

# **Part I. Site Significance and Discovery**



The Union Chapel Mine in January, 2000. Photo credit: Ron Buta.

## **THE SIGNIFICANCE OF THE UNION CHAPEL MINE SITE: A LOWER PENNSYLVANIAN (WESTPHALIAN A) ICHNOLOGICAL KONZENTRAT- LAGERSTÄTTE, ALABAMA, USA**

ADRIAN P. HUNT<sup>1</sup>, SPENCER G. LUCAS<sup>1</sup>, and NICHOLAS D. PYENSON<sup>2</sup>

<sup>1</sup>New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, New Mexico, 87104, USA

<sup>2</sup>Department of Integrative Biology & Museum of Paleontology, University of California,  
1101 Valley Life Sciences Building, Berkeley, California 94720 USA

**ABSTRACT:** The Union Chapel Mine site (Steven C. Minkin Paleozoic Footprint Site) is located in Walker County, Alabama. The fossil-bearing horizon is in the Mary Lee coal zone (above the Mary Lee coal bed) of the Pottsville Formation (Early Pennsylvanian: Westphalian A). It yields diverse and extensive vertebrate and invertebrate ichnofaunas as well as plant and arthropod body fossils. The significance of the tracksite can be evaluated based upon size, ichnotaxonomy, taphonomy, paleoecology, ichnofacies, geography, biogeography, stratigraphy, biostratigraphy, paleoenvironment, preservation, education, sociology and history. The Union Chapel site is globally significant in most of these categories.

### **INTRODUCTION**

The Union Chapel fossil site (now known as the Steven C. Minkin Paleozoic Footprint Site) is a very large fossil site in northern Alabama of Early Pennsylvanian age. It yields an abundant fossil fauna that includes tetrapod tracks (Minkin, 2000; Haubold et al., 2003, 2005), fish traces (Martin, 2003a), invertebrate trace fossils (Rindsberg and Kopaska-Merkel, 2003, 2005; Lucas and Lerner, 2005), plant megafossils (Dilcher et al., 2005) and arthropod body fossils (Atkinson, 2005). This site is obviously significant, but how does it compare with other fossil sites of similar age and scope? The purpose of this paper is to answer that question.

The majority of the significant fossils from the Union Chapel Mine are tetrapod tracks. Therefore, we establish a set of categories by which the significance of tetrapod tracksites can be assessed, and evaluate the Union Chapel Mine against them.

### **UNION CHAPEL MINE LOCALITY**

The partially abandoned Union Chapel Mine is located in Walker County, Alabama, about 48 km northwest of Birmingham (Fig. 1). The track-bearing horizon at the Union Chapel Mine is in the Mary Lee coal zone, just above the Mary Lee coal bed of the Pottsville Formation (Early Pennsylvanian: Westphalian A) (Pashin, 2005; Fig. 2)(Fig. 1). The majority of ichnofossil and other specimens were collected by members of the Alabama Paleontological Society and the Birmingham Paleontological Society on the surface of “spoil piles” that consist of rock from the overburden of the Mary Lee coal bed. During an 18-month period, more than 1200 slabs containing both vertebrate and invertebrate ichnofossils were salvaged from the Union Chapel

Mine site (Allen, 2005; Buta and Minkin, 2005; Atkinson et al., 2005). Another less significant, and slightly older locality is the Number 11 Mine of the Galloway Coal Company near Carbon Hill (Aldrich and Jones, 1930).

The track-bearing interval at the Union Chapel Mine is in sandstone-shale couplets interpreted as tidal rhythmites (Pashin, 2003, 2005). Invertebrate ichnotaxa in these strata include abundant xiphosuran trails (*Kouphichnium*), insect feeding traces (*Treptichnus*), burrows (*Arenicolites*), as well as less common arthropod walking and feeding traces (Rindsberg and Kopaska-Merkel 2003, 2005; Lucas and Lerner, 2005; Uchman, 2005). Fish swimming traces (*Undichna*) are also present, as are the tracks of small amphibians (*Batrachichnus*) and small captorinomorphic reptiles (*Notalacerta* and *Cincosaurus*) (Haubold et al., 2003, 2005; Martin, 2003a). Indeed, tracks assigned to *Cincosaurus* so dominate the footprint assemblage that local collectors refer to the track-bearing strata at the Union Chapel Mine as the “*Cincosaurus* beds” (e.g., Minkin, 2005). Larger tetrapod tracks include *Attenosaurus subulensis*, *Alabamasauripus aldrichi*, and *Dimetropus* isp. (Hunt et al., 2004). Although the Union Chapel Mine also contains large (>15 cm long) and fragmentary plant debris and three body fossils of insects and arachnids (Dilcher et al., 2005; Atkinson, 2005), the site otherwise yields a fossil record that consists entirely of trace fossils. There are also brachiopods at the locality, but they probably derive from a different stratigraphic horizon (Pashin, 2005).

### **UNION CHAPEL MINE AS A LAGERSTÄTTE**

The term Lagerstätte was introduced by Seilacher to refer to fossil localities that display exceptional preservation in quality, quantity and diversity, after the German word for “motherlode” (Seilacher, 1970; Seilacher



FIGURE 1. Map of Alabama showing location of Union Chapel Mine and generalized stratigraphy of the Pottsville Formation showing location of Mary Lee coal zone and track horizon.

et al., 1985; Seilacher, 1990). This term has since been overused, and arguably only about a dozen fossil localities in the fossil record merit such designation (Selden and Nudds, 2004). These would include famous sites such as the Jurassic Solnhofen quarries of Germany, the Cambrian Burgess Shale of British Columbia and the Chengjiang Biota of Yunnan Province, China.

However, there are a large number of Carboniferous localities that have been “designated” as Lagerstätten, including the Gaskohle of Germany (Fritsch, 1899), Montceau-les-Mines in France (Rolfe et al., 1982), Granton “shrimp-bed” in Scotland (Briggs et al., 1991) and the Castlecomer fauna of Ireland (Orr and Briggs, 1999). In North America, such Lagerstätten include the Bear Gulch Limestone of Montana (Grogan and Lund, 2002), Buckhorn Lagerstätte of Oklahoma (Nutzel et al., 2000), Hamilton Quarry in Kansas (Cunningham et al., 1993), Kinney Brick Quarry in New Mexico (Zidek, 1992), Carrizo Arroyo in New Mexico (Lucas and Zeigler, 2004), Joggins in Nova Scotia (Ferguson, 1988) and Mazon Creek in Illinois (Baird et al., 1985).

Seilacher (1970) recognized two forms of Lagerstätten: (1) *Konzentrat-Lagerstätten* (“concentration mother lodes”) contain large numbers of fossils that largely exclude the preservation of soft parts; these include shell beds and bone beds; and (2) *Konservat-Lagerstätten* (“conservation mother lodes”) are distinguished by the preservation of soft parts and a diversity of taxa and include the Burgess Shale, and the German Posidonienschiefer. Thus, *Konzentrat-Lagerstätten* are distinguished primarily by quantity, whereas *Konservat-*

*Lagerstätten* are distinguished by the quality of preservation (Seilacher, 1990).

The Union Chapel Mine has the characteristics of a *Konzentrat-Lagerstätte* because of the abundance of fossils, although we are not aware of this term having been previously applied to an ichnological assemblage. However, the diversity of taxa of ichnofossils and body-fossils is relatively low, as is the overall representation of phyla. In addition, although there are instances of exquisite preservations, such as the insect wings (Atkinson, 2005), the majority of the fossils are invertebrate and tetrapod trace fossils, and these are dominantly undertracks, and, significantly, there is not extensive preservation of soft tissue (Seilacher, 1970, 1990; Hunt et al., 2004; Haubold et al., 2005). Thus, Union Chapel does not qualify as a *Konservat-Lagerstätte*.

## SIGNIFICANCE OF TERRESTRIAL ICHNOFOSSIL LOCALITIES

### Size

Large sample sizes of any fossil are important for a variety of reasons. This is largely because the variability of the morphology of fossil species, and particularly ichnospecies, is usually very poorly understood. A large sample has implications for most of the following categories, not only because of sample size (e.g., ichnotaxonomy, taphonomy) but also because of public impact (education, sociology).

### Ichnotaxonomy

Tracksites can, by virtue of large sample size or significant individual specimens, provide for a greater understanding of existing ichnotaxa or reveal new ichnotaxa. The Robledo Mountain tracksites from the Lower Permian of southern New Mexico acted as a “Rosetta Stone” for the understanding of global Permian tetrapod ichnotaxonomy (Haubold et al., 1995; Hunt et al., 1995b; Lucas et al., 1995; Haubold, 1996). The Robledo Mountain tracksites are important for ichnotaxonomy because of their large sample sizes and because they preserve a very large range of extramorphological variants, including transitional forms between “ichnotaxa.” In addition, in the Robledo Mountains it is possible to collect a series of successive underprints as well as the original tracks, which allows an understanding of the different morphologies displayed on different sedimentary layers.

### Taphonomy

The taphonomy of nonmarine ichnotaxa, particularly tetrapods, is relatively little studied, with some notable exceptions (e. g., McKee, 1947), although there have been important advances in the past few years (e.g., Gatesy et al., 1999; Gatesy, 2003; Manning, 2004). Individual tracksites can provide information about unknown or unstudied taphonomic contexts. For example, the Clayton Lake tracksite in the Lower Cretaceous of northeastern New Mexico preserves tracks made in a very wet substrate, which produces apparently “webbed”

dinosaur tracks and multiple tail drags (Lockley and Hunt, 1994; Hunt and Lucas, 2004a).

### **Paleoecology**

Tracks were produced by the behavior of living organisms, in contrast to body fossils, which represent carcasses. Therefore, tracks can provide information about aspects of the ecology of organisms that are not possible to infer from body fossils. A classic example of this is Ostrom's (1972) paper on gregarious behavior in theropod dinosaurs based on an Early Jurassic tracksite.

### **Ichnofacies**

Tracksites can establish new ichnofacies or help to elucidate aspects of named ones or extend their ranges. For example, the Paleozoic tracksites of Grand Canyon National Park allowed Baird (1965) to recognize redbed and eolian ichnofacies that were formalized as the *Chelichnus* and *Batrachichnus* ichnofacies (Lockley et al., 1994; Hunt and Lucas, 2005).

### **Geography**

Tracksites can have an importance due to their geographic location. For example, Paleozoic tracks are rare in the southern continents, so relatively low ichnodiversity localities in Argentina (Melchor, 1997, 2001; Melchor and Poiré, 1992; Melchor and Sarjeant, 2004) have a greater importance than they would in Laurasia.

### **Paleobiogeography**

Tracksites can provide valuable paleobiogeographic information. Thus, for example, Lucas et al. (1999) documented an Early Permian tracksite from the Caucasus, Russia, which greatly expanded the paleobiogeographic range of the tetrapod ichnogenera *Dimetropus* and *Dromopus*.

### **Stratigraphy**

Often tracks are restricted to specific intervals within stratigraphic units such as, for example, the tetrapod tracks in the Lower Permian Coconino Sandstone in Arizona (Santucci et al., 2003), the "Dakota" Group of southeastern Colorado and adjacent areas (Lockley et al., 1992) and the Middle Jurassic Entrada Sandstone of central Utah (Lockley and Hunt, 1995). In such instances, the distribution of tracks can have utility in stratigraphic resolution (e.g., correlation by way of track-bearing intervals).

### **Biostratigraphy and Biochronology**

In general, tetrapod ichnotaxa have long stratigraphic ranges because most of them correspond to family or higher taxonomic levels of biotaxa (Lucas, 2005). However, in the absence of other fossils, they can have limited utility for both biostratigraphy and

biochronology. Indeed, in some instances, trace fossils provide the only evidence of an organism's stratigraphic occurrence (Carrano and Wilson 2001).

### **Paleoenvironment and Paleogeography**

Because tetrapod tracks are formed *in situ* and cannot be reworked, they provide *prima facie* evidence of a terrestrial environment and often are indicators of very specific environmental conditions. For example, Mesozoic dinosaur tracks from the Mediterranean area demonstrated that strata formally considered to be shallow marine in origin were actually emergent, with significant implications for the paleogeography of the region (Bosellini, 2002). Statistically significant numbers of one ichnofossil taxon restricted to one lithological horizon, or unit of rock, can serve as predictable paleoenvironmental indicators (e.g., Seilacher, 1967a, 1967b).

### **Preservation**

Relatively few fossil sites are preserved and protected. However, tracksites have a greater potential for *in situ* preservation than other kinds of fossil sites. Most tetrapod bones are relatively sensitive to weathering (and human interference), so most that are preserved *in situ* are housed within buildings (e.g., Dinosaur National Monument in Utah, Hot Springs Mammoth Site in South Dakota, Dashanpu Dinosaur Museum in Sichuan, China, etc.). However, tetrapod bones are rarely preserved in a natural environment. Two exceptions are Jurassic dinosaur bones in the western United States at Dinosaur Ridge near Denver, Colorado, and near Moab, Utah. Tracksites are much more robust, and although some are preserved within buildings or structures (e.g., Rocky Hill Dinosaur State Park, Connecticut; St. George Dinosaur Discovery Site at Johnson Farm, Utah; Lark Quarry, Australia), many are preserved in an unprotected state (Dinosaur Ridge, Clayton Lake State Park, BLM site near Moab). Indeed, there are preserved tracksites on every continent except Antarctica.

### **Education**

Tracks are of intrinsic interest to the public, and they readily invoke past environments and ecologies. Because tracksites are often preserved and open to the public (at different levels), they provide great potential for public education. Probably the most educationally developed tracksite is at Dinosaur Ridge near Denver, which has both adult- and child-oriented exhibits and guidebooks that address both the tracks and other natural history (mainly geological) features of the area (e.g., Lockley and Hunt, 1994; Lockley, 2001).

### **Sociology**

Paleontology is one of the few sciences in which volunteers/avocationalists (nonprofessionally trained and employed) individuals can and do make a huge contribution. Often this involves the finding of fossils, but it

can also include important examples in which volunteers not only discover, but also develop and prepare, the fossils. A great example of this important role is the Peterson Dinosaur Quarry in the Upper Jurassic Morrison Formation of New Mexico, which was found by Rod and Ron Peterson, who now oversee the field collection of specimens (Heckert et al., 2000). Subsequently, the bones are prepared for research and display at the New Mexico Museum of Natural History and Science (NMMNH) by volunteers. The Jurassic Super-giants Exhibit at NMMNH, which opened in August 2004, is the culmination of the work of these volunteers.

Untrained paleontologists have had a great impact on the science of vertebrate ichnology in the past few years. Notable are the efforts of two individuals, whose work has resulted in the study (and in one case preservation) of important tracksites in western North America. Jerry MacDonald found, and brought to scientific attention, the Robledo Mountain tracksites in southern New Mexico, which are the largest and most significant assemblage of Permian tracks known (MacDonald, 1994; Lucas and Heckert, 1995; Lucas et al., 1998). Andrew R. C. Milner played a similar role with respect to Early Jurassic tracksites at St. George in Utah, although he was not the original discoverer. One of these tracksites is preserved at the St. George Dinosaur Discovery Site at Johnson Farm, and in 2006 it will be the subject of a scientific monograph. In Nova Scotia, several significant Paleozoic tracksites have been developed by amateurs, notably Blue Beach (Chris Mansky), Brule (Howard van Allen), Jogjins (Don Reid, Brian Hebert), and West Bay (Eldon George).

### History of Discovery

There is a level of serendipity in the importance of tracksites related to the timing of their discovery. For example, Early Jurassic tracks have been known in north-eastern North America since 1802 (Steinbock, 1989). Thus, more recent finds have less scientific impact because the basic composition of the ichnofauna and its distribution are well understood. This is not to say that new sites might not provide new information or that they might not be important for other reasons, such as preservation and interpretation (e.g., Rocky Hill Dinosaur State Park). In April 2005, the St. George Dinosaur Discovery Site at Johnson Farm opened to the public in Utah. The St. George Dinosaur Discovery preserves the same basic ichnotaxa that are well-known from New England, such as the dinosaur ichnogenera *Grallator* and *Eubrontes*, but it has importance historically because it is the first large tracksite of this age from western North America that is preserved and readily accessible to the public.

## SIGNIFICANCE OF UNION CHAPEL SITE

### Size

The Union Chapel Mine is the largest Carboniferous tracksite known in terms of abundance of track specimens within a narrow stratigraphic range (Cotton et al.,

1995; Hunt et al., 1995a; Lucas, 2003). The current collections lack long trackways (cf. Lucas et al., 2004b), but this clearly reflects the fact that the specimens were all collected from spoil and were not excavated from bedding plane exposures. We hope that bedding plane collections will be made in the future. The Union Chapel Mine site is only surpassed in terms of abundance among Paleozoic tracksites by the Robledo Mountains localities in the Lower Permian of New Mexico (Lucas and Heckert, 1995).

### Ichnotaxonomy

The Union Chapel ichnofauna is of relatively low diversity despite the large number of specimens. Indeed, Pyenson and Martin (Pyenson and Martin, 2001; Martin and Pyenson, 2005) consider that most of the tetrapod tracks from the Union Chapel Mine are assignable to a single ichnotaxon represented by growth stages (however, two of us [APH and SGL] do not accept this conclusion).

The majority of tracks from the Union Chapel Mine site pertain to *Cincosaurus cobbi*, and the ichnotaxonomy of this ichnospecies is now much better understood (Haubold et al., 2005). Large tracks from Union Chapel are conventionally attributed to *Attenosaurus subulensis* (Haubold et al., 2005). However, Hunt et al. (2004) recognized three large ichnotaxa, including *Attenosaurus subulensis*, *Alabamasauripus aldrichi* and *Dimetropus isp.* (Fig. 2). There is consensus about the ichnotaxonomy of the smaller, rarer temnospondyl track *Matthewichnus caudifer* and the amniote *Notalacerta missouriensis*. Two of us (APH and SGL) consider the small temnospondyl that Haubold et al. (2005) assign to *Nanopus reidiae* to pertain to the ichnogenus *Batrachichnus* and are unsure whether it represents a new ichnospecies. All six of the identifiable ichnospecies from the Union Chapel Mine recognized by APH and SGL (Table 1) are restricted to the south-eastern United States.

It is important to note, as did Haubold et al. (2003, 2005) and Hunt et al. (2004), that the vast majority of the Union Chapel Mine tracks are undertracks. This is not a collecting bias, but a true reflection of the ichnofaunas. Thus, although this assemblage is one of the largest Carboniferous ichnofaunas known in terms of number of specimens collected, it lacks diversity and thus is of limited value to ichnotaxonomy. This ichnofauna is thus not as useful a “Rosetta Stone” for Pennsylvanian tracks as the Robledo Mountains assemblages of New Mexico are for Early Permian tracks (Haubold et al., 1995; Hunt et al., 1995a).

### Taphonomy

The Union Chapel site has a very unusual taphonomy. Despite the huge sample of tetrapod tracks, virtually all are undertracks (Hunt et al., 2004; Haubold et al., 2005).

Clearly, at the Union Chapel Mine site, a cyclic sequence of events included a wetting event when the tracks were imprinted followed, in almost all cases, by erosion of the surficial laminae that preserved the true tracks.

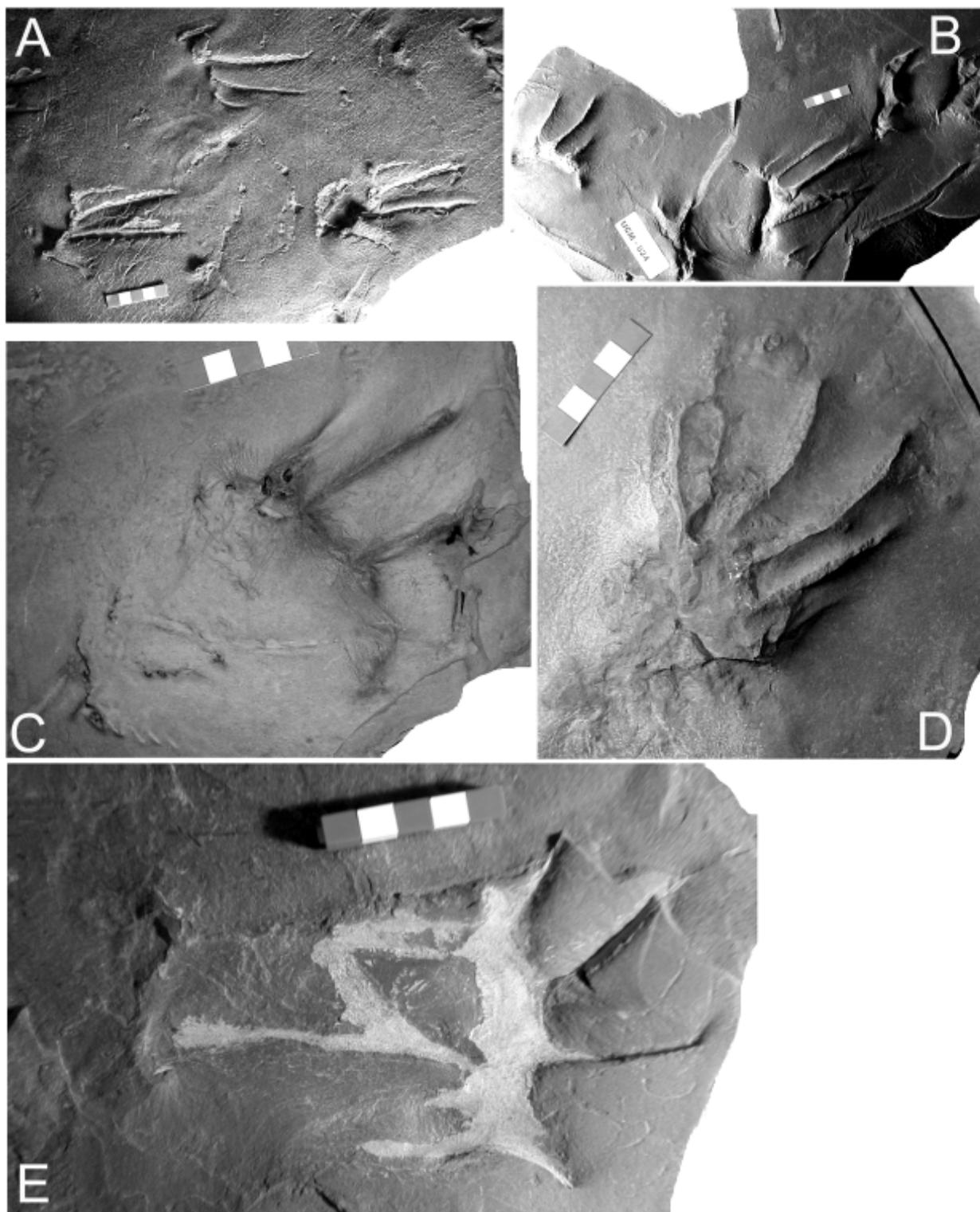


FIGURE 2. Photographs of selected large tetrapod tracks from the Union Chapel Mine. A, ALMNH unnumbered, *Attenosaurus subulensis*. B-C, *Alabamasauripus aldrichi*. B, UCM 024, *Alabamasauripus aldrichi*. C, ALMNH PV987.0001, *Alabamasauripus aldrichi*. D, UCM 021, *Dimetropus* sp. E, NMMNH P-40012, holotype of *Alabamasauripus aldrichi* (after Hunt et al., 2004).

