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Geological Description of the Lower Cretaceous Fort Lancaster Formation on the Comanche Shelf, Southern Trans-Pecos Texas: A Case Study of a Platform-Interior Transgressive-Regressive Carbonate Sequence and Subsequent Extensional and Transtensional Faulting with Karst Modification

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ABSTRACT

During the Cretaceous Late Albian Stage, extensive carbonate deposition occurred across Texas. Many of these carbonates have been well studied, leading to numerous publications. This investigation focuses on the less-studied Upper Albian Fort Lancaster Formation in the Trans-Pecos region. Carbonates in this area were deposited in the shelf interior northwest of the high-energy northern margin of the Maverick Intrashelf Basin, situated on the Comanche Shelf. Later karsting and faulting significantly altered the rocks.

This location lies approximately 180 mi (290 km) landward of the Stuart City Reef Trend. Strata of the Fort Lancaster Formation are interpreted as a high-frequency sequence (HFS) (Albian HFS 21). Deposition began with burrowed, lower energy lithofacies formed in an oxic, deeper water platform setting. This was followed by a regressive, upward-shoaling sequence culminating in a high-energy shoaling environment.

Numerous high-angle transtensional faults cut strata in the studied roadcut, some exhibiting vertical displacement. After Cenozoic subaerial exposure, these faults were conduits for meteoric fluids, resulting in extensive dissolution along fault planes. Some solution-enlarged fault openings are as much as 10 ft (3 m) wide. Many of these karst-enlarged fractures are filled with coarse-crystalline calcite cement and speleothems. Associated cave-sediment fill consists of argillaceous lime mud containing limestone gravel.

The study of the Fort Lancaster Formation contributes to a deeper understanding of the Upper Albian carbonate systems in the Trans-Pecos region, an area that is greatly understudied. This stratigraphic section can now be compared to other areas of Central and West Texas where the Albian HFS 21 sequence appears.

INTRODUCTION

The Lower Cretaceous Fort Lancaster Formation in southern Trans-Pecos Texas was deposited northwest of the high-energy northern margin of the Maverick Intrashelf Basin, situated on the Comanche Shelf (Fig. 1). This location lies approximately 180 mi (290 km) landward of the Stuart City Reef Trend. Our study focuses on an exceptionally well-exposed roadcut of Albian high-frequency sequence (HFS) 21, as defined by Kerans (2002), located about 9 mi (14.5 km) north of Sanderson, Texas. Albian HFS 21 represents a transgressive-regressive (T/R) interval approximately 85 ft (25.9 m) thick in this area.

The transgressive section of Albian HFS 21 begins with burrowed, lower energy lithofacies deposited in an oxic, deeper water platform setting. This is followed by the regressive section, which features an upward-shoaling sequence culminating in a high-energy shoaling environment. The strata in this interval are intersected by numerous high-angle transtensional and extensional faults with evidence of both horizontal and vertical displacement. Significant dissolution resulted in large voids and

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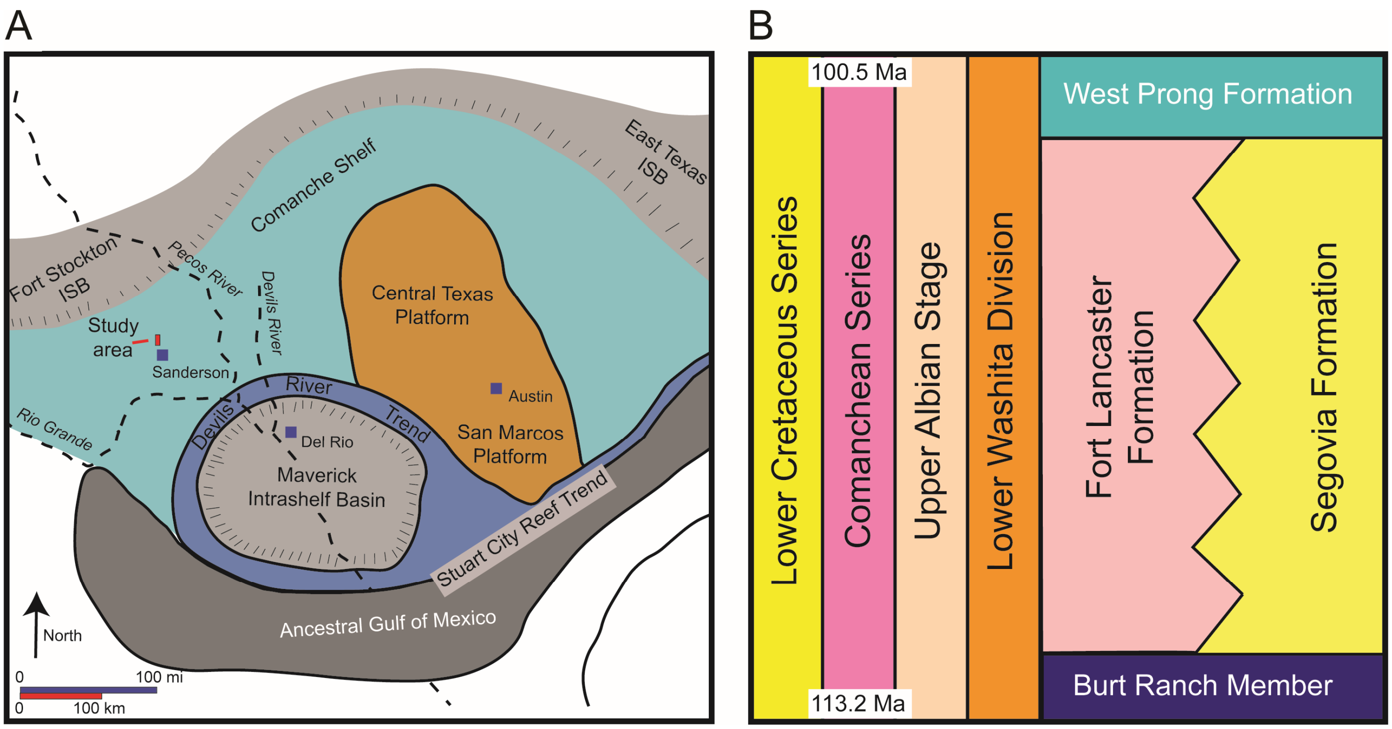


Figure 1. (A) Location of the Sanderson roadcut on the Comanche Shelf. ISB = intrashelf basin. Map adapted from Smith et al. (2000). (B) Local stratigraphic section in the Sanderson area. Column adapted from Smith et al. (2000). Roadcut is located at 30º 15' 36.88" N and 102º 26' 55.12" W.

associated cements along the fault planes caused by Cenozoic subaerial exposure where these faults were conduits for meteoric fluids.

