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Sedimentology and paleontology of a Carboniferous log jam

Robert A. Gastaldo [a,*], Carleton W. Degges [b]

[a] Department of Geology, Colby College, Waterville, ME 04901, United States
[b] Heidelberg Cement Group, Leeds, AL 35094, United States

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Abstract

A localized sandstone split in the Mary Lee coal (Early Pennsylvanian, Langsettian) of the Black Warrior Basin, Alabama, has a channel-form geometry and preserves a concentrated log-and-gravel (pebbles, cobbles, and boulders) assemblage at the top of the fill sequence. Gravel lithotypes within and amongst rooting structures of lycopsid, cordaitean, and calamitean trees are indicative of an Appalachian orogenic provenance, and support an allochthonous origin for some of the logs. In addition, a *Skolithos* ichnological assemblage within the channel is indicative of opportunist colonization during channel fill.

A low sinuosity geometry characterizes the overall channel-form belt, exhibiting a general northwesterly trend. Paleocurrent measurements from the cross-bedded sandstone at the margin of the channel belt indicate flow was to the northwest. Log orientations at these sites are subperpendicular to perpendicular to the overall sediment transport direction and are interpreted to represent an ancient log jam. The genesis of the fluvial channel, the introduction and emplacement of the concentrated log assemblage, the effects of this floating log accumulation on sedimentation within the channel, and the relationship between paleocurrent and log orientation are discussed. The Red River, located in the southern United States, is used as a modern analog for comparative purposes.

Keywords: Paleobotany; Pennsylvanian; Plant taphonomy; Ichnology; Black Warrior Basin

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1. Introduction

The disposition of fossil logs in fluvial environments has been used as a paleoenvironmental indicator to varying degrees of success (e.g., Pelletier, 1958; Colton, 1967; MacDonald and Jefferson, 1985; Fiorillo, 1991; Evans, 1991; Gastaldo, 2004). Although commonly found in ancient channel deposits in channel-lag deposits, no definitive conclusion has been drawn on the significance of wood orientation with respect to current direction. The complexity of this problem is compounded by many factors including the source area of logs, their diameter and length, number of logs, wood and/or periderm density, susceptibility to waterlogging, and resistance to decay (see: Robison and Beschta, 1990; Montgomery and Piégay, 2002).

A localized channel-form sandstone divides the Carboniferous Mary Lee coal into two benches in northwestern Walker County, Alabama (Ward, 1986; Liu and Gastaldo, 1992a). The sandstone attains a maximum thickness of a few meters, thins laterally, and is oriented in a northwestern direction in which an unusual paleontological assemblage occurs. A concentrated log accumulation (xylocoenosis) is preserved at the top of the channel sequence in which extrabasinal gravel found within

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* Corresponding author.
E-mail address: ragastal@colby.edu (R.A. Gastaldo).

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rooting structures indicates an Appalachian-sourced provenance (Liu and Gastaldo, 1992a). Beneath the wood assemblage and these extrabasinal clasts is a more "typical" marine ichnofaunal assemblage preserved in a cross-bedded sandstone unit. This sandstone split and unique fossil assemblages allow for the characterization of this ancient coastal fluvial system, an the assessment of the role that woody detritus played on the development of the fluvial sequence, and an evaluation of the use of fossil logs as paleocurrent indicators.

2. Regional stratigraphy and locality

The Mary Lee coal zone is one of nine basin-wide economic coal-bearing cycles identified in the Pottsville Formation (Langsettian = Westphalian A; Early Pennsylvanian) of the Black Warrior Basin, a triangular foreland basin located between the Appalachian and Ouachita orogenic trends (Thomas, 1988; Fig. 1). Pashin (2004) characterizes the basin as a faulted homocline dipping southwestward towards the Ouachita orogen, with the frontal folds and faults of the Appalachian system superimposed on the southeastern margin. Thirteen cycles within this sequence (Pashin, 1994) are bounded by ravinement surfaces formed during the maximum rate of sea-level rise (Liu and Gastaldo, 1992b), which can be identified not only in outcrop and core (Demko and Gastaldo, 1996), but also in geophysical well logs (Pashin, 1994). These are considered to be coincident with the genetic sequence boundaries (Gastaldo et al., 1993; Pashin, 1994, 2004) as envisioned by Galloway (1989) and the transgressive maximum flooding surfaces of Van Wagoner et al. (1990).

The Mary Lee coal zone consists of the Jagger, Blue Creek, Mary Lee, and Newcastle coal seams underlain by a thick fine- to medium-grained sublitharenite informally called the "Jagger bedrock" sandstone (Gastaldo et al., 1991, 1993). The Mary Lee cycle outcrops over at least a 1000-km^2 area as surface mine highwalls (now mostly reclaimed), road cuts, and natural exposures. Such exposures extended laterally several kilometers allowing for the development of a three-dimensional perspective of facies architecture (Gastaldo et al., 1990). The vertical succession records deposition in nearshore and transitional coastal environments, all of which show evidence of tidal influence (Demko and Gastaldo, 1992, 1996; Gastaldo, 2004).

A stigmarian-rooted tidalite sequence (entisol) directly underlies the Mary Lee coal in Walker County, which Eble et al. (1994) interpret as a planar-to-raised mire. The coal crops out near the edge of the basin in northwestern Alabama where it is locally split by a sublitharenite near the town of Carbon Hill. Here, the Mary Lee attains a maximum thickness of 1.7 m, but is generally less than 1 m thick, and is overlain by tidal-influenced fluvial and

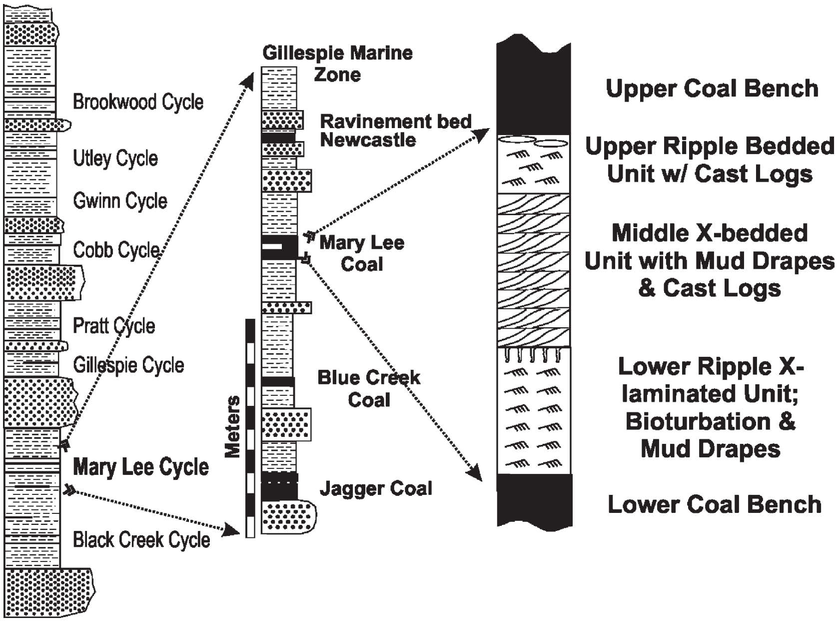

Fig. 1. Generalized stratigraphic column of the Pottsville Formation, Black Warrior Basin, in which the principal, ravinement-bound coal zones are indicated. The Mary Lee Coal zone consists of the Jagger, Blue Creek, Mary Lee and Newcastle coals with intervening tidal-influenced sediments in the northwestern part of the basin. The Mary Lee Coal split in Walker County, Alabama, is subdivided into three units of sublitharenite in which the fossil assemblage is preserved.

coastal deposits. Locally, the coal is split into a rider seam — the Newcastle coal — with an intervening sequence of channel-form sandstone bodies and mudstone lithologies that preserve tidal-influenced sedimentary structures (Gastaldo et al., 1990). Overlying these coals are shallow, wide sheet and channel-form bodies of fine sandstone and siltstone in which rhythmic bedding cycles within accretionary bars along with pinstripe and flaser structures occur (Liu and Gastaldo, 1992a,b). The Newcastle coal and/or the channel-form fine sandstones and siltstones are truncated by a planar erosional surface that can be traced in outcrop and the subsurface for >1800 km^2. Liu and Gastaldo (1992a) described the sedimentological and paleontological variability of the thin overlying lithologies, interpreting these rocks as a condensed section as the result of ravinement processes. These overlying marine sediments are part of the suprajacent Gillespy cycle (Pashin, 2004).