TABLE 1. Differing opinions about the tetrapod ichnotaxonomy of the Union Chapel ichnofaunas

Trackmakers	Haubold et al. (2005)	Hunt et al. (2004; APH and SGL, this paper)
Temnospondyls	<i>Nanopus reidiae</i>	<i>Batrachichnus reidiae</i>
	<i>Matthewichnus caudifer</i>	<i>Matthewichnus caudifer</i>
Anthracosaurs	<i>Attenosaurus subulensis</i>	<i>Attenosaurus subulensis</i>
Amniotes	<i>Cincosaurus cobbi</i>	<i>Cincosaurus cobbi</i>
	<i>Notalacerta missouriensis</i>	<i>Notalacerta missouriensis</i>
		<i>Alabamasauripus aldrichi</i>
		<i>Dimetropus isp.</i>

The thin-bedded nature of the sediment allowed impression of the tracks through multiple bedding planes. This broad pattern of preservation is typical of other tidal flat deposits (e.g., Robledo Mountains tracksites). However, *the pervasive nature of preservation as undertracks in such a large sample is unique for any time period.*

### Paleoecology

The Union Chapel site preserves an array of paleoecological data, including evidence of both individual and group behavior (Pyenson and Martin, 2001; Martin and Pyenson, 2005). The most important feature of the site is the oldest occurrence of group behavior in tetrapods demonstrated by ichnological data (Pyenson and Martin, 2001; Martin and Pyenson, 2005). There is also interesting evidence of schooling in fish as evidenced by the trace fossil *Undichna* (Pyenson and Martin, 2001; Martin and Pyenson, 2005). Furthermore, there is a variety of unusual individual behaviors, including obstacle avoidance demonstrating stimulus response (Pyenson and Martin, 2001; Martin and Pyenson, 2005). It is important to note that the track-bearing Pottsville Formation is devoid of tetrapod body fossils. Thus, our only knowledge of the tetrapod fauna of this age in Alabama is based on the ichnological record. The Union Chapel site thus provides a window into an Early Pennsylvanian ecosystem, especially with regard to tetrapods, fish, arthropods, and plants. However, it lacks many components of the ecosystem that are found in other Carboniferous Lagerstätten.

### Ichnofacies

The tetrapod ichnofauna of the Union Chapel Mine is significant because it is the best known Carboniferous example of the *Batrachichnus* biotaxonichnofacies of Hunt and Lucas (2005). This widespread Paleozoic biotaxonichnofacies is present in water-laid nonmarine strata, and it has previously been referred to as the “red-bed ichnofacies” (e.g., Hunt et al., 1995c; Hunt and Lucas, 1998b) or the *Anthichnium-Limnopus* assem-

blage (Lockley and Meyer, 2000). This ichnofacies extends from the ?Early Mississippian to the Early Permian (Lucas et al., 2004; Hunt and Lucas, 2003, 2004b, 2005). The type ichnofauna of this biotaxonichnofacies is from the Lower Permian Robledo Mountains Formation of the Hueco Group in southern New Mexico.

### Geography

The Union Chapel site is by far the largest tracksite in the Paleozoic of eastern North America. All previously described localities from this region had only yielded a very small number of track-bearing slabs (Aldrich and Jones, 1930; Cotton et al., 1995; Lucas, 2003) (Fig. 3).

### Paleobiogeography

All the recognized ichnospecies from the Union Chapel Mine (*Attenosaurus subulensis*, *Alabamasauripus aldrichi*, *Matthewichnus caudifer*, *Notalacerta missouriensis*, *Batrachichnus reidiae*, *Cincosaurus cobbi*) are apparently restricted to an Appalachian paleobiogeographic province that includes Alabama, Kansas, Kentucky, Missouri, Oklahoma and Tennessee. However, we expect that ongoing studies of the ichnotaxonomy of other areas, notably Nova Scotia in eastern Canada and western Europe, will demonstrate that this apparent paleobiogeographic province is larger than now perceived (cf. Permian; Hunt and Lucas, 1998a).

### Stratigraphy

There are two principal, documented tracksites in the upper Pottsville Formation. The older locality is the Number 11 Mine of the Galloway Coal Company near Carbon Hill (Aldrich and Jones, 1930). The younger is the Union Chapel Mine near Jasper (Pashin, 2003, 2005). The track-bearing horizon at the Number 11 Mine is in the shale immediately above the Jagger coal seam, whereas at the Union Chapel Mine it is above the Mary

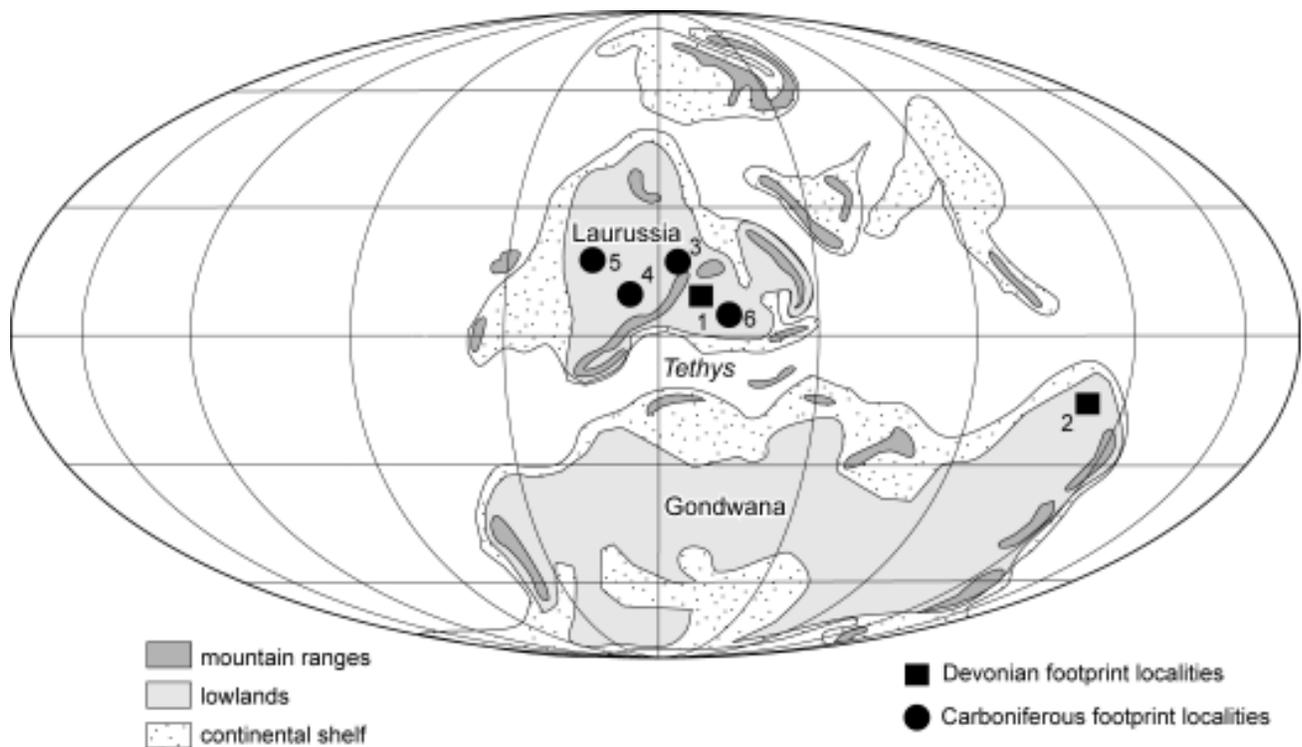


FIGURE 3. Global map of Devonian and Carboniferous tetrapod ichnofaunas showing distribution of principal tetrapod tracksites. Devonian sites are: 1, Ireland and Scotland, 2, eastern Australia. Carboniferous sites are: 3, Nova Scotia, 4, eastern United States, 5, western United States, 6, western Europe. Base map after DiMichele and Hook (1992).

Lee coal bed. The stratigraphic separation of the two track horizons is about 20 m (Metzger, 1965). These two track zones may have importance for correlation within the Pottsville Formation outcrop belt.

In addition, J. Lacefield has collected many specimens from two other sites whose stratigraphic setting has not been documented (Haubold et al., 2005). Thus, there is need for more work to document the stratigraphic level of all tracksites in the Pottsville Formation.

### Biostratigraphy and Biochronology

The stratigraphic distribution of tetrapod tracks in the Paleozoic of the eastern United States is poorly understood, and this limits the biostratigraphic utility of the Union Chapel Mine tracks. However, it is likely that more work will demonstrate long stratigraphic ranges for the ichnotaxa from Union Chapel and that they will have limited use in biostratigraphy and biochronology. Lucas (2003; Fig. 4) has demonstrated that only three intervals can be recognized in the Carboniferous track record:

1. The Mississippian track record (mostly known from North America) is temnospondyl-dominated and has rare captorhinomorph tracks.

2. The Early-Middle Pennsylvanian (Westphalian) record, including the Union Chapel Mine, shows a mixture of temnospondyl tracks (e.g., *Limnopus*, *Schmidtopus*, *Paleosauropus*, *Cursipes*) and

captorhinomorph (e.g., *Pseudobradypus*, *Asperipes*) tracks. It is the abundance of the captorhinomorph tracks that distinguishes the Westphalian sites from the Mississippian sites, and Lucas (2003) termed this interval the *Pseudobradypus* biochron.

3. The Late Pennsylvanian track record includes the lowest occurrences of *Batrachichnus*, *Ichniotherium*, *Dromopus*, *Gilmoreichnus* and *Dimetropus*, ichnotaxa characteristic of the younger, Early Permian ichnofauna. This is the beginning of the *Dromopus* biochron, which continues through the Early Permian.

### Paleoenvironment and Paleogeography

Superficially, the sedimentological context of the Union Chapel site resembles other Permo-Pennsylvanian tracksites. Buildex in Kansas (Pennsylvanian), Mansfield in Indiana (Pennsylvanian), Keota in Oklahoma (Pennsylvanian) and the Robledo Mountains in New Mexico (Permian) are all associated with freshwater tidal flat settings, as is Union Chapel (Lucas et al., 2004b; Pashin, 2005). These tracksites are all characterized by arthropod locomotion, resting and grazing traces, fish swimming traces and an abundance of tetrapod tracks (Lucas et al., 2004). However, the Union Chapel site is conspicuous by its absence of the characteristic insect resting trace *Tonganoxichnus*, which gives its name to the assemblage (or ichnofacies) that includes these other sites. This suggests that Union Chapel represents a significant variant of tidal flat environment.

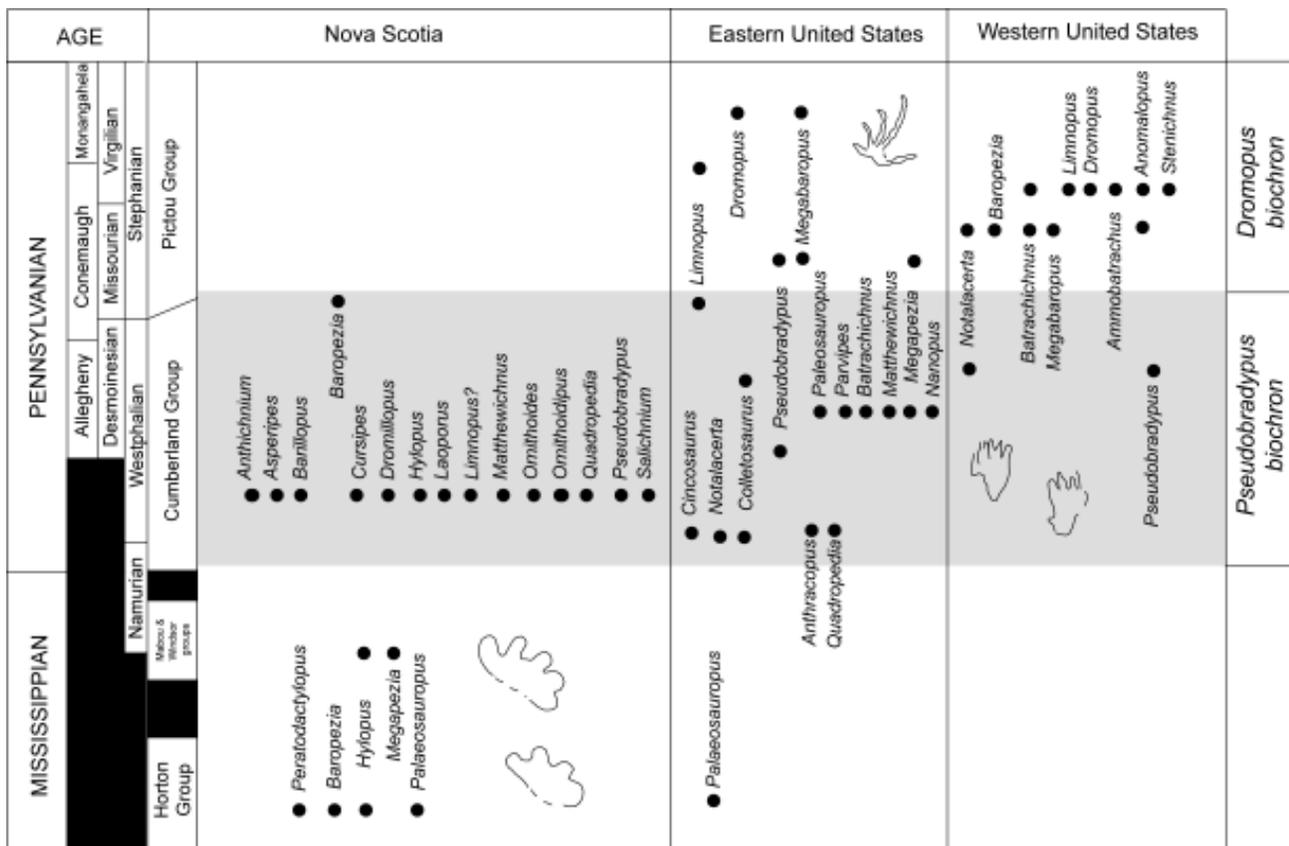


FIGURE 4. Temporal distribution of Carboniferous tetrapod footprint ichnogenera in North America (after Lucas, 2003). Section in Nova Scotia based on Calder (1998)

An alternative hypothesis is that *Tonganoxnichnus* ichnotraces were removed by the frequent erosion of track-bearing bedding planes, which is indicated by the prevalence of tetrapod undertracks.

An interesting sedimentological inquiry would be to investigate why tetrapod tracks are apparently stratigraphically restricted within the Pottsville Formation. In most cases paleontologists construct essentially *ad hoc* hypotheses to explain fossil preservation at a given location instead of viewing the fossil preservation as an indicator of a certain set of environmental and/or diagenetic criteria.

### Preservation

The Union Chapel Mine site is unusual in several aspects of its preservation. Many other preserved tracksites from the Lower Cretaceous of Australia to the Lower Jurassic of Poland are contained within buildings or under canopies. Virtually all other preserved tracksites display to the public one large bedding plane (e.g., Lark Quarry in Australia) or large exposures of several bedding planes (e.g., Clayton Lake State Park in New Mexico). The Union Chapel site is the only tracksite of which we are aware that preserves a spoil pile and unexcavated strata. This could provide a model for the preservation of the Permian Robledo Mountains tracksites of southern New Mexico.

### Education

Tetrapods are intrinsically interesting to the public as they readily invoke past environments. The Union Chapel site has been of tremendous educational utility to the members of the Alabama Paleontological Society and those with whom they have interacted. The Steve Minkin Paleozoic Footprint Site at Union Chapel has tremendous potential for education through signage, printed matter, audio-visual treatments and web-based resources.

### Sociology

There are interesting comparisons to be made between the development of the Union Chapel site and other tracksites. As with the Robledo Mountains tracksites in southern New Mexico and the St. George tracksite in Utah, the site was championed by volunteer effort with early interaction from professional paleontologists. The Union Chapel story differs markedly from the others in that a talented and diverse group of amateurs collaborated in the development of the site (Atkinson et al., 2005; Buta and Minkin, 2005; Laceyfield and Relihan, 2005). In the case of the Robledo Mountains and St. George sites, a single amateur (Jerry MacDonald and Andrew R. C. Milner, respectively) carried the torch. As at St. George, the Union Chapel Mine was saved for posterity

(Atkinson et al., 2005), whereas the Robledo sites, although demonstrated to be of global significance, are being quarried for flagstone or left to be vandalized and eroded. The Alabama Paleontological Society and its associates deserve high praise—they caught the attention of the paleontological community, saved the site from infilling and stimulated a comprehensive study of this site. Two interesting and unique aspects of the promotion of the Union Chapel site are the “Track Meets” (meetings of the Alabama Paleontological Society to catalog and document specimens in private collections) and the superb website that excited the attention of many paleontologists around the world (Buta and Minkin, 2005; Atkinson et al., 2005; Lacefield and Relihan, 2005).

### History of Discovery

The Union Chapel site is important historically as the first large Carboniferous tracksite discovered in the world and as the first significant Paleozoic tracksite found in the eastern United States. A tracksite from the Early Mississippian of Nova Scotia is potentially the oldest large tracksite known (Lucas et al., 2004a).

### CONCLUSIONS

The Union Chapel Mine site (Steve Minkin Paleozoic Footprint Site) is significant because:

1. It is the largest Carboniferous tracksite known.
2. It clarifies the ichnotaxonomy of some of the Carboniferous tetrapod ichnotaxa of the southeastern United States.
3. It has a unique taphonomic setting that preserves abundant tetrapod tracks, which are virtually all undertracks.
4. It preserves the oldest ichnological evidence for group behavior in tetrapods and fish.
5. It is the best known Carboniferous example of the *Batrachichnus* biotaxonichnofacies.
6. The Union Chapel site is by far the largest tracksite in the Paleozoic of eastern North America.
7. It appears to provide evidence for an Appalachian paleobiogeographic province in Carboniferous tetrapods.
8. The track zone may have utility for correlation.
9. It represents a previously unrecognized type of Permian-Pennsylvanian ichnofauna in a freshwater tidal flat setting that lacks *Tonganoxichnus*.
10. It is a preserved tracksite that is neither under a man-made structure nor exposes one or more extensive bedding planes.
11. It has a proven importance for public education.
12. The history of its preservation is unique in that a talented and diverse group of amateurs collaborated in the development and preservation of the site.
13. It is the first large Carboniferous tracksite discovered in the world and the first significant Paleozoic tracksite in the eastern United States.

### ACKNOWLEDGMENTS

APH and SGL thank Andrew K. Rindsberg and Ron

Buta for inviting them to the 2003 symposium on the Union Chapel site (Martin, 2003b) that allowed them to work on the track record from the Union Chapel Mine. We would also like to thank the Alabama Paleontological Society for allowing the NMMNH to obtain a representative sample of the ichnofauna.

NDP would like to thank his undergraduate research advisor, Anthony J. Martin, for providing him with his first academic opportunity to explore paleobiology and also Chris Beck, John Kingston, Lori Marino, James Millette, Andrew K. Rindsberg, Michelle A. Schmitt, Don Shure, Amanda Starnes, Chris Van Loon and John Wegner for their advice, encouragement and friendship during his undergraduate years at Emory University. NDP also thanks Andrew K. Rindsberg and Larry A. Herr for hospitality and wonderful conversation on many occasions. NDP received financial support from a Faculty Senate Nanogrant, two Summer Undergraduate Research Experience (SURE) Fellowships from Emory University and travel funds from the Regents of the University of California. NDP also thanks Randall Irmis for his input. This is UCMP contribution number 1882.

Robert M. Sullivan, Kate Zeigler, and David C. Kopaska-Merkel provided useful reviews of this paper.

### REFERENCES

- Aldrich, T. H., Sr. and Jones, W. B., 1930, Footprints from the coal measures of Alabama: Alabama Museum of Natural History, Museum Paper 9, 64 p.
- Allen, A., 2005, Discovery of the Union Chapel Mine site; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 15-17.
- Atkinson, T. P., 2005, Arthropod body fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., 2005, Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 169-176.
- Atkinson, T. P., Buta, R. J. and Kopaska-Merkel, D. C., 2005, Saving the Union Chapel Mine: how a group of determined amateurs teamed up with professionals to save a world-class trackway site in Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 191-200.
- Baird, D., 1965, Footprints from the Cutler Formation: U. S. Geological Survey, Professional Paper 503C, p. C47-C50.
- Baird, G. C., Shabica, C. W., Anderson, J. L. and Richardson, E. S., Jr., 1985, Biota of a Pennsylvanian muddy coast — habitats within the Mazonian delta complex, northeast Illinois: Journal of Paleontology, v. 59, p. 253-281.
- Bosellini, A., 2002, Dinosaurs “re-write” the geodynamics of the eastern Mediterranean and the paleogeography of the Apula Platform: Earth Science Reviews, v. 59, p. 211-234.
- Briggs, D. E. G., Clark, N. D. L., and Clarkson, E. N. K., 1991, The Granton ‘shrimp-bed’, Edinburgh — a Lower Carboniferous Konservat-Lagerstätte: Transactions of the Royal Society of Edinburgh, Earth Sciences, v. 82 (1), p. 65-85.
- Buta, R. J. and Minkin, S. C., 2005, The salvaging and documentation of trace fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 19-27.

