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Facies Variability and Reservoir Quality in the Shelf-to-Slope Transition, Upper Cretaceous (Cenomanian) Woodbine Group, Northern Tyler and Southeastern Polk Counties, Texas, U.S.A.

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ABSTRACT

The Cenomanian Woodbine Group in northern Tyler and southeastern Polk counties (Texas) represents a shelf-to-slope transition along the Upper Cretaceous shelf margin. The hydrocarbon-productive Woodbine section in northern Tyler County consists of a shallow-marine deltaic succession composed of delta-front, distributary-channel, transgressive, and highstand-shelf facies. This shallow-marine interpretation is based on: (1) *Skolithos* and *Cruziana* ichnofaunal assemblages, (2) upward-shoaling, high net-to-gross ratio, and sandy successions with an upward progression from lower-flow-regime ripples to upper-flow-regime planar stratification, and (3) the proximal paleogeographic position of the Woodbine succession along the underlying Lower Cretaceous Edwards Reef Trend.

In contrast to the productive, shallow-marine Woodbine trend updip and along the Cenomanian shelf edge in northern Tyler and northeastern Polk counties, Woodbine slope deposits downdip of the Cenomanian shelf edge are sandstone-poor, have poor to moderate reservoir quality, and therefore have limited potential for additional oil and gas development. These slope deposits typically contain thin (commonly <1-ft [<0.3-m]) beds of very fine-grained levee sandstones encased in sparsely burrowed mudstone. Sandy slope facies, consisting of channelized-levee deposits occurring within upward-coarsening successions, are composed of multiple upward-fining sandstone beds defined by incomplete Bouma sequences containing graded beds and thin (<2-in [5.1-cm]) zones of convolute bedding. Other sandy slope deposits are represented by heterolithic, erosion-based debris-flow facies with zones of chaotic bedding.

Permeability and limited porosity data from core plugs indicate that primary reservoir-quality facies in Woodbine shallow-marine systems occur in distributary-channel and proximal-delta-front facies, although original porosity has been modified by diagenesis. In contrast, Woodbine slope facies in western Tyler County have low reservoir quality and are nonproductive, although channelized-levee deposits are locally productive. Although there porosity and permeability decrease with depth, variation in reservoir quality also varies between and within both shallow-marine and deepwater facies, as a function of sedimentary facies that control grain size and stratification.

INTRODUCTION

The Upper Cretaceous Woodbine Group is a major oil- and gas-producing stratigraphic unit in the U.S. Gulf Coast. It has produced >5.42 Bstb (billion stock tank barrels) of oil from East Texas Field in the updip Woodbine trend in northeastern Texas (Wang, 2010). The productive Woodbine Group extends southward to the Lower Cretaceous Edwards Reef Trend in southeastern Texas (Fig. 1), where it produces gas, condensate, and lesser amounts of oil along the downdip Woodbine shelf-edge trend in Double A Wells and Sugar Creek fields in Polk and Tyler counties, respectively (Fig. 2). Double A Wells Field, discovered in 1985, produces oil and gas mainly from sandy fluvial-dominated and wave-modified deltaic deposits (Ambrose and Hentz, 2012) and has an expected ultimate recovery of ~0.5 Tcf (trillion cubic ft) of gas and 20 MMbbl (million barrels) of condensate (Stricklin, 2002; Adams and Carr, 2010). Cumulative production in the field is >450 Bcfe (billion cubic ft of gas equivalent) (Bunge, 2011). Ultimate production from these and other extensively-drilled Woodbine fields along the Edwards Reef Trend in these fields is estimated to exceed 1 Tcf of gas and 30 MMbbl of oil and condensate (Byther, 2006). In contrast, Woodbine slope facies south of the Edwards Reef Trend are less productive, with limited production mainly from slope-channel and levee facies (Siemers, 1978).

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Figure 1. (A) Paleographic features (shelf edge and regional depositional setting) for the Upper Cretaceous (Cenomanian) Woodbine Group in southeastern Texas. (B) Upper Cretaceous stratigraphic column in East Texas. Oil and gas fields and distribution of cored wells presented in study are shown in Figure 2. Stratigraphic nomenclature compiled from Childs et al. (1988), Salvador and Muñeton (1989), and Sohl et al. (1991).

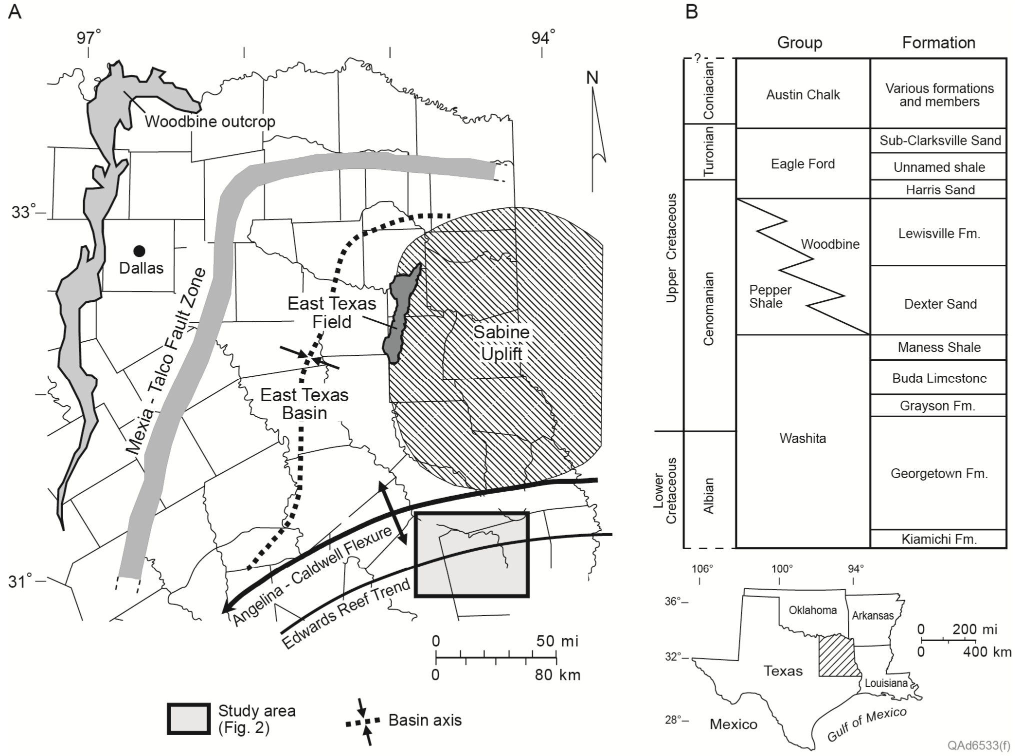
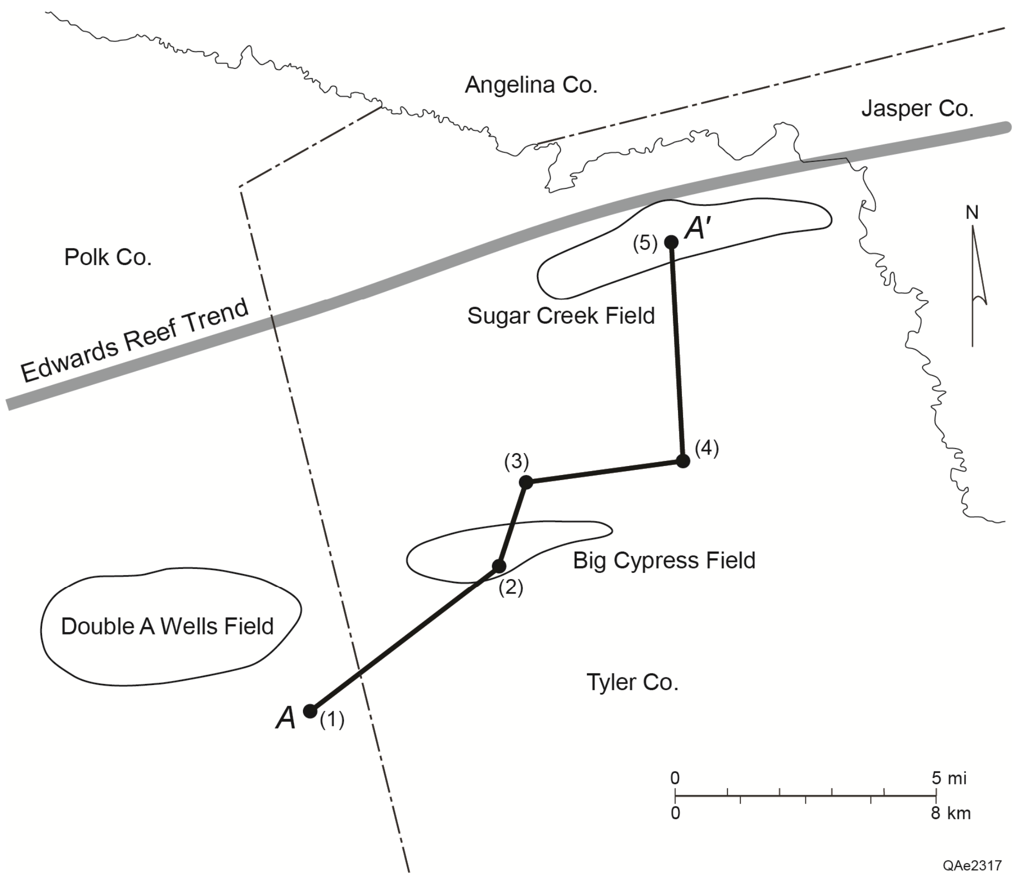


Figure 2. Location of Edwards Reef Trend. Double A Wells, Sugar Creek, and Big Cypress fields in Polk and Tyler counties. Cores presented in this study are included on stratigraphic cross section A–A', shown in Figure 3. Wells on cross section are indicated with number in parentheses, which are also displayed in Figure 3. Area of map is displayed in Figure 1A. Depositional setting of cored wells in this study are depicted in Figure 17.



OBJECTIVES AND DATA

The three main objectives of this study were to: (1) describe and interpret depositional facies and reservoir quality in the shelf-to-slope transition in the Upper Cretaceous (Cenomanian) Woodbine Group in northern Tyler and southeastern Polk counties, (2) characterize vertical permeability trends within sandstones from core data and relate reservoir quality to depositional facies, and (3) contrast facies controls on reservoir quality in Woodbine slope facies versus those in Woodbine shallow-marine systems. These objectives were achieved by describing depositional facies from cored wells along the shelf-to-slope transition and integrating these descriptions with well log and permeability data depicting both lateral and vertical stratigraphic variability.

Data used in this analysis include whole cores from five wells, supplemented with correlations of significant stratigraphic surfaces (flooding surfaces and unconformities) from well logs. Owing to sparse well control outside of oil and gas fields, where many wells are deviated with few penetrating the Woodbine Group, this study was mainly based on core data. The Woodbine Group in this study was divided into four informal stratigraphic units (Lower Woodbine 1, Lower Woodbine 2, Upper Woodbine 1, and Upper Woodbine 2), based on correlation of low-resistivity flooding surfaces (Fig. 3).

Permeability data from cores were derived from a minipermeameter, which employs a pressure-decay system to measure permeability values from 0.001 md (millidarcys) to >30 darcys. Permeability values were corrected for slip (Klinkenberg) for non-darcian flow (Forchheimer Factor [Forchheimer, 1901; Huang and Ayoub, 2006]). Porosity data from plugs were provided for cores in the Cities Service No. B–1 Sutton and Humble No. 1 Howell wells (Figs. 2 and 3). Although core-plug porosity data were not available for the three other cores in the dataset, point-count porosity and mineralogy data from the Humble No. 1 Howell, Standard No. 2 Longbell, and Cities Service No. B–1 Sutton wells were integrated from petrographic studies of cores in Tyler County (Young and Barrett, 2003) to document diagenetic controls on reservoir quality.

Data recorded in core descriptions include grain size, stratification, and contacts, as well as accessory features such as soft-sediment deformation, flame structures, 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 and stratification. A subregional cross section of logs from cored wells displays continuity of major stratigraphic surfaces and progradational successions that documents the shelf-to-slope transition in Tyler County (Fig. 3). Facies interpretations, stratigraphic relations, and paleogeographic elements inferred from this study of the Woodbine Group in Tyler County were integrated with similar data and interpretations of the Woodbine succession in Double A Wells Field in Polk County and adjacent areas, previously documented in Siemers (1978), Foss (1979), Adams and Carr (2010), Bunge (2011), and Ambrose and Hentz (2012).

