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**"PIPE-ORGAN STRUCTURES" IN THE
LEE FORMATION (PENNSYLVANIAN) OF
THE CENTRAL APPALACHIAN BASIN:
ANIMAL OR PLANT?**

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“PIPE-ORGAN STRUCTURES” IN THE LEE FORMATION (PENNSYLVANIAN) OF THE CENTRAL APPALACHIAN BASIN: ANIMAL OR PLANT?

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ABSTRACT—A sequence of unusual vertical tubes, arranged in multiple groups, and each tube several meters high occurs in the Middlesboro Member of the Lee Formation (Lower Pennsylvanian). These structures are controversial with various interpretations suggesting either plant or animal origin. Observations supporting a plant origin include: 1) numerous C- and D-shaped, and multi-chambered tube cross sections are similar to fern and seed fern structures, 2) numerous membrane relicts loosely enclosing the tubes are similar to fern and seed fern tissues, 3) microscopic bundles are observed in cross-sectional thin sections, 4) presence of carbonaceous material and reported fecal pellets over a vertical distance in excess of 5 m are consistent with deteriorating plant material, not escape structures, 5) tubes are composed of casts and molds, but lack spreite or other features typical of escape structures, 6) tubes occur in clusters about one meter in diameter and are associated with coaly material at their base, which suggests that the clusters represent trees, 7) other trace fossils are absent in the enclosing sandstone, 8) tubes branch upward, which is a common structure in plants but unlikely in escape structures, 9) a coalified root structure was found at the base of the sandstone, and 10) all the tubes extend from the bottom of the sandstone to the top. The probability of burrowing animals escaping through as much as 8 m of sand with 100 percent survivorship is low.

The structures may represent a stand of pteridosperms with each “tree” approximately 1–1.5 m in diameter. The individual pipe-organ structures represent aerial stems, shoots, and adventitious roots; each cluster of pipe-organ structures represents a single tree.

Based upon sedimentologic features such as presence of 1) channel form, 2) scoured base, and 3) fining-upward sequence, we interpret the sandstone containing the pipe-organ structures to have been deposited in a sandy fluvial or tidal channel. The unidirectional cross-bed dips, poor sorting, occurrence only of very restrictive fauna and terrestrial flora, position of the sandstone above a possible floodplain facies, and lack of characteristic tidal structures suggest that the sandstone is more probably a sandy fluvial channel that may have minor tidal influence.

INTRODUCTION

UNUSUAL VERTICAL structures as much as 8 m high have been observed in a Lower Pennsylvanian sandstone in northern Tennessee. These structures are tube shaped, variable in cross-sectional size, and in outcrop look like pipe organs, hence the name “pipe-organ structures.” The pipe-organ structures have been studied by Cobb et al. (1986, 1987), Chesnut et al. (in press), and Wnuk and Maberry (1990).

Cobb et al. (1986, 1987) suggested a plant origin for these anomalous structures and proposed that some of the tubes were adventitious roots. Chesnut et al. (in press) recognized evidence for interpretation of the pipe organ structures as animal trace fossils and as plant fossils, and proposed that the structures were trunks and limbs of pteridosperms or tree ferns. Wnuk and Maberry (1990) discounted a plant origin and proposed that the pipe organ structures were either inorganic dewatering or degassing structures or, more likely, marine animal escape structures. Wnuk and Maberry’s (1990) interpretation was supported by evidence suggesting a tidal channel and beach origin for the surrounding sand body. The purpose of this paper is to reevaluate the origin of the pipe-organ structures and interpretations of the depositional environments of the sandstone within which they are found.

MIDDLESBORO MEMBER OF THE LEE FORMATION

The study area consists of a series of roadcuts on Interstate 75, along the crest of Pine Mountain (Figure 1). These roadcuts are located south of Jellico, Tennessee, near the Kentucky–Tennessee state border. The pipe-organ structures are located at mile-marker 146 of the interstate highway in the Pioneer 7.5-minute quadrangle (36°26′00″ north and 80°17′34″ west).

The rocks exposed between mile 146 and mile 153 of the interstate highway are mostly massive sandstones with minor shales and thin, discontinuous coals (Figure 2) of the Middlesboro Member (Englund, 1968). The Middlesboro Member (Namurian C–Westphalian A, Bashkirian) is stratigraphically the lowest member of the Lee Formation as interpreted by Chesnut (1988, in press).

The Middlesboro Member in the study area is composed of four to five units of thick (30 m) sandstone containing quartz pebbles, separated by thinner (0–10 m), finer grained rocks composed of shale, siltstone, subarkosic sandstones, and coals. Festoon and tabular cross-beds generally dip to the southwest. Some sandstones fine upward.

PIPE-ORGAN STRUCTURES

A series of cylindrical (“pipe-organ”) structures was discovered at the base of one of the sandstone bodies of the Middlesboro Member (Figure 2; small box indicates stratigraphic position). These pipe-organ structures vary in diameter from 1 to 7 cm and extend vertically as much as 8 m above the base of the sandstone (Figure 3.1, 3.2). The cylinders occur as clusters approximately 1–1.5 m in diameter (Figure 3.2). Some cylinders diverge and branch upward and others appear to be ribbed (Figure 3.1). In cross section, the cylinders are circular, “D”- or “C”-shaped, and some are multi-chambered (Figure 3.3, 3.4). In cross section the convex parts of adjacent C- and D-shaped cylinders (“celery structures”) are commonly oriented in the same direction (Figure 3.3, 3.4). Convolute membranes appear to loosely enclose several of the cylinders (Figure 3.3). Serial sections were cut through two sandstone blocks that contained the complex relict membrane structures (Figures 4–7). Horizontal cuts approximately 4 cm apart were made with a diamond blade saw; top and bottom orientation of these blocks are not known. Circular, C-shaped, D-shaped, and multi-chambered cylinders are shown in these figures.

