Distribution of the Bandera Shale of the Marmaton Group, Middle Pennsylvanian of Southeastern Kansas

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Abstract

In southeastern Kansas, the Middle Pennsylvanian (Desmoinesian) Bandera Shale consists of sandstone, shale, limestone, and coal deposited between two carbonate formations, the underlying Pawnee Limestone and the overlying Altamont Limestone. Isopach maps and cross sections indicate that the Bandera Shale thickens southeastward towards the Oklahoma and Missouri borders. Analysis of gamma-ray-log signatures, augmented by neutron-log signatures, indicates that the Bandera Shale is rich in mudstone, with sandstones limited to intervals ranging from 10 ft to 30 ft (3–9.1 m) in thickness. Comparisons with previously studied cored and logged siliciclastic portions of overlying Missourian lithologies suggest that the Bandera Shale consists of various proportions of sandstone, siltstone, clay-rich shale, and calcite-cemented sandstone.

Exposures of the Bandera Shale in Bourbon County, Kansas, consist of interbedded shale and calcite-cemented, fine-grained sandstone. Sandstone beds, ranging from 3 cm to 20 cm (1.2–7.9 in) in thickness, are, in places, rhythmically laminated with organic-rich and organic-poor lamina forming 2-mm (0.8-in)-thick couplets. Many sandstone bedding surfaces in the lower and middle portion of the Bandera Shale are bioturbated with horizontal feeding trails and some vertical burrows that suggest marine environments. Thicker sandstone units are either trough cross-bedded, with sets up to 1.5 m (4.9 ft) thick, or amalgamated ripple cross-laminated and flaser laminated.

Outcrop observations coupled with subsurface analysis indicated that Bandera Shale in southeastern Kansas was deposited as a siliciclastic complex that prograded westward during a sea-level lowstand. Siliciclastic sediments may have been deposited in a clastic wedge or deltaic complex, but sedimentary characteristics observed in outcrops record marine influence at least along the margins of the complex. Rhythmic stratification within sandstone beds that are interbedded with shale resemble tidal features described elsewhere in the Pennsylvanian of North America and suggest that embayments were present where tidal cells were amplified along a morphologically irregular shoreline. Bioturbated sandstone units, interbedded with clay shale, record high-energy events that influenced sand distribution.

The purpose of this study was to determine the distribution and characteristics of sandstone units in the Bandera Shale of southeastern Kansas, as well to clarify the stratigraphy and paleodepositional setting of this formation. Our observations were limited to a reconnaissance study of scattered outcrops that extend from Bourbon County southwestward to the Oklahoma state line in Labette County, Kansas, and gamma-ray and neutron logs from 469 wells, copies of which were supplied by the Data Resources Library of the Kansas Geological Survey. It is hoped that this study will serve a stimulus for future detailed studies of the Bandera Shale in the midcontinent region.

The study area (fig. 1) is along the eastern flank of the Western Interior basin (Schenk, 1967), including the north portion of the Cherokee basin, south of the Bourbon arch. The Nemaha uplift separates the Cherokee basin from the Sedgwick basin of south-central Kansas. To the south, the Cherokee basin extends to the Arbuckle Mountains in south-central Oklahoma.

Stratigraphy

The Bandera Shale (Adams et al., 1903, p. 32) is part of the Marmaton Group, which is Desmoinesian in age (fig. 2). It is overlain by the Altamont Limestone and underlain by the Pawnee Limestone. The black shale members of these formations—the Lake Neosho Shale Member of the Altamont Limestone and the Anna Shale Member of the Pawnee Limestone—provide traceable stratigraphic markers in both the subsurface (using gamma-ray and neutron logs) and along the Desmoinesian outcrop belt. In Oklahoma, both of these members, along with the Bandera Shale, are included in the Oologah Limestone (Krumme, 1981, p. 9). The Bandera Shale pinches out to the south and to the west. According to Krumme (1981), it is not recognized south of southern Osage County, Oklahoma, or west of western Kay County, Oklahoma. Although the Oologah Limestone dominates to the south, A. P. Bennison (1997, personal communication) reports finding outcrops of thin Bandera Shale south of the Arkansas River in Tulsa County, Oklahoma.

According to Zeller (1968, p. 26), the Bandera Shale is a “mainly nonmarine gray and yellow, mostly blocky claystone, well bedded shale, and massive to thin-bedded sandstone. Maroon bands are present in the upper part.” The formation contains limonite concretions and veins, with septarian limestone concretions present locally, and in the lower part, north of Crawford County, the Mulberry coal bed is persistent. Shale below the coal is light to dark gray and carbonaceous. Locally, a dark gray limestone, 6–9 ft (1.8–2.7 m) thick, lies just above the Mulberry coal beds (Zeller, 1968).

The strata between the Mulberry coal bed and the Pawnee Limestone consists of a blue-gray shale that grades upward into an underclay at the base of the coal (Whitla, 1940, p. 17). Carbonaceous remains of plant fragments are present in the underclay.

A very local coal bed near the top of the Bandera Shale in Labette County, Kansas, was reported by Jewett (1945, p. 36). The same or a similarly situated coal was observed 0.8 m (2.6 ft) below the base of the Amoret Limestone Member in the SE sec. 11, T. 35 S., R. 18 E., Labette County, Kansas, a few hundred meters north of the Oklahoma state line.

Method of Investigation

Gamma-ray and Neutron Logs

The first step in determining the characteristics of sandstone units in the Bandera Shale in southeastern Kansas was to become familiar with the gamma-ray and neutron signatures of the Bandera Shale and the adjacent

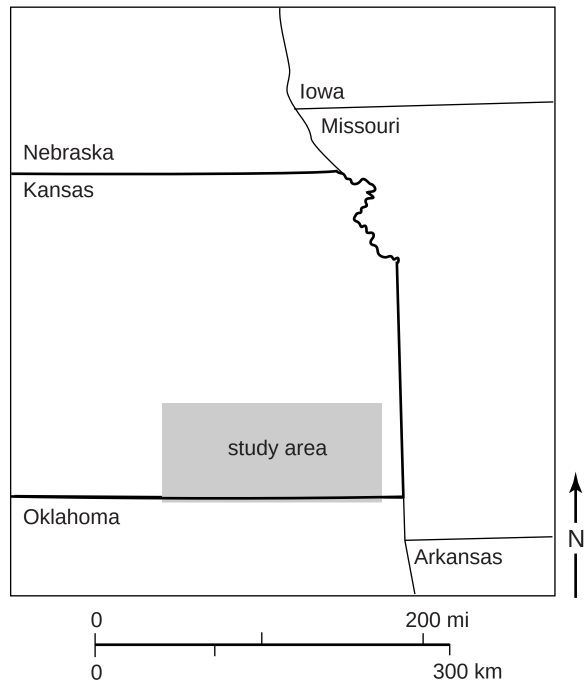


FIGURE 1. Location of study area in southeastern Kansas.

