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# Facies Variability in Paleogeographic Trends from Core Data in the Lower and Middle Frio Formation in South Texas

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## ABSTRACT

**This core-based study of the Oligoene lower and middle Frio formation in South Texas documents facies variability, depositional systems, and sandstone-body architecture in the lower and middle Frio formation in South Texas. A previous study by the Bureau of Economic Geology (BEG) in 1982 characterized the Frio Formation in terms of depositional systems, structural framework, hydrocarbon origin, migration, and exploration potential. Paleogeographic trends in the 1982 study were delineated for the lower, middle, and upper Frio Formation, based mostly on wireline-log data. Core data in this study augment and refine facies interpretations and clarify depositional styles in four paleogeographic trends from the 1982 study in the lower and middle Frio Formation. These trends include (1) lower delta plain/margin, (2) aggradational fluvial, (3) aggradational (multistoried) barrier, and (4) floodplain.**

**With minor exceptions, this study validates and refines interpretations of the regional distribution of lower and middle Frio paleogeography in South Texas in the 1982 study. Four (4) main results of this study include (1) documenting lithology and facies types in these paleogeographic trends, (2) demonstrating that these paleogeographic trends are a composite of multiple transgressive-regressive (T–R) cycles, (3) providing evidence that these fluvial systems are mixed-load, meander belt in origin rather than coarse-grained bedload in origin, based on vertical grain-size profiles and the presence of paleosols that indicate stable, well-developed floodplains, and (4) identifying anomalous occurrences of sandstone-rich fluvial-channel systems in areas previously mapped as sandstone-poor and interpreted to be primarily floodplain in origin. Finally, this study serves as an example of the value of core data in refining interpretations of paleogeography and depositional systems in stratigraphic units that are a composite of multiple T–R episodes.**

## INTRODUCTION

Prior to the year 2000, there was no centralized core or wireline-log database for Bureau of Economic Geology (BEG) researchers or outside users to query. Researchers would have to assemble their lists of relevant logs and cores. In 2000, the first iteration of a core and wireline-log database, the Integrated Core and Log Database (IGOR), was created. The name refers to the name of a server for this database. As more data were added, IGOR was enhanced and expanded. The current iteration of the log and core database is called Continuum. According to Continuum, there are 198 cores identified from the Frio Formation in Texas, of which 24 are whole or slabbed.



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Using these core data, this study presents a refined facies interpretation of a previous interpretation of the lower and middle Frio Formation in South Texas (Galloway et al., 1982). The area of investigation in the study is South Texas. From the set of BEG cores and a core from the Galloway et al. (1982) study, we include detailed descriptions from six (6) selected cores in the BEG database (Fig. 1). These six cores (Humble No. 183 Alazan, Mobil nos. 67 and 70 Minnie Welder, Restech/SUN No. 141 Canales, SUN No. 16–125 Seeligson, and Union Pacific No. 36 Elliff), are selected as being the most representative examples from the BEG database to document additional details of facies and sandstone-body architecture in lower and middle Frio paleogeographic trends, and to provide new insights into depositional systems in these paleogeographic trends.

## GEOLOGIC SETTING

The Oligocene Frio Formation is a series of major, third-order progradational wedges in the Gulf Coast Basin (Brown and Loucks, 2009). The Frio Formation is composed of an updip and relatively-shallow section of interbedded continental and margin-

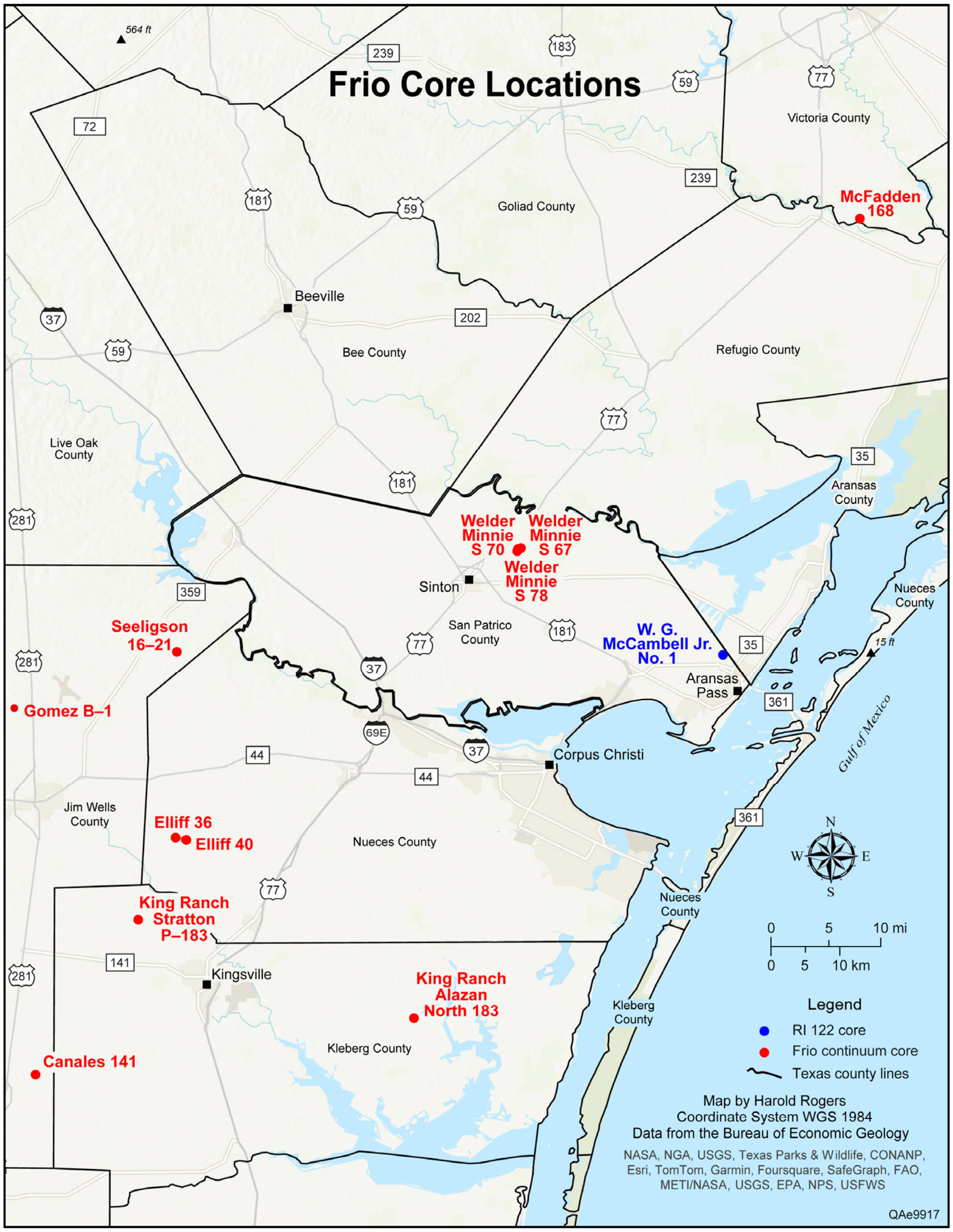



**Figure 1. Study area in South Texas with locations of cored wells in the lower and middle Frio Formation, identified in the Bureau of Economic Geology's Continuum database.**

al-marine deposits underlain by several thousand feet or meters of slope and basinal mudstone (McGookey, 1975; Galloway et al., 1982). During the Oligocene, major sediment influx from sources in northern Mexico and the southwestern United States resulted from uplift and erosion along the western margin of the Gulf Coast Basin (Galloway et al., 1982, 2000). Explosive volcanism and caldera formation along the Sierra Madre Occidental combined with uplift to create a massive influx of recycled sedimentary rocks, volcaniclastics, and reworked ash into the western and central Gulf of Mexico (Galloway, 1977).

The Frio Formation and its updip equivalent, the Catahoula Formation, consist of regionally-extensive fluvial and associated deltaic systems in the Houston and Rio Grande embayments. The volcanic terrains of West Texas and Mexico were the source region for deposits in the Rio Grande Embayment. These sediments contain a large fraction of feldspars and volcanic rock fragments. They also have little to no primary porosity as a result of occlusion by calcite cement and the presence of mainly felsic lithic fragments and volcanic glass shards (Kaiser, 1984; Grigsby and Kerr, 1991; Kerr and Grigsby, 1991).

The Norias delta system in South Texas is an expansive, predominantly-sandy, progradational complex fed by the updip Gueydan fluvial system. This progradational complex effectively filled the Rio Grande Embayment by the end of Frio deposition (Duncan, 1983). Initiation of Norias deltaic progradation was associated with the early rise in sea level following a lowstand. As sea level rose following the lowstand, topographic expression of the pre-existing Vicksburg progradational wedge (prior to 29.7 million years [Ma]) (Brown and Loucks, 2009) also caused a northward deflection of the Gueydan fluvial system within the Rio Grande Embayment (Duncan, 1983).

## METHODS

Initially, the authors searched for all Frio Formation cores in the Continuum database. The cores were classified as being in the lower, middle, and upper Frio Formation, as described in Galloway et al. (1982). Six cores in the study area, representative of paleogeographic trends mapped in the Galloway et al. (1982) study, were described and used to refine interpretations of facies, sandstone-body architecture, and depositional systems. Features described in these cores include lithology, vertical grain-size trends, stratification, contacts between sandstone and mudstone beds, trace fossils, and pedogenic features such as clay nodules, root traces, and sediment coloration. Interpretations of facies and depositional systems from these cores were used to evaluate and constrain interpretations of lower and middle Frio paleogeographic trends from the Galloway et al. (1982) study.

## RESULTS

### Lower Frio Formation

Three cores in this study occur in two lower Frio paleogeographic trends in South Texas (Figs. 2 and 3). The lower Frio Formation is approximately the lower one-third of the Catahoula Group and ranges in age from ~28.1 to 29.7 Ma (Brown and Loucks, 2009). Cores in the lower Frio Formation in this study are from the Humble No. 183 Alazan well and the Mobil nos. 67 and 70 Minnie Welder wells. The Humble No. 183 Alazan well represents the lower delta plain/margin paleogeographic trend, and the Mobil nos. 67 and 70 Minnie Welder wells are located in the stacked barrier (aggradational) paleogeographic trend.

#### Lower Delta Plain/Margin Paleogeographic Trend

The lower delta plain/margin paleogeographic trend is in a transitional area between the fluvial (aggradational) paleogeographic and the stacked barrier (aggradational) trends (Fig. 2). Percent-sandstone values in this trend are commonly 10 to 30%, recording interbedded sandstones and mudstones within predominantly delta-front facies.

**Humble No. 183 Alazan (Kleberg County): Description:** The Humble No. 183 well is on the northeastern margin of the lower Frio lower delta plain/margin paleogeographic trend, where percent-sandstone values are <30 (Figs. 2 and 3, respectively). The 40 ft (12 m) cored section consists of an upward-coarsening succession of shelly and calcareous sandstone beds, with 2 to 4 ft (0.6 to 1.2 m) beds of mudstone rip-up clasts and muddy interbeds with mollusc fragments (Figs. 4 and 5A). Sedimentary structures are obscured by *Teichichnus* and abundant *Ophiomorpha* (Figs. 5B and 5C, respectively), although low-angle planar stratification occurs at the top of the cored interval (Fig. 4). Crossbedding is absent at the top of the cored interval.

**Humble No. 183 Alazan (Kleberg County): Interpretation:** Basal beds in the Humble No. 183 Alazan well core consist of ripple-stratified, very fine- to fine-grained, extensively-burrowed sandstone, interpreted as delta-front deposits. They grade upward at 7875 ft (2400.3 m) into non-borrowed, planar-stratified sandstone in channel-mouth bar facies. The Pennsylvanian Dobbs Valley Member of the Strawn Group southeast of Mineral Wells, Texas, is a growth-faulted outcrop analog of the transition from delta-front to channel-mouth-bar facies (Brown, 1973). Delta-front deposits in the Humble No. 183 Alazan core are composed of ripple-stratified and burrowed sandstones, with many ripples having low-angle, wavy, and symmetrical tops. These delta-front deposits are overlain at 7875 ft (2400.3 m) by relatively coarser-grained, planar-stratified sandstone representing channel-mouth bar deposits in a net-progradational section.