Thin sections cut perpendicular to one of the pipe-organ structures reveal (pyrite-filled?) pores, approximately 0.1–0.5 mm in

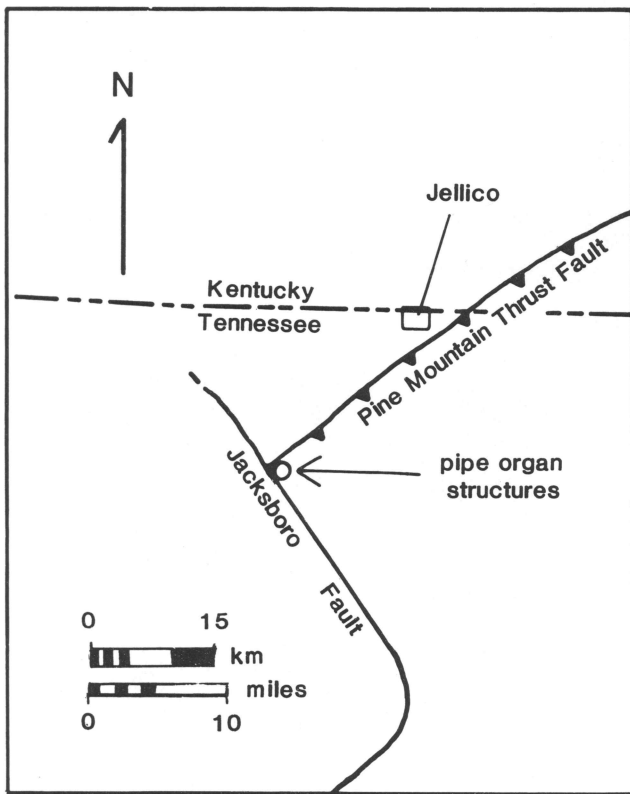
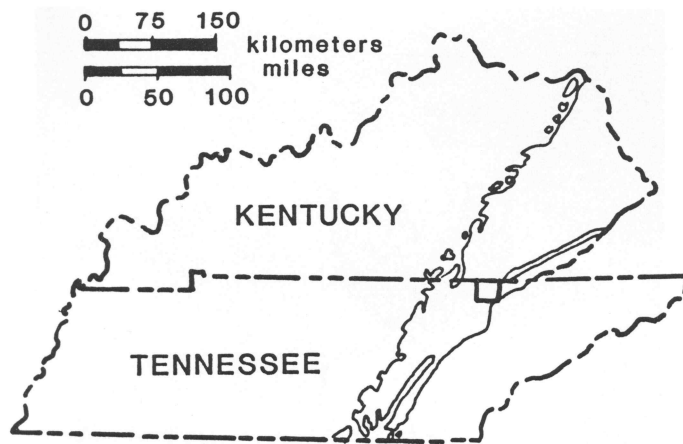


FIGURE 1—Map showing location of pipe-organ structures in relationship to the structural features of northern Tennessee. The fossil site is located on the crest of Pine Mountain at the southwestern end of the Pine Mountain Thrust Fault.

diameter, arranged in apparent ring-shaped bundles within the cylinder boundary. Most of the cylinders are structureless. Wnuk and Maberry (1990) reported fecal pellets along the cylinder boundaries in their thin sections.

The pipe-organ structures abruptly terminate at a basal lag zone composed of coarse-grained sandstone, shale pebbles, transported sheets of coal, and abundant horizontal plant fossils. The plant fossils are *Artisia* (pith casts of *Cordaites*) and limbs of lycopod and other unidentified trees.

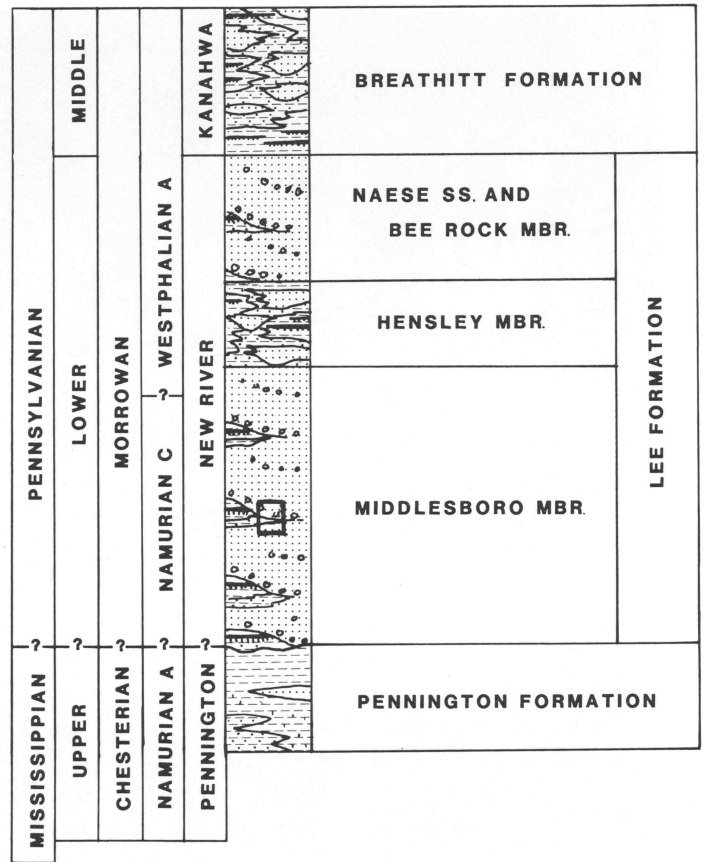


FIGURE 2—Stratigraphic column of units found along Pine Mountain in Tennessee and Kentucky. Box shows relative position of the fossil site within the Middlesboro Member of the Lee Formation.