3. Materials and methods

Data were collected in two surface coal mines formerly operated by Coal Systems, Inc. and recently reclaimed (U.S.G.S. Carbon Hill, AL, 7.5’ Quadrangle, T 13 S., R 10 W., Sections 11, 12, 13, 14, 24; Fig. 2). Surface exposures occurred in highwalls and as “pavement” floor rock exposed by mining operations. Subsurface data were documented in 84 drillers logs from bore holes completed in advance of mining exploitation. Hence, the surface and subsurface data sets provided horizontal and vertical spatial control of the sandstone body allowing for its three-dimensional delimitation. Sandstone thickness data were used to construct an isopach map of the body.

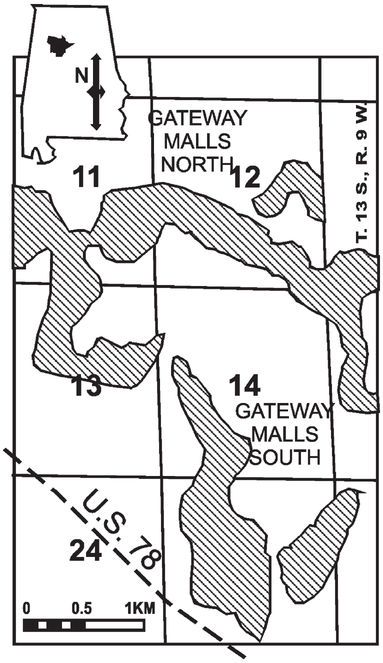

Fig. 2. Location of the study area in Walker County, Alabama (U.S.G.S. 7.5′ Topographic Quadrangle Carbon Hill, AL). Enlarged view of study area in which the Mary Lee Coal split was mapped; cross hatched areas indicate strip mines active at time of study.

Paleocurrent analysis was used to determine the sediment transport direction with 537 small-scale cross beds assessed, specified by azimuth, in the two active mines. Most data ($N=441$) were collected from the southern mine because mining had been discontinued prior to the extraction of the sandstone split and the “pavement” exposures provided many three-dimensional surfaces for examination. Data were analyzed using Raleigh and circular statistics, and the results plotted on rose diagrams in 10-degree increments using ORIANA (V. 1.06, Kovach Computing) to reconstruct prevailing current direction.

Fossil logs were identified to taxon (where possible) and log orientation was defined as the azimuth alignment of the plant’s long axis. A smooth, solid cylindrical rod may align parallel to the flow lines under unidirectional fluid flow. However, there is no tendency inherent in the geometry of the rod itself for a particular end to point upstream. In most cases, due to exposures in which neither tree base nor crown could be determined, the logs were considered symmetrical. Log orientation was plotted such that both ends of each log were represented. A total of 124 log orientations were taken from the North Mine, and 368 were collected from the South Mine. This made it possible to establish the relationships between log orientations, internal directional structures (cross-bedding), and the overall geometry of the sandstone split.

Oriented blocks from a number of sites were cut at various orientations, polished, and used as an aid in the evaluation of both the primary sedimentary structures and preserved ichnofauna. Thin sections were point counted to determine mineral percent compositions (after Hutchison, 1967) and grain size (after Griffiths, 1967). These data were later used to classify the rock type (after Folk, 1980) and estimate the degree of sorting (after Longiaru, 1987).

4. Sandstone geometry and sedimentology

4.1. Geometry

The sandstone body enclosed within the Mary Lee coal splits the coal locally into an upper and lower bench (Liu, 1990; Liu and Gastaldo, 1992a; Fig. 3). The split exhibits a very low sinuosity (thalweg length [1-m contour; Fig. 3]/channel length$=0.76$) and could be

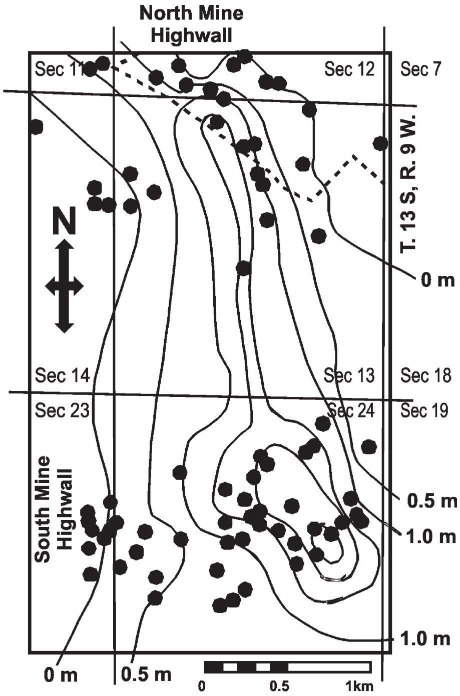

Fig. 3. Isopach map of sandstone body that splits the Mary Lee coal in western Walker County. Isopach map is constructed from outcrop measurements and borehole data (solid circles) provided by Coal Systems, Inc. The positions of mine highwalls at the time of the investigation are indicated by dashed lines. Contour lines are in 0.5 m intervals.

considered a straight channel (Leopold and Wolman, 1957), trends in a northwest–southeast direction, and has a maximum width of more than 2 km. It pinches out to the west and to the east of the open cast mines. Typically, the channel averages ~1 m in thickness but ranges from 0 m at the margins of the body to a maximum thickness of more than 2.8 m. The sandstone body is channel-form in transverse section, and visual examination was limited only to the western margin where active mining had exposed the split. Here, it was comprised of multiple, shallow *en echelon* stacked channels.

4.2. Sedimentology

Overall, the split is composed of fine- to medium-grained quartz sand with minor amounts of lithics and finer clastics. The sandstone is subdivided into three distinct units based upon characterizations of the thin channel-forms observed at the margin of the sandstone body. A lower flaggy sandstone directly overlies the Mary Lee coal and preserves erect lycopsid trees and isolated, prostrate calamitean pith casts (Fig. 4A). A middle unit is characterized by cross-bedded and interlayered ripple cross-laminated sandstone and mudstone in which an ichnofauna and prostrate wood assemblage are preserved (Fig. 4B). The upper unit is fine-grained and ripple-cross laminated in which numerous vitrainized and sandstone-cast logs and intercalated gravel are found (Liu and Gastaldo, 1992a).

4.2.1. Lower flaggy sandstone

This unit is a tan to medium light-gray (Munsell color, N6), thickly-bedded, flaggy sublitharenite in which primary sedimentary structures are difficult to discern. The basal contact is undulose and disconformable with the underlying coal. The sandstone is composed of fine- to medium-grained quartz sand with small amounts of silt, clay-size material, and muscovite. However, several of the medium-grained samples are quartz arenites (Degges, 1991), and rarely are quartz pebbles found in this unit. Where pebbles are encountered, they are isolated clasts within the sand body and not concentrated along the basal contact.

