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ORIGIN OF THE MIDDLESBORO MEMBER OF THE LOWER PENNSYLVANIAN-AGE LEE FORMATION (BASHKIRIAN) IN THE CENTRAL APPALACHIAN BASIN, EASTERN USA, AND ITS UNIQUE FOSSIL OCCURRENCE

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ABSTRACT

The Middlesboro Member of the Lee Formation is an Early Pennsylvanian (Namurian, Bashkirian) sandstone in the central Appalachian Basin in Kentucky, Tennessee, and Virginia, eastern USA. Outcrops on Pine Mountain in Tennessee indicate well-defined channel and floodplain facies The channel facies is composed of very poorly sorted, lithic, subarkosic sandstone in thick, irregular, massive to cross-stratified beds. It has a scoured base and consists of a poorly developed fining-upward sequence that contains several types of stem and branch fossils. The floodplain facies is composed of shale, siltstone, coal, and underclay. It contains abundant organic debris, plant fossils, and rooting. Nearly meters of the floodplain facies are irregularly truncated against the overlying channel facies. Burrowing and marine fossils were not found in either facies.

An extraordinary occurrence of numerous vertical "pipe-organ" structures in the basal beds of the channel facies is problematic in origin, but appears to be sandstone casts of plants. These probable plant fossils are several meters tall and occur in groups. The structures may represent a stand of pteridosperms. Other explanations for these unique features, such as burrows, do not appear to fit available data.

According to sedimentological evidence, the origin of this sandstone was a bedload-dominated fluvial system of low sinuosity with subsidiary overbank and peat-swamp deposition. Although the origin of this unit has been controversial, with both marine and terrestrial models being advocated, the evidence from this occurrence supports a terrestrial fluvial environment of deposition.

INTRODUCTION

The Pennsylvanian rocks of the Central Appalachian Basin, located in northern Tennessee, eastern Kentucky. western Virginia, and southern West Virginia, are the most important source of high-quality bituminous coal in the world. The dominant lithologies of these Pennsylvanian rocks are the massive, dominantly quartzose sandstones of the Lee Formation and the Breathitt Formation. The Lee Formation occurs as large lenses within the coal-bearing shales and subarkosic sandstones of the Breathitt Formation, at the expense of the coal-bearing rocks. Stratigraphic and geometric relationships of these rocks. are described elsewhere in these volumes.[1] Here, we will describe the sedimentological and paleontological structures associated with the Middlesboro Member of the Lee Formation at a locality in northern Tennessee, and suggest a depositional environment for the sandstones of this member.