The primary aim of this investigation is to document a well-exposed carbonate T/R high-frequency sequence in the Trans-Pecos region of Texas. Specific objectives include:

(1) Establishing the general depositional and stratigraphic setting,
(2) Describing the lithofacies and their stacking pattern,
(3) Interpreting the evolution of depositional environments,
(4) Documenting high-angle transtensional and extensional faults, and
(5) Characterizing karst features associated with faults.

This geologic description of the stratigraphic interval near Sanderson, Texas, contributes to the regional understanding of Lower Cretaceous T/R high-frequency sequences in the platform interior, Trans-Pecos area. Additionally, it provides valuable documentation of an upper Albian section rarely addressed in existing literature.

DATA AND METHODS

The roadcut located north of Sanderson, Texas, on Highway 285 (Fig. 1A) examined in this study is oriented approximately in the dip direction (north-northwest to south-southeast). It spans a length of 1360 ft (414 m) and has a thickness of 102 ft (31 m) (Fig. 2). Excellent exposures are present on each side of the road, and the gradient allows one to walk through the complete section. Samples were collected from each well-defined bed, then slabbed and etched with 10% HCl to enhance the visibility of depositional fabric, texture, and allochems. Forty-one thin sections were prepared for petrographic analysis, and their stratigraphic locations are illustrated in Figure 2 (see unit numbers).

STRATIGRAPHY AND DEPOSITIONAL SETTING

The Fort Lancaster Formation, dated to be late Albian, is part of the Lower Washita Division (Smith et al., 2000) (Fig. 2). According to Smith et al. (2000), the Fort Lancaster Formation corresponds to the Santa Elena and Sue Peaks formations to the west and the Segovia and upper Devils River formations to the east. In the study area, it overlies the Burt Ranch Member and underlies the West Prong Formation.

As previously noted, the study area is situated approximately 180 mi (290 km) inland from the shelf margin of the Stuart City Reef Trend (Fig. 1B). It lies on the broad, shallow-water interior Comanche Shelf positioned between the Maverick Intrashelf Basin to the southeast and the Fort Stockton Intrashelf Basin to the northwest (Fig. 1A). The stratigraphic section exposed in the Fort Lancaster roadcut reveals that the base of the T/R high-frequency sequence began in deeper waters based on rock texture and biota, estimated at around 100+ ft (30+ m) in depth, and transitioned to shallower conditions, most likely less than 5–10 ft (1.5–3 m). This indicates a depositional setting near or above the fair-weather wave base, with oxic bottom-water and sediment conditions.

LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS

The lithofacies described in the measured section range from mudstones to grainstones with some boundstones (Fig. 2). Lithology of the section is limestone and contains intervals rich in chert nodules. Thirteen lithofacies are presented in the measured section, but for ease of description, they are grouped into 7 lithofacies groups (Fig. 2B). The major allochems are peloids, bivalves, and echinoid fragments. The upper section is rich in rudist fragments and whole rudists. Some sections contain lesser amounts of oysters, gastropods, benthic foraminifers, ostracods, worm tubes, and sponge spicules. The section shallows upward, which is reflected in a biotic and lithologic change (Fig. 2).

Burrowed Skeletal Peloidal Mudstone Lithofacies (Figs. 3C and 3D)

The matrix of the mudstone lithofacies is composed of highly compacted peloids. Thin-sections are needed to recognize the compacted peloids. The abundance of skeletal-hash fragments is less than 10 percent. This lithofacies represents a very low-energy, oxic depositional environment that favored bioturbation, including common *Thalassinoides* burrows. However, the depositional environment was restricted enough to inhibit larger skeletal biota development. This is probably the deepest water setting, especially at the maximum flooding surface (Fig. 2A) and most restricted lithofacies, and it was probably at the lowest interval of the fair-weather wave base or even may have been below the storm-wave base.

Burrowed Skeletal Peloidal Wackestone Lithofacies (Fig. 3A)

The wackestones have a peloidal matrix and skeletal-hash content greater than 10%. Common *Thalassinoides* burrows are present, indicating a well-oxygenated environment. The depositional setting was oxic, low-energy conditions. Larger biota, such as benthic foraminifers and bivalves, lived in this setting. Water depth was probably shallower than the mudstone lithofacies and was likely at the lowest part of the fair-weather wave base. Abundant bioturbation destroyed indicative sedimentary structures that could define an accurate estimation of water depth.

Burrowed Skeletal Peloidal Mud-Dominated Packstone Lithofacies (Figs. 3B, 3E, 3F, 4A, and 5A–5C)

This lithofacies is similar to the wackestone lithofacies but contains more allochems such as bivalves, echinoid fragments, benthic foraminifers (no miliolids), and ostracods. Layers of chert nodules are present (Fig. 5C). Common *Thalassinoides* burrows are present. The burrowing and amount of lime mud indicate a low-energy, oxic bottom-water environment.

Burrowed Skeletal Peloidal Grain-Dominated Packstone Lithofacies (Figs. 4B and 4F)

Skeletal and peloidal allochems dominate this lithofacies, which also contains lime mud. Common *Thalassinoides* burrows are present. The low amount of lime mud suggests a moderate-energy setting and abundant skeletal grains and bioturbation indicate oxic bottom-water conditions.

Burrowed Skeletal Peloidal Grainstone Lithofacies (Fig. 4C)

This lithofacies contains no lime mud. The grains are rounded and reasonably well sorted. Grain types include echinoid and bivalve fragments and lesser caprinid fragments. The lack of mud, the presence of rounded grains, and fair sorting indicate higher energy shoaling conditions within a fair-weather wave base.

Cross-Bedded Skeletal Grainstone Lithofacies (Figs. 4E and 6)

This lithofacies is similar to the skeletal peloidal grainstone lithofacies, but it is well cross-bedded (Fig. 6), and the grains are more rounded and better sorted than the burrowed skeletal peloidal grainstone. The cross-bedding and texture characteristics indicate a shallow-water shoaling environment.

Rudist Grainstone (Bafflestone) Lithofacies (Figs. 4D and 7)

The rudist grainstone (bafflestone) is composed of whole and fragmented caprinid fragments. Figure 7 shows a lens of whole rudists (bafflestone biostrome) laterally transitioning into a rudist grainstone dominated by rounded grains. This lithofacies represents a moderate- to high-energy environment within a fair-weather wave base.

DESCRIPTION OF STRATIGRAPHIC SECTION AND STACKING PATTERN

The measured stratigraphic section is divided into several intervals (Fig. 2). The lower interval, spanning 0 to 16 ft (0 to 4.9 m), represents the upper part of a shallowing cycle transitioning from wackestones to mud-dominated packstones. This interval is interpreted as the regressive phase of an earlier HFS, and although it indicates shallowing, it does not appear to transition into a shoaling environment.