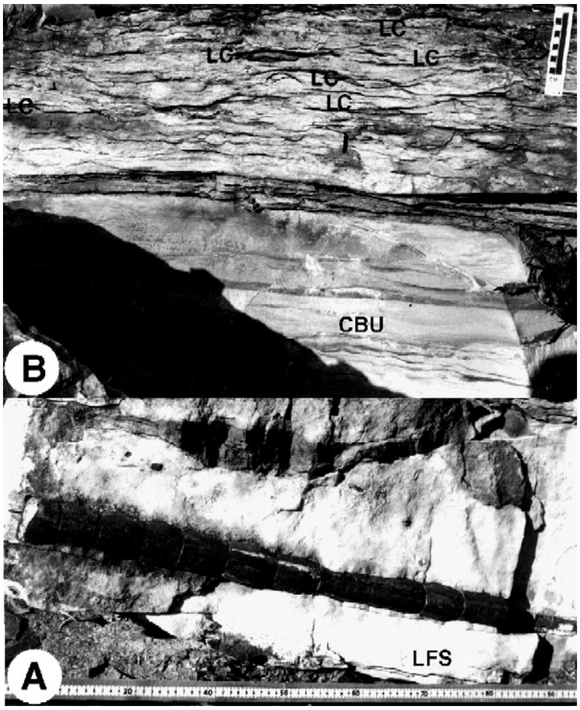

Fig. 4. Photographs of the sandstone split in vertical exposure found in the Coal Systems, Inc., South Mine floor. (A) The lower flaggy sandstone (LFS) is in contact with the overlying cross-bedded sandstone, and the lower bench of the Mary Lee coal underlies this litharenite. An isolated *Calamites* axis cast is preserved within this lower unit. Scale in dm. (B) A vertical section of the split in which the cross-bedded unit (CBU) is in contact with the upper rippled unit comprised of coalified and cast interlayered logs (LC). Logs in this uppermost part of the sandstone may be sandstone or pebble-cast; gravel clasts occur near the base and between logs (see: Liu and Gastaldo, 1992a). Scale in cm.

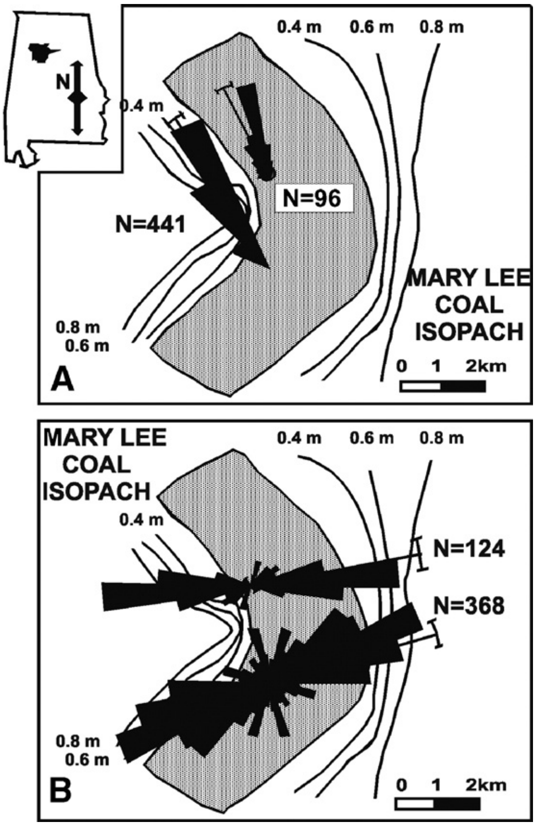

Fig. 5. Abandoned channel sandstone (shaded) superimposed on isopach map of the Mary Lee coal (contours in 0.2-m intervals). (A) Paleocurrent based on cross bed measurements depicted by rose diagrams. Mean vector and circular statistic standard deviation indicated for North (T. 13 S., R. 10 W., Sec. 13) and South Mine (T. 13 S., R. 10 W., Sec. 24) data (see Table 1). (B) Rose diagrams of log orientations based on measurements of long axes. Mean vector and circular statistic standard deviation indicated for North and South Mine data (see Table 1).

4.2.2. Cross-bedded middle sandstone

The middle unit is also a medium light-gray sublitharenite in which cross bedding is common. Cross-bed sets are repeated vertically throughout this unit, and each bed set begins as medium-scale trough cross-stratification. Small-scale trough cross-stratification and ripple cross-laminations are found within each larger bedform. Foresets and bottomsets are present, topsets are missing due to erosion during reactivation. Thin mud drapes (up to 4 mm in thickness) blanket each cross-bed set and are discontinuous owing to subsequent reactivation. A maximum of 23 cross-bed sets were observed in vertical profile, each varying between 1.5 to 2.5 cm in thickness, decreasing in thickness and grain size upsection vertically.

Paleocurrent measurements were taken on small-scale cross beds (Fig. 5A) and indicate sediment transport was to the north-northwest. Although the data originate from the western margin of the channel belt, each data set represents cross-stratification within a single shallow channel-form body. Paleocurrent direction in the South Mine is strongly unimodal (μ vector = 328°), with primary sediment transport towards the northwest; a similar orientation is found for the North Mine data although here there is more variability in crossbed orientation (Table 1). Nonetheless, the overall pattern is strongly unimodal directed towards the northwest.

Biogenic alteration includes vertical pipe-like and star-shaped burrows, both of which are dispersed throughout the sandstone in varying densities. Vertical burrows, assigned to cf. *Skolithos* and cf. *Monocraterion*, crosscut individual cross-bed sets and are truncated at reactivation surfaces. Star-like, horizontally radiating burrows, assigned to cf. *Asterichnus*, are found most often at the top of cross-bed sets on truncation surfaces near ripple crests.

4.2.3. Upper sandstone

The unit is a medium dark gray (N4) to dark gray (N3) lithic arenite that is distinguished by an increasing abundance of log material, an alternation of fine-grained sandstone and shale, and an increase in fine clastics (Fig. 4B). Most primary structures are indistinguishable due to the extremely disrupted nature of the unit and the

Table 1
Results of statistical analyses conducted on paleocurrent measurements of logs and cross beds in the Gateway Malls North and South Mines using Oriana v. 1.06

	Lycopsids	Calamites	Cordaites	Composite	South Mine logs	North Mine logs	South Mine cross beds	North Mine cross beds
Observations	156	62	122	340	369	124	226	96
Mean vector (μ)	71.59°	72.71°	72.94°	72.25°	73.51°	79.33°	328.03°	333.52°
Circular variance	0.18	0.39	0.22	0.23	0.23	0.12	0.02	0.09
Circular standard deviation	35.57°	56.56°	39.88°	41.22°	41.92°	29.04°	12.23°	24.26°
Standard error of mean	2.82°	7.41°	3.57°	2.21°	2.16°	2.60°	0.81°	2.47°
95% confidence interval (−/+) for μ	66.06°	58.18°	65.94°	67.91°	69.27°	74.23°	326.44°	328.67°
99% confidence interval (−/+) for μ	77.13°	87.24°	79.94°	76.58°	77.74°	84.43°	329.63°	338.37°
Rayleigh test of uniformity (p)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

abundance of large logs; the uppermost 3 cm to 20 cm is characterized by small-scale ripples. Terrigenous clastics are interbedded with coalified, sandstone-cast, and compression–impression prostrate log material, with a few stigmarian rooting structures preserved within this horizon. The lower contact with the middle sandstone and the upper contact with a bench of the Mary Lee coal seam is gradational. However, there is a sharp contact with the overlying coal where the sandstone is thinnest.