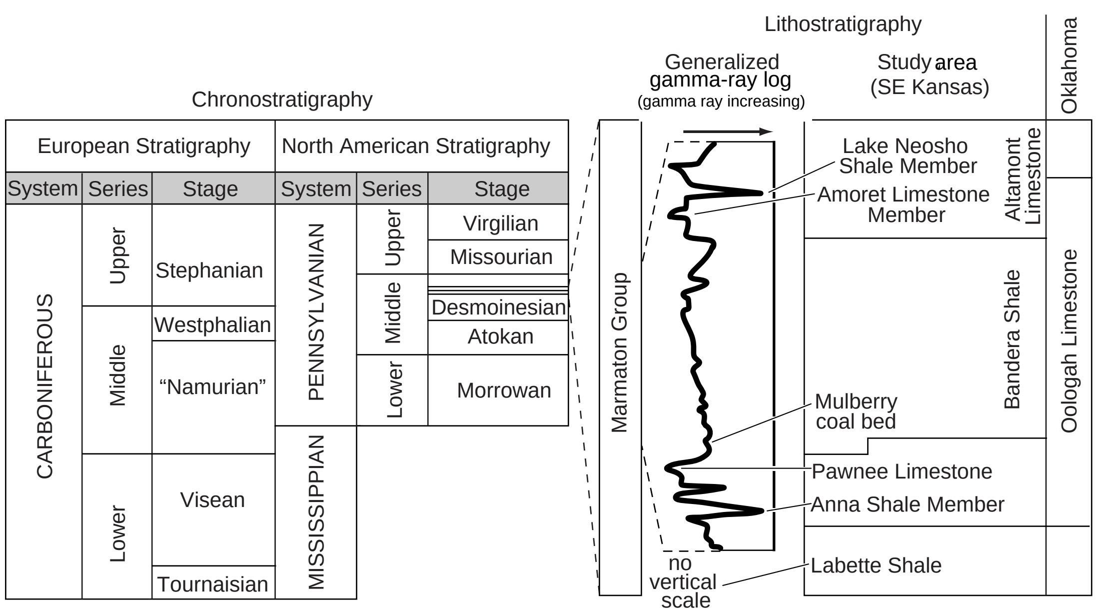


FIGURE 2. Stratigraphic terminology for the Marmaton Group in southeastern Kansas and chronostratigraphic relations with North American and European scales. Chronostratigraphic relationships between Europe and North America came from COSUNA stratigraphic correlation charts (Salvador, 1985, fig. 1, p. 182). Generalized gamma-ray log illustrates typical signatures for the portion of the Marmaton Group studied.

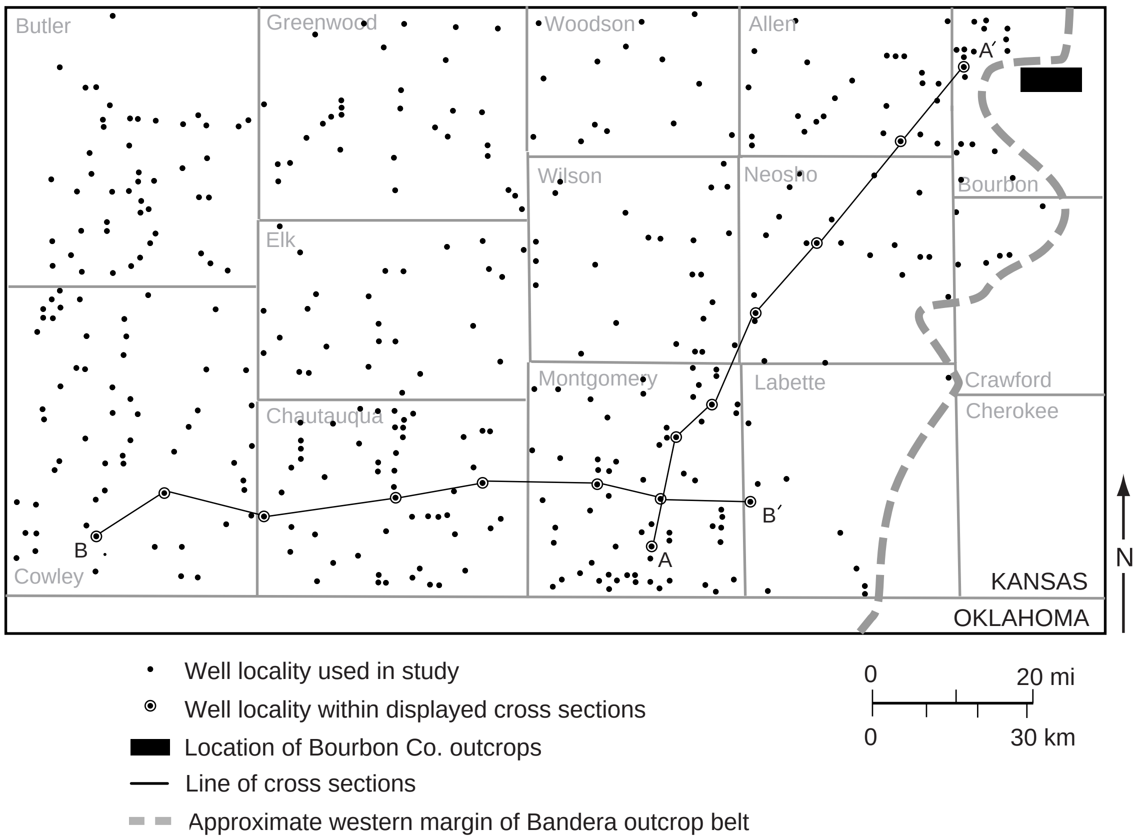


FIGURE 3. Distribution of Bourbon County outcrops, well logs, and cross sections used in this study.

formations of the Marmaton Group. Because the thickness and general characteristics of the Altamont and Pawnee Limestones are variable, the thin, strongly radioactive black shales of the Lake Neosho and Anna Shale Members provided consistent stratigraphic markers that were found in all well logs, defining an easily recognized interval that was not truncated by post-depositional erosion.

The gamma-ray and neutron logs available for this study are from 469 wells, which are distributed across an area of about 1,280 square miles (3,315 km^2) (fig. 3), averaging one log for every 2.73 sections. The distribution, however, determined in part by the distribution of potential petroleum accumulations, is not even. Another factor influencing data distribution is the fact that much of the petroleum-exploration drilling in the region predates the advent of geophysical well-logging.

Cross Sections

Cross sections (locations on fig. 3) were constructed using the Lake Neosho Shale Member as a datum. These cross sections (figs. 4, 5), combined with a grid of similar sections that were constructed, were used along with isopach and sandstone isolith maps (see figs. 6, 7) to verify the correlations and to study the character and distribution of the sandstones. Several cross sections were prepared to aid correlation and to help with paleoenvironmental interpretations. Two of these are shown for illustrative purposes: cross section A–A′ (fig. 4), parallel to and west of the Bandera outcrop belt, and section B–B′ (fig. 5), along township 33 N., near and parallel to the Oklahoma state line.

Sandstones were interpreted on each gamma-ray log by constructing a shale baseline and a sandstone baseline representing approximately 100% shale and approximately 100% sandstone, respectively. Deflections to the right of the sandstone baseline that were less than halfway to the shale baseline were considered to be either sandstone or limestone. Other than known limestone units such as the Amoret Limestone Member and Pawnee Limestone, intervals with low gamma counts were interpreted as sandstone.

The sandstones seem to appear at random in the section. No zones could be identified as likely to bear sandstones. Because of the low density of gamma-ray logs, few sandstone units could be carried to an adjacent log, indicating that most sand bodies were stratigraphically discontinuous. For the same reason the shapes of individual sand bodies could not be delineated.