#### Stacked Barrier (Aggradational) Paleogeographic Trend

The stacked barrier (aggradational) paleogeographic trend is a strike-oriented (southwest-northeast) band of barrier/strandplain deposits northeast of the lower delta plain/margin paleogeographic trend (Fig. 2). This band of barrier/strandplain deposits is ~30 mi (~48 km) wide and extends northeastward along the Texas Gulf Coastal region toward southeastern Texas (Galloway et al., 1983).

**Mobil No. 67 and 70 Minnie Welder (San Patricio County): Description:** Two closely spaced (<1 mi [<1.6 km]) wells in Portilla Field in San Patricio County, the Mobil nos. 67 and 70 Minnie Welder, are located along the axis of a strike-oriented, sandy trend where percent-sandstone values are ~40% (Figs. 2 and 3). Both cored intervals in these wells are composed of aggradational (multistoried) successions of fine- to medium-grained sandstone with abundant burrows and shell fragments (Figs. 6–9). Many sandstone beds in these cores contain moderately to well-sorted sand grains within zones of low-angle, planar stratification (Figs. 7B and 9A). Other sandstone beds are more heterogenous, composed of poorly-sorted, burrowed zones of mollusc fragments and mudstone rip-up clasts (Fig. 9B). Stratification in the lower half of upward-coarsening section in the Mobil No. 70 Minnie Welder core is obscured by burrows (7425 to 7448 ft [2263.1 to 2270.2 m], whereas it is better preserved above from 7414 to 7425 ft (2259.8 to 2263.1 m) (Fig. 6).

**Mobil No. 67 and 70 Minnie Welder (San Patricio County): Interpretation:** The lower 60% of the Mobil No. 70 Minnie Welder core contains a section of upper-shoreface, forebeach, lagoonal, and vegetated backbarrier and transgressive deposits that collectively extend from the base of the core to ~7405 ft (~2257.0 m) within an interval that is 43 ft (~13 m) thick (Fig. 6). This succession is overlain by a 5 ft (1.5 m) section of mudstone that contains a flooding surface, representing relative sea-level rise and flooding of the barrier/strandplain system. Upper-shoreface deposits in the Mobil No. 70 Minnie Welder core from 7426 to 7448 ft (2263.4 to 2270.2 m) are composed of fine-grained, moderately-burrowed sandstone (bioturbation index 2 to 3) with *Ophiomorpha* and minor *Planolites* (Fig. 7A), whereas overlying forebeach deposits that extend to 7418 ft (2261.0 m) consist of unburrowed, medium-grained sandstone with low-angle, inclined stratification (Fig. 7B). Lagoonal and vegetated backbarrier deposits in the core are part of an overall upward-fining succession that ranges from fine- to medium-grained, sparsely-burrowed sandstone at the base to very fine- to fine-grained sandstone with calcareous nodules (Fig. 7C), root traces, and gray-green, variegated mudstone. These lagoonal and vegetated backbarrier deposits are, in turn, overlain by burrowed, gray mudstone with *Planolites* representing transgressive deposits associated with relative sea-level rise and inundation of the vegetated backbarrier.

The Mobil No. 67 Minnie Welder core is almost entirely composed of sandstone, except for a thin (<1 ft [<0.3 m]) bed of muddy siltstone at 8069.0 ft (2459.4 m) (Fig. 8). The sandy section below this muddy siltstone bed contains multiple, 0.5 to 2.0 ft (0.15 to 0.6 m), well-stratified sandstone beds with strata-bound zones of calcite cement (Fig. 9A). In contrast, the upper sandy section above the thin, silty mudstone is finer grained, ranging from very fine- to fine-grained sandstone in a net upward-coarsening succession (Fig. 8). Stratification in this section is almost entirely absent, and most sandstone beds contain abundant mollusc fragments (Fig. 9B).

The Mobil No. 67 Minnie Welder core is composed of a lower succession of upper-shoreface deposits from 8073 to 8105 ft (2460.1 to 2470.4 m) (Fig. 8). Characteristics of these upper-shoreface deposits include upward-coarsening grain size, abundant *Ophiomorpha*, and bedforms that low-angle, planar stratification where not obscured by burrows. An abrupt increase in grain size from fine- to medium-grained sandstone at 8073 ft (2460.1 m) marks the base of upward-fining transgressive-beach deposits capped by a thin (<1 ft [<0.3 m]) bed of muddy siltstone at 8069.0 ft (2459.4 m). Characteristics of transgressive-beach deposits include an overall upward-fining grain-size profile, erosion surfaces recording wave ravinement, and accessory features

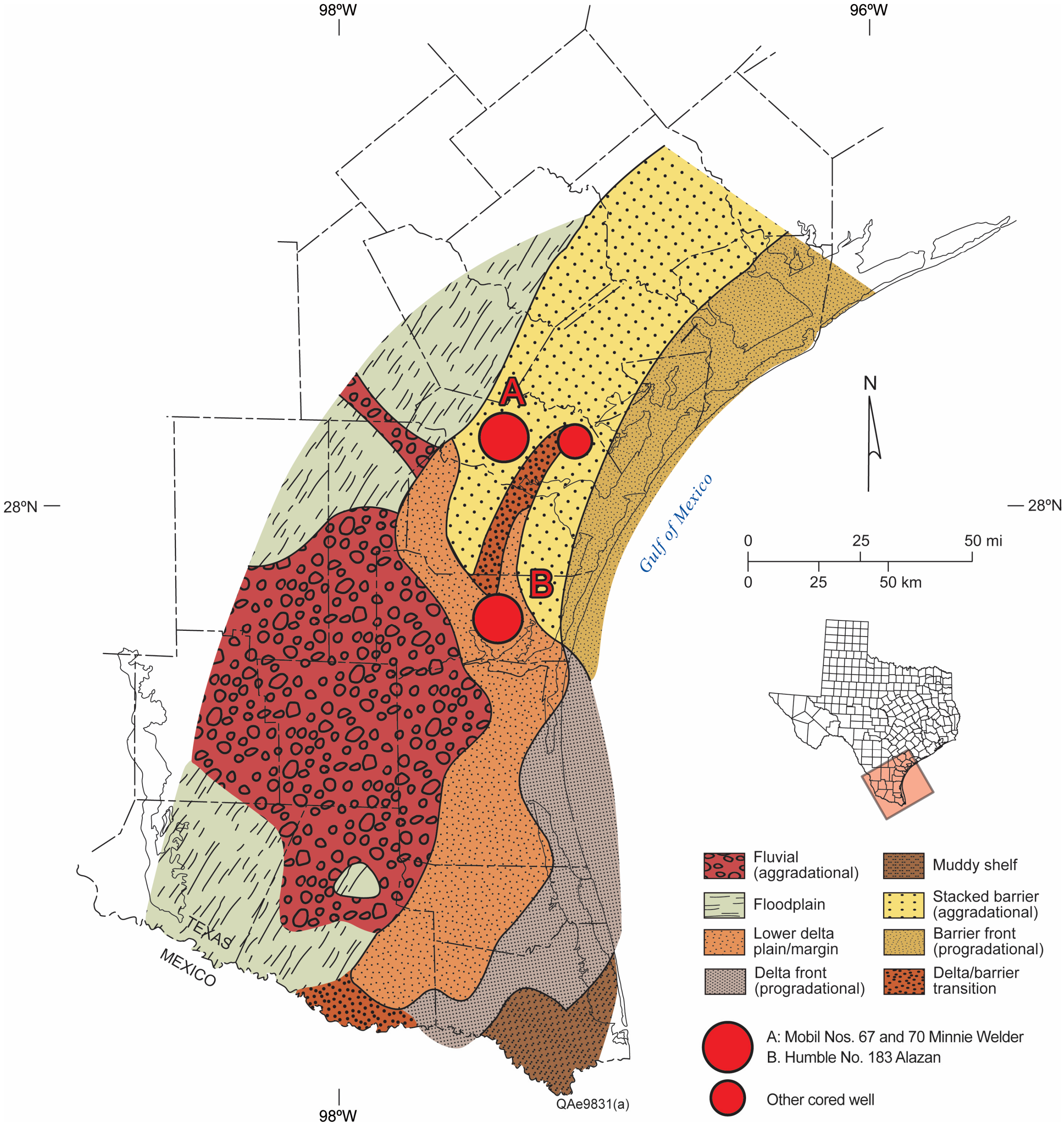



**Figure 2. Paleogeography of the lower Frio Formation in South Texas (modified after Galloway et al. [1982]) with paleogeographic trends in color and core locations in this study. These cores provide additional detail of facies variability in the stacked barrier (aggradational) and lower delta plain/margin paleogeographic trends.**

such as shell debris and plant fragments, the result of beach destruction during periods of relative sea-level rise (Stephens et al., 1976; Ruby, 1981; Hayes and Sexton, 1989). The very fine- to fine-grained, upward-coarsening section in the upper half of the core records a progradational succession of lower-shoreface deposits above a flooding surface at 8069 ft (2459.4 m) (Fig. 8). Characteristics of lower-shoreface deposits include very fine-grained sandstone, in contrast to fine- to medium-grained sandstone in upper-shoreface deposits, and mainly horizontal burrows. Three features that support a lower-shoreface interpretation for these deposits are (1) stratigraphic position above transgressive-beach deposits and the overlying silty mudstone bed representing a flooding surface, (2) fine-grained content relative to upper-shoreface deposits in the lower half of the core, and (3) absence of high-energy bedforms such as plane beds and trough and high-angle cross-stratification common in shoreface

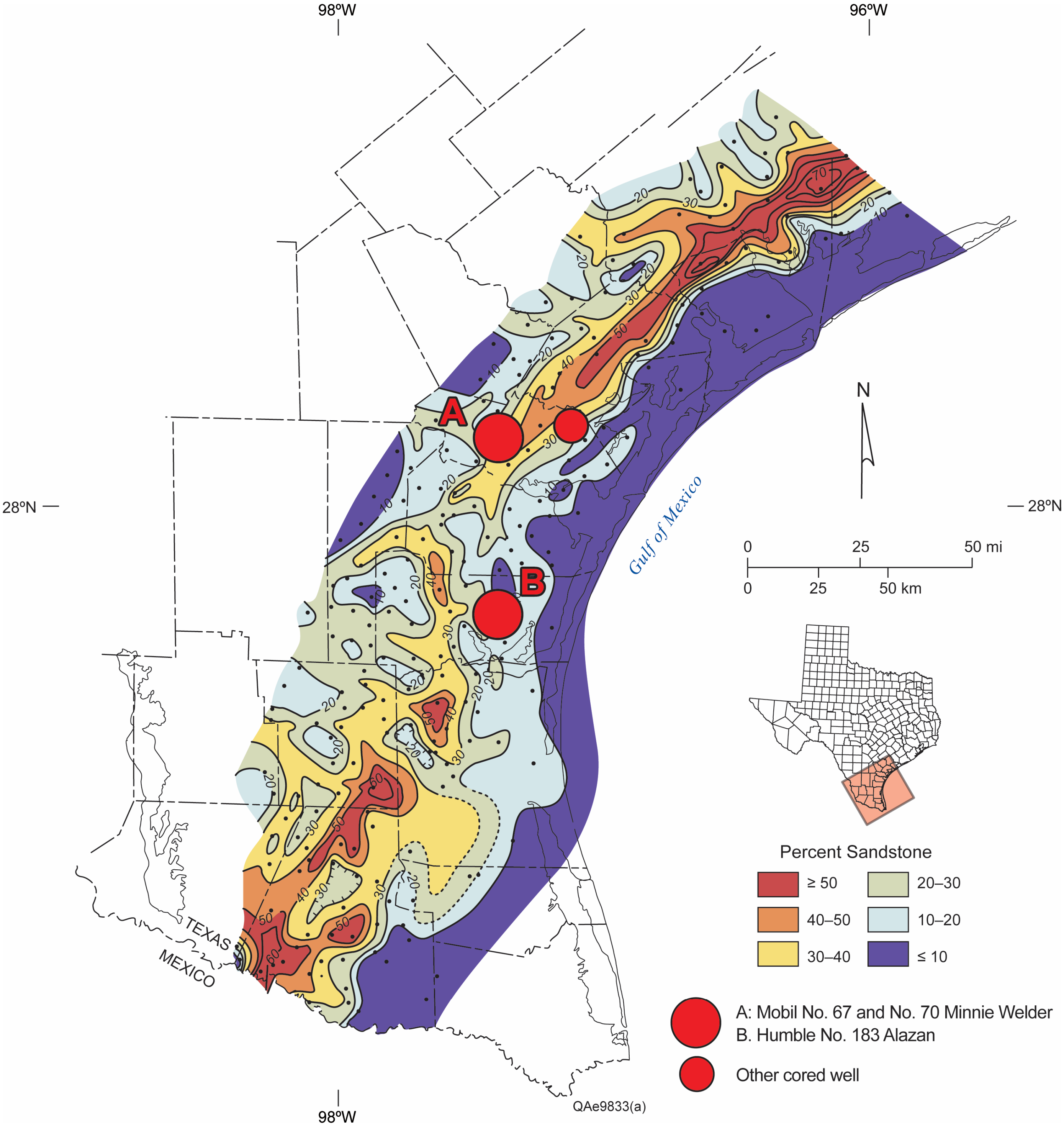



**Figure 3. Percent sandstone in the lower Frio Formation in South Texas (modified after Galloway et al. [1982]) with core locations in this study. These cores provide additional detail of facies variability in the stacked barrier (aggradational) trend (well A) and lower delta plain/margin paleogeographic trend (well B).**

and foreshore settings (Howard and Reineck, 1979; McCubbin, 1982).

