CHAPTER 2:

FACIES ANALYSIS

2.1 Introduction

The designation of strata into lithologic facies and characterization of stratigraphic intervals using defined facies were used to interpret depositional environments and to develop a sequence-stratigraphic framework for better understanding coalbed gas production and resource potential. Previous investigations by Harris (1984), Staton (1987), and Huffman (1991) defined lithofacies for Cherokee Group rocks in southeastern and east-central Kansas from cores, outcrops, and lithologic to well-log relationships. Walton (1996) expanded on the facies and conclusions of these studies and placed the Cherokee Group into a sequence stratigraphic framework.

The current study utilizes these previous investigations as well as the recent work of Lange (2003), who defined 10 lithofacies based on detailed description of two continuous cores from Labette and Montgomery counties, southeastern Kansas. In this study, 13 facies across the Bourbon arch region were identified and defined from the Desmoinesian intervals of two continuous cores (Table 2.1). Facies descriptions include lithology and thickness, color, composition, grain characteristics, bedding characteristics, sedimentary structures, nature of overlying and underlying contacts, trace and body fossils, and post-depositional features (Appendix A; Johnson, 2004). Facies are based solely on available cores and may not reflect characteristics in other areas of eastern Kansas. Facies descriptions are followed by discussion of the depositional processes and environments.

Table 2.1 Lithofacies of Desmoinesian strata in the Bourbon arch.

Lithofacies	Depositional Process	Depositional Interpretation
Coal	Peat accumulation and coalification	Raised, floating, or low-lying mire
Underclay	Weathering and pedogenesis of existing facies	Paleosol
Black Shale	Low-energy sediment fallout; sediment reworking	Deep water shelf; storm deposits
Gray Shale	Sediment fallout > low-energy periodic sedimentation	Restricted estuarine basin or embayment; or restricted offshore transition
Heterolithic Siltstone	Low-energy tidal currents and slackwater fallout	Lower tidal flat or subtidal coastline
Heterolithic Sandstone	High-energy tidal currents > slackwater fallout	Upper tidal flat, channel, or coastline (subtidal-intertidal)
Mudstone-Wackestone Limestone	Low-energy carbonate production	Open marine; shallow restricted marine (subtidal-intertidal)
Packstone-Grainstone Limestone	High-energy carbonate production; current reworking	Intertidal shoal or channel overbank; shallow subtidal shoal; storm deposit
Chaetetid Boundstone-Rudstone	In situ growth or reworking	Shallow, high-energy, open marine
Conglomerate	High-energy, unidirectional traction currents; weathering of Mississippian Carbonate	Fluvial channel bar (mud-sand basal lag); residuum (chert conglomerate)
Cross-bedded Sandstone	High-energy, unidirectional traction sedimentation	Fluvial channel sand bar
Interbedded Sandstone-Siltstone	Unidirectional traction and suspension sedimentation (varying energy)	Non-tidal prodelta, delta-front
Bioturbated Sandstone	Transgressive biologic and storm current sediment reworking	Transgressive lag; storm deposits

2.2 Facies Analysis

2.2.1 Coal Facies (Fig. 2.01)

Description

The coal facies consists of true coal (high volatile C- to A bituminous) to very carbonaceous siltstone. In core, thickness ranges from a few inches or centimeters to 2.5 feet (0.8 m), with 1 foot (0.3 m) being common. Well log interpretation indicates that coals may reach thicknesses of 3.8 feet (1.2 m) within the study area. The distribution of coals can be local or continuous, with individual seams extending into adjacent townships or basins. The coal facies is typically black to very dark-brown with vitreous luster on cleat surfaces, but can also have a duller appearance as silt increases (silty carbonaceous shale). Sedimentary structures range from structureless to thinly (1-3 mm) or thickly (3-10 mm) laminated, and can sometimes be inclined (less than 15˚; Fig. 2.01). Silt seams, or splits, may be present. Millimeter- to cm-scale vertical cleating is common, except in carbonaceous siltstone (Fig. 2.01). Upper contacts are sharp with overlying gray or black shale facies. Lower contacts are either sharp or gradational with the underlying underclay facies.

The coal facies contains abundant plant remains such as leaves, bark, and stems. Rooting within the facies is rare. Higher ash coals, or carbonaceous shales, may include fossil hash in upper portions, including brachiopod shells and fragments. Post-depositional features include nodular pyritization as well as calcareous mineralization in cleat spaces (Fig. 2.01).

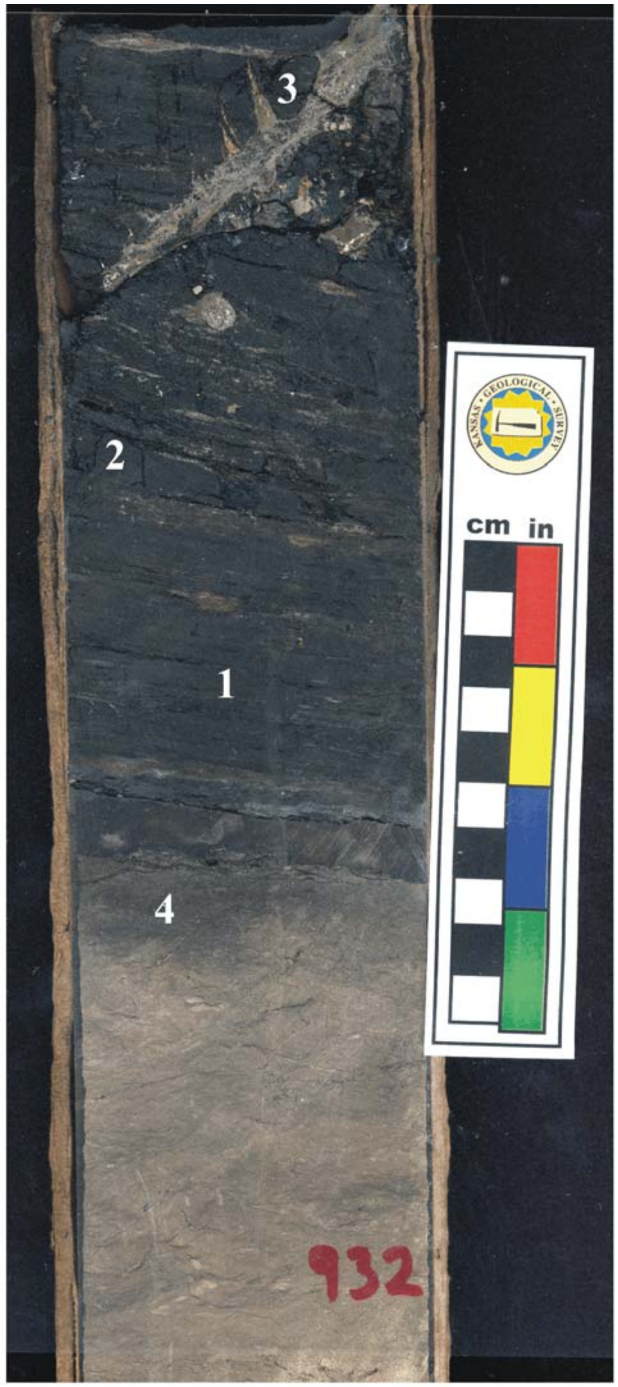

Figure 2.01 *Coal Facies.* Scanned core image of the Neutral coal (931.2'-931.8') and underclay facies (931.8'-932.1') of the Rose Hill #1-6 well (Johnson, 2004). Note the sharp contact between facies (separated by casting resin), inclined and laminated nature of the coal (1), vertical and horizontal cleating (2), pyrite and calcite mineralization (3), and organic-rich horizon of the underlying underclay (4).

Interpretation

The processes of deposition and formation of the coal facies are peat accumulation, burial, and coalification. This is evident by the high organic content, preserved plant remains, and laminated and compacted nature. Despite the root structures of the underclay facies that typically underlies the coal facies, a significant depositional hiatus occurs between a coal and its underlying sediments and the two facies are not genetically related (McCabe, 1984). On the other hand, coals that sharply overlie non-rooted facies—particularly higher energy sandstone and conglomerate facies—were eroded and transported from a nearby peat-forming environment and are genetically related to underlying sediments (McCabe, 1984). Coals with higher sulfur contents or pyritization and overlying black shale facies point to development in proximity to marine conditions. Subsequent marine flooding highly influences the quality of underlying coal. Coal with higher ash or splits indicate development in proximity to active marine or nonmarine siliciclastic depositional environments (McCabe, 1984). Coals of the Desmoinesian in eastern Kansas are attributed to a continental or marginal marine mire environment; either raised, low-lying, or floating (McCabe, 1987; 1991).

2.2.2 Underclay Facies (Fig. 2.02)

Description

The underclay facies corresponds to Lange's (2003) "Blocky Mudstone" facies, and although both facies names imply fine-grained sediment, the underclay facies may be of any siliciclastic or carbonate lithology depending on the nature of