Sandstone Distribution

An isopach map was prepared of the interval between the Lake Neosho and the Anna Shale Members, including the Amoret Limestone Member and Pawnee Limestone as well as the Bandera Shale (fig. 6). Initially, this map was

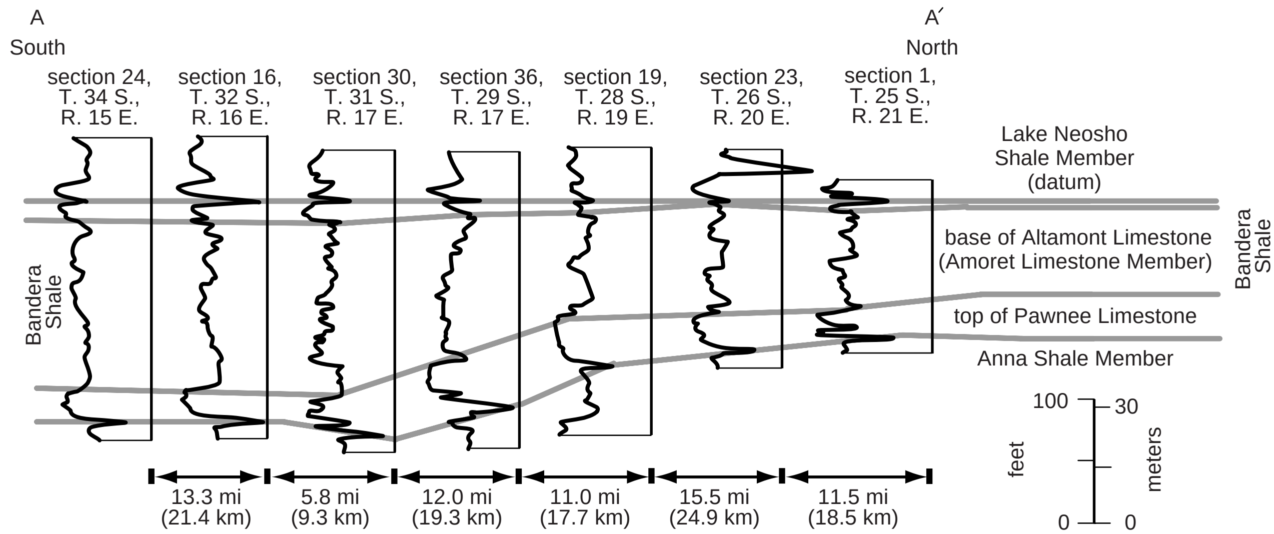


FIGURE 4. Gamma-ray logs along cross section A–A′, showing a portion of the Marmaton Group between northeastern Allen County and south-central Montgomery County, Kansas, and illustrating the variation in stratigraphy and thickness parallel to the Bandera outcrop belt. See fig. 3 for location of cross section.

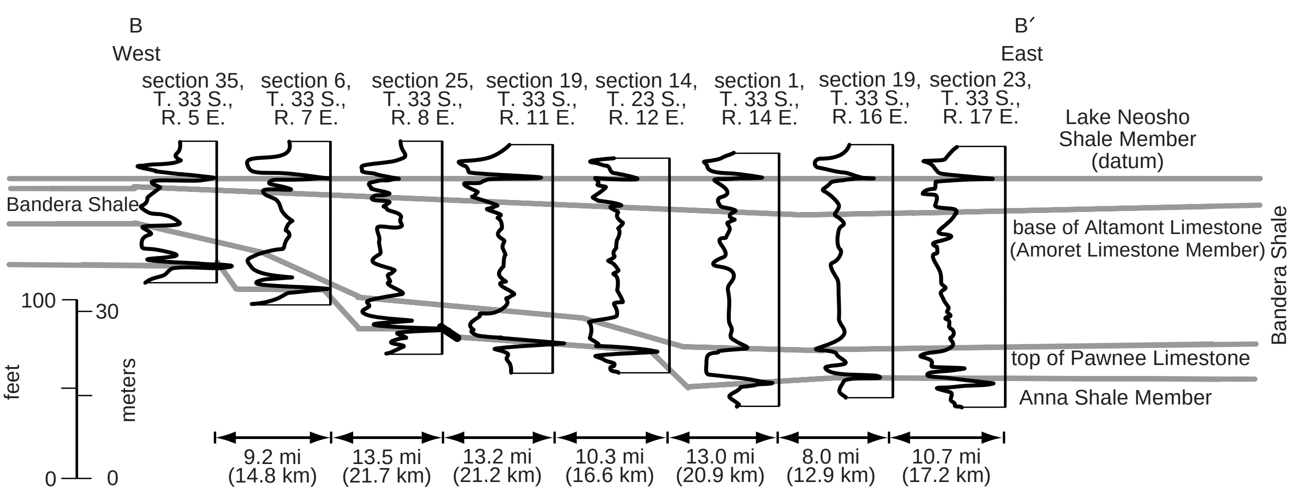


FIGURE 5. Gamma-ray logs along cross section B–B′, showing a portion of the Marmaton Group between south-central Cowley County and southwestern Labette County, Kansas, and illustrating the variation in stratigraphy and thickness perpendicular to the Bandera outcrop belt. See fig. 3 for location of cross section.

constructed manually; then the contours were traced into our computer (using Canvas™ for Windows). The mapped interval, which is coeval to the Oologah Limestone of Oklahoma (see fig. 2), thickens to the southeast from less than 80 ft (24 m) in Coffey and Cowley counties to over 180 ft (54.9 m) in Montgomery County, Kansas. This distribution of sediments reflects variations in siliciclastic sediment accumulations, suggesting an easterly source for siliciclastic sediments. Configuration of contour lines in the southeastern portion of the isopach map area suggests sandstone bodies that are elongated in a southwest-northeast direction (fig. 6). Gamma-ray log characteristics from wells in this area indicate the presence of sandstones but lack the blocky well-log curve characteristics usually associated with channel-fill lithologies (e.g., eastern end of cross section B–B′, fig. 5). The overall geometry of the Lake Neosho-Anna interval suggests that sediments accumulated in a generally podlike form (see fig. 7).

An isopach map of the Bandera Shale in the northern tier of Oklahoma counties, constructed by A. P. Bennison (personal communication, 1997), shows that the siliciclastic complex in southeastern Kansas thins southward and disappears as the Bandera gives way to the Oologah Limestone. This precludes the possibility of a southern source for siliciclastics. Post-Pennsylvanian erosion northeast of the study area prevents us from