- Calder, J. H., 1998, The Carboniferous evolution of Nova Scotia; in Blundell, D. J., and Scott, A. C., eds., *Lyell: The past is the key to the present: Geological Society of London Special Publication*, no. 143, p. 261-302.
- Carrano, M. T. and Wilson, J. A., 2001, Taxon distributions and the tetrapod track record: *Paleobiology*, v. 27, p. 563-581.
- Cotton, W. D., Hunt, A. P. and Cotton, J. E., 1995, Paleozoic tracksites in eastern North America: *Bulletin of New Mexico Museum of Natural History and Science*, no. 6, p. 189-211.
- Cunningham, C. R., Feldman, H. R., Franseen, E. K., Gastaldo, R. A., Maples, G. K., Maples, C. G., and Schultze, H.-P., 1993, The Upper Carboniferous Hamilton Fossil-Lagerstätte in Kansas: a valley-fill, tidally influenced deposit: *Lethaia*, v. 26, p. 225-236.
- Dilcher, D., Lott, T. A., and Axsmith, B. J., 2005, Fossil plants from the Union Chapel Mine, Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 153-168.
- DiMichele, W. A. and Hook, R. W., 1992, Paleozoic terrestrial ecosystems; in Behrensmeyer, A. K., Damuth, J. D., DiMichele, W. A., Potts, R., Sues, H.-D., and Wing, S. L., eds., *Terrestrial ecosystems through time*. Chicago, University of Chicago Press, p. 205-325.
- Ferguson, L., 1988, The fossil cliffs of Joggins: Halifax, Nova Scotia Museum, 52 p.
- Fritsch, A., 1899, *Fauna der Gaskohle und der Kalksteine der Permformation Böhmens: Prague, Vieter Band, Heft 1*.
- Gatesy, S. M., 2004, Direct and indirect track features: What sediment did a dinosaur touch?: *Ichnos*, v. 10, p. 91-99.
- Gatesy, S. M., Middleton, K. M., Jenkins, F. A. and Shubin, S. H., 1999, Three-dimensional preservation of foot movements in Triassic theropod dinosaurs: *Nature*, v. 399, p. 141-144.
- Grogan E. D., and R. Lund. 2002. The geological and biological environment of the Bear Gulch Limestone (Mississippian of Montana, USA) and a model for its deposition: *Geodiversitas*, v. 24, p. 295-315.
- Haubold, H., 1996, *Ichnotaxonomie und Klassifikation von Tetrapodenfährten aus dem Perm: Hallesches Jahrbuch für Geowissenschaften*, ser. B, v. 18, p. 23-88.
- Haubold, H., Hunt, A. P., Lucas, S. G. and Lockley, M. G., 1995, Wolfcampian (Early Permian) vertebrate tracks from Arizona and New Mexico: *Bulletin of New Mexico Museum of Natural History and Science*, no. 6, p. 135-165.
- Haubold, H., Allen, A., Atkinson, P., Lacefield, J., Minkin, S. and Relihan, B., 2003, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama, in Martin, A. J., ed., *Workshop on Permo-Carboniferous Ichnology, Program and Abstracts*. University of Alabama, Tuscaloosa, p. 5-7.
- Haubold, H., Allen, A., Atkinson, T. P., Buta, R. J., Lacefield, J. A., Minkin, S. C. and Relihan, B. A., 2005, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 75-111.
- Heckert, A. B., Lucas, S. G., Zeigler, K. E., Peterson, R. E., Peterson, R. E. and D'Andrea N. V. "D.", 2000, Stratigraphy, taphonomy, and new discoveries from the Upper Jurassic (Morrison Formation: Brushy Basin Member) Peterson quarry, central New Mexico: *New Mexico Museum of Natural History and Science Bulletin*, no. 17, p. 51-59.
- Hunt, A. P. and Lucas, S. G., 1998a, Implications of the cosmopolitanism of Permian tetrapod ichnofaunas: *New Mexico Museum of Natural History and Science Bulletin*, no. 12, p. 55-57.
- Hunt, A. P. and Lucas, S. G., 1998b, Vertebrate ichnofaunas of New Mexico and their bearing on Lower Permian vertebrate ichnofacies: *New Mexico Museum of Natural History and Science Bulletin*, no. 12, p. 63-65.
- Hunt, A. P. and Lucas, S. G., 2003, Tetrapod ichnofacies in the Paleozoic; in Martin, A. J., ed., *Workshop on Permo-Carboniferous Ichnology, Program and Abstracts*. University of Alabama, Tuscaloosa, p. 8-11.
- Hunt, A. P. and Lucas, S. G., 2004a, Multiple, parallel, dinosaur tail drags from the Early Cretaceous of New Mexico: *Journal of Vertebrate Paleontology*, v. 24 (supplement to no. 3), p. 73A.
- Hunt, A. P. and Lucas, S. G., 2004b, Tetrapod ichnofacies in the Paleozoic: 32nd International Geological Congress Italia 2004 Abstracts Part 1. International Union of Geological Sciences, p. 600.
- Hunt, A. P. and Lucas, S. G., 2005, Tetrapod ichnofacies and their utility in the Paleozoic; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 113-119.
- Hunt, A. P., Lucas, S. G. and Lockley, M. G., 1995b, Paleozoic tracksites of the western United States: *Bulletin of New Mexico Museum of Natural History and Science*, no. 6, p. 213-217.
- Hunt, A. P., Lucas, S. G. and Lockley, M. G., 2004, Large pelycosaur footprints from the Lower Pennsylvanian of Alabama, USA: *Ichnos*, v. 11, p. 39-45.
- Hunt, A. P., Lucas, S. G., Haubold, H. and Lockley, M. G., 1995a, Early Permian (late Wolfcampian) tetrapod tracks from the Robledo Mountains, south-central New Mexico: *Bulletin of New Mexico Museum of Natural History and Science*, no. 6, p. 167-180.
- Hunt, A. P., Lucas, S. G., Lockley, M. G., Haubold, H. and Braddy, S., 1995c, Tetrapod ichnofacies in Early Permian red beds of the American Southwest. *Bulletin of New Mexico Museum of Natural History and Science*, no. 6, p. 295-301.
- Hunt, A. P., Lucas, S. G., Calder, J. H., Van Allen, H. E. K., George, E., Gibling, M., Hebert, B. L., Mansky, C. and Reid, D. R., 2004, Tetrapod footprints from Nova Scotia: the Rosetta Stone for Carboniferous tetrapod ichnology: *Geological Society of America, Abstracts with Programs*, v. 36(5), p. 66.
- Lacefield, J. A. and Relihan, B. A., 2005, The significance of the Union Chapel Mine site to Alabama paleontology; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 201-204.
- Lockley, M. G., 2001, A field guide to Dinosaur Ridge: Morrison, Colorado, Friends of Dinosaur Ridge, 34 p.
- Lockley, M. G. and Hunt, A. P., 1994, A guide to the fossil footprints of the Dinosaur Ridge area: Morrison, Colorado, Friends of Dinosaur Ridge, 37 p.
- Lockley, M. G. and Hunt, A. P., 1995, Dinosaur tracks and other fossil footprints of the western United States: New York, Columbia University Press, 338 p.
- Lockley, M. G., and Meyer, C., 2000, Dinosaur tracks and other fossil footprints of Europe: New York, Columbia University Press, 323 p.
- Lockley, M. G., Hunt, A. P. and Meyer, C., 1994, Vertebrate tracks and the ichnofacies concept: implications for paleoecology and palichnostratigraphy; in Donovan, S., ed., *The palaeobiology of trace fossils*: London, John Wiley, p. 241-268.
- Lockley, M., Hunt, A. P., Holbrook, J., Matsukawa, M. and Meyer, C., 1992, The dinosaur freeway: a preliminary report on the Cretaceous megatracksite, Dakota Group, Rocky Mountain Front Range, and High Plains, Colorado, Oklahoma and New Mexico; in Flores, R. M., ed., *Field Guidebook, Mesozoic of*

- the Western Interior: SEPM 1992 Theme Meeting. Rocky Mountain Section SEPM (Society for Sedimentary Geology), Fort Collins, Colorado, p. 39-54.
- Lucas, S. G., 2003, Carboniferous tetrapod footprint biostratigraphy and biochronology: Newsletter on Carboniferous Stratigraphy, no. 21, p. 36-41.
- Lucas, S., G., in press, Tetrapod footprint biostratigraphy and biochronology: *Ichnos*.
- Lucas, S. G., and Heckert, A. B., 1995, eds., 1998, Early Permian footprints and facies: New Mexico: Bulletin of New Mexico Museum of Natural History and Science, v. 6, 301 p.
- Lucas, S. G. and Lerner, A. J., 2005, Lower Pennsylvanian invertebrate ichnofossils from the Union Chapel Mine, Alabama: a preliminary assessment; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 147-152.
- Lucas, S. G., and Zeigler, K. E., eds., 2004, Carboniferous-Permian transition at Carrizo Arroyo, central New Mexico: New Mexico: Bulletin of New Mexico Museum of Natural History and Science, no. 25, 300 p.
- Lucas, S. G., Estep, J. W. and Hoffer, J. M., eds., 1998, Permian stratigraphy and paleontology of the Robledo Mountains, New Mexico: Bulletin of New Mexico Museum of Natural History and Science, no. 12, 98 p.
- Lucas, S. G., Lozovsky, V. R. and Shishkin, M. A., 1999, Tetrapod footprints from the Early Permian redbeds of the northern Caucasus, Russia: *Ichnos*, v. 6, p. 277-281.
- Lucas, S. G., Anderson, O. J., Heckert, A. B. and Hunt, A. P., 1995, Geology of Early Permian tracksites, Robledo Mountains, south-central New Mexico: New Mexico Museum of Natural History and Science Bulletin, no. 6, p. 13-32.
- Lucas, S. G., Hunt, A. P., Mansky, C. and Calder, J. H., 2004a, The oldest tetrapod footprint ichnofaunas, from the Lower Mississippian Horton Bluff Formation, Nova Scotia, Canada: Geological Society of America, Abstracts with Programs, v. 36(5), p. 66.
- Lucas, S. G., Lerner, A. J., Bruner, M. and Shipman, P., 2004b, Middle Pennsylvanian ichnofauna from eastern Oklahoma, USA: *Ichnos*, v. 11, p. 45-55.
- MacDonald, J., 1994, Earth's first steps: tracking life before the dinosaurs: Boulder, Colorado, Johnson Books, 290 p.
- Manning, P. L., 2004, A new approach to the analysis and interpretation of tracks: examples from the Dinosauria; in McIlroy, D., ed., The application of ichnology to paleoenvironmental and stratigraphic analysis: Geological Society of London Special Publication, p. 93-123.
- Martin, A. J., 2003a, *Undichna*: A trace fossil bridging the gap between fish and tetrapods; in Martin, A. J., ed., Workshop on Permo-Carboniferous ichnology, Program and Abstracts. University of Alabama, Tuscaloosa, p. 9-21.
- Martin, A. J., ed., 2003b, Workshop on Permo-Carboniferous Ichnology, Program and Abstracts: University of Alabama, Tuscaloosa.
- Martin, A. J. and Pyenson, N. D., 2005, Behavioral significance of vertebrate trace fossils from the Union Chapel site; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 59-73.
- McKee, E. D., 1947, Experiments on the development of tracks in fine, cross-bedded sand: *Journal of Sedimentary Petrology*, v. 17, p. 23-28.
- Melchor, R. N., 1997, Permian tetrapod ichnofaunas from Argentina: further evidence of redbed shallow lacustrine and Aeolian vertebrate ichnofacies: Workshop on the Ichnofacies and Ichnotaxonomy of the Terrestrial Permian, Abstracts and Papers, Halle, p. 59-60.
- Melchor, R. N., 2001, Permian tetrapod footprints from Argentina: *Hallesches Jahrbuch für Geowissenschaften*, ser. B, v. 23, p. 35-43
- Melchor, R. N. and Poiré, D., 1992, Sedimentological and paleoecological implications of invertebrate and tetrapod ichnocoenosis from a Permian fluvial/lacustrine sequence: Carapacha Formation, La Pampa Province, Argentina: Cuarta Reunión Argentina de Sedimentología, Actas III, p. 247-257.
- Melchor, R. N. and Sarjeant, W. A. S., 2004, Small amphibian and reptile footprints from the Permian Carapacha Basin, Argentina: *Ichnos*, v. 11, p. 57-78.
- Metzger, W. J., 1965, Pennsylvanian stratigraphy of the Warrior basin, Alabama: Geological Survey of Alabama Circular 30, 80 p.
- Minkin, S. C., 2000, Pennsylvanian vertebrate trackways, Walker County, Alabama: Alabama Geological Society Newsletter, v. 13 (4), p. 7-10.
- Minkin, S. C., 2005, Paleoenvironment of the *Cincosaurus* beds, Walker County, Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 31-38.
- Nutzel, A., Yancey, T. E., and Mapes, R. H., 2000, Exceptional preservation of gastropods in the Buckhorn Lagerstätte, (Late Carboniferous, Desmoinesian) Buckhorn asphalt quarry, Oklahoma: Abstracts with Programs, Geological Society of America, v. 32 (7), p. 97.
- Orr, P.J. and Briggs, D. E. G., 1999, The Castlecomer fauna from the Leinster Coalfield in south-eastern Ireland is an arthropod-dominated Konservat-Lagerstätte of basal or early Westphalian (Late Carboniferous) age: Special Papers in Palaeontology, vol., p. 62-68.
- Ostrom, J. H., 1972, Were some dinosaurs gregarious?: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 10, p. 287-301.
- Pashin, J., 2003, Stratigraphy of the Union Chapel Mine in its regional context; in Martin, A. J., ed., Workshop on Permo-Carboniferous Ichnology, Program and Abstracts. University of Alabama, Tuscaloosa, p. 25-26.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 39-58.
- Pyenson, N. D. and Martin, A. J., 2001, Paleontological and behavioral significance of amphibian tracks from the Pottsville Formation (Lower Pennsylvanian: Westphalian A), Union Chapel Mine, Alabama: Geological Society of America, Abstracts with Programs, v. 33 (2), p. 2.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2003, *Treptichnus* and related trace fossils from the Union Chapel Mine (Langsettian, Alabama, USA): in Martin, A. J., ed., Workshop on Permo-Carboniferous Ichnology, Program and Abstracts. University of Alabama, Tuscaloosa, p. 27-28.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, *Treptichnus* and *Arenicolites* from the Steven C. Minkin Paleozoic Footprint site (Langsettian, Alabama, USA); in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 121-141.
- Rolfe, W. D. I., Schram, F., Pacaud, G., Sotty, D., and Secretan, S., 1982, A remarkable Stephanian biota from Montceau-les-Mines, France: *Journal of Paleontology*, v. 56, p. 426-428.
- Santucci, V. L., Hunt, A. P. and Lucas, S. G., 2003, Stratigraphic distribution of tetrapod and invertebrate ichnofossils in the Permian Coconino Sandstone of Grand Canyon National Park and adjacent areas, northern Arizona: Geological Society of

- America, Abstracts with Programs, v. 35 (6), p. 498-499.
- Selden, P. A. and Nudds, J. R. 2004, Evolution of Fossil Ecosystems. Mason Publishing: 192 p.
- Seilacher, A., 1967a, Fossil behavior: Scientific American, v. 217, p.: 72-80.
- Seilacher, A., 1967b, Bathymetry of trace fossils: Marine Geology, v. 5, p. 413-428.
- Seilacher, A., 1970, Begriff und Bedeutung der Fossil- Lagerstätten: Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, v. 1970, p. 34-39.
- Seilacher, A., 1990, Taphonomy of fossil-Lagerstätten; in D. E. G. Briggs and P. R. Crowther, eds., Paleobiology: a synthesis. London, Blackwell, p. 266-270.
- Seilacher, A., Reif, W. E., and Westphal, F., 1985, Sedimentological, ecological and temporal patterns of fossil Lagerstätten; in Whittington, H.B. and Conway Morris, S., eds., Extraordinary Fossil Biotas: their ecological and evolutionary significance: Philosophical Transactions of the Royal Society of London, v. B311, p. 5-26.
- Steinbock, R. T., 1989, Ichnology of the Connecticut Valley: a vignette of American science in the early nineteenth century; in Gillette, D. D. and Lockley, M. G., eds., Dinosaur Tracks and Traces. Cambridge, Cambridge University Press, p. 27-36.
- Uchman, A., 2005, *Treptichnus*-like traces made by insect larvae (Diptera: Chironomidae: Tipulidae); in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 143-146.
- Zidek, J., ed., 1992, Geology and paleontology of the Kinney Brick Quarry, Late Pennsylvanian, central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 138, 242 p.

#### **AUTHORS' E-MAIL ADDRESSES**

Adrian P. Hunt: ahunt@nmmnh.state.nm.us  
 Spencer G. Lucas: slucas@nmmnh.state.al.us  
 Nicholas D. Pyenson: pyenson@berkeley.edu

## DISCOVERY OF THE UNION CHAPEL MINE SITE

ASHLEY ALLEN

Oneonta High School, Oneonta, Alabama 35121, USA

**ABSTRACT:** The discovery of the Union Chapel Mine as a major track fossil site is described, and photographs of the first trackways found are presented. From the first day, it was clear that Union Chapel Mine was not a typical fossil site. The abundance and detailed preservation of the trackways, both vertebrate and invertebrate, were obvious. Thanks to cooperation from the mine owner and an alert high school student, a fossil site that might have escaped notice was drawn to the attention, first of amateurs, and then of professional paleontologists.

### INTRODUCTION

In the early fall of 1999, I was introducing the general content of my seventh grade science class to my students. The usual topic of field trips was discussed. I told my students of many successful trips I had made to north Alabama coal mines for Pennsylvanian plants. Jessie Burton, an energetic young pupil (Fig. 1), volunteered the information that his grandmother owned a coal mining company and suggested that the class visit one of her mines for a field trip. Always willing to investigate a new site, I took the information and prepared to make a scouting expedition. When I contacted Mrs. Dolores Reid, owner of New Acton Coal Mining Company, she was glad to host 75 seventh graders exploring the tailings of a coal mine in search for the usual plant fossils. Mrs. Reid contacted her employees and was informed by Messrs. Tommy Lata and Billy Orick that they noted more fossils in the Union Chapel Mine than in the company's other mines. Arrangements were soon made for me to scout the mine for field trip suitability.



FIGURE 1. Jessie Burton. Photo taken at the Union Chapel Mine, July 2004, by Ron Buta.

### THE FIRST TRACKWAYS FOUND

After less than half an hour of scouting, I exclaimed "Yahoo!" when I found a large invertebrate trackway (Fig. 2). This indicated the proper environment and conditions for the potential preservation of amphibian tracks (Aldrich and Jones, 1930) — the finding of which has been a long-term goal for me. Another invertebrate trackway was found within minutes (Fig. 3). Then, as I was walking up a newly bulldozed road, I saw a long, flat, layered rock jutting out of the hillside. One blow of hammer on chisel and the rock popped into tablet-like halves revealing three separate — and definite — tetrapod trackways (Fig. 4). There was even a small, round *Calamites* protruding through the laminae at a sharp angle to boot. The exclamation at this point went beyond "Yahoo!" A hybrid feeling of excitement, satisfaction, and disbelief would make the next few hours of searching seem like seconds. About a dozen more tetra-

pod trackways and three more invertebrate trackways, one with associated plants, were collected. Figures 5 and 6 show other trackways found during this first visit.

Afterwards, I contacted Dr. Jim Lacefield, author of *Lost Worlds in Alabama Rocks: A Guide to the State's Ancient Life and Landscape*, for confirmation of the nature of the trace fossils with the knowledge that Dr. Lacefield was familiar with Pennsylvanian trace fossils of Alabama — tetrapod trackways in particular. With the identity confirmed, I took some of the specimens to the December 1999 meeting of the Birmingham Paleontological Society (BPS, incorporated as the Alabama Paleontological Society in 2002). It was quickly decided that the Union Chapel Mine would be the site for its next monthly field trip. Since the first scouting trip in late November, the Union Chapel Mine has been visited many times by members of the BPS (and then later the



FIGURE 2. First trackway found.



FIGURE 3. Second trackway found, consisting of *Kouphichnium* undertracks.



FIGURE 4. The first definite tetrapod trackways found, a slab with at least three different trackways.



FIGURE 5. Another invertebrate trace found on the first day.



FIGURE 6. Two oppositely directed tetrapod trackways from the first visit.

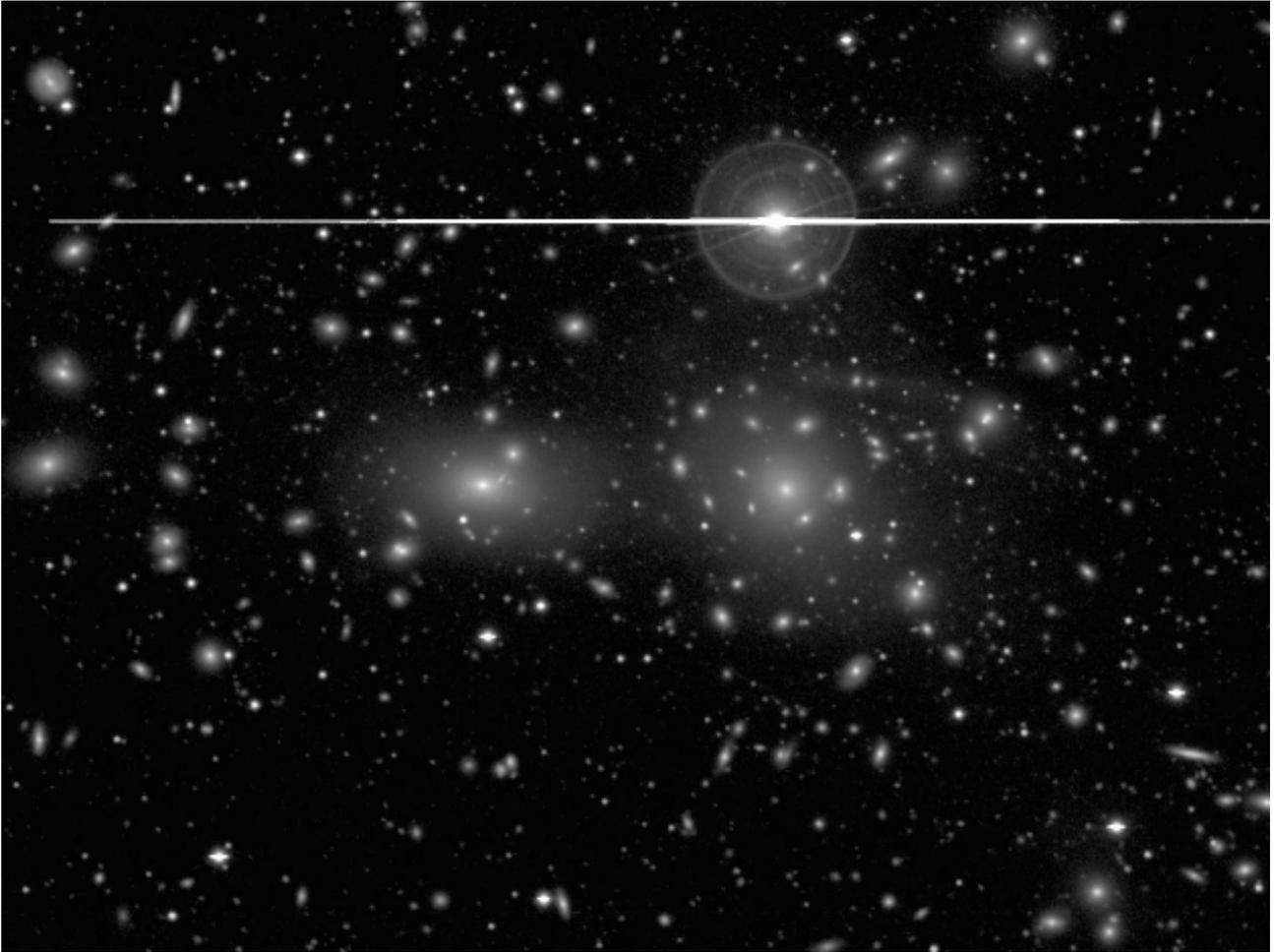
APS), area universities, and even the class that was looking for a place to take a field trip. Thanks to active student participation, we have an excellent Pennsylvanian tracksite that will be studied for some time to come.

#### **ACKNOWLEDGMENTS**

I am grateful to Mrs. Reid for her generosity in allowing me to scout the Union Chapel Mine, and to the mine personnel for making the visit practical. I am also indebted to Jessie Burton for recognizing my interest in fossils and alerting me to the existence of this wonderful fossil-collecting site.

#### **REFERENCE**

Aldrich, T. H., Sr., and Jones, W. B., 1930, Footprints from the Coal Measures of Alabama: Alabama Museum of Natural History, Museum Paper, no. 9, 64 p.



At 300 million light years, the Coma Galaxy Cluster (Abell 1656) represents early Pennsylvanian light reaching us today (original image courtesy C. Mihos, Case Western Reserve University; prepared by Ron Buta).