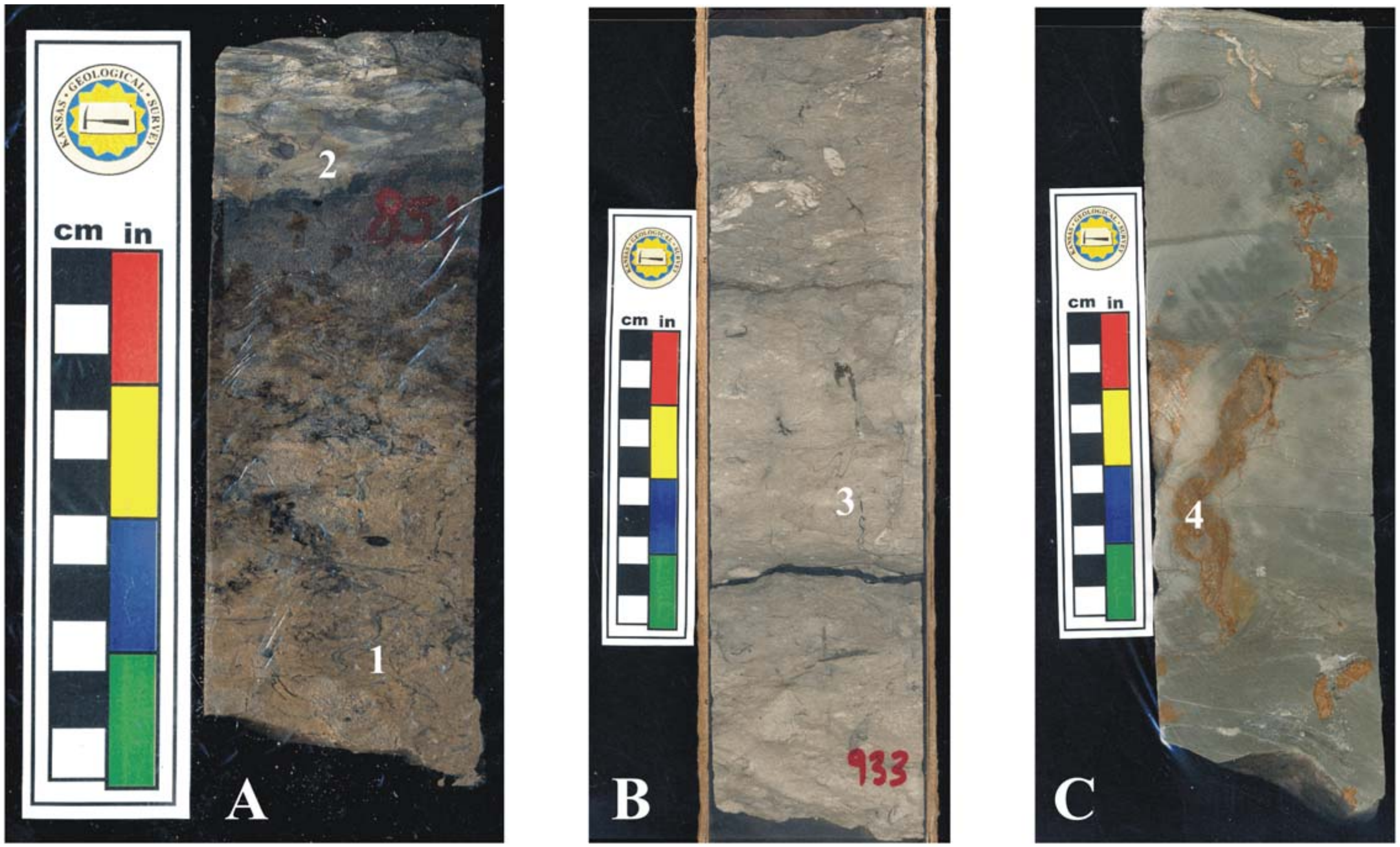

Figure 2.02 *Underclay Facies* (A) Scanned core image displaying mottled texture, carbonaceous root traces (1), and overlying ravinement surface (2) from the Franklin County core (850.9’-851.4’; Appendix A). (B) Sandy to silty underclay with carbonaceous root traces (3) directly underlying the Neutral coal in the Rose Hill #1-6 core (932.1’-933.0’; Johnson, 2004). (C) Underclay facies displaying siderite- and calcite-lined root traces , or “rhizoconcretions” (4), from the Rose Hill #1-6 core (745.0’-745.9’; Johnson, 2004).

the underlying parent material. When overprinting sandstone and conglomerate lithologies, the underclay facies is generally poorly sorted with silt or clay matrix. Additionally, grain size and the degree of sorting may be segregated, separating the facies into gradational, but discernable horizons. Thickness, from the upper contact to the first appearance of relict sedimentary structure, ranges approximately 1 to 20 feet (0.3 to 6 m), with 4 feet (1.2 m) being most common. The color of the underclay ranges from light to dark gray, with occasional shades of greenish-gray, brownish-gray, or very rarely maroon. Most sedimentary structures of the underclay facies are post-depositional based on cross-cutting relationships. However, structures previously found in the parent material (relict structures) may be present. Post-depositional structures include platy, subangular-blocky, or angular-blocky mudstone "clods" and rare columnar- and prismatic-shaped mudstone "clods", all of which may commonly be clay coated (i.e., cutanic). Another post-depositional structure in the underclay facies is clay-coated slickensides that were observed in clay-rich intervals. As with grain size and sorting, post-depositional sedimentary structures can segregate into horizons. Lower contacts are gradational with post-depositional structures overprinting underlying sediments of any facies, while upper contacts are typically sharp (sometimes erosional) but can be gradational into coal (or carbonaceous shale), black shale, gray shale, or heterolithic sandstone or siltstone facies. The underclay facies is correlative on both local (basin-wide or smaller) and regional (basin-wide and greater) scales.

Fossil features of the underclay facies include plant fragments (i.e., stems and leaves) and various types of root traces. Root traces include preserved carbonized root structures, calcite- or siderite-lined root-shaped concretions, and rare drab-haloed traces that give the facies a mottled-color appearance (Fig. 2.02). Invertebrate body fossils or trace fossils are rare unless the facies has overprinted facies containing such features. Post-depositional features generally include calcite or siderite nodules and cement.

Interpretation

Paleosols have three distinguishing characteristics: root traces, soil structure, and soil horizons (Retallack, 1988; 2001). The underclay facies of this study, which includes one or more of these characteristics, is interpreted as a paleosol forming from weathering and pedogenic processes during subaerial exposure. Paleosol features are indicative of the conditions present during soil formation such as paleoclimate, paleoenvironment, duration of exposure, but may also be influenced by overlying conditions brought about by marine flooding as well as composition and mineralogy of underlying parent material (Gustavson, 1991; Retallack, 2001).

Root traces can disclose information concerning the water table and drainability of a soil. Carbonaceous root traces are best preserved in poorly drained, watery soils, although they do not extend below mean water table. Therefore, more vertically spreading root traces reflect relatively more well drained soils, whereas more laterally spreading root traces reflect poorly drained, waterlogged soils in swampy or low-lying areas. Calcite- and siderite-lined root traces, or rhizoconcretions, reflect drier, well-drained, alkaline soils where fresh, nutrient-rich waters are absorbed by roots, leaving nutrients behind and forming concretions around the root. Drab-haloed root traces are indicative of stagnant water and reducing conditions (Fig. 2.02; Retallack, 2001).

Soil structures may also provide clues to soil maturity and drainability. Platy soil clods, referred to as pedogenic structures or "peds", indicate initial disruption of relict bedding and immaturity, whereas angular-blocky and subangular-blocky peds form from longer periods of pedogenesis and more mature soils. Columnar and prismatic peds result from clayey soils with high salt content and high shrink-swell capability. Pedogenic slickensides, commonly found in the underclay facies and commonly clay-coated, are clay shrink-swell features characteristic of slightly more developed soils in environments with defined (but not necessarily equal) wet and dry seasons (Retallack, 2001).

With development over time, soils may segregate into discernible horizons based on grain size, pedogenic structures, previous sedimentary features, and chemical attributes. Horizon definition based on these features is a step towards paleosol classification. Pedogenic horizons (e.g. grain size, pedogenic features, chemical precipitates, and depth to visible previous sedimentary structures) were observed in the underclay facies (Appendix A; Johnson, 2004). The detailed classification of Desmoinesian paleosols is beyond the scope of this study. In general terms for interpretation of the depositional environments of coals and surrounding strata, the majority of Desmoinesian paleosols are interpreted as non-oxidized (from drab, gray colored soil), semi-vertic (based on slickensides), very weakly developed (minimal horizonation) Entisols or weakly developed Inceptisols; or even moderately developed Vertisols (Retallack, 1988; 2001).

2.2.3 Black Shale Facies (Fig. 2.03)

Description

The black shale facies can be described as having three variations: phosphatic black shale, pyritic black shale, and fossiliferous black siltstone (Fig. 2.03). These variations are equivalent to Lange's (2003) "Phosphatic Shale" and "Dark Gray Shale" facies. The black shale facies consists of black, dark-gray, or dark-brown siltstone, silty-shale, to shale. Thickness ranges from 0.5 to 20 feet (0.2 to 6 m), averaging about 1 foot (0.3 m) for most phosphatic and fossiliferous black shales, and 10 feet (3 m) for pyritic black shale. Sedimentary structures include very thin (<1 mm) to thin (1-3 mm) unfossiliferous horizontal laminae, and more fossiliferous and silty thin (1-3 mm) to thick (3-10 mm) laminae to very thin (1-3 cm) beds. Fissility is common. Both upper and lower contacts are either sharp or gradational. Underlying facies include coal, underclay, mudstone-wackestone, or heterolithic siltstone. Overlying facies include heterolithic siltstone, mudstone-wackestone, or gray shale.

Occurrence of body and trace fossil constituents ranges from minor to abundant. Phosphatic black shale tends to have significantly lower fossil concentrations than non-phosphatic black shale (Fig. 2.03). The exception is microfossils (e.g. conodonts; Heckel, 1977). Most body fossils are fragmented, but whole specimens of brachiopods, crinoid stems, fusulinids, and other foraminifera are