## Middle Frio Formation

The middle Frio Formation is interpreted in this study to range in age from ~27.1 to 28.1 Ma, based on it being approximately equivalent to the middle one-third of the Catahoula Group (Brown and Loucks, 2009). Three cores in the middle Frio represent fluvial and muddy floodplain deposits, based on Galloway et al. (1982), Jirik (1990), Kerr (1990), Kerr and Jirik (1990), and Ambrose et al. (1992). Cores presented in this study are from the (1) Restech/SUN No. 141 Canales, (2) SUN No. 16–125 Seeligson, and (3) Union Pacific No. 36 Elliff wells (Figs. 10 and 11).

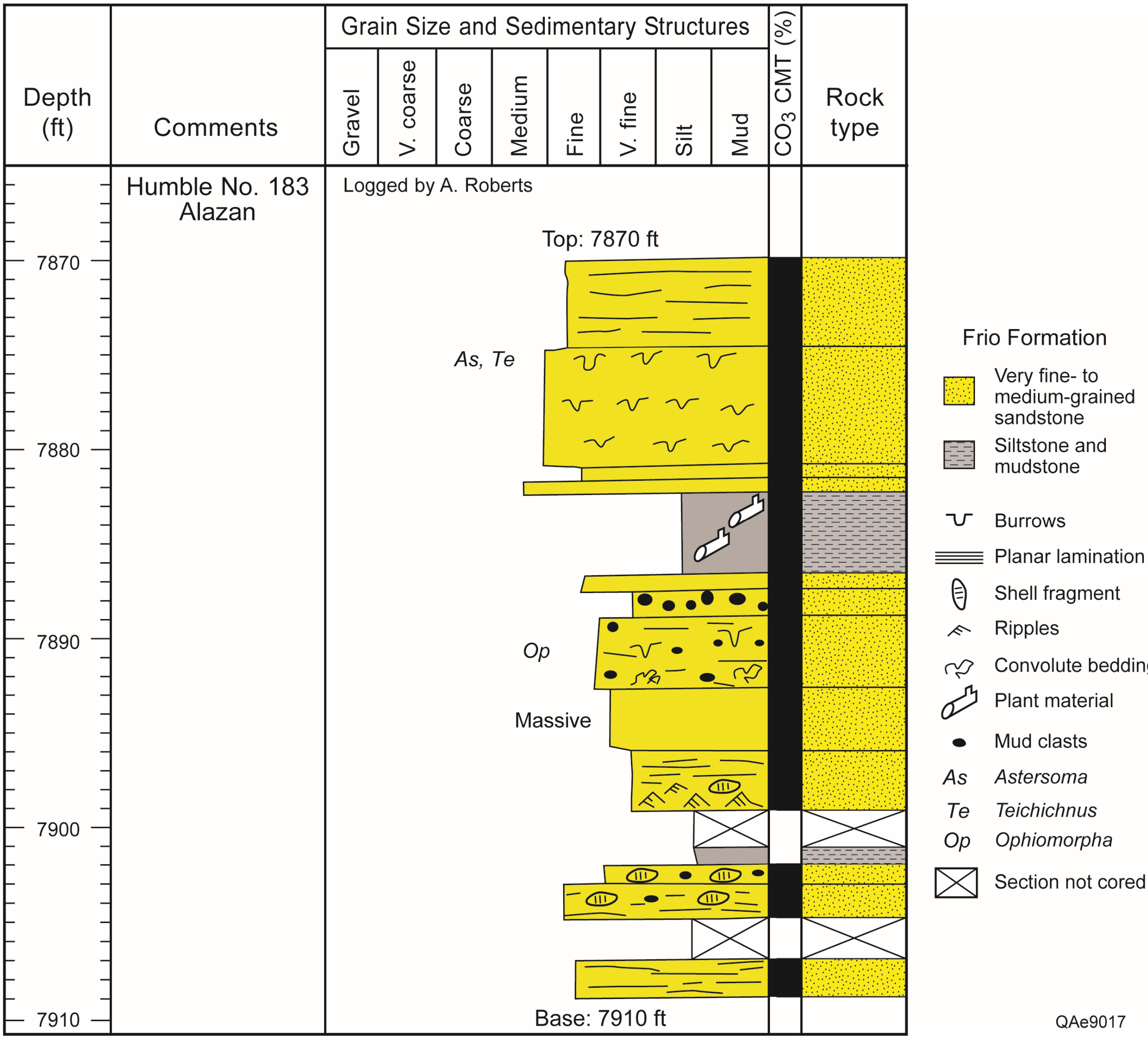



**Figure 4. Core description of deltaic deposits in the lower Frio Formation in the Humble No. 183 Alazan well in Kleberg County. Medial-delta-front deposits, ranging in depth from 7882 to 7910 ft (2403.0 to 2411.6 m), are a heterogenous succession of mudstone beds and very fine- to fine-grained grained sandstone beds. In contrast, mudstone beds are absent in overlying proximal-delta-front deposits that consist of fine- to medium-grained sandstone beds. Core photographs are shown in Figure 5. Location of well is shown in Figures 2 and 3.**

### Fluvial (Aggradational) Paleogeographic Trend

**Restech/SUN No. 141 Canales and SUN No. 16–125 Seeligson (Jim Wells County):** Description: The Restech/Sun No. 141 Canales and SUN No. 16–125 Seeligson cores in Seeligson Field are located on the northeastern margin of a major, sandy fluvial depositional axis in the middle Frio fluvial (aggradational) paleogeographic trend (Figs. 10 and 11). The Restech/SUN No. 141 Canales core is composed of a lower, 10 ft (3 m) section of silty mudstone and thin (≤1 ft [≤0.3 m]) beds of very fine-grained sandstone with dark-gray, in situ clay nodules (Figs. 12 and 13A). The overlying interval consists of multiple erosion-based beds of fine- to medium-grained sandstone with abundant mudstone rip-up clasts (Figs. 12 and 13B). Individual beds range in thickness from 0.5 to 2.0 ft (0.15 to 0.6 m). Stratification in this sandy section includes low-angle plane beds with 2 to 4 in (5.1 to 10.2 cm) zones of climbing ripple cross-stratification (Fig. 13C).

The SUN No. 16–125 Seeligson core is composed of a 20 ft (6 m) section of fine- to medium-grained sandstone underlain and overlain by variegated mudstones with a variety of pedogenic features that include nodules and root traces (Figs. 14 and 15). These pedogenic features have a variety of colors that include gray-green, brownish-red (Fig. 15B), and tan/white (Fig. 15C). Features diagnostic of paleosols include nodules, root traces, sediment coloration such as brown, yellowish-brown, green, and greenish-gray that correspond to different states of oxidation and reduction of iron, and mineralogical changes that include the formation of clays, argillaceous matrix, and cement, which in the SUN No. 16–125 Seeligson core are dominated by calcite ce-

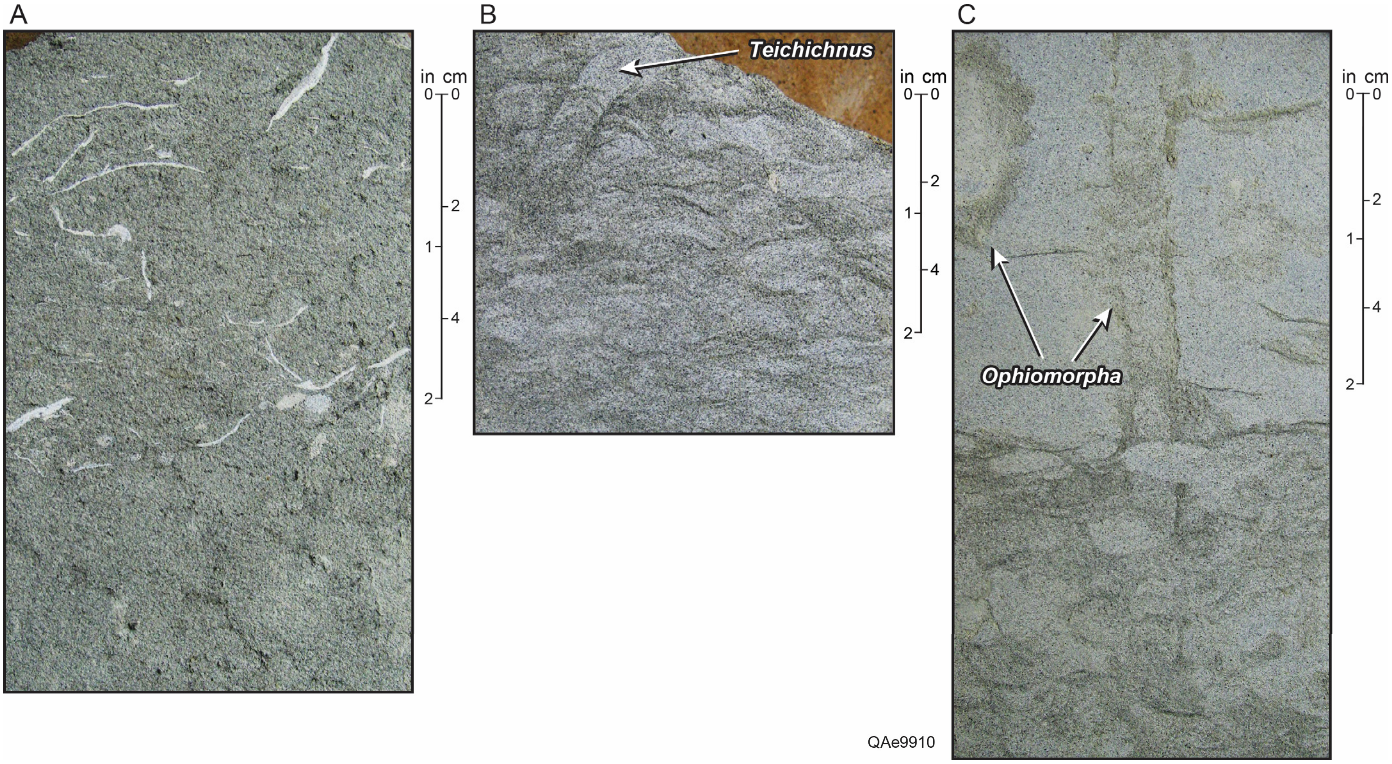



**Figure 5. Core photographs of deltaic deposits in the lower Frio Formation in the Humble No. 183 Alazan well in Kleberg County. (A) Fine-grained, shelly and burrowed sandstone in medial-delta-front facies at 7904.5 ft (2409.3 m). (B) Upper-fine-grained sandstone with *Teichichnus* in proximal-delta-front facies at 7879.4 ft (2401.6 m). (C) Upper-fine-grained sandstone with prominent *Ophiomorpha* in proximal-delta-front facies at 7875.6 ft (2400.5 m). Core description is shown in Figure 4. Location of well is shown in Figures 2 and 3.**

ment. These diagnostic features for paleosols, e.g., Retallack (1991), Kraus (1999), and Hasiotis and Platt (2012), are comparable to those observed in the middle Frio Formation in Seeligson Field, of which the most salient are clay nodules and zones of sediment coloration, summarized in columns on the right side of the core description (Fig. 14).