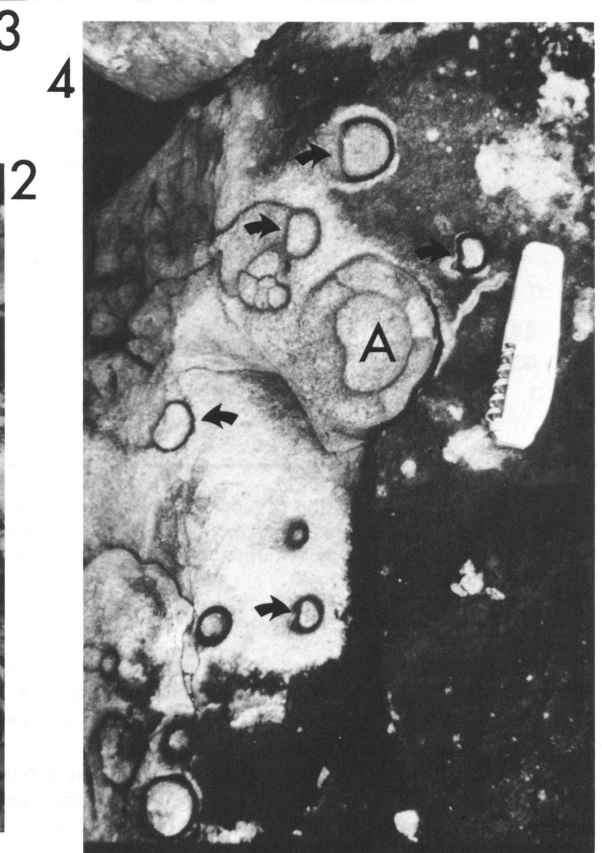
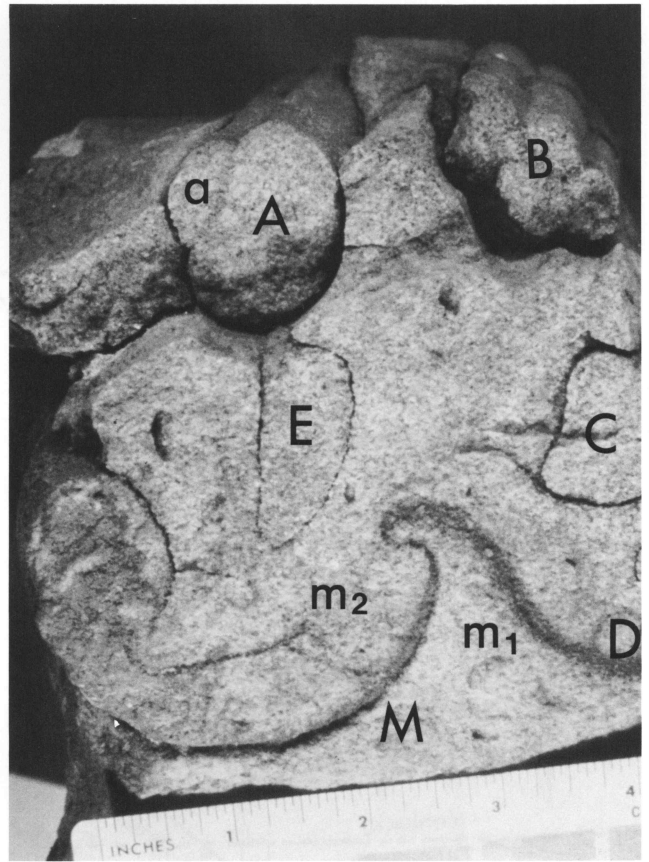
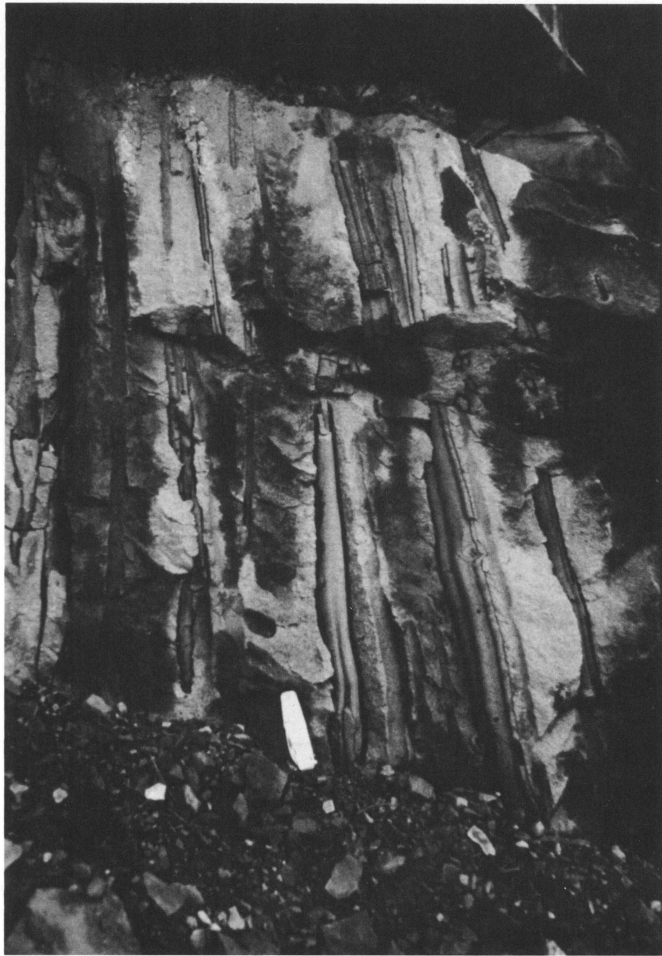
PIPE-ORGAN SANDSTONE

The vertical pipe-organ structures occur in a 30-to-40-m-thick sandstone body (Figure 8). This sandstone is divided into three parts: a basal conglomerate, a massive lower sandstone, and a cross-bedded upper sandstone. The upper sandstone (unit 4 of Wnuk and Maberry, 1990) contains beds ranging from 15 to 150 cm thick with planar and low-angle trough cross-beds (Figure 8). Unimodal cross-bed directions indicate paleoflow to the southwest. Bedding thins upward. Thin shaly partings occur between the cross-bed sets, and coaly stringers may be found in the lower beds.

The massive lower sandstone (unit 3 of Wnuk and Maberry, 1990), which contains the pipe-organ structures, ranges from 3 to 7.5 m (Figure 8). It exhibits accretion bedding (apparently dipping to the southwest) several tens of meters to the southwest of the pipe-organ structures, but otherwise bedding is indistinct. In places the sandstone contains conglomeratic zones of shale pebbles and coal. The base is undulating and erosional.

A thin basal conglomerate (unit 2 of Wnuk and Maberry, 1990), 0–50 cm thick, has an erosional base and is also erosionally truncated by the overlying sandstone unit (Figure 8). This conglomerate contains shale and siltstone pebbles, very abundant horizontal plant limbs and debris, and a matrix of fine to very coarse quartz sand.