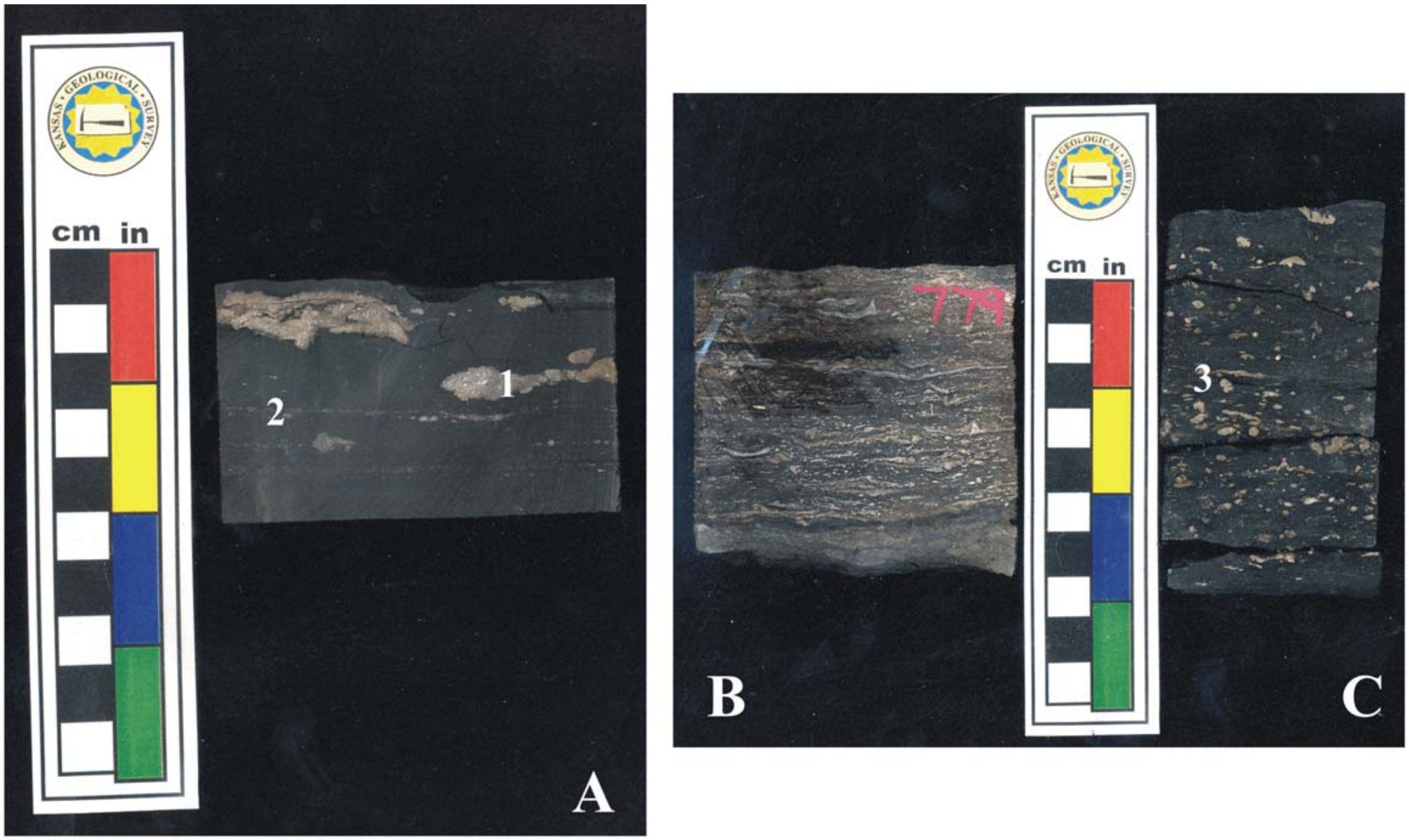

Figure 2.03 *Black Shale Facies* (A) Phosphatic black shale facies variant (Anna Shale) from the Rose Hill #1-6 core (576.0’-576.2’; Johnson, 2004). Phosphate may form as nodules (1) or bands (2). (B) Fossilferous black shale facies variant directly overlying the Chelsea Sandstone (Scammon coal is absent) in Rose Hill #1-6 (779.0’-779.3’; Johnson, 2004). (C) Pyritic black shale directly overlying the Tebo coal in the Franklin County well (Appendix A). Pyrite in the black shale facies typically forms as nodules (3), bands, or as mineral replacement in fossils.

present. Observed trace fossils include flat, vertical, and spiral burrows of undetermined species. Calcite, in the form of thin laminae, body fossils, or cement was observed throughout the facies, although more diagnostic in areas of higher fossil content. Pyrite, as nodules (up to 2 cm diameter) or recrystalized body fossils, is common in the non-phosphatic variant. Phosphate nodules (up to 3 cm diameter) or thin laminae are characteristic of a variant of the black shale facies (Fig. 2.03).

Interpretation

The black color, fine-grained composition, laminated structure, and pyritic or phosphatic, and rare calcareous nature of this facies indicates deposition by suspension sediment fallout in a low-energy, anoxic, offshore marine environment. Absence of macroscopic plant debris indicates offshore conditions where the portion of organic debris that is deposited is broken down and not preserved. Where calcareous and pyritic, coarser-grained, more fossiliferous, and thicker-laminated, the black shale facies is indicative of a slightly higher energy, offshore, dysoxic marine environment.

The fossiliferous variant typically overlies shallower facies (e.g., coal or underclay facies) and underlies deeper facies (e.g. pyritic or phosphatic black shales). The fossiliferous variant of the black shale facies is interpreted as a transgressive lag deposit. In terms of the “Kansas-type” cyclothem, the pyritic and phosphatic components of the black shale facies correspond to the core shale member, while the fossiliferous black shale component is interpreted as the lower Desmoinesian equivalent to the Missourian middle limestone (Heckel, 1977).

Heckel (1977) postulated that the core shale of the cyclothem represented maximum transgression (depth of ~ 100 m) and was deposited from upwelling and circulation of cold, organic- and phosphate-rich marine waters within a quasi-estuarine, shallow epicontinental sea. On the other hand, Suchy and West (2001) hypothesize that the black shale facies was not the time of maximum transgression, rather that formation was in response to a warmer, wetter, greenhouse climate in which less-prevailing winds minimized ocean circulation, resulting in a stratified cratonic sea. The black shale facies, particularly the pyritic and phosphatic components, are typically correlative on a regional scale. Based on this regional extent, deeper water shelf environments are favored over shallower interpretations. Black shales are further differentiated between phosphatic, "Heebner-type" and non-phosphatic "Mecca Quarry-type" (Schultz, 1991). The presence of phosphate in black shale is believed to be indicative of deeper water, offshore settings relative to more nearshore, deep marine settings when non-phosphatic (Heckel, 1977; Schultz, 1991).

2.2.4 Gray Shale Facies (Fig. 2.04)

Description

The gray shale facies is composed of medium-gray to dark-gray, sometimes micaceous, siltstone, silty-shale, or shale ("Sideritic Gray Shale" facies of Lange, 2003). The facies is regionally extensive across the study area and into surrounding basins. In the Cherokee basin, the gray shale facies is restricted to within incised valleys (Lange, 2003). In the Bourbon arch study area, the gray shale facies is widely

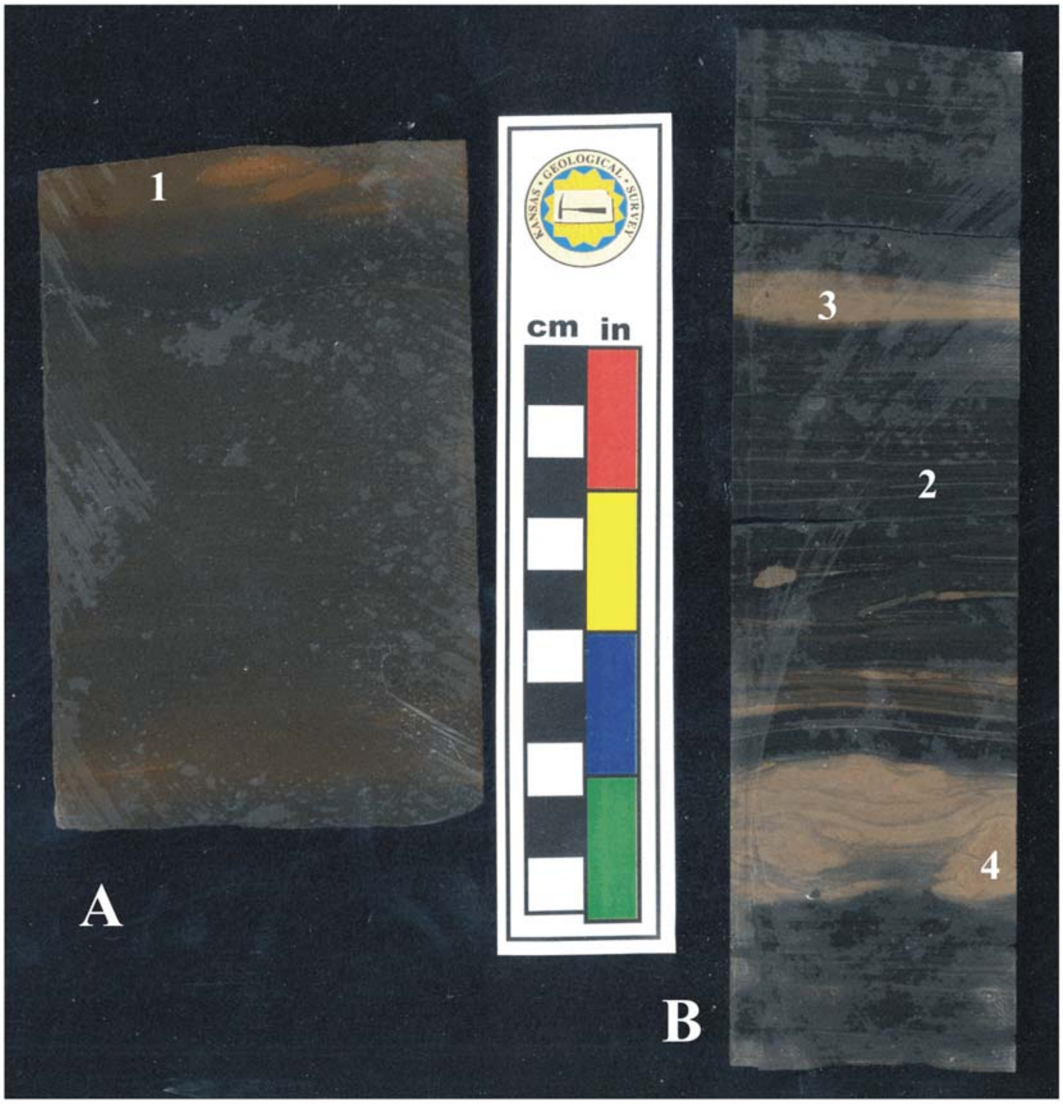

Figure 2.04 *Gray Shale Facies* (A) Scanned core image of gray shale with siderite cementation (1) from Rose Hill #1-6 (980.9'-981.0'; Johnson, 2004). (B) Gray shale facies from the Franklin County core (801.3'-801.8') displaying very thin (<1 mm) to thin (1-3 mm) laminae (2) and siderite bands (3) and nodules (4; Appendix A).

distributed. Thickness ranges from 2 to 20 feet (0.6 to 6m) and averages 8 feet (2.4 m). Sedimentary structures typically include thin (1-3 mm) to very thin (<1 mm) parallel, horizontal or slightly inclined (<5˚) laminae (Fig. 2.04). Relatively rare, thin (1-3 mm), slightly lenticular siltstone laminae were observed, but are more abundant in the heterolithic siltstone facies. Thin to very thin, repetitive, fining-upward laminae sets were observed in parts. Laminae can be fissile. The gray shale facies tends to coarsen upward, with upper contacts being gradational with overlying heterolithic siltstone facies or sharp with overlying heterolithic sandstone facies. Lower contacts are generally sharp with underlying black shale, underclay, or coal facies.