## THE SALVAGING AND DOCUMENTATION OF TRACE FOSSILS FROM THE UNION CHAPEL MINE

RONALD J. BUTA

Department of Physics and Astronomy, University of Alabama, Box 870324, Tuscaloosa, Alabama 35487, USA

STEVEN C. MINKIN

Anniston, Alabama, USA (deceased February 20, 2004)

**ABSTRACT:** The discovery of high-quality vertebrate and invertebrate trace fossils at the Union Chapel Mine in late 1999 led to an extraordinary salvaging effort by members of the Birmingham Paleontological Society (BPS, incorporated as the Alabama Paleontological Society, or APS, in 2002) during the following 18 months. Trackways, fish trails, feeding traces, a pair of wings, and other fossils were collected from the residual rock piles left by the mining operation, and could be found at most locations in the mine. So many high-quality trackways were found that the BPS/APS organized four “Track Meets” to photographically document the finds as well as record the current repository (e.g., in private collections, museums, universities, etc.). We describe here the salvaging and documentation of Union Chapel Mine trace fossils and how this led to a remarkable cooperation between amateur and professional paleontologists in Alabama and elsewhere. We also describe what the mine was like before and after its partial reclamation in December 2000, and what kinds of rocks yielded different kinds of trace fossils.

### INTRODUCTION

The BPS/APS began its explorations of the rocks and fossils of the Union Chapel Mine in January 2000. At the regular BPS meeting held at the Homewood Public Library that month, Ashley Allen (see Allen, 2005) recounted his initial findings of tetrapod trackways at the mine, and the group decided to make the mine the focus of its next field trip. Mrs. Dolores Reid, owner of the New Acton Coal Mining Company, gave her permission to collect fossils from the site. The field trip took place on January 23, a rather bleak day that started out rainy but ended up being just mostly cloudy during the BPS visit. Because of the weather, only 11 people attended the event. Several of these later became part of a core group that diligently hunted for trackways at the site on as many visits as possible. Over the next year, the BPS also held several more organized field trips to the site. Minkin (2000) wrote a preliminary review of the group’s findings.

The trackways were found in spoil piles of rocks left over from the mining operation (Figs. 1 and 2). The spoil piles came from the overburden of the Mary Lee coal seam of the Mary Lee cycle of the Pottsville Formation, below the New Castle coal seam (Pashin, 2005; see also Fig. 3). The way trackways were found among these piles depended as much on the diligence of the collector as it did on the recognition of the right types of rocks. Any fine-grained, layered rock could potentially hold tracks. For the smaller tetrapod tracks (*Cincosaurus cobbi* and others; Haubold et al., 2005), the best rock type was a clay shale. This shale is mostly gray but occasionally had some reddish tint, likely due to oxidation of the sediments when they were exposed to the atmosphere at the time of deposition. Shale that contained silt, sand, or mica grains yielded few of the small tetrapod trackways. Burrows were generally absent from

the vertebrate trackway-bearing shale.

Another type of rock that yielded trackways was a gray siltstone, in which burrows are common. This rock type indicates a standing body of water that animals walked in. It was a common host rock for the larger vertebrate trackways, especially *Attenosaurus subulensis* (Aldrich and Jones, 1930; Haubold et al., 2005).

Although invertebrate traces were found in similar kinds of rocks, certain vertebrate and invertebrate traces are rarely found on the same slabs. In fact, multiple trackways on the same bedding plane are commonly either the same kind of trackway or a mix of different kinds of vertebrate or invertebrate trackways. The trackmakers evidently did not intermingle very much, although several examples of vertebrate and invertebrate trackways on the same bedding plane have been found.

A few other features correlated with the presence of tracks. For example, small circular depressions or elevations, superficially resembling raindrop imprints and their counterparts (but which are more likely to be gas-escape features; Rindsberg, 2005a), were commonly associated with tracks, as were uncommon small plant parts (such as individual pinnules of seed ferns). Occasionally, a whole fern frond would be found on a track-bearing slab. The track-bearing slabs themselves are also found mixed with slabs bearing many fossil plant impressions, including casts of lycopod trunks and *Calamites* piths.

The weather and time of day were also important factors in the finding of trackways, which were most easily noticed on sunny days when the Sun was not too high. On less favorable days, moisture can enhance the appearance of trackways that might be virtually invisible on a dry, overcast day. Although trackways were found over most of the mine, some areas were clearly richer in trackways than others. Before the reclamation



FIGURE 1. Spoil piles at the Union Chapel Mine yielded numerous trackways.

of the mine in December 2000, searching for trackways was often a precarious process involving the climbing of steep spoil piles (Fig. 2).

Some trackways are exposed directly on the surface, either face-up or after turning over a slab, whereas others are found only after a slab was split along a bedding plane. In general, only one or a few bedding planes in a given rock yield trackways, implying that the main track-bearing layer is fairly narrow even within a boulder-thick interval. It is unlikely, however, that there is only one major track-bearing layer in the section. Commonly, only a single trackway is found in a given rock, but particularly for *Kouphichnium* (horseshoe crab trackways), there may be numerous criss-crossing trackways.

In some cases, the same trackway involves several impressions whose character differs with depth away from the animal's feet. These track imprints did not necessarily cut across several bedding planes but deformed bedding planes downward as the animal stepped on the soft sediment. These are particularly important because they can show how the morphology of a given track depends on the layer that is exposed. Such specimens are known as undertracks and allow one to connect trackways that, when found separately, might not be recognized as being made by the same trackmaker. Note, however, that some of the largest tracks may cut through different laminae.

Most of the trackways found were made by small animals whose track lengths range from a few millimeters to a few centimeters. Large tracks, more than 15 cm in length (the size of a human hand), were also found, but continuous trackways of animals this large are very rare owing to the broken nature of the spoil. Most slabs yield no more than one or a few tracks of the largest animals. The lack of *in-situ* excavations prevented us from finding the long, continuous trackways of larger animals that characterize other sites such as the Permian Robledo Mountains tracksite of New Mexico (MacDonald, 1994).

The diligence of the 23 collectors who contributed to the documentation of the Union Chapel Mine resulted in the salvaging of more than 1000 high-quality trackways and other traces over an 18-month period, followed by an additional 1500 specimens over the subsequent three and a half years. The convenient location of the mine, only 30 miles west of Birmingham, made it possible for collectors to access the site repeatedly. It



FIGURE 2. Picture from the first visit to the Union Chapel Mine on January 23, 2000. The picture shows one of the steep rock piles that was typical of the site at the time.

was the landowner's cooperation that led to the salvaging of so many specimens in such a short period of time. Because the salvaging began almost immediately after the mining operations ended, it was possible to collect many specimens before they had a chance to suffer significant weathering.

## RECOGNITION OF SIGNIFICANCE OF SITE

From the initial visits, it became clear to members of the core group mentioned above that the Union Chapel Mine was an extraordinary tracksite, especially significant for the early development of terrestrial vertebrate life in Alabama. We realized that the UCM trackways were extremely rare and that the academic community should be made aware of the BPS collection. Two critical decisions were made at this time (spearheaded by A. Allen and S. Minkin). The first was to hold a meeting to bring trackways to a central location for photographic documentation. The second was to invite local professional ichnologists to inspect the trackways and assess the significance of the site. Were it not for these decisions, the trackways collected would have simply ended up in private hands with no new knowledge coming out of their existence. The first studies of the trackways led Pyenson and Martin (2001a) to conclude early on that the Union Chapel Mine is "one of the most important Carboniferous tracksites in the world." The only comparable site for the same geologic period is found in Joggins, Nova Scotia (Ferguson, 1988).

## THE "TRACK MEETS"

The meeting to photographically document the Union Chapel Mine trackways was held on August 19, 2000 at the Alabama Museum of Natural History, on the campus of the University of Alabama in Tuscaloosa. This event, jokingly dubbed a "track meet" during e-mail correspondence between the authors of this paper, turned out to be only the first of four such meetings that were needed to cover the significant quantity of material collected from the mine up to that time. The second meet-



FIGURE 3. The New Castle coal seam is visible as the dark band across the middle of this picture, taken before the mine was formally reclaimed. The Mary Lee coal seam is well below this layer and not visible above ground level.

ing was held on October 14, 2000 at Oneonta High School in Oneonta, Alabama; the third was held on May 12, 2001 at the Anniston Museum of Natural History in Anniston, Alabama, and, finally, the fourth was held on August 9, 2003 at Buta's private residence. We will refer to these meetings as TM1, TM2, TM3, and TM4 respectively. It was felt appropriate that TM1 be held at the Alabama Museum of Natural History because of cooperation with local paleontologists at both the Museum and the Geological Survey of Alabama, also on the campus of the University of Alabama, and also because the Museum houses some of the original track specimens described by Aldrich and Jones (1930). The event was held on the ground floor and in two second-floor rooms close to the glass case with the stunning Aldrich and Jones specimens. Figure 4 shows a T-shirt designed by Ron Buta and Deborah A. Crocker to commemorate the event.

TM1 was the best organized of the four track meets. Collectors arrived at the Museum at 9 a.m. to prepare their specimens for labeling and inspection. Several tables were set up for this purpose in the ground-floor foyer. Two types of labels were used. One was a permanent label, glued on the reverse side, indicating the name and location of the mine. The second was an address

label with a running UCM number for cataloguing purposes. As each specimen was inspected, a tally sheet listed the UCM number, the identity of the collector, and a brief note about what the trackway was (vertebrate, invertebrate, etc.). These inspections were carried out mainly by Andrew K. Rindsberg of the Geological Survey of Alabama (GSA), who also made the selections as to which specimens would be photographed. High-priority specimens were given two red dot stickers, while low-priority specimens were given a green dot. The tally sheet was compiled by T. Prescott Atkinson, who entered the information into a computer database that could be accessed by all the APS members and others who might be interested in studying the tracks. Once all labels and stickers were affixed, the specimens entered an "assembly line" where the higher priority specimens were taken to the second floor for photography.

In addition to the labeling and selection, TM1 included several oral presentations, giving the event an air of professionalism. The group was welcomed by Richard Diehl, then Director of the Alabama Museum of Natural History. Ed Hooks, former Collections Manager of the museum, spoke on the importance of the amateur paleontologist. Kathy Twieg, former president

# Footprints from the Past



Amphibian Trackways • Union Chapel Mine, Walker County, Alabama • 310 Million Years

## The Birmingham Paleontological Society Geological Survey of Alabama Alabama Museum of Natural History **'Track Meet'**

**August 19, 2000 • Smith Hall, University of Alabama**

FIGURE 4. T-shirt design commemorating the first track meet (TM1) held at the Alabama Museum of Natural History.

of the BPS, spoke about the planned monograph to illustrate the trackways. A. K. Rindsberg (GSA) spoke on ethics in collecting, trading, and selling fossils, and Jack Pashin, also of the GSA, discussed the geology of the Pottsville Formation and its relationship to the Union Chapel Mine. Expanded and updated versions of some of these presentations are included elsewhere in this monograph (Hooks, 2005; Pashin, 2005; Rindsberg, 2005b).

The local press and media were invited to these presentations and inspections. Also, even before TM1, there was press interest in the tracks. Tom Spencer drove from Birmingham with a cameraman to talk about the tracks, and he wrote a thoughtful article for the August 20 *Birmingham News* (Spencer, 2000). Bob DeWitt (2000) wrote a similar article for the *Tuscaloosa News*. In both cases, they were drawn to see actual specimens of the tracks. A few days after TM1, Joe Bryant of the *Crimson White*, the University of Alabama student newspaper, wrote an article featuring a large picture of A. K. Rindsberg holding a track specimen (Bryant, 2000).

As in TM1, there was also professional inspection of trackways at TMs 2 and 3, this time by A. K. Rindsberg, Anthony J. Martin, and Nicholas D. Pyenson. At these later meets also, measurements of the vertebrate trace fossils, including trackway lengths, widths, paces, and relative manus and pes sizes, were obtained. Features related to behavior were also recorded. This

information has formed the basis of some of the research presented elsewhere in this monograph (Martin and Pyenson, 2005). At TM4, A. K. Rindsberg was once again on hand for interpretation of specimens.

### SELECTION OF SPECIMENS FOR PHOTOGRAPHY

The goal of TM1 was to photograph only the specimens of the highest quality or the greatest scientific interest. This was a subjective judgment that had to be made in haste owing to the large number of specimens. Although the event lasted all day, only 175 specimens were photographed at TM1. At TM2 and TM3, the selection criteria were relaxed for three reasons. The first was that photographing all specimens was more efficient than at TM1. All specimens brought to TMs 2 and 3 were immediately given UCM numbers and taken directly to the camera station. The judgment as to whether a specimen was important or not was deferred. The second reason for relaxing the selection criteria was the recognition that some weak or less than perfect specimens nevertheless contain important information. If these were left out of the database, then the sample would be biased. The time needed to inspect all specimens in sufficient detail was not available at the track meets. The third reason for photographing all specimens was the recognition of the significance of the site. It was deemed



FIGURE 5. *Top left:* Ashley Allen sits among many specimens to affix the permanent labels at TM2. *Top right:* Kathy Twieg, Mike Robitaille, and Dave Claybourn prepare and label specimens for photography, also at TM2. *Bottom left:* A scene from the main hall at the Anniston Museum of Natural History, where TM3 was held. Gerry Badger is in the background. *Bottom right:* Sam Hood (right) and other TM3 participants prepare and label specimens.

prudent to take all material seriously. For these reasons, the number of specimens to photograph at TMs 2 and 3 became very large, and efficiency was critical to complete documentation. Figure 5 shows several scenes from TM2 and TM3. The general procedure at TM4 was the same as for TM2 and TM3.

## PHOTOGRAPHY

Photographs of all specimens brought to TMs 1, 2, and 3 were taken using a Nikon 6006 35-mm camera. The procedure for doing the photography changed from TM1 to TMs 2 and 3. At TM1, large rocks were photographed by Ron Buta while smaller rocks were photographed by Larry A. Herr. It was considered desirable at first to include in all photographs the complete length of any trackway. However, because of the setup used, only a few closeups were obtained, especially on the larger rocks. At TMs 2 and 3, Buta adopted a policy of taking one or more closeups of trackway sections, in addition to complete trackways, in order to maximize the details documented. This approach, together with the improved efficiency, considerably increased the number of photographs taken in TMs 2 and 3 compared to TM1. Whereas 175 photographs were taken at TM1, 500 were taken at TM2 and 400 were taken at TM3. In addition to these, about 300 photographs were taken in Buta's backyard or on the loading dock of Mary Harmon

Bryant Hall, of specimens that were not included in any of the track meets. Also, T. Prescott Atkinson took several hundred images with a digital camera in his backyard. TM4 was the first all-digital photography trackmeet.

The UCM numbers were assigned at the various photographic sessions. The largest number assigned up to TM3 was 1250. The Photographic Trackway Database (PTD), as of August 2004, includes 2853 photographs of 1929 slabs or specimens. It is stored on an internet website with the URL :

<http://bama.ua.edu/~rbuta/monograph/>

In the PTD, the traces are divided into groups referring to the basic kind of animal that likely made the trackway: "V" for vertebrate trackway or trace, or "I" for invertebrate trackway or trace. Of the nearly 3000 slabs/specimens, about half have definite or possible vertebrate trackways and traces whereas half have definite or possible invertebrate tracks and traces. About 30% of the slabs/specimens are part and counterpart of the same trackway or trace. In some cases, different collectors found the part or counterpart of the same trackway. In an unknown number of cases, the same trackway is represented on different slabs, separated because of the broken nature of the rocks.

The number of vertebrate genera and species in the



FIGURE 6. The “Track Meet” exhibit was on display at the Alabama Museum of Natural History for nearly a year.

database is still under debate. Pyenson and Martin (2001b; see also Martin and Pyenson, 2005) suggest that virtually all of the vertebrate trackways are due to a single species, *Cincosaurus cobbi* (Aldrich, 1930). In contrast, Haubold et al. (2005) present evidence for five different types of tetrapod trackways. The only other kind of vertebrate trace included in the database is the fish trail *Undichna* (Martin and Pyenson, 2005).

The invertebrate database includes a more varied range of traces than the vertebrate database, most of which are thought to be the horseshoe crab trace fossil *Kouphichnium*. Other invertebrate traces include likely arthropod traces, bivalve burrows, and the resting trace *Arborichnus*, thought also to be made by horseshoe crabs. The invertebrate tracks and traces are discussed further by Rindsberg and Kopaska-Merkel (2005) and Lucas and Lerner (2005).

The great value of the PTD website is that it allows the world community to access the entire photographic record of trace fossils from a single site. The website was developed by Buta on an 80 Gbyte hard drive purchased for another project. Despite the large number of images, the website uses less than 5% of the hard drive’s storage capacity.

#### A “PLANT FEST”

The Union Chapel Mine also yielded many high-

quality fossil plants associated with the track-bearing rocks. These fossils included compressions of lycopod bark, leaves, cones, ferns, and numerous “stump casts,” all typical of Coal Age rocks in Alabama. Because these fossils provide important information on the ecology of the area at the time the track makers were alive, TM3 also included a “Plant Fest” at which several hundred of the more important plant fossils were photographically documented. These are discussed by Dilcher et al. (2005).

#### A TRACKWAY EXHIBIT

One of the great honors for the APS that has come out of the Union Chapel Mine experience is a display case that was in the Alabama Museum of Natural History for more than a year (Fig. 6). This was arranged by the Museum’s former Collections Manager, Ed Hooks. The display included a large *Undichna* and several tetrapod trackways ranging from typical small specimens to one track as large as a human hand. The specimen used for the Track Meet T-shirts (Fig. 4) was one of the vertebrate trackways on display. The Museum display also included the fine pre-dragonfly wings discovered by Atkinson (2005), several photographs of the mine and some plant fossils from the mine, and one of the Buta/Crocker Track Meet T-shirts, of which about 20 were made.



FIGURE 7. The Union Chapel Mine after partial reclamation, February 2001.

### **WORKSHOP ON PERMO-CARBONIFEROUS ICHNOLOGY**

By early 2003, so many high quality vertebrate and invertebrate trackways had been salvaged from the Union Chapel Mine that it was decided to hold a professional meeting to bring various trackway researchers together to discuss what had been found at the mine and to place these finds into a global context. This meeting, the Workshop on Permo-Carboniferous Ichnology, was held at the Alabama Museum of Natural History on May 2-4, 2003. Organized by Andrew K. Rindsberg, Anthony J. Martin, David C. Kopaska-Merkel, G. Ed Hooks, Nicholas D. Pyenson, and Ronald Buta, the meeting included speakers from as far away as Birmingham, England (see Atkinson et al., 2005)

### **THE APPEAL OF THE TRACKS**

For an amateur fossil-collecting group like the BPS/APS, the discovery of the Union Chapel Mine trackways was an unexpected collectors delight. The appeal of the trackways to many of the collectors involved is the way these preserved traces depict life as opposed to death. The trackways record the ordinary behaviors of long extinct animals for which no bones have yet been found. The significant number of early tetrapod trackways further makes the Union Chapel Mine database one of the most scientifically valuable collections in the world. Even

though most of the trackway research in this monograph is concerned with the tetrapod tracks, it is clear that the invertebrate traces also have a lot to offer and will provide further new insights on the paleoenvironment of the site.

The idea of preparing a monograph based on specimens collected by many different individuals from the site of a routine BPS field trip was unheard of prior to the UCM experience, at least in Alabama. The partial reclamation of the mine in December 2000 (Fig. 7) capped off a spectacular year of discovery for the group, and the UCM experience marked the beginning of a remarkable cooperation between APS amateur rock collectors and four professional institutions, the Geological Survey of Alabama, the Alabama Museum of Natural History, the Anniston Museum of Natural History, and Emory University, a cooperative venture that led to this monograph. It is significant that even three years after reclamation, the mine continued to yield high quality vertebrate and invertebrate traces, although at a reduced frequency than before.

On July 1, 2004, the Union Chapel Mine was transferred to the State of Alabama and exempted from the requirements of the Surface Mining and Reclamation Act of 1977 (Atkinson et al., 2005). This guarantees the preservation of the site for additional trackways and research for years to come. In September, 2004, after a bulldozer moved some of the buried rock piles, the site again began to yield trackways at a high frequency (Fig.



FIGURE 8. This specimen (UCM 2494, collected by Ron Buta) was found in September 2004 after the State of Alabama sent a bulldozer to the Union Chapel Mine and moved around some of the previously buried rock piles. The specimen shows numerous criss-crossing *Kouphichnium* trackways of high quality.

8). Thus, the future of the project will include more track meets, further documentation, and more knowledge of the natural history of Alabama. In fact, one of the most significant outcomes of the UCM experience is heightened awareness among both amateurs and professionals that Walker County could be a “megatracksite” similar to the one discovered in the Robledo Mountains in 1987 by Jerry MacDonald (MacDonald, 1994). If this is true, then paleo-ichnology has a bright future in Alabama.

#### ACKNOWLEDGMENTS

We thank David Kopaska-Merkel and Andrew K. Rindsberg for comments on the manuscript. The success of the track meets depended on cooperation with the Alabama and Anniston Museums of Natural History. We thank Ed Hooks and Dan Spaulding for this privilege. Ron Buta would like to thank Rickey Yanaura, University Relations of the University of Alabama, for much helpful photographic advice and for lending us the lighting equipment needed for the indoor photography at TM1 and TM3. Steve Minkin is also grateful to the paleontologists at the Idaho Museum of Natural History who impressed on him many years ago the impor-

tance of the collaboration between the scientific community and responsible collectors.

#### REFERENCES

- Aldrich, T. H., Sr., and Jones, W. B., 1930, Footprints from the Coal Measures of Alabama: Alabama Museum of Natural History, Museum Paper, no. 9, 64 p.
- Allen, A., 2005, Discovery of the Union Chapel Mine site; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 15-17.
- Atkinson, T. P., 2005, Arthropod body fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., 2005, *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 169-176.
- Atkinson, T. P., Buta, R. J. and Kopaska-Merkel, D. C., 2005, Saving the Union Chapel Mine: how a group of determined amateurs teamed up with professionals to save a world-class trackway site in Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 191-200.
- Bryant, J. D., 2000, Taking steps back in time: Tuscaloosa, University of Alabama, *The Crimson White*, August 25.

