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Evaporite Zones and Associated Dissolution-Collapse Breccias in the Upper Jurassic Smackover Formation in Northeastern Texas: Are they a Concern for Heterogeneity?

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ABSTRACT

The Upper Jurassic Smackover Formation in northeastern Texas is being intensely investigated as a reservoir for lithium-rich brines. Reservoir quality, controlled by lithofacies and diagenesis, is important for understanding lithium-brine deliverability. Production of lithium-rich brines is not dependent on trapping mechanisms, as the brines occur in continuous reservoirs. However, even in continuous reservoirs, reservoir heterogeneity must be defined and evaluated to understand controls on production. In the upper Smackover coated-grain grainstone belt in northeastern Texas, dolomitized peloidal/oncoid/ooid grainstones contain the highest reservoir quality, being the dominant lithofacies for high flow rates in brine production. Within the upper part of the coated-grain grainstone sections, beds of evaporites (anhydrite) and evaporite dissolution-collapse breccias may form vertical permeability barriers. These evaporite beds were deposited in saline ponds and within sabkha sediments landward of ooid-dominated strandplain deposits. The evaporites, where preserved, occur as anhydrite-bearing beds several feet thick. Where the evaporites were dissolved, the evaporite zones occur as dissolution-collapse breccias. The anhydrites are crudely bedded but sometimes nodular, indicating dominant salina deposition with some precipitation within sabkha sediments. Other evaporite zones are mixtures of small anhydrite nodules, peloids, and coated grains. The evaporite-related collapse breccias contain early cemented breccia clasts of ooid grainstones within a dolomudstone matrix. The evaporite-dominated zones and some dissolution-collapse breccias are tight and form vertical barriers to flow; however, well control is insufficient for defining their lateral extent.

INTRODUCTION

The Upper Jurassic Smackover Formation in northeastern Texas has historically been a focus of hydrocarbon exploration and production (Fig. 1); however, this area has recently emerged as a target for lithium-rich brines (Heaton and Rhymes, 2023). Exploration for lithium-rich brines in the Smackover Formation does not rely on structural traps but instead depends on assessing its reservoir quality (Loucks, 2025). Reservoir quality encompasses factors such as porosity and permeability, essential for storage capacity and fluid deliverability, as well as lateral and vertical heterogeneity, which are important in recovery efficiency.

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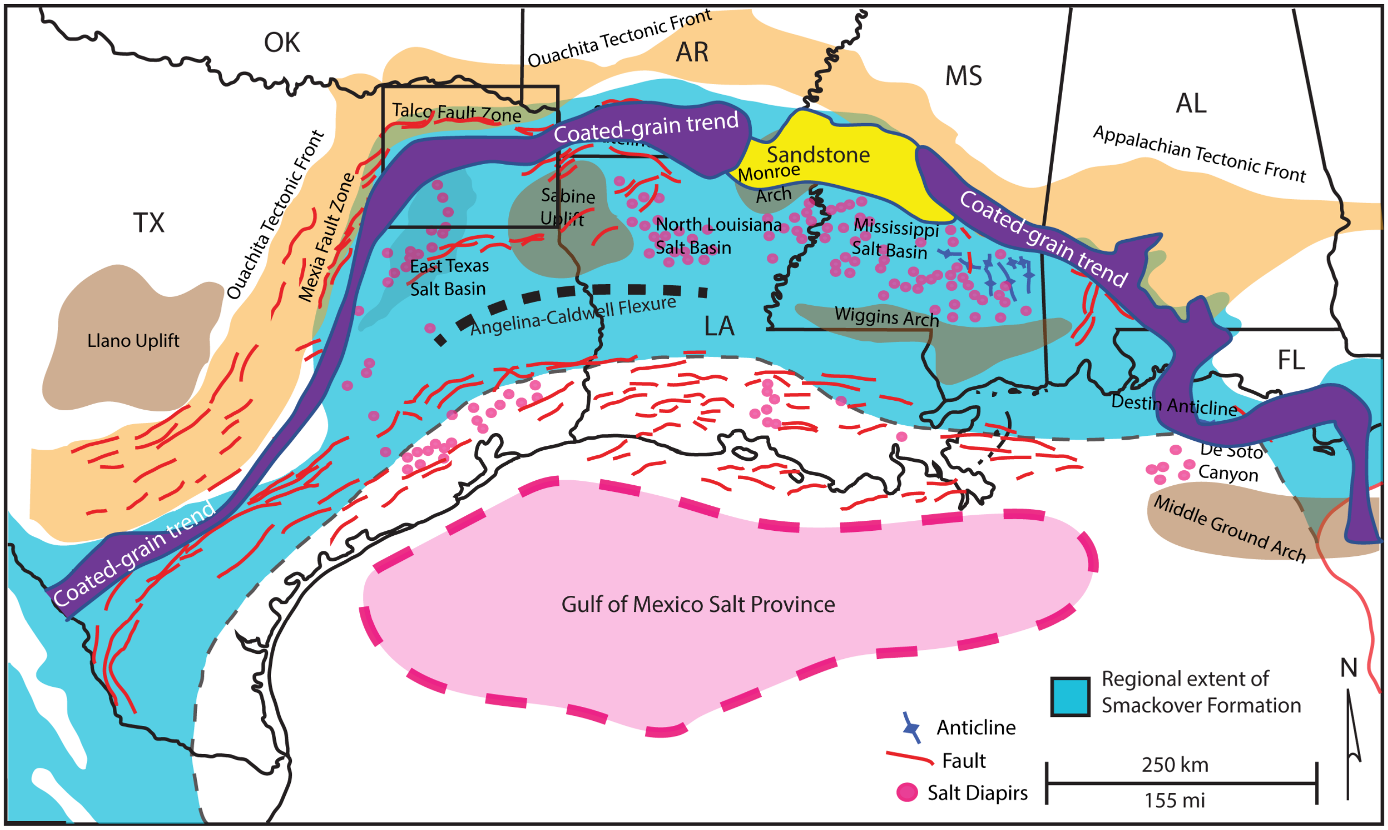
The primary reservoir section within the upper Smackover Formation consists of coated-grain grainstones that require dolomitization either to preserve primary pores or to create secondary pores. The extent of dolomitization varies spatially, introducing uncertainty about reservoir quality at the interwell scale. Lateral reservoir variability is generally assessed through wireline-log studies, whereas vertical reservoir variability is best analyzed using sections cored through the upper Smackover grainstones.

Within upper Smackover coated-grain grainstone sections, evaporite beds and associated dissolution-collapse breccias with a dolomudstone matrix may form vertical permeability barriers (Fig. 1B). Despite their potential significance, these evaporite beds have been rarely mentioned in the literature (e.g., Stewart, 1984). The dissolution-collapse breccias have not been previously noted or discussed in the literature. This study aims to document these evaporite beds and related dissolution-collapse breccias, as they may influence reservoir heterogeneity by forming vertical permeability barriers.

Specific objectives of this investigation are to:

(1) provide general background information on the stratigraphy and depositional setting of the Smackover Formation,