GEOLOGIC FRAMEWORK

The Upper Cretaceous (Cenomanian) Woodbine Group in northern Tyler and southeastern Polk counties was deposited

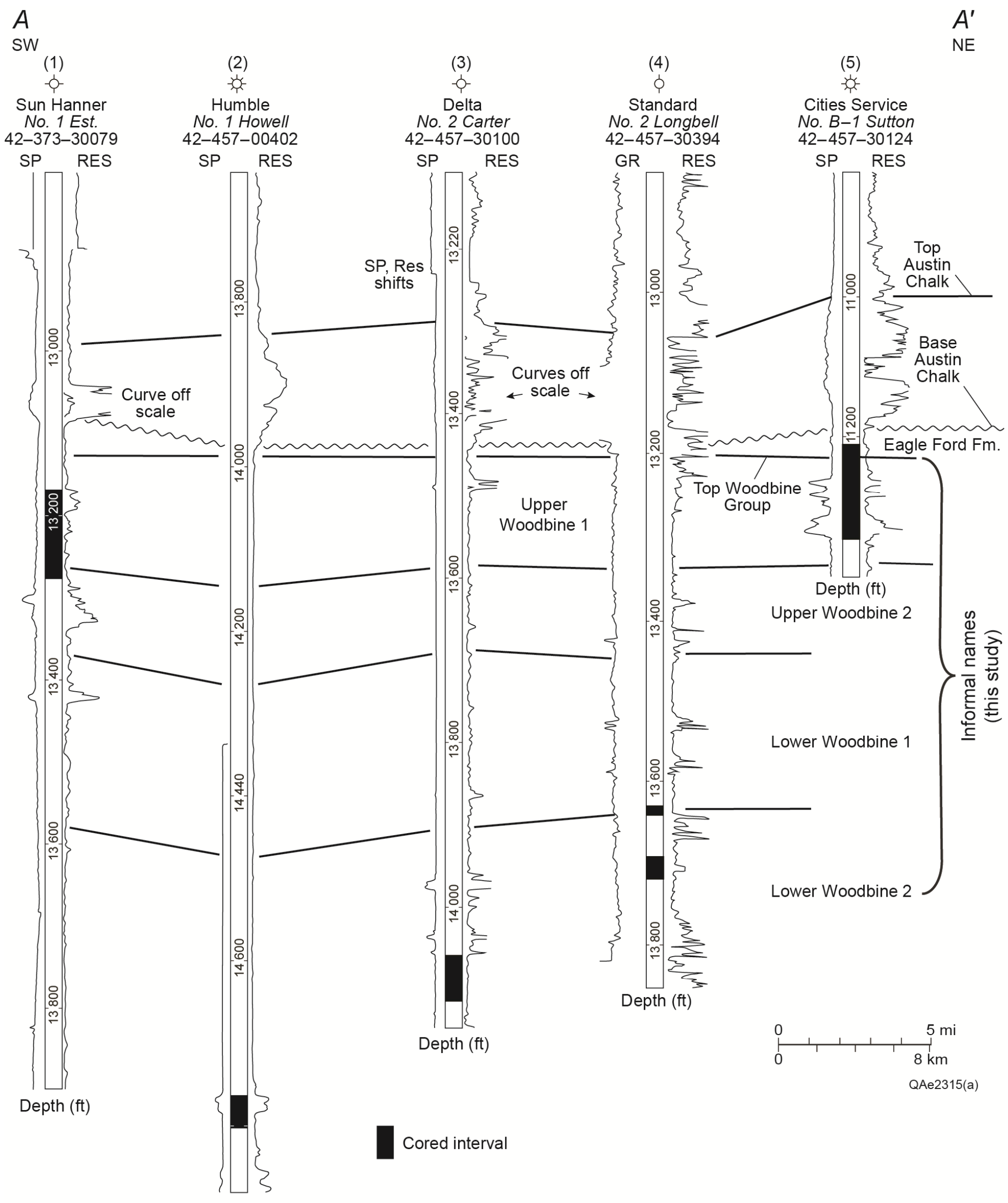


Figure 3. Stratigraphic cross section A–A' in southeastern Polk and northwestern Tyler counties, showing stratigraphic position of the five cored wells in this study. Datum is the top of the Woodbine Group. SP = spontaneous potential, and GR = gamma ray. Locations of cross section and cored wells are shown in Figure 2. Depositional setting of cored wells in this study are shown in Figure 17.

along the Lower Cretaceous Edwards Reef Trend (Fig. 1A). During periods of sea-level fall, Woodbine incised-valley systems delivered sediment southward and southwestward from the west flank of the Sabine Uplift in northeastern Texas to the Woodbine shelf edge (Ambrose et al., 2009; Ambrose and Hentz, 2010). The Edwards Reef Trend and the Angelina-Caldwell Flexure north of Tyler and Polk counties were associated with the Upper Cretaceous shelf break (Siemers, 1978; Foss, 1979; Sohl et al., 1991; Mancini and Puckett, 2005; Bunge, 2007). However, the Upper Cretaceous shelf-to-slope stratigraphic succession in Double A Wells Field to the west in eastern Polk County suggests that the Woodbine shelf edge may have been basinward of the underlying Edwards Reef Trend (Ambrose and Hentz, 2012).

The lower part of the Woodbine Group in southeastern Polk and Tyler counties consists of up to 500 ft (152 m) of a mudstone-dominated succession, with individual sandstone bodies commonly <15 ft (<4.5 m) in thickness (Fig. 3). This lower Woodbine succession was interpreted by Siemers (1978) and Foss (1979) as a deepwater-slope system with well-developed, muddy slump and debris-flow deposits. Slope instability was controlled by the underlying Lower Cretaceous carbonate-shelf margin, where thin turbidites were deposited in narrow, dip-elongate channel systems (Berg, 1981).

In contrast, the upper part of the Woodbine Group in southeastern Polk and Tyler counties is composed of relatively sandier, upward-coarsening strata with individual sandstone bodies typically >20-ft (>6-m) thick within successions of 50 to 100 ft (15.2 to 30.4 m) in thickness (Fig. 3). The upper part of the Woodbine Group in these areas consists of intensely burrowed sandstones of deltaic and shelf origin that were deposited over the lower Woodbine prograding slope section (Berg, 1981). Upper Woodbine deltaic deposits have characteristics of shelf-margin deltas that include: (1) growth faults associated with high subsidence rates and sediment loading, (2) isopach maxima (Adams and Carr, 2010; Ambrose and Hentz, 2012), (3) topset-foreset geometry within thick, gently-dipping (3–6º) clinoformal strata (Bunge, 2007), (4) gravity sliding features at a variety of scales that include large slump blocks recognized in seismic data and small-scale sediment gravity flows observed in core (Ambrose and Hentz, 2012), and (5) transitional neritic-to-upper bathyal ichnofaunal assemblages marking the shelf break. Many of these characteristics are commonly associated with shelf-edge deltaic depositional systems (Winker and Edwards, 1983; Mougenot et al., 1983; Kolla et al., 2000; Posamentier and Morris, 2000; Porębski and Steel, 2003).

SHALLOW-MARINE SYSTEMS

Proximal Shallow-Marine

Proximal shallow-marine systems in northern Tyler County are represented by the Cities Service No. B–1 Sutton well (Fig. 4). This well produced ~36,400 bbl (barrels) of oil and condensate, as well as >1.96 Bcf (billion cubic ft) of gas from 1976 to 1984. The Woodbine Group in the Cities Service No. B–1 Sutton is composed of two sandstone-rich, upward-coarsening progradational cycles containing *Palaeophycus* burrows, interbedded with mudstone-rich zones dominated by *Planolites* burrows. The lower sandstone-rich section, from 11,292 to 11,323 ft (3442.7 to 3452.1 m), has an overall blocky vertical grain-size profile, although the lower 6 ft (1.8 m) coarsens upward (Fig. 4).

The upper sandy interval from 11,250 to 11,284 ft (3429.9 to 3440.2 m) coarsens upward from very fine-grained sandstone with ripple stratification at the base to a relatively thicker section composed of fine-grained sandstone with inclined planar stratification (Fig. 4). This upper sandy interval is overlain by a thick (50-ft [15.2-m]) section of mudstone interbedded with thin (<1-ft [<0.3-m]) beds of very fine-grained sandstone with wave-ripple stratification. Ichnofauna in this muddy section are dominated by *Planolites* (Figs. 4, 5B, and 5D).

The Woodbine Group in the Cities Service No. B–1 Sutton well was interpreted by Siemers (1978) as deepwater in origin, based on dominance of massive stratification within the lower sandstone section from 11,292 to 11,322 ft (3442.7 to 3451.9 m) (Fig. 4) and sparse burrowing. In contrast, we interpret the section as shallow-marine in origin, based on observations presented in the following sections "Distributary Channel" and "Transgressive and Highstand Shelf." These observations include: (1) its proximal position along the Edwards Reef Trend, updip of mudstone-dominated slope deposits in central and western Tyler County, (2) *Skolithos* and *Cruziana* ichnofaunal assemblages (Figs. 4, 5A, 5B, and 5D), (3) shallow-marine fauna, including gastropods (Fig. 5E), and (4) a sandstone-rich vertical succession with upward progression from lower-flow-regime ripples to upper-flow-regime planar stratification, consistent with upward-shoaling depositional processes (Fig. 4).

Distributary Channel

Distributary-channel deposits in the Cities Service No. B–1 Sutton core, occurring from 11,292 to 11,322 ft (3442.7 to 3451.9 m) (Fig. 4), are composed at the base of weakly planar-stratified, upper-fine-grained sandstone with clay clasts. The section grades upward to 11,299.6 ft (3445 m) into very fine- to fine-grained sandstone with ripples and planar stratification. The section has an abrupt base at 11,322 ft (3451.9 m), with clay clasts recording erosion of underlying muddy delta-front facies (Fig. 4). The upper one-half of the distributary-channel facies is composed of very fine- to fine-grained sandstone with prominent, inclined *Palaeophycus*, representing clay-lined dwelling burrows of polychaetes (Fig. 5A). The *Palaeophycus* interpretation is based on burrows being: (1) distinctly clay-lined, (2) cylindrical, and (3) having sediment fill the same as the host stratum. They are interpreted as *Palaeophycus* rather than *Skolithos* or *Planolites* because they have a greater width-to-length ratio than *Skolithos*, are clay-lined, and are inclined rather than truly vertical, although *Skolithos* can assume some of these characteristics (Pemberton and Frey, 1982; Frey et al., 1990). *Palaeophycus* is distinguished from *Planolites* by being significantly mudstone-lined, whereas *Planolites* commonly lacks mudstone walls. Unlike *Thalassinoides*, *Palaeophycus* is not branching and not developed in a muddy substrate; it also differs from *Ophiomorpha* by having thin clay walls. *Palaeophycus* also differs from *Diplocriterion* and *Arenicolites* by lacking spreiten and diagnostic U- and J-shapes (Pemberton et al., 1992). *Palaeophycus* burrows are commonly associated with the *Skolithos* ichnofacies assemblage, recording a high-energy, shallow-marine setting, although *Palaeophycus* can also be encountered in lower-energy depositional environments (Pemberton et al., 1992).

The uppermost 7 ft (2.1 m) of the distributary-channel facies consists of fine-grained sandstone with low-angle planar stratification. The lower 1 ft (0.3 m) of this section coarsens upward, whereas the upper 1 ft (0.3 m) grades upward into burrowed, sideritic mudstone (Fig. 4). *Planolites* is common at the top (Fig. 5B). Sparse core-plug porosity data indicate an upward decrease in porosity from 17.5% near the base to 7.5% near the top of the distributary-channel facies (Fig. 4). Although the vertical trend in permeability trend is similar to that of porosity, these values increase upward from the base, reach a maximum of 74.8 md at 11,313.4 ft (3449.2 m) in the lower one-third of the section, and systematically decrease upward to 0.2 md at the top of the section (Fig. 4).

Delta Front

Delta-front deposits in the Cities Service No. B–1 Sutton core, divided into distal and proximal facies, extend from 11,250 to 11,292 ft (3429.9 to 3442.7 m) (Fig. 4). The delta-front section coarsens upward, ranging from burrowed mudstone at the base to fine-grained sandstone with inclined planar stratification at the top (Fig. 5C). Sections from 11,260 to 11,267 ft (3432.9 to 3435.0 m) and 11,275 to 11,285 ft (3437.5 to 3440.6 m) contain abundant soft-sediment deformation and distorted ripple stratification (Fig. 4), recording sediment failure and gravity-sliding processes. Similar stratification occurs in distal-delta-front facies in the East Texas Field (Ambrose et al., 2009) and Double A Wells Field (Ambrose and Hentz, 2012). Permeability values in the distal-delta-front facies are low, ranging from less than 1.0