**AUTHOR'S E-MAIL ADDRESS**

- DeWitt, R., 2000, Historical specimens represent one of state's largest finds: Tuscaloosa News, August 20.
- Dilcher, D. L., Lott, T. A., and Axsmith, B. J., 2005, Fossil plants from the Union Chapel Mine, Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 153-168.
- Ferguson, L., 1988, *The Fossil Cliffs of Joggins*: Nova Scotia Museum, 52 p.
- Haubold, H., Allen, A., Atkinson, T. P., Buta, R. J., Lacefield, J. A., Minkin, S. C. and Relihan, B. A., 2005, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 75-111.
- Hooks, G. E., 2005, The importance of the amateur paleontologist; in Buta, R.J., Rindsberg, A.K., and Kopaska-Merkel, D.C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 187-188.
- Lucas, S.G. and Lerner, A. J., 2005, Lower Pennsylvanian invertebrate ichnofossils from the Union Chapel Mine, Alabama: a preliminary assessment; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 147-152.
- MacDonald, J., 1994, *Earth's First Steps: Tracking Life Before the Dinosaurs*: Boulder, Colorado, Johnson Printing, 290 p.
- Martin, A. J. and Pyenson, N. D., 2005, Behavioral significance of vertebrate trace fossils from the Union Chapel site; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 59-73.
- Minkin, S. C., 2000, Pennsylvanian vertebrate trackways, Walker County, Alabama: Alabama Geological Society Newsletter, v. 13 (4), p. 7-10
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 39-58.
- Pyenson, N. D. and Martin, A. J., 2001a, Paleontological and behavioral significance of amphibian tracks from the Pottsville Formation (Lower Pennsylvanian: Westphalian A), Union Chapel Mine, Alabama: Geological Society of America, *Abstracts with Programs*, v. 33(2), p. 2.
- Pyenson, N. D., and Martin, A. J. 2001b, Uses of amphibian trackways from the Union Chapel Mine (Lower Pennsylvanian: Westphalian A) of Alabama for estimating amphibian population compositions: *Journal of Vertebrate Paleontology*, v. 21 (Supplement to no. 3), 91A.
- Rindsberg, A. K., 2005a, Gas-escape structures and their paleoenvironmental significance at the Steven C. Minkin Paleozoic Footprint Site (Early Pennsylvanian, Alabama); in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 177-183.
- Rindsberg, A. K., 2005b, Ethics for collectors and curators of fossils; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 189-190.
- Spencer, T., 2000, Fossil hunters follow tracks to distant past: Birmingham News, August 20.

Ronald J. Buta: rbuta@bama.ua.edu



## **Part II. Geology and Paleontology**



The family of Steven C. Minkin looks on as Jim Griggs, director of the State Lands Division, Alabama Department of Conservation and Natural Resources, unveils the the plaque at the newly dedicated Steven C. Minkin Paleozoic Footprint Site (the Union Chapel Mine), March 12, 2005. Photo credit: Andrew K. Rindsberg.

## PALEOENVIRONMENT OF THE *CINCOSAURUS* BEDS, WALKER COUNTY, ALABAMA

STEVEN C. MINKIN

Anniston, Alabama, USA (deceased 20 February 2004)

**ABSTRACT:** Early Pennsylvanian rocks in the Black Warrior Basin of north central Alabama in the Pottsville Formation represent large volumes of fluvial-deltaic sediments spanning a broad range of marine and terrestrial environments. The environmental setting of the Union Chapel Mine trackway beds was that of an estuarine tidal flat in a coastal lowland region near the paleoequator. The tropical area supported extensive peat swamps. Tracks of tetrapods and invertebrates were made on the tidal flats at low tide. Tetrapod tracks, invertebrate tracks, traces, burrows, and fish trails were made in both the subaerial and subaqueous environments of the tidal flats, tidal channels, and coastal marine environments.

### INTRODUCTION

Pennsylvanian vertebrate and invertebrate trace fossils have been collected since 2000 in an inactive part of the Union Chapel Mine, an abandoned surface coal mine in Walker County, Alabama (Fig. 1). The vertebrate tracks are similar to material previously collected in Walker County, Alabama (Aldrich and Jones, 1930; Rindsberg, 1990). The tracks are in shale of the Mary Lee coal zone of the Pottsville Formation, 1.5-3 m (5-10 ft) above the Mary Lee coal bed. The trackways were collected in the spoil piles near the highwall that remained after mining was completed. Collecting trackway specimens from undisturbed shale layers was not feasible due to the instability of the high wall and thickness of overburden which reached heights of 30 m (100 ft) or more. The Alabama Paleontological Society (APS) members who collected the track fossils and fossil plants for an 18-month period made important observations on the rocks exposed in the Union Chapel Mine. These observations help explain the depositional environment of the track-bearing Mary Lee rocks.

### STRATIGRAPHY AND PALEOGEOGRAPHY

The Pennsylvanian strata exposed in the Union Chapel Mine consist of interbedded shale, siltstone, sandstone, and coal in the Mary Lee coal zone of the Pottsville Formation (Pashin, 2005). The coal-bearing strata of the Mary Lee zone were deposited near the paleoequator in a coastal lowland along a shallow seaway that covered parts of eastern North America during the Pennsylvanian Period (Fig. 2). The depositional patterns in the Union Chapel Mine are typical of fluvial-deltaic deposits in Pennsylvanian rocks of the Appalachian and Black Warrior Basins. Rain forests were prevalent in the coastal areas of the Pennsylvanian equatorial land masses. Streams that were fed by high rainfall deposited enormous quantities of sandy, silty, and muddy sediment. Waterlogged lowland environments supported extensive forests of wetland plants dependent on the reliable supply of fresh or brackish water. Coastal plain forests were dominated by aborescent lycopods such as *Lepidodendron*, *Lepidophloios*, *Sigillaria*, and seed

ferns, pteridosperms, sphenophytes (*Calamites*) and *Cordaites*. The edges of the lowland environments were periodically exposed along tropical swamp margins during ebb tide. Highland areas of the Appalachian Mountains were being lifted landward of the coastal region. Much of this area was drained by a large river system terminating as a delta and estuarine environment responsible for depositing large volumes of sediment into the subsiding Black Warrior Basin. The sediments exposed in the Union Chapel Mine represent deposition in this estuarine and deltaic system.

### OBSERVATIONS

The track-bearing rocks and fossil plants were found in spoil piles next to the west-facing highwall of the Union Chapel Mine (Fig. 3). The highwall reaches a height of about 30 m (100 ft) and much of the outcrop is unstable and dangerous. However, a north-south examination of the highwall was made by Jack Pashin during an APS field trip. The traverse was made along the highwall to examine the shale sequence overlying the Mary Lee coal seam (Pashin, personal commun., 2001). To the north along the highwall, the dark gray shale overlying the Mary Lee coal seam contains abundant macerated plant material including an *in-situ* seed fern stump and *Calamites*. This is represented by area A in Fig. 3. Proceeding south along the highwall, the shale overlying the coal grades into a lighter-colored shale and contains the highest concentration of vertebrate and invertebrate tracks in the Union Chapel Mine. This area is illustrated as area B in Fig. 3. The large tetrapod tracks, seen in Fig. 4, were collected from area B of the spoil piles directly in front of the highwall. The small tetrapod tracks, seen in Fig. 5, were also collected in the spoil piles of area B. In addition to the tetrapod tracks, numerous invertebrate tracks were also collected in area B. A horseshoe crab trackway from area B is shown in Fig. 6. A myriapod trackway, also collected in area B, is shown in Fig. 7. The predominant track-bearing rock is a red-brown, dark gray, or black shale. The shale is very well-sorted, very fine-grained, and generally lacks macroscopic plant material. However, *Calamites* are present in life position in the track-bearing shale. In many



FIGURE 1. Walker County and Black Warrior Basin, Alabama

cases, the track-bearing shale has a sheen due to the presence of very fine-grained mica and possibly also the alignment of clay minerals. The color ranges from red-brown to gray to black; however, gray is the predominant color of the track-bearing shale. The red-brown color is the result of weathering, indicating the presence of pyrite (iron sulfide). Generally, the vertebrate and invertebrate tracks, preserved in the very fine-grained shale, are sharply defined and well-preserved. Tracks are usually absent in the part of the shale unit that grades vertically and laterally into sediment containing silt, sand, coarse mica flakes, or macroscopic plant material. The tracks occur in laminated to thin-bedded shale strata from 0.5 to 2 cm (0.25 to 1 in) thick. The well-sorted, very fine-grained shale grades laterally, southward, along the highwall into a highly burrowed shale containing abundant macroscopic plant material and a lighter gray siltstone. Ripple marks and cross beds are in the silt-shale. The large tetrapod tracks have been identified from the burrowed shale and gray siltstone. These large tracks commonly have curled or bent toes, indicating that the tetrapod toes were flexible in the soft, water-saturated mud (Fig. 8). Another type of vertebrate trail observed in this shale is *Undichna*, interpreted as fin traces of swimming fish (Martin and Pyenson, 2005; see Fig. 9).

#### ENVIRONMENTS OF DEPOSITION

The vertebrate and invertebrate trackways collected from the Union Chapel Mine are believed to have been



FIGURE 2. Paleogeographical setting of Union Chapel Mine in the Pennsylvanian Period (from Lacefield, 2000).

made by animals that inhabited an estuarine tidal flat environment during the deposition of the Pottsville sediments in the Early Pennsylvanian (Fig. 10). The animals apparently moved across the mud flat for feeding or transit to another area. No body fossils of the tetrapods or horseshoe crabs, though abundant as trace fossils, have been found in the estuarine *Cincosaurus* beds of the Union Chapel Mine. Fig. 11 shows a north-south profile of the lateral relationships of the estuarine and tidal flat environments along the highwall. Large and small tetrapod trackways were made in the intertidal environment. Burrows, large tetrapod trackways, and fish and larval amphibian traces were made in a subaqueous environment. The vegetation of the Pennsylvanian swamps was established beyond the limits of the Union Chapel Mine on ground upslope from the tidal flat. The tetrapod tracks range from small footprints about 1.0 cm (0.5 in) long (Fig. 5) to large footprints longer than 15 cm (7 in) (Fig. 4). Small tetrapod tracks are restricted to fine-grained shale, which is interpreted as an intertidal mud flat that was exposed during low tide. Once this area was exposed to the atmosphere, vertebrates and invertebrates moved about on the tidal flat. The foot, tail, and body impressions were made in the soft mud. Many of the trackway impressions do not show the tail and body impressions because these tracks represent footprints (underprints) made in layers of soft mud levels below the surface where the animal traversed. The tracks in the mud that grades upslope into a coarser sediment are less distinct or nonexistent. Sediment that changes from the tidal flat mud upslope toward a vegetated area generally contains abundant macerated plant material in the mud, and tracks are less distinct or nonexistent in this lithology also. The small tetrapods and small invertebrates left their trackways and trails in the soft, moist mud near the edge of the water. Once the small animal stepped from the shoreline into the water body, the track became distorted due to the water saturated mud surface. Small animals were not tall enough to travel across deep water. The well-defined small tet-

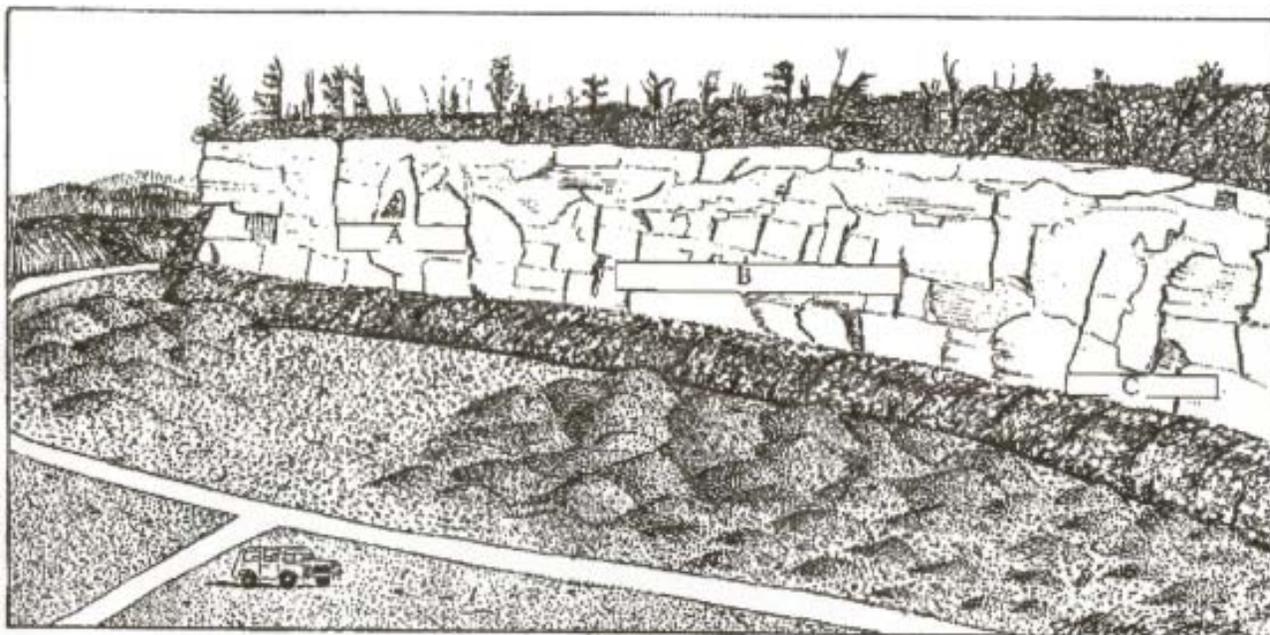


FIGURE 3. West-facing highwall at Union Chapel Mine. North is to the left. A, B, and C refer to different locations along the highwall above the coal seam, discussed in the text.

rapod and invertebrate trackways higher up on the mud flat were filled with fine sediment during the next tidal cycle, possibly during ebb tide when mud was supplied by the continuing fresh water influx, with fine particles being deposited as these fluvial systems met the calmer waters of the estuary within hours of being made. The very fine-grained, well-sorted trackway-bearing shale may have a reddish-brown color indicative of subaerial weathering of pyrite in the tidal flat. Although subaerially exposed, the lack of mud cracks suggests that this area was continually moist. Burrows are typically not present in the track-bearing shale of the tidal mud flat. Large amounts of macroscopic plant material were generally not observed in the track-bearing shale. However, *in situ Calamites* have been described from the low-diversity environment of the tidal mud flat. Large tetrapod tracks have been collected from sediments distributed over a more widespread extent than the fine-grained tidal flat mud sediments that contain the small tetrapod and invertebrate trackways. The large tetrapods left impressions in the same well-sorted, fine-grained mud as the small tetrapods; however, the larger animals evidently could also wade across shallow bodies of water adjacent to the subaerially exposed tidal flat. The smaller animals could not wade across shallow bodies of water. Footprints of the larger animals were commonly distorted due to the weight of the heavy animal on the saturated mud surface under water. Large tetrapod tracks were collected in silty mudstone and are commonly associated with vertical and horizontal burrows and current ripple marks which support a subaqueous interpretation for these trace fossils. In addition, large tetrapod tracks have also been described from sediments containing silt, sand, and abundant plant material which suggests that the weight of the animal was sufficient for its feet to make impressions in coarser sedi-

ment. The smaller tetrapod and invertebrate tracks are generally absent from this lithology because the lighter animals' feet would not be able to make much of an impression in the coarser sediment containing sand or plant fragments. The larger invertebrate trackways consist mainly of xiphosuran (horseshoe crab) trackways. Tracks and other traces of horseshoe crabs, as well as tetrapod tracks, have been documented from surface coal mines in Walker County (Rindsberg, 1990). The horseshoe crab trackways have been generally identified from the Mary Lee tidal mud flat sediments, but have also been collected from subtidal, tidal, and shallow near-shore marine siltstones.

## SUMMARY

The north-south traverse along the Union Chapel Mine highwall shows a lateral facies change from terrestrial forest carbonaceous shale southward to estuarine tidal flat shales to nearshore marine siltstones. The daily tidal cycle exposed a tidal flat composed of very fine-grained mud that partially dried during the brief subaerial exposure. Once this environment was exposed, large and small vertebrates and invertebrates crossed the tidal flat during the ebb tide. The drying mud was an ideal substrate for small tetrapods and invertebrates to leave their tracks and trails. The animal tracks were quickly covered with mud during the next tidal cycle, which accounts for their excellent preservation. The tidal flat was an area of low plant diversity (Dilcher et al., 2005), but was close to a terrestrial forest or swamp on the edges of the estuarine channels. The Pennsylvanian forests, swamps, and marshes were inhabited by abundant vertebrate and invertebrate animals. The tidal flats were areas that these vertebrates and invertebrates went in search for food or crossed during ebb tide, then



FIGURE 4. Typical large tetrapod trackway.

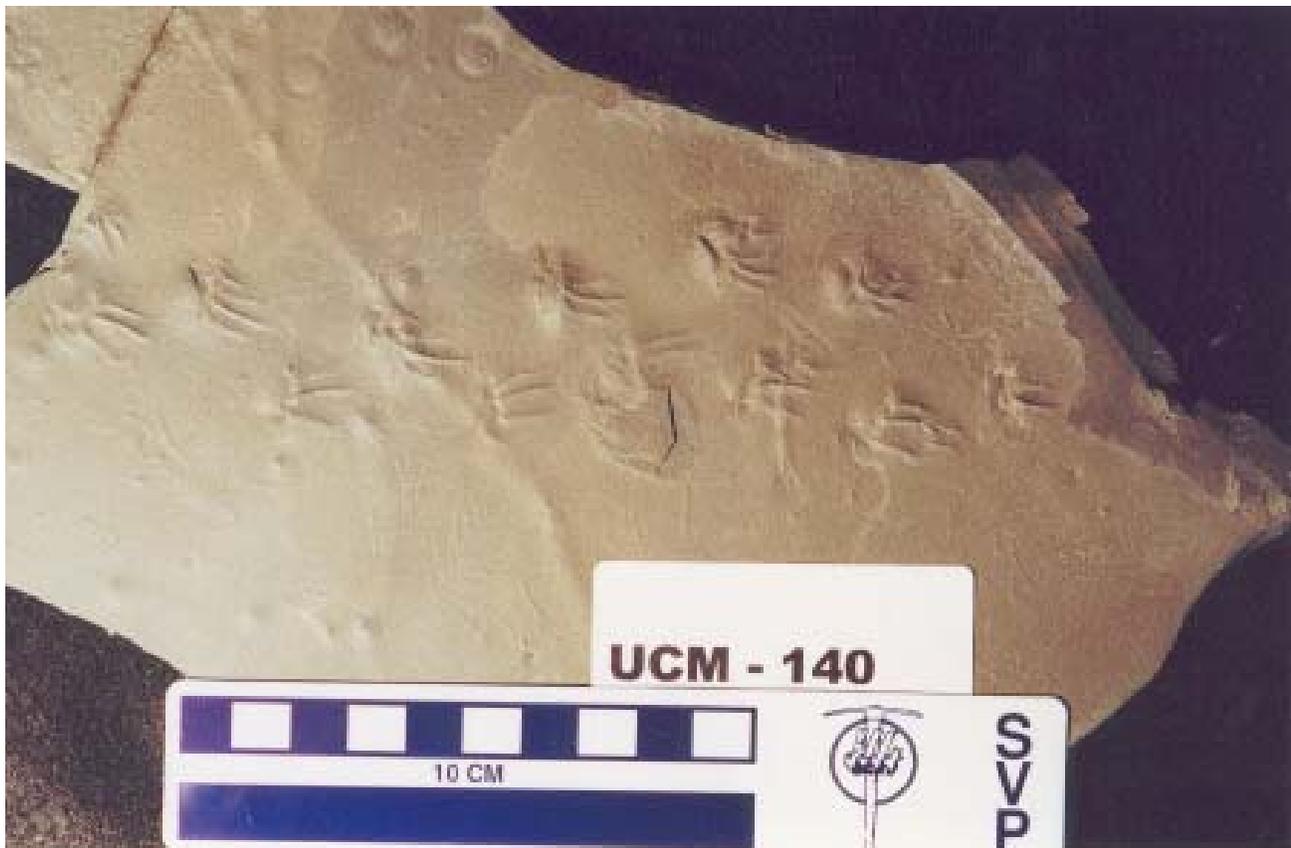


FIGURE 5. Typical small tetrapod trackway.



FIGURE 6. Possible horseshoe crab trackway (but see Haubold et al., 2005).



FIGURE 7. Myriapod trackways (*Diplichnites*).



FIGURE 8. Large tetrapod trackway in gray silt shale made with flexible toes in soft mud.

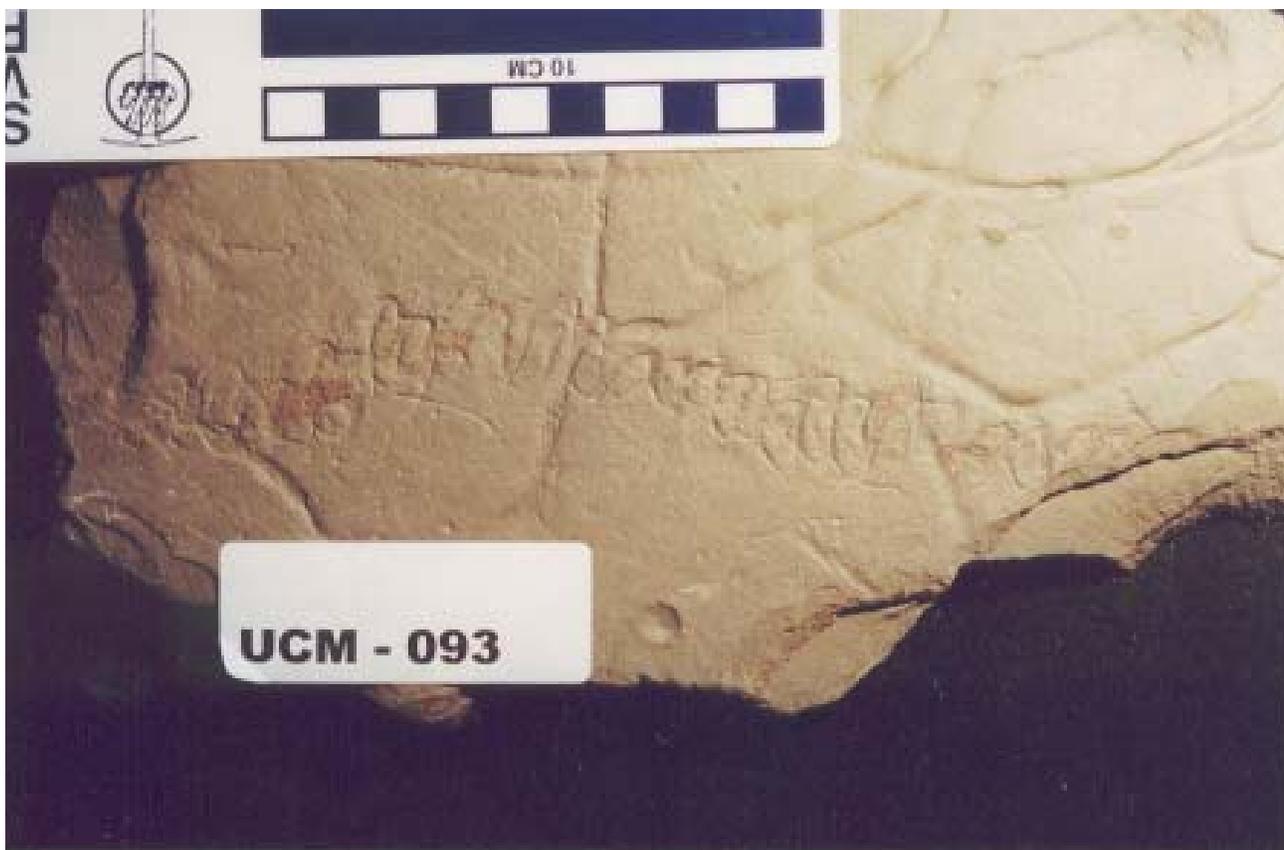


FIGURE 9. Fish swimming trail (*Undichna*)