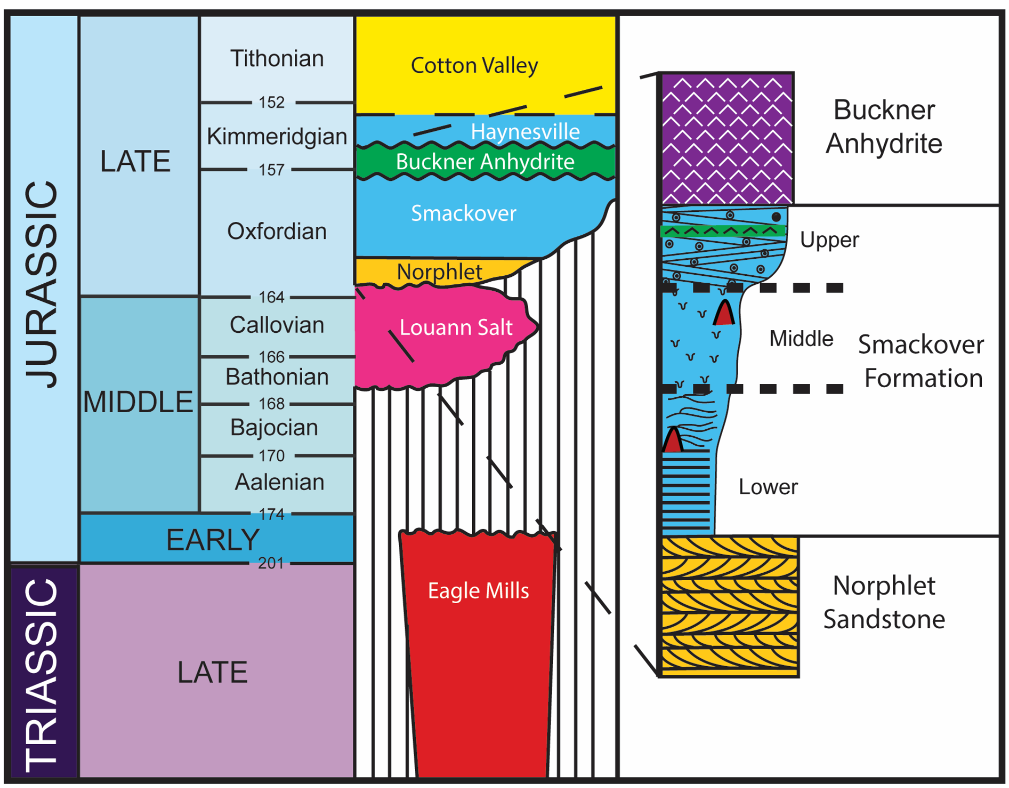


Figure 1. Regional map and stratigraphic column. Figures adapted from Schemper et al. (2022). (A) Geologic map showing structural and geomorphic features along the northern Gulf of Mexico, with the Smackover mixed-coated-grain trend displayed. Box in upper-left part of map denotes the area shown in Figure 2. (B) Stratigraphic column of northeastern Texas, including a lithostratigraphic section. Green chevron pattern represents evaporites and red mounds denote thrombolites.

(2) describe Smackover evaporites and evaporite-related dissolution-collapse breccias,
(3) present a depositional model of the evaporite zones, and
(4) evaluate the role of evaporite zones and dissolution-collapse breccias as vertical permeability barriers.

Understanding reservoir heterogeneity is crucial in any reservoir study. This investigation of the evaporite beds and associated dissolution-collapse breccias of the upper Smackover Formation offers insights into potential vertical flow barriers that may also exhibit broad lateral continuity.

DATA AND METHODS

The primary data used in this investigation consist of 10 cores, 6 of which are presented in this paper (Figs. 2–4). Three of the cores have preserved evaporite zones (No. 1 Chitsey, No. 1 Tate, and No. 1 Price; Fig. 3), and three of the cores display evaporite-related dissolution-collapse breccias (No. 1 Linda's, No. 1C Miller, and No. 1 Baum Estate) (Fig. 4). These cores were slabbed and etched with 10% HCl to help estimate dolomite content and to clean the limestone surfaces. Core descriptions were made using a binocular microscope. Thin sections were prepared for assisting in analyzing the fabric, texture, allochems, and paragenesis, including limestone and dolomite diagenesis. Photographs of various upper Smackover lithofacies were taken, and selected images are included in this report.

GENERAL STRATIGRAPHY AND REGIONAL SETTING

The Smackover Formation is a tripartite carbonate unit (Fig. 1B) deposited on a ramp within a restricted basin in the ancestral Gulf of Mexico during Late Jurassic Oxfordian time (Fig. 5) (e.g., Budd and Loucks, 1981; Iturralde-Vinent, 2006). The lower section is composed of dark, laminated mudstones with microbial mats; the middle section is composed of peloidal wackestones and packstones, with some thrombolites; and the upper section is composed of oncoid and ooid packstones, transitioning into ooid grainstones (Fig. 1B). The upper section of Smackover carbonates has an interval of evaporites and associated evaporite-dissolution-collapse breccias. These evaporites were deposited in salinas on a sabkha or within the sediments on the sabkha. It is important to note that the upper grainstone section was not deposited in one sequence; instead, the section consists of multiple, higher order sequences (Moore, 1984; Handford and Baria, 2007) that are difficult to distinguish in intensely dolomitized grainstone cores.

DESCRIPTION OF CORED SECTIONS WITH EVAPORITE BEDS

The preserved evaporite zones (anhydrites) in three studied cores show several expressions of evaporite deposition. The No. 1 Chitsey and No. 1 Tate cores show bedded evaporite-dominated sections 11 to 15+ ft (3.4 to 5+ m) thick (Figs. 3A and 3B), whereas the No. 1 Price core shows a 2 ft (0.6 m) mixed dolomite-nodular evaporite section (Fig. 3C). These two contrasting styles of evaporites in the upper Smackover section are discussed below.

Jake Hamon No. 1 Chitsey Core (API# 42159300010000)

The evaporite zone in this core is in the middle section of a cross-bedded ooid dolograinstone interval; however, there is a 16 ft (4.9 m) gap in the core between the ooid grainstone below and the evaporite zone (Fig. 3A). Above the evaporite zone is a moderately burrowed, ooid peloidal dolopackstone that is below an ooid oncoid lime grainstone (Fig. 6A).

These evaporites show a horizontal fabric (Figs. 6B–6E); however, diagenesis of the evaporites obscured some of the origi-

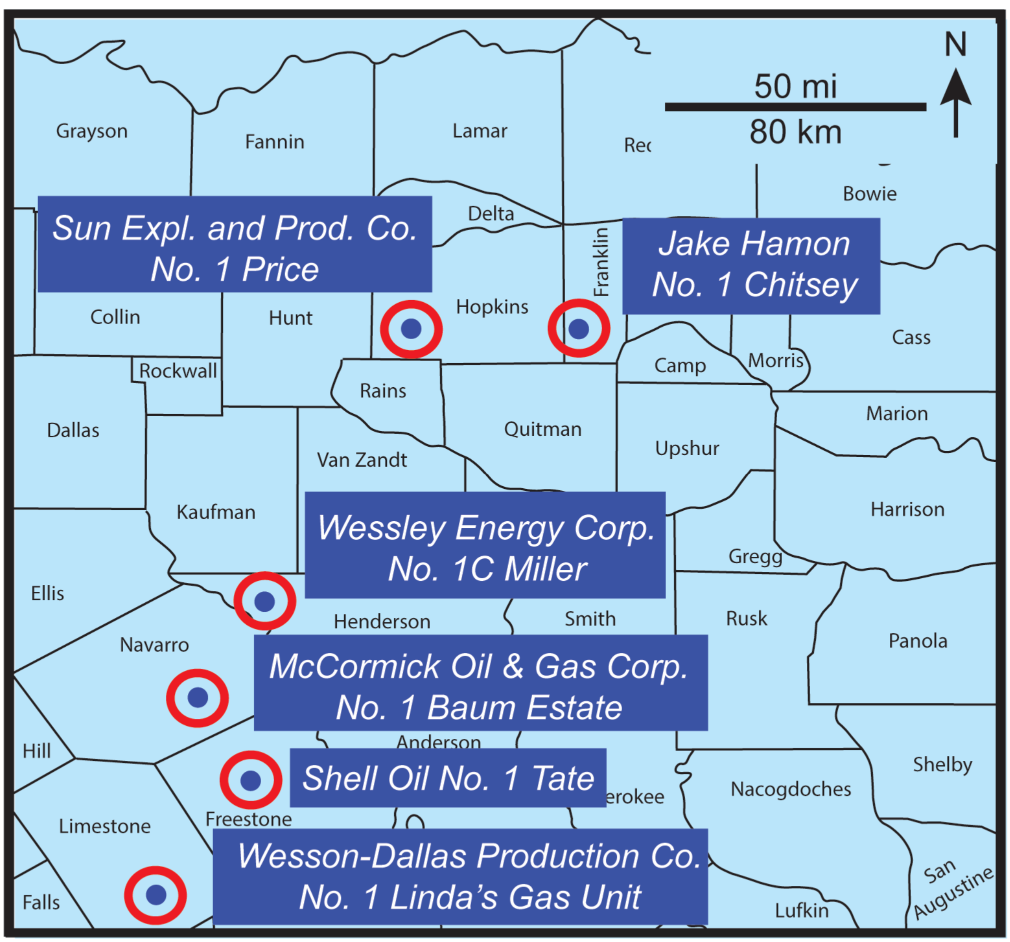


Figure 2. Location of cores used in study. See Figure 1A for map location in Texas.