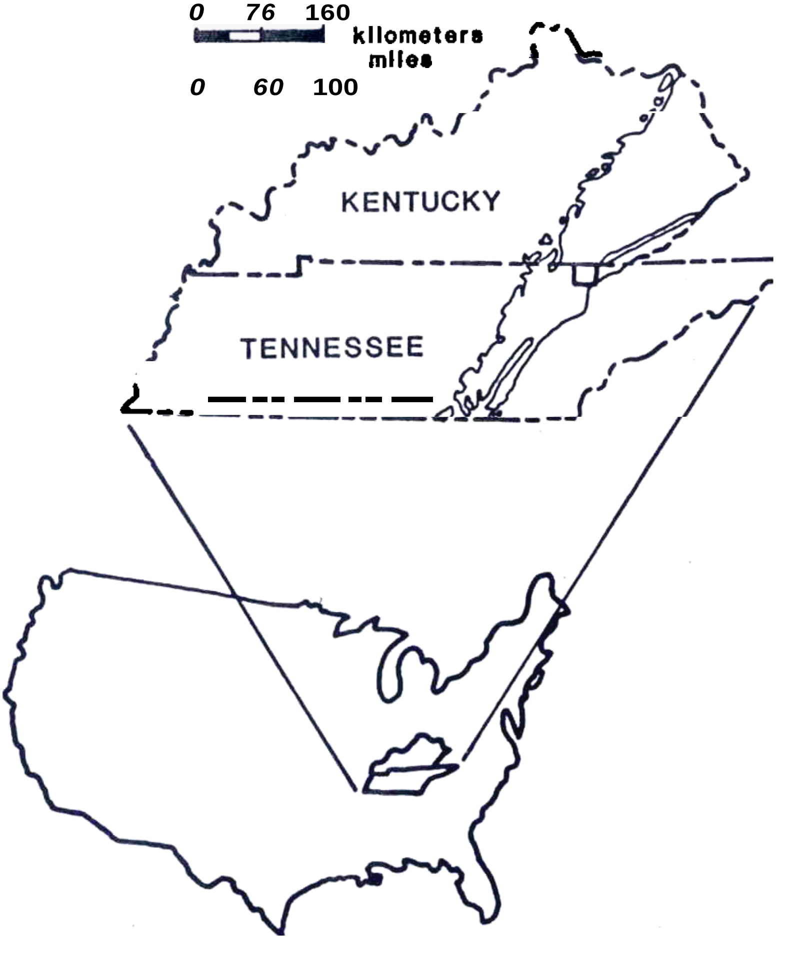

Fig. 1 Location map

MIDDLESBORO MEMBER

The study area consists of a series of excellent highway roadcuts on Interstate Highway 75, exposed along the crest of Pine Mountain. These roadcuts are located between Jellico, Tennessee, at the Kentucky-Tennessee state border, and the Jacksboro Fault in northern Tennessee (Figs. 1, 2). Pine Mountain was formed by the Pine Mountain overthrust fault, and represents the northwestern preserved edge of the Cumberland overthrust sheet.

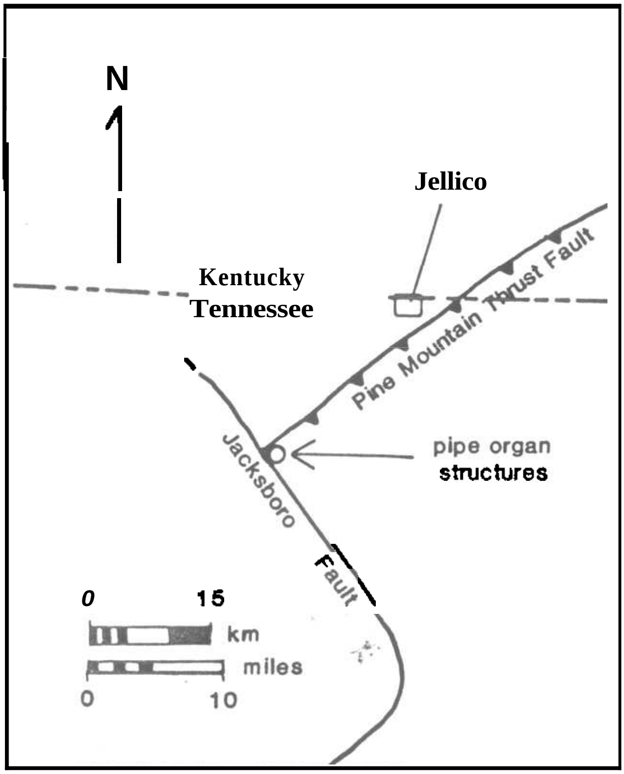

Fig 2 **Pipe-organ structure locality**

The rocks exposed along the southwestern half of this highway segment are largely massive sandstones with minor shales and thin, irregular coals (Fig. 3) of the Middlesboro Member.[2] The Middlesboro Member is stratigraphically the lowest member of the Lee Formation, and is equivalent to the combined Sewanee and Warren Point Sandstones discussed by Chesnut.[1] The Middlesboro is a useful stratigraphic term where the Sewanee and Warren Point Members are difficult to differentiate.

The rocks of the Middlesboro Member exposed in the study area are composed of four of five units of thick, lithic, subarkosic to quartzarenitic sandstones containing quartz pebbles, separated by thinner, finer grained rocks composed of shale, siltstone, subarkosic sandstones, and coals. The sandstones exhibit poorly to well-developed fining-upward sedimentary sequences. The bases of the sandstones are scoured, and the basal rocks are commonly conglomeratic, and composed of shale, siderite or quartz pebbles, horizontal logs, and limbs, as well as sheets and pieces of coal. Festoon and tabular crossbeds generally dip to the southwest.

The finer grained rocks separating the sandstone bodies described above are truncated erosionally against the overlying sandstones, and commonly display slickensides and contorted bedding due to compaction. These finer grained rocks are gray shales interbedded with coal, siltstone, and thin, local sandstone lenses. Only plant fossils are observed, and include compressions of leaves, stems, and bark. In addition, rooting and leached seat rock are found. No marine body fossils or trace fossils were found in any of the fine-grained rocks or sandstones of the Middlesboro Member. Additional details and measured sections are available as open-file information at the Kentucky Geological Survey.

One enigmatic and unusual fossil occurrence in the Middlesboro Member, however, deserves additional comment.