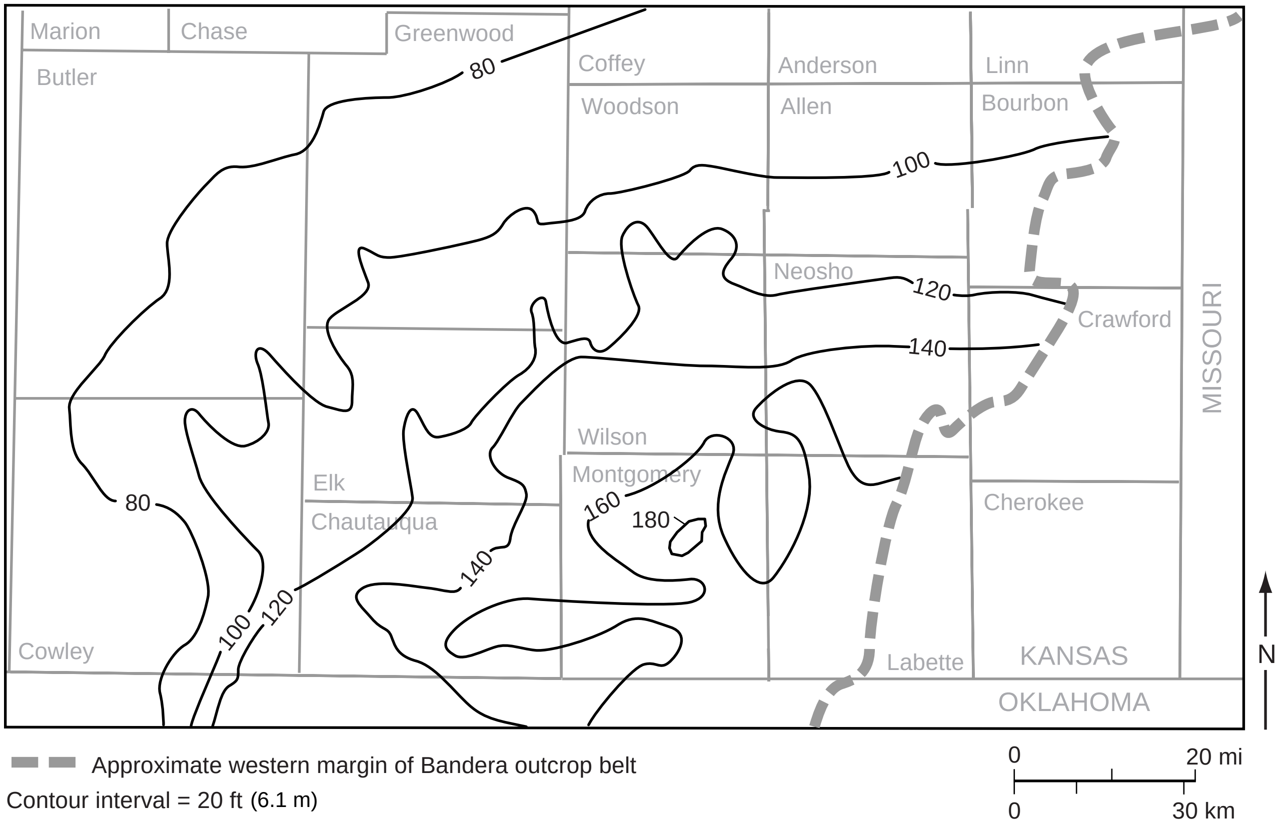


FIGURE 6. Lake Neosho-Anna Shale Members isopach map of study area. Thickest portion of the interval is in the southeast, and the interval thins northwestward.

evaluating the possibility that siliciclastics were brought into the area from the northeast by southwest-flowing fluvial systems.

A sandstone isolith map of the cumulative thicknesses of sandstone in the Bandera Shale (fig. 7), constructed in the same way as the isopach map, indicates that these sandstones were lenticular and elongate in a northeast-southwest direction. Cumulative thicknesses of sandstone range from 0 ft to 81 ft (0–24.7 m) and include at least 79 counted sandstone beds that were thick enough to be detected by gamma-ray logs. The presence of much thicker sandstone bodies in the southeastern portion of the study area also suggests an easterly source for the sand. As mentioned above, the presence of the Oologah carbonate-dominated platform in east-central Oklahoma during the time of Bandera deposition makes a southerly source for these sands unlikely (Krumme 1981, p. 45). It seems more likely that the Bandera sands entered southeastern Kansas from a more easterly source, perhaps even a northeasterly source.

Facies Analysis

Observation of the Bandera Shale was limited to a few outcrops, from Bourbon County to the Oklahoma border in Labette County, Kansas. The most vertically extensive of the outcrops studied were in Bourbon County, where a total of 15 m (49.2 ft) of a 22 m (72.2 ft) interval beneath the Amoret Limestone Member is exposed in two quarries. The Bandera Sandstone quarry (NW NW SE sec. 29, T. 25 S., R. 23 E.) and the abandoned Marmaton River quarry (SE NE SE sec. 30, T. 25 S., R. 23 E.) are about 0.6 mi (1 km) apart and are dominated by sandstone interstratified with millimeter-scale shale and cross-bedded sandstone units that are up to 0.5 m (1.6 ft) thick. These lithologies relate closely to gamma-ray and neutron-log signatures from a well a few miles to the west (fig. 8). Lithologies observed at other exposures along the outcrop belt (see fig. 3) include silty shales, mottled claystones, thin coal beds and lignitic shales. However, the reconnaissance nature of our field study did not provide the information required to relate these outcrops directly to our well-log network. For this reason we do not know exact stratigraphic positions of these outcrops. Our facies analyses concentrated on the lithologies well exposed in Bourbon County and those interpreted from well-log signatures.

Interbedded Sandstone and Shale Facies

Bourbon County Exposures. Exposed in the lower portion of the Bandera quarries, about 22 m (72 ft) below the Amoret Limestone Member, is about 3.2 m (10.5 ft) of fine-grained, calcite-cemented sandstone slabs. The sandstone slabs are thin to medium bedded, range in

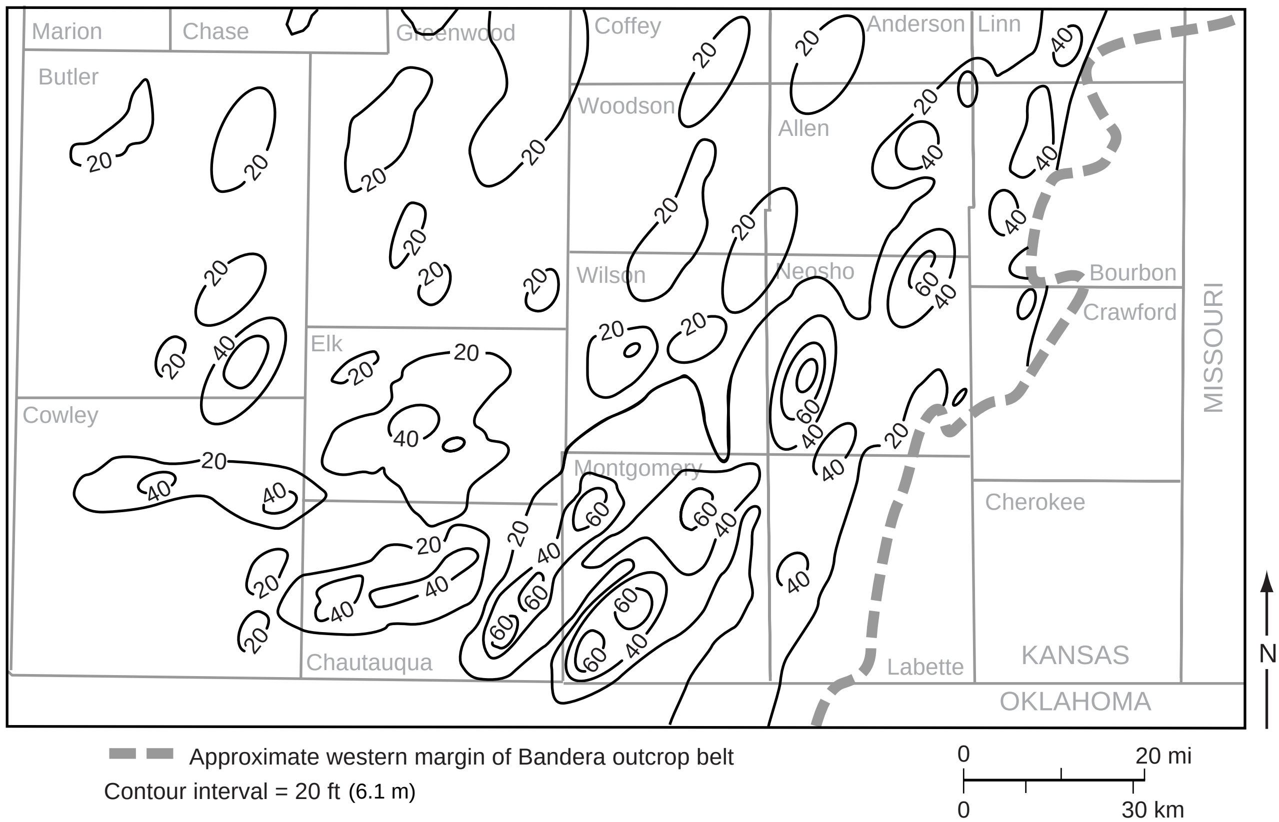


Figure 7. Sandstone isolith map of the Bandera Shale show concentrations of sandstone units in northeast-southwest orientation, with highest sandstone content in the southeastern portion of study area.

thickness from 4 cm to 13 cm (1.6–5.1 in), and are separated by a few millimeters of medium-dark gray (N4) clay shale (fig. 9A). The lowest meter is ripple-laminated, with wave lengths averaging about 0.5 m (1.65 ft) between straight-crested ripple forms (fig. 9B). Sandstone slabs in the remainder of the interval are characterized by homogenous stratification with some distinct but unrecognizable vertical burrows lined with carbonaceous material. This interval is overlain by 2.0–2.5 m (6.6–8.2 ft) of fine-to-medium-grained, large-scaled, cross-bedded sandstone (see discussion below) that loads down about 1.0 m (3.3 ft) into the top of the interstratified unit (fig. 9C). Above this unit lies 2.0 m (6.6 ft) of fine-grained sandstone slabs separated by thin (millimeter-scale) lamina of gray shale. Slabs of homogeneous, fine-grained sandstone in the lower 1.0 m (3.3 ft) of this interval are covered with horizontal traces belonging to at least two ichnogenera, *Olivellites* (Fenton and Fenton, 1937) and *Palaeophycus* (Hall, 1847).