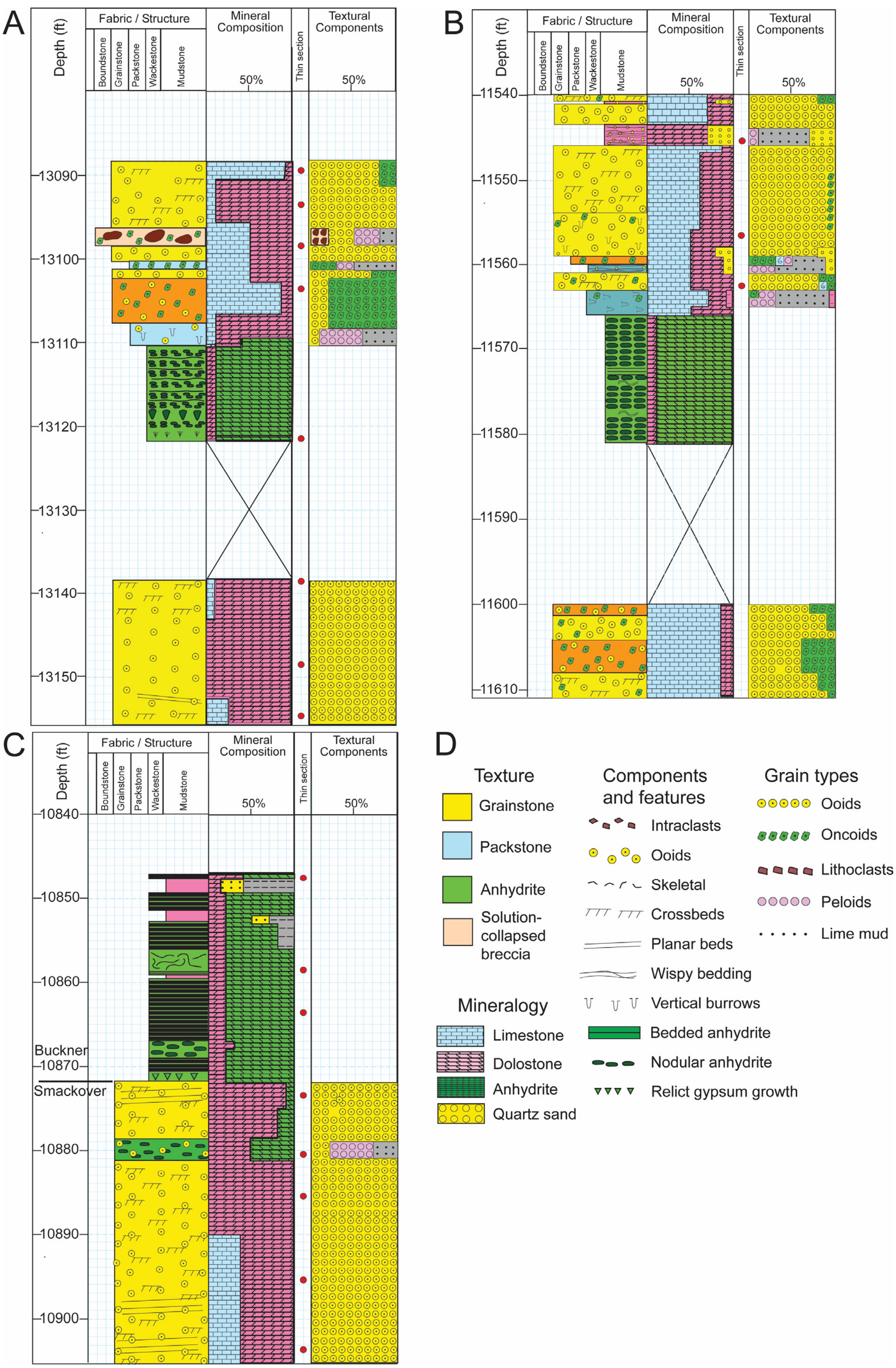


Figure 3. Description of cores with preserved Smackover evaporites. Core locations are shown in Figure 2. (A) Jake Hamon No. 1 Chitsey, Franklin County, Texas. (B) Shell Oil Company No. 1 Tate, Freestone County, Texas. (C) Sun Oil No. 1 Price, Hopkins County, Texas. (D) Core description legend for Figures 3 and 4.

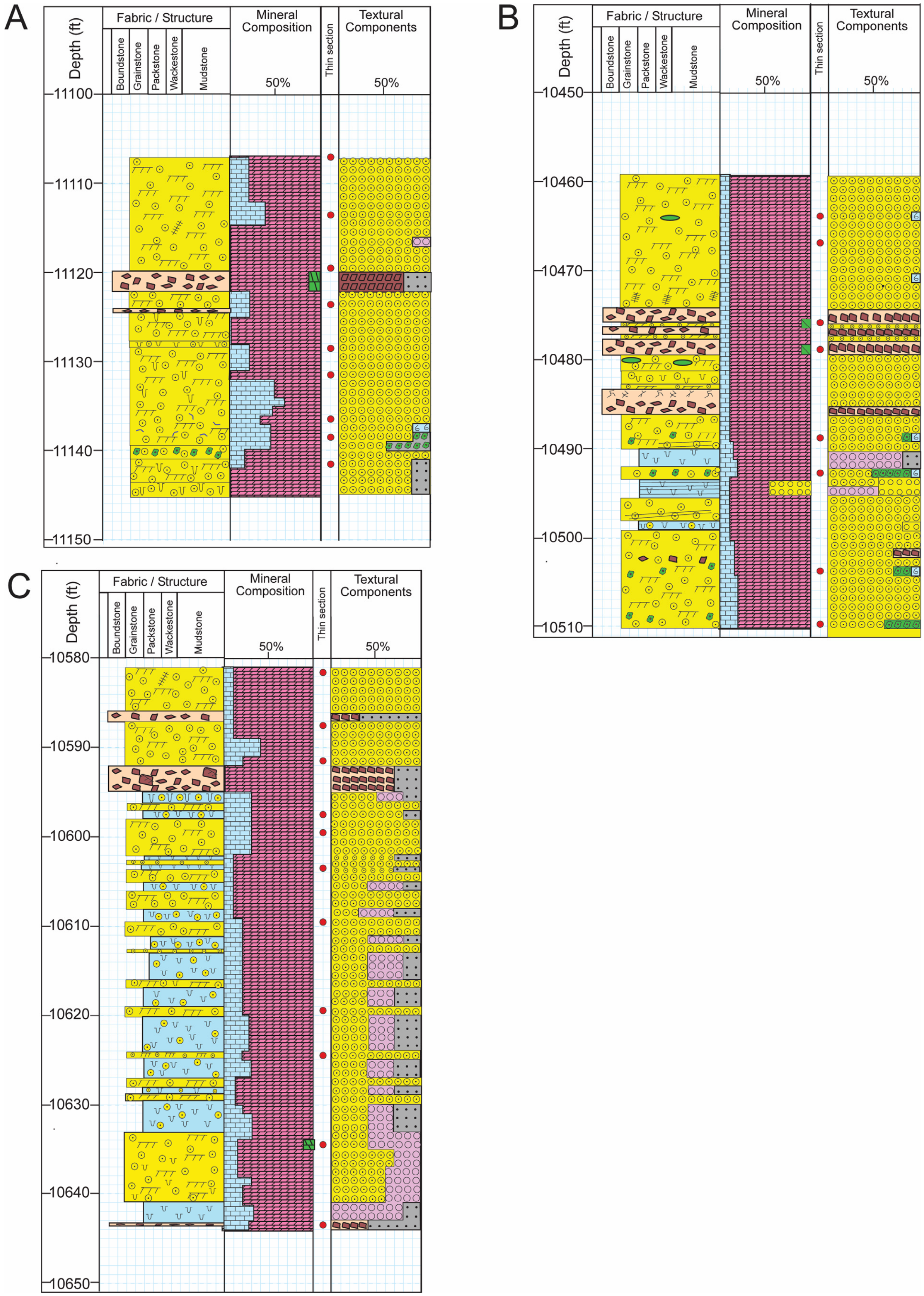


Figure 4. Description of cores with evaporite-related dissolution-collapse breccias. Core locations are shown in Figure 2. (A) Wesson-Dallas Production No. 1 Linda's Gas Unit, Freestone County, Texas. (B) Wessley No. 1C Miller, Henderson County, Texas. (C) McCormick Oil & Gas Corp. No. 1 Baum Estate, Navarro County, Texas. Legend for these core descriptions is shown in Figure 3D.