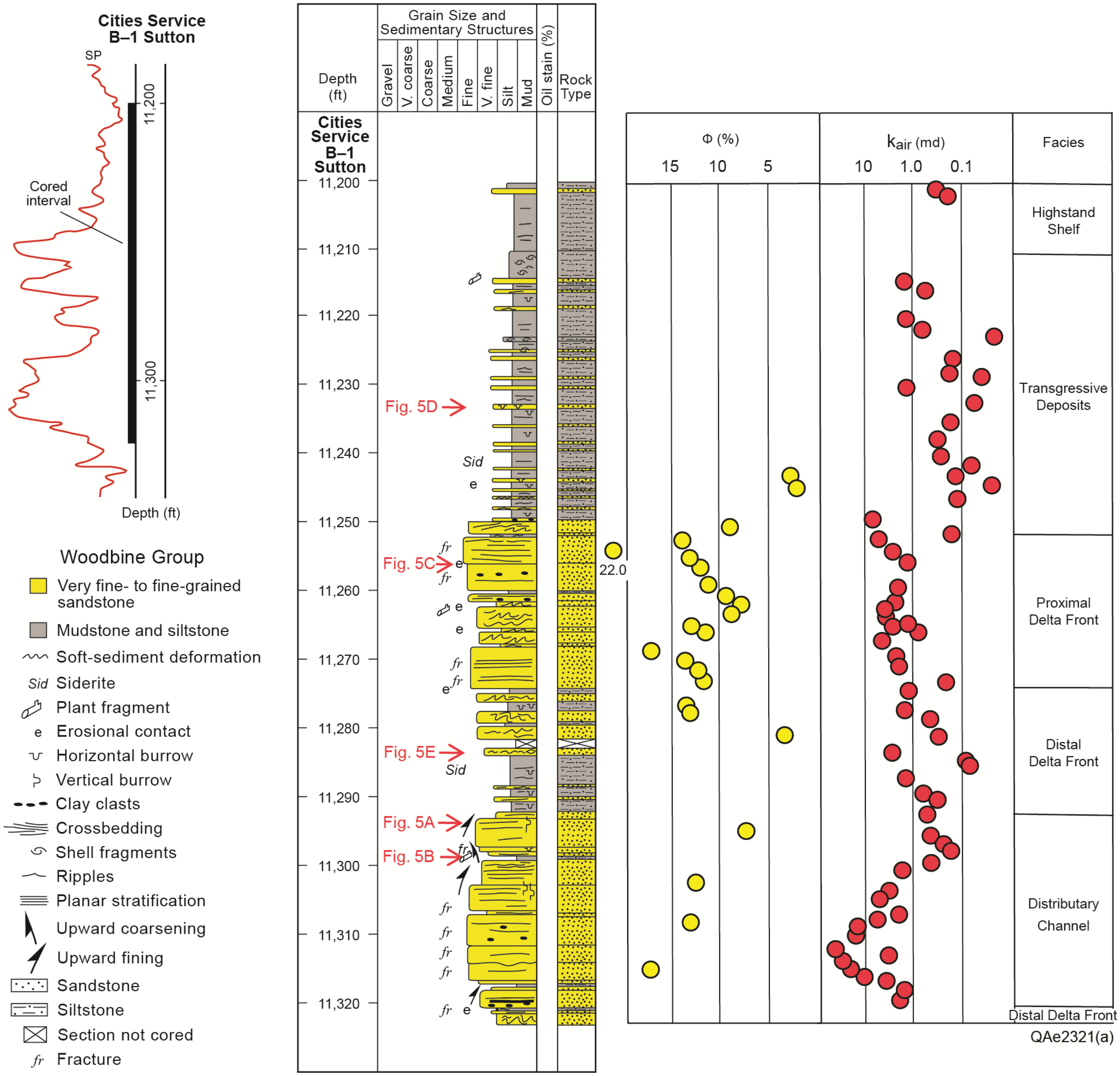


Figure 4. Core description of the Cities Service No. B–1 Sutton well, located in Figure 2 and shown in Figure 3. Core photographs are shown in Figure 5.

md to 3.7 md (Table 1) and displaying an upward-increasing trend (Fig. 4).

Sandstone beds in the overlying proximal-delta-front facies are thicker and coarser grained than those in the distal-delta-front facies, with bedforms consisting predominantly of planar stratification (Fig. 4). Soft-sediment deformation occurs in a 5-ft (1.5-m) zone in the middle of the section, whereas clay clasts are more abundant in the upper one-third. Porosity from core-plug data widely range from 7.5 to 22.0%. Although the greatest value of 22.0% occurs near the top (Fig. 4), an overall vertical trend is poorly defined, except for the section above 11,265 ft (3434.5 m), where porosity values systematically increase upward with increasing grain size.

Depositional analogs for channel-mouth-bar deposits in proximal-delta-front facies in the Cities Service No. B–1 Sutton core include Pennsylvanian, amalgamated bar-crest sandstones near Wizard Wells in Jack County, Texas. These bar-crest deposits are composed of fine- to medium-grained sandstone with low-angle planar stratification, trough crossbeds, and clay rip-up clasts (Brown et al., 1973). Bar-crest facies in the Turonian Ferron Delta in Utah, another analog for the Cities Service No. B–1 Sutton core, consist of amalgamated, unidirectional cross-stratification with poorly-sorted material containing clay clasts and organic matter (Barton, 1994; Olariu and Bhattacharya, 2006). They contain numerous reactivation surfaces and scour-and-fill structures, the product of high-energy currents in a terminal distributary-channel setting where channel-mouth-bar deposits are well developed and merge with distributary-channel deposits (Fielding et al., 2005).

Transgressive and Highstand Shelf

Transgressive facies, which represent wave and storm reworking of foundered delta-front deposits, range from 11,209 to

Table 1. Summary of porosity and permeability data from whole cores in this study.

Facies	Well	Depth Range (ft)	Porosity Range (%)	Median Porosity (%)	Permeability Range (md)	Median Permeability (md)
Highstand shelf	Cities Service No. B–1 Sutton	11,201–11,209	N/A	N/A	0.2–0.3	N/A
Transgressive deposits	Cities Service No. B–1 Sutton	11,209–11,250	2.1–2.9	N/A	0.03–7.6	0.2
Proximal delta front	Cities Service No. B–1 Sutton	11,250–11,274	7.5–22.0	12.6	0.15–8.5	2.2
Distributary channel	Cities Service No. B–1 Sutton	11,292-11,322	7.5–17.5	12.8	0.2–74.8	5.5
Distal delta front	Cities Service No. B–1 Sutton	11,274–11,292; 11,322–11,323	3.9–13.2	11.8	0.09–3.7	0.6
Distal delta front	Sun No. 1 Hanner May Estate	13,183–13,205	N/A	N/A	0.04–1.1	0.5
Muddy slump	Sun No. 1 Hanner May Estate	13,166–13,182	N/A	N/A	0.07–0.6	0.2
Prodelta/shelf	Sun No. 1 Hanner May Estate	13,205–13,262	N/A	N/A	0.05–2.1	0.4
Channelized levee	Humble No. 1 Howell	14,766–14,784	5.7–12.1	9.4	0.4–4.5	1.6
Levee	Humble No. 1 Howell	14,784–14,807	N/A	N/A	0.1–0.5	0.2
Levee	Standard No. 2 Longbell	13,639–13,641; 13,691–13,717	N/A	N/A	0.07–2.0	0.4
Levee	Delta No. 2 Carter	14,061–14,117	N/A	N/A	0.2–4.8	1.0
Debris flow	Standard No. 2 Longbell	13,630–13,639	N/A	N/A	0.08–6.3	0.7

11,250 ft (3417.4 to 3429.9 m) in the Cities Service No. B–1 Sutton core. This facies consists of mudstone interbedded with thin (commonly 2- to 3-in [5.1- to 7.6-cm]), very fine-grained burrowed sandstones, with common *Planolites* (Figs. 4 and 5D). The base of the section is defined by a sharp-based, 6-in (15.2-cm) bed of very fine-grained sandstone with clay clasts. Shell fragments are common in the upper one-third of the section, which is bounded at the top by an 8-ft (2.4-m) zone of dark-gray mudstone that represents a flooding surface (Fig. 4). This flooding surface is also defined from electric logs by the maximum rightward deflection of the SP (spontaneous potential) curve (left part of Figure 4). Highstand shelf deposits occur above this flooding surface, part of an upward-coarsening cycle associated with subsequent deltaic progradation.

Permeability values in the transgressive facies, along with overlying highstand shelf deposits, are the lowest of all facies in the Cities Service No. B–1 Sutton core (Table 1; Fig. 4). Values range from 0.03 to 1.2 md, with a median value of 0.2 md (Table 1). Limited core-plug porosity data indicate values of 2.1 to 2.9% in thin, very fine-grained sandstone beds (Fig. 4).

Modern depositional analogs for the thin sandy, basal section in transgressive deposits in the Cities Service No. B–1 Sutton core include: (1) the wave-dominated transgressive shoreline near the Santee Delta in South Carolina where the shoreline is punctuated by numerous, thin washover fans (Stephens et al., 1976), (2) Cape Romain, a cuspate, landward-retreating headland 10 mi (16 km) south of the Santee Delta, where the transgressive shoreline is composed of shelly sandstone and detrital organic fragments (Ruby, 1981), and (3) microtidal transgressive shoreline deposits in Texas and Alabama (Wilkinson and Basse, 1978; Davies and Hummell, 1994, respectively). Analogous deposits occur in the upper Woodbine section in Double A Wells Field, where transgressive facies 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 and abundant *Planolites* burrows (Ambrose and Hentz, 2012).

Distal Shallow-Marine

Distal shallow-marine systems in the Woodbine Group in southeastern Polk County are represented by the Sun No. 1 Hanner May Estate well (Figs. 2, 3, and 6). This well is in a distal position relative to a major deltaic depocenter in Double A Wells Field to the northwest (Ambrose and Hentz, 2012). The Woodbine Group in the Sun No. 1 Hanner May Estate core is composed of a 100-ft (30.5-m), fine-grained section of sparsely burrowed mudstones interbedded with thinner (2- to 6-in [5.0- to 15.2-cm]) beds of very fine- to fine-grained, laminated and mostly structureless sandstone (Fig. 6). Many sandstone beds in the succession have abrupt erosional bases and undulose tops. The number of individual sandstone beds increase upward to 13,182 ft (4019.0 m), above which the section is composed almost entirely of contorted mudstone (Fig. 6).

Prodelta/Shelf

The lower 57 ft (17.4) m of the Sun No. 1 Hanner May Estate core (13,205 to 13,262 ft [4025.9 to 4043.3 m]) is composed of burrowed mudstone with thin (commonly <0.2- to 2-in [0.5- to 5.1-cm]) beds of very fine-grained, ripple- to planar-stratified sandstone (Fig. 6). Starved ripples, defined as ripples deposited in conditions with a limited supply of coarse-grained material wherein sand has been eroded from the stoss side and deposited on the lee side (Reineck and Singh, 1975), are the most common bedforms in the offshore/prodelta facies. Ichnofauna are dominated by *Planolites* and minor *Teichichnus*. The section has a baseline GR (gamma ray) log response, although the resistivity response has a weakly serrate character (Fig. 6). Permeability values in the section are low, ranging from 0.05 to 2.1 md with median values of 0.4 md (Table 1; Fig. 6).

The thickest sandstone beds (2-in [5.1-cm]) in the prodelta/shelf facies have abrupt and sharp bases, as well as irregular and wavy tops directly overlain by burrowed mudstone (Fig. 7A).

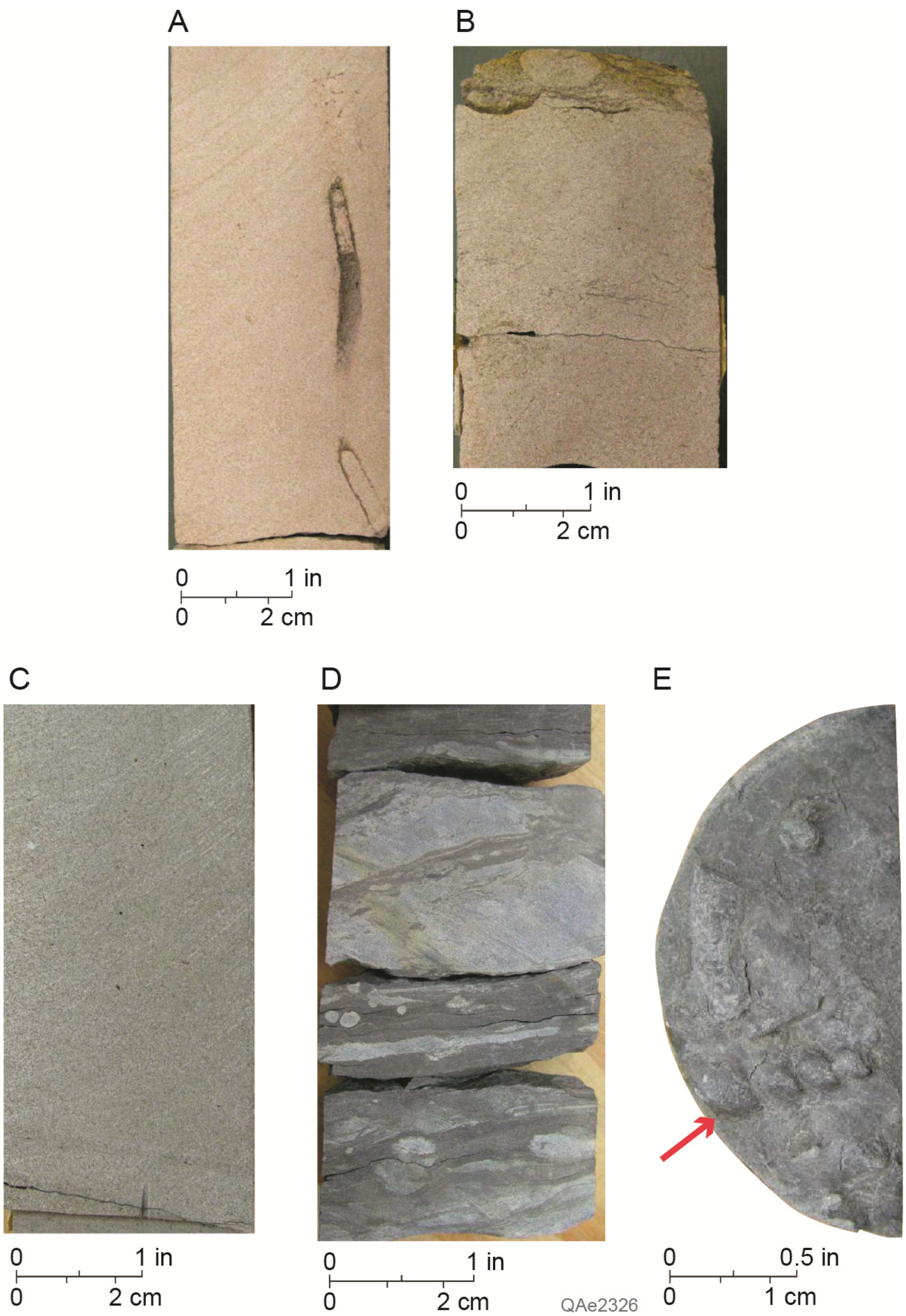


Figure 5. Core photographs of proximal shallow-marine depositional systems in the Cities Service No. B–1 Sutton well, located in Figure 2 and shown in Figure 3. (A) Upper-distributary-channel-fill deposits at 11,295.3 ft (3443.7 m) composed of fine-grained sandstone. (B) Marine-reworked shorezone deposits at 11,298.6 ft (3444.7 m) consisting of fine-grained sandstone with weak planar stratification and *Planolites* burrows at top. (C) Proximal-delta-front facies at 11,256 ft (3431.7 m), containing upper fine-grained sandstone with inclined planar stratification from upper left to lower right. Saw marks are from lower left to upper right. (D) Transgressive deposits at 11,233.5 ft (3424.8 m), composed of burrowed mudstone interbedded with thin, very fine-grained sandstone beds with soft-sediment deformation. (E) In situ gastropod fossil (indicated by arrow) at 11,283.5 ft (3440.1 m) in distal-delta-front facies. Core description is shown in Figure 4.