In point counts of thin sections, the pipe-organ sandstone, a sublitharenite to lithic subarkose (classification of Folk, 1968), varies from fine to coarse grained and contains subangular to subrounded grains dominated by quartz (75–90 percent) with



1 3 4

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minor plagioclase feldspar (5–10 percent). The massive lower sandstone is poorly to moderately sorted and fine to coarse grained, whereas the cross-bedded upper sandstone shows moderate to well sorting of very fine- to fine-grained sand. The basal conglomerate is poorly to very poorly sorted, and the matrix is fine- to very coarse-grained quartz sand. Our point counts of seven thin sections at various intervals within the pipe-organ sandstone differ from the petrographic descriptions of Wnuk and Maberry (1990), who reported rounded to subrounded, fine- to medium-grained, well-sorted quartzarenite (their units 3 and 4).

The basal contact of the sandstone truncates finer grained rocks (unit 1 of Wnuk and Maberry, 1990), which consist of interbedded shales, siltstones, claystones, thin sandstones, and thin coals (Figure 8). This finer grained unit, 3.6–12 m thick, contains several layers with abundant root structures, common horizontal plant stems, and abundant plant debris. Siderite nodules also occur in several layers. The thin siltstone and sandstone lenses and layers exhibit current ripples and small-scale cross-stratification. No animal body fossils or trace fossils were found in our investigation.

INTERPRETATION

Regional relationships of the Lee Formation.—The depositional environments of quartzose sandstones of the Lee Formation have been interpreted as beach-barrier bar (Ferm et al., 1971; Miller, 1974), braided fluvial (Bement, 1976; Rice, 1984), and ebb-flow-dominated tidal straits (Blaine Cecil, personal commun.). The beach-barrier bar interpretation was partially based upon the high quartz content of the sandstones and the supposed facies relationship of the Lee Formation with terrestrial coal-bearing rocks to the southeast and with marine limestones and shales to the northwest (Ferm and Cavaroc, 1969). However, a significant regional unconformity has been demonstrated between the Lee Formation (Pennsylvanian) and the marine limestones and shales (Mississippian Slade, Newman, and Paragon Formations and Pennington Group), thereby decoupling this supposed facies relationship (Ettensohn, 1980; Chesnut, 1988). In fact, the various members of the Lee Formation overlap the unconformity to the northwest and are in facies relationship only with the coal-bearing rocks of the Breathitt Formation (Chesnut, 1988). The thin marine strata that occur in the lower part of the Pennsylvanian section (Chesnut, in press) are not in facies relationship with the thick sandstone units of the Lee Formation, but are associated with periodic transgressions inhibiting deposition of the sandstones, and are not of sufficient lateral extent to represent a large inland sea to the northwest of the sandstones (the supposed marine side) capable of producing beach-barrier bars at the scale of the sandstone units of the Lee Formation (Chesnut, 1988).

Pipe-organ sandstone.—Features of the pipe-organ sandstone, such as an erosional base, conglomeratic lag, accretion bedding, and poorly defined fining-upward sequence, can be expected in both fluvial and tidal channels. However, the fine-grained facies below the sandstone contains coal beds, paleosols (multiple rooting and leach zones), and abundant plant fossils, suggesting

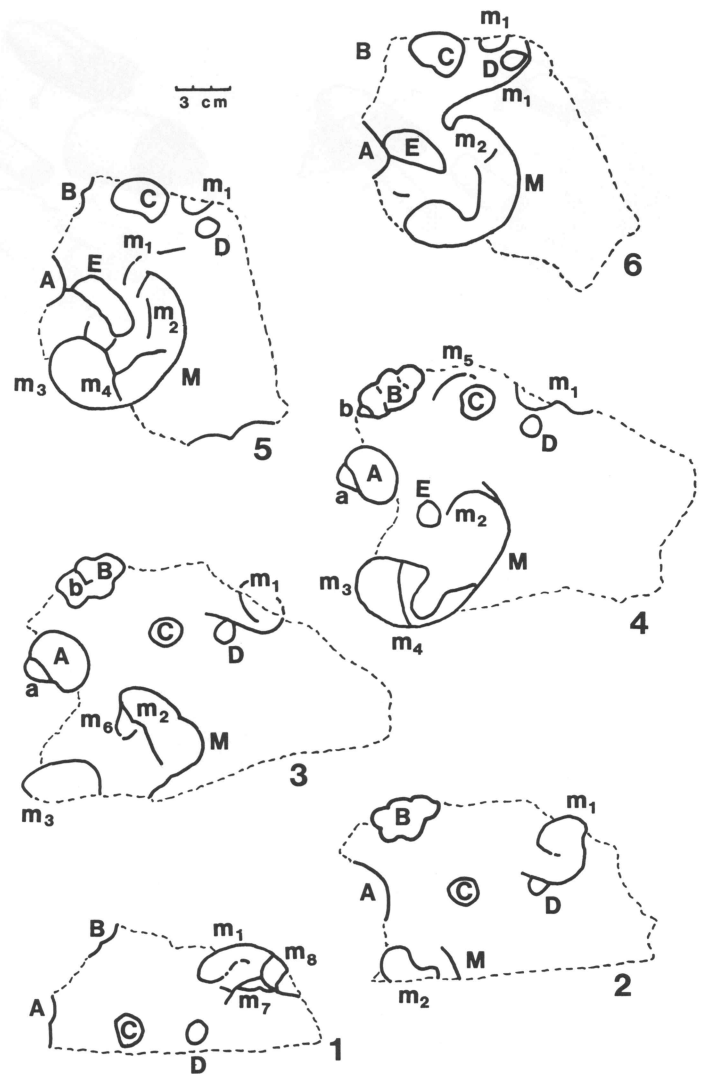


FIGURE 4—Serial sections through a sandstone block (KGS1423); sections are approximately 4 cm apart; letters identify equivalent structures in Figure 3.3; scale in centimeters; top and bottom of these vertical structures are unknown; therefore, the sections are shown front (1) to back (6); note convolute membrane (m1–m8).

that this facies probably represents deposition in a freshwater floodplain or possibly near-coastal environment. Also, cross-bed dips in the sandstone itself are unimodal (to the southwest). Features supporting an interpretation of tidal conditions, such as cyclical rhythmites, herringbone cross laminations, reactivation surfaces, ladderback ripples, double-crested ripples, mud drapes, and marine body and trace fossils, were not noted in our investigation, although such features are known in other Pennsylvanian sandstones in the Appalachian Basin.