**Restech/SUN No. 141 Canales and SUN No. 16–125 Seeligson (Jim Wells County): Interpretation:** The Restech/Sun No. 141 Canales and SUN No. 16–125 Seeligson cores record fluvial channel-fill and muddy-floodplain facies with paleosols. Seeligson Field is located in the updip, fluvial part of the Norias delta system, interpreted initially to consist of coarse-grained bedload deposits within low-sinuosity channel-fill complexes having great width-to-depth ratios in excess of 40:1 (Galloway, 1981). Later studies, using 3D seismic data and closely spaced wireline logs, demonstrated that fluvial systems in the Seeligson Field are instead composed of sinuous, coarse-grained meander-belt deposits with small to moderate width-to-depth ratios (Jirik,1990; Kerr and Jirik, 1990; Ambrose et al., 1992). Channel-fill facies in Seeligson Field and nearby Stratton and Agua Dulce fields in Nueces County are inferred to range in thickness from 10 to 30 ft (3 to 9 m) and are flanked by thinner, widespread crevasse-splay facies and floodplain mudstone and siltstone beds. These channel-fill facies are ~2500 ft (~762 m) wide, but where they coalesce, their combined width is >1 mi (>1.6 km) (Kerr, 1990; Kerr and Jirik, 1990).

### Floodplain Paleogeographic Trend

The floodplain paleogeographic trend, defined in Galloway et al. (1982), is an extensive, mudstone-dominated area northeast of the fluvial (aggradational) paleogeographic trend (Figs. 10 and 11). It commonly contains less than 20% sandstone (Fig. 12).

**Union Pacific No. 36 Elliff (Nueces County): Description:** The Union No. 36 Elliff core is located in the floodplain paleogeographic trend in the middle Frio Formation, where sandstone-percent values are ~10% (Figs. 10 and 11). However, a 75 ft (23 m) section of core from the Union No. 36 Elliff well is composed of >80% sandstone (Fig. 16). Two sandy sections are included in this 95 ft (29 m) core. The lower sandy section from 5725 to 5755 ft (1745.0 to 1754.1 m) is composed of very fine- to fine-grained sandstone with clay nodules and root traces. In contrast, the upper sandy section from 5680 to 5725 ft (1731.3 to 1745.0 m) is composed of fine- to medium-grained sandstone beds with multiple erosional surfaces and zones of mudstone rip-up clasts (Figs. 16, 17A, and 17B). Architectural elements in the upper sandy section are defined by erosion-based, upward-fining sandstone beds that individually range in thickness from 1 to 5 ft (0.3 to 1.5 m).

**Union Pacific No. 36 Elliff (Nueces County): Interpretation:** The lower, sandy section is composed of splay and splay-channel deposits, whereas the overlying, relatively coarser-grained, sandy section records multistoried, fluvial-channel deposits (Fig. 16). Features consistent with a fluvial-channel interpretation include a succession of scour-based sandstone beds that collectively have an upward-fining vertical grain-size profile (Fig. 16, a transition in bedforms from crossbedding to ripples (Figs. 16 and 17A), and multiple scour surfaces overlain by clay rip-up clasts (Fig. 17B). The lower- and middle-channel fill is capped by a fine-grained section of silty mudstone representing abandoned-channel-fill deposits (Fig. 17C).

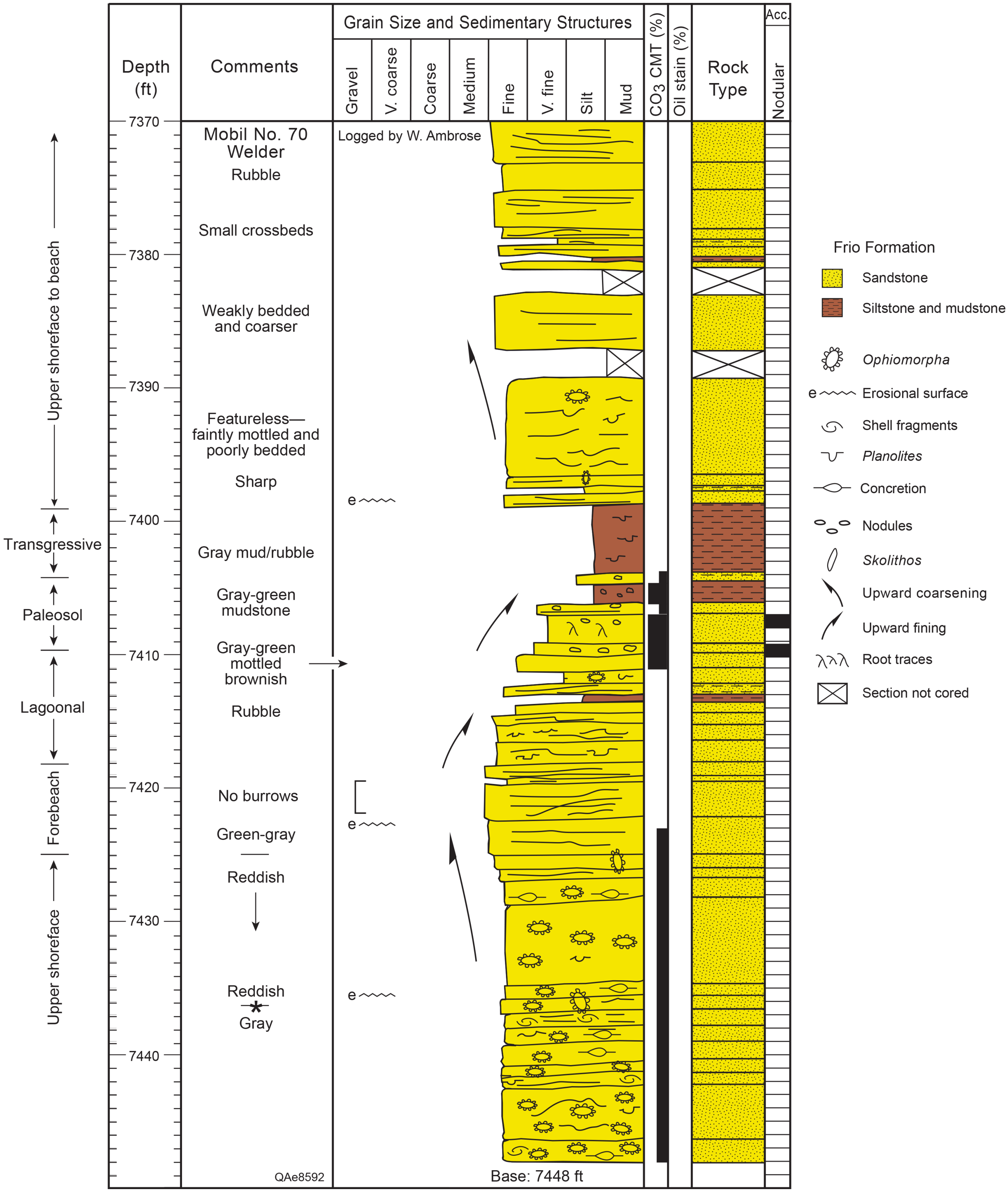



**Figure 6. Core description of a 78 ft (23.8 m) section in the lower Frio Formation in the Mobil No. 70 Minnie Welder well in San Patricio County. The lower 60% of the core from ~7400 to 7448 ft (~2256 to 2270.7 m) is a facies succession composed of shoreface, foreshore, lagoonal, paleosol, and transgressive-marine deposits. The upper 40% of the core is an upward-coarsening succession of shoreface and beach deposits abruptly overlying an 8 ft (2.4 m) section of mudstone beds. Core photographs are shown in Figure 7. Location of well is shown in Figures 2 and 3.**

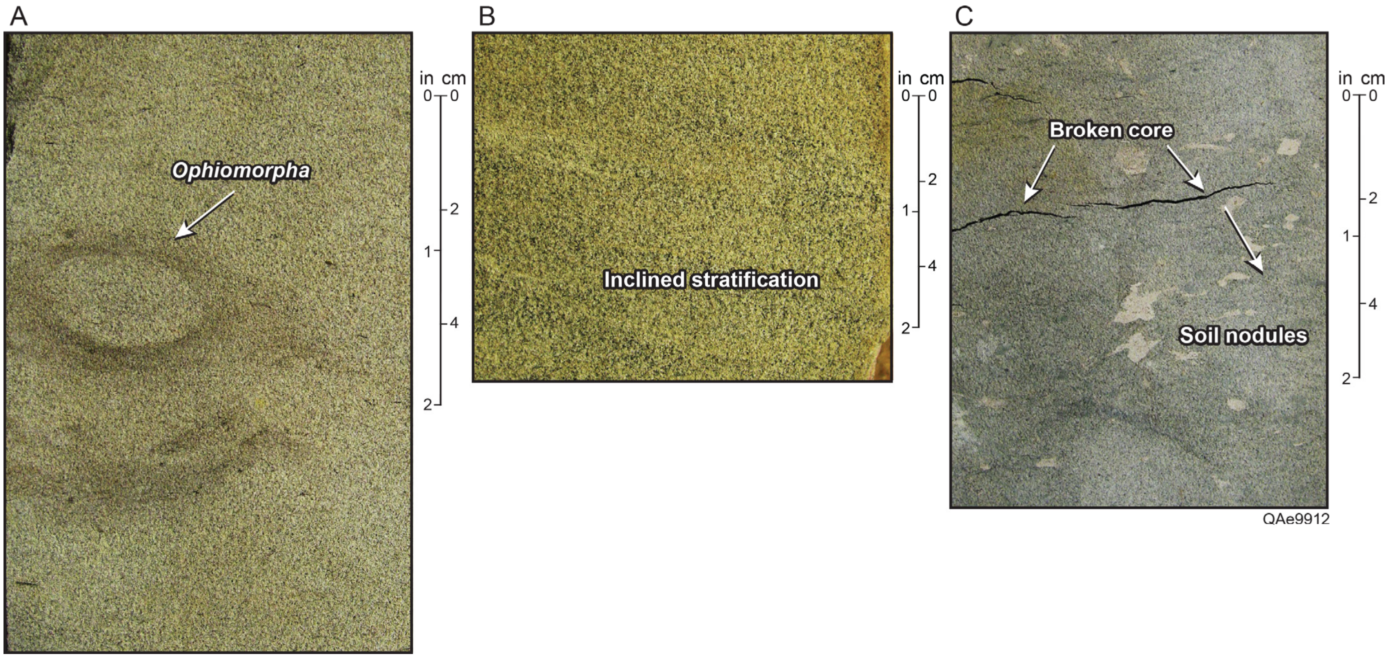



**Figure 7. Core photographs of upper-shoreface, forebeach, and paleosol deposits in the lower Frio Formation in the Mobil No. 70 Minnie Welder well in San Patricio County. (A) Fine-grained sandstone with *Ophiomorpha* in upper-shoreface facies at 7433.7 ft (2265.8 m). (B) Lower-medium-grained sandstone with faint, inclined-planar stratification in forebeach facies at 7422.1 ft (2262.3 m). (C) Very fine-grained sandstone with calcareous soil nodules in paleosol facies at 7407.0 ft (2257.7 m). Core description is shown in Figure 6. Location of well is shown in Figures 2 and 3.**