Most sandstone beds in this facies are moderately deformed, either as a result of burrowing or sediment compaction (Fig. 7B).

The prodelta/shelf facies in the Sun No. 1 Hanner May Estate core represents relatively long periods of suspension sedimentation that were intermittently interrupted by traction currents associated with either distal frontal splays or storm activity. Stronger storms are recorded by zones of broken and disrupted sandstone beds with mudstone clasts and shell fragments, for example at 13,242 ft (4037.2 m), similar in form to tempestite deposits described in Myrow and Southard (1996).

Distal Delta Front

The distal-delta-front facies in the Sun No. 1 Hanner May Estate core, extending from 13,183 to 13,205 ft (4019.2 to 4025.9 m), has a serrate resistivity log response (Fig. 6). It is composed of relatively thicker and coarser-grained sandstones than those in the underlying prodelta/shelf facies (Fig. 6). Individual sandstone beds in the distal-delta-front facies are very fine- to fine-grained and are as much as 1 ft (0.3 m) thick (Figs. 6 and 7C). These sandstone beds are commonly sharp-based and have low-angle to planar stratification with burrowed tops (Fig. 7C). Permeability values are low, ranging from 0.04 to 1.1 md, with median values of 0.5 md (Table 1; Fig. 6). An upward increase in permeability from 0.5 to 1.1 md at the base of the section from 13,196 to 13,203 ft (4023.2 to 4025.3 m) corresponds to a slight upward increase in average grain size, although no similar trend in permeability is observed in the upper part of the section from 13,182 to 13,196 ft (4018.9 to 4023.2 m) (Fig. 6).

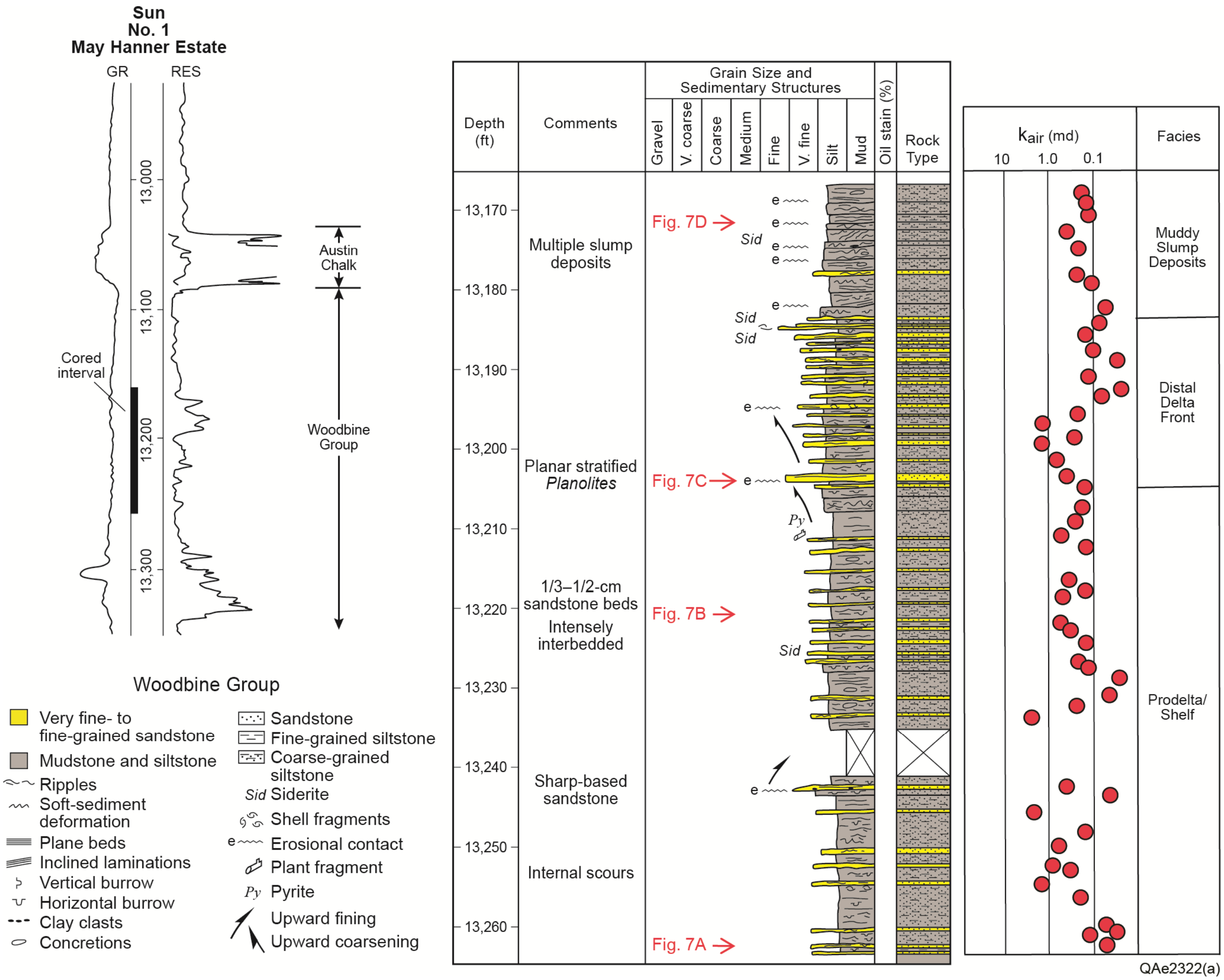


Figure 6. Core description of distal shallow-marine facies in the Sun No. 1 Hanner Mae Estate well, located in Figure 2 and shown in Figure 3. Core photographs are shown in Figure 7.

Sharp-based, structureless to parallel-laminated sandstone beds in the upper, relatively sandy part of the Sun No. 1 Hanner May Estate core record hyperpycnal, turbidite deposits in a distal-deltaic setting. Representing rapidly-deposited frontal splays, hyperpycnal turbidites (hyperpycnites) are 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). Similar features are well developed in delta-front facies in cores in the Woodbine Group in Double A Wells Field (located in Figure 2), which include sharp, erosional bases, soft-sediment deformation, laminated bedding, and internal scour surfaces (Ambrose and Hentz, 2012).

Hyperpycnites commonly contain abrupt, erosional bases, low-angle and plane-parallel lamination (Figs. 7A and 7C), and undulating, rippled crests Plink-Björklund et al., 2001; Plink-Björklund and Steel, 2004). They exhibit vertical trends that reflect waxing-to-waning energy (Mulder et al., 2001), although vertical profiles of hyperpycnites in shelf-edge deltas and genetically-associated, downdip, slope-channel deposits can exhibit considerable variation such as internal scour surfaces, randomly aligned clay clasts, and zones of soft-sediment deformation, owing to steep gradients and intermittent slope failure associated with the shelf edge (Petter and Steel, 2006).

Muddy Slump

The upper 16 ft (4.9 m) of section in the Sun No. 1 Hanner May Estate core (13,166 to 13,182 ft [4014.0 to 4018.9 m]), which has baseline GR and resistivity responses, consists of contorted mudstone beds with sediment clasts. Individual beds, as thin as 2 in (5.1 cm), are separated by sediment-shear surfaces (Figs. 6 and 7D). Sediment clasts in the section occur either as mudstone or very fine-grained sandstone interbedded in a sideritic mudstone matrix (Fig. 7D). Permeability ranges from 0.07 to 0.6 md, with median values of 0.2 md (Fig. 6 and Table 1).

The section from 13,166 to 13,182 ft (4014.0 to 4018.9 m) represents sediment-failure deposits on an unstable, muddy substrate in a distal-delta-front setting, marking the onset of relative water deepening. The stratigraphic position of these muddy, slumped deposits is problematic because they occur above rather than within the lower part of a progradational succession. Slumps in shelf-edge deltaic systems are common during periods of lowstand, recording high depositional rates and sediment loading accompanying deltaic progradation on an unstable shelf margin (Sydow and Roberts, 1994; Morton and Suter, 1996; Petter

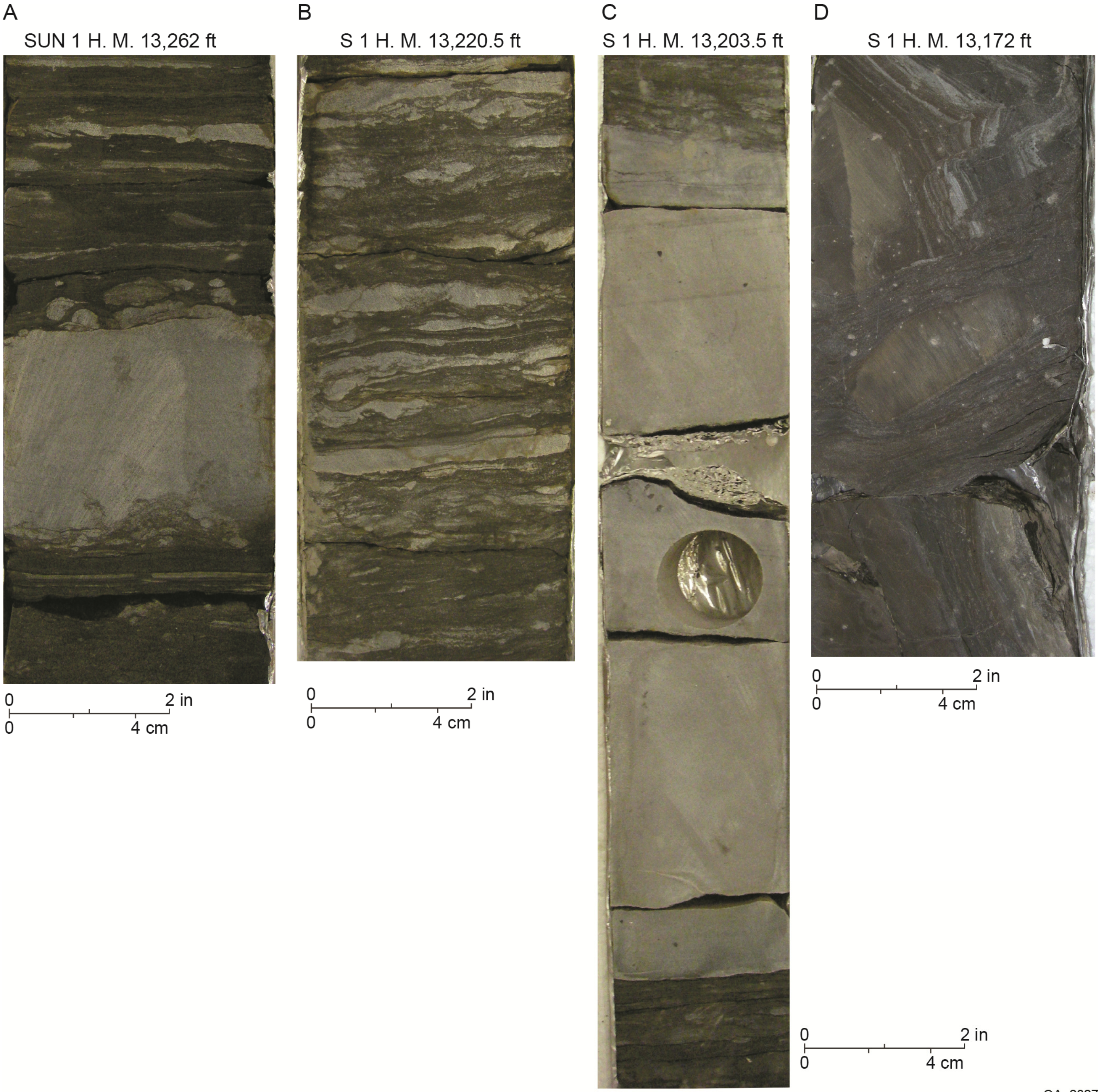


Figure 7. Core photographs of distal shallow-marine depositional systems in the Sun No. 1 Hanner Mae Estate well, located in Figure 2 and shown in Figure 3. (A) Prodelta/shelf deposits at 13,262.0 ft (4043.3 m) consisting of 2-in (5.1-cm) bed of very fine-grained sandstone with sharp base and rippled and burrowed top, encased in dark-gray mudstone. (B) Prodelta/shelf deposits at 13,220.5 ft (4030.6 m) composed of burrowed mudstone with thin (<1-in [<2.5-cm]) beds of very fine-grained sandstone. (C) Distal-delta-front deposits at 13,203.5 ft (4025.6 m) consisting of up to 1-ft (0.-3m), very fine- to fine-grained, sharp-based laminated sandstone interbedded with burrowed mudstone. (D) Muddy slump deposits at 13,172 ft (4015.9 m), containing sediment shear-surfaces, contorted mudstone beds, microfaults, and sediment clasts. Core description is shown in Figure 6.

and Steel, 2006). Well-developed slumps, however, are observed above progradational sections in offshore/prodelta facies in equivalent strata in other parts of Double A Wells Field (Ambrose and Hentz, 2012), suggesting that even muddy, relatively sediment-starved inner-shelf deposits in shelf-edge systems are inherently prone to failure, owing to their proximity to large sections of slump blocks along the Woodbine shelf edge (Bunge, 2011).

