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Sequence-Stratigraphic and Depositional Controls on Reservoir Quality in Lowstand Incised-Valley-Fill and Highstand Shallow-Marine Systems in the Upper Cretaceous (Cenomanian) Tuscaloosa Formation, Louisiana, U.S.A.

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ABSTRACT

Upper Cretaceous (Cenomanian) lowstand incised-valley systems in the Tuscaloosa Formation in central Louisiana and southwestern Mississippi and equivalent strata in the Woodbine Group in the East Texas Basin are significant stratigraphic features in the Gulf of Mexico. This study, using lithology, porosity, and permeability data from five whole cores, defines systems tracts by integrating lithologic data and log stacking patterns and documents sequence stratigraphic and facies controls on reservoir quality in lowstand incised-valley and underlying highstand deltaic systems in the Tuscaloosa Formation in central Louisiana. Greatest reservoir quality exists in sandy, non-conglomeratic bedload-fluvial deposits within these incised-valley systems. However, underlying highstand deltaic systems also contain good reservoir quality in proximal-delta-front sandstones at the top of progradational successions.

Tuscaloosa incised-valley-fill systems in central Louisiana, collectively composing up to ~400 ft (~120 m) of predominantly fluvial deposits, record multiple episodes of incision into shallow-marine strata. These amalgamated valley-fill systems are locally >40-mi (>64-km) wide and contain a variety of fluvial and estuarine facies. The lower half of the incised-valley-fill succession is composed of coarse-grained, including conglomeratic, braided-stream systems that grade upward into mixed-load meanderbelt deposits overlain by a regionally-continuous mudstone interval, 10 to 25 ft (3.0 to 7.6 m) thick), recording a period of valley inundation and subsequent development of estuarine systems.

Coarse-grained bedload-fluvial facies in the lower half of the Tuscaloosa incised-valley fill are composed of thick (commonly >100 ft [>30 m]) multistoried and aggradational successions of chert-clast conglomerates interbedded with medium-grained sandstone and pebbly, coarse- to very coarse-grained sandstone beds. They are commonly comprised of multiple 4 to 10 ft (1.2 to 3.0 m) thick, upward-fining intervals that record high-energy, downstream migration of channel-floor gravel and sand bars mantled by fine-grained sandstone representing waning-flow, bar-top deposits. Interchannel facies consist of heterogeneous upward-coarsening sections of very fine- to fine-grained, ripple-stratified sandstone beds with abundant soft-sediment deformation and dispersed organic material.

Tuscaloosa bedload-fluvial channel-fill deposits have moderately-blocky vertical permeability profiles, with greatest values as much as 1000 millidarcys (md) in fine- to coarse-grained, nonconglomeratic sandstone, mainly in the middle part of channel-fill successions. Median values (~45 md) in Tuscaloosa sandy bedload-fluvial channel-fill deposits are one order of magnitude greater than those in mixed-load fluvial deposits near the top of the incised-valley fill (~4 md). These mixed-load fluvial deposits display complex vertical permeability trends that are principally related to increasing mudstone content from channel-floor to upper-point-bar facies. In contrast, upward-increasing permeability trends in the basal section of the transgressive systems tract at the top of the incised-valley-fill succession are controlled by an upward decrease in muddy matrix that record increasing depositional energy and winnowing from wave and storm processes.

Knowledge of porosity and permeability variations within facies, as well as contrasting values between facies, can be used to infer controls on reservoir quality in the Tuscaloosa Formation. Significant vertical contrast in permeability occurs between Tuscaloosa facies, including (1) highstand deltaic sandstones locally truncated by low-porosity and low-permeability chert-clast conglomerates or clay-clast-rich

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sandstone beds at the base of lowstand incised-valley-fill deposits, (2) heterogeneous and muddy estuarine deposits above sandy bedload-fluvial deposits, and where sandy, marginal-marine deposits occur near the upper part of the Tuscaloosa incised-valley-fill succession. High porosity and permeability values (100s of md) are common in individual thin (<1 ft [0.3 m]) Tuscaloosa sandstone beds in highstand distal-delta-front facies, but their reservoir potential is limited because of numerous mudstone layers between sandstone beds. Although the greatest reservoir quality in the Tuscaloosa Formation in central Louisiana occurs within lowstand incised-valley bedload-fluvial deposits and decreases upward along with decreasing average grain size, significant variation in permeability occurs between conglomeratic and sandy bedload-fluvial facies. These fluvial facies are commonly interbedded at fine scales (<2 ft [<0.6 m]) that may be difficult to differentiate from wireline logs in the absence of core data.

INTRODUCTION AND OBJECTIVES

The Upper Cretaceous (Cenomanian) Tuscaloosa Formation in Louisiana and its stratigraphic equivalent in the East Texas Basin, the Woodbine Group, are major oil- and gas-producing stratigraphic intervals in the Gulf Coast. They also contain widespread incised-valley-fill systems of lowstand origin that have been mapped in the East Texas Basin, east-central Louisiana, and southwestern Mississippi (Ambrose et al., 2009; Woolf, 2012) (Fig. 1).

Ranges of reservoir quality have been documented within each major facies within highstand (HST), lowstand (LST), and transgressive systems (TST) tracts in the Woodbine Group in the East Texas Field (Ambrose et al., 2009; Loucks, 2010; Loucks et al., 2015, this volume), as well as in Woodbine highstand shelf-edge deltaic systems in the southern part of the East Texas Basin in Polk and Tyler counties (Ambrose et al., 2014). Reservoir quality, expressed in terms of porosity and permeability, in lowstand incised-valley-fill deposits in the East Texas Field, is strongly related to fluvial facies stacking patterns, composed of an upward progression from coarse-grained, including conglomeratic bedload to fine- and medium-grained mixed-load fluvial systems (Bonnaffé et al., 2008). A similar stratigraphic succession exists in lowstand incised-valley-fill deposits in the Tuscaloosa Formation, although additional facies complexity within the Tuscaloosa incised-valley-fill succession is introduced by estuarine and marginal-marine deposits that record a period of marine incursion (Woolf, 2012).

For many years, researchers have noted that porosity is preserved in some deep, hot Tuscaloosa sandstones in which thick, continuous chlorite coats formed around detrital grains and inhibited quartz cementation (Thomson, 1979; Smith, 1985; Pittman et al., 1992; Dutton et al., 2013). Where chlorite coats are either not present or are discontinuous, porosity has been significantly reduced by quartz cementation. The goal of this paper, however, is to determine where the best original porosity was located as a result of depositional processes, and not to examine later diagenetic modifications to reservoir quality.

Accordingly, the objective of this study is to determine sequence-stratigraphic and depositional controls on reservoir quality (defined as porosity and permeability) in the Tuscaloosa Formation in central Louisiana. This was achieved by three main tasks: (1) defining the sequence stratigraphic framework, (2) describing and interpreting facies within each sequence from wireline log and core data, and (3) characterizing lithology and facies types with high-resolution permeability data from a minipermeameter, supplemented with core-plug porosity and permeability data.

DATA AND METHODS

Permeability data from cores were provided from a minipermeameter, which employs a pressure-decay system (designed by Core Labs) to measure permeability values from 0.001 md to >30 darcys. Permeability values were corrected for slip (Klinkenberg) for non-Darcian flow (Forchheimer Factor [Forchheimer, 1901; Huang and Ayoub, 2006]). Approximately 1500 permeability values from the minipermeameter, 28 porosity and permeability values from core plugs, and 34 porosity (combined primary, secondary, and microporosity) values from thin-section point counts were plotted on core descriptions, with results summarized in Tables 1–5. Because of limited available porosity data, discussions of geologic controls on porosity in the Tuscaloosa Group in this investigation were confined to lowstand and transgressive systems tracts, although discussions on geologic controls on permeability also include highstand systems tracts. Limited permeability data from plugs were also provided to compare and validate permeability data obtained from the minipermeameter. These data were integrated with other data obtained from thin-section descriptions, including mineralogy and cement types.

All data used in this study are from the subsurface in the Tuscaloosa Formation in central Louisiana. These data include whole cores from five wells (Fig. 2). Data recorded in core descriptions include grain size, stratification, and contacts, as well as accessory features such as soft-sediment deformation, roots, burrows, clay clasts, and shell and organic fragments diagnostic of sedimentary processes and depositional environments. Core descriptions were supplemented by photographs to illustrate bed contacts, stratification, and rock fabrics.

This study also characterized significant stratigraphic surfaces (unconformities, flooding surfaces, and transgressive surfaces of erosion) from whole cores. Unconformities were recognized from vertical juxtaposition of unburrowed, sandy conglomerates and conglomeratic sandstone beds onto sections of burrowed, fine- to medium-grained sandstone. Flooding surfaces were identified as beds of featureless mudstone at the top of upward-fining successions of burrowed siltstone and very fine-grained sandstone. These upward-fining successions are underlain by transgressive surfaces of erosion, recognized in whole core as scour surfaces commonly overlain by shell debris, clay clasts, and organic fragments and which occur below flooding surfaces.

Facies interpretations in this study were based on detailed core descriptions from these five wells and stratigraphic relationships inferred from wireline log correlations (Figs. 2 and 3). Facies interpretations were supplemented with interpretations from previously published sources on the Tuscaloosa Formation in central Louisiana and southwestern Mississippi, including Chasteen (1983), Stancliffe and Adams (1986), Hamlin and Cameron (1987), Klicman et al. (1988), Barrell (1997), Sheppard et al. (1997), Dubiel et al. (2003), Mancini et al. (2008), Woolf and Wood (2010), and Woolf (2012), as well as from analogous facies profiles from lowstand incised-valley-fill deposits in the stratigraphically-equivalent Woodbine Group in the East Texas Basin (Bonnaffé et al., 2008; Ambrose et al., 2009).

Systems tracts were defined by integrating significant stratigraphic surfaces (unconformities, flooding surfaces, and transgressive surfaces of erosion) from whole-core data with log stacking patterns, although quantitative relationships were not observed between gamma ray (GR) log responses and grain size in these cores. HSTs were interpreted from upward-coarsening successions that range at the base from sparsely burrowed mudstone interbedded with thin (commonly <1 ft [<0.3 m]) beds of very fine-grained sandstone to ripple-stratified, fine-grained sandstone capped by low-resistivity and high-GR log responses (Figs. 4 and 5). LSTs were recognized from successions of coarse- and very coarse-grained sandstone beds interbedded with chert-clast conglomerates that occur within thick (commonly >200 ft [>60 m]) intervals with blocky GR and SP (spontaneous potential) log responses (Figs. 6–9). TSTs were identified from whole cores within upward-fining intervals that commonly grade upward from beds of very fine- to fine-grained, burrowed sand-

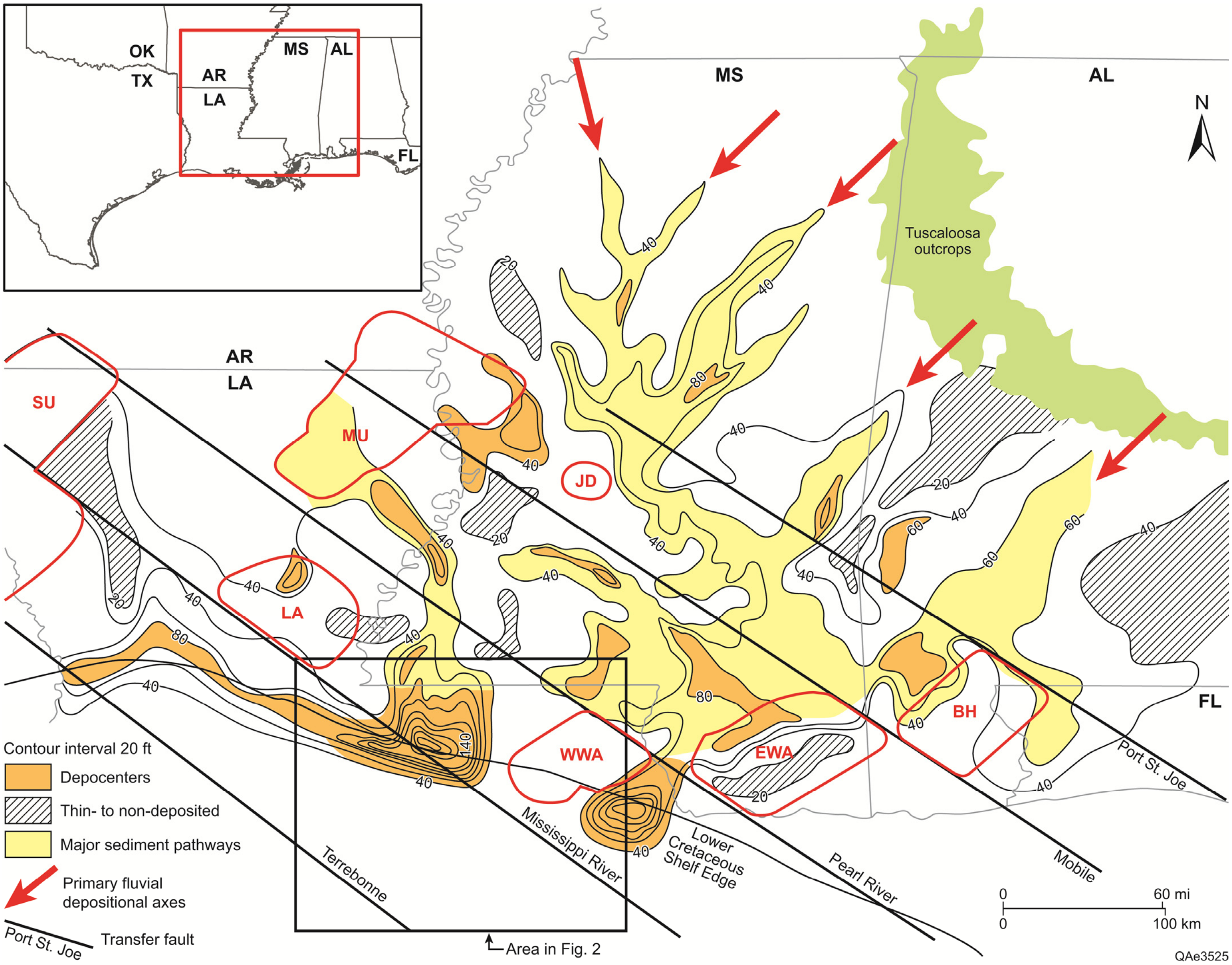

Figure 1. Regional distribution of middle Tuscaloosa lowstand-incised-valley systems from Woolf (2012). Red arrows indicate prominent fluvial feeder axes and colors indicate major sediment pathways, also from Woolf (2012). Northwest-southeast trending transfer faults are from Stephens (2009). Abbreviations: BH (Baldwin High), EWA (East Wiggins Arch), JD (Jackson Dome), LA (La Salle Arch), MU (Monroe Uplift), SU (Sabine Uplift), and WWA (West Wiggins Arch). Area of this study (rectangle in south part of map) is shown in Figure 2.

stone to sparsely burrowed or featureless mudstone within zones with high-GR (rightward deflection) log responses (Figs. 8 and 9C). Where only log data were available, TSTs were interpreted to occur between the top of low-GR (sandy) successions with blocky to upward-fining log responses and the base of successions with upward-decreasing (upward-coarsening) log responses (wireline log in Figure 10). A major interval of predominantly TST deposits was interpreted to occur above Tuscaloosa incised-valley-fill deposits, where it consists of a 300 ft (90 m) thick section below a regional, low-resistivity zone interpreted to represent a maximum flooding surface (MFS) at the base of the Upper Tuscaloosa Marine Shale (Fig. 3). This major TST is illustrated in greater detail in Figures 6 and 8.