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FIGURE 3—Pipe-organ structures. 1, pipe-organ structures extending vertically from base of an exposure near knife; knife (7.5 cm) for scale; 2, a cluster of pipe-organ structures; arrow at upper left points to Robert Bob on the outcrop for scale; 3, cross-sectional view of pipe-organ structures (KGS1423); letters correspond to equivalent structures shown in Figures 4 and 5; A–E are pipe-organ structures; A, C, and E are C- and D-shaped structures; M represents membranes; scale in inches; 4, cross-sectional view of pipe-organ structures; arrows point to C- and D-shaped structures; A represents a multichambered structure with a C-shaped structure at the center; note that the C- and D-shaped structures are oriented in the same direction; knife (7.5 cm) for scale.

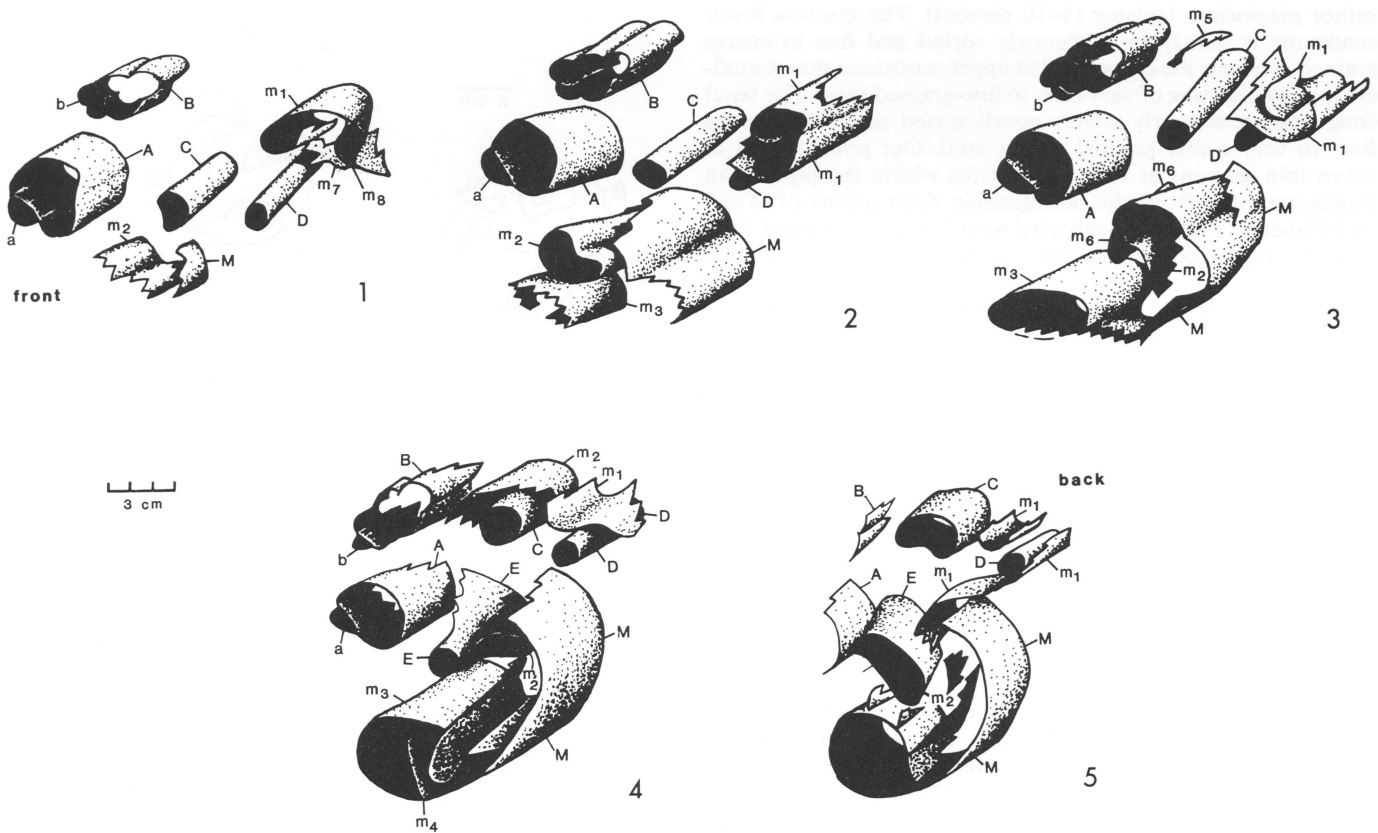


FIGURE 5—Reconstructed sections of pipe-organ structures (KGS1423) based on sections in Figure 4; letters correspond to structures in Figure 4. 1, reconstruction of serial sections 4.1 and 4.2; 2, from serial sections 4.2 and 4.3; 3, from serial sections 4.3 and 4.4; 4, from serial sections 4.4 and 4.5; 5, from serial sections 4.5 and 4.6

Wnuk and Maberry (1990) reported that they found several *Dactyloidites* Hall (1886) in thin sandstones within the fine-grained facies and inferred a “saline” environment based upon this trace occurrence. Based on Wnuk and Maberry’s photograph (fig. 2.1), this trace fossil could also be *Stelloglyphus* Vyalov (1964), or dewatering structures, or even root bases or trunk bases of erect plants. Coeval marine trace fossil assemblages in the Central Appalachian Basin typically contain a diverse and abundant fauna including the robust species *Asterosoma* von Otto (1854), *Conostichus* Lesquereux (1876), *Teichichnus* Seilacher (1955), and in some places *Zoophycos* Massalongo (1855) (Miller and Jackson, 1984; Martino, 1989). Other, less robust forms are also common in these assemblages. The low diversity (only *Stelloglyphus*) and low abundance of trace (“several”) or body (none) fossils in this unit indicates a very restricted environment. Based upon the faunal and floral assemblages, we propose that this unit represents a coastal(?) floodplain environment with freshwater to possibly slightly brackish-water(?) conditions. Similar interpretations have been proposed for other Lee sandstone units farther to the west (Jackson, 1984; Jackson and Miller, 1984; Miller and Jackson, 1984).