SLOPE SYSTEMS

Overview

Slope systems in the Woodbine Group in Tyler Country are represented by cores from the Humble No. 1 Howell, Delta No. 2 Carter, and Standard No. 2 Longbell wells (Figs. 2 and 3). These wells are south (downdip) of shelf-edge deposits in the Cities

Service No. B–1 Sutton well (Figs. 2 and 3). Sandy facies in these cores occur in slightly upward-coarsening successions with multiple upward-fining sandstone beds (Fig. 8) and erosion-based, upward-fining sections with chaotic bedding (Fig. 9). Mudstone-dominated facies in these slope systems contain thin (commonly <1-ft [<0.3-m]) beds of very fine-grained sandstone interbedded with sparsely burrowed mudstone (lower one-half of the cored section in Figure 9 and all of the cored section in Figure 10). The main log response of the mudstone-dominated facies is serrate to baseline (Figs. 9 and 10).

Humble No. 1 Howell

Overview. The Humble No. 1 Howell well is located in Big Cypress Field, east of the Double A Wells Field (Fig. 2). The Humble No. 1 Howell well produced only ~5220 bbl of oil and condensate, as well as 147.7 MMcf (million cubic ft) of gas from 1965 to 1967. Two cored sections are within a 40-ft (12-m), upward-coarsening interval inferred from SP and resistivity log responses, as well as an overall vertical grain size profile (Fig. 8). The lower cored interval from 14,797 to 14,807 ft (4511.3 to 4514.3 m) is composed of mudstone interbedded with thin (<0.5-in [<1.3-cm]) beds of very fine-grained sandstone. Permeability values in this lower cored section are low, ranging from 0.1 to 0.5 md (Table 1; Fig. 8).

The upper cored interval from 14,766 to 14,784 ft (4501.8 to 4507.3 m) features an upward-coarsening succession of very fine- and fine-grained sandstone that truncates a muddy interval at 14,780 ft (4506.1 m). This muddy interval is inferred to be part of the same fine-grained succession below a 15-ft (4.6-m) uncored section (Fig. 8). In contrast to the lower cored interval, the upper cored interval features greater permeability values that range from 0.4 md to as much as 4.5 md, with a median value of 1.6 md (Table 1). Although these permeability values are low, they are an order of magnitude greater than those in the lower muddy section. Core-plug porosity values increase upward, approximately corresponding to an upward increase in overall grain size (Fig. 8). These values range from 5.7 to 12.1% with a median value of 9.4%. Lowest values are associated with either thin, very fine- to fine-grained sandstone beds near the base of the section from 14,799 to 14,807 ft (4511.9 to 4514.3 m) or with clay-clast-rich, fine-grained sandstone beds in the upper one-third of the section from 14,768 to 14,774 ft (4502.4 to 4504.3 m).

Facies Interpretation. Levee deposits in the Humble No. 1 Howell core consist of thin (commonly <1-in [<2.5-cm]) beds of very fine-grained sandstone interbedded with sparsely burrowed mudstone (Fig. 11A). Sandstone beds are predominantly ripple-stratified and lenticular, representing starved ripples that record a limited sandy sediment supply or short-lived periods of traction-current deposition. The bases of individual rippled sandstone beds are commonly deformed, recording differential compaction.

Channelized-levee facies, in erosional contact with levee facies (Fig. 11B), are dominated by fine-grained sandstone beds interbedded with relatively thin (commonly <1-ft [<0.3-m]) mudstone beds (Fig. 8). Although Woodbine channelized-levee deposits overall are slightly upward-coarsening, sandstone beds within this facies occur in 2- to 4-ft (0.6- to 1.2-m), upward-fining sections with incomplete Bouma sequences. Stratification in these upward-fining sections ranges from massive bedding and obscure plane beds at the base to ripples within mudstone at the top (Fig. 11C). Zones of convolute bedding alternating with weakly planar-stratified sandstone and erosion-based, massively-bedded sandstone are common (Fig. 11D). Sections of planar-stratified, fine-grained sandstone, draped with mm-scale organic and muddy material occur throughout the section.

The cored section in the Humble No. 1 Howell well represents, from base to top, levee and channelized-levee deposits in a slope setting. This deepwater interpretation is based on: (1) paleogeographic position downdip (south) of the Woodbine shelf margin, and (2) succession of thin (commonly <0.3-ft [<0.1-m]) debrites and incomplete Bouma sequences in the upper

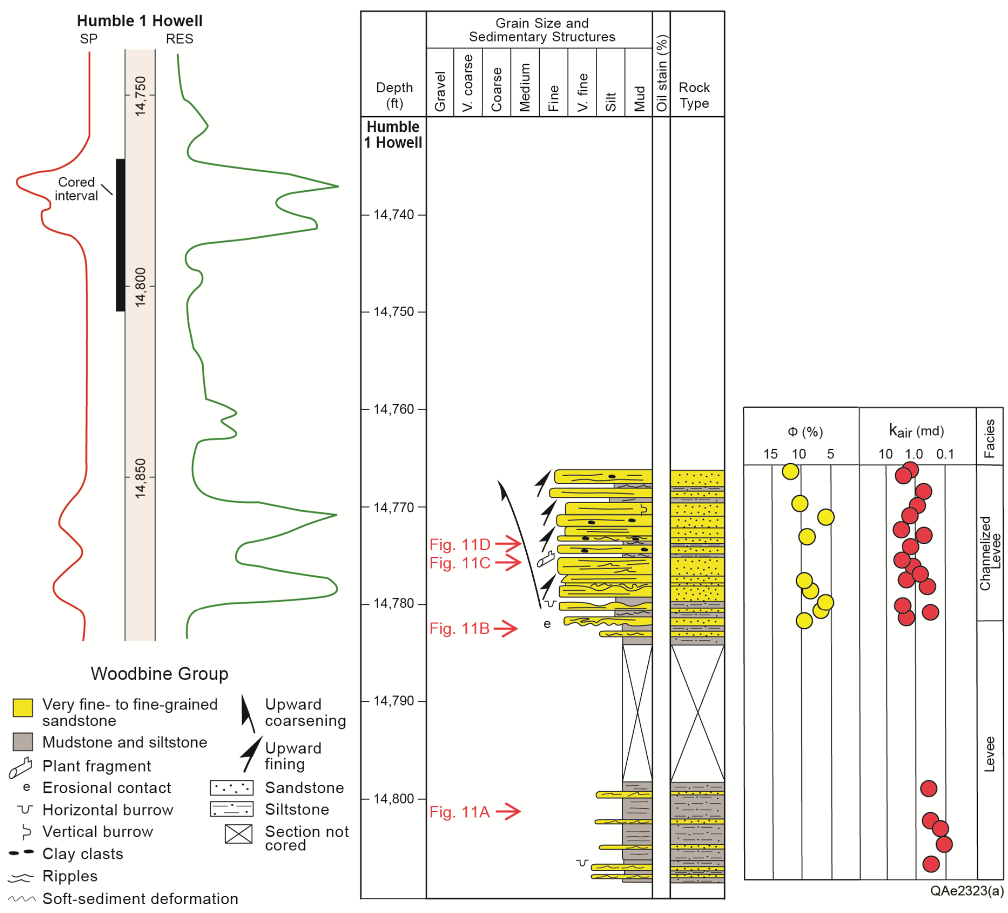


Figure 8. Core description of levee and channelized-levee facies in the Humble No. 1 Howell well, located in Figure 2 and shown in Figure 3. Core photographs are shown in Figure 11.

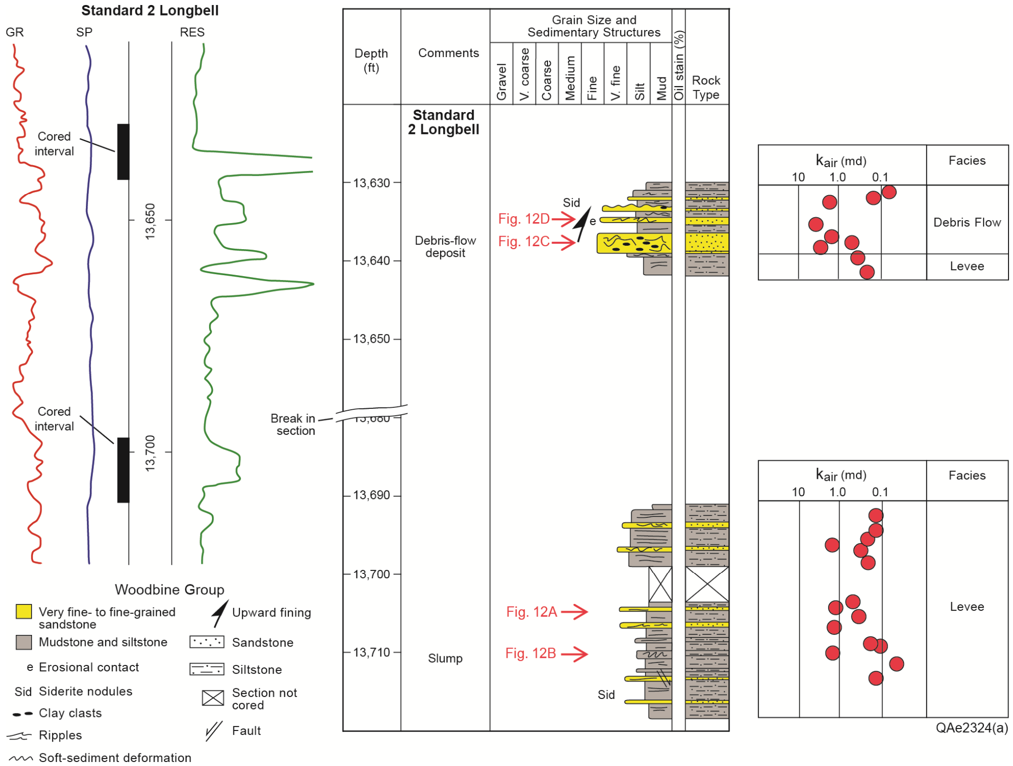


Figure 9. Core description of debris-flow and levee deposits in the Standard No. 2 Longbell well, located in Figure 2 and shown in Figure 3. Core photographs are shown in Figure 12.

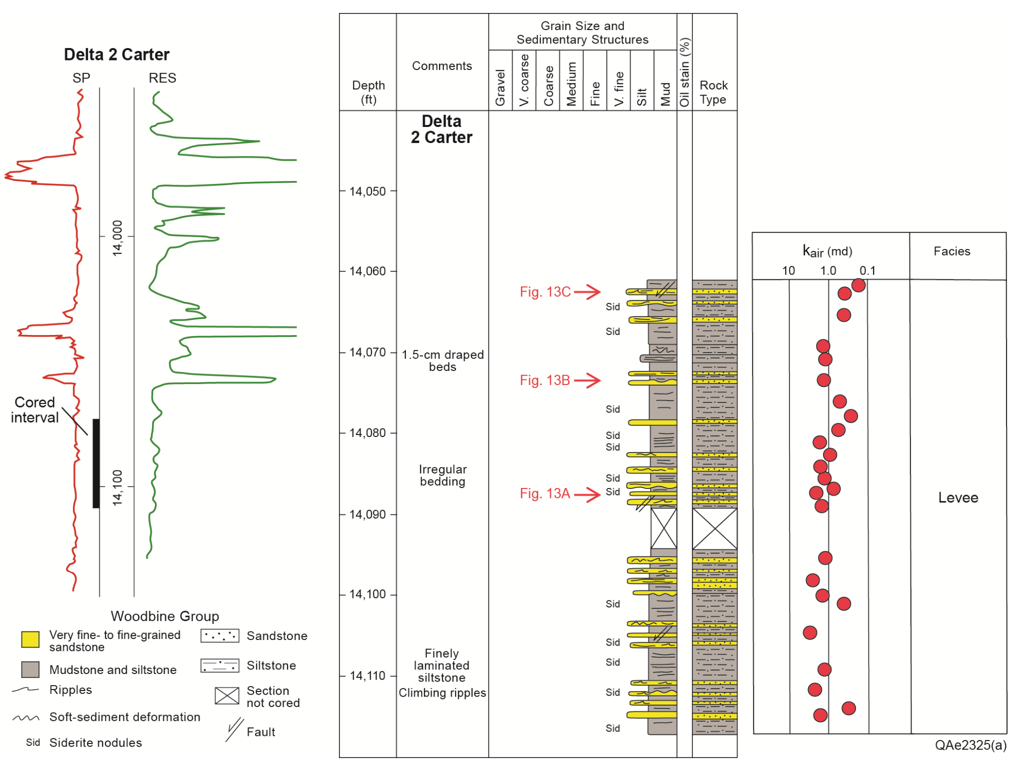


Figure 10. Core description of levee deposits in Delta No. 2 Carter well, located in Figure 2 and shown in Figure 3. Core photographs are shown in Figure 13.

cored interval. These sequences are similar to those described by Bouma (1962) for erosion-based sandstones with massive to weakly planar stratification (Bouma A and B) grading upward into ripple-laminated sandstones (Bouma C) overlain by mudstone (Bouma D).