Above this, from 16 to 37 ft (4.9 to 11.3 m), lies the transgressive systems tract of Albian HFS 21. This is followed by the regressive phase, which extends from 37 to 100 ft (11.3 to 30.5 m). These transgressive-regressive sections form a high-frequency sequence, identified as Albian HFS 21 (Kerans, 2002). The uppermost portion of the section, from 100 to 102 ft (30.5 to 31.1 m), may represent the base of Albian HFS 22 of Kerans (2002).

The transgressive section of Albian HFS 21 is characterized by lime mudstones, representing the deepest water setting within Albian HFS 21, likely below or near the storm-weather wave base. At 37 ft (11.3 m) above the base of HSF 21, an increase in skeletal content marks the transition (maximum flooding surface) into the regressive phase of Albian HFS 21. This phase is dominated by skeletal peloidal mud-dominated packstones in the lower part, whereas the upper part transitions to skeletal peloidal grain-dominated packstones, grainstones, and lesser boundstones. The lower grainstone interval shows bioturbation, whereas the upper grainstone interval is well cross-bedded. Several rudist-rich zones are also present. The younger Albian HFS 22(?) above is represented by 2 ft (0.6 m) of peloidal skeletal grain-dominated packstone.

HIGH-ANGLE TRANSVERSE AND EXTENSIONAL FAULTING

Strata exposed along the roadcut are extensively faulted (Fig. 8). The faults are characterized as high-angle transtensional faults with well-developed, low-angle slickensides (Figs. 8A and 8B) trending in a northeast-to-southwest direction. These faults also exhibit minor extensional displacement. A second set of high-angle extensional faults is present with a northwest-to-southeast orientation (Fig. 9A). These are extensional faults with no sign of oblique slip. Both sets of the high-angle faults were conduits for meteoric fluids, leading to pronounced

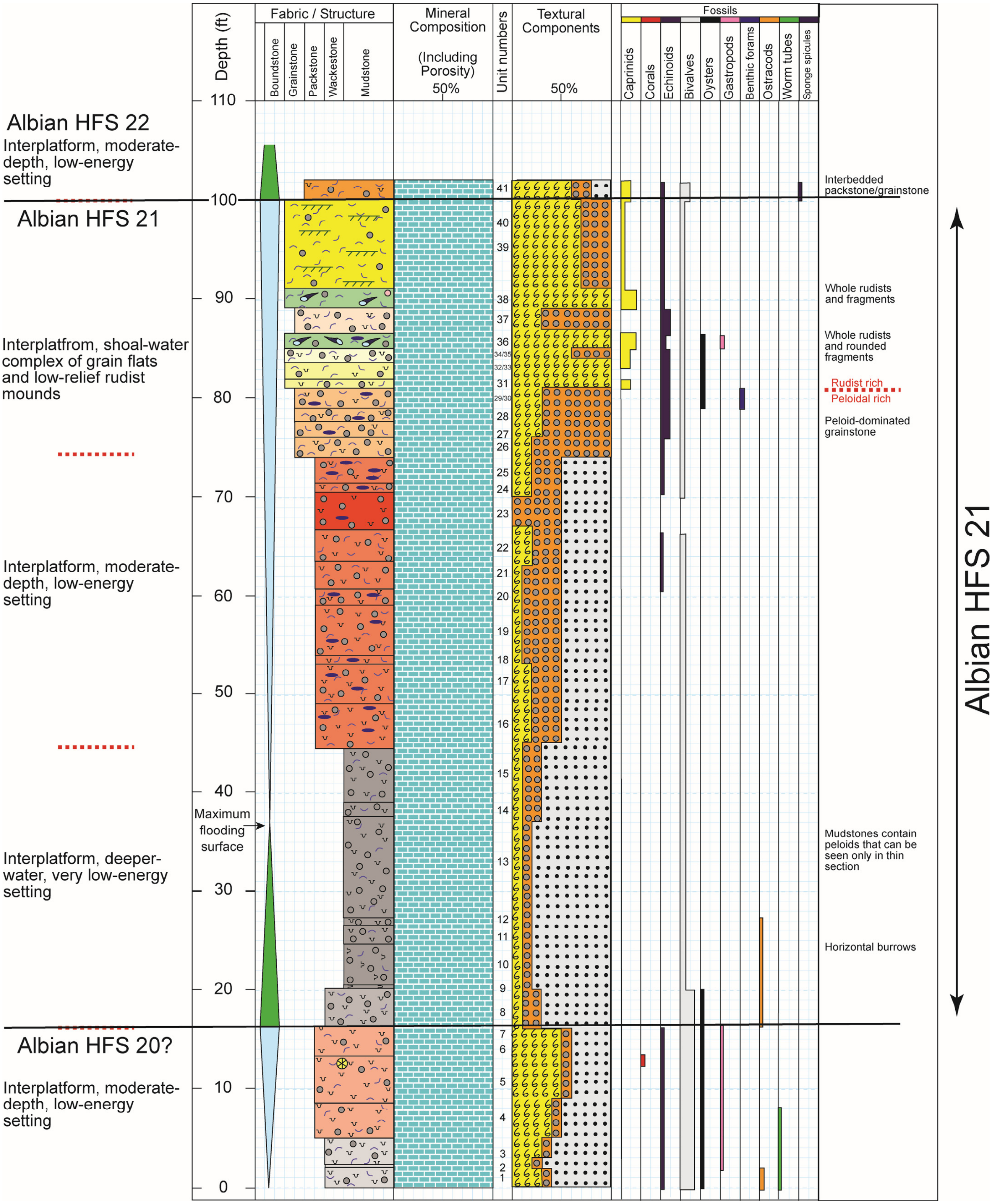
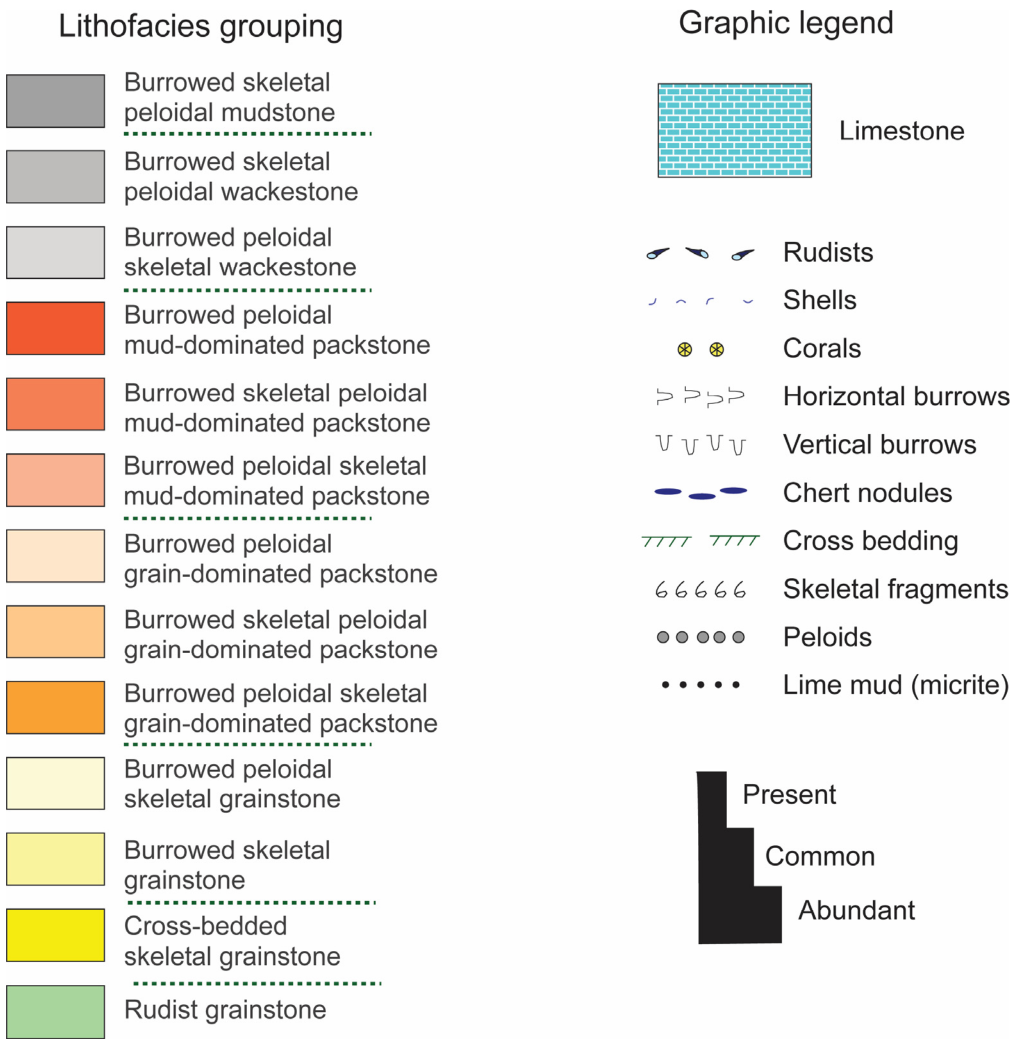