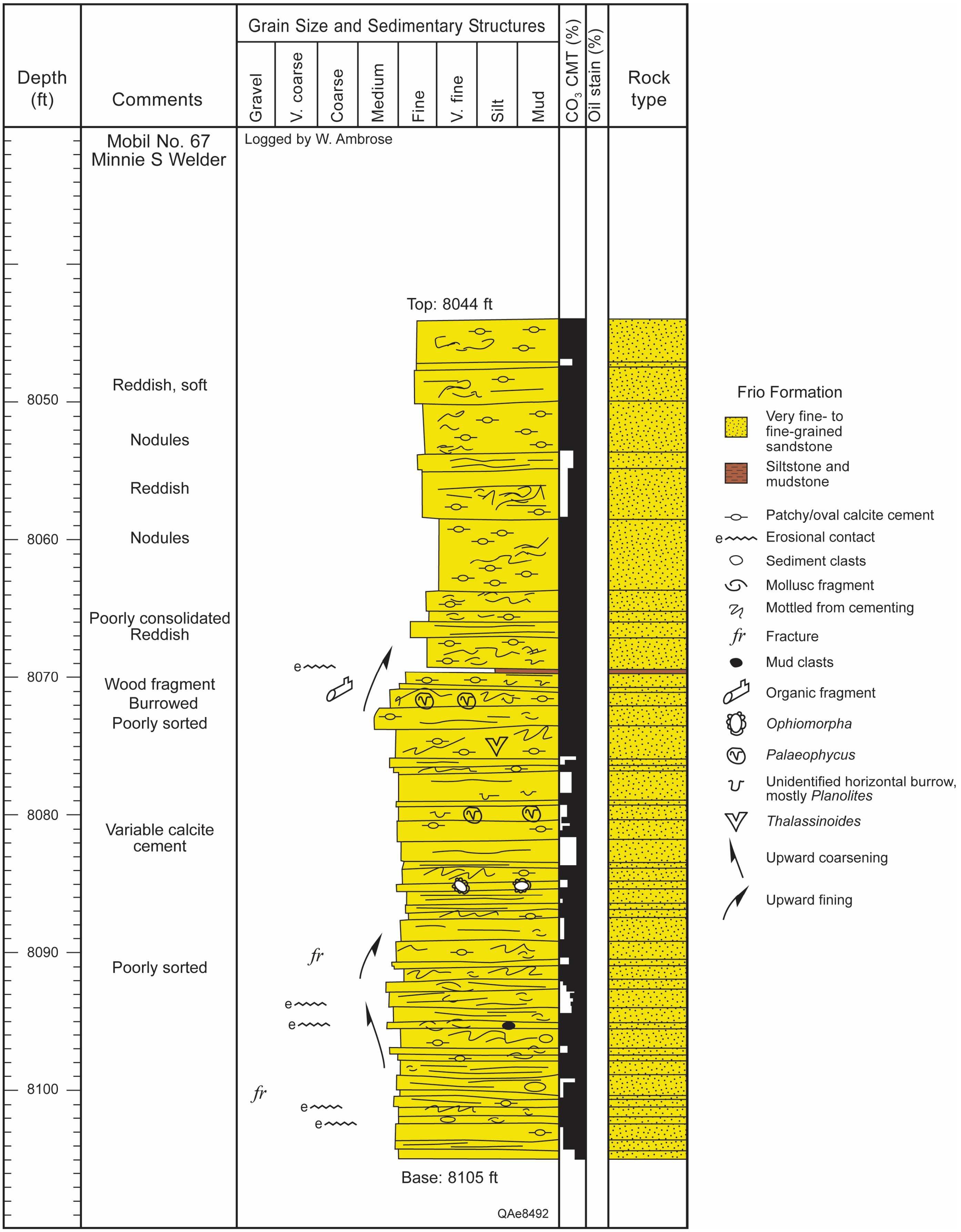
## DISCUSSION

Interpretations from core data presented in this study, with minor exceptions, validate the regional distribution of lower and middle Frio paleogeographic trends in South Texas as depicted in Galloway et al., 1982). This study documents lithology and facies types in lower and middle Frio paleogeographic trends and aids in differentiating axial versus marginal areas in these trends (Figs. 2 and 3). It also demonstrates that paleogeographic trends interpreted in the Galloway et al. (1982) study are a composite of multiple depositional episodes and that facies types vary considerably within these paleogeographic trends (Figs. 4 and 6). This study shows that sandstone-body architecture and styles of deposition in some paleogeographic trends are more complex than inferred in the Galloway et al. (1982) study (Figs. 14 and 16). For example, the middle Frio fluvial (aggradational) paleogeographic trend, based on channel-fill characteristics in cores in this study, as well as 3D seismic data from other studies (e.g., Ambrose et al. [1992]), and net-sandstone maps from closely-spaced wireline logs (Kerr and Jirik, 1990) are interpreted to be mixed load, meander belt in origin rather than sandy, bedload systems.

As the lower and middle units of the Frio Formation are each as much as 2000 ft (610 m) thick in South Texas, they are composed of multiple transgressive-regressive (T–R) depositional cycles (Galloway et al., 1982). Individual T–R cycles in the lower Frio Formation are commonly <200 ft (<61 m) thick. Upper parts of these cycles, typically only 40 to 50 ft (12 to 15 m) thick, are composed of several distinct facies that include upper-shoreface, forebeach, and transgressive-beach deposits (Fig. 6). The lower Frio stratigraphic succession is punctuated by numerous, thin (5 to 20 ft [1.5 to 4 m]), muddy intervals that contain flooding surfaces that record coastal inundation and periods of relative sea-level rise. Consequently, a paleogeographic map of the entire lower Frio Formation depicts an average, overall position of the paleoshoreline in South Texas, whereas cores provide a higher-resolution record of shoreline positions and coastal facies variability within different T–R cycles. Moreover, many flooding surfaces in the lower Frio stratigraphic succession occur within laterally extensive mudstone intervals that serve as reservoir seals that cannot be depicted in paleogeographic maps that encompass thick (~2000 ft [~610 m]) intervals composed of multiple depositional units. For example, the 8 ft (2.4 m) mudstone in the middle part of the Mobil No. 70 Minnie Welder core (Fig. 6), defines the top of the 7400 ft (2255 m) reservoir in Portilla Field in San Patricio County (location denoted by letter "A" in Figs. 2 and 3). A paleogeographic map of the stratigraphic interval bounding the 7400 ft (2255 m) reservoir would depict a higher-resolution of the lower Frio paleoshoreline and associated barrier/strandplain facies than one encompassing the entire lower Frio Formation.

The vertical facies succession interpreted in cores in the middle Frio Formation, in conjunction with wireline-log and 3D seismic data from other studies (Kerr [1990] and Ambrose et al. [1992], demonstrate that the middle Frio fluvial (aggradational) paleogeographic trend is mixed load, meanderbelt in origin rather than bedload systems as suggested from net-sandstone maps in the Galloway et al. (1982) study. Although locally thick ~40 ft (~12 m]), multistoried successions of sandstone occur in some middle Frio fluvial-channel deposits (Fig. 16), the fine- to medium-grain size and absence of coarse-grained sandstone, net upward-fining grain-size profiles, the absence of large-scale bedforms such as tabular crossbeds, and the presence of mudstones with pedogenic fabrics associated with stable floodplains suggest a mixed-load system in which mud was a significant component.

Conversely, core data also show that sandstone-rich fluvial-channel systems locally occur within mudstone-dominated areas in the middle Frio paleogeographic trend, away from sandy depositional axes. Sandy and thick (~40 ft [~12 m]) fluvial channel-fill deposits in the Union Pacific No. 36 Elliff core occur in areas with <10% sandstone in the undivided middle Frio stratigraphic succession (Fig. 11). Net- and percent-sandstone maps that en-



Depth (ft)
Comments
Grain Size and Sedimentary Structures
Gravel
V. coarse
Coarse
Medium
Fine
V. fine
Silt
Mud
CO3 CMT (%)
Oil stain (%)
Rock type
Mobil No. 67
Minnie S Welder
Logged by W. Ambrose
Top: 8044 ft
Reddish, soft
8050
Nodules
Reddish
8060
Nodules
Poorly consolidated
Reddish
8070
Wood fragment
Burrowed
Poorly sorted
8080
Variable calcite cement
8090
Poorly sorted
8100
Base: 8105 ft
QAe8492
Frio Formation
Very fine- to fine-grained sandstone
Siltstone and mudstone
Patchy/oval calcite cement
Erosional contact
Sediment clasts
Mollusc fragment
Mottled from cementing
Fracture
Mud clasts
Organic fragment
Ophiomorpha
Palaeophycus
Unidentified horizontal burrow, mostly Planolites
Thalassinoides
Upward coarsening
Upward fining

**(FACING PAGE) Figure 8. Core description of a 61 ft (18.6 m) section in the lower Frio Formation in the Mobil No. 67 Minnie Welder well in San Patricio County. Upper-shoreface deposits in the lower part of the core are overlain at 8073 ft (2461.3 m) by a 4 ft (1.2 m), upward-fining section of transgressive-beach deposits, in turn overlain by an upward-coarsening section of lower-shoreface deposits. Core photographs are shown in Figure 9. Location of well is shown in Figures 2 and 3.**

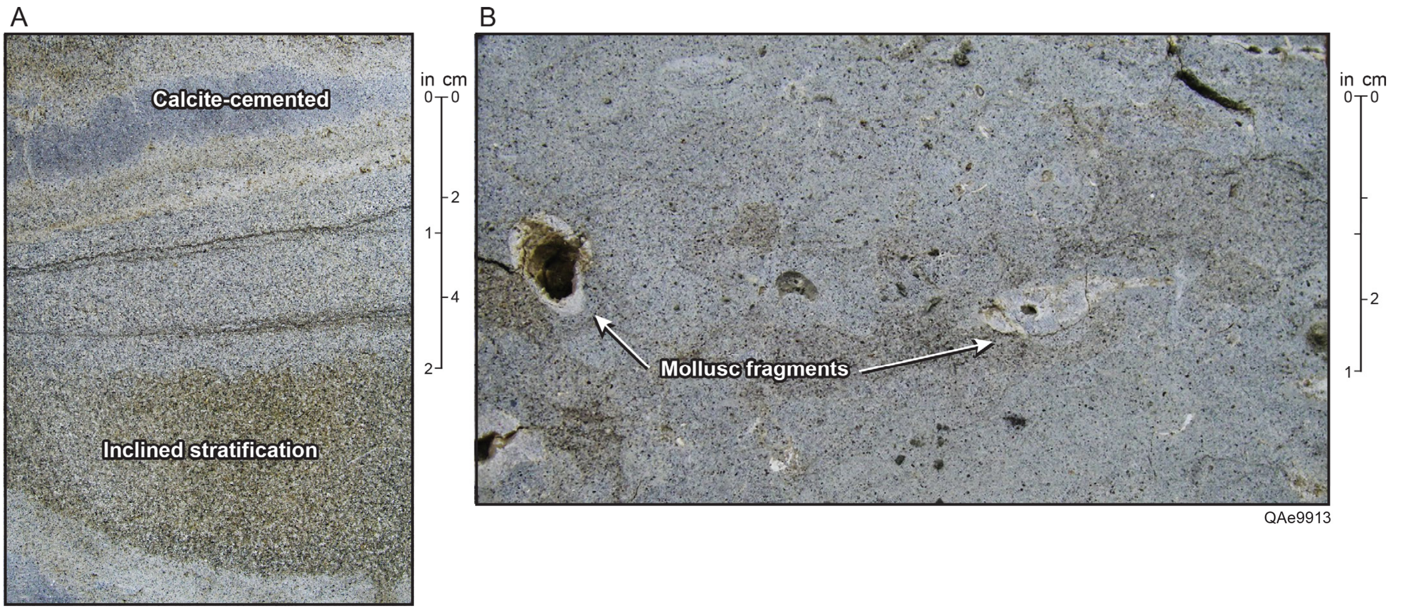



**Figure 9. Core photographs of upper-shoreface and transgressive-beach deposits in the lower Frio Formation in the Mobil No. 67 Minnie Welder well in San Patricio County. (A) Fine- to medium-grained sandstone with inclined stratification and variably calcite-cemented zones in upper-shoreface facies at 8097.7 ft (2468.2 m). (B) Fine-grained sandstone with mollusc fragments in transgressive-beach facies at 8068.1 ft (2459.2 m). Core description is shown in Figure 8. Location of well is shown in Figures 2 and 3.**

compass thinner stratigraphic intervals at the level represented by the cored section in the Union Pacific No. 36 Elliff well would result in a higher-resolution depiction of fluvial systems in the widespread floodplain paleogeographic trend, as well as other paleogeographic trends in South Texas.

## CONCLUSIONS

This core-based study of the lower and middle Frio Formation in South Texas, an extension of an earlier study by Galloway et al. (1982), has four (4) main results:

(1) With minor exceptions, it validates and refines interpretations of the regional distribution of lower and middle Frio paleogeography in South Texas in the Galloway et al. (1982) study.