SEQUENCE STRATIGRAPHY

The Tuscaloosa Formation in central Louisiana in this study is divided into three main sections: (1) a lower, commonly >1000 ft (>300 m) thick section composed of predominantly highstand, shallow-marine deposits that grade upward from deep-water slope deposits, (2) an overlying sandstone-rich (>500 ft [150 m] thick) section, consisting of lowstand, incised-valley fill, primarily fluvial deposits, that truncate this lower section (Fig. 3). This incised-valley section is, in turn, overlain by (3) a shaly 500 to 800 ft (150 to 240 m) thick interval known as the Tuscaloosa Marine Shale within the Upper Tuscaloosa Formation (John et al., 1997; Dubiel et al., 2003; Lu et al., 2011) (Fig. 3).

Sandy intervals in the lower Tuscaloosa section commonly have upward-coarsening and serrate GR and SP responses, recording deltaic and shoreface progradational episodes (high-frequency regressive-transgressive cycles) in a highstand (HST) shelf setting (Chasteen, 1983; Barrell, 1997). In this study, high-frequency regressive-transgressive cycles in the lower part of the Tuscaloosa Formation, ranging from 100 to 200 ft (30 to 60 m) thick, are recognized primarily from log stacking patterns (Fig. 3). These regressive-transgressive cycles display great continuity along depositional strike (east to west) (Fig. 3). In contrast, the sandstone-rich section that truncates this lower Tuscaloosa section contains bedload, braided-stream systems within a wide (~40 mi [~64 km]) incised-valley complex (Fig. 3). These Tuscaloosa lowstand (LST) incised-valley-fill systems are documented by Woolf and Wood (2010) and Woolf (2012) in southwestern

Table 1. Permeability data (derived from permeameter) for the Tuscaloosa Formation from cores in this study, summarized for major facies within TSTs, LSTs, and HSTs.

Systems Tract/Facies	Depth Range (ft)	Number of values	Permeameter Permeability Range (md)	Permeameter Permeability Average (md)	Permeameter Permeability Median (md)
TST/transgressive valley-fill	15,301–16,362	99	0.03–243.000	18.931	8.835
LST/mixed-load tidally-modified fluvial	15,310–15,353	274	0.0155–1550.000	34.055	4.340
LST/sandy bedload-fluvial channel fill	16,376–18,845	571	0.00426–5410.000	240.118	45.300
LST/conglomeratic bedload-fluvial channel-fill	16,373–16,591	73	0.0633–383.000	33.8105	2.495
LST/overbank and splay	18,815–18,828	95	0.005–524.000	10.197	0.070
HST/crevasse-splay	20,057–20,076	85	0.0129–119.000	3.796	0.297
HST/distal-delta-front	16,595–20,117	385	0.00154-–3130.000	49.835	0.395

Table 2. Permeability data (derived from core plugs) for the Tuscaloosa Formation from cores in this study, summarized for major facies within TSTs, LSTs, and HSTs.

Systems Tract/Facies	Depth Range (ft)	Number of values	Core-Plug Permeability Range (md)	Core-Plug Permeability Average (md)	Core-Plug Permeability Median (md)
TST/transgressive valley-fill	15,301–15,301	1	52.700–52.700	52.700	52.700
LST/mixed-load tidally-modified fluvial	15,312–15,350	5	0.070–69.700	32.714	36.500
LST/sandy bedload-fluvial channel-fill	16,394–18,848	15	0.010–630.800	103.787	21.950
LST/conglomeratic bedload-fluvial channel-fill	16,571–16,594	4	0.100–34.700	8.778	0.155
LST/overbank and splay	N/A	0	N/A	N/A	N/A
HST/crevasse-splay	20,057–20,073	3	0.001–0.600	0.217	0.050
HST/distal-delta-front	N/A	0	N/A	N/A	N/A

Table 3. Primary and secondary porosity data (derived from point counts) for the Tuscaloosa Formation from cores in this study, summarized for major facies within TSTs, LSTs, and HSTs.

Systems Tract/Facies (# of Data Points)	Primary Point-Count Porosity Range (%)	Primary Point-Count Porosity Average (%)	Primary Point-Count Porosity Median (%)	Secondary Point-Count Porosity Range (%)	Secondary Point-Count Porosity Average (%)	Secondary Point-Count Porosity Median (%)
TST/transgressive valley-fill (1)	9.5–9.5	9.5	9.5	4.5–4.5	4.5	4.5
LST/mixed-load tidally-modified fluvial (5)	0.5–14.0	7.4	6.0	0.0–6.5	3.3	3.5
LST/bedload-fluvial channel-fill (17)	0.0–17.5	8.0	9.5	0.0–2.0	0.8	1.0
LST/conglomeratic bedload-fluvial channel-fill (7)	0.0–11.0	6.1	6.5	0.0–2.0	0.4	0.2
HST/crevasse-splay (2)	0.0–3.5	1.0	0.3	0.0–1.5	0.5	0.8

Mississippi and east-central Louisiana, as well as in Tuscaloosa-equivalent (Woodbine) strata in the East Texas Basin, where a similarly wide (up to 40 mi [65 km]) valley-fill complex in the East Texas Basin was associated with fluvial systems providing sediment directly to the Cretaceous shelf edge in southeastern Texas (Ambrose et al., 2009; Hentz, 2010). The Tuscaloosa Formation was deposited during a major middle and late Cenomanian regressive event following a pronounced lowering of the relative sea level that affected the entire Gulf Coast Basin (Mancini and Puckett, 2005). This relative sea-level fall exposed shelves and platforms around the basin to subaerial exposure (Salvador, 1991). The magnitude of incision along this unconformity into Lower Cretaceous-, Jurassic-, Triassic-, and even Paleozoic-age strata suggests that the exposure and erosion associated with the incised-valley system in the Tuscaloosa Formation are most likely due to the combined effects of both eustatic sea-level drop and

Table 4. Microporosity and total porosity data (derived from point counts) for the Tuscaloosa Formation from cores in this study, summarized for major facies within TSTs, LSTs, and HSTs.

Systems Tract/Facies (# of Data Points)	Microporosity Range (%)	Microporosity Average (%)	Microporosity Median (%)	Total Point-Count Porosity Range (%)	Total Point-Count Porosity Average (%)	Total Point-Count Porosity Median (%)
TST/transgressive valley-fill (1)	0.3–0.3	0.3	0.3	14.3–14.3	14.3	14.3
LST/mixed-load tidally-modified fluvial (5)	0.0–4.0	2.0	1.8	5.2–17.5	12.7	14.3
LST/bedload-fluvial channel-fill (17)	1.2–16.1	9.2	10.7	2.5–27.1	18.1	23.1
LST/conglomeratic bedload-fluvial channel-fill (7)	2.7–17.5	9.9	8.9	2.7–25.3	15.7	16.6
HST/crevasse-splay (2)	4.8–10.7	7.8	7.8	4.8–10.7	7.8	7.8

Table 5. Core-plug porosity data from the Tuscaloosa Formation from cores in this study, summarized for major facies within TSTs and HSTs.

Systems Tract/Facies (# of Data Points)	Core-Plug Porosity Range (%)	Core-Plug Porosity Average (%)	Core-Plug Porosity Median (%)
TST/transgressive valley-fill (1)	15.8–15.8	15.8	15.8
LST/mixed-load tidally-modified fluvial (5)	5.7–14.9	12.2	14.3
LST/bedload-fluvial channel-fill (17)	2.5–27.6	18.4	23.4
LST/conglomeratic bedload-fluvial channel-fill (7)	2.5–25.8	15.7	16.6
HST/crevasse-splay (2)	4.8–10.7	7.8	7.8

regional tectonic uplift of the northern Gulf Coast (Salvador, 1991; Mancini and Puckett, 2005). This unconformity, known as the mid-Cenomanian unconformity or the mid-Cretaceous sequence boundary (Buffler et al., 1980; Buffler and Sawyer, 1985; Winker and Buffler, 1988), is significant because it is widely recognized and easily correlated across the Gulf of Mexico. Moreover, it represents a major change in sedimentation style from a predominantly carbonate section below to a predominantly clastic section above (Salvador, 1991).

Tuscaloosa incised-valley fill systems extend to the Lower Cretaceous Shelf Edge, where they merge with sandy, shelf-edge deltaic depocenters containing more than 140 ft (45 m) of gross sandstone (Fig. 1). Cores in this study with incised-valley fill deposits in the Tuscaloosa Formation are located closely updip (north and northeast of the shelf edge shown in Figure 2). Lower-incised-valley-fill deposits in southwestern Mississippi and central Louisiana commonly consist of coarse-grained, including conglomeratic, multistoried, aggradational fluvial channel-floor bar or single-story point-bar deposits (Stancliffe and Adams, 1986; Lu et al., 2011). Woodbine incised-valley-fill systems in East Texas Field are comprised of chert-clast conglomerate beds interbedded with medium- to very coarse-grained sandstone beds. These incised-valley-fill deposits in East Texas Field and other areas in the East Texas Basin truncate highstand deltaic deposits composed of mudstone beds and very fine- and fine-grained delta-front sandstone beds (Bonnaffé et al., 2008; Ambrose and Hentz, 2010; Adams and Carr, 2010). Subjacent lower Tuscaloosa successions in Louisiana, Mississippi, and Alabama are primarily deltaic and shelf in origin (Berg and Cook, 1968; Barrell, 1997).

The upper 50 to 150 ft (15 to 45 m) of the Tuscaloosa incised-valley fill in the study area is overlain by a TST (Fig. 3). This TST is in turn overlain by a regionally continuous maximum flooding surface (MFS in Figure 3) that marks the base of an extensive HST, a major component of the Tuscaloosa Marine Shale that is widely distributed in the Louisiana-Mississippi Gulf Coast (John et al., 1997).

LOWER TUSCALOOSA DELTAIC SYSTEMS

Chevron No. 1 Lorio

The lower part of the Tuscaloosa section in the Chevron No. 1 Lorio core (Fig. 4) consists of a 40 ft (12 m) thick section of sparsely burrowed mudstone interbedded with thin (commonly <2 in [<5.1 cm]) beds of very fine-grained sandstone. This basal section is overlain by a 36 ft (11 m) interval of sideritic mudstone, bounded at the top at 20,117 ft (6133.2 m) by a 42 ft (12.8 m) section of intensely interbedded mudstone and sandstone beds individually 2 to 6 in (5.1 to 15.3 cm) thick. The upper 18 ft (6 m) of the cored section from 20,057 to 20,075 ft (6114.9 to 6120.4 m) is an upward-coarsening section that grades upward from very fine-grained sandstone with ripple stratification to fine-grained sandstone with scour surfaces, mud-draped ripples, and low-angle plane beds capped by narrow (mm-scale), vertical filaments (Figs. 4, 5C, and 5D).

Prodelta/Shelf

Description. The most sandstone-poor section in the Chevron No. 1 Lorio core, which extends from 20,117 to 20,153 ft (6133.2 to 6144.2 m) (Fig. 4), is composed mainly of silty mudstone. Stratification is poorly developed in this section, represented by discontinuous (commonly 0.5 in [1.3 cm]), silty laminae within thin (<2 in [<5.1 cm]) beds of very fine grained sandstone. Burrows are dominated by sparse *Planolites* and thin

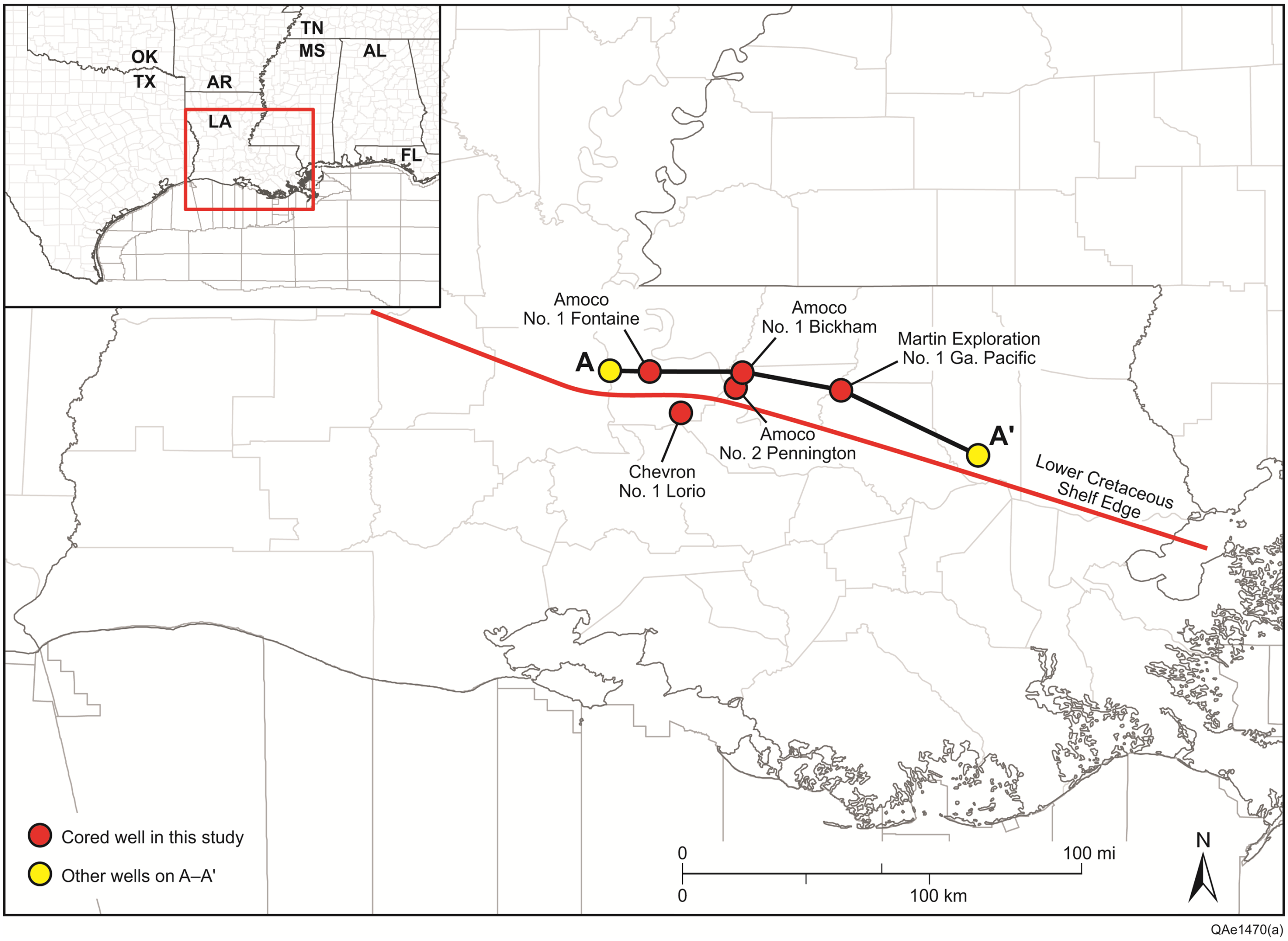

Figure 2. Distribution of cored wells in this study. Lower Cretaceous shelf edge is from Woolf (2012). Map area is also shown in Figure 1. Stratigraphic cross-section A–A' is shown in Figure 3.

(commonly <1 in [<2.5 cm]) bands of siderite occur throughout the section.

Facies Interpretation. The interval from 20,117 to 20,153 ft (6133.2 to 6144.2 m) in the Chevron No. 1 Lorio core is composed of prodelta/shelf facies that represent relatively long periods of suspension sedimentation in a low-energy setting seaward of the delta front, intermittently punctuated by traction currents associated with either frontal splays or storm activity. Although the prodelta section appears to be homogenous overall, diffuse banding caused by slight variations in grain size reflect variations in suspended-sediment influx (Kelling and George, 1971; Elliott, 1978). Sparse and low-diversity bioturbation in the prodelta have been ascribed classically to episodic suspension sedimentation and low-salinity water from freshwater, hypopycnal distributary plumes (Bates, 1953; Scruton, 1960). However, recent studies by Allison and Neill (2002), Neill and Allison (2005), and Bhattacharya and MacEachern (2009) suggest that bottom-hugging turbidity currents comprised of hyperpycnal suspensions (fluid muds) are dominant processes in prodelta facies in fluvial-dominated deltaic settings such as the modern Atchafalaya Delta and in ancient fluviodeltaic systems in the Cretaceous Western Interior Seaway, respectively.