Lower and upper sandstone facies.—Wnuk and Maberry (1990) interpreted the lower sandstone facies (their unit 3) as a tidal-channel deposit based upon the rounded, well-sorted quartzarenite composition of the sandstone, a composition considered to be mature. They stated (p. 441) that “the degree of maturity attained by these arenites indicates prolonged reworking that occurs most typically in marine rather than fluvial environ-

ments,” and then cited numerous workers who interpreted the Lee sandstones as being deposited in barrier-bar and tidal-channel deposits.

Our petrographic studies indicate that the sandstones are sub-angular to rounded, in places poorly sorted, sublitharenites (and perhaps lithic subarkoses) and are not always compositionally mature. Regardless, compositional maturity is not restricted to marine environments. Petrographic studies of other Lee sandstones, where larger scale bedding architecture can be better observed, have also determined fluvial environments of deposition for equivalent sandstones in Tennessee (Jackson, 1984; Jackson and Miller, 1984) and Kentucky and Virginia (Bement, 1976; Wizevich, 1991). Quartzarenites can be found in fluvial environments where the source area is quartz rich, the drainage basin is undergoing tropical weathering (Johnsson, 1990), there is repeated reworking of bed load (e.g., reworking of bars in a braided stream), and there are diagenetically altered sandstones (e.g., ganisters). The general argument that Lee sandstones must be beach-barrier bar/tidal-channel deposits based on quartz content cannot be supported without primary sedimentological structures or architectural or facies analysis that also indicate tidal deposition.

Wnuk and Maberry (1990) reported rare occurrences of *Helminthopsis* Heer (1877) in the upper cross-bedded sandstone (their unit 4). Based on photographs in Wnuk and Maberry (1990, fig. 2.2), this trace may be *Cochlichnus* Hitchcock (1858). Horizontal traces occur in environments ranging from marine to terrestrial, but the low diversity and low abundance of only

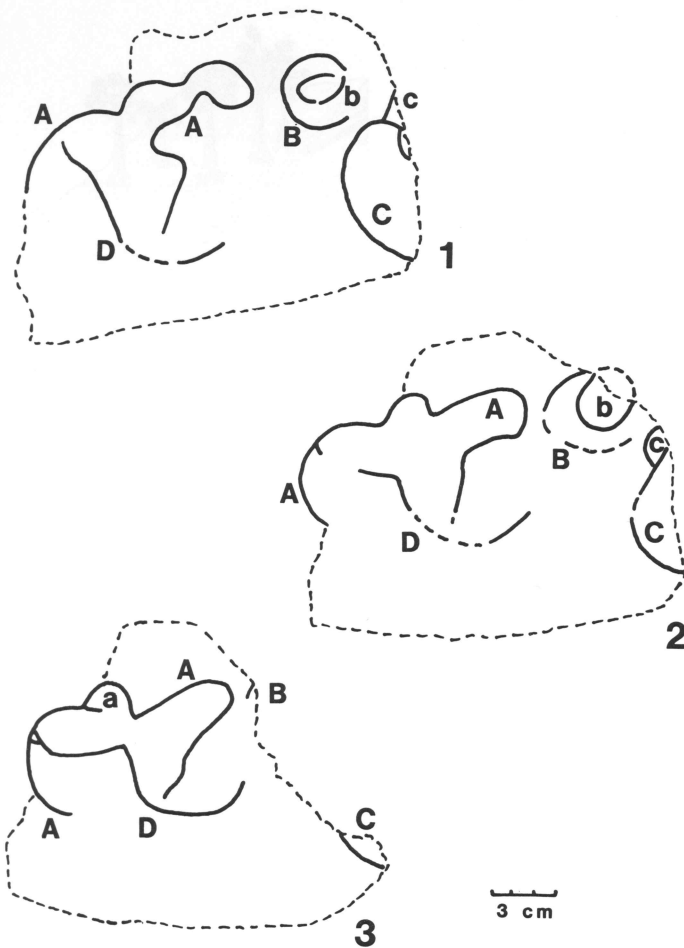


FIGURE 6—Serial sections through a sandstone block (KGS1424); sections are approximately 4 cm apart; letters identify individual structures from section to section; scale in centimeters; top and bottom of these vertical structures are unknown; note membrane structures A and D.

small diameter horizontal traces (Miller and Jackson, 1984) suggests a very restricted environment, probably freshwater to slightly brackish-water for the deposition of this sandstone rather than marine conditions.

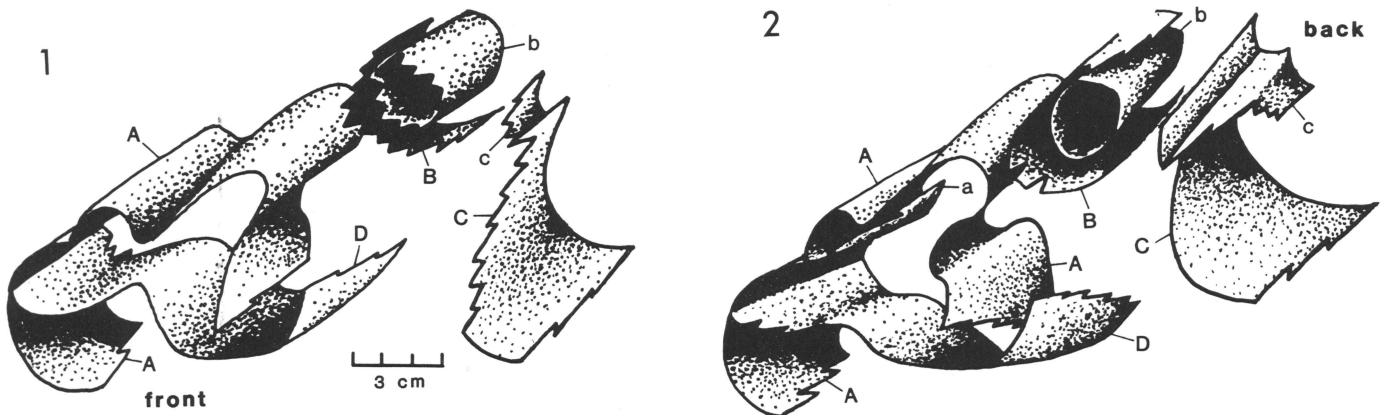


FIGURE 7—Reconstructed sections of pipe-organ structures (KGS1424 based on sections in Figure 6; letters correspond to structures in Figure 6). 1, reconstruction of serial sections 6.1 and 6.2; 2, from sections 6.2 and 6.3.