Olivellites sp. aff. *O. plummeri* is a highly sinuous, flattened, bandlike, horizontal, unbranched trace that ranges in width from 1.0 cm to 1.5 cm (0.4–0.6 in). It is bilobate with a very narrow medial ridge (fig. 10A). Medial ridges are less than 1 mm wide. Very fine transverse ridges on lateral lobes were visible on some slabs, but most of the slabs studied were sufficiently weathered so those lobes appeared unornamented. These traces formed an overlapping network, suggesting that levels of bioturbation were high relative to sedimentation rate of overlying muds. This could be explained by alternating periods of rapid sand deposition followed by periods of mud deposition at very slow rates under quiet-water conditions. Originally described from shallow subtidal sandstones (Fenton and Fenton, 1937), *Olivellites* was thought to represent the grazing activities of mobile, deposit-feeding, epibenthic gastropods. Häntzschel (1962) considered *Olivellites* to be in the Scolicia group of gastropod traces. However, Yochelson and Schindel (1978) suggested that the trace-maker was an arthropod, and Knox and Miller (1985) described *Olivellites* from lagoonal, tidal flat, and distributary mouth bar facies.

Palaeophycus sp. are straight to slightly sinuous tubular traces that are typically elliptical to nearly circular in transverse cross section. They are typically smooth, horizontal, and unbranched with diameters ranging from 0.4 cm to 1.0 cm (0.16–0.39 in). Pemberton and Frey (1982) interpret *Palaeophycus* as feeding or crawling traces of predaceous or deposit-feeding errant polychaetes. However, Häntzschel (1962) believes that it could also represent other organisms. Regardless of exact origin, these traces are found forming dense networks that make some traces appear to be branched (fig. 10B), suggesting environments similar to those of *Olivellites*, with alternating periods of rapid sand deposition followed by periods of very low rates of mud deposition under quiet-water conditions.

Olivellites and *Palaeophycus* may represent opportunistic, facies-crossing ichnotaxa that are very abundant locally but are members of low-diversity assemblages (Archer and Maples, 1984). This situation suggests strata deposited in stressed environments (Buatois et al., 1997). Opportunistic organisms can exist and perhaps flourish under conditions that discourage or exclude most other organisms (Ekdale, 1985; Martino, 1989).

Well-log Signature. The interbedded sandstone and shale facies would probably have an intermediate gamma count and neutron value and would be indistinguishable from the signatures of a silty or sandy shale or of a clay-rich sandstone unit. Such a signature, seen in the intervals between 265 ft to 270 ft (80.7–82.3 m) and 240 ft to 245 ft (73.1–74.7 m) on the Benson Mineral Group well in Bourbon County, probably represent this mixed rock facies (fig. 8).

Interpretation. Intervals of slabby, well-sorted, fine-grained sandstone with intercalated, millimeter-scale shale lamina represent alternation of relatively high energy sand-sedimentation events separated by low-energy suspension-depositional conditions. The characteristics of the sandstone slabs, ranging from ripple cross-

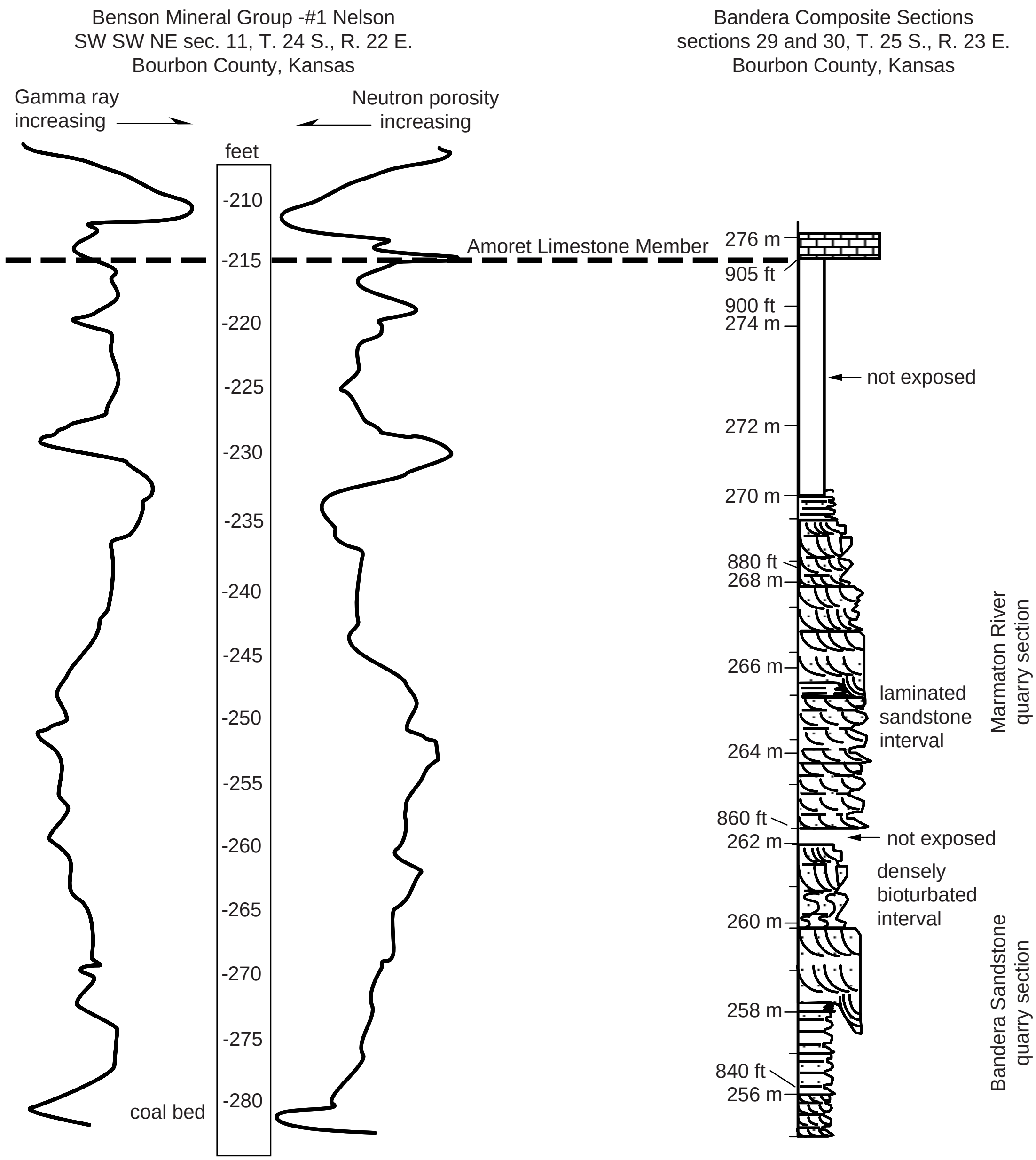


Figure 8. Comparison between well-log signatures and a composite surface section from the Bandera quarry in Bourbon County, Kansas. Depths on the well log are measured from the drill rig's Kelly Bushing and are approximately equivalent to depth below the surface. Elevations above sea level are shown on the composite section. See fig. 3 for location of surface composite section.