Pebble- to boulder-sized clasts are common, with pebbles restricted to clusters within hollow logs whereas cobbles and boulders occur dispersed between logs and within presumed tree bases and rooting structures. Isolated cobbles and boulders often are found within the Mary Lee coal at sites adjacent to the sandstone. Liu and Gastaldo (1992a) have provided details of these clasts.

5. Paleontology of sandstone split

5.1. Paleobotany

Plant fossils are preserved either as coalifications, adpressions, and/or sandstone casts. Plant parts include rooting structures (rhizophores), aerial stems, leaves (petioles and rarely laminae), and seeds, with aerial trunks without canopy branches the predominant organ (although a few canopy branches are present). Most logs can be identified to major plant groups utilizing characteristic morphological features and include lycopsids, sphenopsids, and cordaiteans. Lycopsid trunk casts often preserve external bark features on which characteristic diamond-shaped scale-like scars (leaf cushions) persist after leaf dehiscence. Lycopsids still can be recognized even where degradation of the bark has occurred, resulting in characteristic patterns identified as the form genera *Knorria* and *Syringodendron*. All lycopsids are casts indicating that sediment fill followed internal tissue decay (Gastaldo, 1986a,b). The outermost periderm tissue often is coalified around casted stem interiors. *Calamites* and *Cordaites* also are preserved as pith casts with wood and bark tissues compressed or coalified. These plants differ from the lycopsids because their casts exhibit interior features of the pith and are the result of infilling of a central void developed during the life of the plant. *Calamites* are differentiated on the jointed character of the cast on which longitudinal ribs and grooves, representing features of the inner surface of the stele, alternate between nodes. Nodes may bear circular scars that represent the points of origination of lateral branches. Pith casts of *Cordaites* (= *Artisia*) have transverse lines, or grooves, across the cast that represent the impressions of parenchymatous plates (diaphragms) that crossed the pith during life.

Logs are found either prostrate (lycopsids, calamiteans, and cordaiteans) or erect (lycopsids). Isolated prostrate logs are found only in the lowest sandstone (Fig. 4A), whereas logs are concentrated in the upper sandstone (Fig. 4B). Most prostrate logs are elliptical in transverse section, the result of incomplete infilling (Gastaldo et al., 1989), although several specimens were filled completely and are circular in cross section. Several upright sandstone-cast lycophyte stumps are preserved in the limited outcropping of the channel belt, restricted to the channel base. Some stumps are circular in cross section, rooted in the lower bench of coal, and extend into the upper coal bench; most do not cross-cut the entire sandstone sequence. *Stigmaria* rooting structures also are sandstone cast and are found preserved in the lower bench of the Mary Lee coal.

5.1.1. Log orientation

A cumulative plot of the orientations of all logs indicates a general northeast–southwest azimuth direction (Fig. 5B). The general trends do not change markedly between the North and South Mine (Table 1). Plots of individual taxa (lycophytes, *Calamites*, and *Cordaites*) do not show significant deviation from the overall trend (Fig. 6). Lycophyte axes exhibit the least divergence (Fig. 6A) and are unimodal in their orientation. Although *Cordaites* show a greater variability in

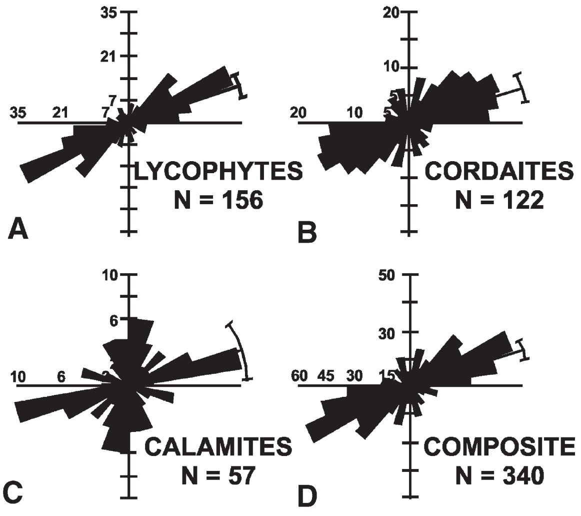

Fig. 6. Rose diagram plots of identifiable logs in the South Mine. (A) Orientations of lycophytes with mean vector and circular statistic standard deviation indicated. (B) Orientations of calamites with mean vector and circular statistic standard deviation indicated. (C) Orientations of cordaites with mean vector and circular statistic standard deviation indicated. (D) Composite diagram of lycophyte, calamite, and cordaite data collected from pavement outcrop of the top of the sandstone split at the Hope Galloway South Mine.

spread, their trend is statistically no different than the lycopsid axes. The plot of *Calamites* differs from the generalized northeast–southwest alignment by exhibiting a bimodal trend, although the data fail the Raleigh test for uniformity (Table 1). The main vector is oriented parallel to the other plant groups (μ vector = 73°), while there is a subordinate north–south trend displayed by other axes.

5.2. Ichnology

Two distinct types of trace fossils are found restricted to the middle sandstone. Cylindrical burrows conform to the ichnogenera *Skolithos* and *Monocraterion* occur perpendicular to bedding and cross-cut bed sets (Fig. 7A). Star-shaped burrow systems assigned to *Asterichnus* are parallel to bedding and are restricted to ripple crests (Fig. 7B).

Vertical burrows are straight, generally uniform in diameter, and are visible both on cut or weathered surfaces. They are distinguished easily because of a slight discoloration that may be related to diagenesis of a secreted mucus lining or annulations of the tube wall. Grain size in the burrows may be slightly smaller, but no mineralogical difference between burrow fills and surrounding sediment can be detected petrographically (Degges, 1991). Burrows are either concentrated (>60 per 5 cm^2) or scattered (<10 per 5 cm^2); a gradational relationship between the two distribution patterns was not found.

Skolithos burrows are straight, subcylindrical, unbranched sediment-plugged tubes (Fig. 7A) with burrow diameters ranging from 1 to 4 mm. Burrow length may exceed 30 cm, though it is generally 10 cm or less (N = 54), but burrow diameters remain constant within a given tube. Specimens conforming to *Monocraterion* are plugged tubes similar to *Skolithos* but terminate vertically in a funnel-shaped structure. Funnels generally range between 2 and 6 mm in diameter, are circular in transverse section, and generally cup- or trumpet-shaped in longitudinal profile (N = 54). When viewed in transverse section, they appear as a series of concentric rings; successive laminae are deflected downwards toward the burrow axis in vertical section.

Star-like burrows assigned to *Asterichnus* (Bandel, 1967) occur on the surfaces of some bedding planes (Fig. 7B). They are sandstone infilled, preserved in epirelief, and occur in dense clusters (approx. 100 to 150 per m^2) concentrated along ripple crests. The star-shaped burrow is further accentuated by the presence of a fine-clastic drape. A single burrow consists of a cluster of rays (generally > 8) and is typically 7 cm in diameter (N = 40). Individual arms radiate from a central locus, are nearly circular in transverse section, and each ranges from approximately 1 to 5 mm in diameter (N = 60). Rays do not branch and are lined with fine-grained mud and plant detritus. There is not a distinct change in general grain-size between the burrow fills and the surrounding sandstone matrix.