Levee and channelized-levee deposits in the Humble No. 1 Howell core are inferred to occur between major depositional axes on the basis of: (1) an overall upward-coarsening grain-size trend reflecting a net-progradational rather than aggradational setting, (2) absence of large-scale erosional features and coarse-grained lags commonly encountered at the base of primary deep-water channel-fill deposits (Mayall et al., 2006), (3) overall small scale of the sandstone-dominated section (<25 ft [<7.6 m]) (Fig. 8), and (4) large number of incomplete Bouma sequences, many individually <2-ft (<0.6-m) thick. In contrast, debrites in the Humble No. 1 Howell core, characterized by zones of convolute bedding, record slope-instability and mass-flow processes. They are commonly overlain by zones of parallel-laminated and ripple-stratified sandstones representing traction-current deposits, suggesting a co-genetic relationship between debris-flow deposits

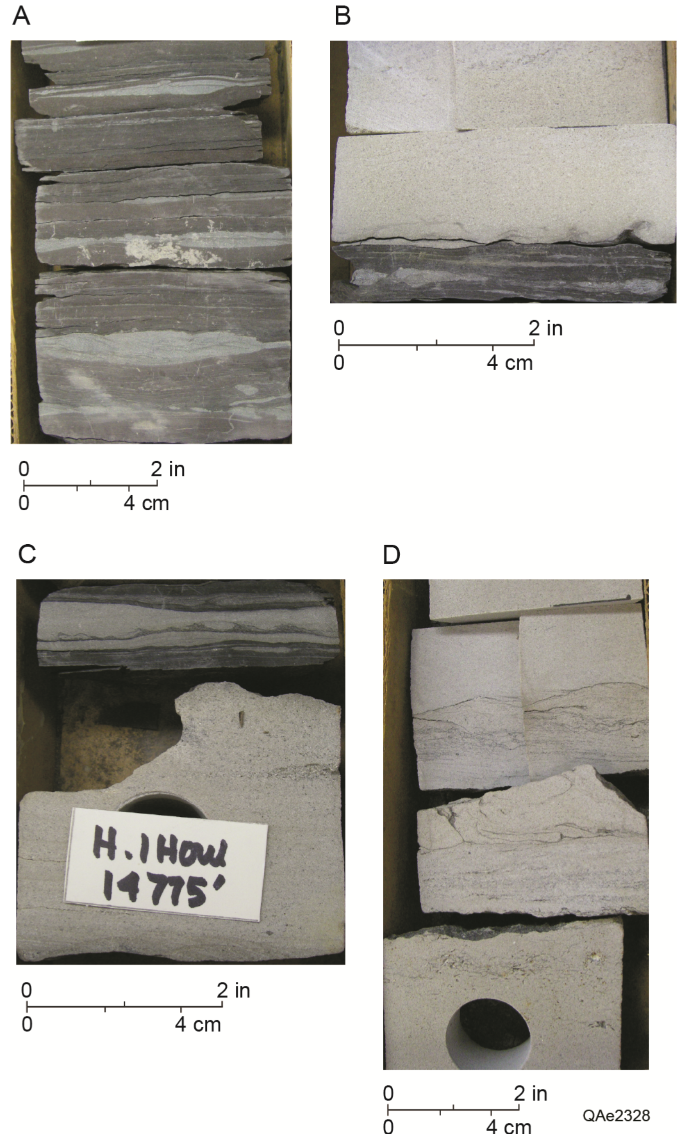


Figure 11. Core photographs of slope depositional systems in the Humble No. 1 Howell well, located in Figure 2 and shown in Figure 3. (A) Levee deposits at 14,800.5 ft (4512.3 m) containing starved ripples and lenticular bedding within weakly sideritic mudstone. (B) Basal channelized-levee facies at 14,782.0 ft (4506.7 m) with well-developed flame structures at the base of planar-stratified, fine-grained sandstone. (C) Ripple-laminated, fine-grained sandstone at the top of the photograph, with small flame structures above planar-stratified, fine-grained sandstone in channelized-levee facies at 14,775.0 ft (4504.6 m). (D) Complexly-bedded channelized-levee facies at 14,773.0 ft (4504.0 m), composed from base to top of: (1) nonstratified, fine-grained sandstone with organic and shell fragments, (2) planar-stratified, very fine-grained sandstone, (3) thin (1-in [2.5-cm]), fine-grained sandstone with convolute bedding above planar-stratified sandstone, and (4) massively-bedded fine-grained sandstone. Core description is shown in Figure 8.

and overlying turbidites (Amy et al., 2005; Amy and Talling, 2006).

Standard No. 2 Longbell

Overview. The Standard No. 2 Longbell well, east of the Humble No. 1 Howell well, is downdip of the Cities Service No. B–1 Sutton well (Figs. 2 and 3). The core contains two intervals, with a lower, mudstone-dominated interval from 13,691 to 13,720 ft (4174.1 to 4182.9 m) and a shorter (11-ft [3.4-m]), upper interval from 13,630 to 13,641 ft (4155.5 to 4158.9 m) (Fig. 9). The lower mudstone-dominated interval contains thin (commonly <1-in [<2.5-cm]), very fine-grained sandstone beds with ripple stratification (Fig. 12A). Laminated siltstone beds occur in 1-in (2.5-cm) zones with upward-thickening bedsets (Fig. 12A). Some siltstone beds are greatly distorted and steeply dipping (Fig. 12B). Permeability values in this lower cored interval, although low, exhibit a wide range from 0.07 to 2.0 md, with a median value of 0.4 md (Table 1; Fig. 9).

The upper interval is upward-fining, although individual sandstone beds are heterolithic and complexly bedded (Figs. 12C and 12D). The basal fine-grained sandstone bed in this upward-fining interval is a heterolithic assemblage of poorly aligned, subrounded clay clasts in a sandy matrix (Fig. 12C). This sandstone bed is in erosional contact with underlying muddy strata. Zones of tightly-folded, muddy strata with broken beds are common higher in the section (Fig. 12D). Permeability values in the upper cored interval reach a maximum of 6.3 md in a thin (<1-ft [<0.3-m]), fine-grained sandstone bed in the middle part of the section at 13,635.0 ft (4157.0 m) (Table 1; Fig. 9). Values are slightly lower (4.2 md) in the thicker, relatively coarser-grained sandstone at 13,638.0 ft (4158.0 m), which contains clay clasts and abundant disseminated organic material. Permeability values (<0.1 md) are lowest in mudstone-rich beds at the top of the section.

Facies Interpretation. The lower cored section in the Standard No. 2 Longbell core represents slope deposits that record short-lived episodes of traction-current deposition alternating with long-term episodes of suspension sedimentation. Stratification in thin sandstones is dominated by asymmetric ripples, indicating lower-flow-regime sedimentation on an unstable muddy substrate (Fig. 12A), as recorded by zones of contorted and high-angle bedding (Fig. 12B).

The upper cored section, also described by Siemers (1978), consists of debris-flow deposits. Although the section is upward-fining and has an erosional base, it is distinguished from levee-channel facies by: (1) coarser grain size, (2), poor sorting, (3) chaotic bedding, and (4) zones of folded strata. The base of the debris-flow section is marked by arcuate and high-angle shear surfaces (Fig. 12C) that record stratal detachment and gravity flow. Gravity-flow deposits in slope settings can occur either as turbulent flows in which suspension and collapse fall-out processes are important, or as viscous slumps, wherein the bulk of the transported material is transported en masse and coherent beds are separated by shear surfaces (Stow et al., 1996; Stow and Mayall, 2000).

Rounded and sub-rounded clay clasts within stratified zones, as well as coarse-grained sediment clasts, indicate mass transport of material eroded from the muddy substrate and incorporated in the debris flow. These debris-flow deposits are similar to cohesive deposits described by Lowe (1982), but they represent a hybrid between cohesive debris-flow and suspended-flow deposits. In the latter, clasts are partly aligned, supported by matrix buoyancy and suspended within a fine-grained, sandy matrix above a basal scour surface (Fig. 12C). Highly contorted and folded strata are the result of toe-of-slope compression at the downdip (terminal) end of the debris flow (Fig. 12D).

Delta No. 2 Carter

Overview. The Delta No. 2 Carter well is located 7.5 mi (12 km) west of the Standard No. 2 Longbell well (Figs. 2 and 3). The cored section is composed of sideritic, finely-laminated mudstone interbedded with thin (commonly 2- to 4-in [5.1- to 10.2-cm]), very fine-grained sandstone beds (Figs. 10, 13A, and 13B). The log expression is baseline to weakly serrate (Fig. 10). Sandstone beds in the section are commonly sharp-based and contain crosscutting ripple stratification and subparallel, planar laminae. Graded beds are common (Fig. 13B), and some sandstones are intensely microfaulted (Fig. 13C). Permeability values

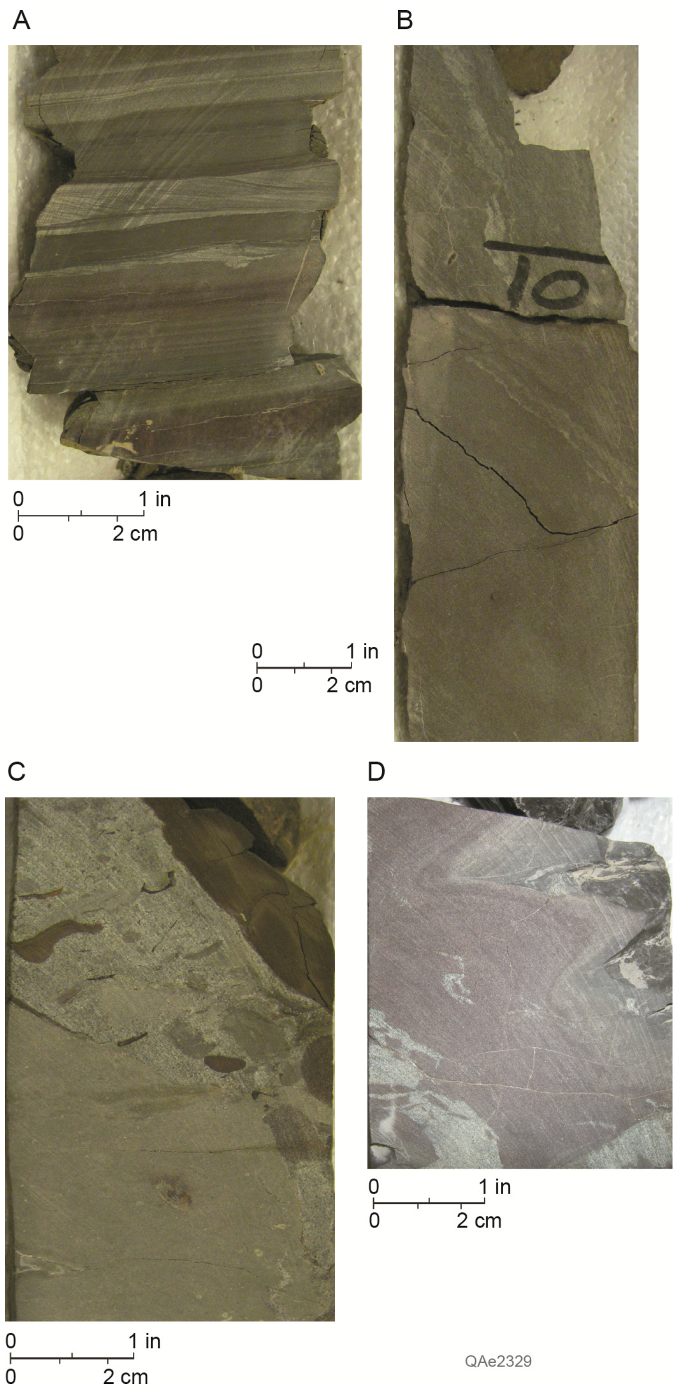


Figure 12. Core photographs of slope depositional systems in the Standard No. 2 Longbell well, located in Figure 2 and shown in Figure 3. (A) Distal-levee deposits at 13,705.0 ft (4178.4 m) with centimeter-scale beds of ripple-laminated and planar-stratified, very fine-grained sandstone interbedded with sideritic mudstone. (B) Slump deposit at 13,709.7 ft (4179.8 m), exhibiting tilted and deformed beds of sideritic, silty mudstone. (C) Lower part of debris-flow deposit composed of shale-clast conglomerate in erosional contact with silty mudstone at 13,637.5 ft (4157.8 m). (D) Middle part of debris-flow deposit with contorted bed of sideritic, silty mudstone at 13,635.0 (4157.0 m). Core description is shown in Figure 9.

in the Delta No. 2 Carter well exhibit no systematic vertical trends. The values are low, with a median value of 1.0 md within a range of 0.2 to 4.8 md (Table 1; Fig. 10).

Facies Interpretation. The cored section in the Delta No. 2 Carter well represents slope levee facies. Traction currents are recorded by sharp- and irregular-based, ripple-laminated sandstone beds with internal scours (Fig. 13A). Graded beds (Fig. 13B) indicate rapid deposition from turbidity flows, whereas low-angle microfaults associated with distorted laminae record sediment loading (Fig. 13C).