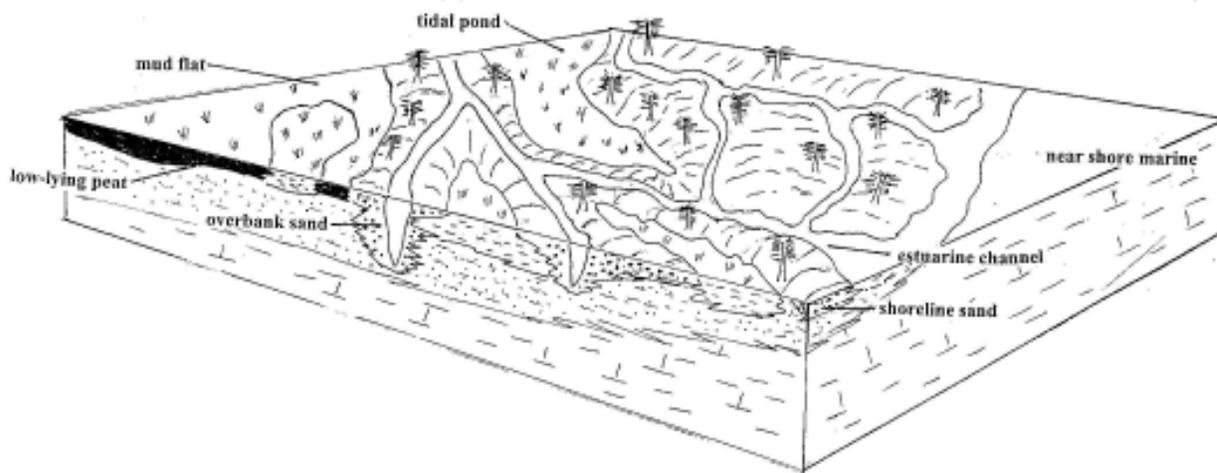
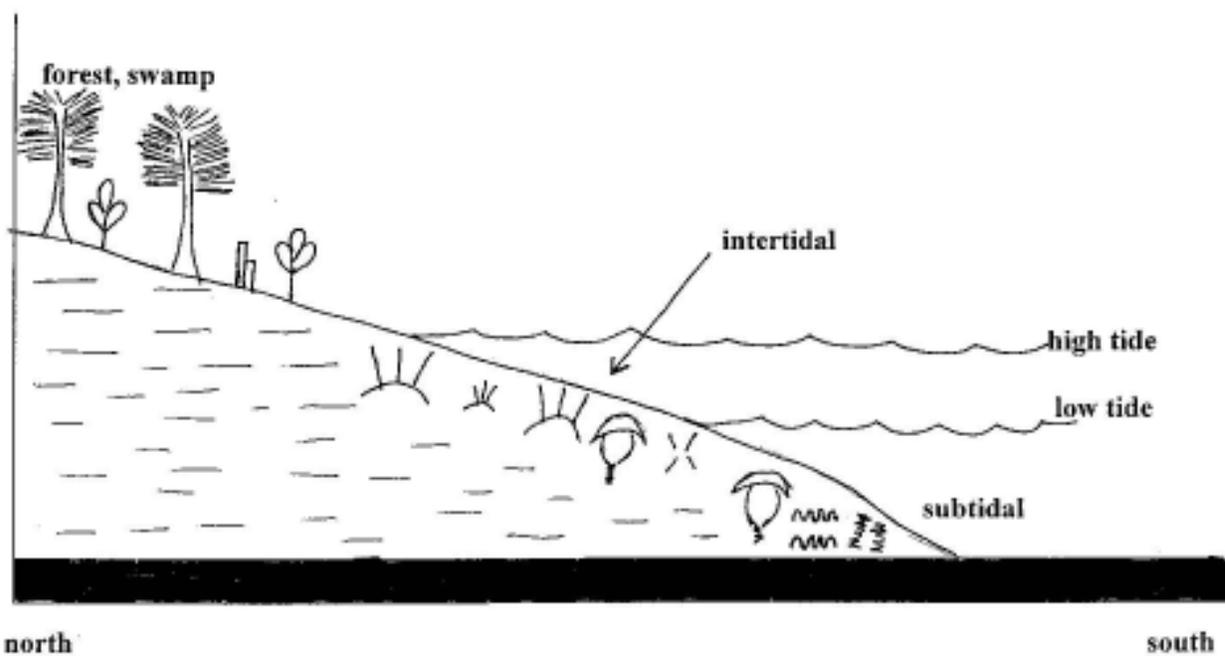


FIGURE 10. Estuarine tidal flat environment of the track-bearing Mary Lee shale.



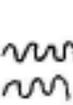
lycophod trees	ferns	Calamites	insect tracks	large/small tetrapod tracks	fish traces	burrows
						

FIGURE 11. Profile of estuarine tidal flat environments and track-bearing sediments. The symbol immediately below the arrowhead refers to a xiphosuran trace.

returned to their terrestrial habitats once the tidal mud flat again became inundated with the next high tide.

## REFERENCES

- Aldrich, T. H., Sr., and Jones, W. B., 1930, Footprints from the coal measures of Alabama: Alabama Museum of Natural History, Museum Paper no. 9, 64 p.
- Haubold, H., Allen, A., Atkinson, T. P., Buta, R. J., Lacefield, J. A., Minkin, S. C. and Relihan, B. A., 2005, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 75-111.
- Dilcher, D., Lott, T. A., and Axsmith, B. J., 2005, Fossil plants from the Union Chapel Mine, Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 153-168.
- Lacefield, J. A., 2000, Lost Worlds in Alabama Rocks: A Guide to the State's Ancient Life and Landscape: Birmingham, Alabama Geological Society, 124 pp.
- Martin, A. J. and Pyenson, N. D., 2005, Behavioral significance of vertebrate trace fossils from the Union Chapel site; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 59-73.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 39-58.
- Rindsberg, A. K., 1990, Freshwater to marine trace fossils of the Mary Lee coal zone and overlying strata (Westphalian A) Pottsville Formation of Northern Alabama, in Carboniferous Coastal Environments and Paleocommunities of the Mary Lee Coal Zone, Marion and Walker Counties, Alabama, Gastaldo, R. A., Demko, T. M., and Liu, Y., eds.: Guidebook for Field Trip VI, 39th Annual Meeting, Southeastern Section, Geological Society of America.

## POTTSVILLE STRATIGRAPHY AND THE UNION CHAPEL LAGERSTÄTTE

JACK C. PASHIN

Geological Survey of Alabama, P.O. Box 869999, Tuscaloosa, Alabama, 35486-6999, USA

**ABSTRACT:** Amphibian trackways from the Pennsylvanian-aged Pottsville Formation at the Union Chapel Mine are part of a fossil-lagerstätte, or motherlode, that provides exceptional insight into ancient life and environments. The trackways come from the *Cincosaurus* beds, which constitute one of many fossiliferous intervals exposed in the mine. These intervals contain different fossil assemblages representing a spectrum of terrestrial to marine environments of deposition.

The Mary Lee coal bed is a source of low-sulfur coal and represents a widespread peat swamp; it was mined at Union Chapel as a source of high-quality fuel for electric power generation. The *Cincosaurus* beds were deposited on an estuarine mudflat that formed as the Mary Lee swamp was inundated by sediment-laden water. The *Cincosaurus* beds represent a dynamic environment in which amphibians (makers of the trackway *Cincosaurus cobbi*) and a variety of invertebrates ventured onto the mudflat at low tide. Deposition of the *Cincosaurus* beds apparently ended with a drop of relative sea level and widespread soil development. This event was succeeded by a return to peat-swamp sedimentation, as represented by the overlying New Castle coal, which was also mined at Union Chapel. The roof shale of the New Castle coal contains standing fossil forests and represents a swamp that was prone to flooding by mud-laden water. Above the roof shale is a thin bed of nodular limestone containing brachiopods and bivalves, which records a major marine transgression. Above the limestone is a thick, coarsening-upward succession of shale and sandstone that contains marine trace fossils and was deposited in prodelta and delta-front environments during a relative highstand of sea level.

### INTRODUCTION

The Union Chapel Mine has yielded a prolific assemblage of amphibian trackways (*Cincosaurus cobbi* Aldrich, 1930) and associated invertebrate trace fossils that provides a unique window into life during Early Pennsylvanian time. The fossil locality at Union Chapel has characteristics of a Konzentrat-Lagerstätte because of exceptional abundance and a Preservat-Lagerstätte because of exceptional preservation of detail (e.g., Seilacher, 1990). The Union Chapel Mine is a surface coal mine in the Warrior coal basin of Walker County, Alabama (Fig. 1). The mine covers parts of the eastern half of sec. 21 and the western half of sec. 22, T. 14 S., R. 6 W. in the Cordova 7.5-minute topographic quadrangle and is excavated into Pennsylvanian-age strata of the Pottsville Formation. Nearly all of the fossil material recovered has come from the mine spoils and, prior to some stabilization and reclamation activities, strata were preserved intact in a highwall that was in places taller than 30 m. Examination of the mine face indicates that strata containing a series of distinctive fossil assemblages were deposited in a wide range of depositional environments that place the trackway discovery into geologic context.

Amphibian trackways have been known from Alabama's coal mines for more than 75 years (Aldrich and Jones, 1930; Rindsberg, 1990), yet little is known about the ancient environments in which the trackways were preserved. The objective of this paper is to charac-

terize the Union Chapel lagerstätte in terms of stratigraphy (i.e., the time-space relationships of sedimentary rock) and environments of deposition. These strata provide evidence for local conditions as the trackways formed and also provide a compact record of the tectonic and climatic processes that operated globally as continental masses came together to form the supercontinent Pangaea.

Characterization of the Union Chapel lagerstätte underscores the relevance of geology to our everyday lives and demonstrates that fossil finds are not merely academic curiosities. The Pottsville Formation is an important source of coal and natural gas that are used for many purposes, including electric power generation, metallurgy, and home heating. Geologists routinely characterize the paleontology, stratigraphy, and sedimentology of these strata to predict the distribution, quantity, and quality of coal and natural gas resources, thereby ensuring a stable supply of energy for the future.

### POTTSVILLE FORMATION

Economic coal-bearing strata in Alabama are restricted mainly to the Pottsville Formation of Early Pennsylvanian age (Morrowan Epoch), which has been dated using fossil spores and marine invertebrates (Butts, 1926; Eble and Gillespie, 1989; Eble et al., 1991). The Union Chapel Mine is in the Warrior coal basin, which underlies most of Walker, Jefferson, and Tuscaloosa counties and includes nearly 90 percent of Alabama's bitumi-



FIGURE 1. Location of the Union Chapel Mine in the bituminous coal fields of Alabama.

nous coal resources (Ward, 1984) (Fig. 1). The Pottsville Formation contains mainly shale, sandstone, and bituminous coal, and the total thickness of the formation approaches 2 km in the Warrior coal basin (McCalley, 1900; Butts, 1926; Thomas, 1988) (Fig. 2). Coal resources are estimated to exceed 21 billion metric tons (Ward, 1984), and demonstrated reserves are nearly 4 billion metric tons (Carroll, 1997). McCalley (1900) recognized that coal beds in the Alabama Pottsville are concentrated in stratigraphic clusters which he called coal groups. Coal groups, which are properly termed coal zones to avoid confusion with formal stratigraphic nomenclature, have formed the basis of most subsequent stratigraphic subdivisions of the Pottsville Formation (e.g., Butts, 1910, 1926; Culbertson, 1964; Metzger, 1965).

The lower Pottsville Formation is dominated by sandstone and contains few mineable coal beds, whereas the upper Pottsville contains nearly all of the coal reserves in the Warrior coal basin (Fig. 2). Within the upper Pottsville, the Black Creek, Mary Lee, Pratt, and

Brookwood coal zones are economically most important. More than two thirds of the 19.3 million short tons of coal mined in Alabama during 2001 came from the Blue Creek and Mary Lee beds of the Mary Lee coal zone (R.E. Carroll, personal commun., 2002), which includes the Union Chapel Mine.

Nearly 12 million short tons of coal was produced from deep underground mines in the Blue Creek and Mary Lee coal beds between depths of 300 and 700 m during 2001. These mines include the deepest vertical shaft underground coal mines in North America, and the high natural gas content of these coal beds has been an acknowledged mining hazard since the 19th century (McCalley, 1886; Butts, 1926). During the 1970s, the U.S. Bureau of Mines investigated the possibility of producing natural gas from Blue Creek coal to improve mine safety (Elder and Deul, 1974), and thus the modern coalbed methane industry, which now spans the globe, was born in Jefferson County, Alabama. Annual coalbed methane production exceeds 3 Bcm (billion cubic meters), and cumulative production exceeds 35 Bcm. Coalbed methane resources (i.e., the total amount of gas in the coal) in west-central Alabama are estimated between 280 and 570 Bcm (Hewitt, 1984; McFall et al., 1986) and, according to the U.S. Geological Survey, reserves (i.e., the amount of that gas that is recoverable using current technology) exceed 100 Bcm (J. R. Hatch, personal communication, 2002). Commercial production of coalbed methane began from the Mary Lee coal zone in 1980, and today natural gas is produced from the Black Creek through Utley coal zones (Pashin and Hinkle, 1997). Alabama remains a world leader in the development and application of coalbed methane technology. Today, coalbed methane accounts for about 25 percent of the natural gas produced in Alabama, and the state ranks 9th nationally in natural gas production.

In addition to being a source of natural gas, coal is a potential sink for greenhouse gases, such as carbon dioxide. Bituminous coal can hold about twice as much carbon dioxide as methane, and injection of carbon dioxide into coal through wells has the potential to increase coalbed methane recovery (e.g., Reichle et al., 1999; Gentzis, 2000). In a preliminary investigation of the Warrior coal basin, Pashin et al. (2001) suggested that potential exists to sequester more than 35 years of greenhouse gas emissions from coal-fired power plants serving the Birmingham-Tuscaloosa area.

## TECTONICS AND PALEOCLIMATE

The late Paleozoic was a time of major plate-tectonic and climatic changes associated with the assembly of Pangaea (Fig. 3). During this time, ancestral North America and Europe, or Laurussia, collided with a large continental mass called Gondwana. Plate reconstructions suggest that tectonic activity in southeastern Laurussia was related to closure of a small Mediterranean-type ocean basin called the Rheic Ocean (e.g., Scotese, 1990; Scotese et al., 1994). As this basin closed, the Laurussian plate drifted northward, and what is now the Warrior coal basin moved from a latitude of about 25° S, which is in the arid southern tradewind belt, to a latitude of

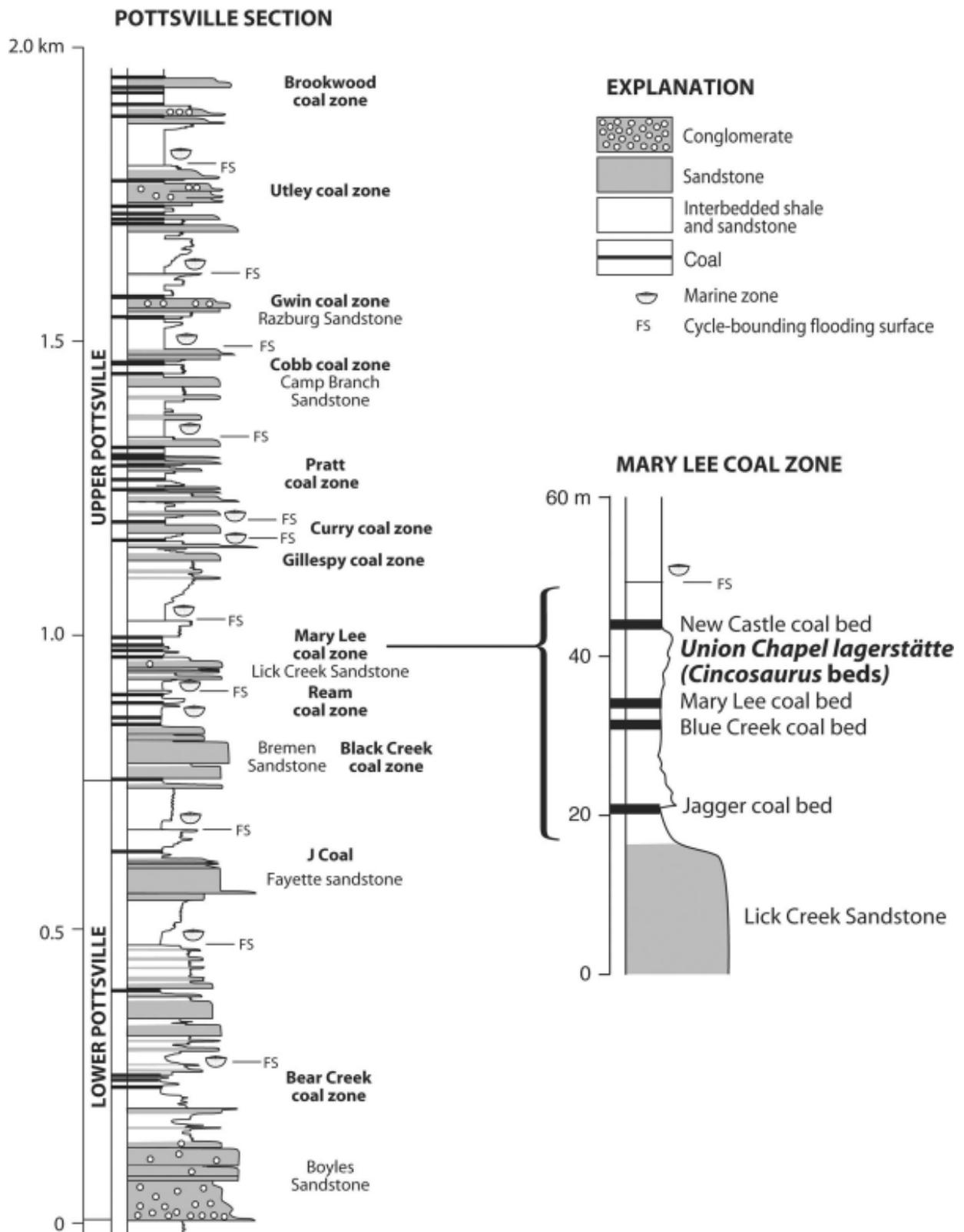


FIGURE 2. Generalized stratigraphic section of the Pottsville Formation in the Warrior coal basin showing stratigraphic position of the Union Chapel lagerstätte.

about 10° S, which is in the humid equatorial belt. In eastern North America, including the Warrior coal basin, this humidification is reflected partly by the occurrence of Bahama-type limestone banks of Mississippian age followed by widespread peat (i.e., coal) swamps of Pennsylvanian age (Cecil, 1990; Pashin, 1994a).

Although the Warrior coal basin was near the paleoequator, the Gondwanan continental mass was centered on the South Pole and provided a nucleus for a major continental ice sheet that waxed and waned from Late Devonian through Middle Permian time (Caputo and Crowell, 1985; Frakes et al., 1992) (Fig. 3). Depositional cyclicity is a salient feature of Pennsylvanian-age rocks, and sea-level changes recorded by these cycles have long been thought to have been driven by waxing and waning of the Gondwanan ice sheet (e.g., Wanless and Shepard, 1936; Heckel, 1986). Glacially driven sea-level change probably exceeded 40 m in magnitude during the Early Pennsylvanian (Maynard and Leeder, 1992). Numerous marine-nonmarine depositional cycles have been identified in the Pottsville Formation, and the high frequency of these cycles appears to be compatible with glacially driven sea-level change (Pashin, 1994a, 1994b).

The Warrior coal basin is part of a larger sedimentary basin called the Black Warrior Basin (Fig. 4). Sedimentary basins that form adjacent to collisional mountain ranges, or orogenic belts, are called foreland basins. The Black Warrior Basin formed at the juncture of the Appalachian and Ouachita orogenic belts, which intersect at near right angles (Mellen, 1947; Thomas, 1977, 1985) (Fig. 4). The crust of the earth thickens in the collision zones where orogenic belts form and, to compensate for the load of this thickened crust, the adjacent crust flexes downward, and a foreland basin is formed (Fig. 5). Uplifting mountains also provide source areas for sediment, which can be eroded from the orogenic highlands and deposited in the adjacent foreland basin.

The Black Warrior Basin formed on a prominence of the Laurussian continental platform called the Alabama promontory (Thomas, 1977, 1985) (Fig. 4). The Ouachita orogen formed by collision on the southwest margin of the promontory, whereas the Appalachian orogen formed on the southeast margin. According to Thomas (1974, 1976, 1985), the Black Warrior Basin began forming in Late Mississippian time (~335 Ma [million years ago]) with the inception of Ouachita orogenesis on the southwest part of the Alabama promontory. Although the Appalachian orogen began forming during Ordovician time (~450 Ma), early tectonic activity was remote to the Black Warrior Basin. Consequently, sedimentation driven by Appalachian orogenesis did not affect the eastern Black Warrior basin until Pottsville deposition (~315 Ma), when a new, more localized downwarp was superimposed on the still-active Ouachita foreland basin (Pashin et al., 1991; Pashin, 1994b).

### POTTSVILLE DEPOSITIONAL ENVIRONMENTS AND CYCLES

Following establishment of the basic stratigraphic

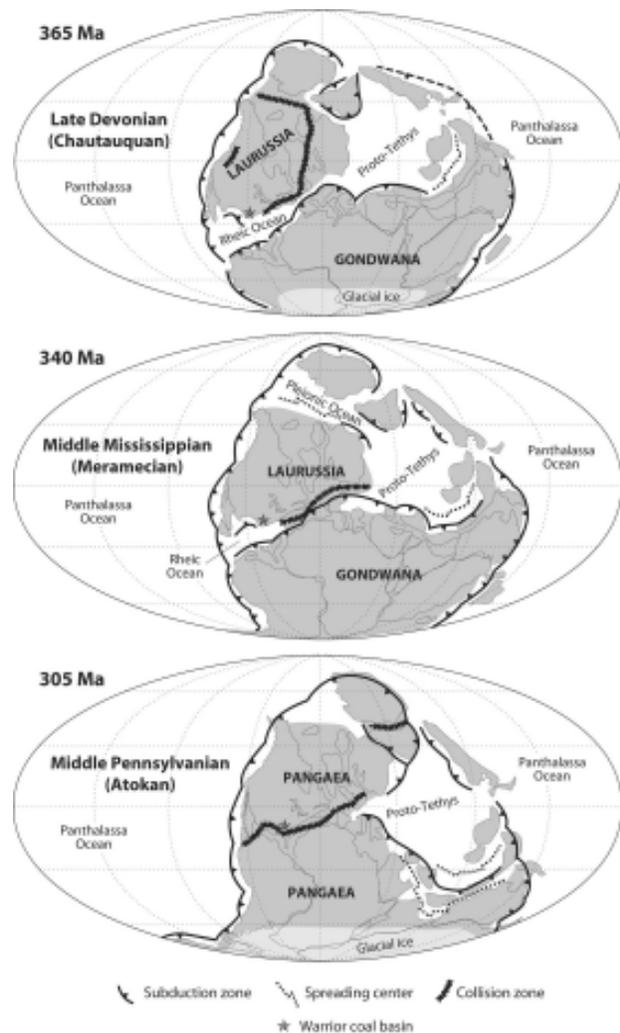


FIGURE 3. Generalized plate reconstructions for Devonian through Pennsylvanian time showing formation of Pangaea, northward drift of ancestral North America, and generalized location of the Gondwanan ice sheet (after Scotese, 1990).

framework by McCalley (1886, 1900), Butts (1926) recognized the evidence for repeated marine transgressions and regressions during Pottsville deposition. During the mid-20th century, studies of coal-bearing strata in the eastern United States focused on depositional cyclicity, which is a salient characteristic of Pennsylvanian-age sedimentary rocks (e.g., Weller, 1930; Wanless and Shepard, 1936). During this time, however, little work was done on the Alabama Pottsville. In the 1960s, models of modern depositional environments and sedimentary sequences began emerging that encouraged investigators to piece together the details of Pottsville stratigraphy and sedimentation in Alabama and to provide new perspectives on Pennsylvanian coal-bearing strata.