6. Discussion

Our perceptions and understanding of fluvial regimes have been altered dramatically with the advent of civilization. Man's desire to maintain navigable rivers through the removal of wood accumulations has changed the way in which those rivers function (Montgomery and Piégay, 2002). When woody detritus of various dimensions has been reintroduced to river systems once cleaned by man's activities, the fluvial system and its ecosystem have reverted to a more natural state (Keller and Swanson, 1979; Keller and Tally, 1982; Robison and Beschta, 1990 and references therein). It is this unaltered condition that is to be found in the stratigraphic record and preserved in the Mary Lee coal split.

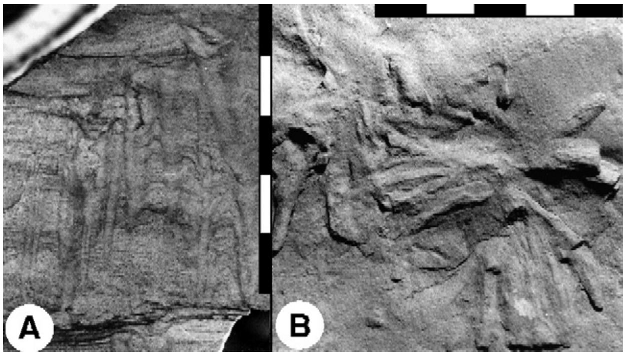

Fig. 7. Trace fossil assemblage in the middle unit of the Mary Lee coal sandstone split. (A) Vertical burrows cf. *Skolithos* originating at reactivation surfaces that cross cut bedding. (B) Horizontal burrows cf. *Asterichnus* preserved in the uppermost part of the cross-bedded sandstone unit that are found principally on ripple crests. Scale in cm.

To better understand the interrelationships and feedback mechanisms between the components of this assemblage, several interrelated questions must be addressed. The first involves the mechanism responsible for the genesis of the ancient fluvial channel, whereas the second concerns the introduction and emplacement of a concentrated log assemblage at the top of a channel-fill deposit. The third problem includes assessing the influence that these logs may have had on the sedimentological and paleontological features recorded in the sandstone split, while the fourth focuses on the relationship between paleocurrent (as determined from sedimentological parameters) and log orientation (Gastaldo, 2004).

6.1. Genesis of channel-form sandstone

Coal bed discontinuities may be caused by either autogenic or allogenic processes. Autogenic processes include channel-bank slumping, deposition within or overbank discharge from fluvial or tidal channels, and channel avulsion (Raistrick and Marshall, 1939; Ferm and Horne, 1979; McCabe, 1984). Allogenic mechanisms include growing structural highs, underlying topographic variations (Demko and Gastaldo, 1996), faulting (Weisenfluh and Ferm, 1984), and coseismic subsidence (Phillips et al., 1994; Phillips and Bustin, 1996; Gastaldo et al., 2004).

Periodic overbank flooding from entrenched fluvial channels transecting a peat swamp generally results in thin, fine-grained, persistent partings in coal beds when the peat swamp is either rheotrophic or in the initial stages of ombrogeny (planation and doming). In ombrogenous mires, these splits tend to be aerially restricted to sites immediately adjacent to the channels (Staub and Esterle, 1994; Staub et al., 2000). Channel avulsion through rheotrophic or immature ombrotrophic mires can be generated by anomalous high-discharge events, resulting in the redirection of flow away from a main distributary and accompanied by erosion within the path of the new channel. Overbank sedimentation associated with the avulsion may result in the deposition of a coarser-grained sediment overtopping the peat body in the adjacent areas.

Where channels have avulsed through a peat swamp, organic accumulation is replaced for a short period of time by clastic deposition in the channel. Because of the time required for the deposition of split-forming material (100s–1000s years) compared to that needed for deposition of the coal itself (1000s–10,000s years), peat continues to accumulate adjacent to the channel. The peat beneath the channel is compressed under the weight of denser clastic sediment, as compared with the remainder of the peat body, resulting in subsidence along the channel and, thus, allowing for the deposition of a thicker clastic sequence. With continued progradation of the channel, a point is reached at which it is no longer able to maintain its gradient and channel abandonment occurs. Vegetation is re-established once detrital influx stops, and peat accumulation resumes. After compaction, the channel is preserved as a lenticular body within the coal.

The Mary Lee split may be an abandoned avulsed channel that cut through the peat mire, and several lines of evidence can be used to support this interpretation. The channel is enclosed within the mire as a lenticular sandstone body when reconstructed in cross section (Figs. 3 and 5), and was deposited contemporaneously with peat accumulation. The channel base does not extend beneath the coal seam, as one would expect if it was entrenched into the coastal plain either prior to peat accumulation or during the subsequent lowstand systems tract. Rather, lycopsid trees rooted in the thin (30 cm) underlying lower bench are preserved upright as sandstone casts in the basal most sandstone indicating that the channel traversed the peat body. The localized, sinuous sandstone channel-form is the only one in the western part of Walker County (Gastaldo et al., 1990; Eble, 1990). Its' shallow (<3 m) depth and less than 2 km width developed in a pre-existing topographic low (Demko, 1990), and is composed of several small channels in this part of the channel belt. The system was governed by several variables including low slope, a variable discharge (see below), cohesive bank material with a low potential for bank erosion (McCabe, 1984), and moderate amounts of fine terrestrial clastics.

The avulsion event would have been generated by a very high-magnitude, low-frequency flood that also influenced adjacent areas. Directly to the east (Townley, Jasper, and Cordova Quadrangles), the Mary Lee coal is covered by up to 5 m of sandstone and shale in which the peat forest is buried erect (Gastaldo et al., 1990). Hence, a large quantity of fine-grained clastics was deposited on top of the mire in a geologic instant. Such Fossil Lagerstätten may be indicative of short-term, anomalous high sedimentation rates (Gastaldo, 1986b, 1987), although allocyclic mechanisms also may be responsible for such preservation (Gastaldo et al., 1995; Gastaldo et al., 2004). The Newcastle coal developed regionally on top of this clastic sequence, and the Newcastle and Mary Lee coals are seen to merge at the Prospect Mine (Nauvoo 7.5′ Quadrangle T 13 S., R 9 W., Sec. 16), demonstrating that the former coal is equivalent to the upper bench of the latter in western Walker County (Gastaldo et al., 1990). The burial of the peat swamp in the east and the incision of the channel into the peat swamp in the west is interpreted to represent the same event.

Other evidence to support genesis during a high-magnitude discharge event is found in the unusual suite of clasts, including gravel (pebbles and cobbles) and boulders (up to 0.5 m in diameter), concentrated at the top of the channel and in the adjacent Mary Lee coal (Liu and Gastaldo, 1992a). Liu and Gastaldo (1992a,b) discussed the hydrodynamic requirements for transport of these clasts within a flow regime that only moved fine sand in bedload, and concluded that these clasts were moved either within rooting structures of floating trees, rafted downstream on top of logs, or within “Sudd” (see below; Ridley, 1930). The clasts are of sedimentary, metasedimentary, metamorphic, and igneous origin and are characteristic of the suite of rocks found in the southern Appalachian Piedmont Province, situated more than 100 km east/southeast from the collection site (Liu and Gastaldo, 1992a). A higher than normal flow regime was required to move these gravel-laden logs long distances, and is attested to by the fact this is the only known occurrence of such clasts in the coastal lowlands of the Warrior Basin. The addition of such clasts, especially located at one end of a tree if entwined within rootstocks, would change the distribution of weight within the tree. Most likely, under normal flow conditions, the rootstock would float below the water interface and easily ground in shallow areas. The presence of boulders within the Mary Lee coal in areas adjacent to the channel would indicate that these clasts were transported over the channel margin and deposited directly on the peat swamp. This requires unusually high flood conditions, conditions that would be associated with high energy levels during which time an avulsion event could occur.