PIPE-ORGAN STRUCTURES

A series of cylindrical structures was discovered at the base of one of the sandstone bodies of the Middlesboro Member (Fig. 3; small box indicates stratigraphic position). These cylindrical structures, dubbed "pipe-organ" or "celery" structures by us, vary in diameter from 1 to 7cm, and extend vertically as high as 5 meters from the base of the sandstone (Plate 1, figs. 1, 2). The cylinders appear to occur as clusters approximately 1 meter in diameter. Some cylinders gradually diverge and branch upward at a small angle, and others appear to be ribbed. In cross section, the cylinders are circular, "D"- or "C" shaped, and some are multi-chambered (Plate 2, figs. 1, 2). Adjacent C-and D-shaped cylinders are commonly oriented in the same direction (Figs. 6, 7). Thin sections cut perpendicular to the pipe-organ structures reveal pores, approximately 0.1 to 0.5mm in diameter, arranged in apparent ring-shaped bundles along the cylinder boundary,

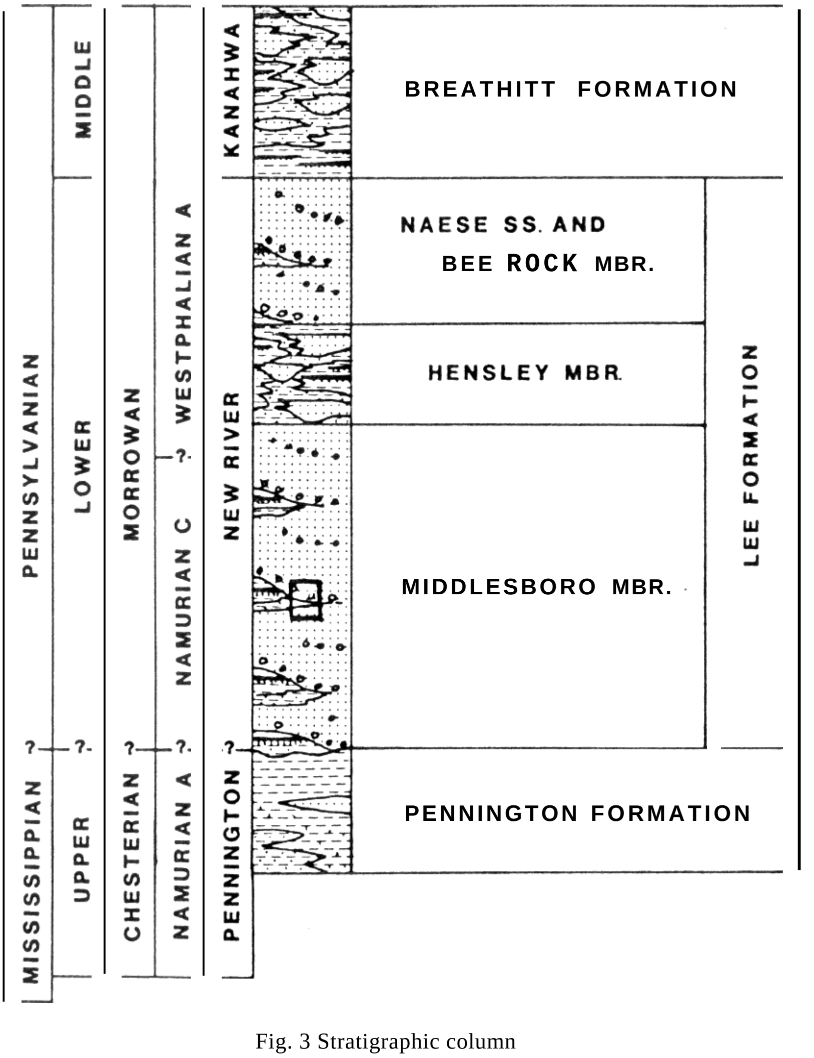

Fig. 3 Stratigraphic column

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*), as well as limbs of lycopod and other unidentified trees.

PIPE-ORGAN SANDSTONE

The vertical pipe-organ structures occur in a 30 to 40m thick sandstone body (Plate 1, fig. 3; Fig. 4 in page 24). This sandstone is divided into three parts: a basal conglomerate, a massive lower sandstone, and a crossbedded upper sandstone. The upper sandstone contains irregular beds, 15 to 150cm thick, with unidirectional tabular to tangential crossbeds. Bedding thins upward. Thin shaly partings occur between the crossbed sets, and coaly stringers may be found in the lower beds.