(2) It documents details of lithology and facies types in lower and middle Frio paleogeographic trends, discriminating between axial versus marginal areas in these trends.

(3) It demonstrates that paleogeographic trends interpreted in the Galloway et al. (1982) study are a composite of multiple depositional episodes (T–R cycles). Core data demonstrate that facies types vary considerably in these paleogeographic trends. In addition, these cores aid in identifying individual T–R cycles capped by muddy flooding surfaces that serve as seals for reservoir units that cannot be accurately depicted on paleogeographic maps of thick (~2000 ft [~610 m]) intervals that are a composite of multiple T–R cycles.

(4) In conjunction with other studies such as Kerr (1990) and Ambrose et al. (1992), it constrains interpretations on scales and of styles of depositional systems, as for example the middle Frio fluvial (aggradational) paleogeographic trend, where fluvial systems, based on channel-fill characteristics in core and morphology from 3D seismic data and net-sandstone maps from closely-spaced wireline logs are interpreted to be mixed load, meanderbelt in origin rather than bedload systems as previously interpreted. In addition, core data in this study show that sandstone-rich fluvial-channel systems locally occur with the middle Frio paleogeographic trend, even within areas previously mapped as having <10% sandstone.

## ACKNOWLEDGMENTS

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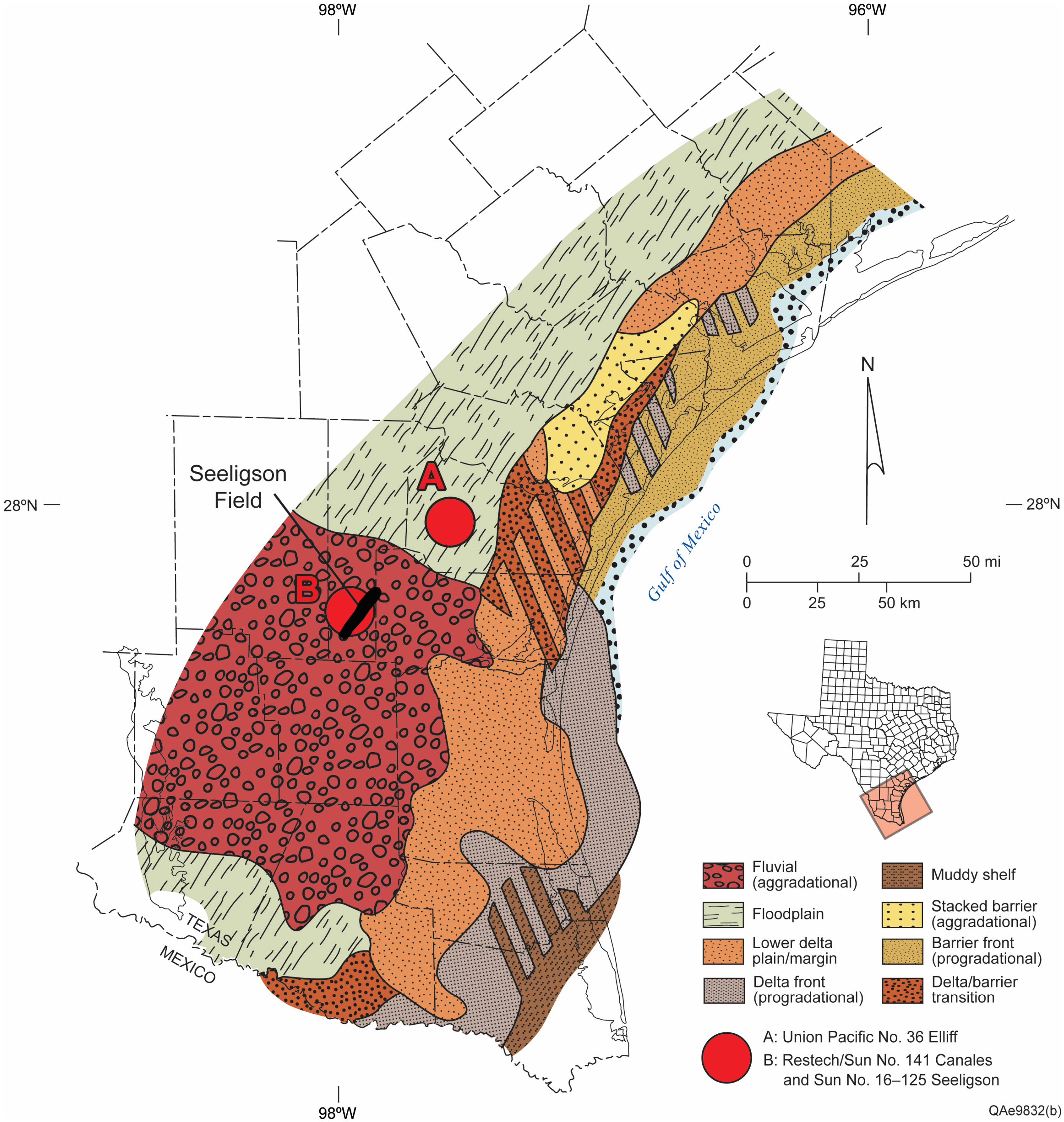


**Figure 10. Paleogeography of the middle Frio Formation in South Texas (modified after Galloway et al. [1982]) with paleogeographic trends in color and core locations in this study. These cores provide additional detail of facies variability in floodplain and fluvial (aggradational) paleogeographic trends.**

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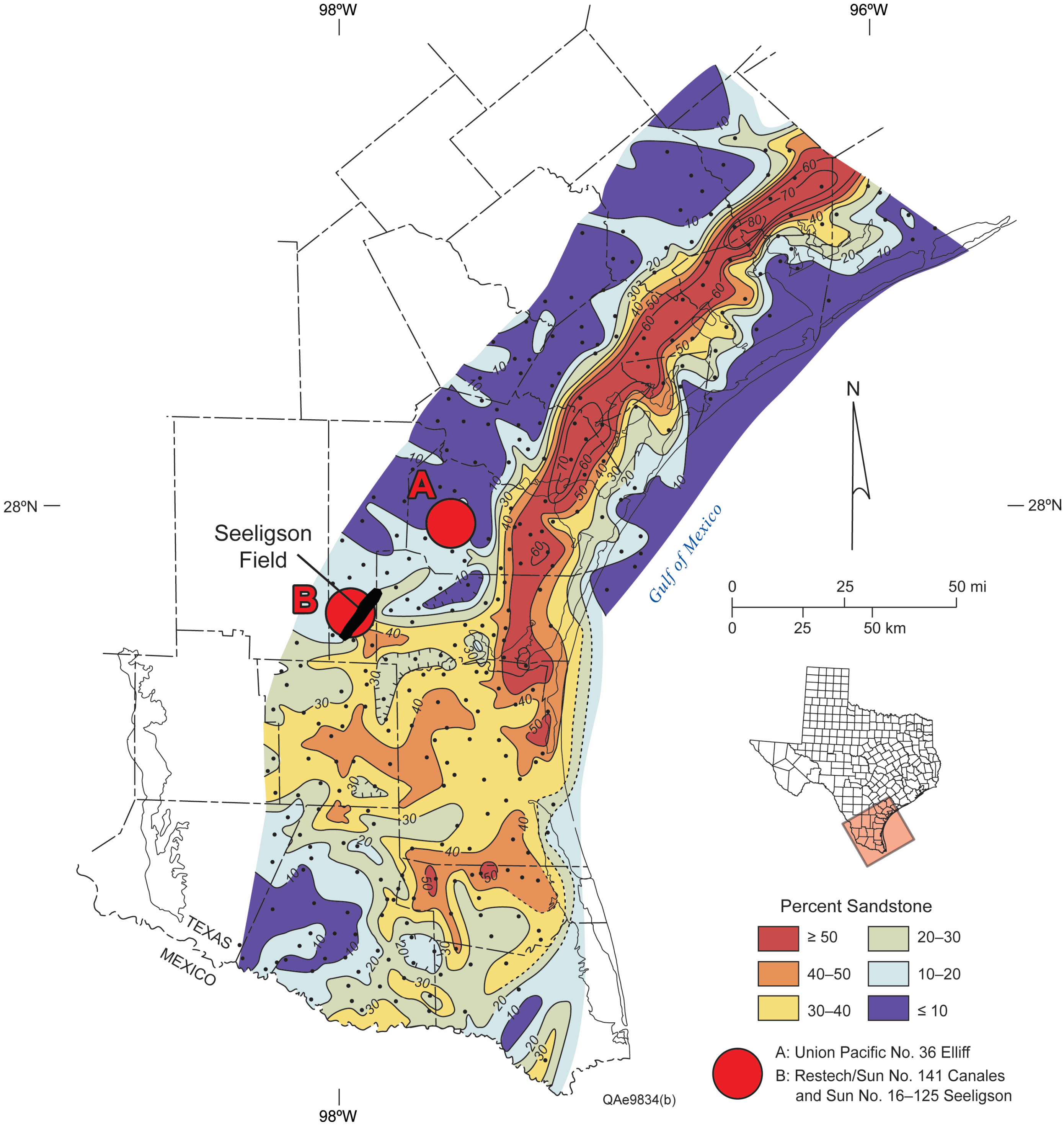


**Figure 11. Percent sandstone in the middle Frio Formation in South Texas (modified after Galloway et al. [1982]) with paleogeographic trends in color and core locations in this study. These cores provide additional detail of facies variability in floodplain and fluvial (aggradational) paleogeographic trends (wells A and B, respectively).**


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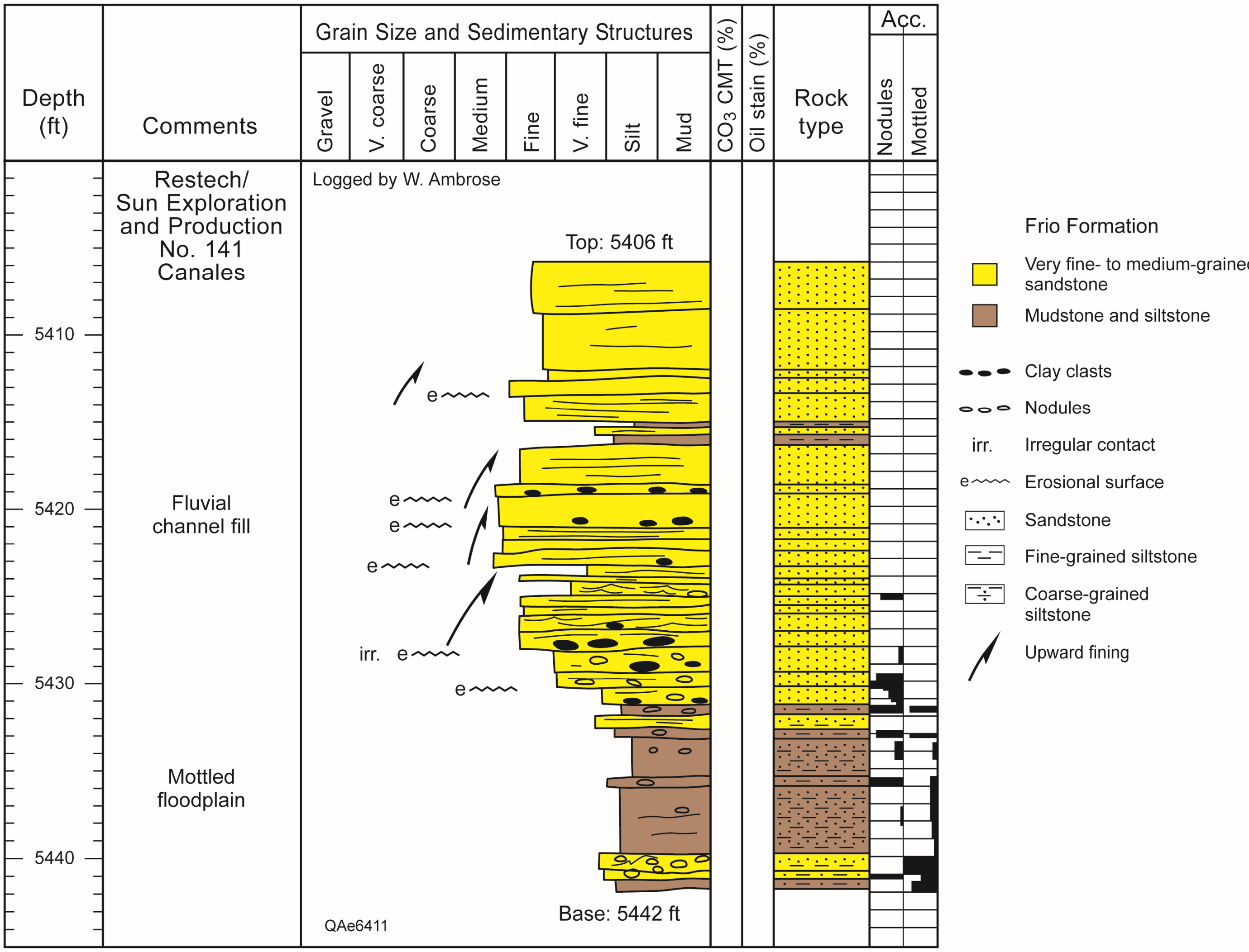