Body fossils in the gray shale facies are rare, except for sparse articulated brachiopod shells. Plant debris can range from absent to abundant. Trace fossils, such as horizontal and vertical burrows, are common. Several instances of *Planolites* were observed in core. Siderite, in the form of nodules, cement, or bands is a very common diagenetic or post-depositional feature (Fig. 2.04). Calcareous matrix is a less common diagenetic or post-depositional feature.

<u>Interpretation</u>

Thin, parallel, horizontal to inclined laminae without reactivation surfaces reflect suspension sediment fallout without traction currents. Minor episodic, but intra-cyclic (including those with a repetitive, fining-upward nature), lenticular laminae resembling ripple laminae suggests deposition from episodic low energy currents. The presence of macroscopic plant debris indicates deposition proximal to continental or marginal marine environments. The low trace fossil diversity and presence of siderite indicate stressed, brackish water with fresh water input (Potsma, 1982; Buatois et al., 1999). Based on these criteria, the gray shale facies is interpreted as being deposited by suspended sediment fallout and periodic low-energy currents in a slightly restricted basin or an offshore, moderate-depth setting.

2.2.5 Heterolithic Siltstone Facies (Figs. 2.05)

Description

The heterolithic siltstone facies corresponds in part to Lange's (2003) "Interlaminated Sandstone and Siltstone" facies. The heterolithic siltstone facies is composed of bimodal, well-sorted, medium- to dark-gray siltstone and silty very fine-grained (vfL) sandstone, which tends to coarsen upward to very fine-grained (vfL-vfU) sandstone. Thickness ranges from 1 to 10 feet (0.3 to 3 m) with 4 feet (1.2 m) average. Based on core observations, the facies is regionally correlative. Sedimentary structures include very thin (<1 mm), thin (1-3 mm), to thick (3-10 mm) horizontal silt laminae, interlaminated with thin to thick lenticular silty-sand laminae and minor starved unidirectional ripple lamination sets (3-10 mm; some sigmoidal; Fig. 2.05). Mud drapes are common between coarser laminae. The heterolithic siltstone facies includes very thin to thin fining-upward laminae, sometimes with a repetitive thick-thin nature, as well as repetitive, or "bundled" laminated couplets within thickening- and thinning-upward lamination sets. Reactivation surfaces are common (Fig. 2.05). Strata may be inclined up to 10° and may be locally convolute. Upper contacts tend to be gradational. Overlying facies commonly include the

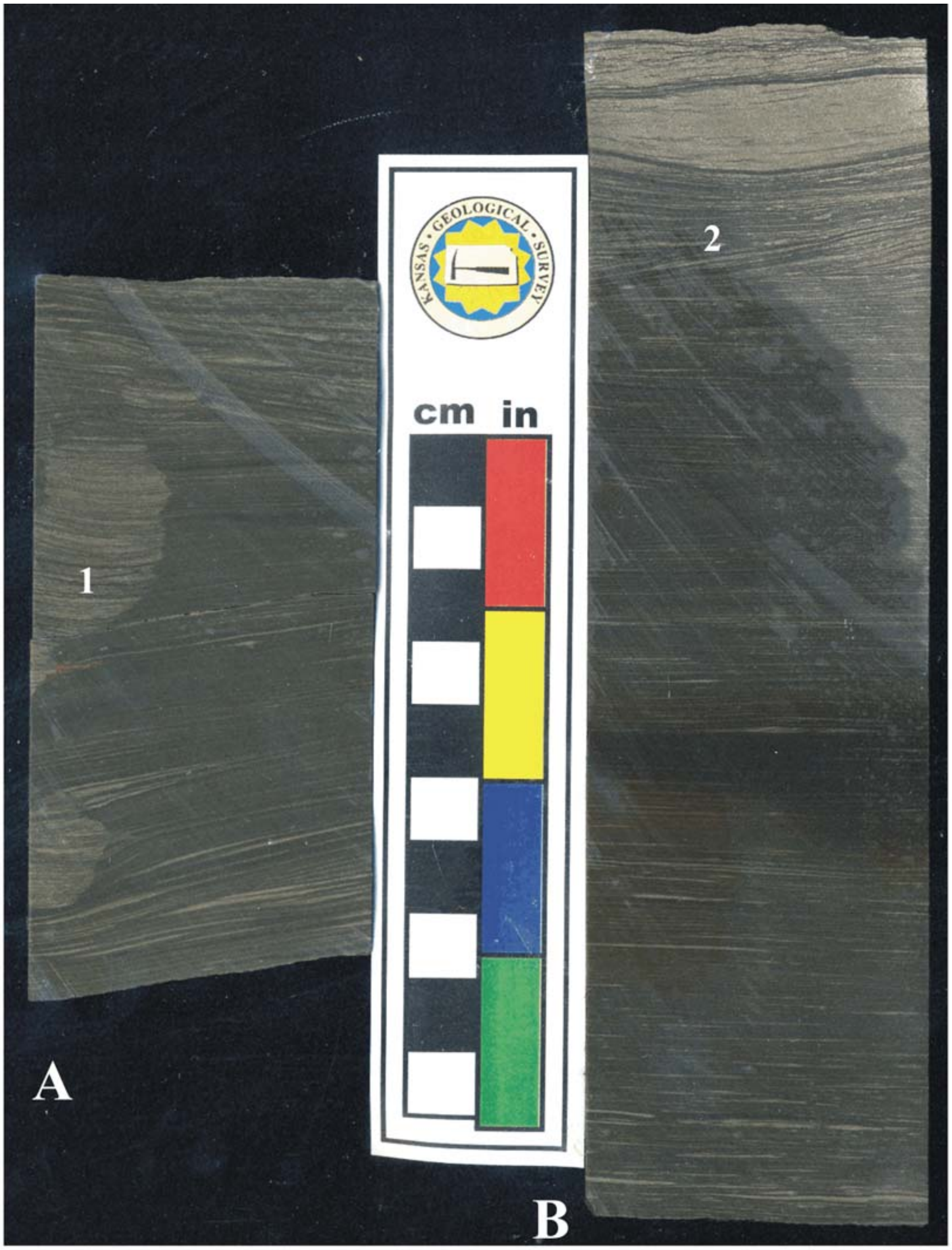

Figure 2.05 *Heterolithic Siltstone Facies* (A) Heterolithic siltstone facies within the Bandera Quarry sandstone of the Franklin County core (578.3’-578.6’) displaying very thin (<1 mm) to thick (3-10 mm) parallel and lenticular laminae and *Teichichnus* burrows (1; Appendix A). (B) Scanned image from the same core (581.5’-582.0’) with similar sedimentary features as well as a reactivation surface (2; Appendix A).

heterolithic sandstone facies, and less commonly the underclay, black shale, and bioturbated sandstone facies. Basal contacts tend to be gradational with underlying coal, gray shale, black shale, and heterolithic sandstone facies.

Body fossils in the heterolithic siltstone facies are rare. In core, one whole brachiopod was observed in a horizontal burrow. Transported plant debris is very common (e.g. leaves and fragments). Trace fossils are also common, such as *Teichichnus* and *Planolites*, but are more abundant constituents in the heterolithic sandstone facies (Fig. 2.05). Other unidentified vertical and horizontal burrows, as well as structureless bioturbated zones, were observed. When overlain or overprinted by the underclay facies, minor carbonaceous or siderite-lined root traces are present. Common diagenetic features include siderite (nodules, banding, and cement), and more rarely, calcite cementation.

Interpretation

The heterolithic siltstone facies is interpreted as forming from alternating flood-ebb tidal currents and intervening slackwater suspension fallout in lower tidal flat or subtidal coastline settings. This interpretation is primarily based on sedimentary structures found within the facies that are credited to tidal origins (Nio and Yang, 1992). Tidal processes can be inferred from four exclusive criteria: 1) mud couplets or drapes (observed in facies), 2) lamination bundles and bundle sequences (observed in facies), 3) reactivation surfaces (observed in facies), and 4) diurnal or semidiurnal, cyclic bundle thickness variation. Additional indicators that are not exclusive to—but are associated with—tidal deposits include sigmoidal cross-stratification (observed in facies) and herringbone strata (Nio and Yang, 1992). Tide-related criteria of tidal rhythmites include 1) coarse- and fine-grained lamination couplets (observed in facies) and 2) vertical couplet thickness variation (observed in facies).

Trace fossils such as *Planolites* associated with *Teichichnus*, indicate a brackish-water environment with moderate sedimentation rates, which forces burrowers to actively maintain their burrows (Pemberton, et al., 1992; Buatois et al., 1999). Siderite suggests freshwater infiltration, and plant debris indicates proximity to continental and marginal marine environments (Potsma, 1982).