The massive lower sandstone, which contains the pipe-organ structures, is as thick as 7.5m, and is very irregular in thickness. It has indistinct bedding, but contains conglomeratic zones of shale pebbles and coal spar. The base is undulating and erosional.

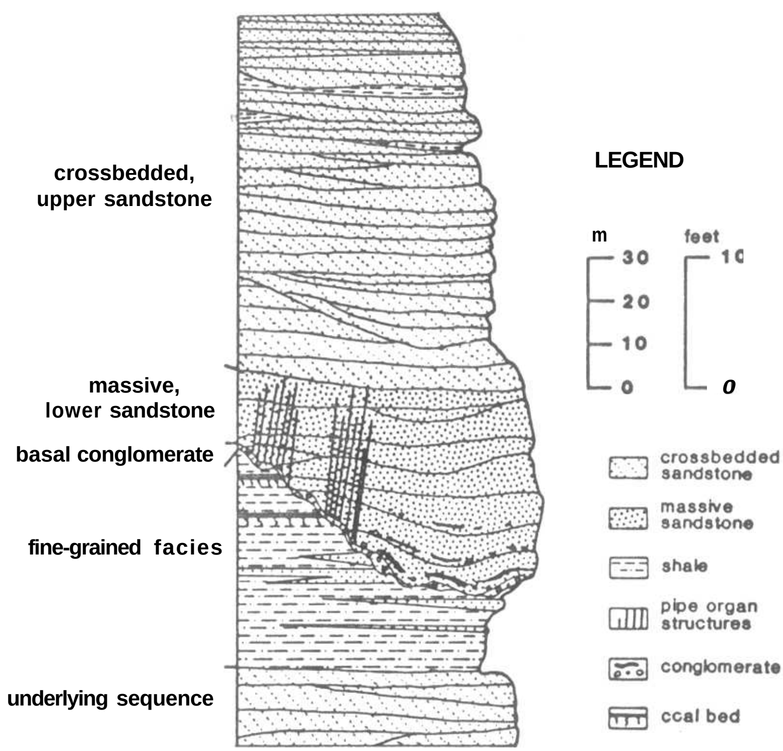

Fig. 4 Measured section

A thin basal conglomerate, 0 to 50cm thick, has an erosional base, and is also erosionally truncated by the overlying sandstone unit. 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 thin sections described by Stephen Greb (Kentucky Geological Survey), the sandstone varies from fine to coarse grained, and contains subangular to subrounded grains composed of quartz (75 to 90 percent), plagioclase (5 to 10 percent) and other common mineral and rock fragments (2 to 5 percent). The massive lower sandstone is poorly sorted and fine to coarse grained, whereas the crossbedded upper sandstone shows moderate sorting of very fine-grained sand. The basal conglomerate is poorly to very poorly sorted, and the matrix is fine to very coarse-grained quartz sand.

The basal contact of the sandstone truncates finer grained rocks, which consist of interbedded shales, siltstones, claystones, thin sandstones, and coals (Fig. 4). This finer grained unit, 3.6 to 12m thick, contains several layers of abundant rooting, organic-rich zones, common horizontal plant stems, abundant plant debris, and siderite nodules. The thin siltstone and sandstone lenses and layers exhibit ripples and cross-stratification. No animal body fossils or trace fossils were found in this unit.

INTERPRETATION

The depositional environments of quartzose sandstones of the Lee Formation have been interpreted as beach-barrier bar,[3] braided fluvial,[4,5] and ebb-flow-dominated tidal channel (Blaine Cecil, personal communication, 1985). The beach-barrier bar interpretation was founded in large part on the 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. However, a significant regional unconformity has been demonstrated between the Lee Formation and the marine limestones and shales, thereby decoupling this supposed facies relationship.[6-8] In fact, the various members of the Lee Formation overlap the unconformity to the northwest,[1] and are in facies relationship only with the coal-bearing rocks of the Breathitt Formation. The thin marine strata that occur in the Breathitt do not represent environments capable

Table 1 Features found in fluvial and tidal channels

SANDY FLUVIAL CHANNEL VS	SANDY TIDAL CHANNEL
ELONGATE GEOMETRY	ELONGATE GEOMETRY
EROSIONAL HASE	EROSIONAL BASE
COARSE-LAG DEPOSIT	COARSE-LAG DEPOSIT
FINING-UPWARD SEQUENCE	FINING-UPWARD SEQUENCE
LATERAL FLOODPLAIN FACIES	LATERAL TIDAL FLAT FACIES
UNIMODAL CURRENTS	BIMODAL CUKRENTS
POORLY SORTED	WELL SORTED
TERRESTRIAL FLORA	MARINE AND/OR TERRESTRIAL FAUNA

of producing beach-barrier bars on the scale of the Lee Formation.