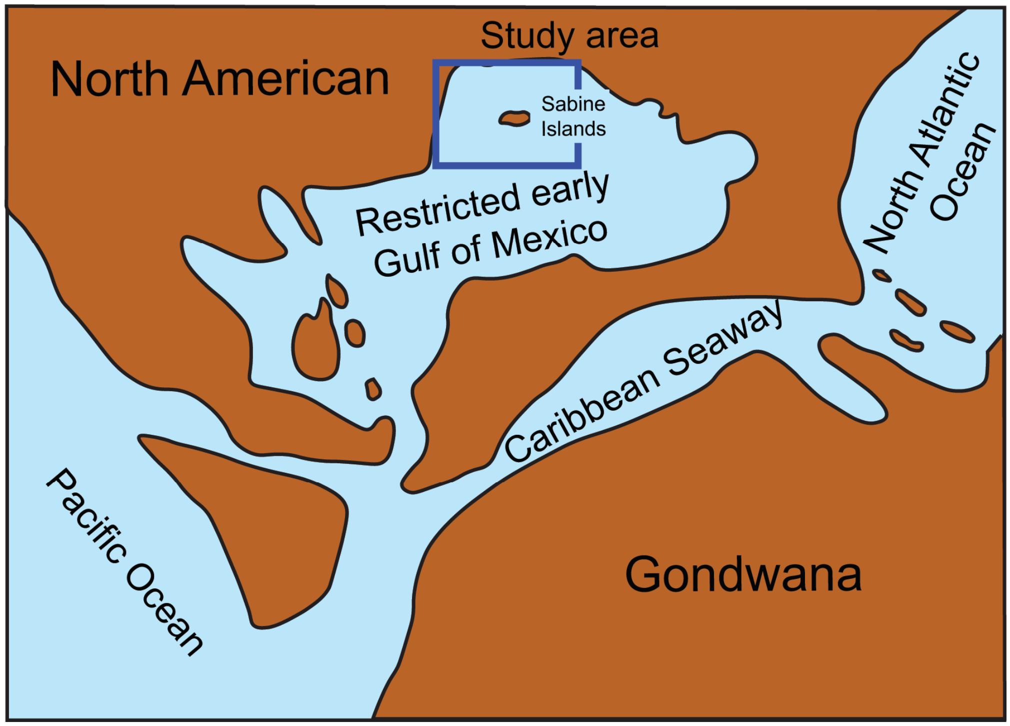


Figure 5. Paleogeographic map of the Late Jurassic Oxfordian showing the area of study within a restricted paleobasin. Map adapted from Iturralde-Vinent (2006).

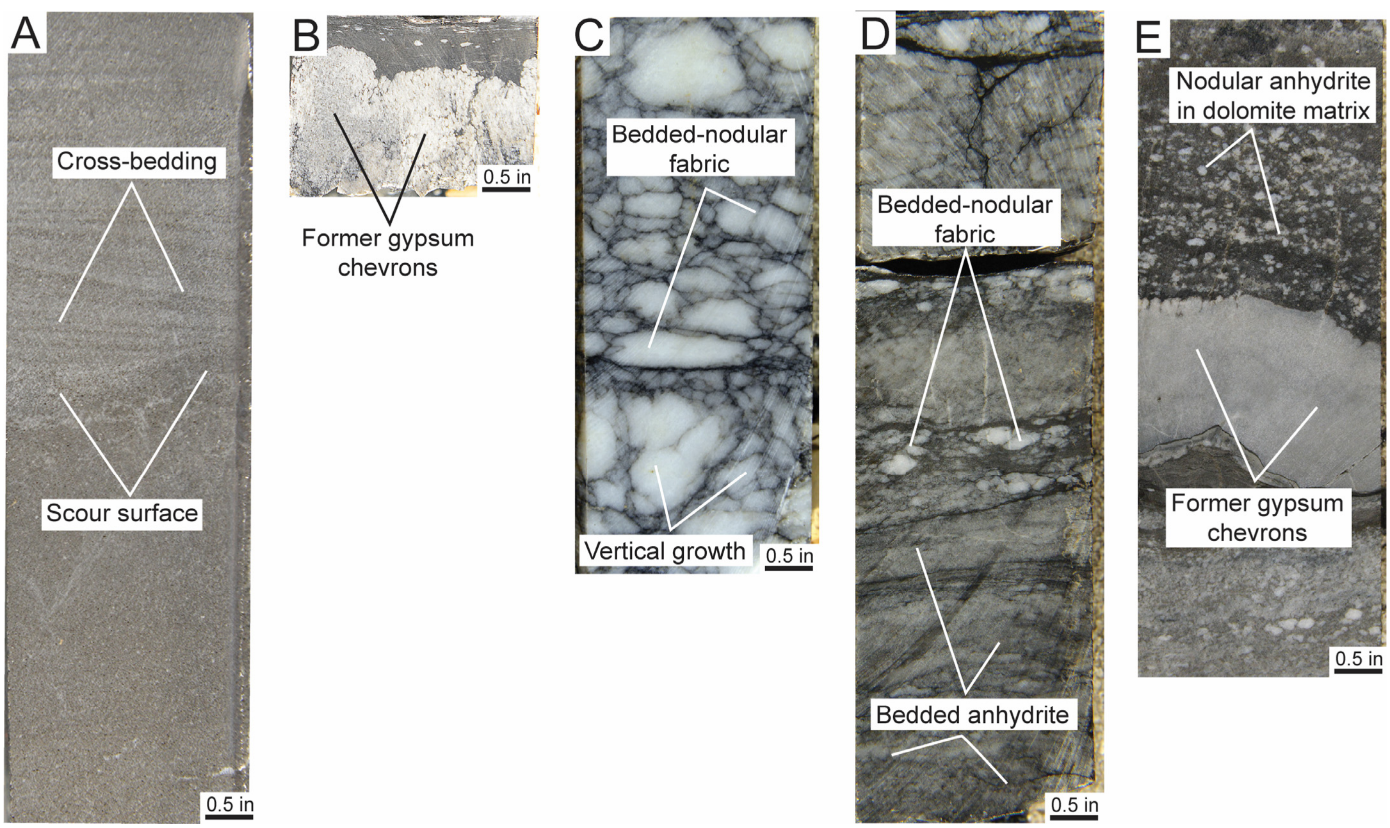


Figure 6. Jake Hamon No. 1 Chitsey core photographs. Core location is shown in Figure 2. (A) 13,138 ft (4004.5 m). Cross-bedded ooid grainstone overlying massive ooid grainstone. Contact is a scour surface. (B) 13,120 ft (3999 m). Former gypsum chevrons are indicative of subaqueous salina precipitation. Chevrons are overlain by dolomudstone. (C) 13,119 ft (3998.7 m). Nodular fabric anhydrite. Nodules at the base display a vertical to oblique orientation and may be former anhydrite chevrons, whereas the nodules above display a horizontal orientation (i.e., bedded). (D) 13,115 ft (3997.5 m). Anhydrite shows a bedded fabric suggestive of salina deposition. (E) 13,110 ft (3995.9 m). The top of the evaporite unit has a layer of former gypsum chevrons. Abundant small anhydrite nodules are in a dolomudstone matrix.

nal fabric. The lowest section of the unit displays a thin bed (~1 in [2.54 cm] thick) of relict gypsum chevrons (now anhydrite) (Fig. 6B). The section above (Fig. 6C) has some vertical growth anhydrite overlain by nodular to nodular-bedded anhydrite. This fabric is capped by several feet of crudely bedded anhydrite (Fig. 6D). The uppermost section is capped by more relict gypsum chevrons (now anhydrite) and small anhydrite nodules in a dolomite matrix (Fig. 6E).

Much of this evaporite section was deposited in a salina (i.e., brine pond) on a sabkha behind the carbonate strandplain (Fig. 7). Some of the more nodular beds (e.g., Fig. 6C) may be related to precipitation in sabkha sediments or to exposure of the salina evaporites when the ponds dried out. This interpretation is based on the evaporites, location above a thick, cross-bedded ooid grainstone section, the bedded character of the evaporites, and the presence of former gypsum chevrons. Also, the top of the evaporite section may be the top of a higher frequency cycle, where overlying oncolites were deposited during the next cycle.