2.2.6 Heterolithic Sandstone Facies (Figs. 2.06; 2.07)

<u>Description</u>

The heterolithic sandstone facies is composed of moderate- to well-sorted, very fine- to medium-grained (vfL-mL) sandstone with an overall coarsening-upwards trend (corresponds to Lange's [2003] "Ripple Cross-laminated Muddy Sandstone" facies). Based on core descriptions and log interpretation, the heterolithic sandstone facies is less regionally extensive than the heterolithic siltstone facies. Thickness ranges from 2 to 10 feet (0.6-3 m), averaging 4 feet (2.4 m). Color varies, but is typically light to medium gray. Characteristic sedimentary structures include thin (3-10 cm) to medium (10-30 cm) beds of thin (1-3 mm) to thick (3-10 mm) heterolithic flaser or wavy laminae (sometimes sigmoidal-laminated) interlaminated with thin (1-3 mm) mud drapes (sometimes double-draped; Figs. 2.06 and 2.07); very thin (1-3 cm) to thin (3-10 cm) unidirectional current ripple beds with or without mud

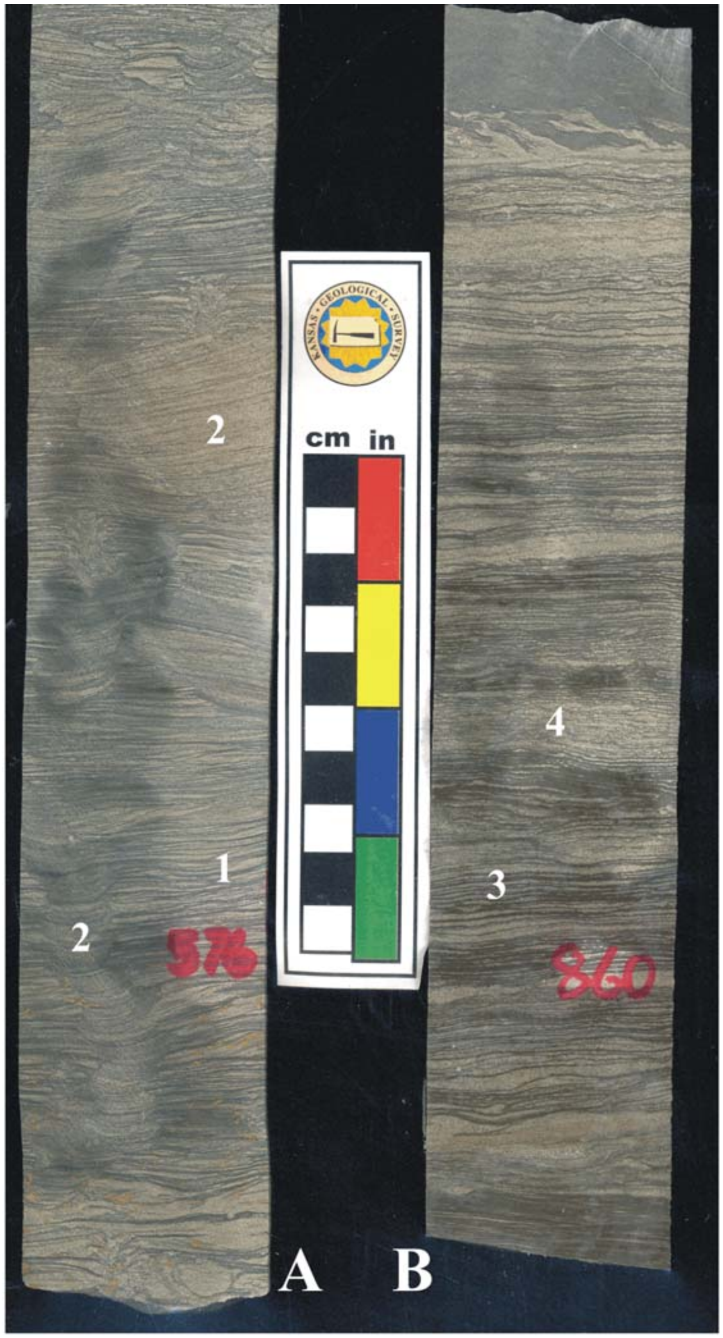

Figure 2.06 *Heterolithic Sandstone Facies* (A) Heterolithic sandstone facies within the Bandera Quarry Sandstone interval of the Franklin County core (575.1'-576.2') with heterolithic wavy laminae (1) and abundant *Teichichnus* burrows (2; Appendix A). (B) Scanned core image within the Upper Bluejacket sandstone interval of the Franklin County core (859.3'-860.2') displaying wavy laminae with sand-mud bundles (3) and thickening-thinning bundle sequences (4; Appendix A).

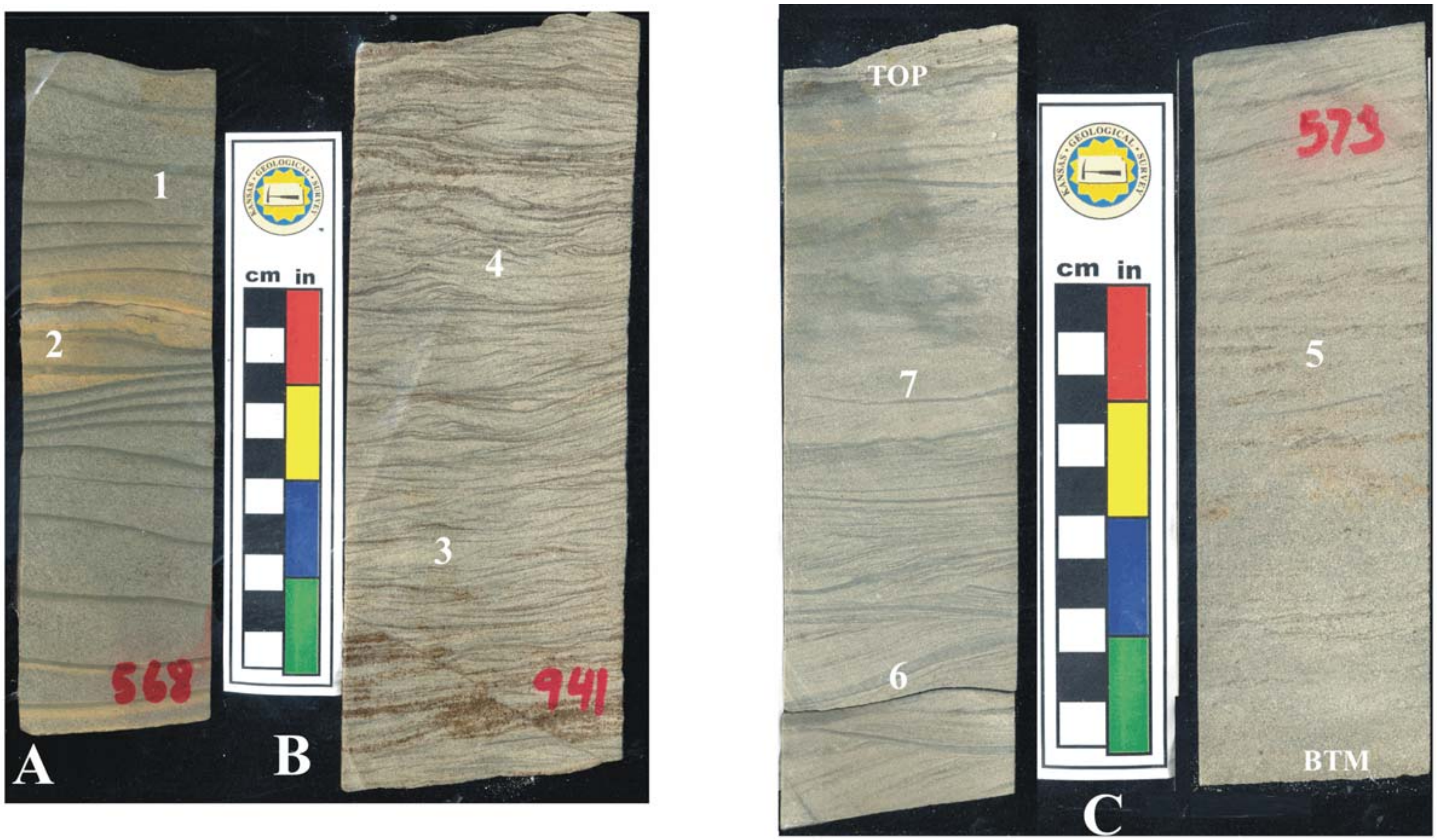

Figure 2.07 *Heterolithic Sandstone Facies (con't.)* (A) Mud-draped, fining-upward flaser beds and laminations with reactivation surface (1) and siderite cement (2) from the Bandera Quarry Sandstone in the Franklin County core (567.5'-568.0'; Appendix A). (B) Flaser laminae with mud drapes and couplets (3) and ripple laminae (4) from the Rose Hill #1-6 well (940.1'-941.1'; Johnson, 2004). (C) Continuous core image from the Franklin County well (572.9'-574.0') displaying unidirectional ripple laminae (5), grading into sigmoidal cross-lamination with mud drapes (6) and flaser lamination with mud drapes (7; Appendix A).

drapes (Fig. 2.07); very thin (1-3 cm) fining-upward beds (Fig. 2.07); and some thin to thick lenticular laminae. Laminae can have distinct bundling (Fig. 2.06). Sedimentary structures are horizontal or inclined up to 15° and can switch current directions from bed to bed. Often, convolute strata cap the heterolithic sandstone facies. Reactivation surfaces and structureless intervals are common features (Fig. 2.07). Upper contacts can be sharp with overlying coal or deeper water facies (e.g. black or gray shales) or gradational when capped by the overlying underclay or limestone facies. Lower contacts are gradational, or sharp and erosional with underlying heterolithic siltstone or gray shale facies.

Body fossils in the heterolithic sandstone facies are very rare, however, trace fossils and bioturbation are common (e.g., *Teichichnus*; Fig. 2.06). Post-depositional features include siderite (nodules, bands, and cement), and calcareous cementation (Fig. 2.07). Pyrite nodules were rarely observed in core.

Interpretation

The heterolithic sandstone facies includes several exclusive features of tidal deposits, including mud drapes and couplets within flaser, wavy, and lenticular laminae indicating ebb-flood currents with intervening slackwater suspension deposition; and reactivation surfaces indicating fluctuating flow velocities (Nio and Yang, 1992). Bundles and bundle sequence patterns were present, but difficult to observe in coarser-grained deposits. Minor tidal associated criteria—herringbone cross-lamination—was observed in several instances of the heterolithic sandstone facies. The abundance of *Teichichnus* coupled with siderite diagenetic features suggests stressed, brackish environment (Potsma, 1982; Pemberton et al., 1992; Buatois et al., 1999). The heterolithic sandstone facies is interpreted as forming from alternating flood-ebb tidal currents with intervening slackwater suspension fallout in upper tidal flat, tidal channel, or upper subtidal coastline settings.