**Figure 12. Core description of floodplain and fluvial channel-fill deposits in the middle Frio Formation in the Restech/Sun Exploration No. 141 Canales well in Jim Wells County. Floodplain deposits extend from 5432 to 5442 ft (1656.1 to 1659.1 m) and are composed of mottled siltstone and mudstone beds. They are overlain by fluvial channel-fill deposits consisting of very fine- to medium-grained sandstone beds. Individual sandstone beds in the channel-fill succession range in thickness from 1 to 4 ft (0.3 to 1.2 m). Many of these sandstone beds are erosion-based and upward-fining. Core photographs are shown in Figure 13. Location of well is shown in Figures 10 and 11.**


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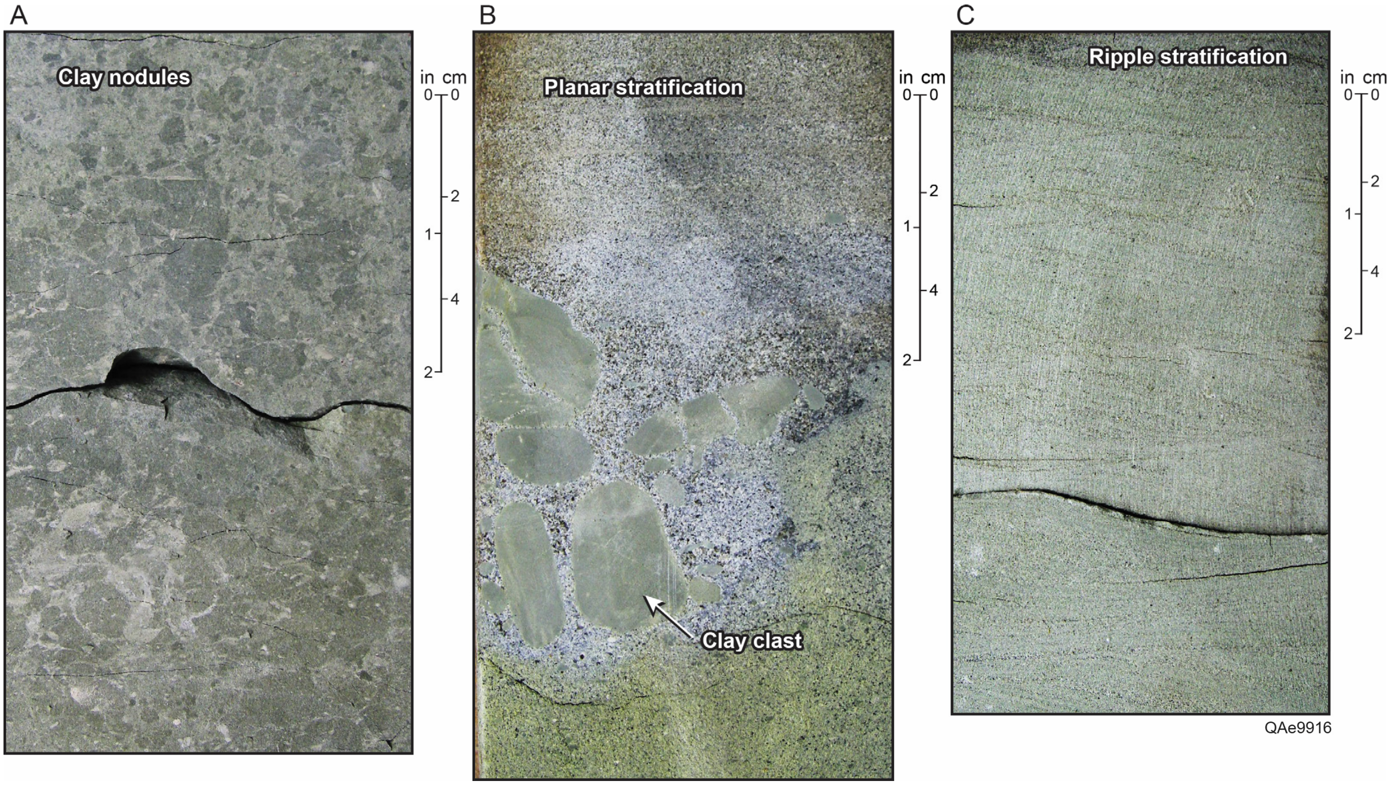


**Figure 13. Core photographs of floodplain and fluvial channel-fill deposits in the middle Frio Formation in the Restech/Sun Exploration No. 141 Canales well in Jim Wells County. (A) Muddy siltstone with in situ clay soil nodules in paleosol (floodplain facies) at 5441.0 ft (1658.8 m). (B) Fine- to medium-grained sandstone with transported mudstone clasts in basal fluvial-channel facies at 5427.5 ft (1654.7 m). (C) Very fine-grained sandstone with climbing-ripple stratification in fluvial-channel facies. Core description is shown in Figure 12. Location of well is shown in Figures 10 and 11.**

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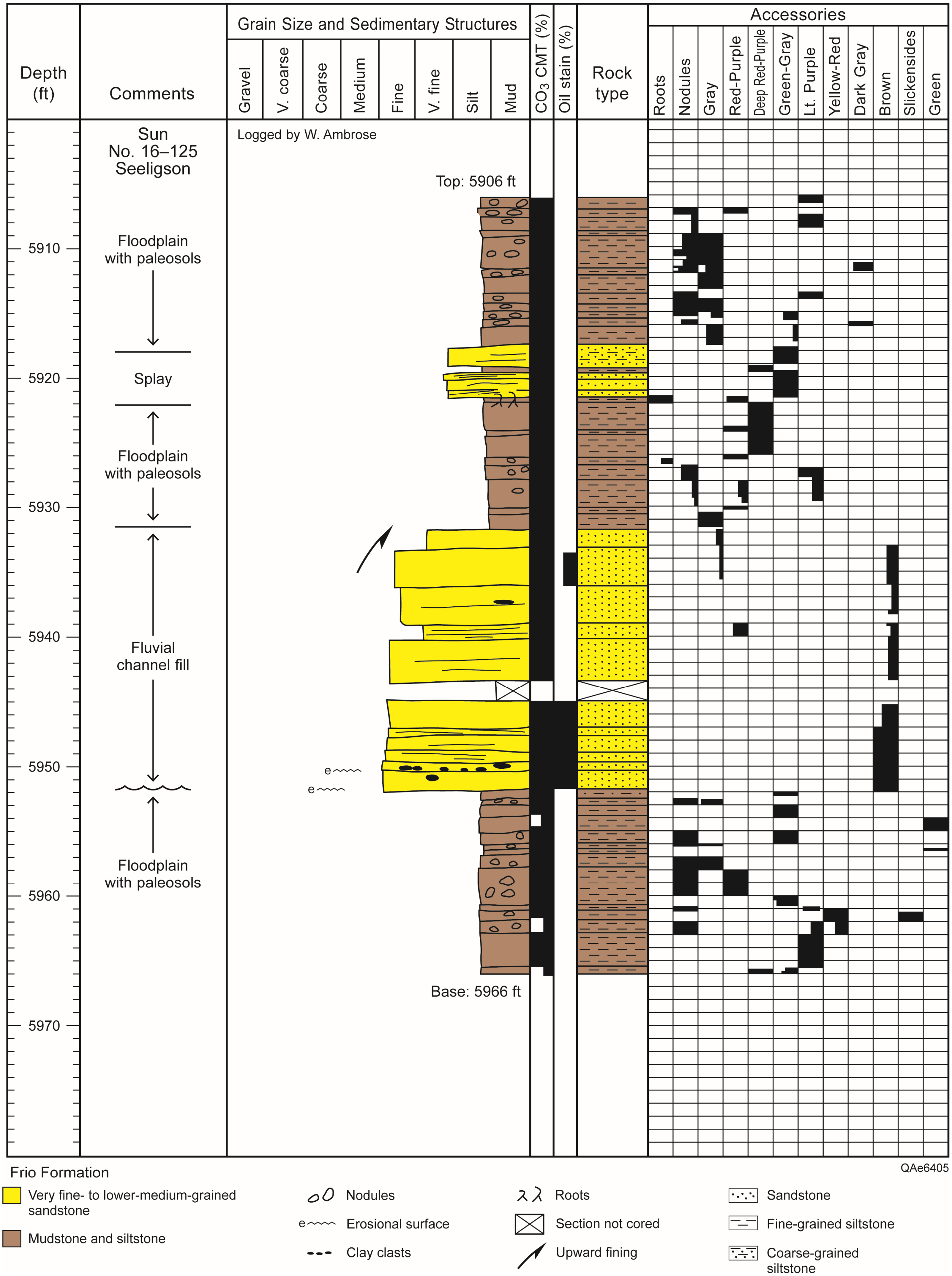

Depth (ft)
Comments
Grain Size and Sedimentary Structures
Gravel
V. coarse
Coarse
Medium
Fine
V. fine
Silt
Mud
$CO_3$ CMT (%)
Oil stain (%)
Rock type
Accessories
Roots
Nodules
Gray
Red-Purple
Deep Red-Purple
Green-Gray
Lt. Purple
Yellow-Red
Dark Gray
Brown
Slickensides
Green
Sun
No. 16–125
Seeligson
Logged by W. Ambrose
Top: 5906 ft
Base: 5966 ft
5910
5920
5930
5940
5950
5960
5970
Floodplain with paleosols
Splay
Floodplain with paleosols
Fluvial channel fill
Floodplain with paleosols
Frio Formation
QAe6405
Very fine- to lower-medium-grained sandstone
Mudstone and siltstone
Nodules
Erosional surface
Clay clasts
Roots
Section not cored
Upward fining
Sandstone
Fine-grained siltstone
Coarse-grained siltstone

**(FACING PAGE) Figure 14. Core description of floodplain, fluvial channel-fill, and crevasse-splay deposits in the middle Frio Formation in the Sun No. 16–125 Seeligson well in Jim Wells County. Floodplain deposits are composed of muddy siltstone beds with abundant paleosols characterized by variable colors, nodules, and root traces. Fluvial channel-fill deposits consist of Fine- to medium-grained sandstone beds in a net upward-fining section. Splay deposits occur in a 4 ft (1.2 m) section in the upper part of the core and are composed of very fine-grained sandstone beds above a zone with root traces at 5922 ft (1805 m). Core photographs are shown in Figure 15. Location of well is shown in Figures 10 and 11.**