Distal Delta Front

Description. The Chevron No. 1 Lorio core contains two sections composed of interbedded mudstone and sandstone beds individually 2 to 6 in (5.1 to 15.3 cm) thick. These sections occur from 20,153 to 20,193 ft (6144.2 to 6156.2 m) and 20,075 to 20,117 ft (6120.4 to 6133.2 m) (Fig. 4). These intervals are each composed of silty mudstone interbedded with very fine-grained sandstone beds, individually 2 to 6 in (5.1 to 15.3 cm) thick. These sandstone beds are sharp-based and contain weak planar stratification and deformed bedding (Fig. 5A). Tops of some beds feature small-scale ripples or undulose stratification. Burrows are dominated by *Planolites* and *Schaubcylindrichnus* (Fig. 5B).

Facies Interpretation. Sharp-based, parallel-laminated and deformed sandstone beds in the Chevron No. 1 Lorio core, particularly in the intervals from 20,080 to 20,116 ft (6122.0 to 6132.9 m) and 20,154 to 20,192 ft (6144.5 to 6156.1 m) (Fig. 4) record frontal-splay deposits in a distal-deltaic setting, common in both modern delta-front environments (Wright et al., 1988; Mulder and Syvitski, 1995; Mulder et al., 2003; Neill and Allison, 2005) as well as in ancient shallow-marine, progradational settings (Plink-Björklund et al., 2001; MacEachern et al., 2005; Petter and Steel, 2006; Bhattacharya and MacEachern, 2009; Olariu et al., 2010). Hyperpycnal frontal-splay deposits commonly contain abrupt, erosional bases, low-angle and plane-parallel lamination, and undulating, rippled crests at the top, representing waxing-to-waning energy (Plink-Björklund et al., 2001; Mulder et al., 2003; Plink-Björklund and Steel, 2004).

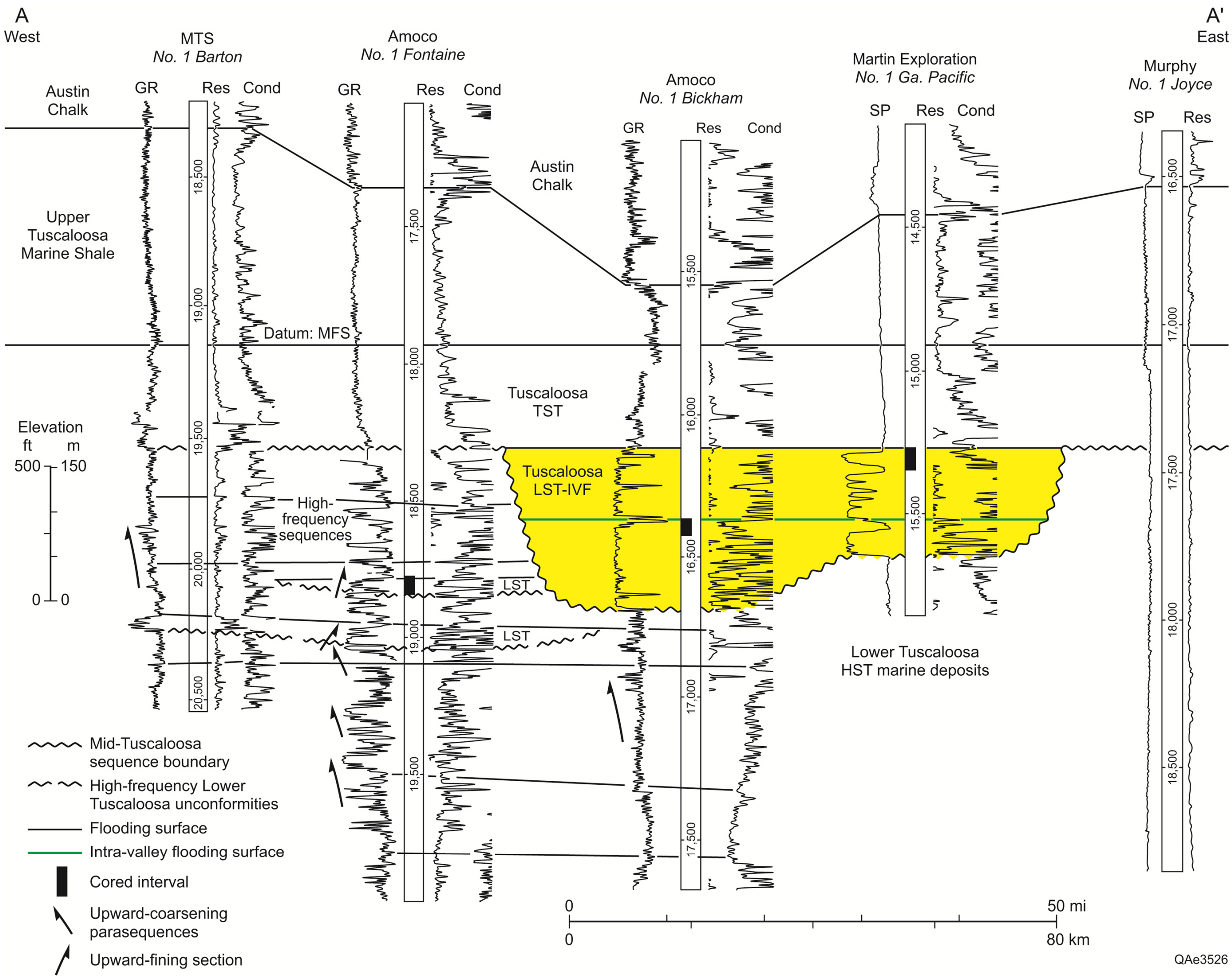

Figure 3. Stratigraphic cross-section A–A' depicting stratigraphic surfaces and sequences, with emphasis on lowstand incised-valley systems in the Tuscaloosa Formation in eastern Louisiana. Abbreviations: Cond (conductivity), GR (gamma ray), Res (resistivity), and SP (spontaneous potential). Details of stratigraphic surfaces and log stacking patterns, as well as systems tracts and facies interpretations are illustrated in the three cored wells in this section: Amoco No. 1 Bickham (Fig. 8), Amoco No. 1 Fontaine (Fig. 10), and Martin Exploration No. 1 Georgia Pacific (Fig. 12). Location of cross section is shown in Figure 2.

Crevasse Splay

Description. The upper 18 ft (5.5 m) of the core in the Chevron No. 1 Lorio well is an upward-coarsening section that grades upward from very fine-grained sandstone with ripple stratification to fine-grained sandstone with scour surfaces, mud-draped ripples, and low-angle plane beds capped by narrow (mm-scale), vertical filaments (Figs. 4, 5C, and 5D). Clay clasts, organic fragments, and root filaments occur in the upper part of the section (Fig. 5D). Some ripples in the upper 10 ft (3.0 m) of the section are double-draped, with thin (<1 mm) drapes commonly composed of organic material (Figs. 5C and 5D).

Facies Interpretation. The upper, 18 ft (5.5 m) thick section of the Chevron No. 1 Lorio core represents crevasse-splay deposits that record levee breach and the sudden incursion of sediment-laden waters onto either the delta plain or in interdistributary areas. Crevasse-splay deposits are commonly upward-coarsening, recording progradation of a subdelta (Coleman and Gagliano, 1964; Arndorfer, 1973). Progradation of the splay produces a lobate apron fed by small-scale, anastomosing streams (splay channels); continued progradation of splays into interdistributary bays may result in filling of the bay and emergence of a splay platform for vegetation (Bernard and Le Blanc, 1965; Kolb and van Lopik, 1966; Frazier, 1967). Recognition criteria for crevasse-splay facies in the Chevron No. 1 Lorio core, which are also common in fluvial-dominated deltaic successions in the Woodbine Group in East Texas Field, as well as several fields in Leon County, Texas (Ambrose and Hentz, 2010; Hentz et al., 2014, respectively), include upward-coarsening grain-size profile, ranging from coarse-grained siltstone at the base to very fine- and fine-grained sandstone at the top. Bedforms at the base are dominated by horizontal laminations with soft-sediment deformation, grading upward into small-scale ripples (Bhattacharya and Walker, 1992). Stratification at the top is mainly large-scale current ripples and small-scale crossbeds with clay clasts, organic fragments, and root mottling. Soft-sediment deformation, pedogenic structures, and burrows may also be associated with the crevasse-splay facies. Multiple scour surfaces and alternating horizontal laminations and ripples in the levee facies record episodic flooding and scouring of the distributary margin by traction currents, followed by post-flood, suspension sedimentation

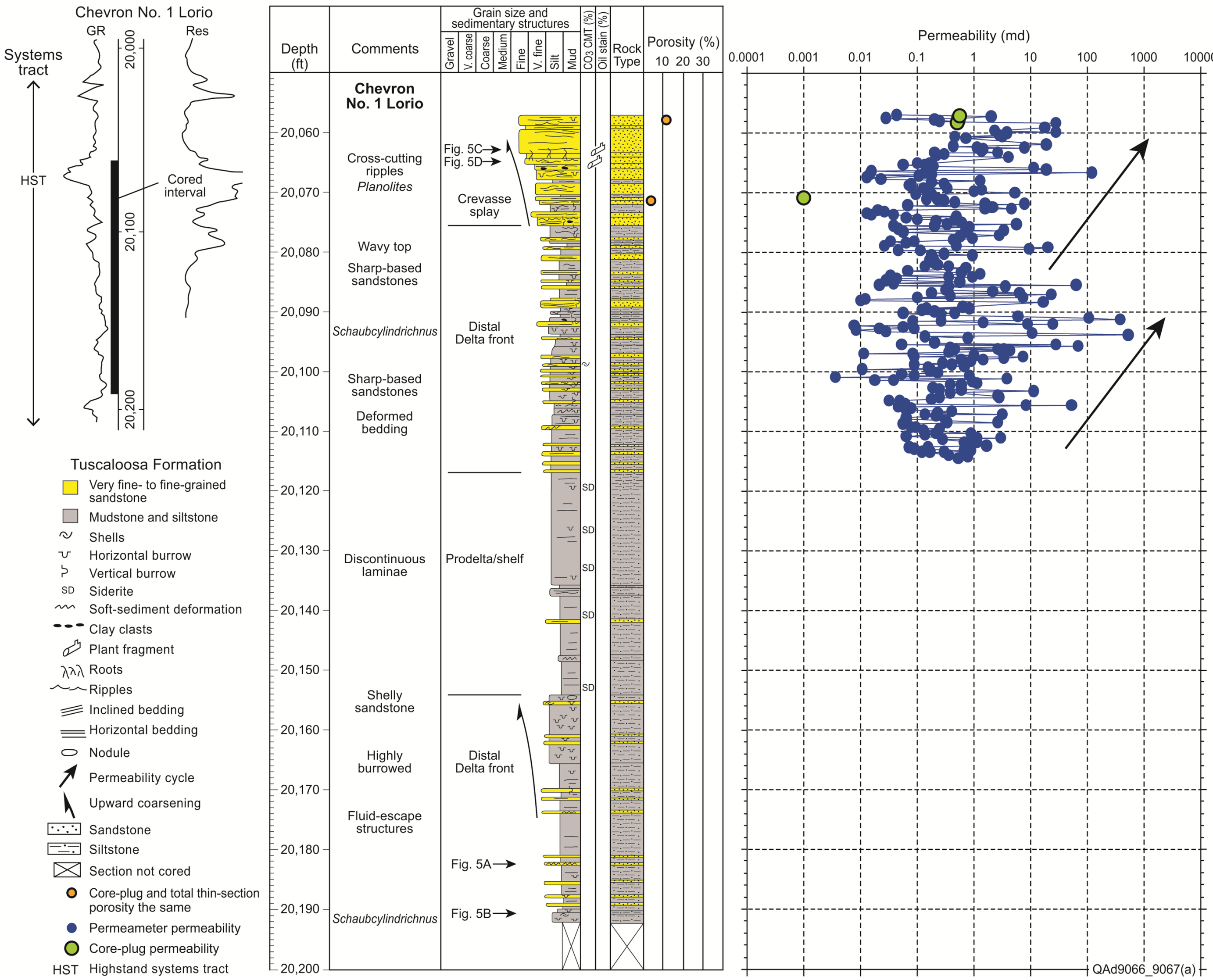

Figure 4. Description of the Chevron No. 1 Lorio core, showing prodelta/shelf, distal-delta-front, and crevasse-splay facies. Permeability profile is also shown for the upper 55 ft (17 m) of the core. Location of well is shown in Figure 2. Core photographs are shown in Figure 5.

(Elliott, 1974, 1978). The log response of the crevasse-splay facies is commonly upward coarsening, reflecting an upward decrease in clay and muddy matrix. The presence of root filaments and thin, double mud drapes in crevasse-splay facies in the Chevron No. 1 Lorio core (Figs. 4C and 4D) suggests an embayment environment with weak tidal influence rather than a high-energy, wave-dominated setting.

Porosity and Permeability

Sparse core-plug and thin-section porosity data from the crevasse-splay facies indicate poor reservoir quality, with values ranging from 4.8 to 10.7% (Fig. 4; Tables 3–5). However, abundant permeability data display a first-order relationship between upward-increasing grain size and reservoir quality (Fig. 4). Permeability data from the upper 60% of the cored interval in the Chevron No. 1 Lorio well, which encompasses the upward-coarsening interval from 20,057 to 20,137 ft (6114.9 to 6139.3 m), illustrate two cycles, each 25 to 30 ft (7.6 to 9 m) thick, of upward-increasing permeability values that range from <0.1 md at the base to locally >100 md near the top (Fig. 4). The top of the lower permeability cycle occurs midway through the distal-delta-front facies at ~20,092 ft (6125.6 m). The top of the second permeability cycle is less well-defined, approximately corresponding with the top of the cored interval within splay-platform facies. Maximum permeability values (>100 md) occur in the lower cycle. In contrast, maximum permeability values are only slightly greater than 100 md in the upper cycle (Fig. 4), inconsistent with expectations of increasing reservoir quality associated with an upward increase in average grain size. These trends suggest that reservoir quality, in this case inferred from permeability values, can be high in individual thin (<1 ft [0.3 m]) sandstone beds in the lower and middle parts of progradational parasequences. However, vertical reservoir continuity in the distal-delta-front sandstone beds is expected to be greatly diminished, because of the presence of numerous interbedded mudstone layers between individual sandstone beds.