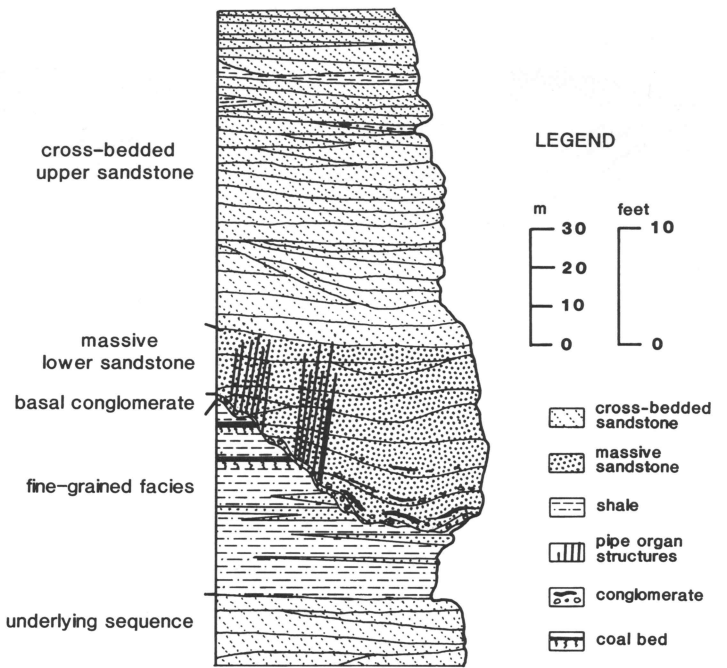


FIGURE 8—Lithologic column of pipe-organ sandstone.

Although much of the sandstone is massive, measurements of the planar cross-beds, trough cross-beds, and current ripples in the cross-bedded upper sandstone, as well as sandstones above and below the pipe-organ sandstone, all exhibit southwesterly flow with no evidence of tidal reversal in either primary (cross-beds) or secondary (ripples) bedforms. Planar cross-beds show no evidence of reworking or alteration typical of tidal sediments or shoreface deposits (de Raaf and Boersma, 1971; Klein, 1977; Van den Berg, 1982; Reineck and Singh, 1986; Terwindt, 1988). No coarsening-upward shoreface sequences have been found in any of the sandstone bodies in this extensive series of roadcut exposures, nor have any probable marine strata been identified in the Middlesboro Member in these roadcuts. Also, there is no evidence of cyclic alternation in bedform type, bedform thickness, or sediment grain size typical of tidal systems (De Boer et al., 1989; Kvale et al., 1989; Williams, 1989a, 1989b).

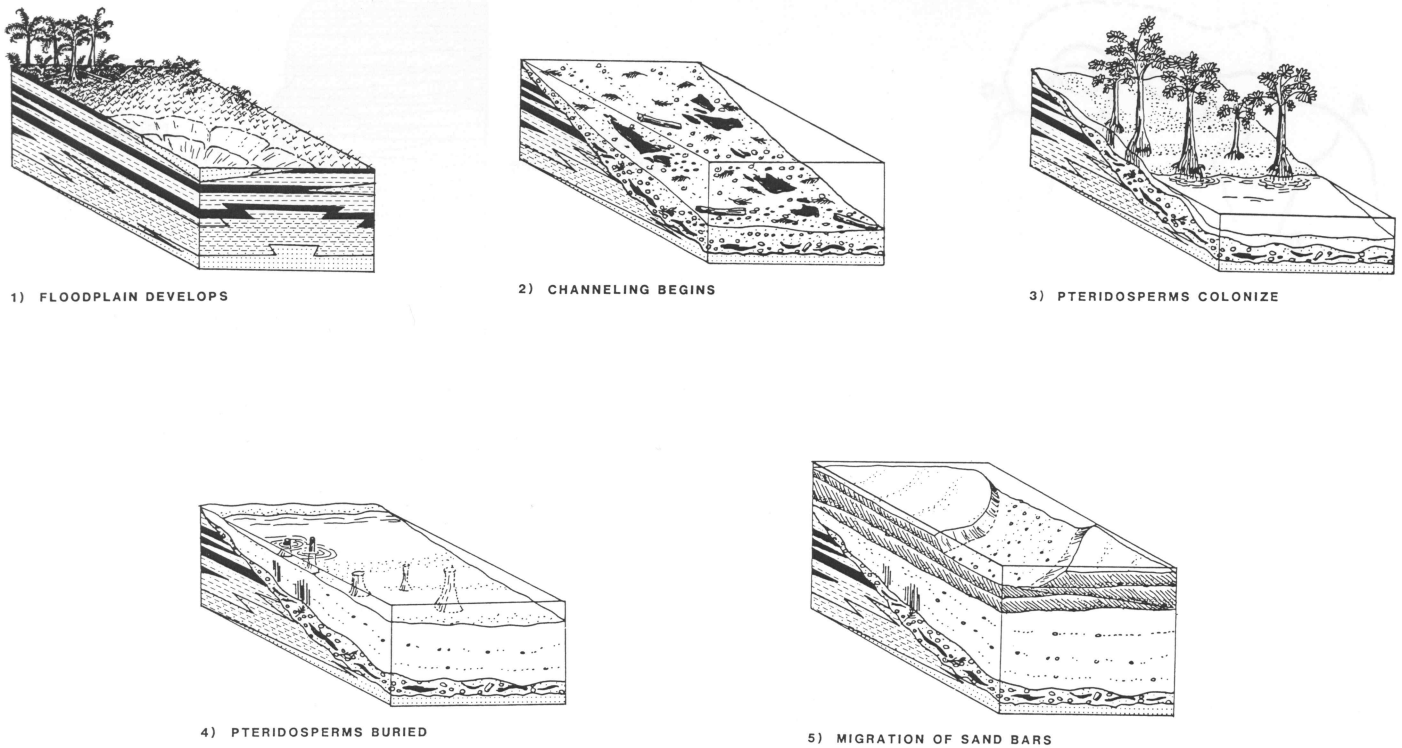


FIGURE 9—Sequence of events. 1, development of floodplain (fine-grained facies); 2, development of channel scour and deposition of channel lag (conglomeratic unit); 3, colonization by pteridosperms; 4, pteridosperms buried (lower massive sandstone); 5, migration of sand bars (upper cross-bedded sandstone).