Shell Oil Company No. 1 Tate Core (API# 42161200430000)

The evaporite zone in this core is in the middle section of a cross-bedded ooid dolograinstone, horizontally burrowed dolomitic lime wackestone, and oncoid-ooid dolograinstone section approximately 80 ft (~24 m) thick. The evaporite interval is at least 15+ ft (5+ m) thick. There is a 19 ft (5.8 m) coring gap at the base of the anhydrite section (Fig. 3B).

The evaporite section is mainly composed of bedded nodular and nodular anhydrite with various amounts of dolomudstone matrix (Fig. 8). Several layers of former gypsum chevrons are visible (Fig. 8A), as is also an enterolithic vein structure. Interbeds of dolomudstone are present, probably related to storm events (Figs. 8C and 8D). Figure 8D shows a dolomudstone and a sheared anhydrite layer and an erosional contact at the top of the core sample, possibly related to subaerial exposure.

This evaporite section was deposited in a brine pond on a sabkha and within sediments of the sabkha that formed behind a strandplain setting (Fig. 7). The dolomudstone layers may indicate proximity to mud-rich lagoonal sediments where lime mud was transported into the salina during storms. The erosional and disturbed layers in Figure 8D suggest that the saline ponds periodically dried out.

Sun Exploration and Production Company No. 1 Price Core (API# 42223304150000)

The evaporite zone in the No. 1 Price core is in the upper part of a thick (>43 ft [>13 m]), cross-bedded, ooid, calcareous dolograinstone (Fig. 3C). It is 8 ft (2.4 m) below the Buckner anhydrite section (e.g., Figs. 3C and 9C). The evaporite zone is 2 ft (0.6 m) thick (Fig. 3C) and is dominated by less than centimeter-size anhydrite nodules; this zone is intermixed with ooids and peloids in a dolomudstone matrix (Figs. 9A, 9B, 9D, and 9E). There is a crude alignment of evaporite nodules within the dolograinstone (Figs. 9A and 9B). Figure 9A shows a change in bedding between the ooid grainstone and the evaporite section. The lower cross-bedded ooid grainstone is truncated, and the bedding above appears to be relatively horizontal (Fig. 9A).

This evaporite-rich section was likely deposited as sediments within the sabkha that formed behind the strandplain setting (Fig. 7). The evaporitic environment was affected by lower

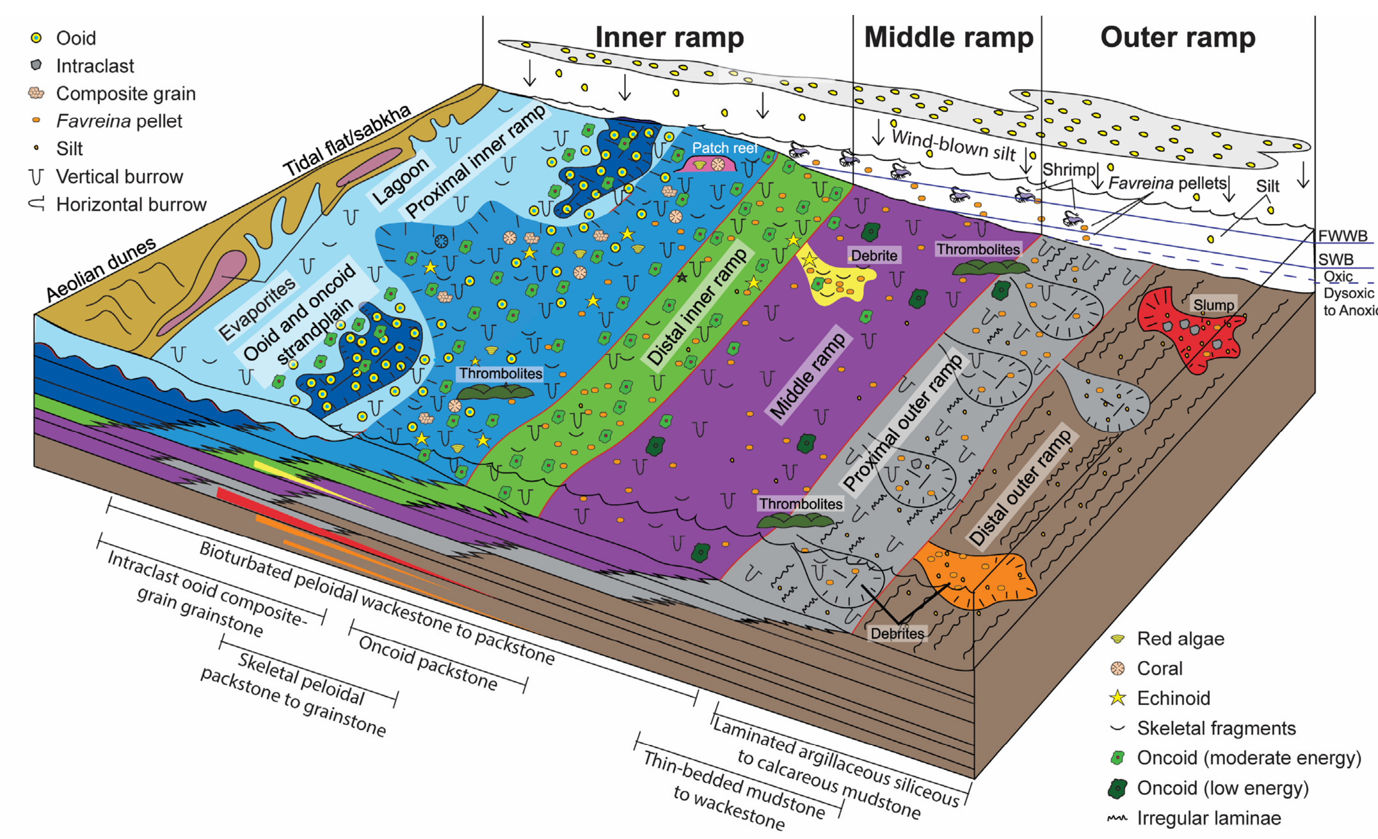


Figure 7. Schematic depositional ramp model of the Smackover Formation in northeastern Texas (modified after Loucks [2025]).