Figure 2. (A, ABOVE) Graphic measured section of the Sanderson roadcut. Unit numbers also refer to thin-section locations. (B, FACING PAGE) Grouping of lithofacies and legend of symbols.



dissolution (karsting) along the fault planes and adjacent strata (Fig. 9). Thick zones of coarse-crystalline calcite cement were precipitated in the northeast, transtensional faults with only minor amounts of calcite being present in the northwest set. Some calcite cement is highly twinned (Fig. 8B and 8C), which is related to late movement along the faults. Chris Zahm, a co-author of this paper, is conducting a more detailed analysis of these transtensional and extensional faults. His findings will be published in the future.

FRACTURE-CONTROLLED KARSTING

The well-developed fracture system of high-angle faults provided efficient pathways for Cenozoic meteoric water to infiltrate the shallow strata after uplift and subaerial exposure. Slightly acidic meteoric water contributed to the solutional enlargement of many fractures, a process evident in Figure 9. Karst features are commonly observed, including speleothem cements (Fig. 9C) and cave-sediment fills (Figs. 9A and 9B). The speleothem cements exhibit various forms, such as laminated calcite crusts and spherical speleothem (i.e., "cave popcorn") (Fig. 9C). The cave sediment fill consists of argillaceous lime mud with mixed gravel (Fig. 9B).

CONCLUSIONS

The Lower Cretaceous Fort Lancaster Formation, discussed in this study, was deposited during the Upper Albian Stage on the Comanche Shelf in the Trans-Pecos Texas region. It formed on a broad, shallow-water interior shelf between the Maverick Intrashelf Basin to the southeast and the Fort Stockton Intrashelf Basin to the northwest. The stratigraphic section represents a high-frequency T/R cycle (Albian HFS 21 of Kerans [2002]) consisting of a transgressive section dominated by lime mudstone and a regressive section. The regressive section transitions from low-energy lime mudstones at the base to higher-energy skeletal packstones and grainstones at the top. Many of the grainstones exhibit well-developed cross-bedding, and some rudist deposits are present in the upper section.

High-angle extensional and transtensional faulting has affected the section, with these faults being conduits for meteoric water, leading to extensive karstification along the fault planes. The enlarged fault zones display thick layers of calcite cement and cave sediment fill deposits and associated speleothems.