Ferm et al. (1967) explained the heterogeneous distribution of shale, sandstone, and coal in the Pottsville Formation by developing a depositional model based on sedimentary processes in coastal and shallow marine environments. This model signaled a shift in thinking

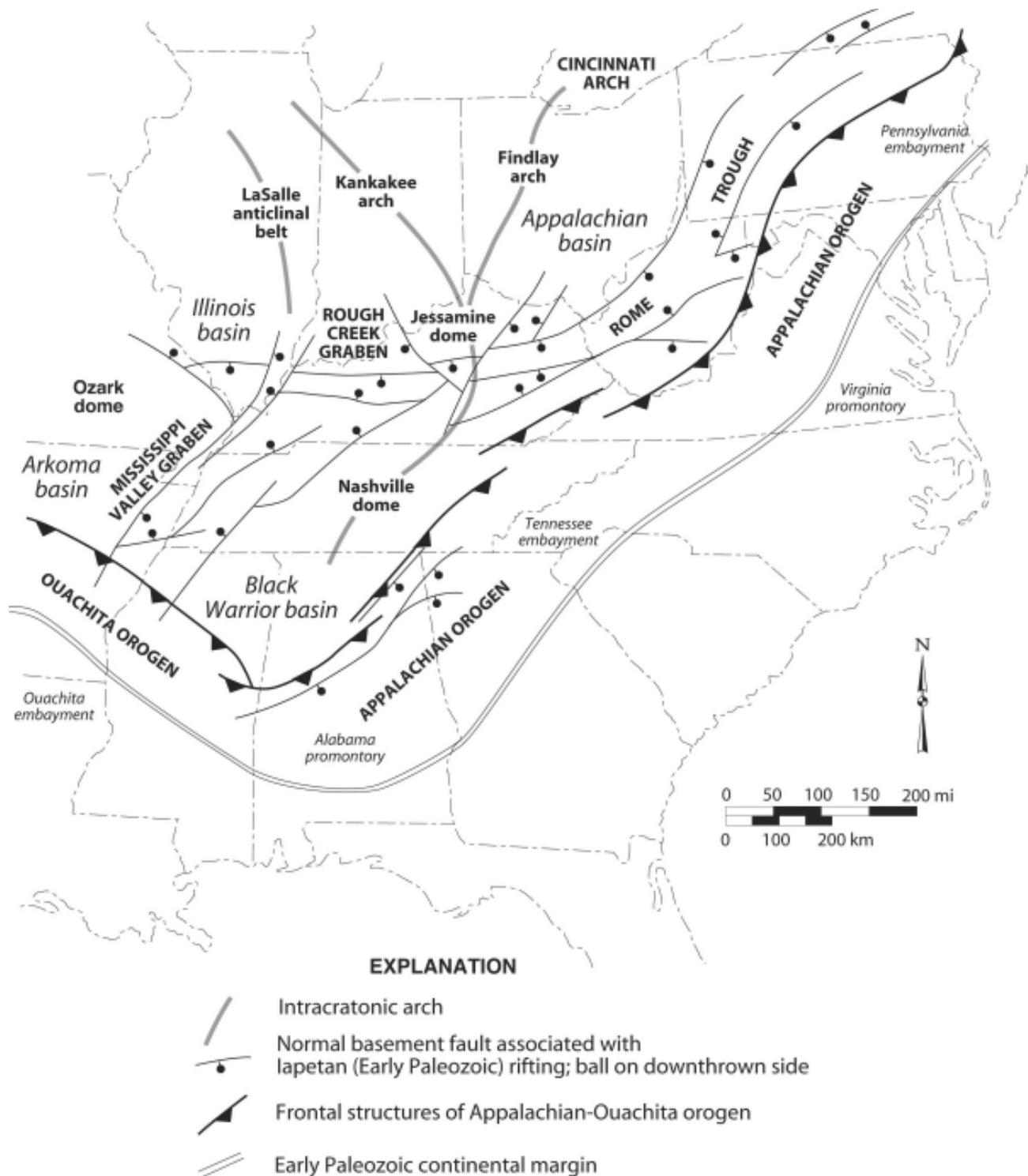


Figure 4. Tectonic setting of the Black Warrior basin (after Thomas, 1998).

toward paleoenvironmental modeling in the coal-bearing successions of the Appalachian region, and subsequent investigators have interpreted the Pottsville Formation within this general framework (e.g., Hobday, 1974; Horsey, 1981; Rheams and Benson, 1982; Thomas, 1988; Ferm and Weisenfluh, 1989) (Figs. 6, 7).

Exploration for oil and gas in the Black Warrior basin has had a strong influence on recent interpretations of Pottsville stratigraphy and sedimentation. Sub-surface studies by Thomas and Womack (1983) and Sestak (1984) indicated that the Ouachita orogen was an important source of fluvial (i.e., riverine) and deltaic

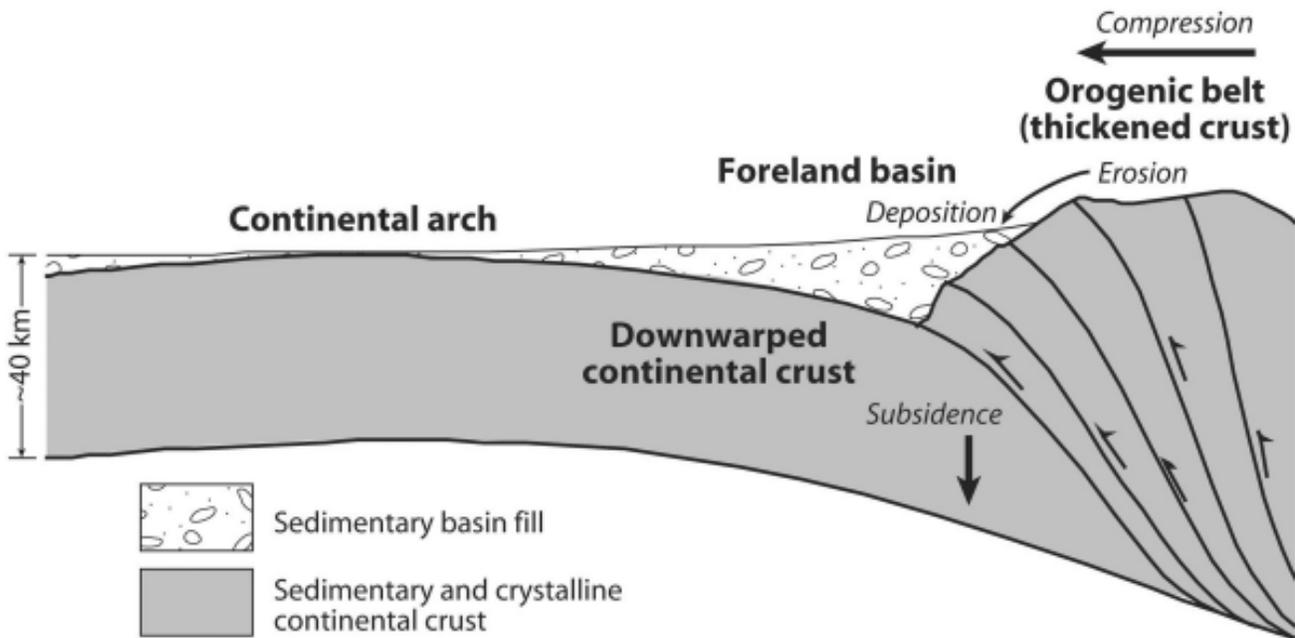


FIGURE 5. Diagram showing flexure of the earth's crust adjacent to mountain ranges to form foreland basins.

sediment during Pottsville deposition and confirmed that the upper Pottsville coal zones could be traced across the basin. Intensive coalbed methane development in the eastern Black Warrior basin provided new data indicating that the Appalachian orogen was a more important source of sediment than was previously thought (Pashin et al., 1991; Pashin, 1994a).

While recognizing the extreme vertical and lateral heterogeneity of the Pottsville Formation, Pashin et al. (1991) found that the Pottsville Formation contains regionally extensive depositional cycles ranging in thickness from 10 to 200 m. Each cycle contains (1) a marine shale unit at the base, (2) a fluvial-deltaic or barrier-shoreline sandstone near the middle, and (3) a lithologically heterogeneous coal zone of fluvial-deltaic origin at the top (Figs. 2, 6). Recent investigators have applied the concepts and nomenclature of sequence stratigraphy (Vail, 1987; Galloway, 1989) to the Pottsville cycles (e.g., Gastaldo et al., 1993; Pashin, 1998). Contacts between cycles are typically sharp or intensely burrowed by animals and have been interpreted as major marine flooding surfaces by Liu and Gastaldo (1992). The flooding surface is characteristically overlain by a thin (<1 m) interval of limy shale or clayey to sandy limestone containing a condensed marine fossil assemblage dominated by brachiopods, molluscs, and crinoids (e.g., Gibson, 1990). Such condensed assemblages form in response to reduced sedimentation rate during the most rapid parts of marine transgressions (i.e., marine flooding events).

The thick mudstone unit (10-75 m) in the lower part of each cycle is dark gray and coarsens upward into sandstone; the shale is considered to represent constructive deltaic systems that marched basinward during relative highstands of sea level (Gastaldo et al., 1993; Pashin,

1998) (Figs. 6, 7). Sandstone and conglomerate units near the middle of the cycles are medium to light gray and very fine- to coarse-grained; they represent diverse depositional environments including deltaic deposits, incised valley fills, beach-barrier systems, and marine sand banks. Although much of the deltaic sandstone was deposited during relative highstands, most of the beach-barrier and incised valley deposits were deposited following lowstands. The economic coal zones forming the top of most cycles represent a spectrum of coastal plain environments, including muddy estuaries and destructive deltaic systems that were deposited mainly during the early stages of marine transgression.

Pashin (1994a) suggested that the upper Pottsville depositional cycles each represent an average timespan of less than 0.5 my (million years), which is compatible with the high-frequency global changes of sea level associated with Gondwanan glaciation. Waxing and waning of continental ice sheets is thought to be regulated by Milankovitch orbital parameters, which refer to periodic changes in the earth's orbit around the sun (Imbrie and Imbrie, 1980; Imbrie, 1985) (Fig. 8). Variation of insolation (incident solar radiation; Berger and Loutre, 1991) in concert with the long eccentricity cycle (ellipticity of earth's orbit; 0.4 my) is commonly cited as the cause for depositional cyclicity during Pennsylvanian time (Heckel, 1986, 1994) (Fig. 9). However, the oxygen isotope record indicates that the short eccentricity (~0.1 my) and obliquity cycles (~0.04 my) dominated Pleistocene glaciation (Imbrie and Imbrie, 1980; Rial, 1999). Pashin et al. (2003) discovered that three minor flooding surfaces of regional extent can be traced within many Pottsville cycles, which suggests the short eccentricity signal (Fig. 10). Accordingly, they interpreted that falling sea level in the short eccentricity band contrib-

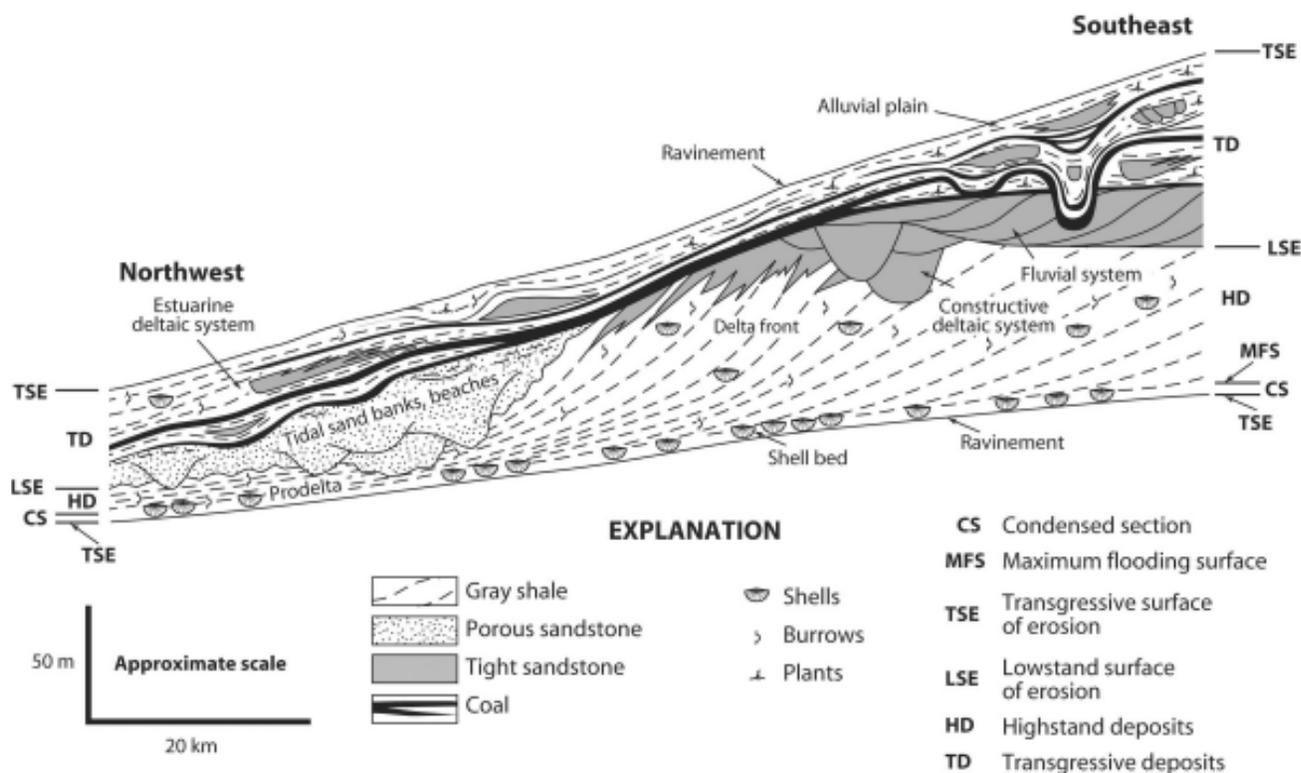


FIGURE 6. Idealized Pottsville depositional cycle in the Black Warrior Basin of Alabama (after Pashin, 1998). Ravinement surfaces and condensed sections apparently formed during the most rapid parts of relative sea level rises. Constructive delta deposits formed during times of high relative sea level, whereas the major coal zones include alluvial plain and estuarine delta deposits that apparently formed during the early stages of sea-level rise.

uted to incision of river channels and valleys at multiple stratigraphic levels within each cycle. By the same token, rising sea level favored high water table conditions and formation of the widespread peat swamp complexes which have been preserved as coal beds.

### THE UNION CHAPEL SECTION

The Union Chapel Mine covers approximately two square kilometers in the Cordova 7.5-minute quadrangle. The Pottsville Formation is approximately 400 m thick in this area, and the Mary Lee coal zone spans about 30 m of section (Metzger, 1965; Tolson, 1986). Strata exposed in the mine face include the upper part of the Mary Lee coal zone and the thick marine mudstone below the Gillespy coal zone (Figs. 2, 11). Effectively all of the *Cincosaurus cobbi* trackways collected at the mine came from the mine spoils, thus careful examination of the mine face is required to identify the beds in which they originated.

The following discussion is based on a description and measured section of the mine face that was made using standard field procedures (e.g., Lahee, 1961). The section was measured on August 8, 2000, during a field trip of the Birmingham Paleontological Society. Additional information on the geologic setting of the mine and the quality of the coal was derived from mine records in the open files of the Geological Survey of Alabama.

### Mary Lee Coal Bed

**Characteristics.** The Mary Lee coal zone contains four named coal beds, which in ascending order are the Jagger coal, the Blue Creek coal, the Mary Lee coal, and the New Castle coal (Fig. 2). The Jagger and Blue Creek beds are absent in the Cordova Quadrangle, and so the Mary Lee and New Castle beds are the chief mining targets in the Union Chapel area (Tolson, 1986). Although the coal was concealed below talus when the section was measured, mine records indicate that the Mary Lee bed maintains a uniform thickness of 0.6 m in and around the Union Chapel Mine.

The Mary Lee coal in the Union Chapel area is bright-banded in hand sample and contains no significant partings of shale or sandstone (Tolson, 1986). Microscopic examination of coal banding reveals that the Mary Lee coal in Walker County contains a diverse flora dominated by lycopods (treelike club mosses), calamiteans (horsetail-like sphenophytes), and fernlike foliage (Winston, 1990; Eble et al., 1994) (Fig. 12). Thick, bright bands in coal are called vitrain and consist of coalified woody material, including the axes, branches, and roots of coal-forming plants. Hard, dull coal bands are called clairain and durain and are dominated by macerated woody debris, leaf litter, and spores. Fusain forms very soft, dull bands in coal that resemble charcoal and consists of intensely oxidized plant remains.

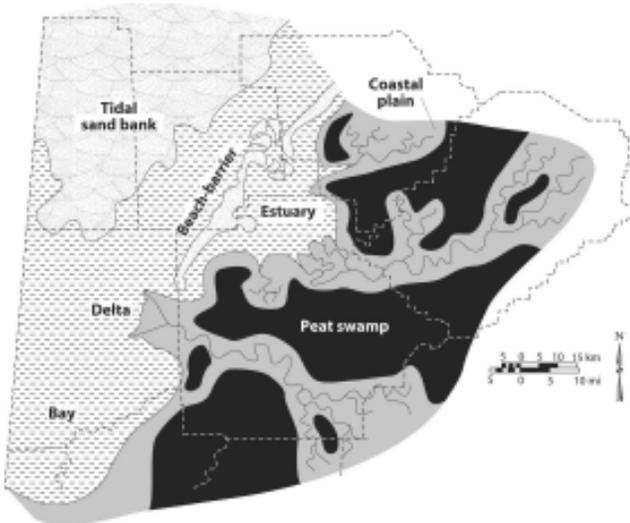


FIGURE 7. Generalized upper Pottsville paleogeography in the Black Warrior basin of Alabama (after Pashin et al., 1991).

The Mary Lee coal is of exceptional quality, having a heating value of about 12,000 Btu/lb, ash content between 13 and 16%, and only 0.4 to 0.9% total sulfur (Bragg et al., 1998). The high heating value and low sulfur content of the coal makes it an attractive fuel for electric power generation.

**Interpretation.** The Mary Lee coal bed represents a widespread peat swamp that formed on the Pottsville coastal plain. The composition and quality of the coal reveals that the Mary Lee swamp was a dynamic environment consisting of a lycopod forest with an understory of sphenophytes and fernlike foliage (Winston, 1990; Eble et al., 1994) (Fig. 12). Vitrain, clarain, and durain bands preserve plants and forest litter, whereas intensely oxidized plant material in fusain bands provides evidence for swamp fires that occasionally ravaged the lycopod forest. Plants are compressed greatly to make coal, and in Appalachian coal beds, peat is thought to have compacted by a factor of 10 (Cobb et al., 1981; Pashin, 1994c). Accordingly, the original thickness of Mary Lee peat at the Union Chapel Mine was about 6 m.

Coal ash is the non-combustible portion of coal and consists mainly of mineral matter, such as pyrite, clay, and quartz. Mineral matter can be introduced into coal by flooding, wind, volcanic eruptions, and chemical reaction (Spears, 1987). Some mineral matter may be derived directly from plants in the form of platelets called phytoliths (Renton and Cecil, 1979). Volcanic ash layers have not been identified in the Warrior coal basin, thus most clay and quartz in Alabama coal was introduced by flooding and perhaps to a minor extent by wind.

Peat swamps can be classified as domed or low-lying (e.g., McCabe, 1984). Peat domes are mounds that are protected from flooding and thus can have ash content lower than 2 percent. Today, tropical peat domes are forming in southeast Asia (Anderson, 1964; Staub

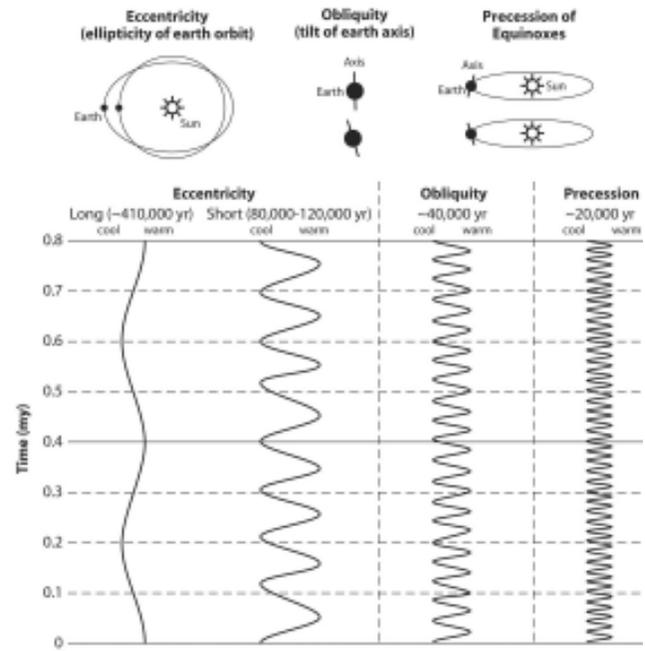


FIGURE 8. Idealized climatic cycles related to Milankovitch orbital parameters.

and Esterle, 1994). By contrast, low-lying swamps are prone to flooding with sediment-laden water and therefore can contain peat with higher ash content. The relatively high ash content of the Mary Lee coal in the Union Chapel area suggests that peat accumulated in a low-lying swamp. The lack of shale partings in the coal further indicates that it formed in interior parts of the swamp that were protected from overbank sedimentation. Low-lying swamps are common in the southeastern United States and include the well-known Okefenokee Swamp of Georgia (Cohen, 1974).

Sulfur not only is a major determinant of the marketability of coal, but it also provides important information on depositional setting (Casagrande, 1987). The primary forms of sulfur in coal are organic sulfur and pyritic sulfur. Organic sulfur is bound to the coal structure and is thought to be derived mainly from coal-forming plants. Pyritic sulfur is in iron sulfide (pyrite;  $\text{FeS}_2$ ) and is thought to be primarily the product of bacterial sulfate reduction in peat. Sea water is saturated with sulfate, and coal with sulfur content higher than 2 percent is typically overlain directly by marine strata (Williams and Keith, 1963). Organic sulfur content in the Warrior coal basin averages 0.1 percent and does not correlate significantly with total sulfur, whereas pyritic sulfur correlates strongly with total sulfur (Pashin et al., 2003). The low sulfur content of the Mary Lee bed in the Union Chapel area indicates that the peat contained only fresh water during early burial.