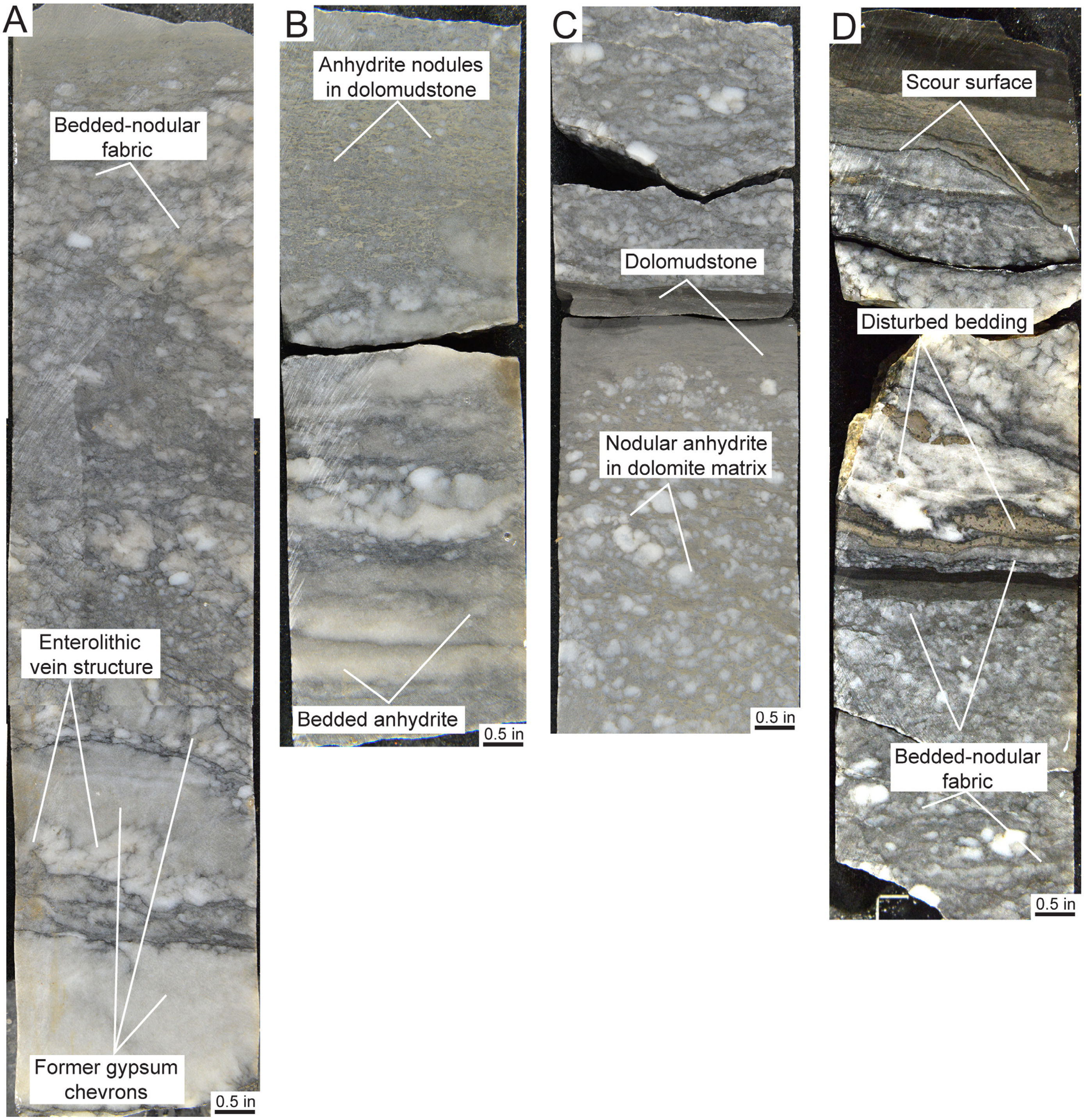


Figure 8. Shell Oil Company No. 1 Tate core photographs. Core location is shown in Figure 2. (A) 11,572 ft (3527.1 m). Layer of former gypsum chevrons overlain by nodular to nodular-bedded anhydrite in dolomudstone. An enterolithic vein structure is displayed and is indicative of precipitation within sabkha sediments. (B) 11,571 ft (3526.8 m). Bedded anhydrite overlain by anhydrite nodules in dolomudstone. (C) 11,567 ft (3525.6 m). Nodular anhydrite in dolomudstone matrix. Bed of dolomudstone in middle of core sample showing an upward-fining grading indicating deposition by a storm event. (D) 11,565 ft (3525.0 m). Bedded-nodular anhydrite with interbedded dolomudstone. Disturbed bedding in the middle of this core sample and an erosion surface near the top of this core sample suggest subaerial exposure.

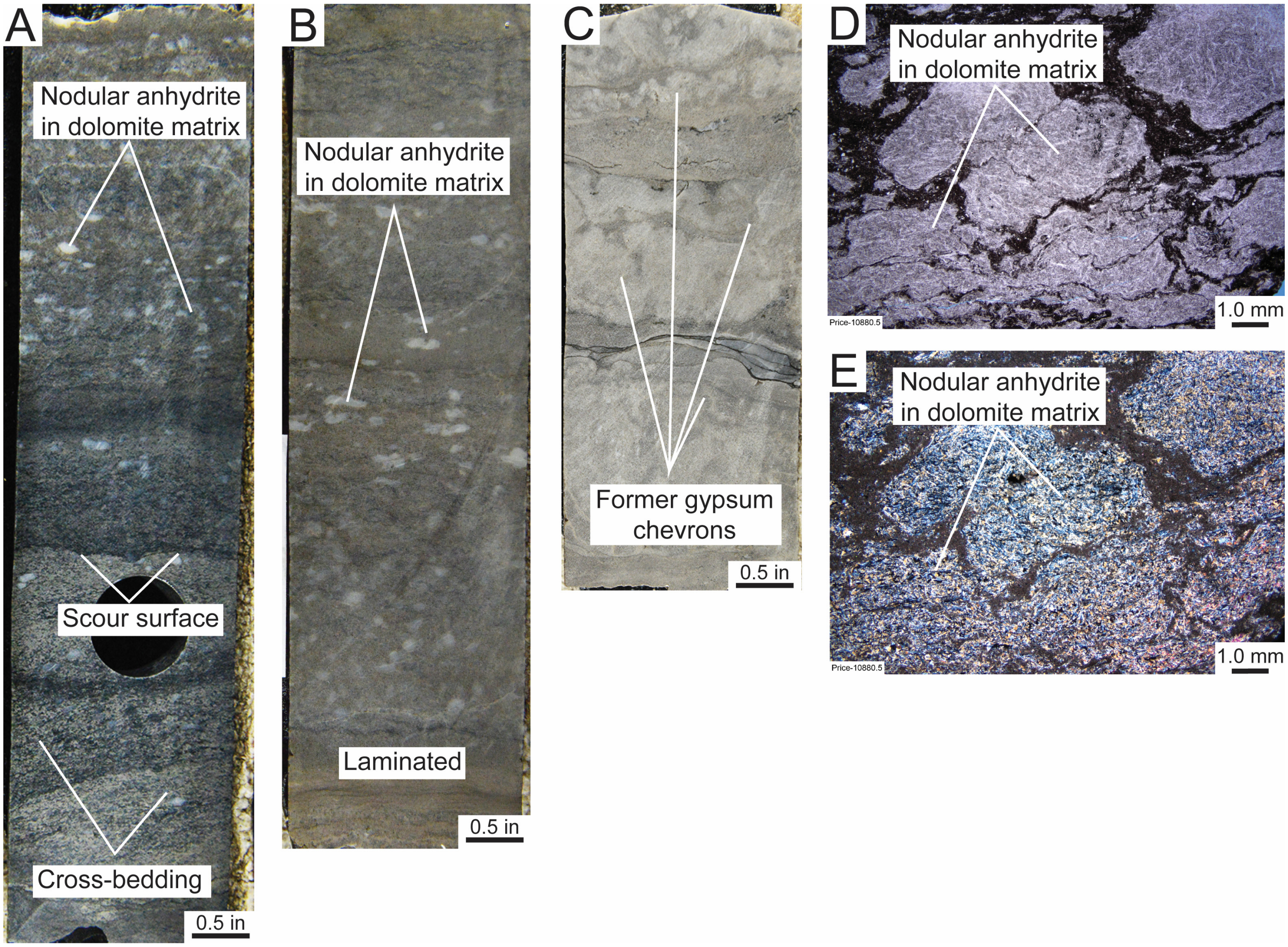


Figure 9. Sun Exploration and Production Company No. 1 Price core photographs and thin-section photomicrographs. Core location is shown in Figure 2. (A) 10,880 ft (3316.2 m). Interval of small evaporite nodules overlying cross-bedded dolograinstone. Contact is scoured. (B) 10,878 ft (3315.6 m). Small anhydrite nodules in dolomudstone matrix overlying laminated dolomudstone. (C) 10,871.5 ft (3313.6 m). Example of anhydrite at base of Buckner Formation. The core slab shows several layers of former gypsum chevrons. (D) 10,880 ft (3316.2 m). Thin-section photomicrograph showing small anhydrite nodules in dolomite mud matrix. (E) 10,880 ft (3316.2 m). Same thin section area as in D but under cross-polarized light.

energy processes than that of the ooid complex, as indicated by the presence of mud and peloids. The ooids were likely washed onto the sabkha setting by storms. There is no evidence of burrowing in the anhydrite-rich ooid deposits, which supports the interpretation that high-salinity waters inhibited biota.

DESCRIPTION OF CORED SECTIONS WITH EVAPORITE DISSOLUTION-COLLAPSE BRECCIA ZONES

Wesson-Dallas Production Company No. 1 Linda's Core (API# 42293308810000)

Within the thick, upper grainstone section in No. 1 Linda's Gas Unit core are two dissolution-collapse breccia beds (Fig. 4A). The lower dissolution-breccia is approximately 0.5 ft (0.15 m) thick (Figs. 4A and 10E), and the upper dissolution-breccia is 2 ft (0.6 m) thick (Figs. 4A and 10A–10D). Dissolution of evaporites created cavities that later collapsed, and the cavities were filled with lithified ooid grainstone clasts in a dolomudstone matrix. Lithoclasts (i.e., breccia clasts) indicate late dissolution following some degree of lithification. The matrix between the lithoclasts appears as peloidal mudstone. This mudstone may be related to sediment infiltration after Smackover deposition and before Buckner deposition.