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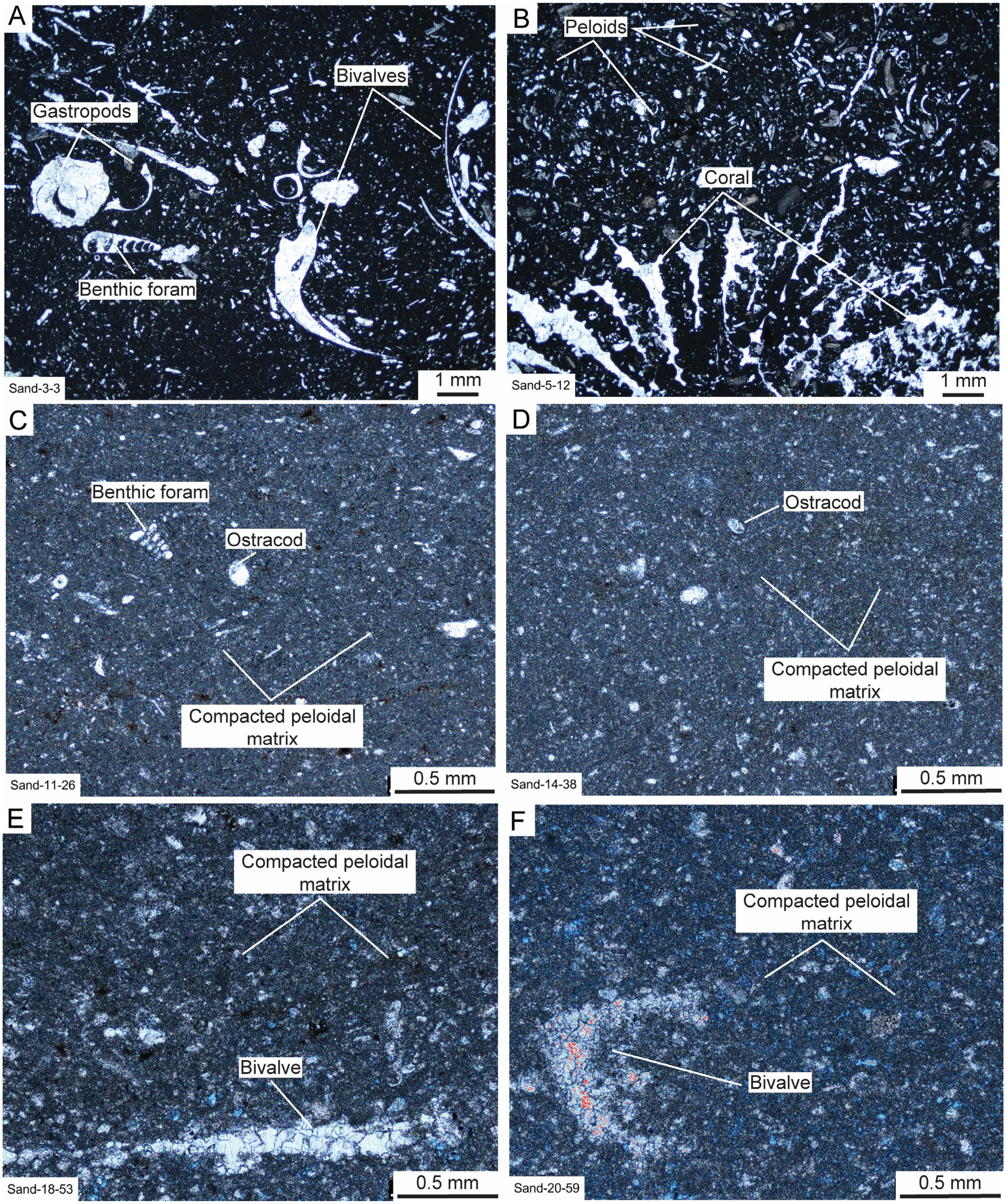

Figure 3. Lithofacies photomicrographs. (A) Burrowed peloidal skeletal wackestone with gastropods, bivalve fragments, and benthic foraminifers in a compacted, peloidal-rich matrix. Unit 3. (B) Burrowed peloidal skeletal mud-dominated packstone containing a solitary coral and some bivalve fragments. Unit 5. (C) Burrowed skeletal peloidal mudstone with benthic foraminifers and ostracods, displaying a compacted peloidal texture. Unit 11. (D) Burrowed skeletal peloidal mudstone with a compacted peloidal texture. Unit 14. (E) Burrowed skeletal peloidal mud-dominated packstone with bivalve fragments. Unit 17. (F) Burrowed skeletal peloidal mud-dominated packstone with bivalve fragments. Unit 20.

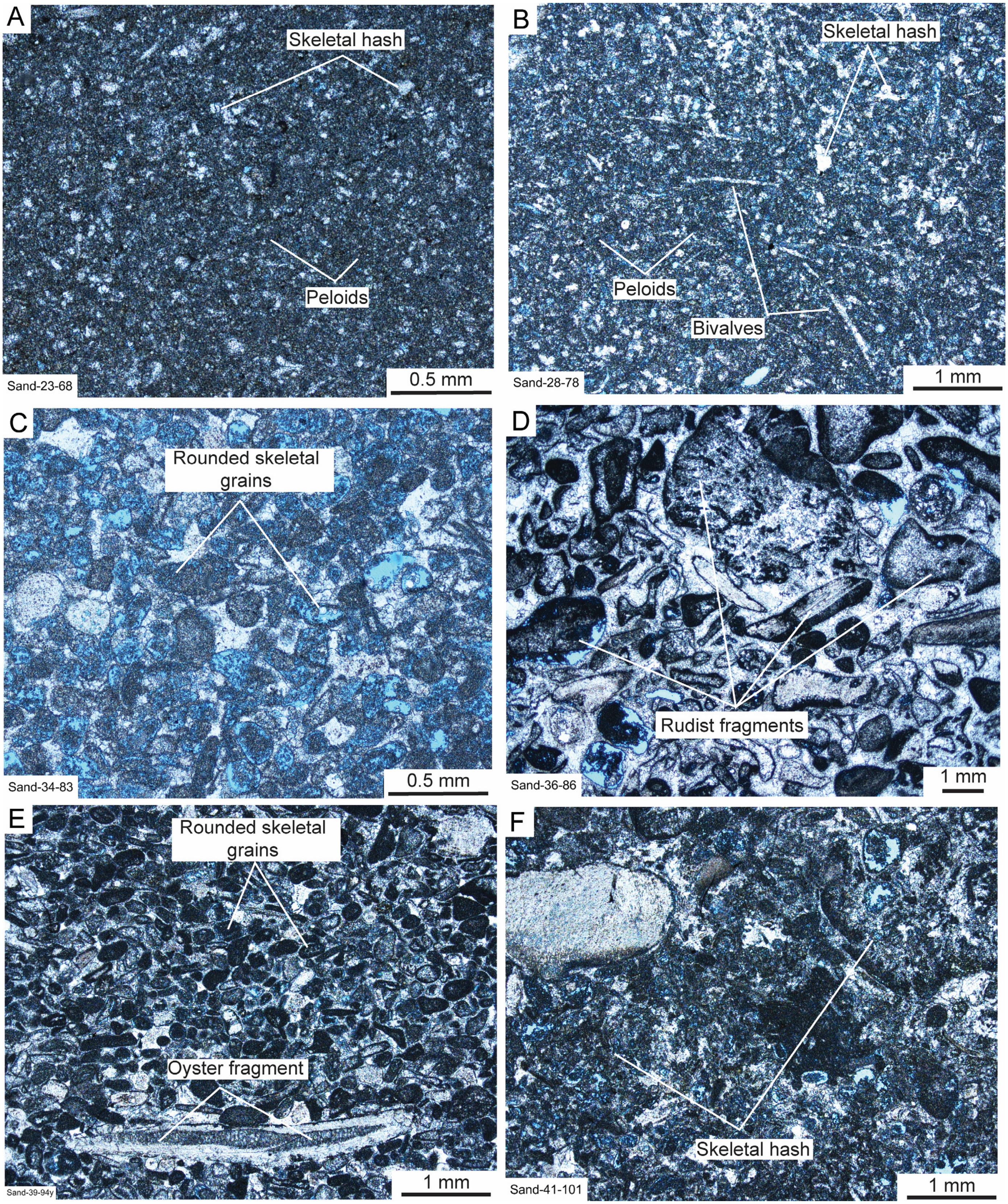

Figure 4. Lithofacies photomicrographs. (A) Burrowed peloidal mud-dominated packstone with very fine-grained skeletal fragments. Unit 23. (B) Burrowed skeletal peloidal grain-dominated packstone containing bivalve fragments. Unit 28. (C) Burrowed skeletal grainstone with rounded allochems. Unit 32. (D) Rudist grainstone with fragmented and rounded rudists. Unit 36. (E) Cross-bedded skeletal grainstone with rounded, highly micritized allochems. Unit 39. (F) Burrowed skeletal peloidal grain-dominated packstone. Unit 41.