Features such as an erosional base, coarse lag deposit and fining-upward sequence of the pipe-organ sandstone bed, however, can be expected in either fluvial or tidal channels. Table 1 lists some of the common features found in both of these environments. In the fine-grained facies below the sandstone, the occurrence of coal beds, multiple rooting and leach zones, presence of plant fossils, and absence of any animal body or trace fossils indicate that this facies probably represents deposition in a floodplain environment. The unidirectional crossbed dips, poor sorting, occurrence only of terrestrial fossils, and association with a floodplain facies suggest that this sandstone represents a sandy fluvial channel rather than a sandy tidal channel (Table 1).

A high width-to-depth ratio, low to moderate relief on the basal scour surface, multilateral channel fills, and poorly developed vertical sequence may indicate a low-sinuosity braided system (Fig. 5). The planar and low-angle accretionary foreset bedding of the crossbedded upper sandstone probably represents fluvial bars. During flood stage, sediment moves over the bars to avalanche down the lee side, producing tabular crossbedding.

The origin of the pipe-organ structures is problematic. They have been interpreted as gas- or water-escape structures, deformation structures, burrows, and plant fossils. Water- or gas-escape structures do not have such well-developed cylinders, especially with C-and D-shapes in cross sections (e. g., Johnson). Also, no features accompany the pipe-organ structures that indicate deformation. A biogenic origin, either plant or animal, seems most likely, although we are uncertain which of the two is correct. Our opinion, based on features listed in Table 2, is that the pipe-organ structures represent erect plants, perhaps pteridosperms. If these are pteridosperms, then the cylindrical structures probably represent aerial stems with attached lateral appendages and adventitious roots. Arguments that these unique 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. We are interested in ideas from the readers who may have seen similar structures, or who may have insights on their origin.

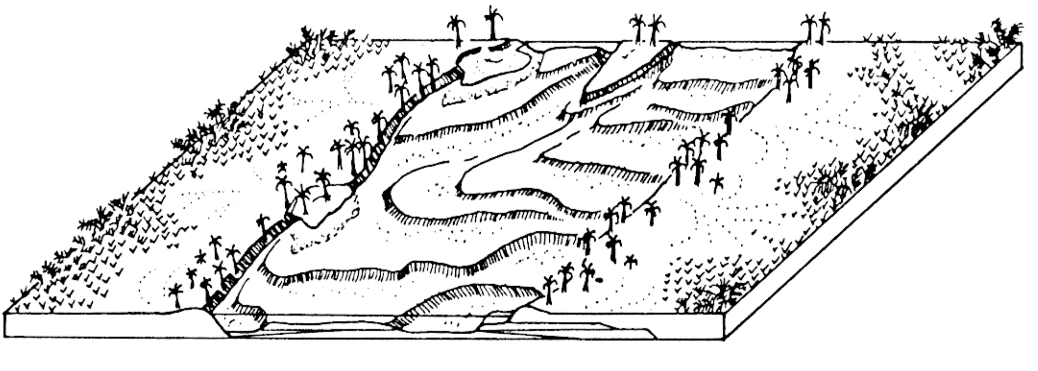

Fig. 5 Deposition model

During preparation of this manuscript, we have learned of two other occurrences of pipe-organ structures; one is from a sandstone in the Tradewater Formation (Pennsylvanian), Union County, in western Kentucky, USA. The other, reported by the staff of the Virginia Division of Mineral Resources, occurs in quartzose sandstone of the New River Formation in Virginia, USA. The New River is coeval with the Lee Formation. However associated sedimentary structures and biogenic features of these occurrences have not been examined by us at this time.