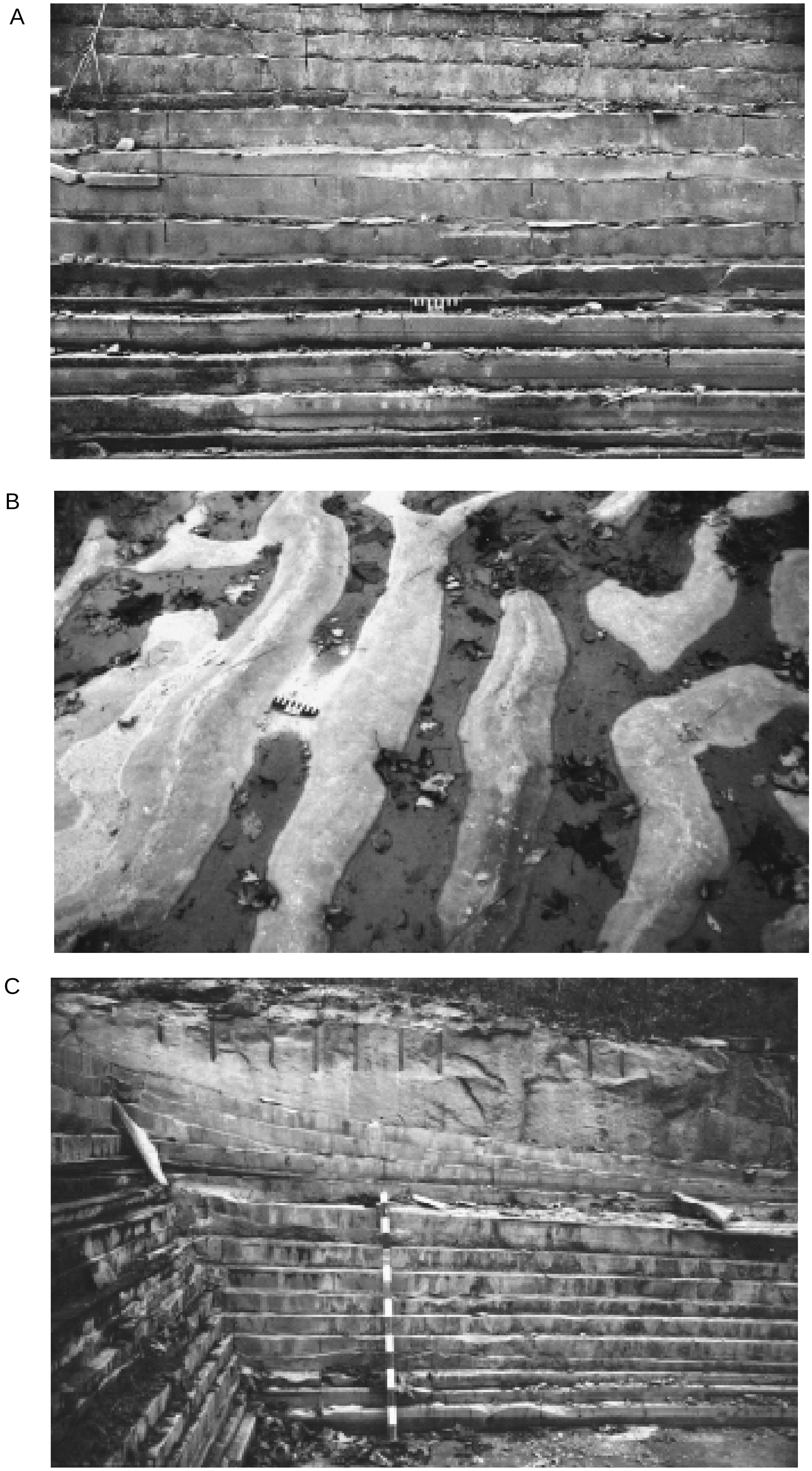


FIGURE 9. Sedimentary features in the Bandera Sandstone quarry, Bourbon County, Kansas. (A) Interbedded sandstone and shale about 2 m (6.6 ft) above base of Bandera Sandstone quarry section; scale is 15 cm (5.9 in). (B) Regularly spaced ripple crests on bedding planes 0.5 m (1.6 ft) above base of Bandera Sandstone quarry section; scale is 15 cm (5.9 in). (C) Dune feature loading down into interbedded sandstone and shale, 3.2 m (10.5 ft) above base of Bandera Sandstone quarry section; rod is 1.5 m (4.9 ft) long.

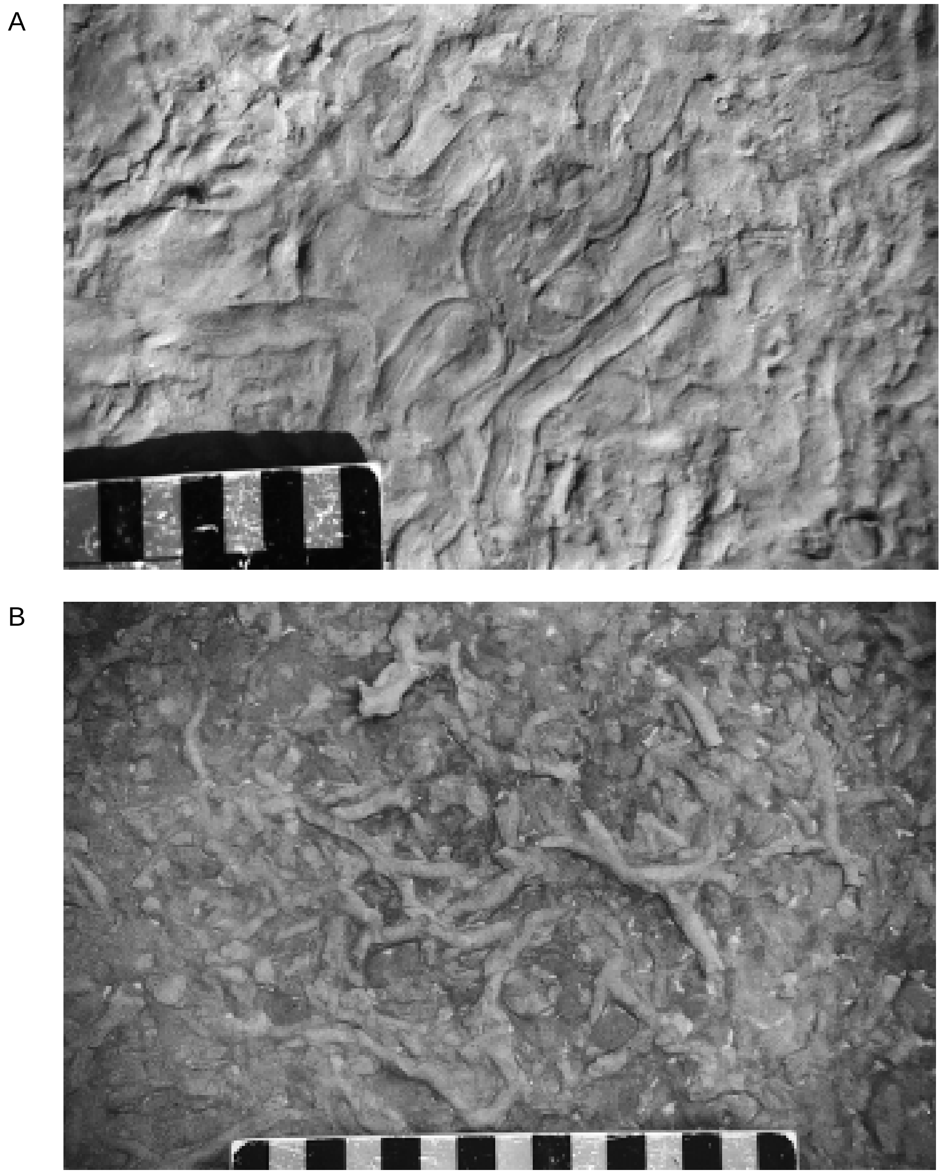


Figure 10. Trace fossils, *Olivellites* (A) and *Palaeophycus* sp. (B), observed between 5.0 m to 6.0 m (16.4–19.7 ft) in the Bandera Sandstone quarry, Bourbon County, Kansas; scale is in centimeters.

stratified to homogenous, indicate that each slab of sand was deposited rapidly. Ripple-cross-stratified slabs either lack or have very sparse trace fossils on their upper surfaces. They may represent sands washed into areas with either constant or regularly occurring currents, while homogenous slabs may represent either sands that were completely reworked by bioturbation or deposited very rapidly in areas that are not usually traversed by currents capable of moving sand. Slabs of homogeneous sandstones, in at least one interval, are capped with dense networks of horizontal feeding or crawling trails. The thin mud laminae would generally indicate relatively short periods of time between high-energy events. Dense networks of trails, along with homogenization of slabs capped by burrows, suggest that (1) enough time elapsed between events to allow bioturbation to take place in settings with this combination of characteristics and (2) mud deposition was slow.