Recognition criteria for levee facies in the Delta No. 2 Carter well are consistent with many listed in Plink-Björklund et al. (2001), namely: (1) erosional bases, (2) internal scours, (3) normal grading, and (4) traction structures, including current ripples. Levee deposits in the Delta No. 2 Carter well occur within fine-grained, mud-rich turbidite systems, such as those described by Bouma (2000) and Stelting et al. (2000) for passive-margin settings. They are commonly associated with well-developed fluvial systems that transport sediments to deltas on wide shelves with efficient net bypass. Other characteristics of fine-grained mud-rich turbidite systems include: (1) main grain size consisting of fine-grained sand, (2) well-developed levees with primary stratification composed of parallel and ripple lamination, (3) dominant overbank material consisting of silty mud, and (4) excellent potential for slump deposits.

DISCUSSION: CONTROLS ON RESERVOIR QUALITY

Facies type and porosity loss caused by compaction are important controls on reservoir quality in sandstones in both shallow-marine and slope systems in the Woodbine Group. Permeability values from cores in this study vary greatly in Woodbine shallow-marine systems by almost four orders of magnitude, whereas permeability values display less variability in deepwater systems (approximately two orders of magnitude) (Figs. 14 and 15). Limited porosity data from a narrow range of depths in shallow-marine facies indicate a wide range in porosity values, although median values are closely clustered (Fig. 16).

Although facies type (Fig. 17) is an important factor controlling reservoir quality in these Woodbine sandstones, diagenesis in the form of chlorite, quartz overgrowths, dolomite, and kaolinite have altered original porosity (Young and Barrett, 2003). Calcite and dolomite occur both as a replacement of detrital grains and as cement, although the degree of calcite and dolomite cementation varies between cored wells, and no secondary dolomite has been observed in the Standard No. 2 Longbell core (Young and Barrett, 2003). Original depositional fabric and structure exerted partial controls on diagenetic alteration, as for example in the Humble No. 1 Howell well, where diagenetic alteration corresponds with cross laminations. However, no correlations are observed between sedimentary structures and quartz overgrowths in the Cities Service No. B–1 Sutton core (Young and Barrett, 2003).

Shallow-Marine Systems

Proximal shallow-marine systems, represented by the Cities Service No. B–1 Sutton well (located in Figure 4), display both the greatest value (74.8 md) and range in permeability values in the study area (Fig. 14). In contrast, distal shallow-marine systems in the Sun No. 1 Hanner Mae Estate well (Figs. 6 and 14) exhibit low permeability values that range from 0.05 to 2.1 md, owing to fine grain size and greater depth of burial (Fig. 14).

Highstand Shelf and Transgressive

Highstand shelf facies, owing to sparse, thin (commonly <2-in [<5.1-cm]), very fine-grained sandstone beds interbedded with mudstone (Fig. 4), are inferred to have the lowest potential for reservoir sandstones in Woodbine shallow-marine systems. Moreover, permeability values in highstand shelf sandstones are uniformly low, ranging from 0.2 to 0.3 md (Table 1; Fig. 14).

Greatest reservoir quality in Woodbine transgressive deposits occurs in fine-grained sandstone beds at their base, where

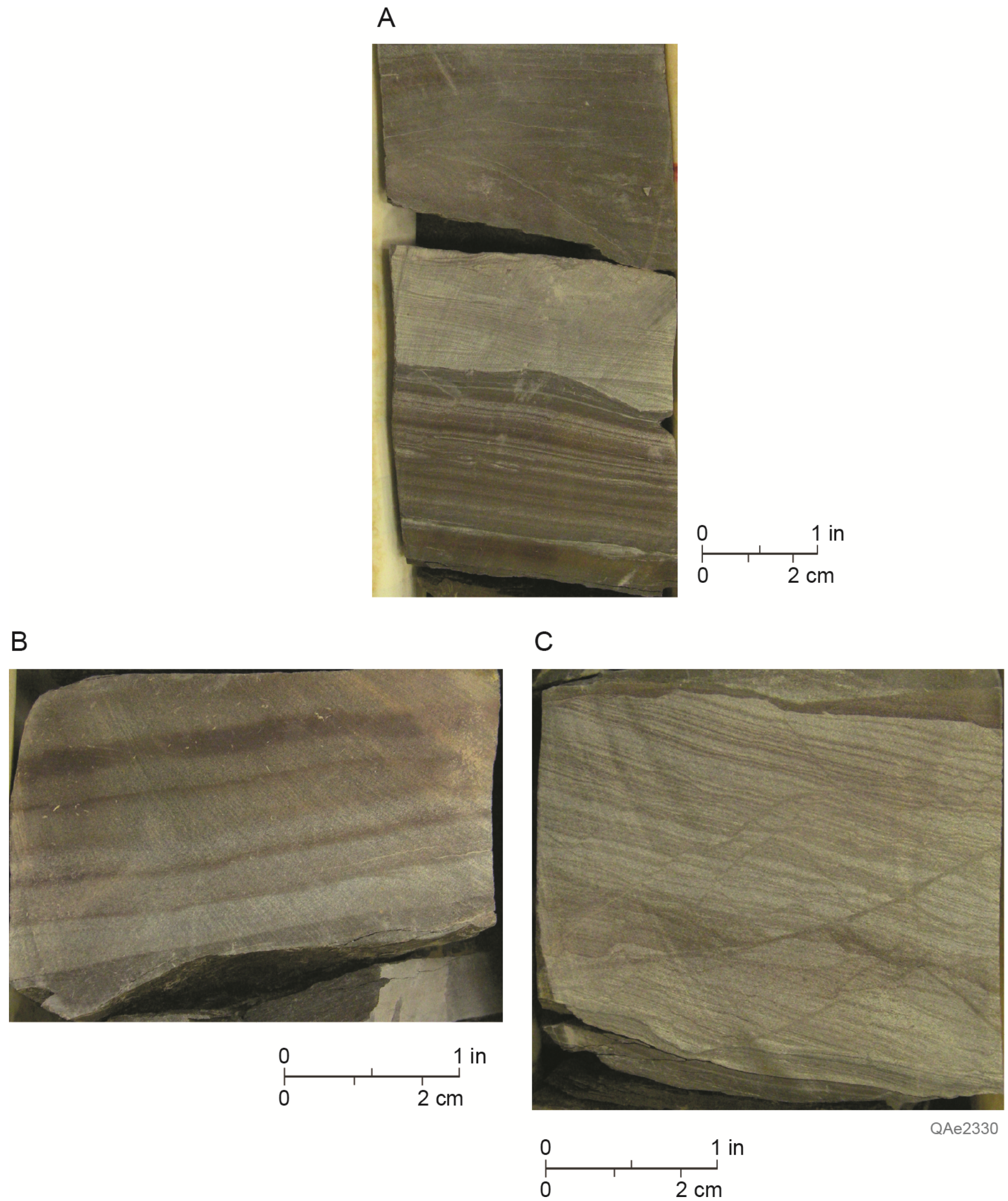


Figure 13. Core photographs of distal-levee facies within slope depositional systems in the Delta No. 2 Carter well, located in Figure 2 and shown in Figure 3. (A) Erosion-based bed of ripple-laminated, very fine-grained sandstone at 14,087.0 ft (4294.8 m). (B) Graded beds at 14,074.0 ft (4290.9 m). (C) Bed of finely-laminated very fine-grained, sideritic sandstone with abundant microfaults at 14,062.2 ft (4287.4 m). Core description is shown in Figure 10.

permeability values are as much as 7.6 md (Table 1; Fig. 4). The thin (>1-ft [>0.3-m]) basal section contains clean, matrix-poor sandstones, representing wave-reworked proximal-delta-front deposits, whereas the overlying section that records water deepening is composed dominantly of mudstone interbedded with thin (individually 2- to 3-in [5.1- to 7.6-cm]), very fine-grained and burrowed sandstones (Fig. 4). With median permeability values of only 0.2 md, the transgressive facies overall contains poor potential for reservoir development, although reservoir-quality sandstones may exist in the sandy, basal section.

Proximal Delta Front

Proximal-delta-front facies in the Woodbine Group in Tyler County exhibit the greatest core-plug porosity value (22.0%) of all facies in this study, although permeability values are higher in distributary-channel facies (Table 1; Figs. 14 and 16). The proximal-delta-front facies displays consistent vertical trends between grain size and porosity and permeability values (Fig. 4). Reservoir quality is inferred to be high throughout most of the proximal-delta-front facies, owing to few mudstone beds, particularly near the top of the sandstone-rich section (Fig. 5C). In contrast, lesser reservoir quality is encountered in the lower one-half of the section, where moderate values of porosity (10 to 15%) and permeability (3 to 5 md) are associated with beds affected by soft-sediment deformation (Fig. 4).

Distal Delta Front

Woodbine distal-delta-front facies have comparable ranges in porosity and permeability values with respect to those in the proximal-delta-front facies, although median-permeability values are lower (Figs. 14 and 16). Unlike the proximal-delta-front facies, they exhibit poorly defined vertical trends in permeability relative to grain size, owing to the great number of thin, matrix-rich sandstone beds and interbedded mudstone (Figs. 4 and 6). Porosity values >12% occur near the top of the distal-delta-front facies in the Cities Service No. B–1 Sutton well, although no vertical trends can be distinguished owing to sparse porosity data.

Distributary Channel

Distributary-channel deposits have the best permeability values in Woodbine shallow-marine systems, both in terms of greatest and median values (Table 1; Fig. 14). Proximal-delta-front facies have greater maximum porosity values than do distributary-channel facies, although median porosity values are

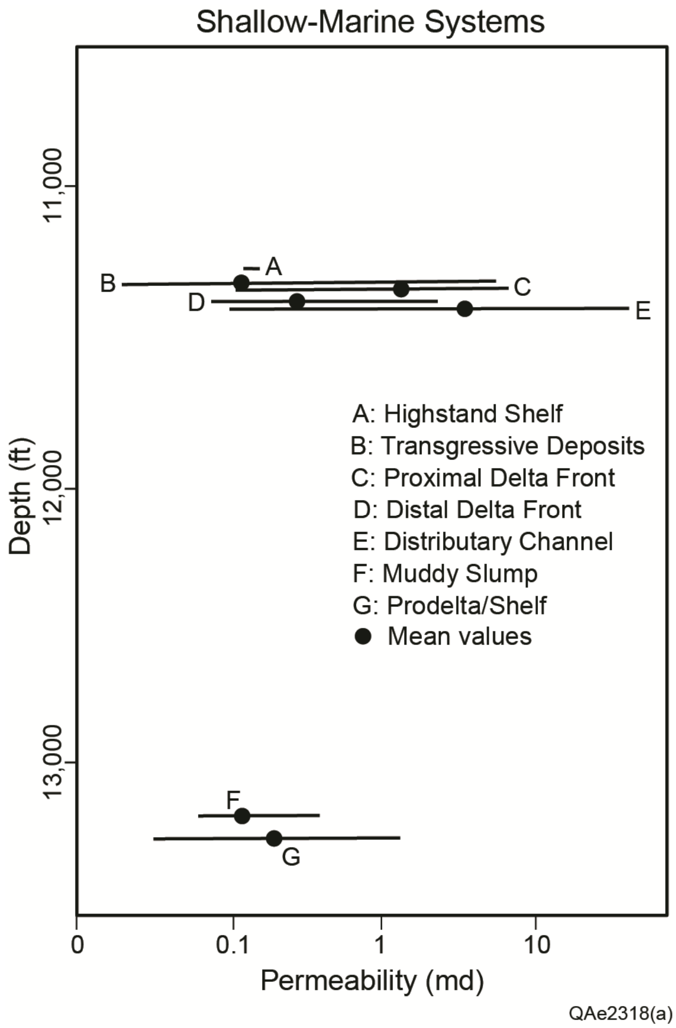


Figure 14. Depth versus permeability crossplot from cored wells in shallow-marine systems in the study area. Facies A to E are from the Cities Service No. B–1 Sutton well, whereas facies F and G are from the Sun No. 1 Hanner Mae Estate well. Wells are located in Figure 2 and shown in Figure 3. Average depth and range in permeability values are represented by horizontal lines and black dots represent median permeability values where available. Permeability data are also summarized in Table 1.

similar (Fig. 16). Vertical permeability and porosity trends in the distributary-channel facies in the Cities Service No. B–1 Sutton well are upward-decreasing, matching the slightly upward-fining grain-size profile (Fig. 4). However, the basal part of the distributary-channel facies, which contains abundant soft-sediment deformation, features low-permeability values that reflect the presence of muddy matrix and clay clasts. Similar reservoir-quality trends are observed in other Woodbine distributary-channel facies in East Texas Field (Ambrose and Hentz, 2010), suggesting that greater reservoir quality may exist in the lower to middle part of this facies rather than at the base.

Muddy Slump and Prodelta/Shelf

Muddy-slumps, along with transgressive deposits, have the lowest median-permeability values with shallow-marine systems in this study (Table 1; Fig. 14). Vertical trends in permeability in the muddy-slump facies are poorly defined, although there is a slight upward increase in the lower two-thirds of the cored section (Fig. 6). Reservoir quality in this facies is inferred to be negligible, owing to: (1) the almost total absence of sandstone beds, (2) lack of permeability values greater than 0.6 md (Fig. 6), and (3) pervasively disrupted stratification (Fig. 7D).

Although Woodbine prodelta/shelf deposits have a greater range of permeability values than do muddy-slump deposits, the median value of permeability (0.4 md) is similarly low (Fig. 14). This facies has no overall vertical permeability trend, reflecting an absence of vertical grain-size trend (Fig. 6). Some thin sandstone beds in the prodelta/shelf facies have permeability values as great as 2.1 md (Table 1). However, owing to fine grain size and thin sandstone beds, the prodelta/shelf facies, as with the muddy-slump facies, is regarded as nonreservoir.