TUSCALOOSA INCISED-VALLEY SYSTEMS

A (Figs. 2 and 3) that is oriented approximately at right angles to the Tuscaloosa incised-valley-fill system pregional depositional strike section in central Louisiana ortrayed in Woolf (2012) displays a wide (>40 mi [>64 km]) lowstand valley-fill complex inferred to truncate the lower Tuscaloosa shallow-marine succession. This lowstand incised-valley-fill complex is

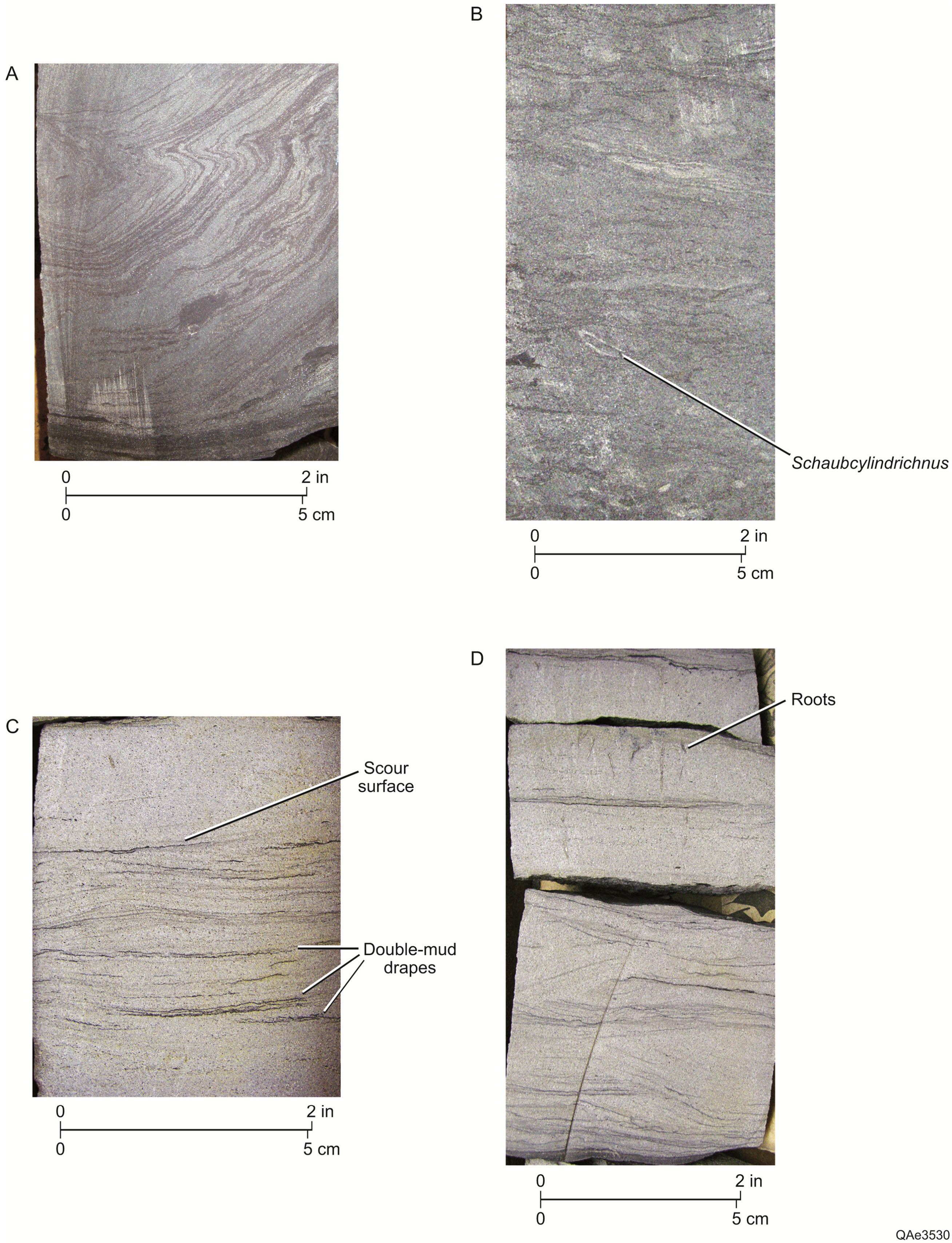

Figure 5. Photographs from the Chevron No. 1 Lorio core, described in Figure 4. (A) Contorted beds of very fine-grained sandstone in distal-delta-front facies at 20,182.7 ft (6153.3 m). (B) Burrowed, silty mudstone in distal-delta-front facies at 20,192.0 ft (6156.1 m), featuring *Schaubcylindrichnus*. (C) Crevasse-splay facies featuring fine-grained sandstone with internal scour surfaces and draped ripples at 20,063.0 ft (6116.8 m). (D) Cross-cutting ripples overlain by rooted zone in crevasse-splay facies at 20,064.5 ft (6117.2 m). Core description is shown in Figure 4.

recognized from blocky wireline-log responses representing aggradational and sandstone-rich bedload-fluvial deposits observed in cores (Figs. 6–8). Similarly wide incised-valley-fill systems are documented in lowstand systems tracts in the Woodbine Group in the East Texas Basin, projected from East Texas Field southward to the Woodbine shelf edge in southeastern Texas (Ambrose et al., 2009). Similarly, Tuscaloosa valley-fill systems in Mississippi and Louisiana delineated by Woolf and Wood (2010) and Woolf (2012), served as conduits for coarse-grained fluvial material to reach the Tuscaloosa shelf edge in central and central Louisiana (Fig. 1).

Alternate interpretations for the blocky wireline-log responses for in middle Tuscaloosa succession in central Louisiana and the Woodbine Group in the East Texas Basin include (1) sandstone-rich, progradational barrier/strandplain deposits (Oliver, 1971) and (2) aggradational, basin-floor-fan facies. However, chert-clast conglomerates and coarse-grained sandstone beds in cores in this study contain no marine trace fossils (Figs. 6–9) and have aggradational rather than progradational stacking patterns (Fig. 3). A deepwater, basin-floor-fan interpretation for the coarse-grained succession in cores in this study is unlikely because of their proximal position (adjacent to the Upper Cretaceous Shelf Edge; Fig. 2). Moreover, thin (commonly <30 ft [<9 m]) fine-grained intervals between these coarse-grained successions with blocky wireline-log responses contain *Cruziana* ichnofauna, inconsistent with a deepwater setting (Figs. 8 and 9C).

Amoco No. 2 Pennington

Highstand Shallow Marine

Description. The basal 27 ft (8.2 m) of the Amoco No. 2 Pennington core (Figs. 3 and 6), from 16,594 to 16,621 ft (5059.1 to 5067.4 m), is a muddy section of burrowed, very fine- and fine-grained sandstone beds with wavy planar beds (Fig. 7C). The section exhibits no overall vertical grain-size trend, although the upper half of the section (16,594 to 16,606 ft [5059.1 to 5062.8 m]), is upward-coarsening, grading upward from burrowed mudstone to fine- to medium-grained sandstone (Fig. 6). Burrows, which are more common in mudstone than in sandstone beds in this lower section, are dominated by *Schaubcylindrichnus* and *Planolites* (Fig. 7D).

Facies Interpretation. The lower 27 ft (8.2 m) section in the Amoco No. 2 Pennington core represents wave-modified, distal-delta-front deposits of highstand shallow-marine origin truncated by a coarse-grained, incised-valley-fill sequence. This shallow-marine, highstand systems tract interpretation is based

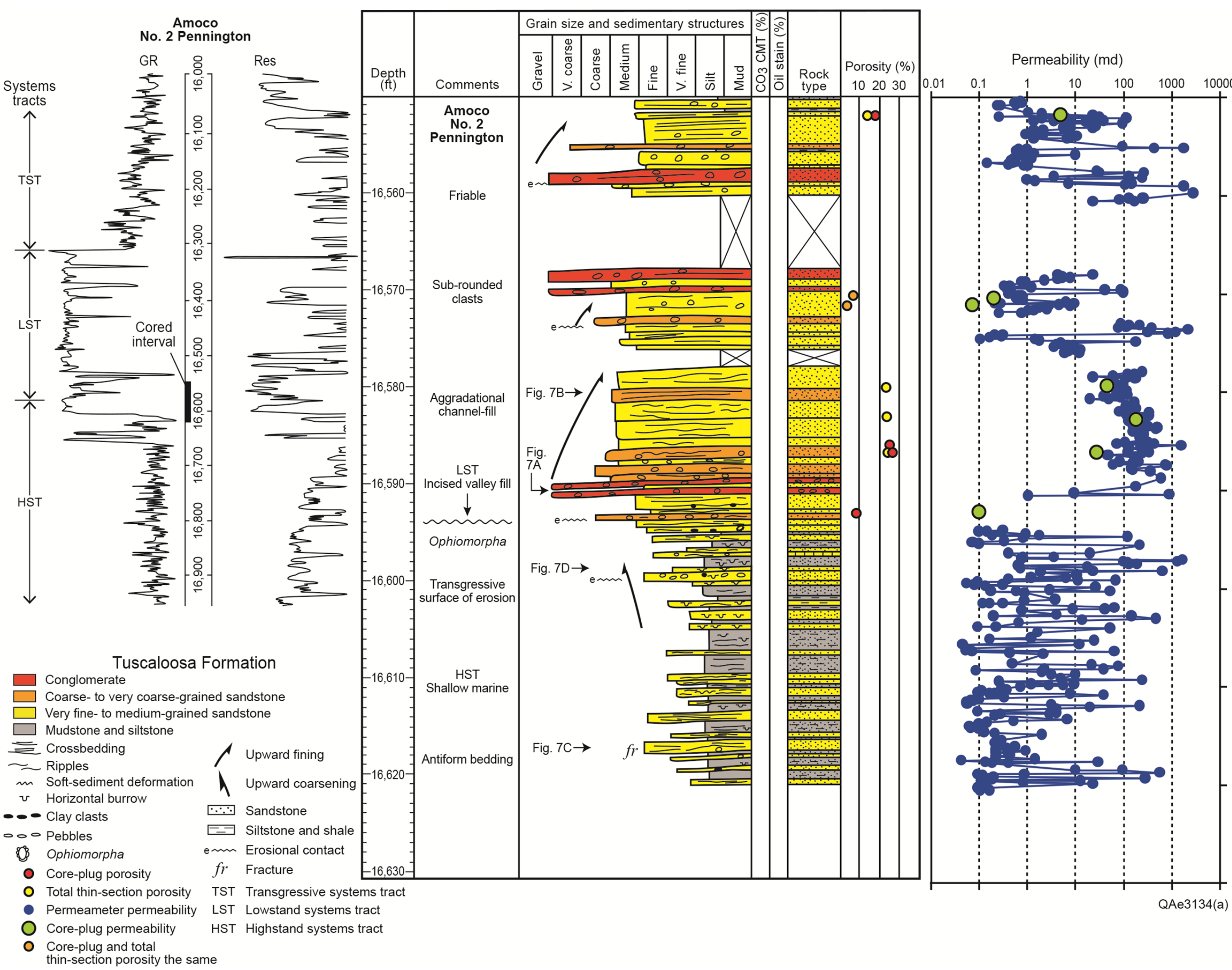

Figure 6. Description of the Amoco No. 2 Pennington core, included in cross-section A–A' in Figure 3. Section displays coarse-grained, lowstand incised-valley-fill section in erosional contact with underlying highstand shallow-marine deposits. Porosity data and permeability profile are also shown. Location of well is shown in Figure 2. Core photographs are shown in Figure 7.

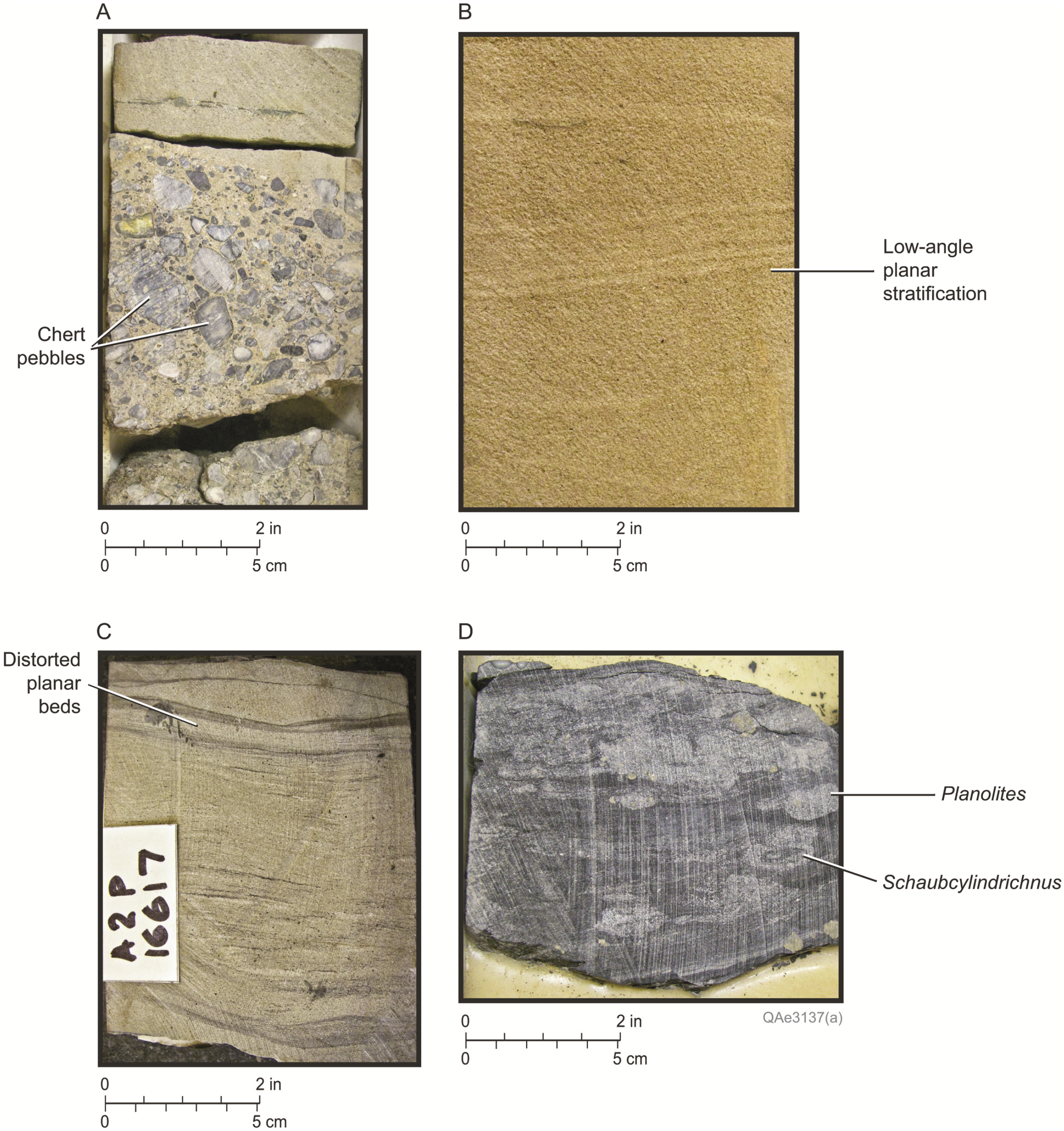

Figure 7. Core photographs from the Amoco No. 2 Pennington well, included in cross-section A–A' in Figure 3. (A) Chert-pebble conglomerate overlain by coarse-grained sandstone at 16,591.0 ft (5058 m). (B) Medium-grained sandstone with low-angle planar stratification at 16,581 ft (5055 m). (C) Fine-grained sandstone with distorted planar stratification at 16,617.0 ft (5066.2 m). D. Muddy siltstone with *Schaubcylindrichnus* and *Planolites* burrows and small (1 to 3 mm) pyrite nodules at 16,598.5 ft (5060.5 m). Core description is shown in Figure 6.

on: (1) presence of marine trace fossils, particularly in mudstone beds, that include *Planolites*, *Schaubcylindrichnus*, (Fig. 7D) and *Ophiomorpha*; (2) overall fine-grained size with intensely-interbedded sections of mudstone and thinly-bedded sandstone beds in upward-coarsening sections; (3) wavy-planar stratification indicating wave-reworking processes (Fig. 7C); and (4) stratigraphic position relative to an overlying coarse-grained, non-marine section by which it is inferred to be truncated (Figs. 3 and 6). A transgressive surface of erosion at 16,600 ft (5061.0 m), is differentiated from a sequence boundary at 16,594 ft (5059.1 m) (Fig. 6) in that the overlying sandstone bed above the transgressive surface of erosion is burrowed and upper-fine-grained, with