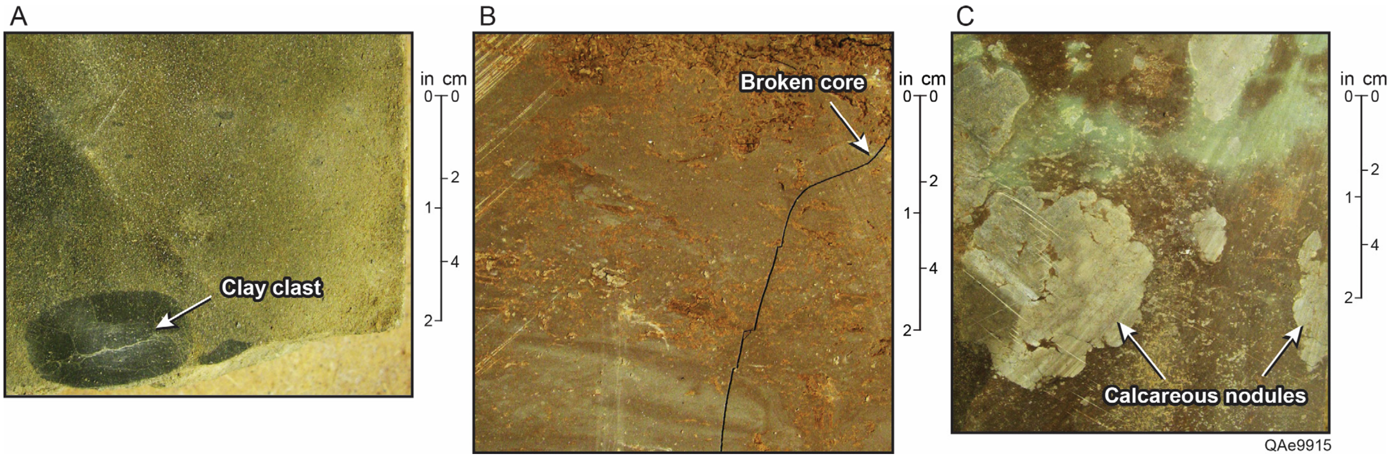
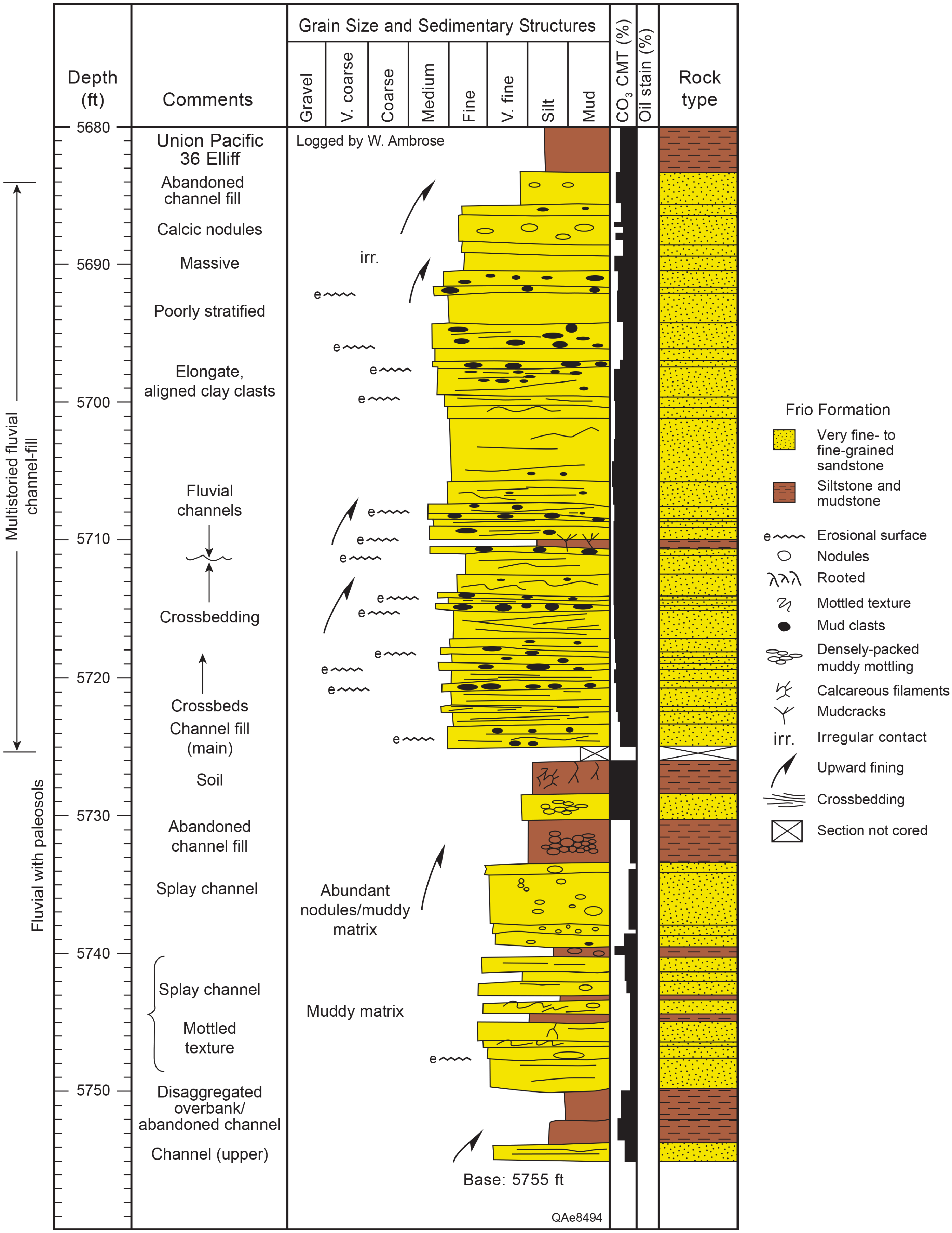



**Figure 15. Core photographs of floodplain and fluvial channel-fill deposits in the middle Frio Formation in the Sun No. 16–125 Seeligson well in Jim Wells County. (A) Fine- to medium-grained sandstone with clay clast in basal fluvial-channel-fill facies at 5950.0 ft (1814.0 m). (B) Reddish-brown, silty mudstone in paleosol deposits in floodplain facies at 5926.5 ft (1806.4 m). (C) Brown, silty mudstone (paleosol) with calcareous soil nodules in floodplain facies at 5907.5 ft (1800.6 m). Core description is shown in Figure 12. Location of well is shown in Figures 10 and 11.**



Depth (ft)
Comments
Grain Size and Sedimentary Structures
Gravel
V. coarse
Coarse
Medium
Fine
V. fine
Silt
Mud
$CO_3$ CMT (%)
Oil stain (%)
Rock type
5680
5690
5700
5710
5720
5730
5740
5750
Union Pacific 36 Elliff
Logged by W. Ambrose
Abandoned channel fill
Calcic nodules
Massive
irr.
Poorly stratified
Elongate, aligned clay clasts
Fluvial channels
Crossbedding
Crossbeds
Channel fill (main)
Soil
Abandoned channel fill
Splay channel
Abundant nodules/muddy matrix
Splay channel
Mottled texture
Muddy matrix
Disaggregated overbank/ abandoned channel
Channel (upper)
Base: 5755 ft
Multistoried fluvial channel-fill
Fluvial with paleosols
QAe8494
Frio Formation
Very fine- to fine-grained sandstone
Siltstone and mudstone
Erosional surface
Nodules
Rooted
Mottled texture
Mud clasts
Densely-packed muddy mottling
Calcareous filaments
Mudcracks
irr.
Irregular contact
Upward fining
Crossbedding
Section not cored

**(FACING PAGE) Figure 16. Core description of crevasse-splay, fluvial channel-fill, and abandoned-channel-fill deposits in the middle Frio Formation in the Union Pacific No. 36 Elliff well in Nueces County. Core photographs are shown in Figure 17. Crevasse-splay deposits extend from 5726 to 5755 ft (1745 to 1754 m) and are composed of very fine-grained sandstone beds with clay nodules, interbedded with mudstone beds with root traces. Fluvial channel-fill deposits occur above these crevasse-splay deposits in a 35 ft (10.7 m) succession of fine- to medium-grained sandstone beds. Individual sandstone beds in these fluvial channel-fill deposits are erosion based and upward fining with abundant mudstone rip-up clasts. The upper 6 ft (1.8 m) part of the core is composed of an upward-fining section of very fine-grained sandstone beds overlain by muddy siltstone in abandoned-channel facies. Location of well is shown in Figures 10 and 11.**

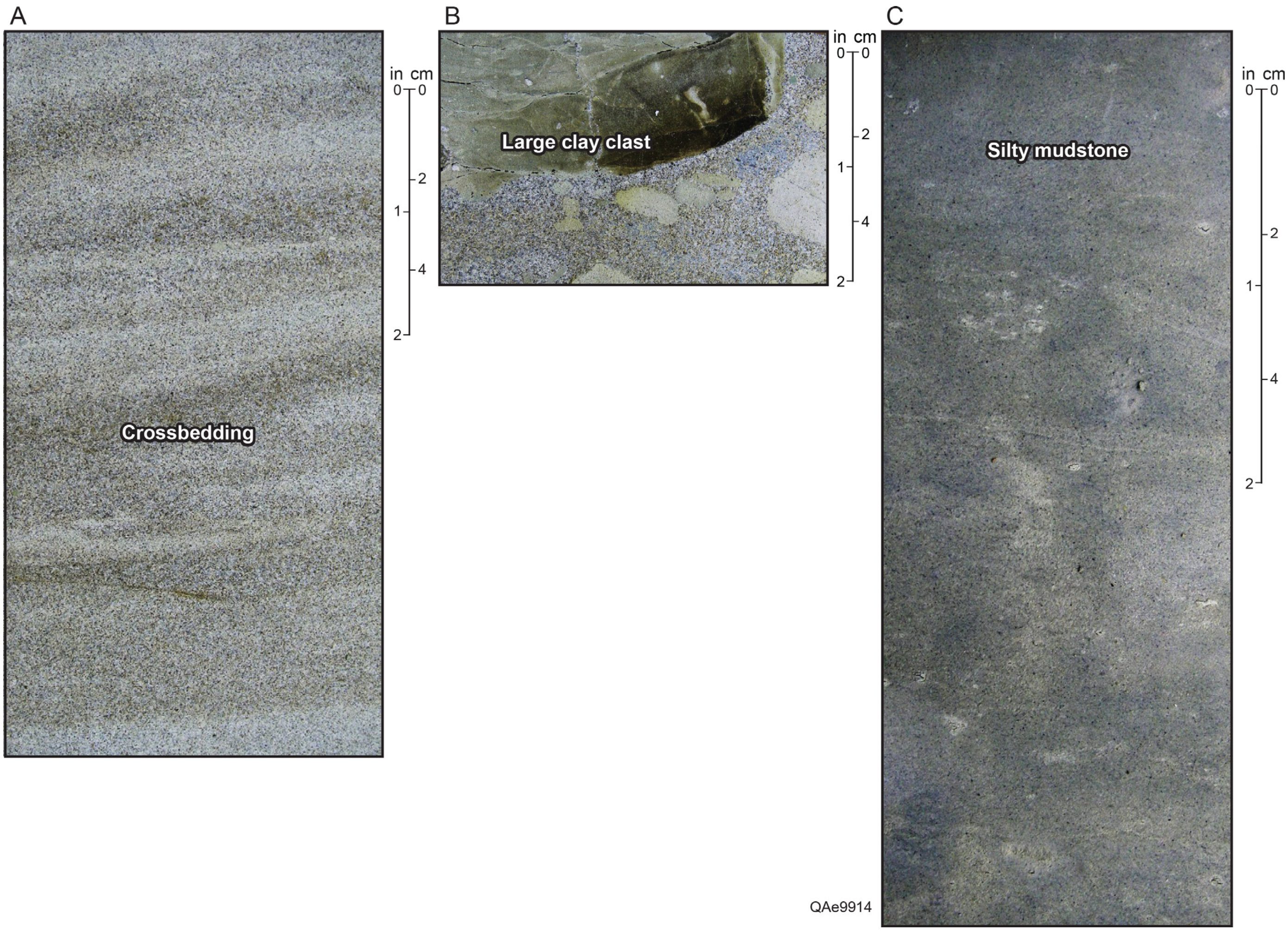



**Figure 17. Core photographs of fluvial channel-fill and abandoned-channel-fill deposits in the middle Frio Formation in the Union Pacific No. 36 Elliff well in Nueces County. (A) Medium-grained sandstone with crossbedding in basal fluvial-channel-fill facies at 5722.2 ft (1744.1 m). (B) Medium-grained, pebbly sandstone with large, subangular clay clast in fluvial channel-fill facies at 5719.0 ft (1743.2 m). (C) Muddy siltstone in abandoned-channel-fill facies at 5682.0 ft (1731.9 m). Core description is shown in Figure 16. Location of well is shown in Figures 10 and 11.**