2.2.7 Mudstone-Wackestone Facies (Fig. 2.08)

Description

The mudstone to wackestone limestone facies can range in color from light gray to black; to light greenish-gray; to light tannish-gray and medium brownish-gray where oil stained. The facies is typically developed on a regional scale. Thickness ranges from 2 to 10 feet (0.6-3 m) with 5 feet (1.5 m) common. Sedimentary structures range from structureless, to thickly (3-10 mm) laminated, or very thinly (1-3 cm) to thinly (3-10 cm) bedded, with minor fenestral fabrics, or brecciated mudstone intraclasts (Fig. 2.08). Matrix typically consists of mud or pelloidal mud. Slight rooting may be present (Fig. 2.08). Upper and lower contacts are sharp (erosional or brecciated appearance) or gradational. Relation to underlying and overlying facies depends on the position of the mudstone-wackestone facies within the cyclothem model (Heckel, 1977). If located within the regressive “upper” limestone member, the mudstone-wackestone facies usually overlies the packstone-grainstone facies or the black shale facies of the “core” shale, and underlies the underclay, packstone-grainstone, or occasionally the black shale facies. If located within the transgressive “middle” limestone member, the mudstone-

Figure 2.08 *Mudstone-Wackestone Facies* (A) Fenestral mudstone (1) from the Franklin County core (Laberdie Limestone; 602.5'-603.2') with possible root traces (2) and brecciation (3), grading down into deeper marine mudstone-wackestone facies (4; Appendix A). (B) Mudstone-wackestone within the Verdigris Limestone from the Franklin County core (750.0'-750.8') displaying unidentified burrows (5) and whole brachiopods (6; Appendix A). (C) Wackestone facies from the Franklin County core (upper Ft. Scott Formation; 634.4'-634.8') displaying phylloid algae (7), brachiopods, and fusulinids (Appendix A).

wackestone facies can overlie the packstone-grainstone, underclay, or coal facies, and underlie the black or gray shale facies. The mudstone-wackestone facies is correlative to the "Bioclastic Mudstone to Wackestone" facies in the Cherokee basin (Lange, 2003).

Body fossils range sparse to abundant, and include whole brachiopods, fusulinids and other foraminifera, gastropods, and phylloid algae; and minor crinoid, phylloid algal, and brachiopod fragments (Fig. 2.08). Bioturbation and vertical and horizontal burrows are common (Fig. 2.08). Diagenetic or post-depositional features include normal and "horsetail" stylolites, and nodular pyrite.

Interpretation

The mudstone-wackestone limestone facies is interpreted as forming in low-energy, open marine and restricted, shallow marine shelf or ramp environments. Mudstone-wackestone with a fenestral fabric, brecciated appearance, frequent pelloidal mud matrix, occasional root traces, and low faunal abundance and diversity indicates a shallow-water, restricted intertidal setting. Shallow-water features typically cap shoaling upward sequences in the regressive limestone (Heckel, 1977), but are also observed in the basal portion of the transgressive limestone unit. Mudstone-wackestone facies without observed fenestral fabric and brecciation is interpreted as originating in a low-energy, open-marine setting below effective wave base, and consists of structureless micritic (sometimes pelloidal) mud matrix, low to moderate faunal abundance and diversity, and laminated shale partings. Episodic storm or other high-energy currents are suggested when mudstone-wackestone limestone facies is interbedded with packstone-grainstone facies. The presence of phylloid algae in the mudstone-wackestone facies supports the interpretation of well-aerated, low-turbidity, open marine conditions (Suchy and West, 2001). The presence of pyrite nodules and common green, glauconitic tint supports deposition in a marine setting.

2.2.8 Packstone-Grainstone Facies (Fig. 2.09)

Description

The packstone-grainstone facies consists of light to medium tannish-gray, to brown (where oil-stained) limestone. Thickness ranges from less than 1 foot to 6 feet (<0.3-1.8 m), averaging 2 feet (0.6 m). Sedimentary structures range from structureless to thickly (3-10 mm) and thinly (1-3 mm) laminated. Intraclasts are common, and elongated bioclastic coated grains (up to 1 cm) and pisoids (up to 4 mm-diameter) are present (Fig. 2.09). Packstone matrix is usually micritic. Upper contacts are gradational into the overlying mudstone-wackestone or underclay facies (Fig. 2.09). Lower contacts are sharp with the underlying chaetetid or mudstone-wackestone facies.

Fossils are fragmented and include crinoid stems, brachiopod and gastropod shells, fusulinids, and phylloid algal plates (Fig. 2.09). Fossils fragments are more common in grainstone, whereas rare whole fossils were observed in packstone. Whole fossils of the packstone-grainstone facies include brachiopod and gastropod shells, and fusulinids and other foraminifera. Post-depositional features include minor pyrite nodule formation, very minor stylolitization, and oil staining.

Figure 2.09 *Packstone-Grainstone Facies* (A) Packstone facies from the Franklin County core (632.0'-632.7'; upper Ft. Scott Formation) with phylloid algal plates (1); brachiopod, crinoid, and gastropod fragments; coated grains (2); and overlying fenestral wackestone and mudstone (3; Appendix A). (B) Crinoidal-grainstone (4) from the lower Ft. Scott Limestone (Franklin County core; 638.2'-638.7') grading into packstone above. Grains also include brachiopod and phylloid algal fragments (Appendix A).

Interpretation

The characteristics and depositional interpretation of the packstone-grainstone facies correspond to Lange's (2003) "Bioclastic Packstone to Grainstone" facies. If intercalated with the shallow, intertidal mudstone-wackestone facies, the packstone-grainstone facies is interpreted as forming from current reworking in shallow tidal shoals or flats, or from tidal channel overbank deposition. Interpretation is based on the presence of coated grains of brachiopods, gastropods, crinoids, and unidentifiable fossil hash; and occurrence proximal to fenestral-structured laminae or thin beds, which can be inclined. If intercalated with the more open-marine variant of the mudstone-wackestone facies, the packstone-grainstone facies is interpreted as deposited from episodic storm currents. Interpretation supported by the fusulinids, disrupted brachiopod shells and fragments, crinoid fragments, and overlying laminae intercalated within the open-marine mudstone and wackestone.

The packstone-grainstone facies is locally observed as a fining-upward sequence of grainstone to packstone. This variant is observed once in the Franklin County core within the Ft. Scott Limestone (Appendix A). The abundance of crinoid, brachiopod, fusulinid, and gastropod fragments and intraclasts in grain-support, very vague cross-laminae, coated grains, and overlying nature with the chaetetid facies supports a subtidal shoal water setting with abundant reworking by high-energy currents.

2.2.9 Chaetetid Facies (Fig. 2.10)

Description

The chaetetid facies was observed twice in one core (Franklin County core; Appendix A) and is considered a minor facies. The lateral extensiveness of this facies is unknown. The chaetetid facies corresponds to chaetetid-bearing intervals of the "Bioclastic Mudstone to Wackestone" facies in the Cherokee basin (Lange, 2003). The first appearance (Amoret Member of the Altamont Limestone) is a light- to medium-gray rudstone of brecciated and overturned Chaetetes coral intraclasts (<30 cm diameter; Fig. 2.10; Appendix A). The facies is clast-supported with interclastic voids composed of mudstone or clay. The upper contact is sharp with an overlying phosphatic black shale facies (Lake Neosho Shale Member). The lower contact is gradational into the underlying mudstone-wackestone facies. Post-depositional features include clay cutans (Fig. 2.10).

The second appearance of this facies (Ft. Scott Limestone) is a light tannish-gray, upright boundstone approximately 0.5 feet (0.15 m) thick (Fig. 2.10; Appendix A). The upper contact is sharp with overlying, upward-fining packstone-grainstone facies. The lower contact is sharp with underlying wackestone or packstone, which immediately overlies the underclay facies. The chaetetid facies at the base of the Ft. Scott Limestone is very porous and oil-stained (Fig. 2.10).

Interpretation

The chaetetid facies is interpreted as in situ growth and/or reworking in a shallow, high-energy, open marine setting. This interpretation is supported by the

Figure 2.10 *Chaetetid Facies* (A) Chaetetid rudstone facies variant from the Franklin County well (551.6'-552.4'; Amoret Limestone) in which chaetetids (1) are overturned and surrounded by muddy matrix with cutanic clay features (Appendix A). (B) Oil-stained chaetetid boundstone lower in the Franklin County core (639.5'-640.3'; lower Ft. Scott Limestone; Appendix A). The chaetetid is attached to a dark gray coated-grained packstone to wackestone (2) with an oncoid (3), and is sharply overlain by crinoidal grainstone (4).

chaetetid specimen in upright, life position overlain by coarse-grained crinoidal grainstone observed within the Ft. Scott Limestone (Franklin County core, Appendix A). The large chaetetid intraclasts in the Amoret Limestone would require strong current energies to overturn (Franklin County core, Appendix A). Chaetetes developed within aerobic, well-circulated, normal marine salinity conditions with low siliciclastic input (Suchy and West, 2001). The paleoenvironmental conditions for chaetetid development have been linked to cooler, windier climates with lower rainfall (increased marine salinity) and lower stream runoff (low nutrient input; Suchy and West, 2001).

2.2.10 Conglomerate Facies (Fig. 2.11)

Description

The conglomerate facies was observed to have two variants: chert-clast conglomerate and mud- and sand-clast conglomerate (Fig. 2.11). Both are considered minor facies in this study. Core observations and well log interpretations indicate that the chert clast conglomerate overlies the Mississippian unconformity throughout eastern Kansas and into adjacent states (Watney et al., 2001). The mud- and sand-clast conglomerate is, however, interpreted to occur only locally within incised fluvial channels, based on core and log interpretation.