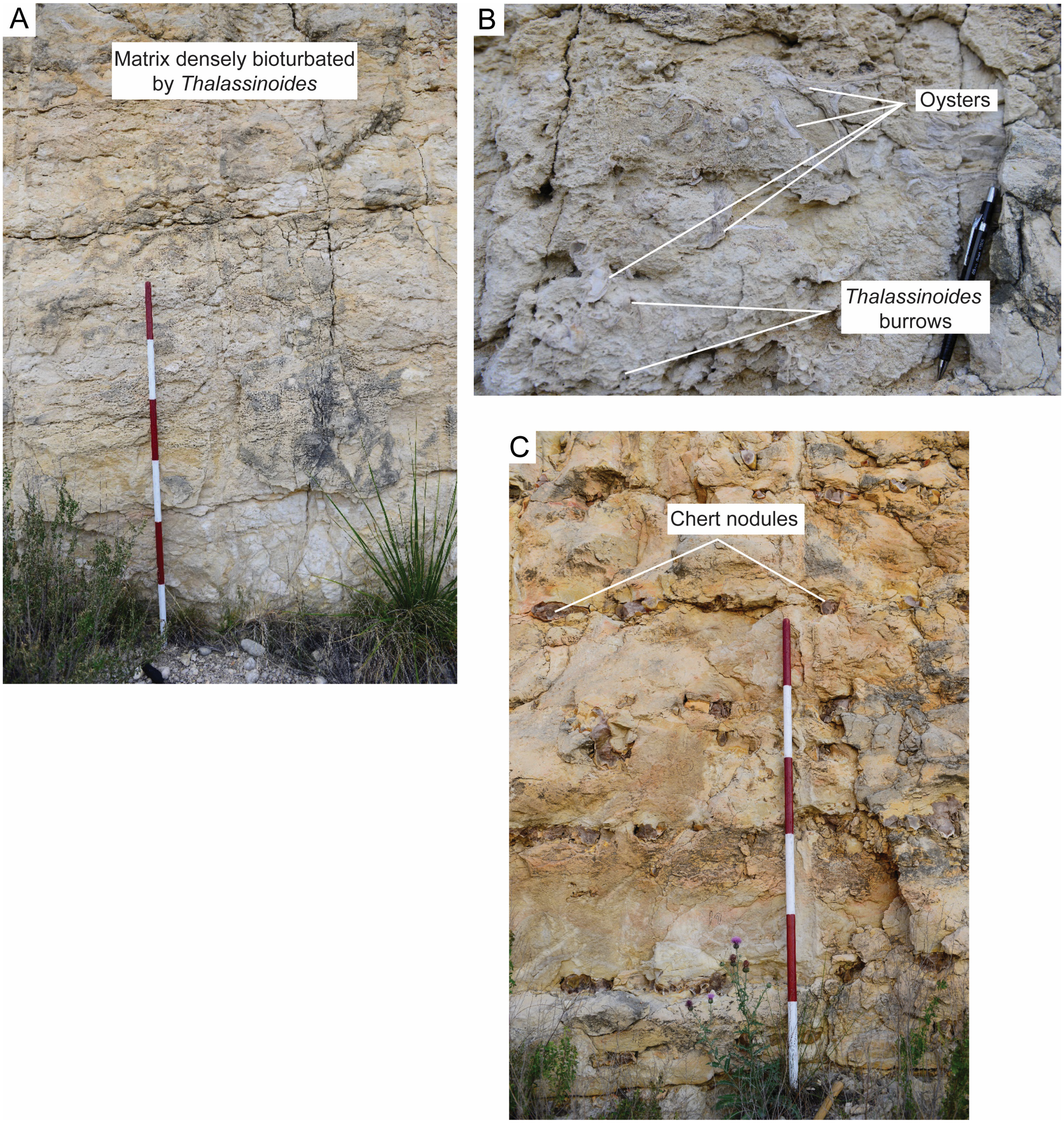

Figure 5. (A) Burrowed, evenly bedded peloidal skeletal mud-dominated packstone. Unit 4. Jacob's staff interval = 1 ft (0.3 m). (B) Same bed as A, showing large oyster fragments and abundant *Thalassinoides* burrows. (C) Burrowed skeletal peloidal mud-dominated packstone with common layers of nodular chert. Units 19 and 20. Jacob's staff interval = 1 ft (0.3 m).