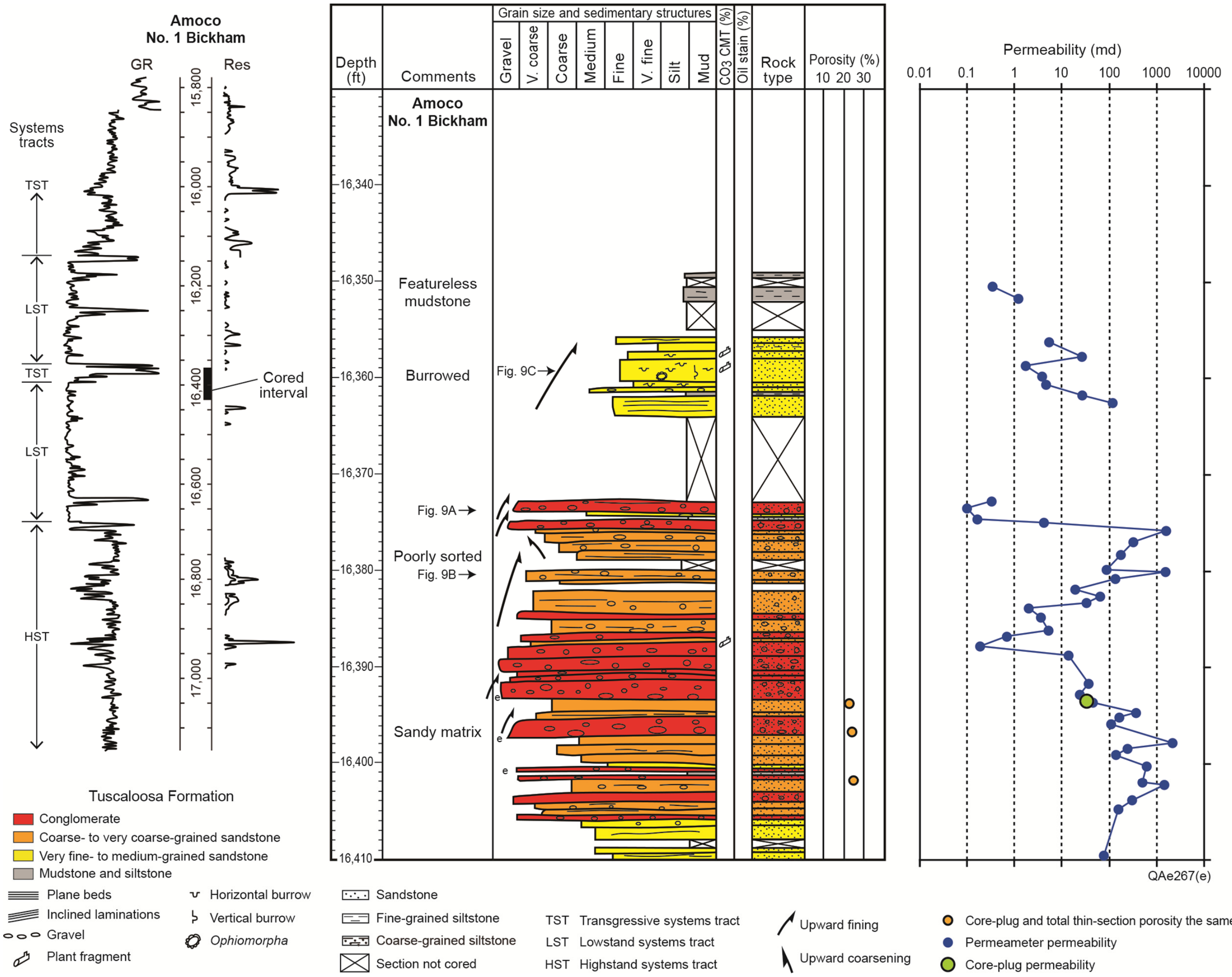

Figure 8. Core description of the Amoco No. 1 Bickham well, included in cross-section A–A' in Figure 3. Section illustrates aggradational architecture of coarse-grained, bedload-fluvial deposits overlain by fine-grained, burrowed, estuarine sandstones and featureless, gray mudstone, recording an episode of marine flooding within the Tuscaloosa paleovalley. Location of well is shown in Figure 2. Core photographs are shown in Figure 9.

clasts composed primarily of mudstone. In contrast, beds above the inferred sequence boundary are mainly chert-clast conglomerates without marine trace fossils (Fig. 7A).

Lowstand Incised-Valley Fill

Description. The section above 16,594 ft (5059 m) in the Amoco No. 2 Pennington core is composed of multiple (1 to 3 ft [0.9 to 1.5 m] beds of fine- to very coarse-grained, unburrowed sandstone interbedded with 1 to 2 ft (0.3 to 0.6 m) beds of sandy pebble conglomerate (Figs. 6 and 7A). Conglomerate beds commonly mark the bases of 3 to 12 ft (0.9 to 3.7 m) upward-fining intervals, each capped by medium-grained sandstone with low-angle, planar stratification (Fig. 7B). Conglomerate beds in the Amoco No. 2 Pennington core, which occur in 2 to 4 ft (0.6 to 1.2 m) thick zones, are composed predominantly of subrounded to subangular chert pebbles with poor internal sorting and stratification (Fig. 7A). In contrast, stratification in the relatively thicker section of upper-fine- to coarse-grained sandstone beds is dominated by horizontal to low-angle plane beds with minor ripples (Fig. 6).

Facies Interpretation. Conglomeratic and coarse-grained sandstone successions in the Amoco No. 2 Pennington well represent bedload-fluvial deposits in a valley-fill system in erosional contact with genetically-unrelated, shallow-marine deposits. Bedload-fluvial systems, in which the dominant sediment load is sand transported in subaqueous dunes by traction currents along the channel floor, occur in broad, well-connected, straight to slightly sinuous sand sheets with high width-to-depth ratios (Galloway, 1977, 1982). Vertical grain-size profiles in these types of fluvial systems are generally blocky and exhibit minor amounts of upward-fining of grain size, recording aggradational processes on the channel floor. Channel-fill successions of modern bedload-fluvial deposits are commonly composed of sandy and gravelly. longitudinal and transverse bars that form by downstream migration in braided-river systems (Ore, 1963; Smith, 1970; Boothroyd, 1972; Smith, 1974), similar to those described by Lunt and Bridge (2004) and Lunt et al. (2004) in the Sagavanirktok River, Alaska.

Porosity and Permeability

Permeability values in the lower interval of highstand delta-front deposits in the Amoco No. 2 Pennington core vary greatly, ranging from slightly less than 0.1 md to >1000 md (Fig. 6).

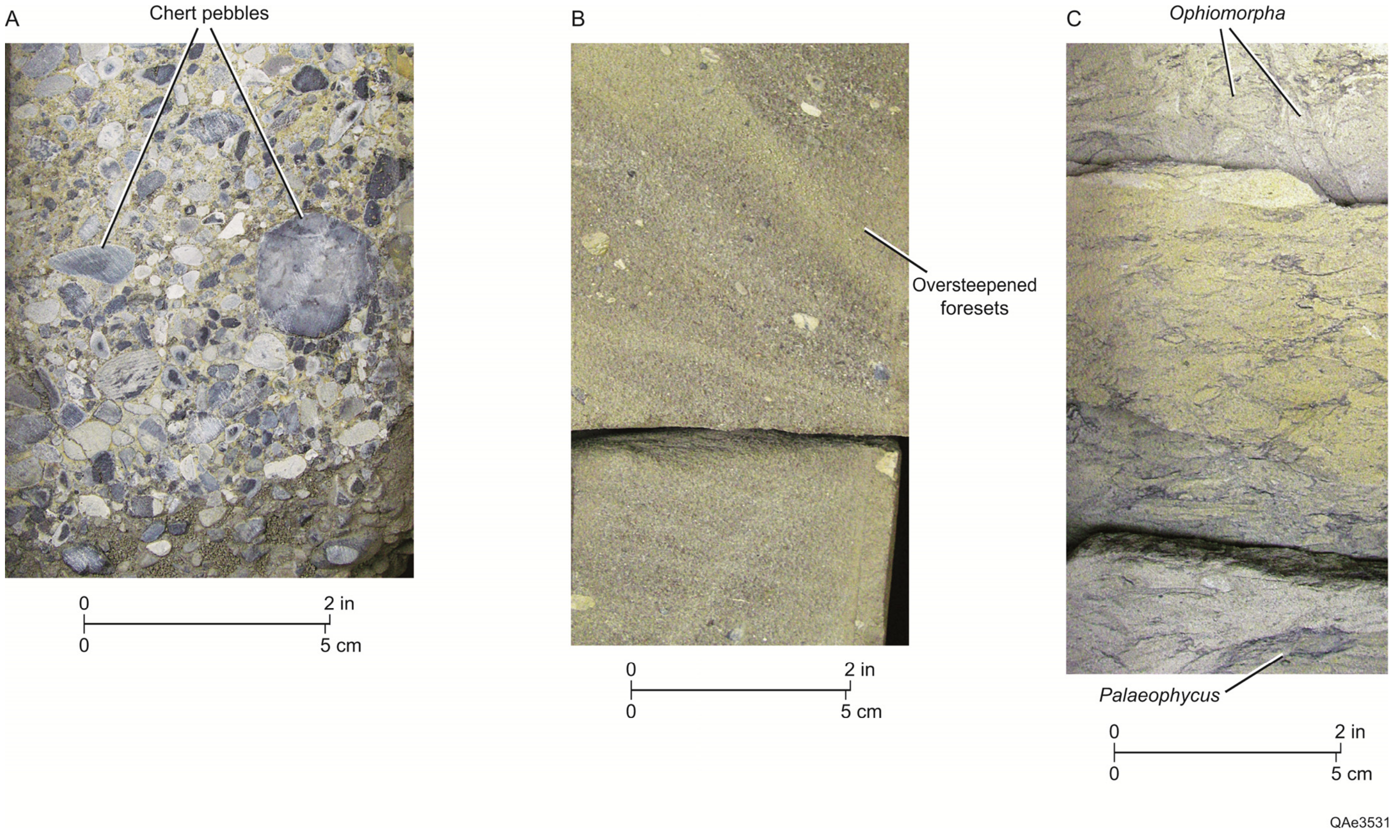

Figure 9. Core photographs from the Amoco No. 1 Bickham well. (A) Poorly-sorted chert-pebble conglomerate overlain by coarse-grained sandstone at 16,374.0 ft (4992.1 m). (B) Very coarse-grained, pebbly sandstone with oversteepened foresets at 16,380 ft (4993.9 m). (C) Extensively-burrowed, fine-grained sandstone with *Ophiomorpha* and *Palaeophycus* at 16,360.0 ft (4987.8 m). Core description is shown in Figure 8.

Zones of high permeability (>100 md) coincide with thin (<1.5 ft [<0.5 m]), very fine- and fine-grained sandstone beds, whereas lowest permeability values (≤0.1 md) occur in mudstone beds and thin (centimeter-scale) beds of very fine-grained sandstone with a silty matrix.

In contrast, permeability values are uniformly high (>100 md) in the basal 14 ft (4.3 m) part of the incised-valley fluvial section and display greater variability where thin (1 to 4 ft [0.3 to 1.2 m]) zones of conglomerate are present. Greatest permeability values (~3000 md) coincide with friable, medium-grained sandstone, as for example at 16,560 ft (5048.8 m).

Core-plug and thin-section porosity data indicate that highest total values (>25%) occur in medium-grained sandstone in the interval from 16,580 to 16,587 ft (5054.9 to 5057.0 m) (Fig. 6). This section also coincides with a zone of consistently high-permeability values (most >100 md). Average- and median-porosity values are lower in conglomerate versus sandstone-dominated beds (Tables 3–5), owing to the presence of sparse sandy matrix in sections dominated by chert pebbles (Fig. 7A), in which porosity in these chert clasts is dominated by microporosity, although microporosity occurs also in bedload-fluvial channel-fill facies (Table 4).

Amoco No. 1 Bickham

The lower part of the Amoco No. 1 Bickham core (Figs. 3 and 8) contains a ~40 ft (~12 m) section of chert-clast conglomerate and medium- to very coarse-grained sandstone beds (Fig. 8). The upper part of the core features a ~15 ft (~4.5 m) section of burrowed, very fine- to fine-grained sandstones and mudstones within a high-GR zone. This high-GR zone composes a regionally continuous mudstone interval (Fig. 3) that contains a marine flooding surface recording retrogradational, shallow-marine deposition (Woolf, 2012) associated with flooding of Tuscaloosa valley-fill systems.

Bedload Fluvial

Description. Most of the Amoco No. 1 Bickham core (from 16,373 to 16,410 ft [4991.8 to 5003.0 m]) is a coarse-grained section of chert-granule and chert-pebble conglomerate interstratified with coarse- to very coarse-grained sandstone with lesser volumes of chert pebbles (Fig. 8). Chert granules and pebbles in the conglomerate beds commonly display little preferred orientation and are subangular to subrounded in shape (Fig. 9A). Sedimentary structures in the sandstone beds range from planar stratification to oversteepened crossbeds (Fig. 9B). This lower, coarse-grained section in the Amoco No. 1 Bickham core displays no overall vertical grain-size trend, although small 2 to 6 ft (0.6 to 1.8 m) upward-fining intervals occur in the section (Fig. 8). Mudstone interbeds in this lower coarse-grained section are scarce, with only one thin (<4 in [<10.2 cm]) bed present at 16,401 ft (5000.3 m).

Facies Interpretation. Bedload-fluvial deposits in the Amoco No. 1 Bickham core are coarser grained than those in the nearby Amoco No. 2 Pennington core (Figs. 3 and 6), being composed of nearly equal aggregate thickness of conglomerate and coarse- to very coarse-grained sandstone beds (Fig. 8). The coarse-grained conglomeratic section in the Amoco No. 1 Bickham core from 16,373 to 16,406 ft (4991.8 to 5001.8 m) exhibits no overall vertical grain-size trend, common in braided fluvial systems with nonsystematic, random lateral and vertical distribution of bars and channel-fill units (Collinson, 1978). The multiple, 2 to 6 ft (0.6 to 1.8 m) upward-fining sections in this lower part of the core record high-energy, downstream migration of sand and gravel bars on the channel floor, followed by lower-energy, waning-flow conditions in which only sand was transported and deposited, mantling the channel-floor bar (Rust, 1972; Bridge et al., 1986, 1998). Channel-floor bar deposits in the Amoco No. 1 Bickham core, commonly composed of massive gravel beds with a relatively finer-grained matrix of medium- to coarse-grained sand (Fig. 9A). The origin of the fine-grained matrix is related to suspended fines that settle into voids between gravel clasts during waning flow (Smith, 1974). The absence of very fine to fine-grained sandstone and mudstone beds records repeated erosion and cannibalization of abandoned-bar deposits by episodes of high-energy river transport.

Transgressive Systems Tract

Description. The upper 15 ft (4.5 m) of section in the Amoco No. 1 Bickham core is an upward-fining interval that ranges from planar-stratified, fine- to medium-grained sandstone from the top of an uncored section at 16,364 ft (4989.0 m) to burrowed, very fine- to fine-grained sandstone overlain by silty mudstone at 16,350 ft (4984.8 m) (Fig. 8). The middle part of the interval is intensely burrowed, but with low-diversity ichnofauna Zsuch as *Palaeophycus* and *Ophiomorpha* in the Amoco No. 1 Bickham core (Fig. 9C) could be interpreted as stressed, nearshore environments typical of brackish-water conditions encountered in the variable-energy, proximal part of the estuary (Nichol et al., 1997; MacEachern and Bann, 2008). However, the high degree of burrowing in this interval in the Amoco No. 1 Bickham core suggests instead a more distal-estuarine setting with relatively stable salinity conditions and a more pronounced marine influence (Allen and Posamentier, 1993).

Porosity and Permeability

Permeability values in Amoco No. 1 Bickham core from 16,373 to 16,410 ft (4991.8 to 5003.0 m) vary greatly, recording both conglomeratic and sandy bedload-fluvial facies (Fig. 8). Greater permeability values (>100 to ~2000 md) in this lower section coincide with coarse- to very coarse-grained sandstone beds with sparse pebbles, whereas lower values (<10 md) mostly occur within conglomerate zones. Given the blocky GR responses in these bedload-fluvial successions wherein lithology varies from sandstone to conglomerate, predicting zones of greater reservoir quality could be difficult from wireline-logs only.

In contrast, the vertical permeability profile in overlying transgressive, marginal-marine facies is less complex, consisting of an upward-decreasing trend, ranging from ~100 md with planar-stratified, fine-grained and unburrowed sandstone at the base, to <10 md in overlying extensively-burrowed, very fine- to fine-grained sandstone. Lowest permeability values (≤1 md) occur in mudstone at the top of the succession (Fig. 8).