The chert-clast conglomerate consists entirely of light-gray to white, very fine pebble-gavel (2-4 mm) to fine cobble-gravel (64-128 mm), angular- to very-angular, matrix or grain-supported chert fragments. Observed thickness is approximately 8 feet (2.4 m). The calcareous matrix is light greenish-gray and consists of fine-grained

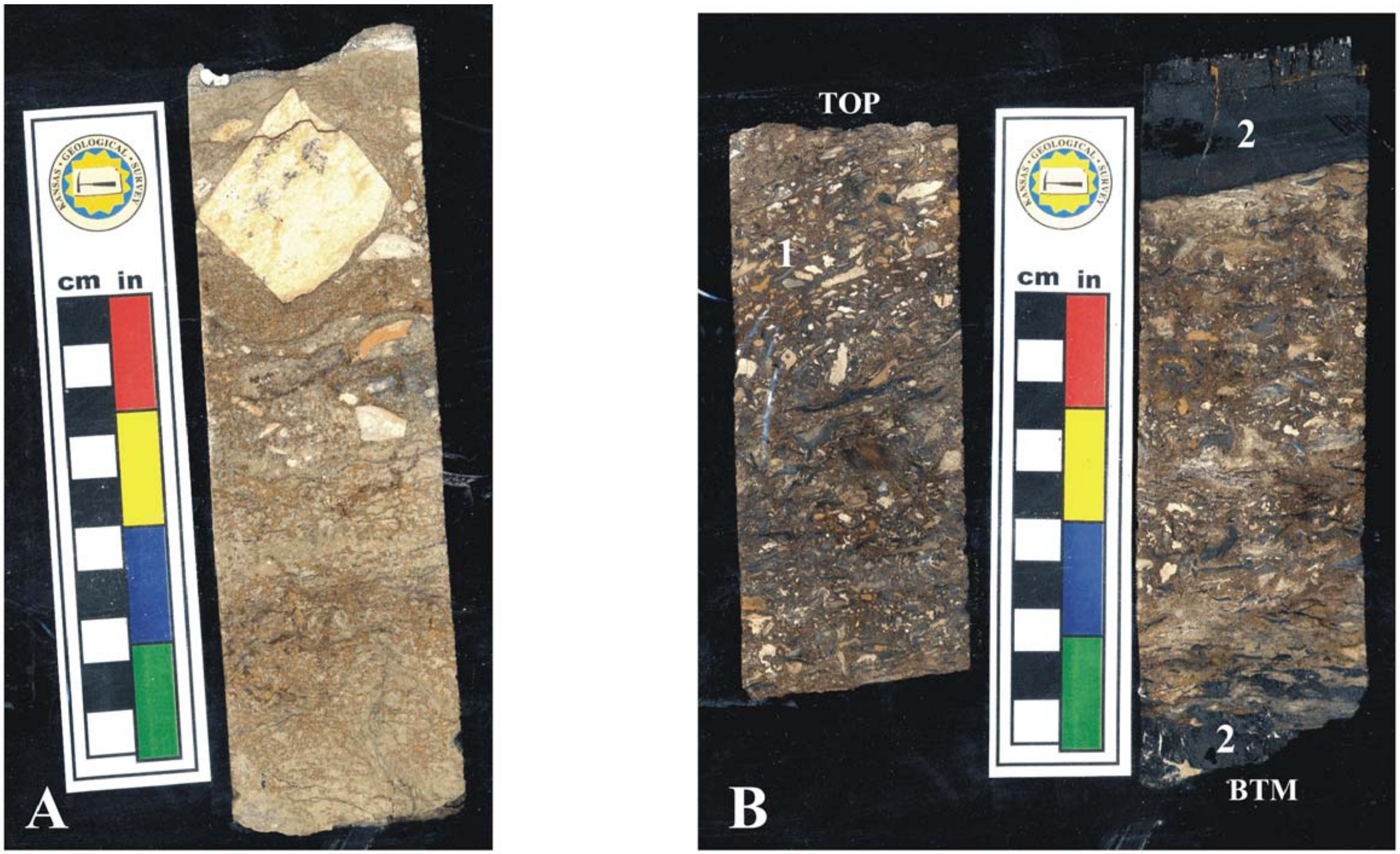

Figure 2.11 *Conglomerate Facies* (A) Angular chert-clast conglomerate facies variant from the Franklin County core (978.4'-978.9'), which overlies the karsted Mississippian uncomformity surface (Appendix A). (B) Scanned continuous core image of the mud- and sand-clast conglomerate facies variation from the Franklin County core (902.0'-903.0'; Lower Bluejacket Sandstone; Appendix A). Note the weakly developed imbrication of clasts (1), thin interbedded coal (2), and absence of root traces within the facies.

(vfL-fU) sandstone. Sedimentary structures were not observed, except for sporadic slickensides and clay cutans. Upper contacts are gradational with overlying underclay facies or sharp with overlying black shale or mud-clast conglomerate facies. Lower contacts are sharp with underlying Mississippian carbonate. Body and trace fossils in the chert variant of the conglomerate facies are absent, except for infrequent carbonaceous rooting. Nodular pyrite and calcareous cement were observed post-depositional features.

The mud- and sand-clast conglomerate is slightly more common than the cherty conglomerate, although still rare relative to other facies. It is generally medium to dark gray, or light to medium brown in color. From three recorded occurrences in core, the facies is approximately 3 feet (0.9 m) thick. The facies consists of rounded, ovoid, clast-supported, very fine pebble gravel (2-4 mm) to coarse pebble gravel (16-32 mm) within a medium- to very coarse-grained (mU-vcU), well-sorted sandstone matrix. Sedimentary structures include very thin (1-3 cm) to medium (10-30 cm) inclined (5-30˚) beds. Forsets are not easily observed within beds, but clasts are weakly imbricated (Fig. 2.11). Very thin (1-3 cm) to thin (3-10 cm) similarly inclined coal beds are observed within the conglomerate facies (Fig. 2.11). Upper contacts can be gradational with overlying underclay facies, or sharp with overlying cross-bedded sandstone or heterolithic sandstone facies. Lower contacts are sharp and erosive, overlying almost any facies in well log, but observed to overlie the heterolithic sandstone or coal facies in core. Body and trace fossils are absent. Interbedded coal is not underlain by root traces. Rare siderite, as cement or as siltstone pebbles, was observed in core.

Interpretation

The coarse-grained chert conglomerate is interpreted as weathered residuum overlying karsted Mississippian rocks at the Mississippian-Pennsylvanian unconformity. This is evident by stratal relationships with the underlying Mississippian surface and by the sharp angularity, poor sorting, large clast size, and cherty composition. The cherty residuum, also known as "chat", is a significant petroleum reservoir throughout Kansas (Watney et al., 2001).

Based on the coarse and imbricated nature of grains, unidirectional inclination of bedding, and stratal relationships to overlying finer-grained facies (e.g. underclay, cross-bedded sandstone, and heterolithic sandstone), the mud-sand clast conglomerate is interpreted as bar deposits in a fluvial channel forming from high-energy unidirectional traction currents and bed load deposition. Sharp, irregular lower contacts suggest erosion into underlying strata. Absence of marine trace or body fossils supports non-marine, freshwater deposition. The siderite may be a diagenetic feature or weathered and transported siderite-cemented siltstone or siderite concretions. Some occurrences of the conglomerate facies include inclined beds of coal. The coal within the mud-clast conglomerate is interpreted as being transported and deposited within the channel. Transport, rather than in situ peat growth, is based on the lack of rooting below coal and bed inclination. What is not known is whether or not the peat was transported and accumulated as litter or as larger blocks.

McCabe (1984) noted that peat strongly resists erosion, and that initially, a peat seam may repress channel incision. When erosion finally occurs, the peat is torn away as a block. A similar depositional process may be responsible for the coals observed within fluvial conglomerates.

2.2.11 Cross-Bedded Sandstone Facies (Fig. 2.12)

Description

The cross-bedded sandstone facies is composed of light- to medium-gray, fine- to coarse-grained (fU-cL), very well- to well-sorted sandstone. Siderite-cemented mud clasts (up to 1 cm diameter) are common (Fig. 2.12). The facies is considered minor. Recorded thickness is 0.5 and 2 feet (0.15 and 0.6 m). Sedimentary structures include thin (3-10 cm) to medium (10-30 cm) beds of trough and planar sandstone cross-laminae with very thin (1-3 cm) intermittent shale seams (Fig. 2.12). Cross lamination forset thicknesses are vague and barely distinguishable, however, irregular upper and lower contacts do provide some three-dimensional surficial evidence of sedimentary structure. Upper contacts tend to be sharp with overlying heterolithic sandstone facies. Lower contacts tend to be sharp and erosive with underlying black shale, gray shale, underclay, or heterolithic sandstone facies.

Body and trace fossils were not observed in core. Post-depositional features include siderite and calcareous cementation.

Interpretation

The cross-bedded sandstone facies is interpreted to form as migrating dunes from high-energy unidirectional traction currents in fluvial channel bars. The

Figure 2.12 *Cross-Bedded Sandstone Facies* Scanned core image (nearly adjacent samples; left, 1039.1'-1039.7'; right, 1040.0'-1040.8') from the Rose Hill #1-6 well displaying faint thickly laminated to very thinly bedded trough- (1) and planar (2) -cross stratification (Johnson, 2004). Intermittent shale seams (3) and siderite mud clasts (4) are present in the facies.

relationships to underlying facies such as mud-sand pebble conglomerates or sharp, erosive basal contacts with deeper water facies, and relationships with finer-grained overlying facies such as heterolithic sandstone or siltstone facies support this interpretation. The cross-bedded sandstone and underlying conglomerate facies succession is similar to facies of fluvial origin described by Stewart (1981). Unidirectionally dipping tough- or planar-laminated forsets suggest unidirectional, uniform currents. The absence of marine trace or body fossils supports deposition in a freshwater environment. As with the fluvial mud-and sand-clast conglomerate facies, the cross-bedded sandstone facies is confined to fluvial channels.

2.2.12 Interbedded Sandstone-Siltstone Facies (Fig. 2.13)

Description

The interbedded sandstone and siltstone facies consists of medium brown (where oil-stained), medium gray, to dark gray, micaceous, silty sand to very fine- to fine-grained (vfL-fL) sandstone. Thickness, as reported from one occurrence in the Lagonda Sandstone interval (upper Cherokee Group) of the Franklin County core, is 37 feet (11.1 m). Grain size tends to coarsen upward through several 8 to 15-ft. (2.4 to 4.6 m) thick intervals (Appendix A). Sedimentary structures generally include horizontal and inclined (5-10˚) thin (3-10 cm) beds of thinly (1-3 mm) laminated sandstone interbedded with thin to thick (3-10 mm) silty-sandstone laminae (Fig. 2.13). When coarser-grained, very thin (<1 mm) to thin, faint, bi-directional ripple laminae were observed (Fig. 2.13). Interbeds become more inclined as the facies coarsens upwards and eventually transition into faint bi-directional ripple laminae.