The location of the Bandera Sandstone quarries north of a so-called sedimentary thick (indicated by the isopach map of the Lake Neosho-Anna) suggests that these localities were in a marginal, perhaps marine-influenced setting on the edge of a siliciclastic complex. High-energy, sand-depositing events were storms, fluvial floods, or a combination of both. Sands were deposited as splays or washover fans, emanating from the siliciclastic sediment thick, either as flood deposits from deltaic distributaries or as storm deposits swept from marine bars into areas that were low energy under fair-weather conditions. Sands deposited in quiet-water environments were later reworked by a low-diversity fauna, leaving *Olivellites* trails and *Palaeophycus* burrows. Both lithologic data and trace-fossil distributions support the interpretation that the interbedded sandstone and shale facies was deposited in a shallow marine setting above storm wave-base, but possibly below fair-weather wave base.

Laminated Sandstone Facies

Bourbon County Exposures. Fine-grained sandstone, horizontally and cross-laminated, occurs from about 14 m to 17 m (46.0–55.8 ft) below the Amoret Limestone in the Marmaton River quarry section. The laminae consist of prominent lighter and darker couplets. The lighter part has little carbon or mica, whereas the darker part (very dark gray, N2) has abundant carbon and mica-rich layers that range in thickness from 2 mm to 5 mm (0.08–0.2 in) (fig. 11A). The rhythmic nature of these lamination couplets are similar to those illustrated and analyzed by Greb and Archer (1995) from the Pennsylvanian Hazel Patch Sandstone of eastern Kentucky, which they interpreted as representing tidal cycles, after analyzing laminae-thickness periodicities. Although precise lamina-thickness data needed to show quantitatively either cyclicity or noncyclicity was not collected in this study, this may be accomplished later as part of a more comprehensive study.

Well-log Signature. The laminated sandstone facies is indistinguishable from other sandstones on well logs due to resolution limits of gamma-ray and neutron logs.

Interpretation. Horizontally laminated sandstones consist of darker-colored (but hydrodynamically lighter) lamina that contain abundant sand-sized mica plates and carbonaceous plant fragments and of lighter-colored (hydrodynamically heavier) lamina made up almost entirely of quartz sand grains. This rhythmically laminated interval is within a section characterized by large-scale, cross-bedded sandstone units and flaser-bedded units of interstratified ripple-laminated sandstone and shale, with some contortion caused by soft-sediment deformation (fig. 11B,C). Indications are that all sandstone units in the Bourbon County exposures were rapidly deposited, suggesting that sandstone rhythmites probably represent short-term oscillations in current conditions. One possible mechanism for these oscillations could have been manifestation of tidal cycles. Pending future mathematical analyses, we postulate that these rhythmites may have resulted from tidal currents related to tidal cells that may have been amplified in bay settings between siliciclastic point-source accumulations.

Large-scale, Cross-stratified Sandstone Facies

Bourbon County Exposures. In both the Bandera Sandstone and Marmaton River quarries in Bourbon County, intervals of interstratified sandstones and shales

A

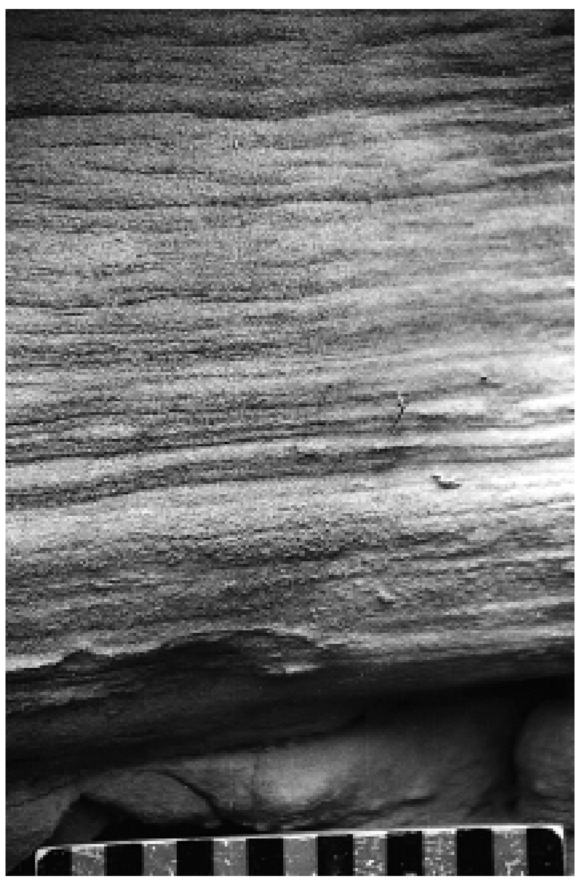
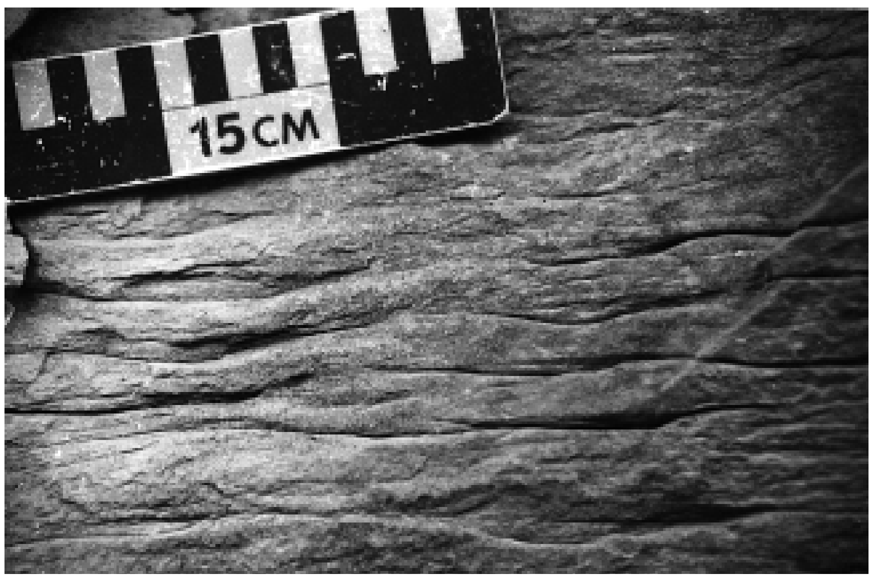


FIGURE 11. Sedimentary features in the Marmaton River quarry, Bourbon County, Kansas. (A) Laminated sandstone at 3.0–3.2 m (9.8–10.5 ft) above base of Marmaton River quarry section; scale is 15 cm (5.9 in). *(continued on facing page)*