Amoco No. 1 Fontaine

The Amoco No. 1 Fontaine well (Figs. 3 and 10), occurs outside the western margin of a major Tuscaloosa incised-valley complex (Fig. 3). The section in the Amoco No. 1 Fontaine well at approximately the same stratigraphic level of the incised-valley fill is composed of a >600 ft (>180 m) section of numerous 30 to 80 ft (9 to 24 m) sandstone intervals interbedded with comparably thick intervals of primarily mudstone (Fig. 3). The core from the Amoco No. 1 Fontaine well, which is from the lower half of this section (Fig. 3), is composed of a lower ~27 ft (8.2 m) section that contains two 10 to 12 ft (3.0 to 3.7 m) upward-fining intervals, with the lower upward-fining interval truncating a 4 ft (1.2 m) section of burrowed, fine-grained sandstone and mudstone (Fig. 10). This lower section is overlain by a 12 ft (3.7 m), upward-coarsening section of very fine- to fine-grained sandstone and mudstone. The upper 14 ft (4.3 m) above the uncored section consists of predominantly planar-stratified fine-grained sandstone (Fig. 10).

Fluvial

Description. The lower, sandy section of the Amoco No. 1 Fontaine core, from 18,828 to 18,851 ft (5740.2 to 5747.3 m) is composed of two upward-fining sections, each 10 to 14 ft (3.0 to 4.3 m) thick (Fig. 10). Each upward-fining interval ranges from pebbly, medium- to coarse-grained sandstone with clay clasts at the base (Fig. 11A) to very fine- to fine-grained, crossbedded and ripple-stratified sandstone at the top (Figs. 10 and 11B). These upward-fining intervals contain numerous scour surfaces, more common near the base of each interval. The middle part of each interval exhibits light oil-staining. The basal 4 ft (1.2 m) of the Amoco No. 1 Fontaine core contains burrowed, fine-grained sandstone interbedded with silty mudstone. Ichnofauna in this lowest section include *Palaeophycus*, *Planolites*, and sparse *Ophiomorpha*.

The lower, sandy section of the Amoco No. 1 Fontaine core is overlain by an upward-coarsening section from 18,815 to 18,828 ft (5736.3 to 5740.2 m) (Fig. 10). The section at the base consists of laminated, silty mudstone and grades upward into laminated and ripple-stratified, very fine-grained sandstone with numerous thin (mm-scale) mud drapes (Fig. 11C). The top of the section is marked by beds of fine-grained sandstone with convolute bedding (Fig. 11D).

The upper section in the Amoco No. 1 Fontaine core from 18,787 to 18,802 ft (5727.7 to 5732.3 m) has an overall blocky vertical grain-size profile, being composed mostly of fine- to medium-grained sandstone (Fig. 10). Stratification in this section is dominated by low-angle plane beds, crossbeds, and minor zones of asymmetrical ripples. The upper 2 ft (0.6 m) is capped by an erosion-based, upward-fining interval of lower-medium-grained sandstone with clay clasts.

Facies Interpretation. The two upward-fining sections in the lower half of the core represent bedload-fluvial channel-fill deposits, each with an erosional base. The upward-fining profile in the two channel-fill sections records an evolution in sedimentary processes from downstream migration of coarse-grained, gravelly sandstone bars to shallow sheetflow processes dominated by plane beds. In contrast, the middle upward-coarsening interval from 18,815 to 18,827 ft (5736.2 to 5739.9 m) represents low-energy, progradational, pond-fill deposits composed of overbank and splay facies, whereas the upper, fine- to medium-grained sandstone interval at the top of the core records subsequent channel-fill deposits.

Although the Amoco No. 1 Fontaine well occurs outside the prominent valley-fill system that includes the Amoco No. 2 Pennington and Martin Exploration No. 1 Georgia Pacific wells (Fig. 3), the juxtaposition of unburrowed, coarse-grained, upward-fining sandstone beds onto burrowed, very fine- and fine-grained sandstone interbedded with mudstone suggests the presence of high-frequency, highstand-lowstand cycles. Log-stacking patterns in the Amoco No. 1 Fontaine well from ~18,300 to ~19,000 ft (5579.3 to 5792.7 m) display sandstone beds with alternating upward-coarsening and blocky GR responses, consistent with highstand parasequences truncated by lowstand fluvial deposits. However, additional data would be required to test this interpretation, including biostratigraphic and high-resolution seismic data to demonstrate truncation of strata and high-frequency stratigraphic cyclicity.

Porosity and Permeability. Porosity values in the Amoco No. 1 Fontaine core, limited to sandy and conglomeratic bedload-fluvial channel-fill facies, range from 6 to 27% (Fig. 10). Most values are greater than 20%, with two lower values occurring near the top of each upward-fining channel-fill interval. Greatest total porosity values (~23 to almost 28%) occur in the lower to

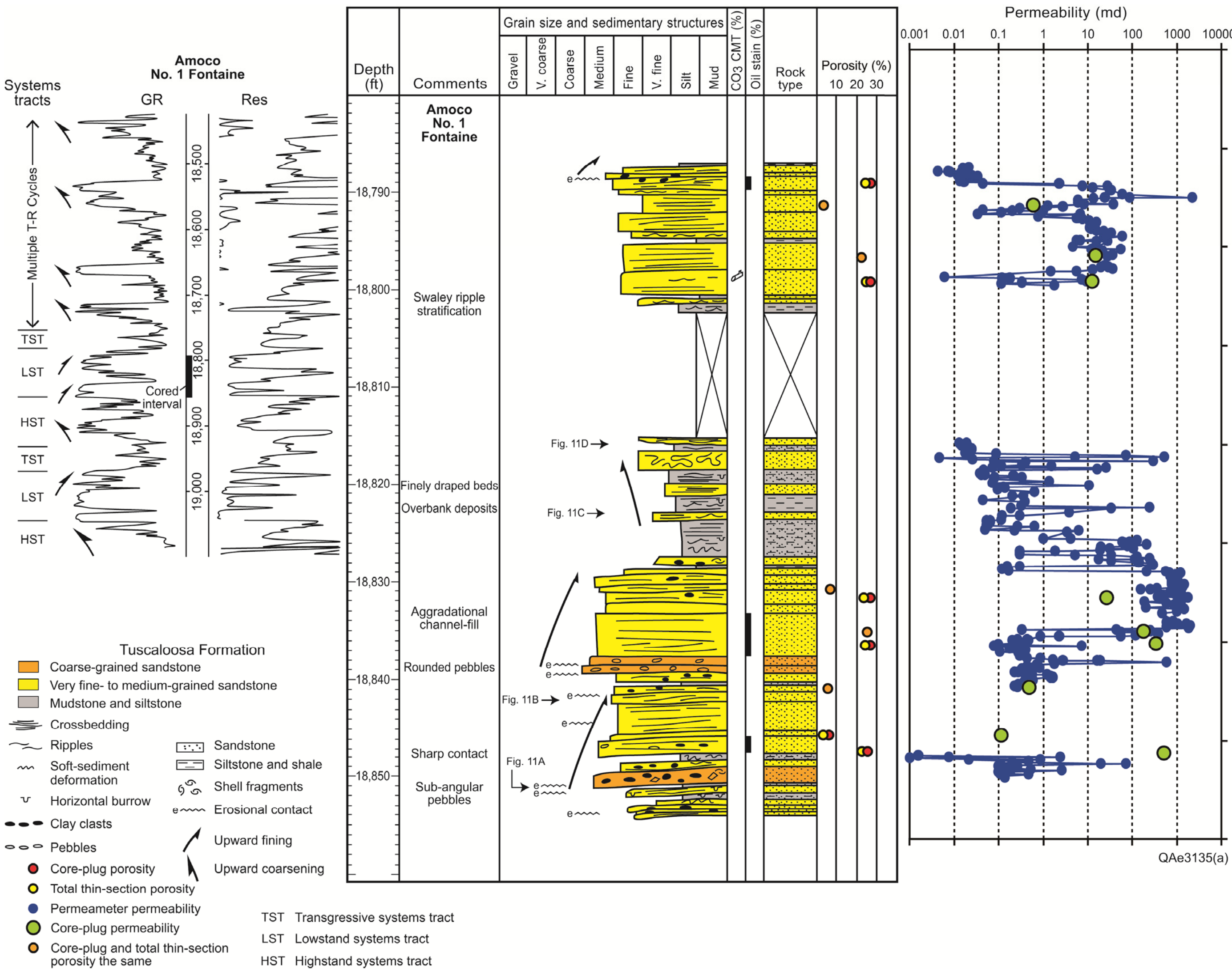

Figure 10. Core description of the Amoco No. 1 Fontaine well, included in cross-section A–A' in Figure 3. Section illustrates fluvial-channel and interfluvial splay and overbank deposits. Limited core-plug porosity data as well as permeability profile are also shown. Location of well is shown in Figure 2. Core photographs are shown in Figure 11.

middle parts of individual upward-fining cycles within sandy bedload-fluvial channel-fill facies (Fig. 10). The greatest individual total porosity value (27.6% [core-plug porosity]), occurring at 18,790 ft (5728.7 m), is from the base of an incompletely cored, upward-fining, channel-fill section composed of medium-grained sandstone with mudstone clasts (Fig. 10).

Permeability values in the Amoco No. 1 Fontaine are as great as 1200 md in sandy, non-conglomeratic medium- and coarse-grained, bedload-fluvial deposits from 18,829 to 18,838 ft (5740.5 to 5743.3 m), although they are only ~90 md in conglomeratic channel-fill deposits near the base of the cored interval (Fig. 10). Despite the presence of significant soft-sediment deformation at the top of the overbank facies at 18,818 ft (5737.2 m), permeability values in this section exceed 800 md. Low to moderate values (<0.1 to 10 md) in the middle part of this facies record thin (<1 in [2.5 cm]), very fine-grained sandstone and silty mudstone beds.

Martin Exploration No. 1 Georgia Pacific

Description

The Martin Exploration No. 1 Georgia Pacific core (Fig. 12) is from the uppermost part of an incised-valley interval (Fig. 3), represented by a 50 ft (15 m) sandy section which features a slightly upward-coarsening GR response overall, but which is composed of multiple sandstone and mudstone beds. The cored section is divided into two sandy intervals with an intervening muddy section. The lower sandy section from 15,331 to 15,353 ft (4674.1 to 4680.8 m) fines upward and consists of multiple beds of fine-grained sandstone with inclined planar stratification (Fig. 13A), grading upward into very fine- to fine-grained, sideritic sandstone with plane beds and mud-draped ripples, some double-draped (Fig. 13B). Mudstone interbeds in the upper half of this lower section are 2 to 5 in (5.1 to 12.7 cm) thick and feature *Planolites* burrows. The middle part of the core (15,319 to 15,331 ft [4670.4 to (4674.1 m]) is mudstone dominated and contains two thin sandstone beds. Stratification in these sandstone beds is dominated by mud-draped ripples. The upper section of Martin Exploration No. 1 Georgia Pacific core from 15,301 to 15,319 ft (4664.9 to 4670.4 m) is sandstone-rich. Sandstone beds in this upper section are predominantly fine-grained, with one medium-grained, clay-clast-rich sandstone bed at 15,306 ft (4666.5 m). Mudstone beds in this upper section are sparse, commonly occurring as 0.5 to 1 in (1.2 to 2.5 cm) thick, laminated zones (Fig. 13C). Accessory features in sandstone

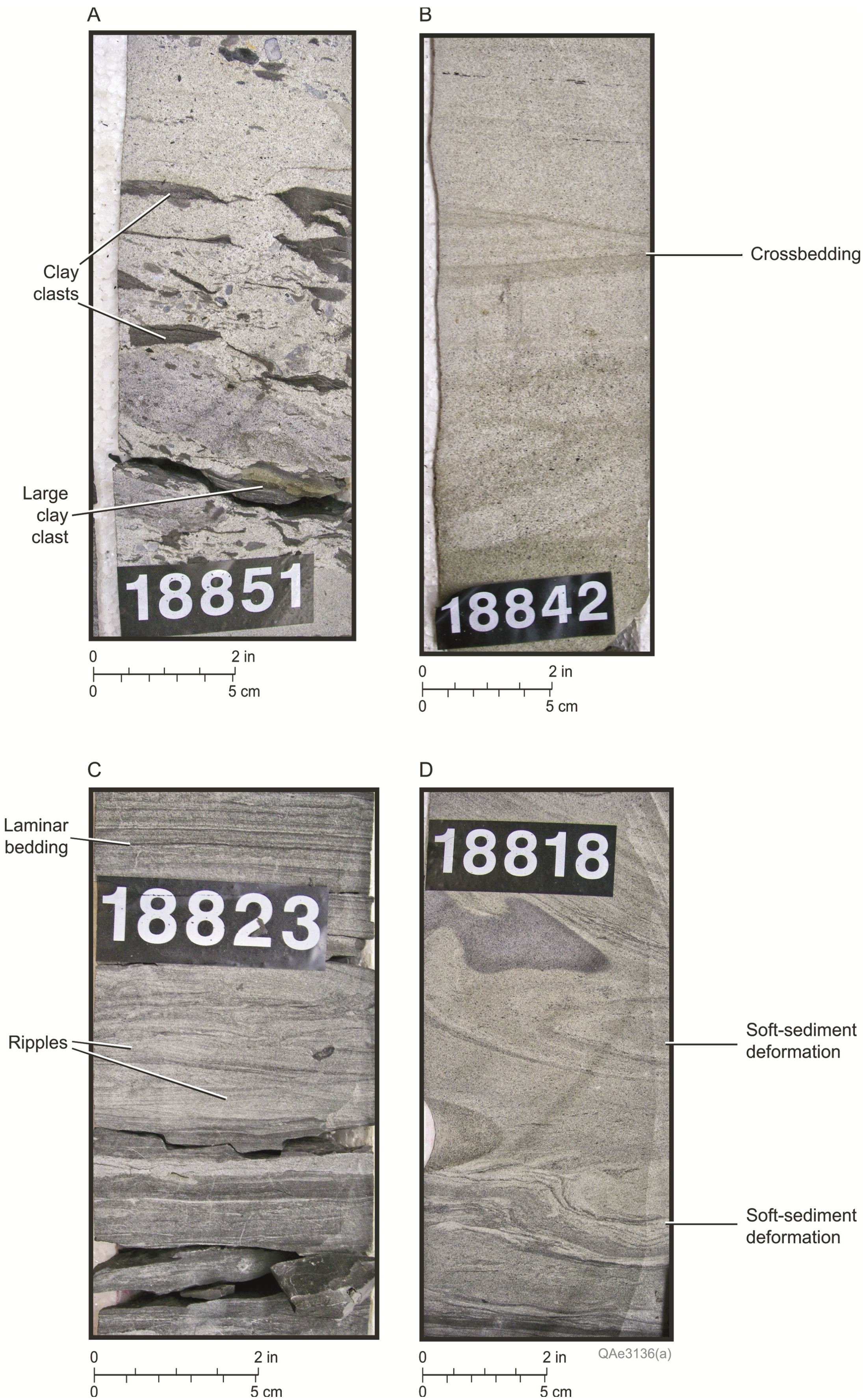

Figure 11. Core photographs from the Amoco No. 1 Fontaine well. (A) Medium-grained sandstone with abundant, subangular clay clasts at 18,851.0 ft (5747.3 m). (B) Fine- to medium-grained, crossbedded sandstone at 18,842.0 ft (5744.5 m). (C) Ripple-stratified, very fine- to fine-grained sandstone overlain by laminated, coarse-grained siltstone at 18,823.0 ft (5738.7 m). (D) Fine-grained sandstone with soft-sediment deformation at 18,818.0 ft (5737.2 m). Core description is shown in Figure 10