Above the collapse zone are fractures related to the collapse of dissolution cavities. These fractures indicate some degree of lithification prior to collapse (Fig. 10B). The fractures are cemented with anhydrite (Figs. 10C and 10D). The position of the dissolution-collapse breccia within a thick ooid sequence suggests deposition of the original evaporites in a sabkha landward of the coated-grain-rich strandplain (Fig. 7).

Wessley Energy Corporation No. 1C Miller Core (API# 42213306130000)

The No. 1C Miller core has four zones of evaporite-related dissolution-collapse breccias within a 12 ft (3.7 m) interval (Fig. 4B). The dissolution-collapse breccias occur in a thick cross-bedded ooid dolograinstone. The lithoclasts, composed of ooid dolograinstone, are as much as several inches in diameter and have rounded edges, suggesting that they were friable but to

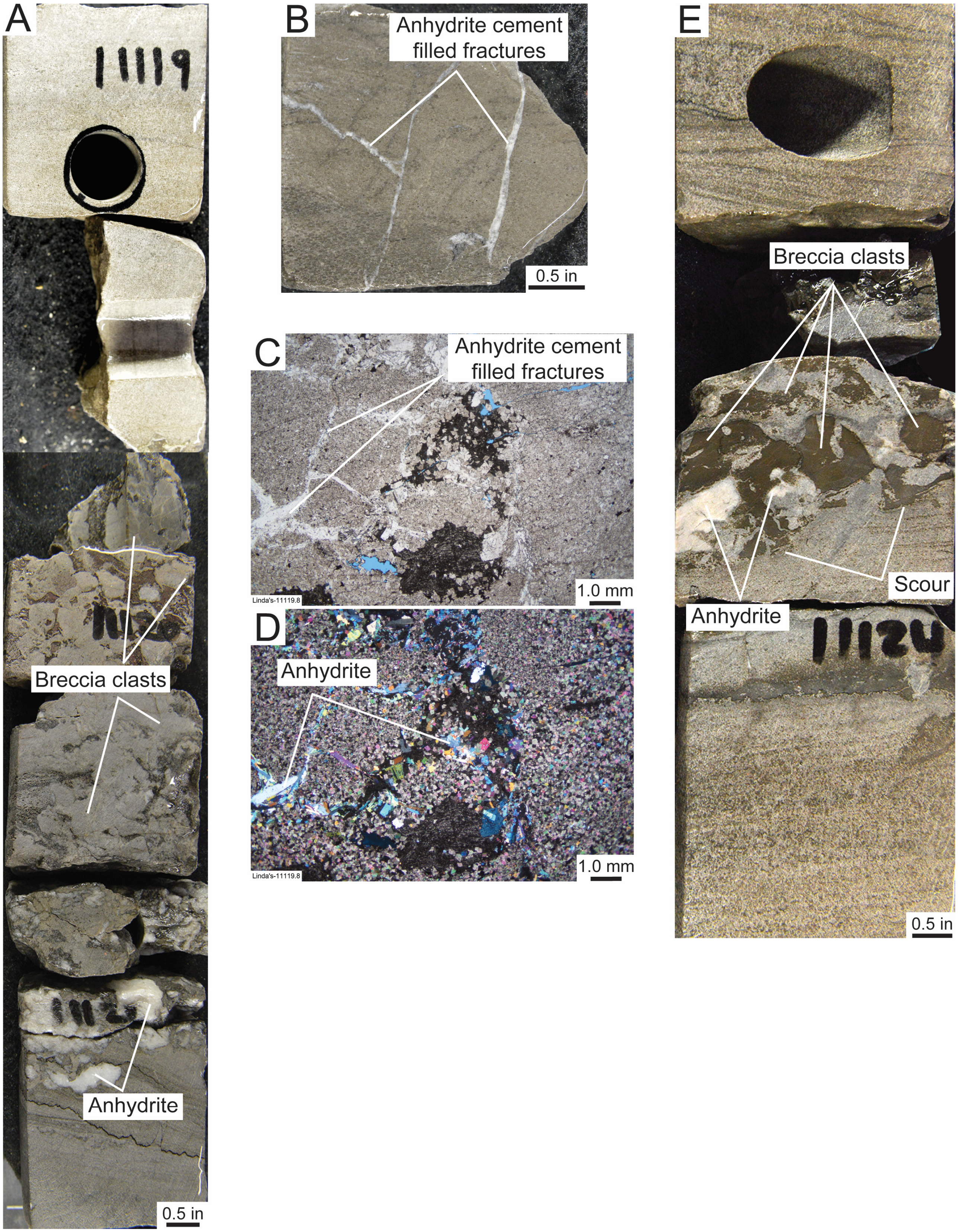


Figure 10. Wessom-Dallas Production No. 1 Linda's Gas Unit core photographs and thin-section photomicrographs. Core location is shown in Figure 2. (A) 11,119 ft (3389.1 m). Collapse breccia after evaporite dissolution. Lithoclasts appear to have been lightly to moderately lithified. (B) 11,114 ft (3387.5 m). Ooid dolograinstone 5 ft (1.5 m) above dissolution-collapse breccia shows compaction fractures filled with anhydrite cement. (C) 11,119.8 ft (3389.3 m). Thin-section photomicrograph showing fractured ooid dolograinstone where fractures are filled with anhydrite cement. (D) 11,119.8 ft (3389.3 m). Same thin section area as in B but under cross-polarized light. (E) 11,123.5 ft (3390.4 m). Thin, evaporite-related dissolution-collapse breccia with an erosional base. Erosion occurred at the beginning of evaporite deposition. Clasts are dolomudstone. Some vugs are filled with anhydrite.

some degree lithified (Fig. 11A). The lithoclasts are closely packed with a dark matrix. Above the dissolution-collapse zone are well-developed fractures related to subsidence compaction (Fig. 11B). Sharp edges of the fractures indicate fracturing after lithification. Dissolution-collapse breccia zones range from 1 to 3 ft (0.3 to 1 m) thick. The lithified ooid grainstone breccia clasts are as much as 3 in (7.6 cm) wide and are separated by dolomudstone. The former evaporites that were dissolved to create the breccias are interpreted as being deposited on a sabkha.

McCormick Oil & Gas Corporation No. 1 Baum Estate (API# 42349306870000)

The No. 1 Baum Estate core has three zones of dissolution-collapse breccias occurring in a section composed of interbedded burrowed ooid calcareous dolopackstone and cross-bedded ooid calcareous dolograinstones (Fig. 4C). The dissolution-collapse breccia zones range from 0.5 to 3 ft (0.15 to 1 m) thick. The lithified ooid grainstone breccia clasts are as much as 5 in (12.7 cm) in length and are separated by light-colored dolomudstone (Figs. 12A and 12B). Above the uppermost dissolution-collapse breccia are fractures (Fig. 12C) that are interpreted to be associated with the collapse breccia zone. As in the No. 1 Linda's and No. 1C Baum cores, the dissolution-collapse breccias are associated with ooid-rich lithofacies, leading to the interpretation that the dissolution-collapse breccias result from evaporites that were deposited on a sabkha just landward of an ooid-dominated strandplain. Each dissolution-collapse breccia zone may indicate the top of a higher frequency depositional cycle.

DEPOSITIONAL MODEL AND DISCUSSION

Figure 7 is a depositional model from Loucks (2025), modified from Budd and Loucks (1981) and Schemper et al. (2022). The model shows the development of brine ponds or salinas associated with sabkhas landward of a coated-grain-rich strandplain. All of the preserved evaporite zones and dissolution-collapse breccias are within cross-bedded coated grainstone zones, with little indication of associated lagoonal lithofacies. Therefore, a sabkha environment probably existed near the grain-rich strandplain.

The ooid lithoclasts that compose the breccias indicate some degree of lithification. At the end of Smackover deposition and before Buckner deposition, Smackover sediments underwent meteoric diagenesis, where calcite cementation was initiated. Associated with meteoric diagenesis, some evaporite beds were dissolved, forming cavities. The overlying lithified ooid grainstone collapsed into the cavities, and post-Smackover carbonate mud filtered down into the cavities from the surface.