Alternatively, an allocyclic mechanism may be responsible for repositioning the surface of the Mary Lee mire at-or-near base level with subsequent erosion and emplacement of the channel. The log assemblage may be unrelated to the initial trangression of the mire, and emplaced in an unrelated subsequent high-discharge event. Gastaldo et al. (2004) demonstrate that the Mary Lee coal zone was affected by coseismic subsidence, similar to what is documented by Phillips et al. (1994) and Phillips and Bustin (1996) for the Changuinola peat mire in Costa Rica. Coseismic subsidence of the eastern margin of this Recent swamp over the past few millennia has resulted in nearly 40% of the mire being placed beneath Almirante Bay. As such, microtidal processes have affected the marginal marine parts of the Changuinola swamp with accompanying fine clastic deposition overlying the submerged peat (Phillips et al., 1994). Such a subsidence mechanism could have lowered this part of the Mary Lee mire similar to what is documented for the underlying Blue Creek mire (Gastaldo et al., 2004). Once at-or-near base level, the topographically lower coastal plain was transgressed either by tidal channels (marine generated erosion) or tidally-influenced distributary channels (fluvial generated erosion and/or avulsion).

6.2. Aspects of the log assemblage

6.2.1. Introduction and provenance of logs

Periodic flooding can be responsible for introducing logs into a channel system (see: Stevenson, 1911) through bank failure associated with erosion and collapse, resulting in the introduction of individual or large numbers of trees at one time (Thorne, 1982; Spicer, 1989). Continued bank failure introduces thousands of trees into a river system over short periods of time (decades to centuries), and as an entire tree may be transported downstream, intact root masses may include soil and underlying substrate. Hence, this mechanism may introduce anomalous sediment (size and shape) into a fluvial system (Liu and Gastaldo, 1992a). Periodic high-discharge flooding also may transport dense masses of vegetation (Sudd) growing in a river channel (Alexander et al., 1999; Nakayama et al., 2002). This Sudd, sometimes considered “islands of trees,” may be comprised not only of trees and small understory plants but also sedimentary material as large as cobbles and boulders (Ridley, 1930). Such allochthonous plants may be transported distances greater than 1000 km into the open ocean before being grounded (see: Darwin, 1906).

On the other hand, the logs preserved within a channel may be autochthonous in origin. Trees growing along the margin of a channel may ultimately reside within the adjacent channel as the result of death or traumatic emplacement (e.g., windstorms), or bank failure and slumping. This requires little or no transport to a tree’s final resting site.

It is probable that some trees originally growing in the Mary Lee mire became part of the log accumulation at the top of the sandstone body (parautochthonous elements), whereas others obviously are allochthonous. Because the stems are identifiable to taxon, the wood assemblage can be compared directly with the preserved Mary Lee flora (Gastaldo, 1990; Eble, 1990; Winston, 1990). The *in situ*, erect macroflora is dominated by lycopsids with few localized *Calamites* growing within the peat forest (Gastaldo, 1990). This assemblage also is reflected in palynological (Eble, 1990; Eble et al., 1994) and coal petrographic profiles (Winston, 1990). Hence, some sphenophytes and lycophytes most likely originated from the peat forest, and these may be the few trees that display a more north–south orientation in the plots (Fig. 6).

It is evident that other logs are not local in origin, and is particularly true for hollowed lycopsid stems that had been infilled with pebbles prior to transport (Liu and Gastaldo, 1992a). The presence of *Cordaites* in the channel assemblage probably is indicative of extrabasinal vegetation (sensu Pfefferkorn, 1980). Although *Artisia* casts are reported from the underlying Blue Creek mire (Gastaldo et al., 2004), rarely are cordaite pith casts or pollen found in the Mary Lee swamp (Gastaldo, 1990; Eble, 1990; Eble et al., 1994), nor is there any indication that these plants played any role in peat accumulation (Winston, 1990). The large number of *Cordaites* trees recovered in outcrop, though, supports the contention that these were transported from outside of the peat-accumulating environments into the coastal lowlands.

6.2.2. Mode of accumulation

Depending upon tree density (a function of wood and bark tissues), trees introduced to aquatic settings may be “floaters” or “sinkers”. This is important with regard to the residency time in suspension load prior to settling to the sediment–water interface. The ability of a non-degraded log to float is determined by the buoyant force that develops in response to the difference between the wood density and that of the water displaced by the fully submerged part (Panshin and de Zeeuw, 1970). Whereas woods that consist of at least two-thirds cell wall substances will sink immediately when introduced into water, most woods must first become saturated, whereupon the air spaces within are filled until the density of the wood equals or exceeds that of the displaced water. At this point, the wood moves to the sediment–water interface. Wood resident in bedload may be reentrained when flow conditions change significantly (Gastaldo, 1994). The time required for transferral from suspension load to bedload may be decades, and when large numbers of logs remain in suspension load they may impede the fluvial system.

Log accretions, or log jams, form in response to obstacles, such as boulders and upright trees, which stop the movement of floating logs (Blair, 1987). The accumulation at the top of the Mary Lee sandstone channel split is interpreted to have formed similarly. When the peat swamp was breached, either through channel avulsion or transgression, large lycopsids growing within the peat swamp were little affected as evidenced by erect, sandstone-cast trees rooted in the lower bench and extending upwards into the lowermost sandstone unit. Hence, after the basal portion of the trunk was buried by bedload and death ensued (see Gastaldo, 1990), the tree projected to heights of several decameters above the channel bed. These trees acted as obstacles to the free movement of trees transported in suspension load during the high-magnitude flood that emplaced the gravel-bearing logs. Accumulations of floating logs around these erect trees probably initiated the formation of the log jam. Most logs remained floating during the channel infill phase as few prostrate log-casts or compressions have been found within the lower units of the sandstone body.

6.3. Aspects of channel fill

6.3.1. Sedimentology

The presence of the log jam influenced the channel sequence in several ways. It is evident that the sediments filled the channel as the logs remained in suspension because the contact between the upper and the middle units is gradational, without any evidence of interruption in or disruption of sediment accumulation. Sedimentation was continuous from the bottom to the top of the channel as indicated by bedload structures found between and within sandstone-cast logs in the upper unit (Degges and Gastaldo, 1989; Degges, 1991). The floating log mat played another role and this involved the continuing reduction in channel velocities as the sediment–water interface accreted upwards. This decrease in flow, accompanied by periodic discharge through the channel, resulted in substrate colonization by macroinvertebrates and provided the mechanism by which these traces could be preserved. Furthermore, accretion in the channel bed was likely accompanied by aggradation of the vegetation-lined flanks of the channel and colonization of shallow water by hydrophytes (e.g., *Calamites* and lycopsids). Although few rooting structures have been identified within the log jam, it is not possible to discern with certainty whether these plants utilized the floating vegetation as a substrate or if these structures represent penetration from a subsequent forest. It is likely, though, that decayed trunks acted as an organic substrate for growth.