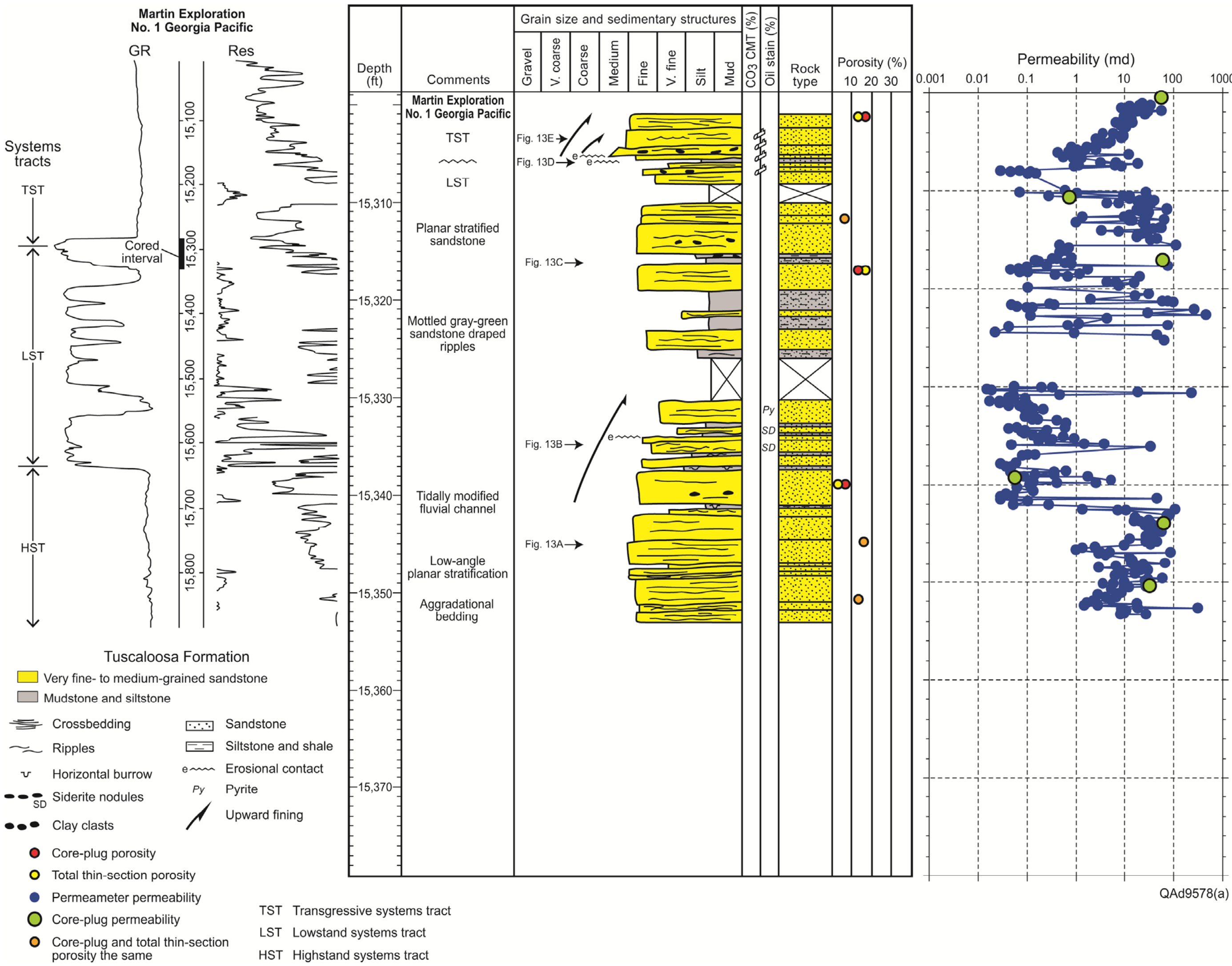

Figure 12. Core description of the Martin Exploration No. 1 Georgia Pacific well, included in cross-section A–A' in Figure 3. Section exhibits a transition from fluvial to marginal-marine deposits in the upper part of an incised-valley-fill section in the Tuscaloosa Formation. Limited core-plug porosity data as well as permeability profile are also shown. Location of well is shown in Figure 2. Core photographs are shown in Figure 13.

beds near the top of the cored section consist of shell clasts, organic fragments, irregular and thin (mm-scale) mud drapes, and truncated burrows (Figs. 13D and 13E).

Facies Interpretation

The cored section in the Martin Exploration No. 1 Georgia Pacific well, which encompasses the uppermost ~50 ft (~15 m) of the Tuscaloosa incised-valley-fill complex, represents a transition from mixed-load, tidally-modified fluvial channel-fill facies to lower-coastal-plain and transgressive-beach facies. The lowest ~30 ft (~9 m) section in the core records channel-fill and point-bar deposits in a tidally-modified setting, based on the upward transition from crossbedded and planar-stratified, upper-fine-grained sandstone grading upward into very fine-grained sandstone with double-draped ripples and silty mudstone with *Planolites* burrows (Figs. 12, 13A, and 13B). Double mud drapes record high- and low-energy conditions alternating during different phases of the tidal cycle (Reineck and Wunderlich, 1968; Terwindt, 1971; Visser, 1980; de Mowbray and Visser, 1984; Dalrymple, 1992). Examples of tidally-modified point bar deposits are documented by Allen and Posamentier (1993) in the Gironde Estuary and in estuarine deposits in St. Helena Sound in Hayes (1976). Tidally-modified point-bar deposits in the fluvial-to-estuarine transition in the Gironde Estuary are composed of ripple-stratified sandstone with abundant mud drapes and reactivation surfaces, whereas similar facies in St. Helena Sound consist of upward-fining, ripple-stratified sandstone with thin (mm-scale) mud layers.

The uppermost 5 ft (1.5 m) in the cored section in the Martin Exploration No. 1 Georgia Pacific represents destructional-beach and washover-fan deposits recording the onset of transgression of the incised-valley-fill section. This facies is characterized by numerous scour surfaces with rip-up clasts (Fig. 13E) and an upward-fining grain-size profile (Fig. 12) recording progressive water deepening and marine inundation. Similar profiles and stratification in transgressive deposits occur in destructional-beach and washover-fan deposits along the South Carolina coastline between the Santee Delta and Cape Romain, where they consist of fine- and medium-grained sand with abundant internal scour surfaces and mud, peat, and shell clasts (Stephens et al., 1976; Ruby, 1981). Other modern analogs of transgressive shoreline deposits with washover fan and other destructional storm-related facies on the landward margin of beach and barrier

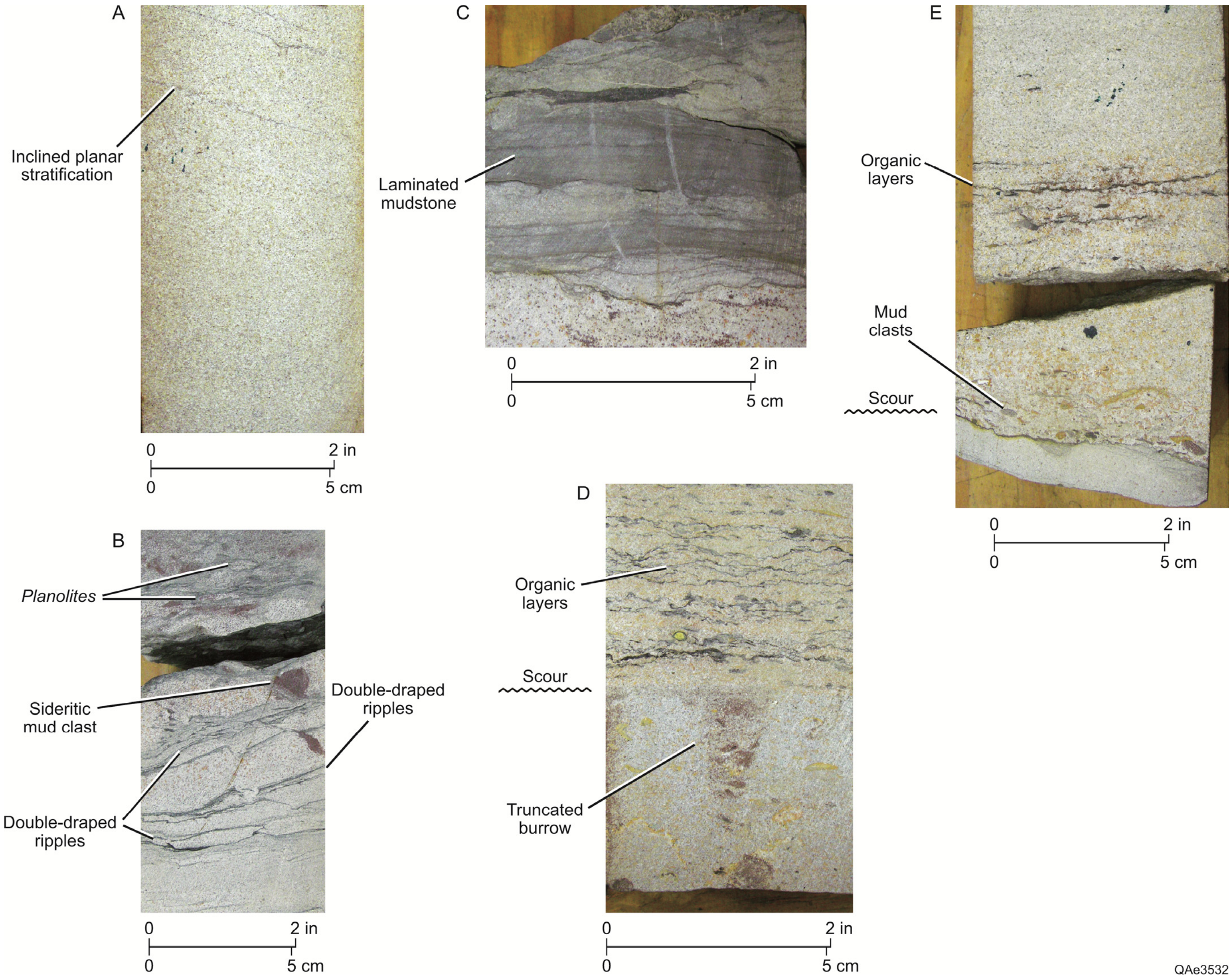

Figure 13. Core photographs from the Martin Exploration No. 1 Georgia Pacific core. (A) Crossbedded, fine- to medium-grained sandstone in fluvial channel-fill deposits at 15,345.0 ft (4678.4 m). (B) Upward-fining section at 15,335.0 ft (4675.3 m) composed of fine-grained sandstone with abundant scour surfaces, overlain by very fine-grained sandstone with minor double mudstone drapes and reddish clay clasts. (C) Thin (1 in [2.5 cm]) mudstone bed at 15,316.0 ft (4669.5 m) overlain by ripple-stratified, very fine-grained sandstone in upper incised-valley-fill interval above fluvial deposits. (D) Lightly-colored, burrowed sandstone truncated by darker-colored sandstone with abundant organic fragments at 15,306.0 ft (4666.5 m). (E) Medium-grained sandstone with elongate clay clasts and thin (mm-scale) organic layers in erosional contact with fine-grained, featureless sandstone at 15,305.0 ft (4666.2 m). Core description is shown in Figure 12.

deposits include sections of the Texas and Alabama coastline—the Matagorda Peninsula (Wilkinson and Basse, 1978) and Dauphin Island (Davies and Hummell, 1994), respectively—where coalesced washover lobes with clay and shell lags, having formed in response to hurricanes and storms, interfinger with muddy lagoonal facies.

Porosity and Permeability

Permeability values in the lower half of the channel-fill section from 15,342 to 15,353 ft (4677.3 to 4680.8 m) in the Martin Exploration No. 1 Georgia Pacific core increase upward from 1 to 100 md (Fig. 12). However, with the exception of five high values greater than10 md, permeability values in the muddier and fine-grained upper half of the channel-fill section from 15,330 to 15,342 ft (4734.8 to 4677.3 m) are low, ranging from 0.01 to 4 md, consistent with point-bar deposits that commonly have upward-increasing mud content. In contrast, the upper half of the core does not exhibit any systematic trend in permeability values, although the top 5 ft (1.5 m) of section, which ranges at the base from clay-clast-rich sandstone to mud-free sandstone at the top, exhibits an upward increase in permeability from <1 md to ~100 md (Fig. 12). This upward increase in permeability in the top 5 ft (1.5 m) of the core reflects increasing depositional energy associated with transgression.

Total porosity values in the Martin Exploration No. 1 Georgia Pacific core range from to 5.2 to 15.8%, with the greatest value of 15.8% (core-plug porosity) at the top of the cored interval in TST transgressive valley-fill facies (Fig. 12; Tables 3–5). In contrast, lowest values (5.2 and 5.7% [thin-section and core-plug porosity values, respectively]), occur in the middle part of the LST mixed-load, tidally-modified fluvial facies, which contains a greater proportion of muddy matrix than relatively clean, upper-fine-grained basal channel-fill deposits below 15,342 ft (4677.4 m) (Fig. 12; Tables 3–5). Microporosity values in the Martin Exploration No. 1 Georgia Pacific core are low, contributing only a small fraction to overall porosity (Table 4).

SANDSTONE COMPOSITION AND DIAGENESIS

Tuscaloosa sandstones in central Louisiana are predominantly sublitharenites having an average composition of $Q_{86}F_1R_{13}$ (sandstone classification of Folk, 1974), with little variation between sandstones with different sequence-stratigraphic origin (Dutton et al., 2013). Volcanic rock fragments (VRFs) are the most common lithic grains, having an average whole-rock volume of 5.4%; they are slightly more common in sandstones of lowstand depositional origin (Fig. 14). VRFs in Tuscaloosa sandstones are interpreted to be fragments of ultrabasic volcanics and volcanoclastics derived from Cretaceous volcanic activity in southwestern Arkansas, north-central Louisiana (Thomson, 1979; Pittman et al., 1992), and Mississippi (Harrelson, 1981).

Chert is a common sedimentary rock fragment (SRF) in Tuscaloosa sandstones in central Louisiana. Although chert is present in all three Tuscaloosa sequence tracts in the study area, large chert clasts (coarser than medium sand) are almost entirely confined to LST systems tracts, being particularly abundant in bedload-fluvial channel systems in the lower part of incised-valley systems (Figs. 6, 7A, and 8A). Average grain size data from thin-section point counts indicate that LST sandstones are the most coarse-grained (0.233 mm), whereas average grain size in HST sandstones is 0.165 mm and 0.154 mm in TST sandstones.

Quartz is the most abundant authigenic cement in Tuscaloosa sandstones in central Louisiana (6.2%), followed by chlorite (5.1%) and carbonate (calcite, Fe-calcite, and ankerite) (4.7%) (Dutton et al., 2013). Porosity is preserved in some deep Tuscaloosa sandstones because thick, continuous chlorite coats formed around detrital grains as a result of dissolution of VRFs and thus inhibited quartz cementation (Thomson, 1979; Smith, 1985; Hamlin and Cameron, 1987; Pittman et al., 1992; Dutton et al., 2013). Chlorite-cement content in the Tuscaloosa Formation in central Louisiana displays little variation with sequence stratigraphic setting, although it is slightly more abundant in LST fluvial deposits (5.9% average) than in HST deltaic deposits (4.7%) or in TST sandstones (4.9%) (Dutton et al., 2013).

DISCUSSION: CONTROLS ON POROSITY AND PERMEABILITY

Porosity loss in Tuscaloosa samples in this study is mainly controlled by cementation, mechanical compaction, and deformation of ductile grains such as clay clasts, micas, VRFs, and metamorphic rock fragments (MRFs). Average intergranular volume in Tuscaloosa sandstones is 23.9%, as calculated by the method of Houseknecht (1987). Most secondary pores in Tuscaloosa sandstones formed by dissolution of VRFs, with lesser amounts from dissolution of feldspars. Estimation of primary porosity loss by compaction and cementation indicates that Louisiana Tuscaloosa sandstones in central Louisiana lost an average of 20.9 porosity units by compaction and 14.6 porosity units by cementation, as calculated by the method of Ehrenberg (1989). Average microporosity, defined as pores having pore-aperture radii <0.5 µm (Pittman, 1979), is 7.5% in Tuscaloosa sandstones. This high volume of microporosity is the result of: (1) abundant chlorite rims that contain micropores between clay crystals, (2) microporous chert clasts, and (3) abundance of rock fragments, particularly VRFs that were susceptible to dissolution (Dutton et al., 2013).