Table 2 Features indicating plant origin

CLASSIFICATION AS PLANTS
1) CASTS AND MOLDS
2) MOLDS HAVE RIBBED PATTERNS
3) LARGE RANGE IN DIAMETERS (0.25-2cm)
4) ENORMOUS VERTICAL EXTENT (1Om)
5) CLUSTERED NOT RANDOM
6) EMANATE FROM ONLY ONE HORIZON
7) BRANCH UPWARDS
8) COMPLEX STRUCTURES IN HORIZONTAL SECTIONS
9) NO DISPLACEMENT OF SEDIMENTS
10) NO CEMENTATION OR FECAL MATTER

POSSIBLE SEQUENCE OF EVENTS

A possible sequence of events for deposition of this pipe-organ sandstone is depicted in Figures 6, 7. After development of the floodplain, channel avulsion onto the floodplain 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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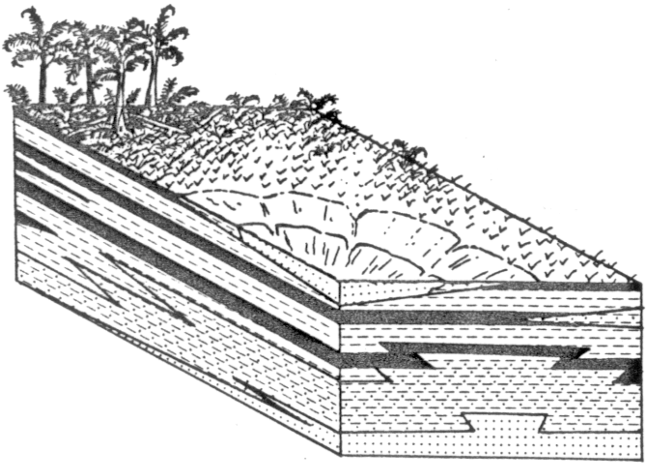
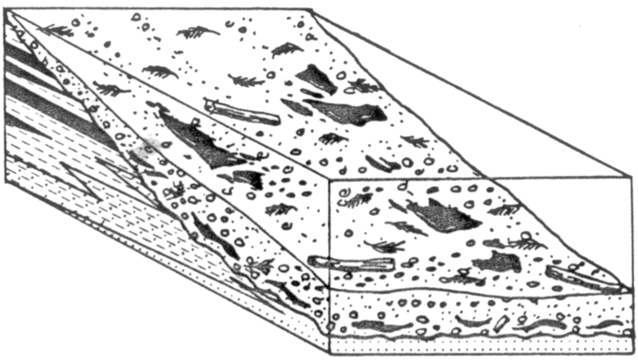
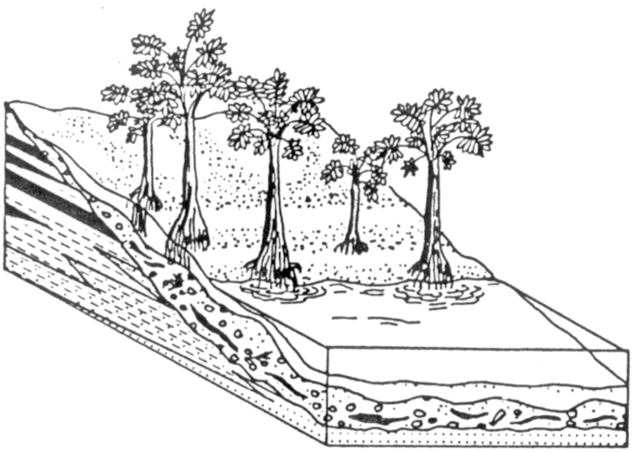


1) FLOODPLAIN DEVELOPS

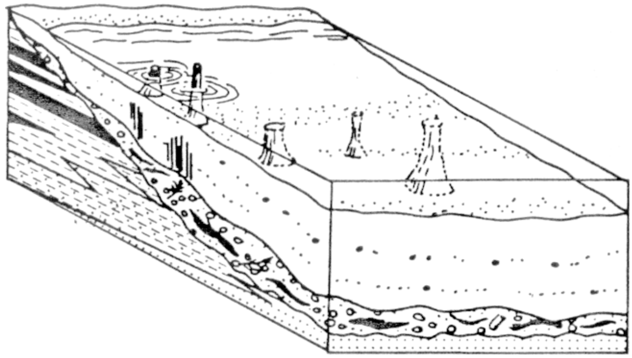


2) CHANNELING BEGINS

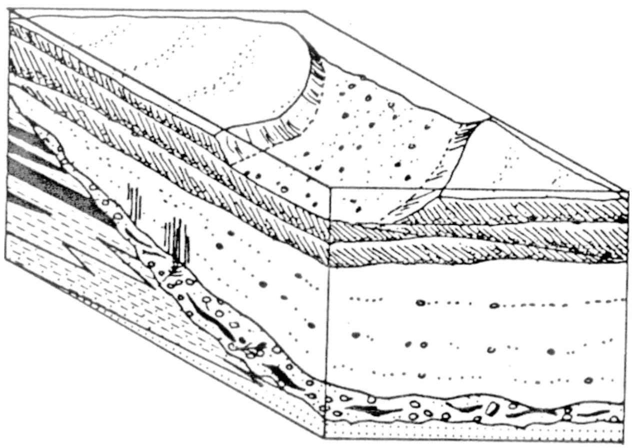


3) PTERIDOSPERMS COLONIZE

Fig. 6 Sequence of events



4) PTERIDOSPERMS BURIED



5) MIGRATION OF SAND BARS

Fig. 7 Sequence of events (continued)

Gillespie, Molly Miller, and Robert Wagner. We did not all agree on the origin of these enigmatic fossils.