6.3.2. Ichnological implications

Periods of very low flow velocities or stagnation provided an environment in which invertebrate activity flourished. The preservation of such activity within terrestrial settings and the taxa preserved are, again, an unusual feature of this channel. Vertical tubes of *Skolithos* and cf. *Monocraterion* are considered as dwelling structures of suspension feeding invertebrates (Pemberton and Frey, 1984). Detritovores that feed on organic matter within sediment normally leave traces that are distinctly different from these straight vertical tubes (Walker, 1984). Their high burrow density indicates bottom conditions were stable for at least short periods of time allowing for one, or more than one animal to opportunistically exploit the substrate (Vossler and Pemberton, 1988). An abundance of densely clustered organisms, particularly in a facies with which they are not generally associated, has been used as one criterion to identify opportunistic behavior (Levinton, 1970; Rhoads et al., 1978) or an adaptation to stressful environments (Thayer, 1983). Annulations within the vertical tube walls may have been produced in response to localized unstable sediment. Although *Skolithos* favored high energy sites (Frey et al., 1990), it appears that burrowing occurred during periods of non-deposition in the channel. The presence of vertical burrows at successive stratigraphic levels reflects consistent physical conditions within the channel following the deposition of each cross-bed set.

The horizontal burrows cf. *Asterichnus* are encountered mainly at mud-draped ripple crests, and such radiating structures are considered to be feeding traces (Rindsberg, 1990). Their presence also is indicative of intervals of low energy, and their restriction to the uppermost part of this unit is evidence indicating a continued reduction in flow velocities within the channel during infill and possible changing water chemistries. These facets may be attributable to the presence of the floating logs, acting as a baffle to flow when the depth to the sediment–water interface had been reduced significantly.

The occurrence of these particular trace fossils provides data for two alternative explanations for their presence and the conditions under which these organisms thrived. *Skolithos* and *Monocraterion* generally are considered as indicative of restrictive nearshore environments (Seilacher, 1967; Frey et al., 1990), whereas *Asterichnus* is used to characterize open marine settings. Their preservation in this coastal channel either indicates opportunistic behavioral patterns known from fully marine environments were duplicated by organisms adapted to freshwater conditions. Or, alternatively, the physical conditions within the channel were conducive to the colonization by typically marine opportunists. This latter hypothesis requires that the channel was connected to the ocean and/or either water-column stratification existed, with salt water residing just above the sediment–water interface, or that a saltwater wedge was introduced periodically into the channels as the result of tidal activity. It is well documented that the Mary Lee coal zone in northwestern Walker County was within a coastal plain setting influenced by a mixed tidal regime (Demko, 1990; Gastaldo et al., 1993, 2004). Tidal deposits are a common feature, and certain lithofacies are characterized by flood-tide dominated deposits (Gastaldo et al., 1991; Gastaldo, 1992). It is possible that the truncation of cross-bed sets may have been the result of higher than normal tidal energies, and overlying mud-drapes the consequence of suspension-load sedimentation that followed a reduction in velocity.

6.4. Relationship between log orientation and paleocurrent

The occurrence of wood, in varying quantities and concentrations, is a common occurrence in ancient fluvial deposits. These logs have been utilized with varying success as paleoenvironmental indicators, but no definitive decision has been made on the significance of log orientation with respect to current direction. Some authors have reported logs oriented parallel with current (Crowell, 1955; Colton, 1967; Potter and Pettijohn, 1977; MacDonald and Tanner, 1983), while others have described logs with their long axes oriented perpendicular to current (Pelletier, 1958; Blair, 1987). Several authors encountered logs where both orientations were represented in a single locality (Sullwold, 1960; Dzulynski and Walton, 1965; Evans, 1991), and others report no preferential orientation of log material (Zangrel and Richardson, 1963; Fiorillo, 1991).

In an attempt to help clarify the relationship between wood and current orientation, MacDonald and Jefferson (1985) conducted a flume study which showed, primarily, that isolated wood fragments resident in bedload tend to adopt current-parallel orientations. There was only a slight tendency towards a perpendicular orientation, whereas interference between wood fragments may prevent any preferred orientation (Hubert, 1967). Log orientations, though, are strongly controlled by physical characters including size, density, and shape. Broad conclusions drawn from these laboratory studies, then, must be considered limited as woods used in the experiment were diminutive and many factors remain unaccountable (Gastaldo, 2004).

In the present study there is a marked discrepancy between paleocurrent direction, as determined from cross-stratification, and that derived from log orientation (Fig. 5). The sinuous channel-form sandstone trends, overall, in a northwestern direction with cross beds near the channel-belt margin displaying a unipolar distribution with low variability (Table 1). Sediment transport was directed to the north/northwest away from the structural front, and this observation is consistent with other reports (Mack et al., 1983; Pashin et al., 1991; Pashin, 2004). Cumulative log orientation plots in a sub-perpendicular trend to that of the cross-bedded sandstone. Although there is more scatter in these plots, logs are predominantly oriented in a northeast–southwestern direction and represent a statistically different population of measurements.

It is not unusual to find transported fossil wood in clusters (MacDonald and Jefferson, 1985). Blair (1987) found that log accumulations (log jams) formed in response to obstacles, such as boulders and upright trees, which stopped floating logs, and that clustering could enhance a preferred orientation (Schwarzacher, 1963). This situation is reflected in the Mary Lee data where upright sandstone-cast lycopsid stumps may have promoted channel blockage whereupon the wood assemblage developed a strong directional trend subperpendicular to flow. Currents oriented the floating driftwood by pinning them against obstructions with orientations maintained when the logs were stranded, either due to the recession of flood waters or channel abandonment. Hence, where large numbers of logs are found within channel-form sandstones, their orientation is expected to be subperpendicular to that as deduced from primary structures.

6.5. Modern analog

The U.S. Army Corps of Engineers has changed the natural state of North American rivers, and the last major U.S. river documented in its natural state was the Red River (McCall, 1988). By comparing the overall characteristics of the Carboniferous site with those of a recent log jam, the interpretation of the ancient deposit is strengthened.

The headwaters of the Red River originate in the southern states of New Mexico and Texas with the meandering river transporting sediment in a southeasterly direction through Oklahoma and Louisiana, where it eventually debouches into the Mississippi River (Fig. 8). Prior to 1836, the Red River was blocked by a log jam that extended for a total distance of 350 km (210 miles) with the toe of the “Great Raft” located at what is now the city of Shreveport, Louisiana. The river was navigable southeast of Shreveport, with depths reported of several meters; beneath the raft, though, the draft dropped to less than one meter (under a few feet) and the river was no longer navigable (McCall, 1984). Active sedimentation occurred below the raft due to velocity reduction caused by the floating logs. Captain Henry M. Shreve, for whom the city is named, was assigned the responsibility to unblock the river channel and this task was completed within several years under severe physical conditions. With the advent of the American Civil War, maintenance of the river channel ceased and by 1873 the log jam had reformed, although not to the limits of its former extent.

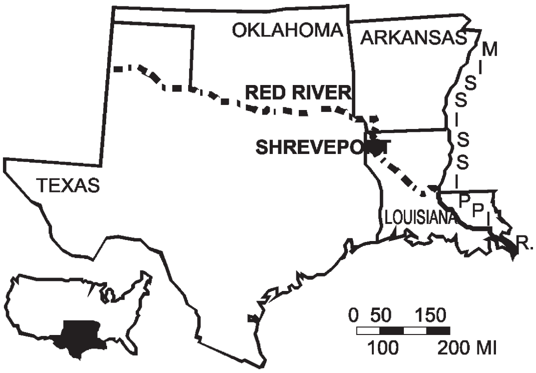

Fig. 8. Location of the Red River in the southcentral United States.

Fig. 9. Red River log jam (1873) representing thirty-four years of accumulation after the initial clearing of the channel and cessation of maintenance. Photographs by R. B. Talfor, United States Army Corps of Engineers. Photograph courtesy of Louisiana State University, Shreveport Archives.