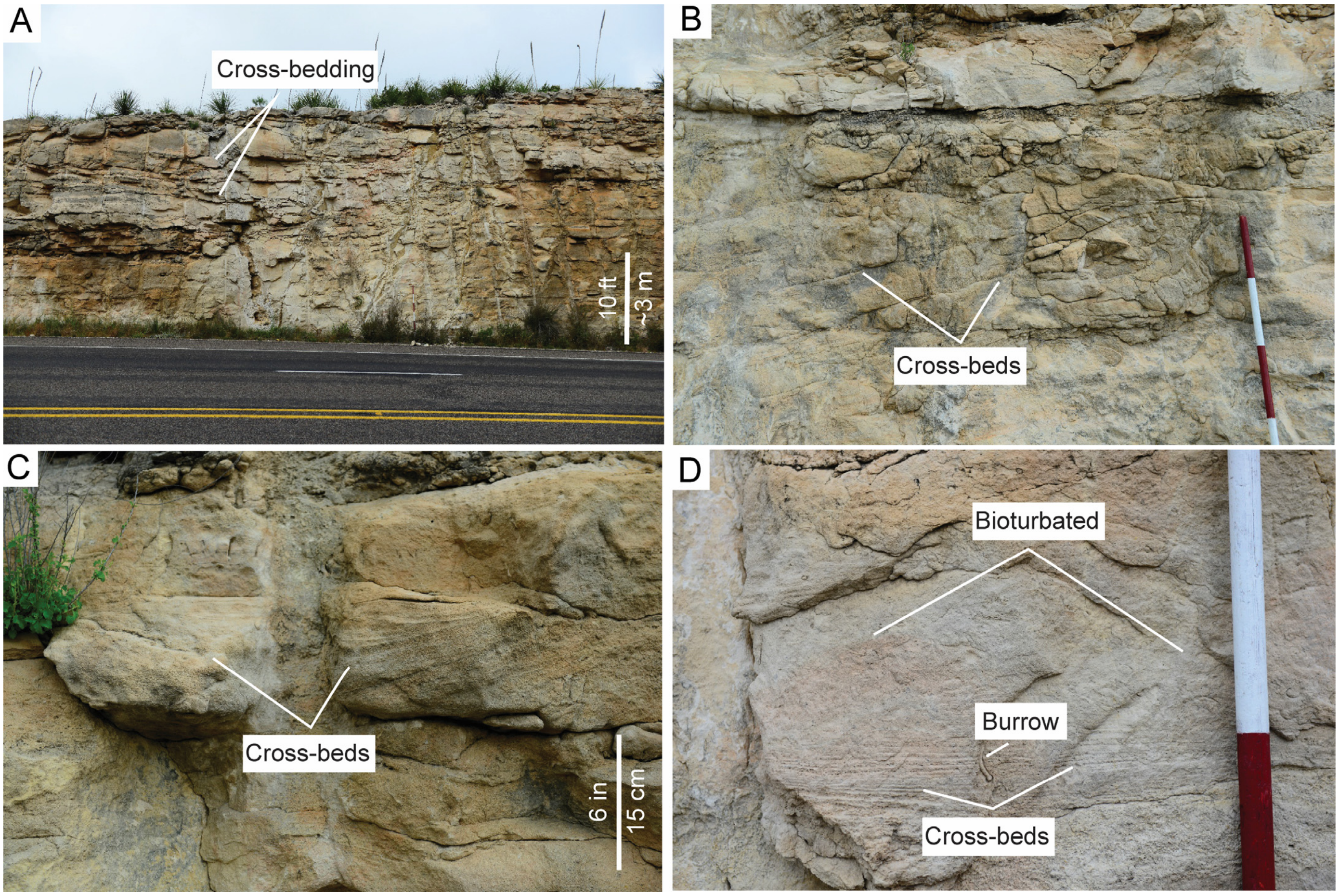

Figure 6. Examples of cross-bedding in skeletal grainstones. (A) Large-scale cross-bedding on the west wall dipping to the north. Unit 39. (B) Cross-bedding on the east wall dipping to the north. Interval on Jacob's staff = 1 ft (0.3 m). Unit 39. (C) Example of trough cross-bedding. Unit 39. (D) Low-angle cross-bedded skeletal grainstone partly bioturbated. Interval on Jacob's staff = 1 ft (0.3 m). Unit 39.

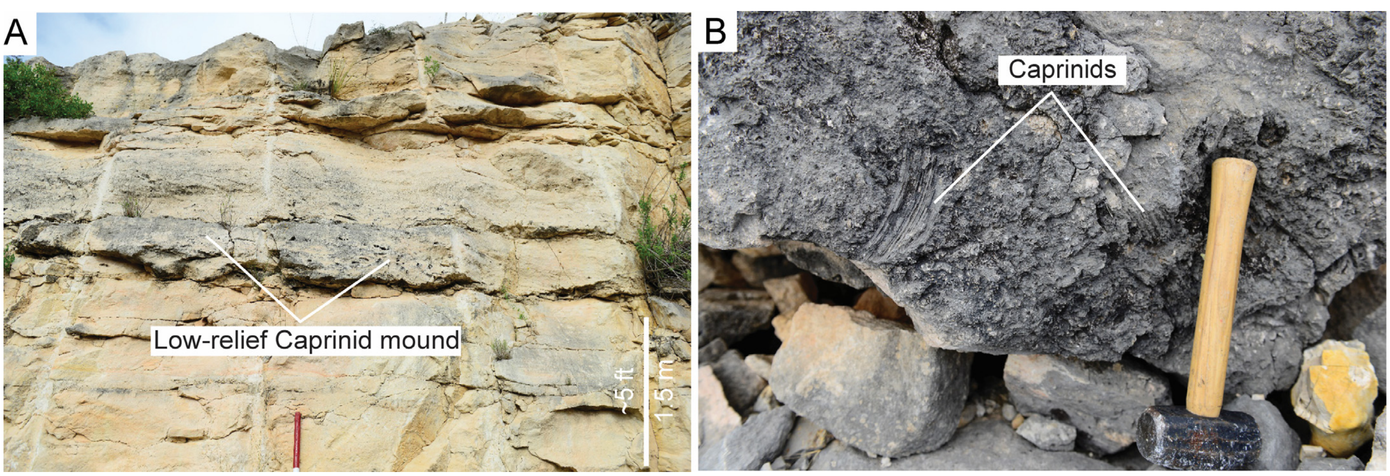

Figure 7. Rudist grainstone/bafflestone. (A) Thin lens (low-relief bioherm) of rudist grainstone/bafflestone. Interval on Jacob's staff = 1 ft (0.3 m). Unit 36. (B) Whole caprinid rudists. Unit 36.