B

C



(Figure 11 continued). (B) Contorted cross-bedded sets, indicating rapid deposition, at 3.5–4.5 m (11.5–14.8 ft) above base of Marmaton River quarry section, Bourbon County, Kansas; scale is 15 cm (5.9 in). (C) Flaser-bedded units of interstratified ripple-laminated sandstone and shale, 5.5–7.0 m (18.0–23.0 ft) above base of Marmaton River quarry section, Bourbon County, Kansas; scale is 15 cm (5.9 in).

are interrupted by 1.0–2.5-m (3.3–8.2-ft)-thick units of cross-stratified, fine-to-medium-grained sandstone with calcite cement. The most prominent units are located between about 16 m to 18.5 m (52.5–60.7 ft), 11.5 m to 13.5 m (37.7–44.3 ft), and 9.0 m to 10.0 m (29.5–32.8 ft) below the Amoret Limestone (fig. 8). The lowest of these units is exposed in the Bandera Sandstone quarry, while the upper two units are exposed in the Marmaton River quarry. Cross-bed dip directions are generally unimodal within any one unit but vary between units. The lowest of these units forms a 1.0–1.5 m- (3.3–4.9-ft)-thick unit that loads down into an underlying interbedded sandstone and shale interval without any indication of erosion (fig. 9C). This unit contains cross-sets that are up to 0.5 m (1.6 ft) thick. The middle unit also contains sets up to 0.5 m (1.6 ft) thick but shows evidence of soft-sediment deformation causing oversteepening of cross-bed dips (fig. 11B). It has a sharp, non-erosional basal contact over interbedded, laminated sandstone and shale. The upper unit has sets up to 0.3 m (1 ft) thick and grades downward into flaser-bedded sandstone with shale drapes (fig. 11C).

Well-log Signature. These calcite-cemented, relatively shale-free intervals are probably represented as low gamma, low neutron spikes on gamma-ray and neutron logs. Some well logs show funnel-shaped signatures, perhaps representing cross-bedded sandstone overlying interstratified or flaser-bedded sandstone and shale (figs. 4, 5). The lenticular and discontinuous distribution of sandstone thicks (depicted on the sandstone isolith map of the Bandera Shale interval) reflects the lack of correlation between consecutive wells of this well-log signature (fig. 7).

Interpretation. The positions of cross-bedded sandstone beds between interstratified sandstone and shale strata suggests that they represent subaqueous dunes that were formed in response to marine processes. We postulate that the discontinuous nature of sandstone intervals interpreted on well logs may represent dunes, sand bars, and bar complexes. These sands may have been transported to the seaway by a fluvial system during a time of sea-level lowstand. Subsequent marine transgression resulted in the deposition of the Bandera Shale and the reworking of sand bodies by combinations of tide-generated and wave-generated currents.

Shale Facies

Labette County Exposure. About 1 m (3.3 ft) of medium-gray (N6) to medium olive-gray (5YR6/1) shale lies directly beneath the Amoret Limestone Member in a roadcut in the SE corner of sec. 11, T. 35 S., R. 18 E., Labette County, Kansas. This shale is clay-rich and contains 4 cm (1.6 in) of coal about 0.9 m (3 ft) below the base of the overlying Amoret.

Well-log Signature. Shales, particularly potassium-rich clay shales, tend to have both high gamma counts and high neutron values. In most wells, the Amoret Limestone Member lies directly above an interval with signatures similar to the one described above. Coals are not commonly detected using well logs in this portion of the Pennsylvanian section, perhaps due to the inherit thinness of many coal beds.

Interpretation. Shales may represent a variety of settings ranging from deltaic interdistributary bays to muddy marine shelves. The shale observed in Labette County between a coal seam and the overlying marine Amoret Limestone probably represents a transgressive mud deposited before waters cleared enough to support carbonate-secreting organisms in sufficient numbers to produce limestone.

Depositional Environment

From the data, observations, and reconstructions presented above, we postulate that sandstones and mudrocks of the Bandera were transported into the Desmoinesian seaway of the Midcontinent from east to west by a fluvial system that drained the craton during sea-level lowstand. This formed an extensive siliciclastic sediment wedge on the eastern shelf of the seaway at lowstand and during the early phases of the subsequent marine transgression, as indicated by the thickness of the interval between the Lake Neosho and Anna black shales in the study area (fig. 6). Limited outcrop control and extensive, subsurface well-log control indicate that most of the siliciclastic complex consisted of sand and mud that were reworked during a subsequent marine transgression. Sandstone units, thick enough to be resolved by gamma-ray logs, appear to coarsen (lower clay content) upward, indicating that final deposition was as bars rather than channel forms. The dominant northeast-southwest trend of sandstone thicks shown on the Bandera sandstone isolith map (fig. 7) indicates that reworked sand-body complexes may have paralleled a postulated paleoshoreline. These bodies may have been shaped in response to currents generated by marine processes, such as tides and storms, rather than from coast-perpendicular or oblique currents that may be expected from a deltaic distributary channel flow jet.

Coastal-plain marsh environments are represented by the Mulberry coal bed, its thin underclay, and a thin coal below the Amoret Limestone Member. These marshes formed as rising sea levels elevated the water tables of coastal plains up to land-surface positions. The Mulberry coal bed, which is traceable over most of the study area, represents a laterally extensive marsh that existed prior to marine regression and deposition of Bandera siliciclastics. The thin, unnamed coal below the Amoret Limestone Member probably represents marshes that formed in ever-wet coastal-plain areas just prior to complete marine flooding that lead to Amoret carbonate deposition.

Outcrops along the northern margin of the Bandera siliciclastic wedge consist mostly of fine-grained sandstone beds interbedded with clay shale lamina and of thicker sets of cross-bedded sandstone (fig. 9). These lithologies are calcite cemented; some contain trace fossils attributed to marine organisms (fig. 10). Some units are laminated in a rhythmic fashion (fig. 11A); others are flaser stratified (fig. 11C), suggesting tidal influence, while nearby units are contorted (fig. 11B) or are loaded into underlying units (fig. 9C), indicating rapid deposition. These characteristics, along with the well-sorted, calcite-cemented nature of sandstone units, strongly suggest that deposition was in a shallow marine setting, where the primary sediment-moving agents were tide-generated and storm- or flood-generated currents.

Conclusions

Outcrop observations coupled with subsurface analysis indicate that sediments of the Bandera Shale in southeastern Kansas were deposited as a siliciclastic complex that prograded onto the Midcontinent seaway shelf during a sea-level lowstand. A generalized, podlike geometry suggests that initial deposition may have been fluvial influenced. Funnel-shaped well-log characteristics of thicker sandstones observed on gamma-ray and neutron logs, combined with the sedimentary characteristics observed in outcrops, indicate marine influence not only along the margins of the Bandera complex, but also within the siliciclastic wedge. Rhythmic stratification within sandstone beds that are interbedded with shale resemble tidal features described elsewhere and suggest that tidally influenced environments were present, perhaps where tidal cells were amplified along a morphologically irregular shoreline. Bioturbated sandstone units interbedded with clay shale record high-energy storm events that influenced sand distribution along wedge margins.

We postulate that the siliciclastic sediments of the Bandera Shale were initially deposited by fluvially influenced siliciclastic wedges or deltas that prograded westward during a period of sea-level lowstand. These sediments were probably generated as low base levels caused channels to incise into underlying strata east of the present-day outcrop belt, in areas that have either been removed by later periods of erosion or are covered by later Pennsylvanian and Pleistocene strata. Subsequent marine transgression reworked these siliciclastics into coast-parallel sand bars that were shaped by currents generated by storm wave and tidal events.

Acknowledgments

We thank Philip H. Heckel and Allan P. Bennison, with whom we had valuable discussions about stratigraphic relations and the locations of key Bandera outcrops. Well logs were provided by the Kansas Geological Survey. We would also like to thank Alan W. Archer, Anthony W. Walton, and Allan P. Bennison for thoughtful and thorough critical reviews that were of great importance in revising this manuscript for publication.

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