C) Ooid dolograins showing aggressive dolomitization. Relict ooids are nearly unrecognizable. Porosity = 29.6%; permeability = 305 md; and matrix density = 2.85 g/cm<sup>3</sup>. (D) Same as C under cross-polarized light. Blue = pores. Abundant intercrystalline pores connect relict, oomoldic pores. (E) Peloid dolopackstone. (F) Same as E under cross-polarized light. Blue = pores. Abundant fine-intercrystalline and moldic pores. Porosity = 12.3%; permeability = 0.769 md; and matrix density = 2.85 g/cm<sup>3</sup>.

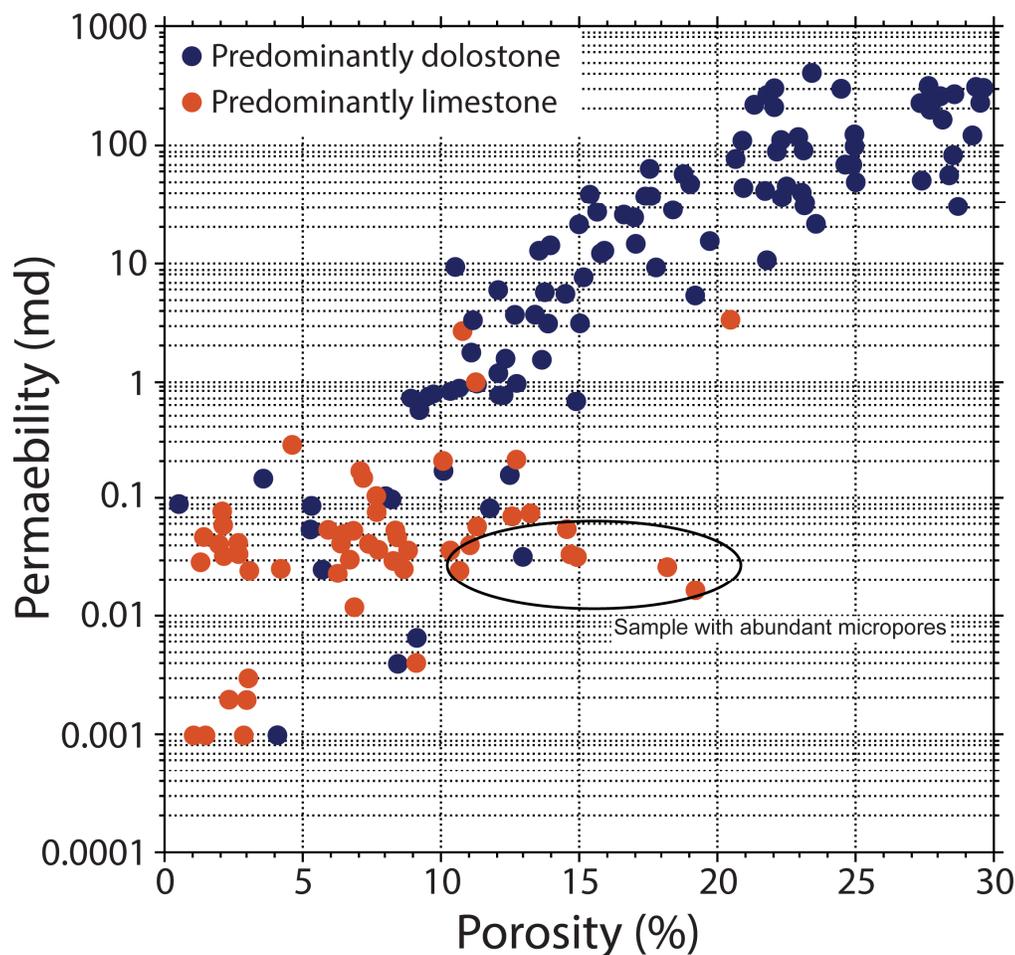


Figure 9. Porosity versus permeability from core-plug analysis separated by dominant mineralogy. Dolostones exhibit higher reservoir quality. Data from Harwood and Fontana (1983) and present study.

This process preserves interparticle pores, replaces the rims of oomoldic pores, and creates connected intercrystalline pores (Figs. 8C and 8D). The resulting pore network has a high porosity and excellent permeability (porosity = 29.6% and permeability = 305 md).

#### Intercrystalline and Relict Oomoldic Pores in Dolowackestones and Dolopackstones

Some dolowackestones and dolopackstones (Figs. 8E and 8F) have developed fine-intercrystalline pores, and the dolomitization process reorganizes the micrite matrix into very fine- to fine-crystalline dolomite rhombs. This pore network provides moderate porosity and poor permeability (porosity = 12.3% and permeability = 0.769 md); without dolomitization, these wackestones and packstones would be tight.

### CONCLUSIONS

Reservoir quality is a significant factor in evaluating potential lithium-rich-brine reservoirs in the Smackover Formation in northeastern Texas. A comprehensive understanding of diagenesis and the resulting pore networks is essential to informed-decision making regarding areas with the highest reservoir quality. One key observation is that more intense dolomitization leads to higher reservoir quality, whereas, in contrast, limestones typically exhibit poor reservoir quality. Many Smackover carbonates display a dual pore network, including macropores—such as oomoldic and interparticle (intercrystalline) pores—and micropores, which are found primarily in micrite envelopes and less commonly elsewhere. Both moldic and micropores contribute less to

permeability than do interparticle and intercrystalline pores. When developing algorithms to plot porosity versus permeability, workers must account for the abundance of each pore type in order to fully understand the relationship between the two properties.

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