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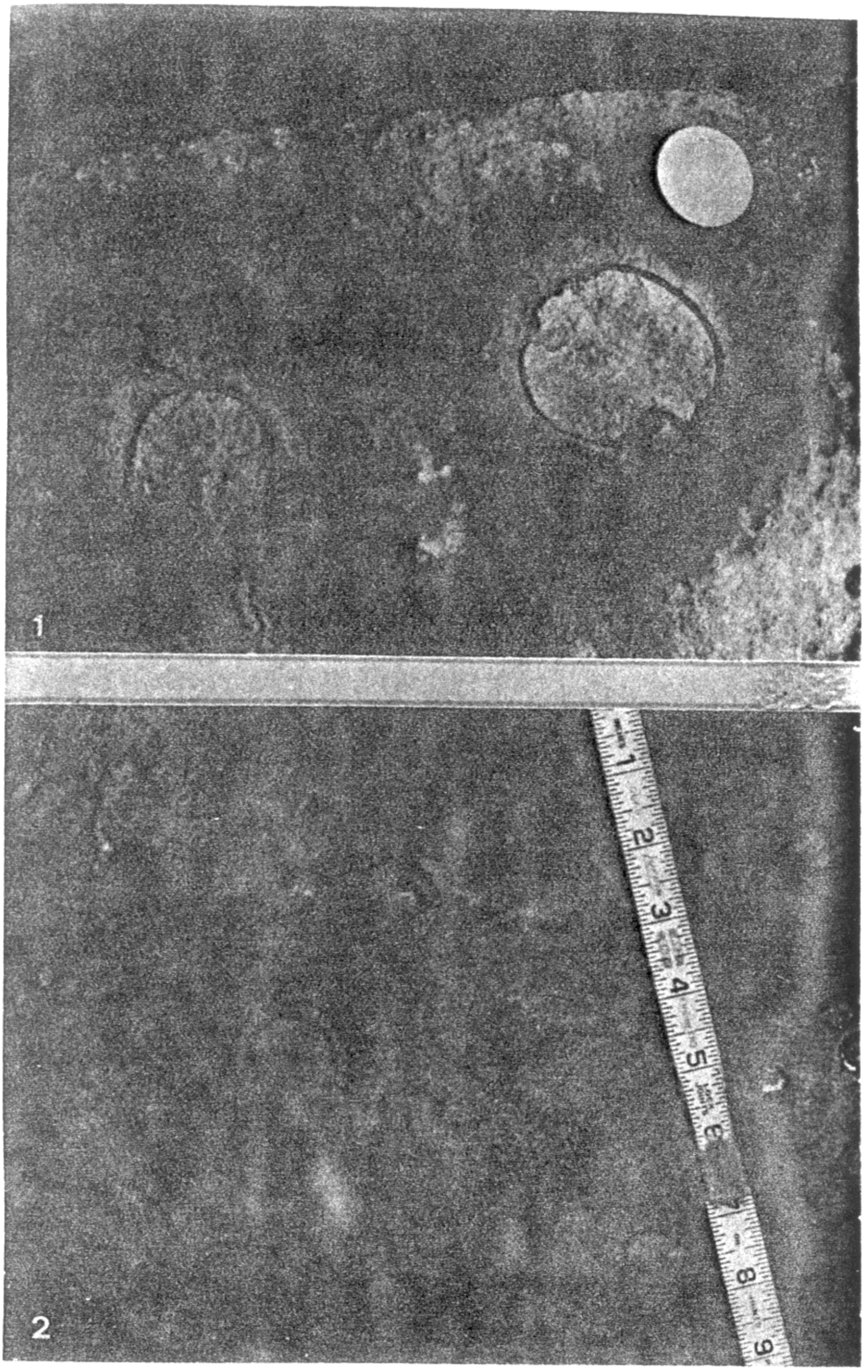
EXPLANATION OF PLATES

Plate 1

1. Pipe-organ structures. Knife for scale.
2. Pipe-organ structures. Scale in inches.
3. Pipe-organ sandstone outcrop. Upper sandstone is pipe-organ sandstone; note the scoured base. Fine-grained facies is in the center and an underlying sandstone sequence is to the lower left. Exact scale unkown, but trees are 6 to 10 feet tall.