The Red River jam began as a consequence of fluvial processes operating within the forested flood plain. Undercutting of the river banks caused entire trees with their interlocking branches to be carried downstream. Grounding of trees in areas of shallow water provided sites for additional accretion and the initiation of a floating debris mass. Log orientations within the raft can be approximated from historical photographs (Fig. 9) and it can be seen that most logs were oriented sub-perpendicular or perpendicular to apparent flow direction. Few logs within any cluster are seen to be oriented parallel to flow.

After the raft continued to increase in size and develop into a jam, subaerial degradation of this debris occurred. Many plants, such as cottonwoods, took root and grew on top of the raft. As the raft continued to accumulate behind the toe, it blocked the outlets of the tributary streams and produced a series of lakes (Lobeck, 1939). The timber in these flooded areas soon died and the exposed portions decayed, leaving extensive areas of the flood plain covered with the stumps of the former forest. As the jam enlarged upstream, the lower portion decayed and was gradually carried down the partly blocked channel.

6.6. Comparison with the Carboniferous example

The Red River provides an analog to explain several characteristics of the channel-form sandstone split in the Mary Lee coal including the condition of logs, their stratigraphic position, shear quantity, and orientation. In the several thousand fossil logs examined, there is little evidence for crown branches attached to aerial trunks, and in most instances, rooting structures were interpreted from coalified material surrounded cobbles and boulders (unpubl. field data). The size and maturity of individual trees, though, may have limited the ability to find crown branches in outcrop. Nevertheless, the data indicate that the accumulation was predominately composed of aerial trunks without significant crown part preservation. From what can be discerned from photographic evidence, most logs in the Red River appear to lack crown and root parts. The trees appear to have lost canopy branches either due to mechanical breakage during transport or degradation while in suspension load. This attribute appears to be a comparable feature between the two accumulations.

Wood is found most commonly at the bottom of channel-form sand bodies (Gastaldo, 2004). This coarse woody debris was resident at the sediment–water interface after sinking, and buried by migrating bedforms. Wood preserved in channel lag deposits often occurs in clusters composed of few individuals. In the Carboniferous example, though, thousands of aerial trunks are at the top of a channel-form sandstone with few specimens encountered near the basal channel deposits. The circumstances recorded in the Red River demonstrate that significant numbers of logs can accumulate within the boundaries of a channel and float for long periods of time at its surface without sinking to the sediment–water interface. And, if sedimentation rate exceeds rate of decay and water logging, the logs can be preserved at the top of the channel in their “floating” position.

Logs begin to accumulate due to the presence of an obstacle impeding their downstream transport. Transport of individual logs generally is parallel to flow up to the time of obstruction. As the log mass accumulates, there is a reorientation of individuals within the channel. No longer are logs oriented parallel to current; rather, they become oriented in a sub-perpendicular to perpendicular orientation to flow (Robison and Beschta, 1990), similar to wave refraction along a coastal shoreface. The downstream end of the log “grounds” first, while the upstream end continues to be transported by the river’s flow. The upstream end pivots around the fulcrum established by the “grounded” downstream end until movement stops and it is in contact with the other log material. These conditions are encountered in both the ancient site and modern analog.

With respect to the sedimentology of the channel, historical accounts (McCall, 1984) disclose that the Red River log jam had a definite affect on within-channel sedimentation. The floating logs acted as a baffle, resulting in sediment accumulation beneath the raft at a much faster rate than that in the open channel. After channel maintenance stopped in the 1860s, the log raft had reformed already by 1873, and at some points within the river the sediment/water interface had contacted the base of the vegetation raft. Such an infilling would account for the preservation of the floating logs at the top of the channel.

In the Carboniferous site, the time required for channel fill would have been geologically short, probably on the order of decades to a few centuries. The primary sedimentary structures developed beneath the Red River log jam are unknown so that direct comparison cannot be made with the Mary Lee channel fill. Nevertheless, periods of bedload transport (cross-bedded sandstone) can be differentiated from intervals of quiet water and/or stagnation (vertical burrowing and mud drapes) in the Carboniferous channel. The periodicity of reactivation cannot be determined, but at least 23 episodes of increased discharge responsible for bedload transport, is documented in the marginal channel position. And as the channel bed accreted upwards to the floating log mass the characteristic sedimentological structures indicative of bedload transport documented within pith casts (Degges, 1991) can be accounted for.

One additional channel feature concerns the reinitiation of peat accumulation above the channel-form sandstone. McCall (1984) records the colonization of the Red River log raft by cottonwoods and vines. These plants rooted in the decaying subaerially exposed parts of the floating logs. If the Red River had been left in its natural state, a hydrosere community would have developed. In the Carboniferous example, the presence of stigmarian “rooting” appendages within the log accumulation is evidence for similar colonization. Winston (1990) found the most hydrophytic lycophyte, *Lepidophloios* (Phillips et al., 1985; Gastaldo, 1987), to be the most common component in the coal above and adjacent to the channel, indicating hydrophyte colonization. Biomass accumulation resulted in the initiation of the upper bench of the Mary Lee coal once the channel was cut off completely from sediment influx.

7. Summary and conclusions

Phytoclasts are integral components of many terrestrial and nearshore depositional environments. Their occurrence often records sedimentological and historical data that could not be deduced from a study of the inorganic components alone. This is certainly true in the Mary Lee coal split.

A tidally-influenced fluvial channel identified within the Mary Lee coal, a Carboniferous peat mire that accumulated within a coastal plain setting, consists of a shallow, sinuous channel belt that is directed towards the northwest away from the Appalachian structural front. The channel formed either during an autogenic high-energy, low frequency flood event or an allogenic, co-seismic subsidence event. The channel belt is composed of several smaller channel-forms that have been documented at its margin. Gravel clasts (pebbles, cobbles, and boulders) are concentrated in an unusual fossil assemblage preserved at the top of the channel, and few gravel clasts are found within the lower parts of the sandstone. Orientations of cross-bedded sandstone indicate that paleocurrent trends were unimodal and directed towards the northwest.

The woody assemblage at the top of the channel represents an ancient log jam. Both autochthonous and allochthonous trees, of various systematic affinity, are preserved as coalifications, adpressions, and/or sandstone casts. Autochthonous erect lycophytes probably acted as obstacles to the transport of floating logs initiating the wood accumulation. Allochthonous logs are interpreted to have been introduced either (1) during the avulsion event or (2) subsequent to a coseismic event that lowered this part of the mire at-or-near base level. The logs are allochthonous because gravel is found both within hollow prostrate logs and between logs, presumably entwined in rootstocks. Logs are oriented subperpendicular to channel geometry and cross-bed paleocurrent trends. *Calamites* orientation is bimodal, and this may record contribution from hydrophyte colonization in sites within or along the margin of the channel.

A preserved ichnofauna includes vertical tubes and horizontal star-like traces with colonization of the substrates occurring during quiet water conditions. The concentration of traces and the disparity in depositional setting with which these genera are normally associated are used as evidence that the ichnofauna exhibits an opportunistic behavior. The presence of typically marine forms in a freshwater setting may indicate that either opportunistic behavioral patterns are not environment-specific, or that there was some marine influence within the channel.

Results reported by various authors demonstrate that paleocurrent directions interpreted from fossil logs are of variable reliability and are dependent on the number of logs within the channel fill. Paleocurrent directions based on individual, isolated logs may more accurately reflect flow direction than accumulations of many logs which tend to orient perpendicular to flow. In this latter case, such an assemblage may represent a channel blockage resulting from a log jam. The presence of such a floating wood assemblage affects sedimentation within the channel and its influence should be considered when interpreting fluvial channel history.

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