Slope Systems

Woodbine slope systems, represented by the Humble No. 1 Howell, Standard No. 2 Longbell, and Delta No. 2 Carter wells (located in Figures 2 and 3), collectively display permeability values over a range of two orders of magnitude, although the range in values for each facies in individual wells is commonly on the order of one magnitude (Fig. 14). Debris-flow facies exhibit the greatest range in permeability values, reflecting their heterolithic nature and complex stratification.

Channelized Levee

Channelized-levee facies, present in the Humble No. 1 Howell core (located in Figures 2 and 3), have the greatest median-permeability value (1.6 md) in slope systems, although this value is not significantly higher than those for other deepwater facies in this study (Table 1; Fig. 15). Porosity values in the channelized-levee facies slightly increase upward, possibly related to average grain size, whereas permeability values show no overall vertical trend (Fig. 8). Numerous thin (2- to 6-in [5.1- to 15.2-cm]) zones with deformed bedding may disrupt vertical reservoir continuity (Fig. 11D). Vertical continuity could also be disrupted by vertical changes in stratification (Fig. 11C).

Levee

Levee facies exhibit similar ranges in permeability values in the less deeply buried cored intervals in the Standard No. 2 Longbell and Delta No. 2 Carter cores, whereas the more deeply buried levee facies in the Humble No. 1 Howell core has a smaller range and lesser median value (Fig. 15). All median-permeability values in the levee facies are low, reflecting the presence of numerous mudstone drapes and microfaults within thin beds of very fine-grained sandstone (Fig. 13). Moreover, many of these thin sandstone beds are lenticular and discontinuous (Fig. 11A).

Debris Flow

Woodbine debris-flow facies exhibit a wider range in permeability values with respect to other slope facies (Fig. 15). This wide range in permeability values is a function of both variability in grain size and stratification, ranging from shale-clast conglomerate to silty mudstone with stratification consisting of either convolute bedding or semi-coherent bedding with aligned shale clasts in a sandy matrix (Figs. 9, 12C, and 12D). The debris flow facies in the Standard No. 2 Longbell core presents a general upward decrease in permeability, although variability exists (0.3 to >5 md) in the basal 2 ft (0.6 m) (Fig. 9). Reservoir continuity in this facies is inferred to be poor, with permeability continuity being locally disrupted by scour surfaces and intensely-folded and disrupted beds (Figs. 12C and 12D).

CONCLUSIONS

The Upper Cretaceous (Cenomanian) Woodbine Group in northern Tyler and southeastern Polk counties, Texas, comprises a shelf-to-slope transition, within which sandstone-body thickness and reservoir quality vary greatly. Shallow-marine Woodbine deltaic deposits in northern Tyler County, interpreted in other studies as deepwater in origin, consist principally of delta-front, distributary-channel, transgressive, and highstand-shelf facies. This shallow-marine interpretation is based on: (1) paleogeographic position overlying the Edwards Reef Trend, updip of mudstone-dominated slope deposits in central and western Tyler County, (2) *Skolithos* and *Cruziana* ichnofaunal assemblages, particularly in mudstones directly overlying the main sandy section in the core, and (3) the presence of upward-shoaling successions with transitions from lower-flow-regime ripples to upper-flow-regime planar stratification.

In contrast, Woodbine slope deposits in northwestern Tyler County, downdip of the Cenomanian shelf edge, are sandstone-poor, have poor to moderate reservoir quality, and therefore have a limited potential for additional oil and gas development. These slope deposits contain thin (commonly <1-ft [<0.3-m]) beds of very fine-grained sandstone encased in sparsely burrowed mudstone. The sandiest slope facies, represented by channelized-levee within incomplete Bouma sequences and graded beds, occur in slightly upward-coarsening successions with multiple upward-fining sandstone beds. Heterolithic Woodbine debris-flow deposits are erosion-based, upward-fining sections with chaotic bedding, respectively.

Although facies origin is an important factor controlling reservoir quality in Woodbine sandstones, original porosity has been modified by diagenesis. Nevertheless, this study shows that permeability and limited porosity data from core plugs display consistent trends between reservoir quality (defined from porosity and permeability values) and depositional facies. Greatest reservoir quality exists in distributary-channel and proximal-delta-front facies within shallow-marine Woodbine systems. In contrast, reservoir quality is low in Woodbine slope facies in western Tyler County, although it is locally moderate in channelized-levee and sandy debris-flow facies. Although there is a decrease in reservoir quality (porosity and permeability) with depth, variation in reservoir quality exists between and within both shallow-marine and deepwater facies as a function of grain size and stratification.

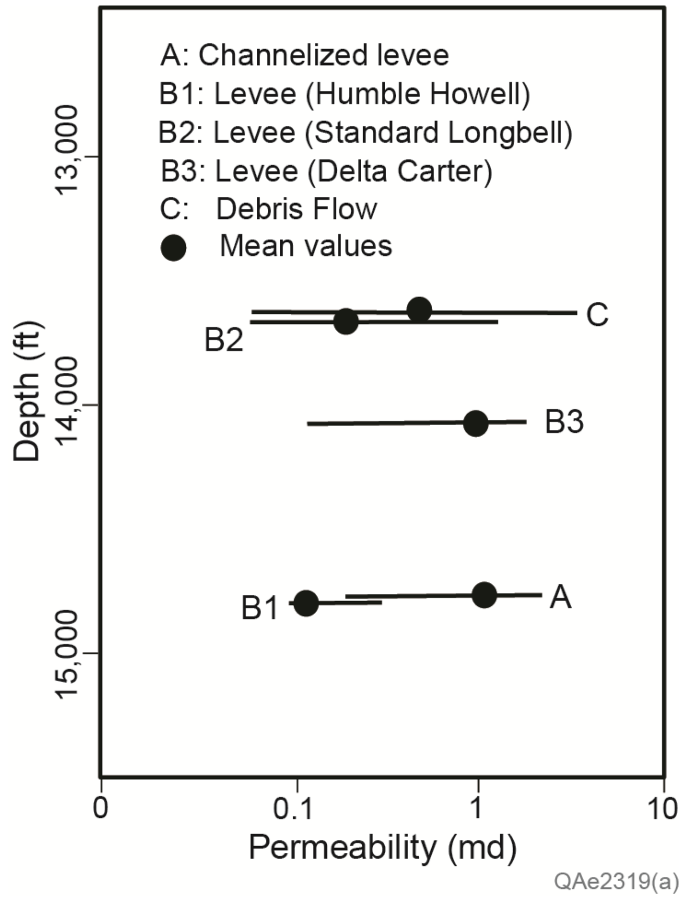


Figure 15. Depth versus permeability crossplot from cored wells in slope systems in the study area. Average depth and range in permeability values are represented by horizontal lines and black dots represent median permeability values where available. Wells are located in Figure 2 and shown in Figure 3. Permeability data are also summarized in Table 1.

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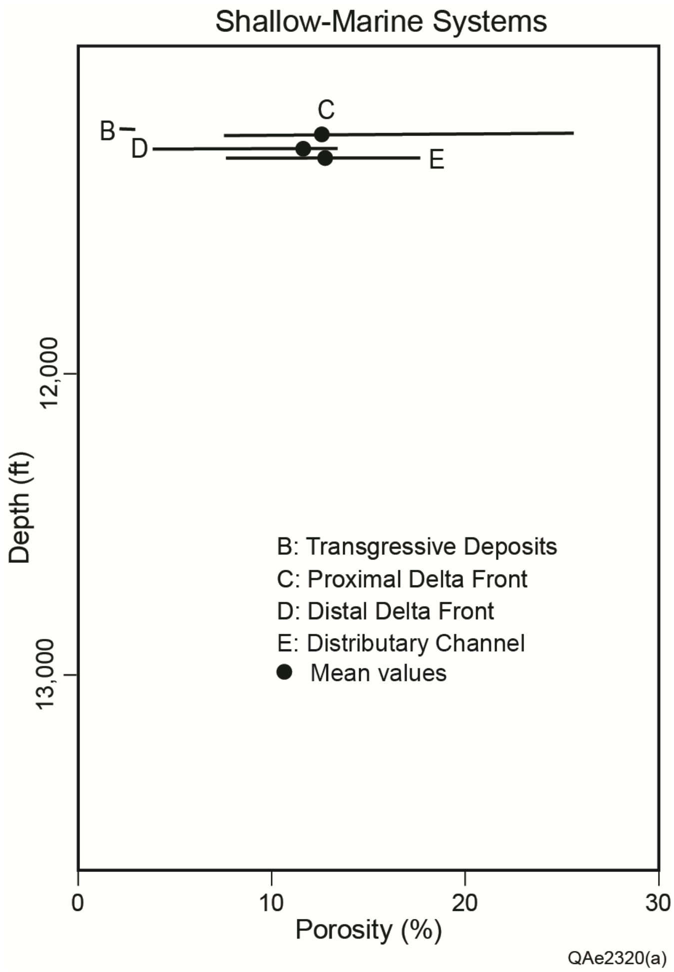

Figure 16. Depth versus porosity crossplot from cored wells in shallow-marine systems from the Cities Service No. B–1 Sutton well, located in Figure 2 and shown in Figure 3. Capital letters B–E representing shallow-marine facies are referenced with those in Figure 14. Porosity data are also summarized in Table 1.

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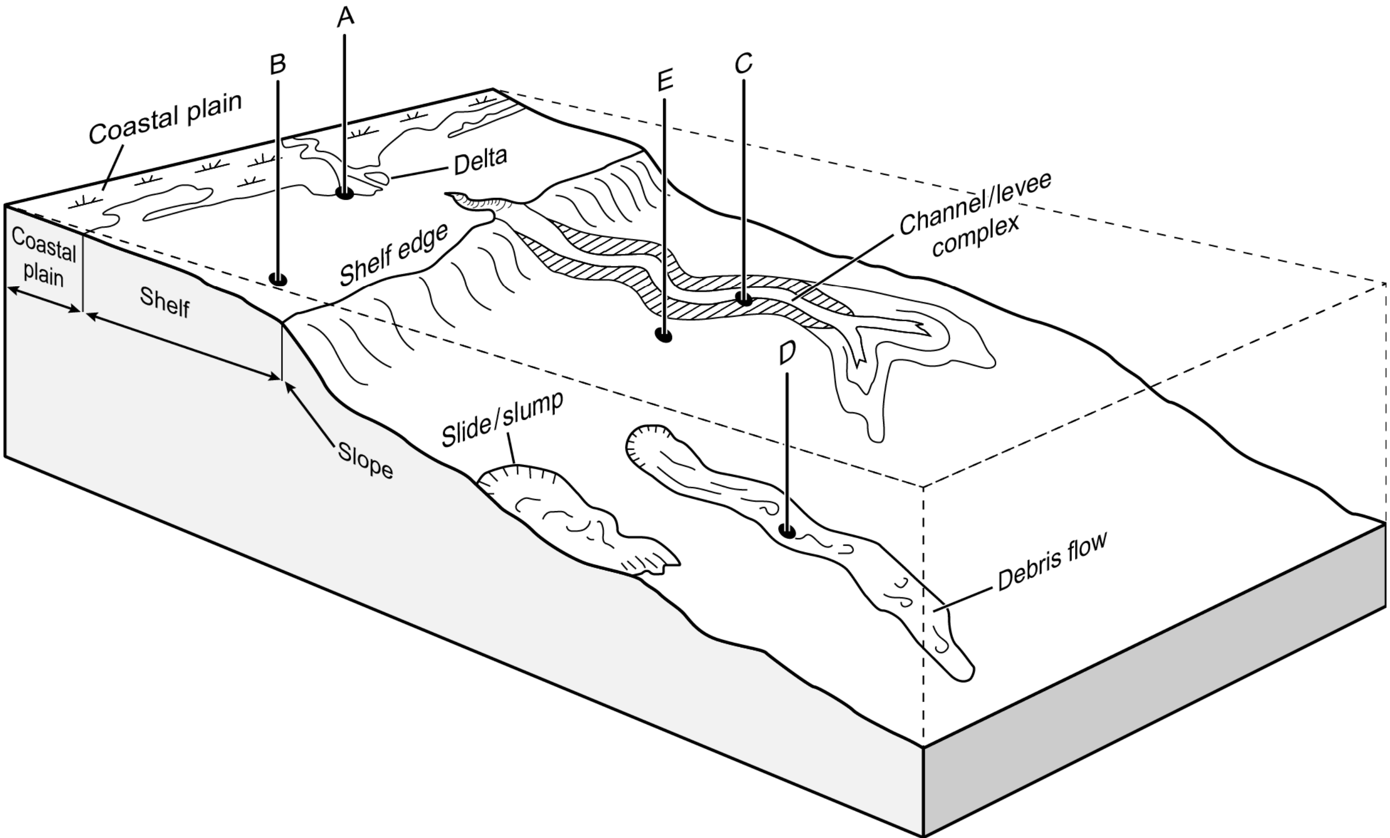

Figure 17. Depositional setting for five cored wells in this study (modified after Bouma et al., 1995; Stow et al., 1996; Stow and Mayall, 2000). (A) Cities Service No. B–1 Sutton well, (B) Sun No. 1 Hanner Mae Estate well, (C) Humble No. 1 Howell well, (D) Standard No. 2 Longbell well, and (E) Delta No. 2 Carter well. Wells are located in Figure 2.

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