The fractures above the dissolution-collapsed breccias are interpreted to be related to cavity collapse and associated subsidence. The sharp edges of the fractures suggest lithification. These fractures are not noted below the dissolution-collapsed breccia zones, supporting the concept that the fractures are related to the dissolution-formed cavities.

CONCLUSIONS

The upper Smackover section in northeastern Texas shows solid evidence of evaporite deposition. The evaporites occur in the upper parts of thick coated-grain grainstone intervals. Where

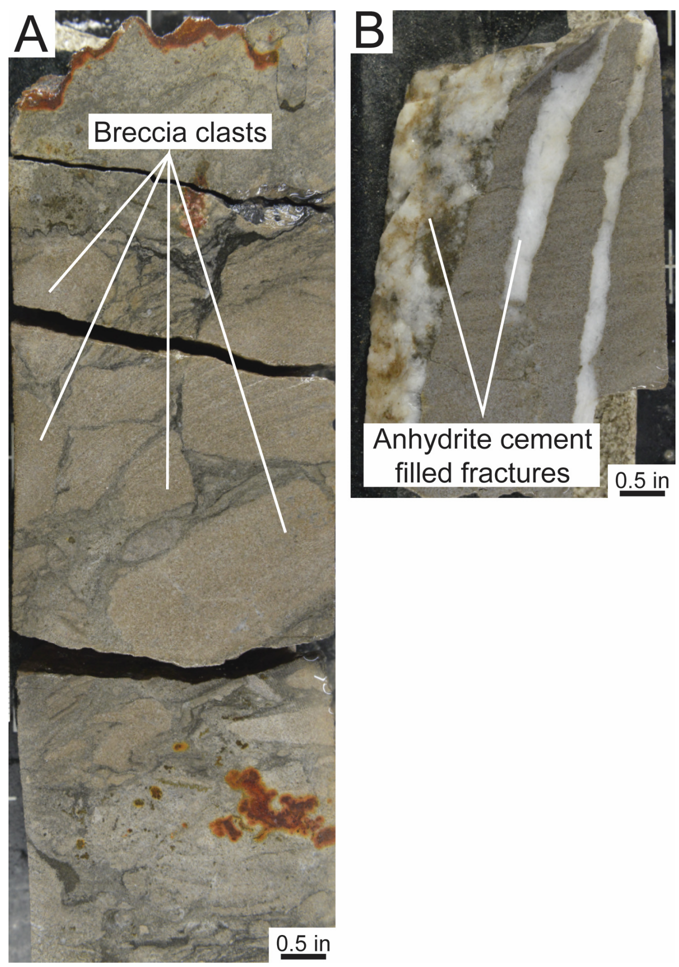


Figure 11. Wessley No. 1C Miller core photographs. Core location is shown in Figure 2. (A) 11,744 ft (3579.6 m). Dissolution-collapse breccia after evaporite dissolution. Breccia clasts are composed of ooid dolograinstone. Note that the rounded edges of the lithoclasts indicate that grainstone lithoclasts were not well cemented. (B) 11,742.5 ft (3579.1 m). Core slab 1.5 ft (0.46 m) above dissolution-collapse breccia zone. Fractures are likely related to subsidence after dissolution of the evaporites.

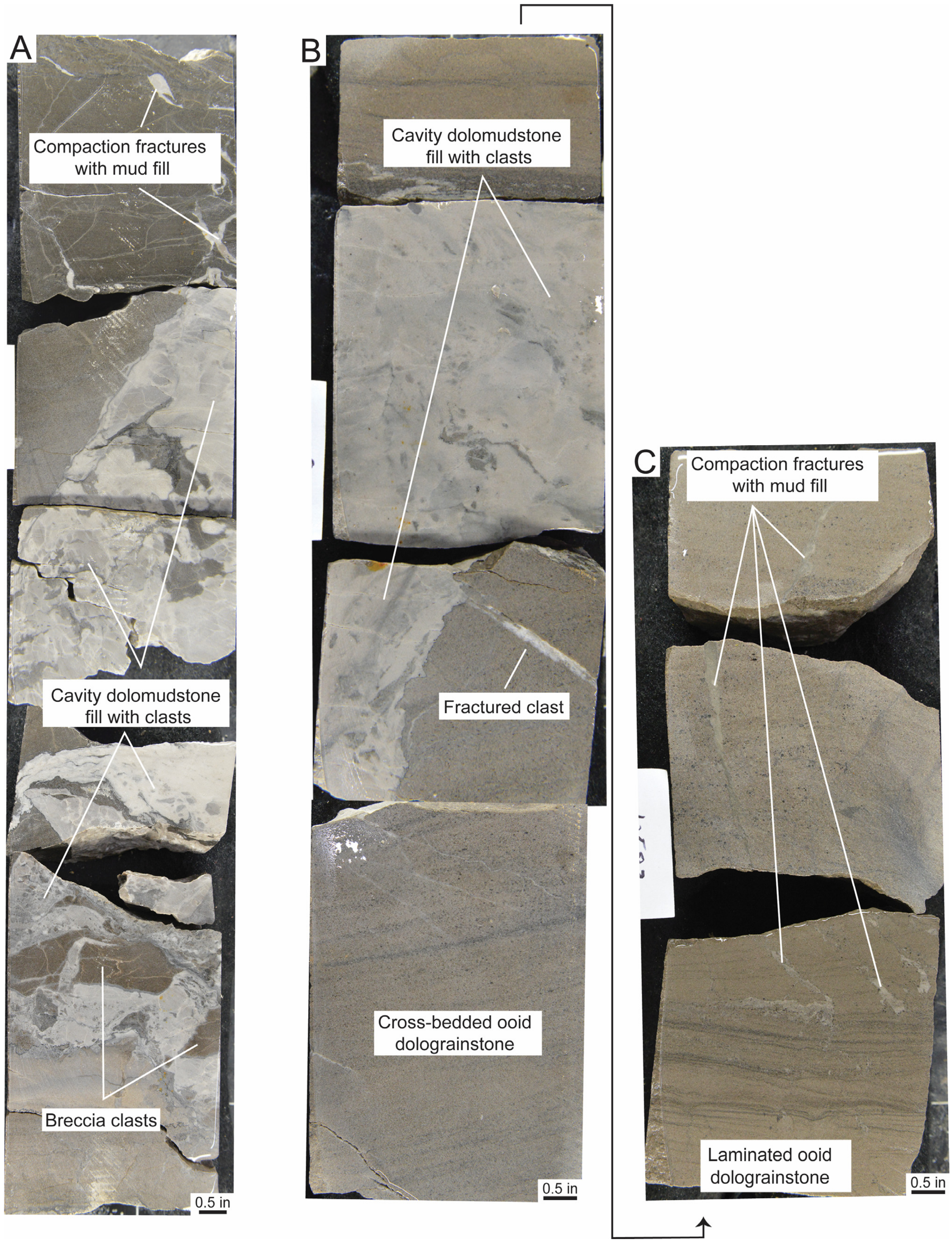


Figure 12. McCormick Oil & Gas Corp. No. 1 Baum Estate core photographs. Core location is shown in Figure 2. (A) 11,594 ft (3533.6 m). Dissolution-collapse breccia with erosional base overlain by ooid dolograinstone with compaction fractures filled with light-colored dolomudstone. Dark patches in light-colored mudstone matrix are a later-stage carbonate mud fill. (B) 11,584 ft (3530.8 m). Dissolution-collapse breccia with light-colored dolomudstone matrix. (C) Core slabs above those shown in B. Dolograinstones show compaction fractures.

anhydrites are preserved, they display a horizontal bedded to nodular bedded fabric. Some layers of former gypsum chevrons are preserved. Depositional settings of these evaporite sections are interpreted as salinas or brine ponds on a sabkha and within sediments on the sabkha. The sabkha appears to have been closely associated with a seaward, coated-grain-rich strandplain. Where anhydrite zones are still present, they form vertical permeability barriers to fluid flow. Some of the dissolution-collapsed breccias appear tight and will also form vertical permeability barriers. Interpreting with available core density cannot define the lateral extent of these zones but rather requires using modern wireline-log suites from which evaporite zones can be identified and correlated.

This investigation documents preserved evaporites composed of anhydrite and dissolution-collapse zones after evaporites. The evaporite zones may be related to higher frequency cycle tops. Identifying these anhydrite zones and associated dissolution-collapsed breccias increases our knowledge of the Smackover proximal inner-ramp depositional history and identifies probable vertical flow barriers.

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