Porosity and permeability values in the Tuscaloosa Formation in central Louisiana display a wide range (Tables 1–5). Median and average point-count and core-plug porosity values are greatest in LST sandy bedload-fluvial channel-fill and conglomeratic bedload-fluvial channel-fill facies (Tables 3–5). In contrast, HST crevasse-splay facies have the lowest median and average porosity values (both 7.8%), although porosity values in this facies are represented by only two data points. All major facies within all three sequence tracts (TST, LST, and HST) locally display low values of permeability (<0.1 md), although greatest values (>1000 md) occur in two systems tracts and three facies (LST mixed-load, tidally-modified fluvial, LST sandy bedload-fluvial channel fill, and HST distal delta front) (Tables 1–2). From minipermeameter data, LST sandy bedload-fluvial channel-fill facies contain the greatest permeability values of all Tuscaloosa facies in this study, with maximum (5410 md), average (~240 md), and median values (45.3 md). Lowest permeability values are associated with crevasse-splay facies, where median values are only 0.3 md (Tables 1–2). Core-plug permeability data indicate that greatest values also occur in LST sandy bedload-fluvial channel-fill facies.

Highstand Systems Tract: Facies

Distal Delta Front and Crevasse Splay

Vertical permeability profiles for both the distal-delta-front and crevasse-splay facies are similar, exhibiting cycles of upward-increasing values, although the overall range in permeability values is slightly greater in the distal-delta-front facies (Fig. 4). Although many sandstone beds in the distal-delta-front sandstone facies are coarser grained and slightly more permeable than sandstone beds in the crevasse-splay facies, they are thinner, reaching only a maximum thickness of 1 ft (0.3 m) individually (Fig. 6). Reservoir quality is difficult to predict in individual sandstone beds in the distal-delta-front facies, regardless of the position of the sandstone bed within an upward-coarsening cycle. For example in the Amoco No. 2 Pennington well, greater permeability values (almost 800 md) occur in thin sandstone beds at the base of an upward-coarsening interval at 16,620 ft (5067.1 m) than near the top of the same upward-coarsening interval at 16,617 ft (5066.2 m) (Fig. 6). Likewise, considerable variation in permeability values occurs within the crevasse-splay facies at the 1 ft (0.3 m) scale, although the net trend is upward-increasing values from 20,067 ft (6118.0 m) to 20,060 ft (6115.9 m) (Fig. 4).

Lowstand Systems Tract: Facies

Sandy Bedload-Fluvial Channel Fill and Conglomeratic Bedload-Fluvial Channel Fill

The sandy bedload-fluvial channel-fill and conglomeratic bedload-fluvial channel-fill facies are discussed together, as they are genetically related and intricately interbedded (Figs. 6 and 8). However, the sandy bedload-fluvial channel-fill facies contains greater porosity and permeability than the conglomeratic bedload-fluvial channel-fill facies within all categories (maximum, average, and median) (Tables 1–5). Low overall permeability values in the conglomeratic bedload-channel fill facies may, in part, reflect dominance of the rock fabric by microporous, low-permeability chert, also observed lowstand incised-valley fluvial deposits in the Woodbine Group in East Texas Field (Loucks, 2010; Loucks et al., 2015, this volume).

In valley-fill sequences in the age-equivalent Woodbine Group in East Texas Field as well as in the Tuscaloosa Formation in southwestern Mississippi (Cranfield Field), the stratigraphic succession generally consists of conglomerate beds at the base, grading upsection into medium- to coarse-grained sandstones, recording an evolution from braided to meanderbelt fluvial systems (McGowen and Garner, 1970; Stancliffe and Adams, 1986; Ambrose et al., 2009; Lu et al., 2011; Hosseini et al., 2013). However, in some wells such as the Amoco No. 1 Bickham well, it may be difficult to predict vertical reservoir porosity and permeability trends on a fine scale (~1 ft [0.3 m]), owing to the high degree of interbedding between sandy bedload-fluvial channel-fill and conglomeratic bedload-fluvial channel-fill facies, especially where chert pebbles occur throughout the section (Fig. 8). For example, both sandy bedload-fluvial channel-fill and con-

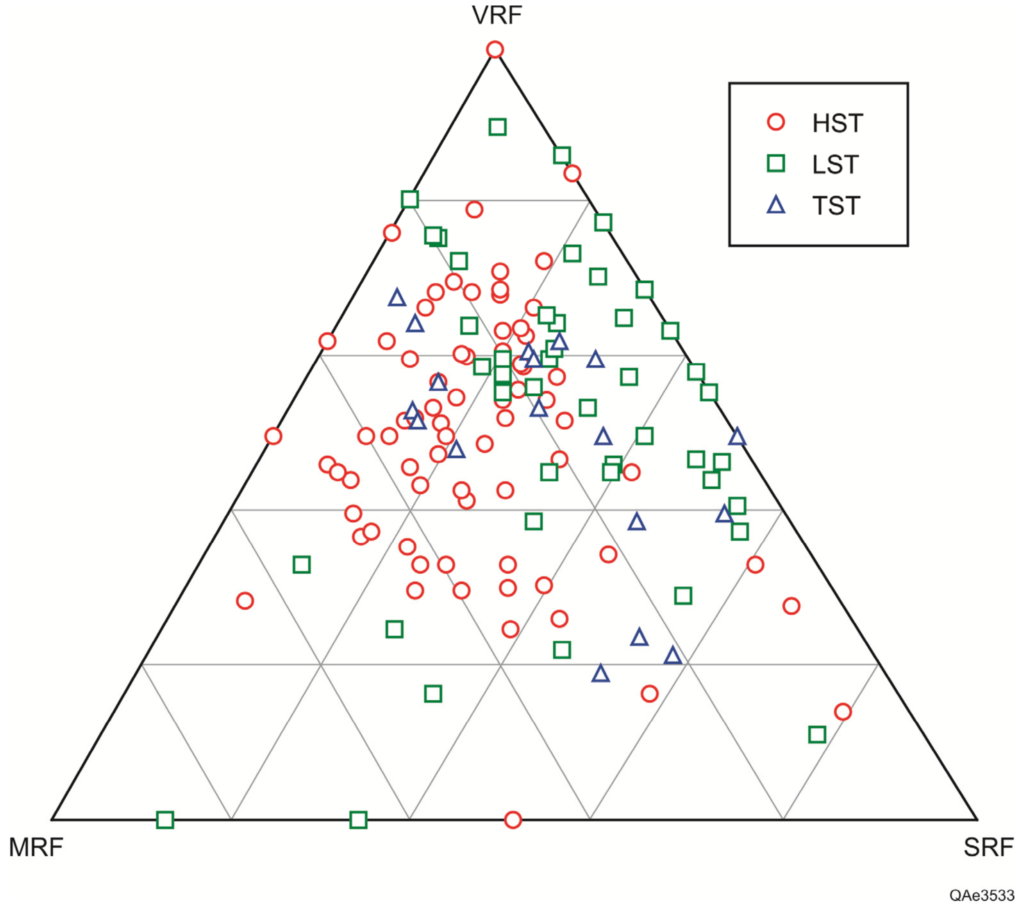

Figure 14. Ternary diagram illustrating sequence-stratigraphic origin of rock fragments (VRF [volcanic rock fragments], MRF [metamorphic rock fragments], and SRF [sedimentary rock fragments]) from Tuscaloosa cores in this study. Chert is included in the SRF fraction, but only those chert clasts from sandstone beds, excluding conglomerate beds. Internal lines in ternary diagram correspond to 20 percentage values.

glomeratic bedload-fluvial channel-fill facies in the cored interval in this well have the same blocky GR response, despite a range in permeability of four orders of magnitude (Fig. 8). The separation between these two lithofacies is more distinct in the Amoco No. 2 Pennington core (Fig. 6), although chert pebbles, which are more common in the conglomeratic bedload-fluvial channel-fill facies, are present throughout much of the sandy bedload-fluvial channel-fill facies.

Overbank and Splay

Although the overbank and splay facies locally contain great permeability values exceeding 500 md (Table 1), these high values coincide with thin (commonly <2 ft [<0.6 m]), fine-grained sandstones that generally have complex internal structure including fine-scale (mm-scale) mudstone laminations and soft-sediment deformation that impart a high degree of fine-scale heterogeneity (Figs. 10, 11C, and 11D). The majority of permeability values in this facies are low, with average values of ~10.2 md and median values of 0.07 md, the lowest of all Tuscaloosa facies analyzed in this study (Table 1). Moreover, continuity and consequent reservoir volumes in these overbank and splay sandstones are interpreted to be limited, owing to their lobate geometry and poor preservation potential in fluvial systems dominated by poorly confined channel belts with large width-to-depth ratios (McGowen and Garner, 1970; Galloway, 1977).

Mixed-Load, Tidally-Modified Fluvial

The mixed-load, tidally-modified fluvial facies contain moderate-to-high permeability values, exceeding those in conglomeratic bedload-fluvial channel-fill facies. Average permeability values for this facies are similar for core-plug and minipermeameter data, although median values differ by an order of magnitude, suggesting a skewed distribution reflecting a great number of low values in the overall distribution of values (Tables 1–2). The lower half of the mixed-load, tidally-modified fluvial succession in the Martin Exploration No. 1 Georgia Pacific core exhibits a good correlation with minipermeameter permeability, possibly related to an upward increase in muddy interbeds, although anomalously high values greater than 100 md occur in the upper channel-fill section between 15,330 and 15,335 ft (4673.8 to 4675.3 m) (Fig. 12). Vertical permeability trends in the upper half (15,306 to 15,326 ft [4666.5 to 4672.6 m]) of the mixed-load, tidally-modified fluvial succession are more complex within a section that exhibits on overall grain-size trend. Vertical permeability continuity is disrupted by muddy drapes, as well as clay and shell clasts, in tidally modified fluvial channel sandstones (Dalrymple et al., 1992; Allen and Posamentier, 1993).

Transgressive Systems Tract

Deposits in the transgressive systems tract feature moderate overall average and median porosity and permeability values (Tables 1–5). Opposing vertical permeability trends in the transgressive systems tract occur in two different cores (upward-decreasing from 16,364 to 16,349 ft [4989.0 to 4984.5 m] in the Amoco No. 1 Bickham core [Fig. 8], versus upward-increasing from 15,306 to 15,301 ft [4666.5 to 4664.9 m] in the Martin Exploration No. 1 Georgia Pacific core [Fig. 12]). In the Amoco No. 1 Bickham core, vertical permeability trends mimic intensity of burrowing and overall mudstone content (Fig. 9C). In contrast, the Martin Exploration No. 1 Georgia Pacific core [Fig. 12]), lowest permeability values (<0.1 md) coincide with the maximum grain size (medium sandstone) in the TST section, owing to abundant, low-permeability clay clasts.

Deposits within TSTs commonly feature complex variability in porosity and permeability at fine scales, owing to complex facies relationships that exist in transgressive shorelines, where wave and storm processes interplay with deltaic and fluvial processes. This variability in reservoir quality commonly controlled by in the occurrence of numerous, thin washover fans that interfinger with fine-grained, organic-rich backbarrier and lagoonal facies, as well as lithologic variability in transgressive-beach facies that includes coarse-grained shell-berm deposits, well-sorted, fine-grained sand within accretionary spits deposits, and muddy rip-up clasts from eroded lower-coastal-plain facies, with primary examples from transgressive sections of the modern South Carolina coastline south of the Santee Delta (Stephens et al. 1976; Ruby, 1981). Analogous deposits in the ancient rock record also occur in the upper Woodbine section in Double A Wells Field in Texas, where transgressive facies in the uppermost Woodbine sandstone reservoir section represent an overall upward-fining section composed of very fine- to fine-grained sandstone at the base, grading upward into silty mudstone with shell fragments with abundant *Planolites* burrows (Ambrose and Hentz, 2012).

CONCLUSIONS

Porosity and permeability values in the Tuscaloosa Formation in central Louisiana, which display a wide range, are related to sequence-stratigraphic and facies origin, as well as diagenesis. The highest reservoir quality exists in sandy, nonconglomeratic bedload-fluvial deposits within incised-valley systems. However, underlying highstand deltaic systems also contain good reservoir quality in proximal-delta-front sandstones at the top of progradational successions, suggesting that sequence-stratigraphic origin is not the sole controlling factor in reservoir quality in the Tuscaloosa Formation.

Tuscaloosa incised-valley-fill systems in east-central Louisiana record deep incision (up to ~400-ft [~120-m]) into highstand deltaic complexes. The lower half of the valley succession typically is composed of coarse-grained, including conglomeratic, braided-stream systems that grade upward into mixed-load meanderbelt deposits, in turn overlain by a regionally continuous (10- to 25-ft [3.0- to 7.6-m]) mudstone interval recording valley inundation and development of estuarine systems.

Coarse-grained bedload-fluvial facies in the lower half of the Tuscaloosa valley fill are composed of thick (commonly >100 ft [>30 m]) multistoried and aggradational successions of chert-clast conglomerate beds with a sandy matrix. These conglomerate beds, which represent migrating channel-floor-bar deposits in a braided-stream system, commonly grade upward into medium- to very coarse-grained sandstone beds that record bar-top facies. Reservoir quality, measured from porosity and permeability data, is greater in the nonconglomeratic sandstone beds.

Median and average point-count and core-plug porosity values are greatest in lowstand sandy bedload-fluvial channel-fill and conglomeratic bedload-fluvial channel-fill facies. In contrast, highstand crevasse-splay and delta-front facies which predate lowstand incised-valley-fill systems, have lower median and average porosity values. Vertical permeability trends in these highstand deltaic successions below incised-valley-fill systems mimic upward-shoaling facies trends. Permeability values in these deltaic deposits range from <0.1 md in distal-delta-front mudstones to >100 md in upward-coarsening, proximal-delta-front facies toward the top of progradational parasequences. Vertical permeability trends in these delta-front successions are complex and display serrate wireline-log patterns, owing to the presence of numerous, thin (commonly <1 ft [0.3 m]) beds of very fine-grained, planar- and ripple-stratified sandstone interbedded with burrowed mudstone.

Tuscaloosa estuarine facies consist of upward-fining sections of intensely burrowed, very fine- to fine-grained sandstone with mud-draped ripples. Ichnofauna are dominated by *Palaeophycus*, *Planolites*, and minor *Ophiomorpha*. Transgressive deposits capping the estuarine succession consist of shelly and organic-rich sandstone beds with abundant mud clasts and internal scour surfaces recording destructional marine processes. In contrast, upward-increasing permeability trends in the basal section of the transgressive systems tract at the top of the valley-fill succession are related an upward decrease in muddy matrix that record increasing depositional energy and winnowing from wave and storm processes.

Knowledge of porosity and permeability variations within facies, as well as contrasting values between facies, can be used to infer controls on reservoir quality in the Tuscaloosa Formation, as well as better predict reservoir quality at a fine scale. Significant vertical contrast in permeability occurs between Tuscaloosa facies, including: (1) highstand deltaic sandstones locally truncated by low-porosity and low-permeability chert-clast conglomerates or clay-clast-rich sandstone beds at the base of lowstand valley-fill deposits; and (2) heterogeneous and muddy estuarine deposits above sandy bedload-fluvial deposits, and where sandy, marginal-marine deposits occur near the upper part of the Tuscaloosa valley-fill succession. Although the greatest reservoir quality in the Tuscaloosa Formation in central Louisiana occurs within lowstand bedload-fluvial incised-valley deposits, significant variation in permeability occurs between conglomeratic and sandy bedload-fluvial facies, commonly interbedded at fine scales (<2 ft [<0.6 m] thickness) that may be difficult to differentiate from wireline logs in the absence of core data.

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