Plate 2

1. Cross section of pipe-organ structures. Note C-shape.
2. Cross section of pipe-organ structures. Note multi-chambered and D-shaped specimens. Scale in inches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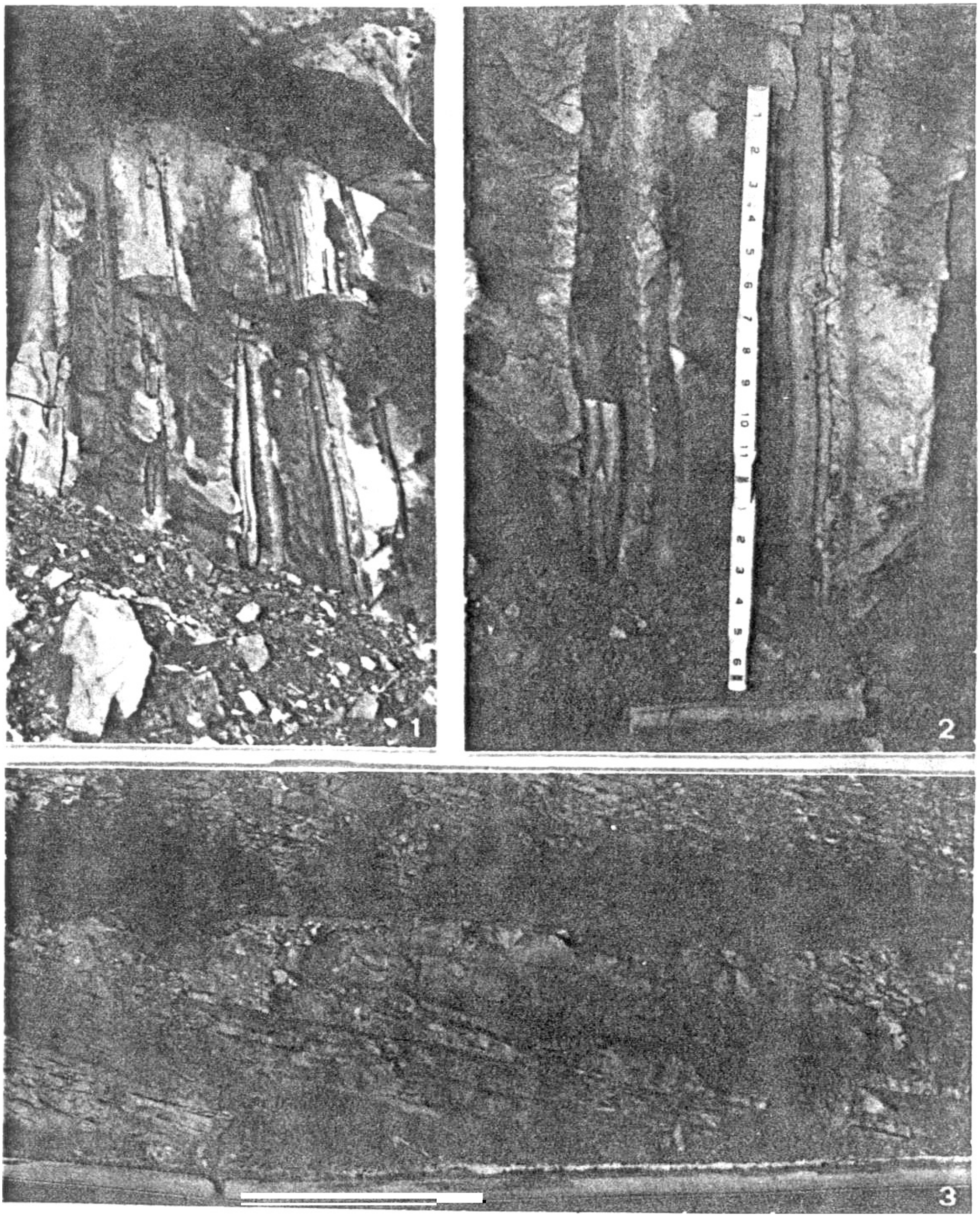
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