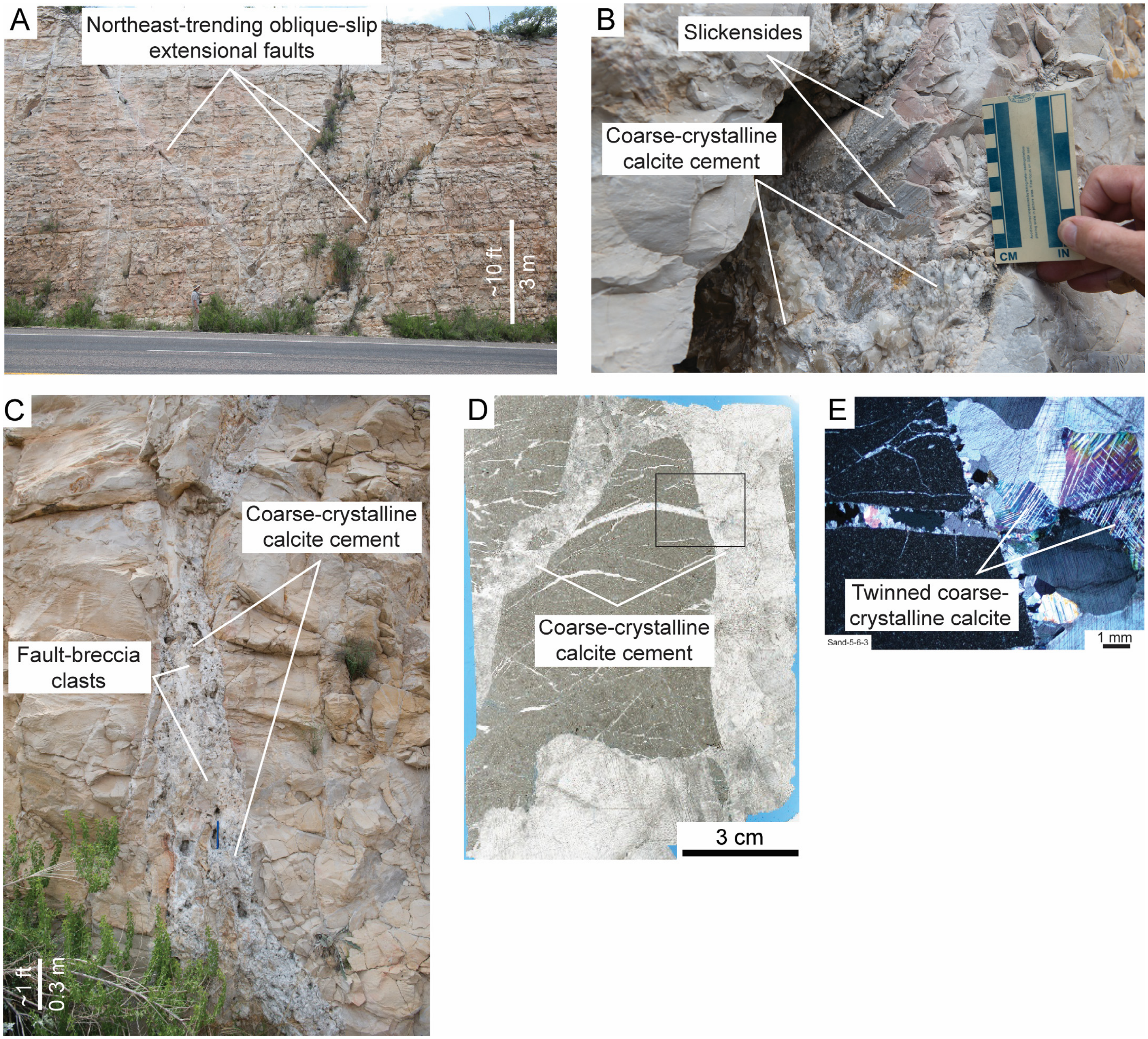

Figure 8. Faults. (A) Example of northeast-oriented extensional fault. (B) Slickensides along a northeast-striking transtensional fault plane where coarse-crystalline calcite precipitated. (C) Transtensional faults with extensive calcite cement development. (D) Thin section showing coarse-crystalline calcite cement fill in fault breccia. (E) Close-up of D, highlighting twinned coarse-crystalline calcite cement fill. Photomicrograph under cross-polarized light.

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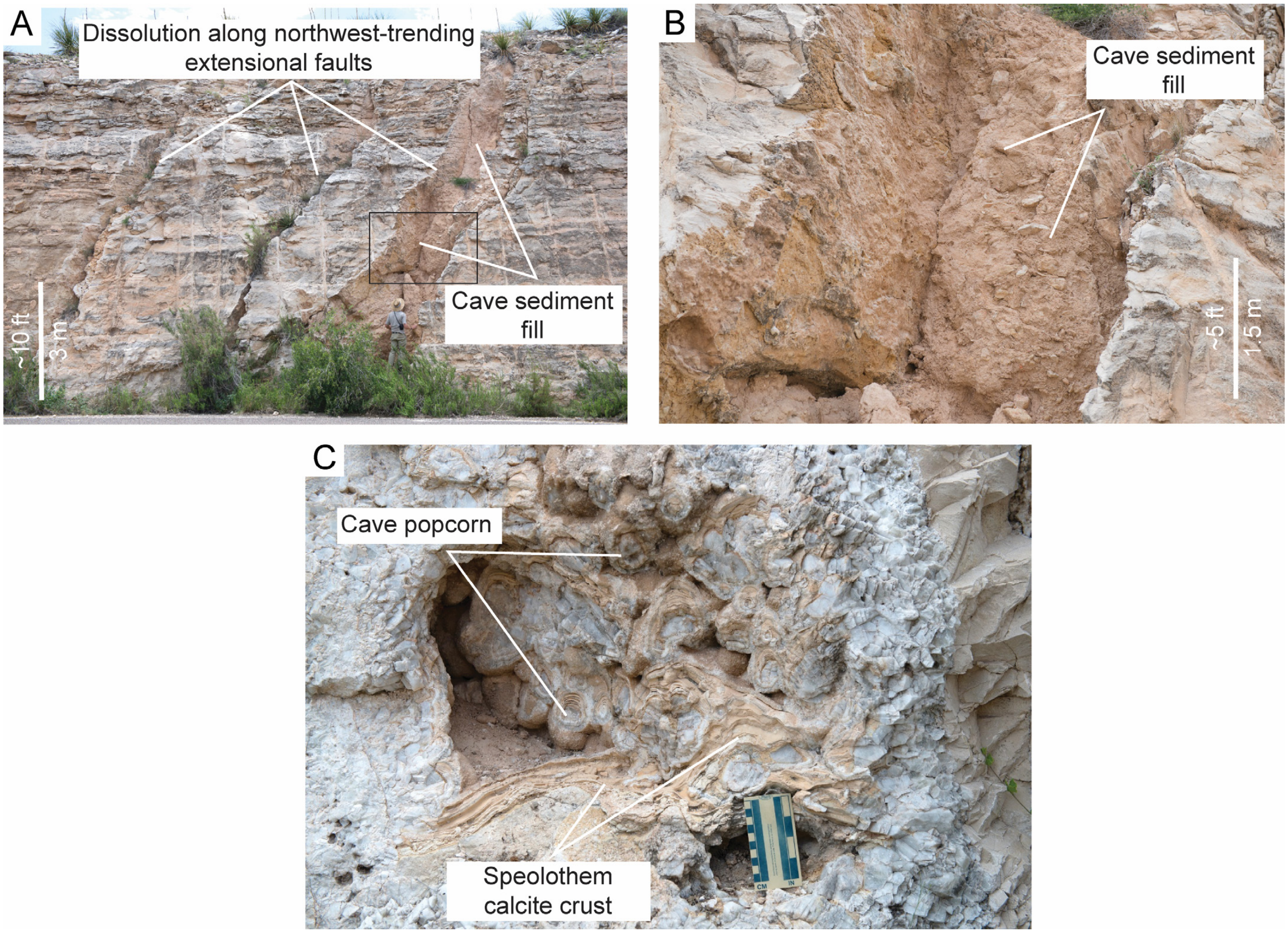

Figure 9. Karst features. (A) Dissolution along northwest extensional faults. Cave sediment fills the fault plane on the right. (B) Close-up of black box in A showing cave sediment fill composed of argillaceous lime mud and limestone gravel. (C) Speleothem cement filling a solution-enlarged fault. Calcite cements occur as laminated crusts and spheroidal calcite ("cave popcorn").