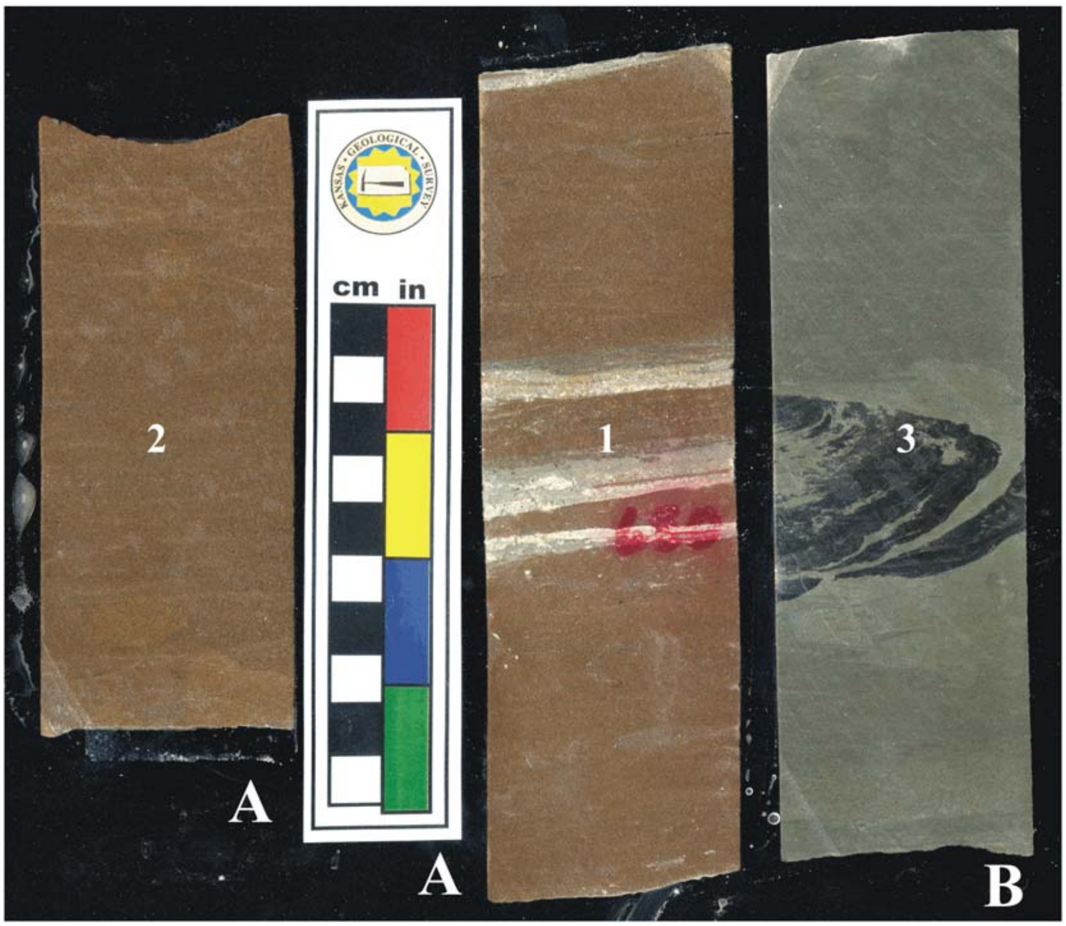

Figure 2.13 *Interbedded Sandstone and Siltstone Facies* (A) Continuous, scanned core image from the Franklin County well (left, 649.3'-649.7'; right, 649.7'-650.3'; upper Cherokee Group) displaying parallel, inclined sandstone and siltstone interbeds (1) coarsening upwards into very faint bidirectional ripple laminae (2). (B) Convolute sandy siltstone laminae (3) slightly lower in the same core (662.0'-662.5'; Appendix A).

Structureless (possibly bioturbated) and convolute strata are common (Fig. 2.13B). Mud drapes and unidirectional ripple laminae were not observed in this facies. Upper contacts are gradational with the overlying underclay facies. Lower contacts are gradational with the underlying gray shale facies.

Body fossils and trace fossils were not observed. However, structureless intervals may be the result of bioturbation. Post-depositional features include minor siderite cements or banding, and rare calcareous cementation. The interbedded sandstone-siltstone facies is considered a minor facies.

Interpretation

The interbedded sandstone-siltstone facies is interpreted as forming from variable velocity, unidirectional traction current and suspension sedimentation. These processes differ from previous tide-related facies in that tidal indicators such as mud drapes, bundles and bundle sequences, and reactivation surfaces are absent, signifying relatively constant flow direction. In addition to the absence of tidal indicators, other evidence supporting these processes include the absence of trace fossils (except for possible bioturbation in structureless portions), suggesting constant sediment supply; and convolute fine-grained strata, implicating soft-sediment slumping. The multiple coarsening upward sequences are suggestive of several episodes of progradational sediment deposition. Minor siderite banding is the result of freshwater infiltration due to proximity to continental or fluvial processes (Potsma, 1982). Based on these features, the interbedded sandstone-siltstone facies is interpreted as being deposited in prodelta and delta front settings for siltstone and sandstone lithologies, respectively.

Based on well log interpretation, occurrence of the interbedded sandstone-siltstone facies is limited to very thick Lagonda sandstone interval deposits (beneath the Mulky coal) located in Franklin, Bourbon, and southeastern Linn counties.

2.2.13 Bioturbated Sandstone Facies (Fig. 2.14)

Description

The bioturbated sandstone facies is composed of very micaceous and organic-rich, medium- to dark-gray, very fine-grained (vfL-vfU; fining upward), moderate to well-sorted sandstone. Thickness ranges from 0.5 to 2 feet (0.15 to 0.6 m), with 1 foot (0.3 m) being average. Other than faint thin (1-3 mm) laminae, sedimentary structures were not observed. The lateral extent of the facies is unknown.

This facies is characterized by a high degree of bioturbation, including lighter-colored vertical and horizontal burrows giving the facies a “mottled” appearance (Fig. 2.14). Burrows are difficult to identify, but include *Planolites*. Rare body fossils include whole brachiopod shells and skeletal fragments. Post-depositional features include calcite cement and pyrite formation.

Interpretation

The bioturbated sandstone facies is considered a transgressive lag or storm deposit forming following either high-energy current deposition due to marine flooding or storm currents that was subsequently bioturbated. This interpretation is evident by the comparison to overlying and underlying facies. The bioturbated sandstone facies caps a shoaling-upward cycle—typically heterolithic siltstone, gray shale, coal, or underclay facies—but may also be interbedded between two black

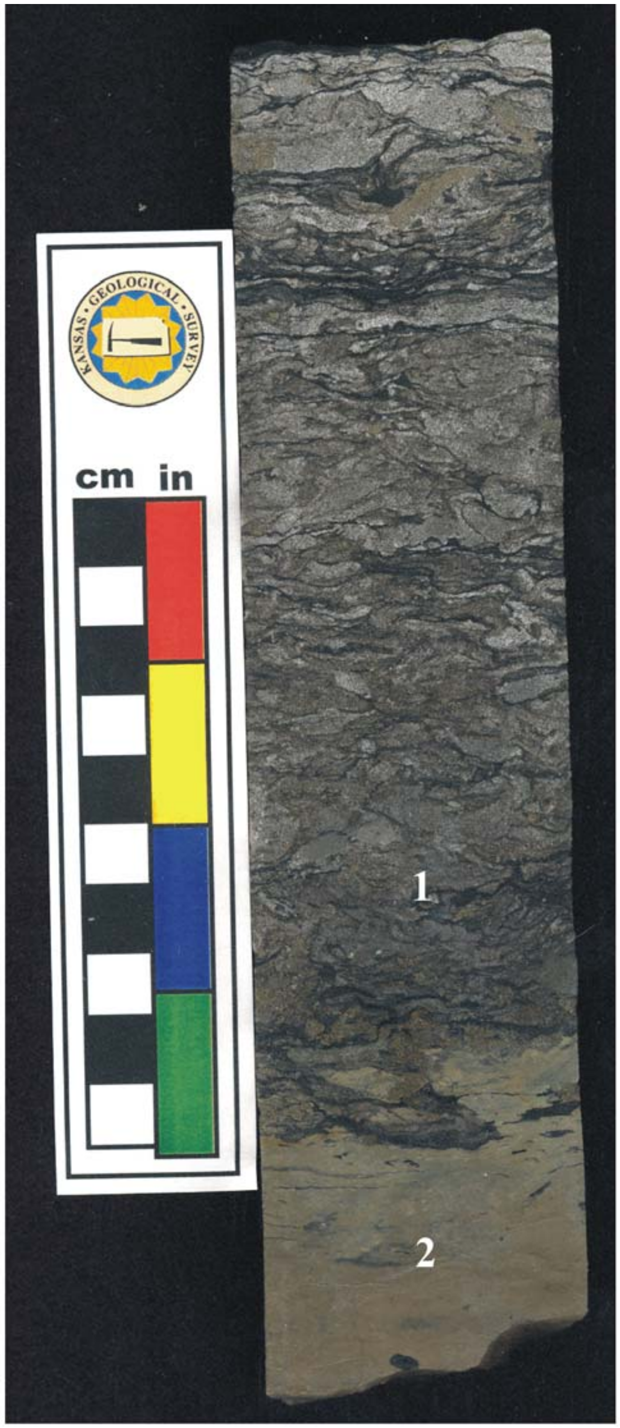

Figure 2.14 *Bioturbated Sandstone Facies* Scanned core image from the Franklin County well (973.1'-973.8') displaying extensively bioturbated sandstone facies (1) overlying the underclay facies (2; Appendix A). Sand and mud-filled burrows penetrate into the underclay facies.

shale beds (Fig. 2.14). The bioturbated sandstone facies is overlain by finer-grained, deeper water facies such as black shale or minor heterolithic siltstone grading into black shale. These relationships suggest a period or episode of higher energy current deposition brought about by marine flooding or storm reworking. Marine conditions are indicated by fossil content and by pyritic and calcitic cement or nodule formation. Conditions were shallow or oxic enough for soft-bodied fauna to colonized and extensively churn the sediment. Bioturbation occurred to a lesser degree in bioturbated sandstone facies intercalated within black shales.