The unidirectional cross-bed dips, areas of poor sorting, occurrence of only a very restricted fauna and terrestrial flora, and position of the sandstone above a possible floodplain facies do not support a tidal-channel interpretation. We suggest that the pipe-organ sandstone may represent a sandy fluvial channel of undetermined morphology. A more detailed interpretation of morphology or sinuosity cannot be reasonably determined because of the weathering and fracturing of the sandstone.

Pipe-organ structures.—The origin of the pipe-organ structures is problematic. They have been interpreted as gas- or water-escape structures, deformation structures, burrow, and plant fossils. Water- or gas-escape structures do not exhibit such well-developed cylinders, especially with C- and D-shapes in cross sections (e.g., Johnson, 1986). Also, no features accompany the pipe-organ structures that indicate deformation.

A biogenic origin, either plant or animal, seems most likely (see Ekdale et al., 1984, p. 29–38). Arguments that these unusual structures must represent plants because no known burrows look like them, or, vice versa, that they must represent burrows because they do not resemble any known plant structures, are invalid conjectures because they are based on negative evidence.

Wnuk and Maberry (1990) suggested that the pipe-organ structures were escape structures of a burrowing marine organism. Our interpretation is that the pipe-organ structures represent erect plants for the following reasons.

1) Many of the pipe-organ structures are C- and D-shaped (Figures 3–7) in cross section (celery structures), and some are multi-chambered (Figures 3–5). Adjacent C- and D-shaped structures are oriented such that their concavity faces the same direction. C- and D-shapes are common in stems and vascular tissues in ferns and in pteridosperms (Stewart, 1983, figs. 17.10–17.14, 18.3, 18.4, 18.10, 18.11, 18.13, 18.15, 18.17, 21.16,

21.18). A C-shape is an unlikely cross section for a burrowing animal, and multi-chambered escape structures are equally unlikely.

2) Convolved membranes loosely enclose many of the cylinders (Figures 3–5). The lateral edges of some of the membranes appear to pinch out into the sandstone. The membranes and their lateral pinchout are difficult to explain in an escape-structure interpretation unless they are a product of sediment liquefaction induced by biogenic activity (C. G. Maples, personal commun.). However, adjacent pipe-organ structures do not show distortions that would support an interpretation of sediment liquefaction. On the other hand, the membranes may be remnants of plant tissues such as bark.

3) Cross-sectional thin sections across a D-shaped celery structure revealed pyrite(?)–filled pores arranged in bundles, a find that supports a plant origin, but is problematic for an escape origin.

4) The pipe-organ structures are lined with carbonaceous material and fecal pellets (Wnuk and Maberry, 1990). It is unlikely that escape structures would be lined with carbonaceous material and fecal pellets, especially over a vertical distance of as much as 8 m (see Ekdale et al., 1984, p. 91–93). Animals do not waste energy secreting a mucous membrane during escape (M. F. Miller, personal commun.). However, such features would be expected with biodegraded plant tissues.

5) The structures are composed of casts and molds. Although casts and molds are common in plants and in animal traces, they are not features recognized in escape structures. V-shaped spreite, which are common in escape structures, are absent; there is no evidence for upward movement in the surrounding sediment or in the internal structure of the casts.

6) The pipe-organ structures occur in clusters approximately

1–1.5 m in diameter, and, according to Wnuk and Maberry (1990, p. 443), the distribution of the structures appears to coincide with the distribution of woody material in the basal lag deposit. This association of clustered tubes and woody material would be expected in an in situ multibranching, fern-like tree.

7) There are no horizontal traces of any kind along the basal or uppermost horizon of the pipe-organ structures that might be indicative of animal activity before or after the sedimentation event.

8) Upward branching, found in some of the pipe-organ structures (Wnuk and Maberry, 1990) is common in plants and unlikely in escape structures.

9) One coalified root structure was observed at the base of the pipe-organ sandstone. This root structure may be related to the pipe-organ structures.

10) Wnuk and Maberry (1990) interpreted the structures as escape burrows of an "enigmatic" animal. This interpretation presumes that at least 250 animals suddenly burrowed as much as 8 m vertically to escape a catastrophic influx of sandstone. Wnuk and Maberry (1990) pointed out the problems with the "sheer magnitude . . . of burrowing through 8 m of rapidly accumulating sediment," and with "the apparent 100 percent survivorship among the burrowers."

We propose that the pipe-organ structures are the casts and molds of tree ferns or fern-like trees. Arborescent pteridosperms were abundant during the Early and Middle Pennsylvanian, but arborescent ferns were not common; therefore, the most likely plants are pteridosperms. If these are pteridosperms, then the pipe-organ structures probably represent aerial stems with attached lateral appendages and adventitious roots. Each one-meter cluster represents one pteridosperm tree.

POSSIBLE SEQUENCE OF EVENTS

A possible sequence of events for deposition of this pipe-organ sandstone is depicted in Figure 9. After development of the floodplain, channel avulsion caused scouring of the floodplain facies. A rubble zone, including plant material, was deposited as a lag deposit along the channel. Pteridosperm trees colonized either a shallow part of the channel or a temporarily abandoned channel of the river system. At intervals, perhaps during flooding, sand washed in and gradually covered the bases of the trees. Eventually, the trees became buried and died, and the area was then covered by migrating fluvial sand bars.

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