### **Cincosaurus Beds**

**Characteristics.** Comparison of the slabs containing *Cincosaurus cobbi* with the mine face indicates that all amphibian trackways found at the Union Chapel Mine

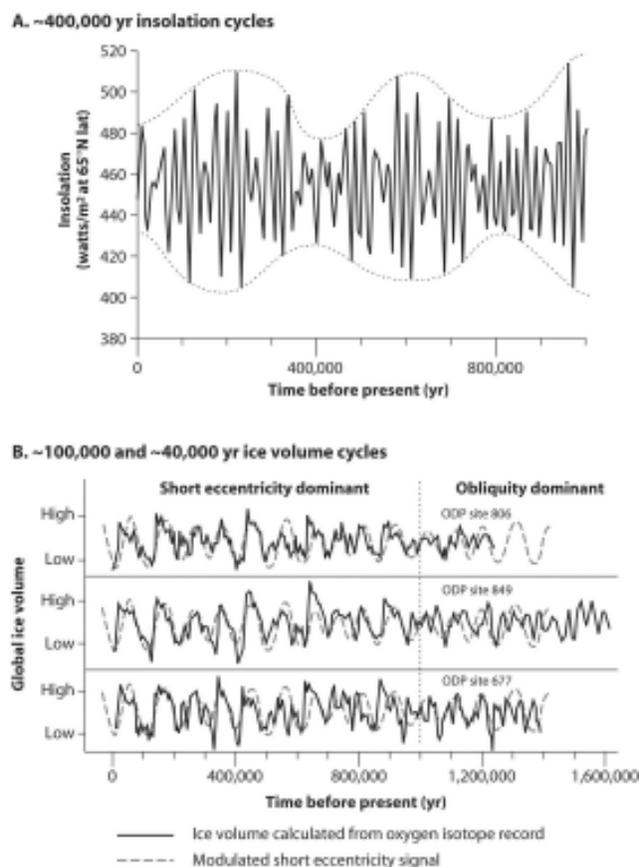


FIGURE 9. Variation of insolation and ice volume during the Pleistocene glaciation (after Berger and Loutre, 1991; Riall, 1999).

came from the interval of dark gray shale between the Mary Lee and New Castle coal beds. Accordingly, this interval is named the *Cincosaurus* beds (Fig. 11). The lower 4 m of this interval is dominated by pinstripe-bedded mudstone (see Klein, 1977). The mudstone comprises numerous siltstone-shale and sandstone-shale beds that are normally graded (i.e., fine upward) and range in thickness from 0.2 cm to more than 4.0 cm (Figs. 13, 14). Siltstone and sandstone form thin, light gray laminae at the bases of most graded beds, and dark gray graded mudstone forms the bulk of the beds. All trackways are preserved as impressions at the tops of the graded beds (Fig. 15) or as casts (undertracks) at the bases.

Progressive thickening and thinning of successive graded beds is common in the *Cincosaurus* beds (Fig. 13A). Locally, thick and thin beds are paired to form couplets (Fig. 13B). Examination of the highwall indicates that the graded beds pinch and swell laterally. In some areas, siltstone-shale beds thicker than 2 cm thin to less than 0.5 cm in a distance of about 5 m. Broad (>5 m), shallow (<0.3 m) scour surfaces also are common in the *Cincosaurus* beds. The thickness of 126 successive beds was measured near the north end of the highwall, and a bar chart demonstrates progressive thickening and thinning of the graded beds (Fig. 14). Although thickness changes appear to be largely progressive, the

minima and maxima of layer thickness are irregularly spaced.

Some types of physical sedimentary structures are common in the *Cincosaurus* beds. Sole markings are on the bases of some graded siltstone-shale and sandstone-shale beds and include groove casts, prod marks, and load casts. The most distinctive physical structures are crater-like impressions at the top of the graded shale beds (Fig. 15). These impressions have variable size and spacing and are characterized by elevated circular rims around central depressions.

Several types of trace fossils are preserved with *Cincosaurus*, including probable horseshoe crab traces (*Kouphichnium* isp.), fish traces (*Undichna* isp.), insect traces (*Treptichnus* isp.), and millipede traces (*Diplichnites* isp.). These traces are illustrated in detail in Buta et al. (2005) and have been identified in other Pottsville exposures (Rindsberg, 1990). Macerated plant debris is common on bedding planes, and most plant fossils in the *Cincosaurus* beds include fragments of fronds and branches derived from seed ferns (*Neuropteris* sp.) and other fern-like foliage, as well as the horsetail-like sphenophyte *Calamites* sp. In the northern part of the mine face, an erect seed fern stump was observed, and several erect specimens of *Calamites* have been recovered from the spoils.

The upper 2 m of the *Cincosaurus* beds contrast sharply with the underlying pinstripe-bedded shale that yielded the trackways (Fig. 11). Above the pinstripe-bedded interval is about 1 m of ripple-bedded (wavy and flaser-bedded) sandstone and shale. The sandstone is very fine grained and light gray, whereas the shale is silty. Discoid pebbles of shale and siderite are common in this bed, as are tubular horizontal burrows of unknown affinity. The uppermost meter of the *Cincosaurus* beds consists of sandy underclay that fines upward. Siderite nodules and root traces are common throughout the underclay interval, and some root traces extend downward into the ripple-bedded sandstone below. Siderite nodules are distinctive because they are hard and have reddish hues. The root traces are assigned to the genus *Stigmaria*, which is the root system of a variety of lycopod types.

**Interpretation.** The *Cincosaurus* beds are interpreted as intertidal mudflat deposits (Fig. 11), and these types of deposits have been known from the Pottsville Formation for many years (Hobday, 1974; Demko and Gastaldo, 1996). The *Cincosaurus* mudflat formed by inundation of the Mary Lee peat swamp with sediment-laden water, and biogenic and physical structures reveal much about the dynamics of the environment where the trackways were preserved. Peat compacts greatly during the early stages of burial below mud and sand (Nadon, 1998), so preservation of the *Cincosaurus* beds may reflect accumulation of sediment above compacting peat as much as rising water level.

The graded siltstone-shale and sandstone-shale beds (Fig. 13) indicate that sedimentation was episodic. Each graded bed represents a single event in which sediment settled from suspension in water at the site of deposition. Groove casts and prod marks formed prior to depo-

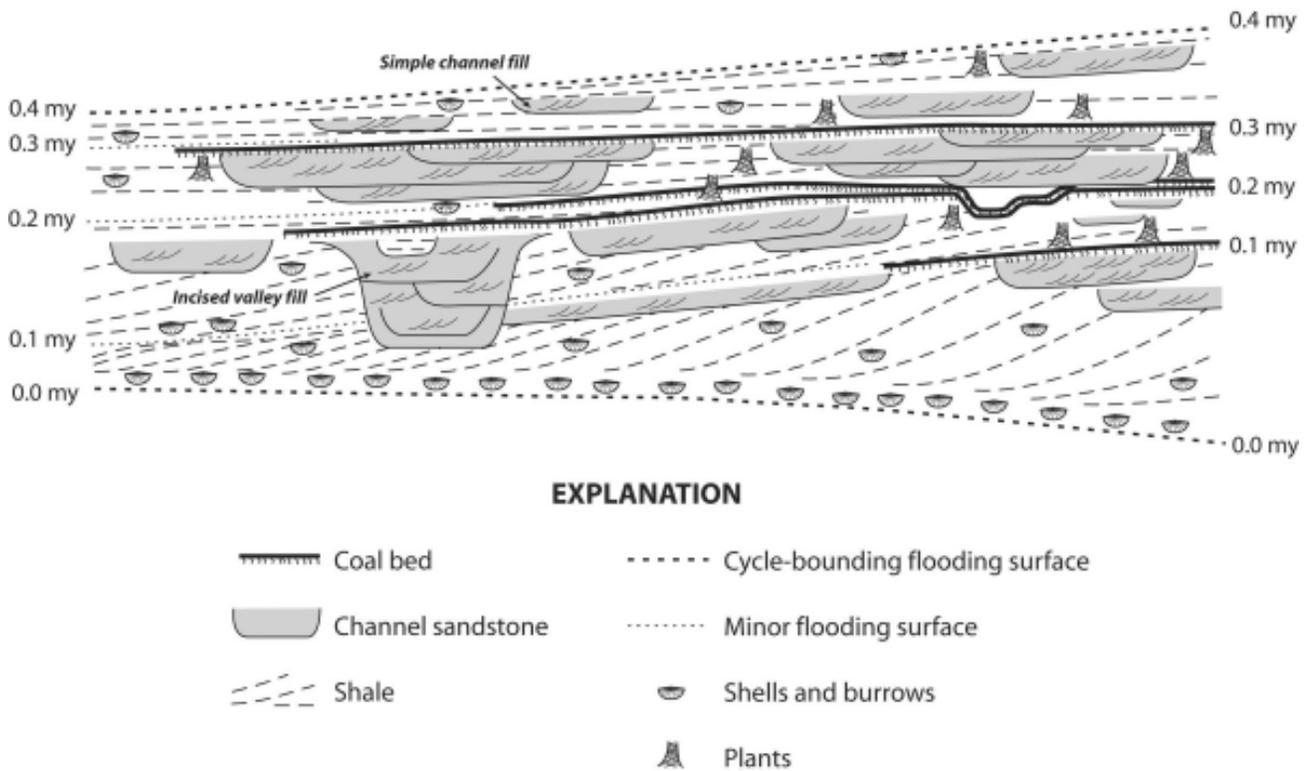


FIGURE 10. Idealized relationship of stratigraphic variation within a Pottsville depositional cycle to 0.1 Ma eccentricity cycles (after Pashin et al., 2003).

sition as vigorous currents caused objects to slide or skip on the sediment surface. Load casts, by comparison, formed later as fluid sediment deformed under the weight of the younger graded beds. Sand and silt settled first from suspension as the current slowed, and the lighter clay settled later, thus forming graded beds. Paired thick and thin graded beds correspond to paired events in which the current depositing the thick bed was stronger. Such paired depositional events are common in tidal systems and can represent the deposits of flood (incoming) and ebb (outgoing) tides. Evidence for the tidal range is not preserved at the Union Chapel Mine, but comparison of Pottsville strata with modern analogs suggests that a mesotidal regime (2-4 m) prevailed during Pottsville deposition (Hobday, 1974; Horne, 1979).

Progressive thickening and thinning of bedding is common in Pennsylvanian-age tidal deposits, and analysis of bedding thickness patterns has been used to characterize monthly (spring-neap) tidal cycles (e.g., Kvale et al., 1989; Archer, 1991). Pashin et al. (1995) and Pashin and Carroll (1999) identified 14-part cycles of bedding thickness in graded strata resembling the *Cincosaurus* beds in Jefferson County, Alabama. They suggested that these cycles are the product of a dominantly diurnal lunar tidal regime (one flood daily) and that each cycle represents 2 weeks. Diurnal systems are typical of embayments that are restricted from the resonance of the open ocean, and this type of tidal system exists today in the Gulf of Mexico. Statistical analysis of the *Cincosaurus* beds indicates poor preservation of spring-neap cyclicity at the Union Chapel Mine (Fig.

16). The dominant periodicity of the thickness cycles is 31.2 layers, and subordinate frequencies include 62.5, 17.8, and 10.4 layers. These cycle periods suggest that spring-neap cycles were masked by other depositional processes, and the frequencies of 62.5 and 31.2 may indicate monthly, seasonal, or even localized changes of sediment flux. This result is not surprising because bedding in the *Cincosaurus* beds pinches and swells laterally, and broad scour-and-fill structures provide first-hand evidence for discontinuous sedimentation.

The extremely low sulfur content of the Mary Lee coal bed indicates that the waters that inundated the swamp were fresh and, indeed, modern amphibians have effectively no tolerance for saline conditions. Therefore, the *Cincosaurus* beds can be interpreted as an estuarine mudflat in which tidal currents primarily moved fresh water about. Other fresh-water tidal deposits have been identified in the roof of Pennsylvanian-aged coal in Indiana by Kvale and Mastalerz (1998), and estuarine mudflats exist today adjacent to low-ash peat swamps on the Rajang Delta in Indonesia (Staub and Esterle, 1994) (Fig. 17). Using the Rajang Delta as a modern analog, sedimentation on the *Cincosaurus* mudflat may have been influenced as strongly by changes in stream levels and deltaic sediment discharge as by spring-neap tidal cycles.

Interpretation of the craterlike impressions is problematic. These structures resemble raindrop imprints, and if this interpretation is correct, the circular outlines indicate that the drops fell under low-wind conditions (Reineck, 1955; Shrock, 1948). Raindrop imprints are

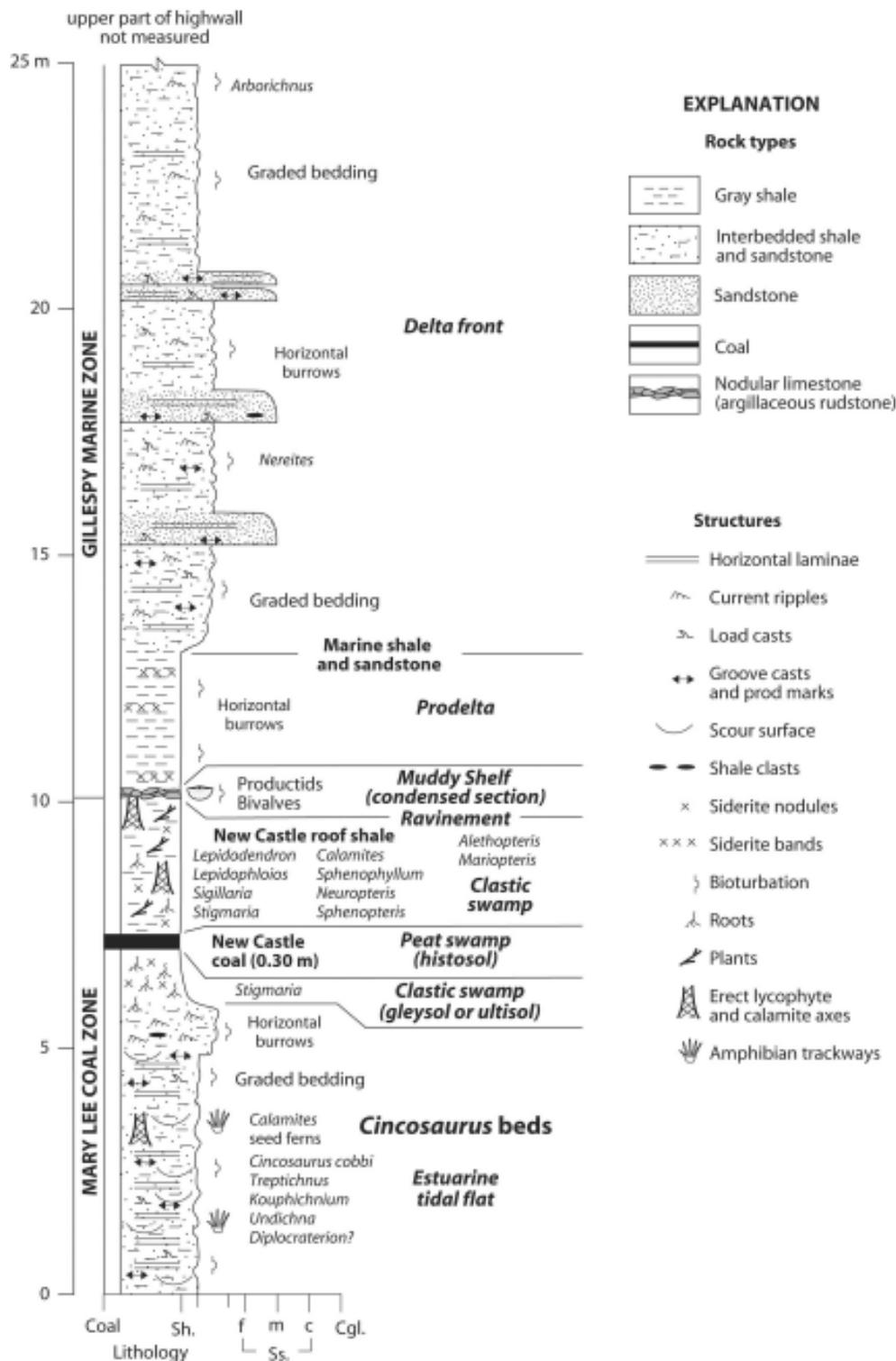


FIGURE 11. Measured section of the Pottsville Formation at the Union Chapel Mine.

compatible with the rainy, equatorial setting of the Pottsville Formation. A lack of mudcracks indicates that the mud flat was never exposed long enough for the sediment to desiccate and crack; thus windows of opportunity for the formation of raindrop imprints were restricted to extreme low-tide conditions. However, many of these

structures have irregular outlines or appear stretched, suggesting that an origin as collapsed gas bubbles is more feasible in many cases (see Rindsberg, 2005). Also, few of the structures overlap, which is atypical of raindrop imprints, and some of the structures appear to pass through multiple layers and may, therefore, include an

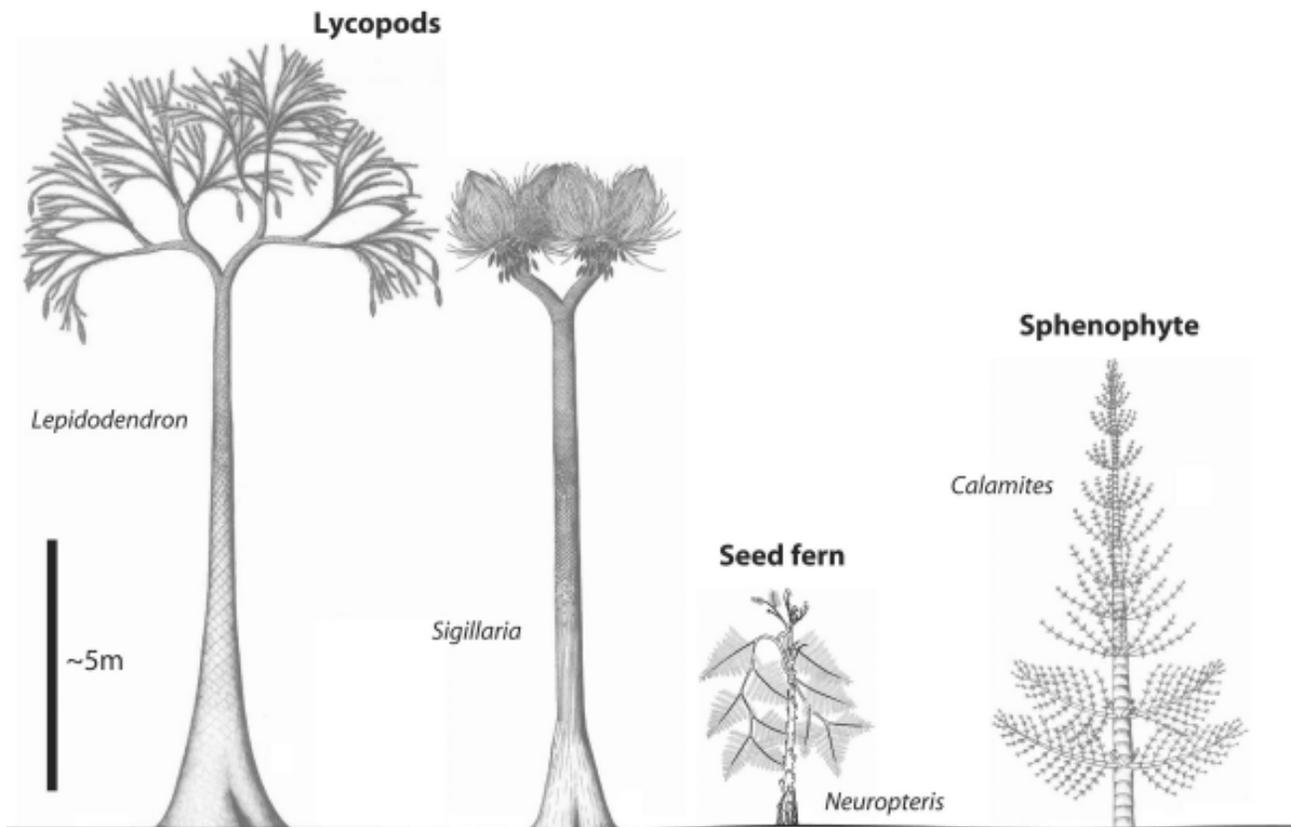


FIGURE 12. Reconstructions of common plant fossils in Pennsylvanian-aged coal-bearing strata (after Gillespie et al., 1978).

enigmatic type of burrow.

*Calamites* and an unidentified seed fern were the only plants preserved in life position in the *Cincosaurus* beds. The mangrove-like root systems of seed ferns (Fig. 12) attest to frequent flooding of the mud flat and suggest analogy with modern mangrove swamps of the muddy shore zone. Whereas some plants resided on the mud flat, the trace fossil assemblage is dominated by locomotion traces, indicating that most fauna were in transit. One possibility is that during low-water conditions, *Cincosaurus* and other creatures entered the mud flat to forage.

The ripple-bedded sandstone and shale near the top of the *Cincosaurus* beds also is characteristic of tidal flats (e.g., van Straaten, 1954) and, based on the overall lithologic character of this interval, it can be interpreted as the deposit of a mixed sand-mud flat. Ripple-bedded sandstone indicates deposition by turbulent flow, whereas the shale represents mud that accumulated during low-flow or slack-water conditions. One possibility is that the ripple-bedded sandstone and shale were deposited in a sandier part of the same mudflat complex where the *Cincosaurus* trackways were preserved.

The underclay at the top of the *Cincosaurus* beds marks a transition from tidal flat to swamp environments, thus foreshadowing formation of the overlying New Castle coal. Intense rooting in underclay beds provides evidence for formation of an ancient soil horizon, or paleosol. Underclay beds generally are interpreted as

hydromorphic paleosols, which are subaqueous wetland soils, but the complete origin of underclay beds is imprecisely known and is controversial (e.g., Gardner et al., 1988; Mack et al., 1993). Most investigators agree that underclay formation began with a lowered water table in which iron and other compounds were leached from the upper part of the soil profile. In Pottsville underclay, the leached iron is preserved in the lower part of the ancient soil profile as siderite nodules. As the water table rises, perhaps in concert with sea level, a swamp forest can be established and, as wetland conditions form, peat can begin to accumulate. Alkaline fluid within peat can react with the sediment below by dissolving quartz and concentrating clay by a process called gleying, which helps explain why underclay beds fine upward. Although the underclay at the top of the *Cincosaurus* beds is silty and thus weakly gleyed, the underclay below the Mary Lee coal is, in places, intensely gleyed and is mined in the Cordova area for ceramic applications.

### New Castle Coal Bed

**Characteristics.** The New Castle coal is 0.30 m thick at the Union Chapel Mine and sharply overlies the *Cincosaurus* beds. Like the Mary Lee coal, the New Castle bed is bright-banded, lacks partings of shale or sandstone, and maintains uniform thickness. The New Castle bed has heating value (12,000 Btu/lb) and ash content (10-16%) similar to the Mary Lee bed, but sul-

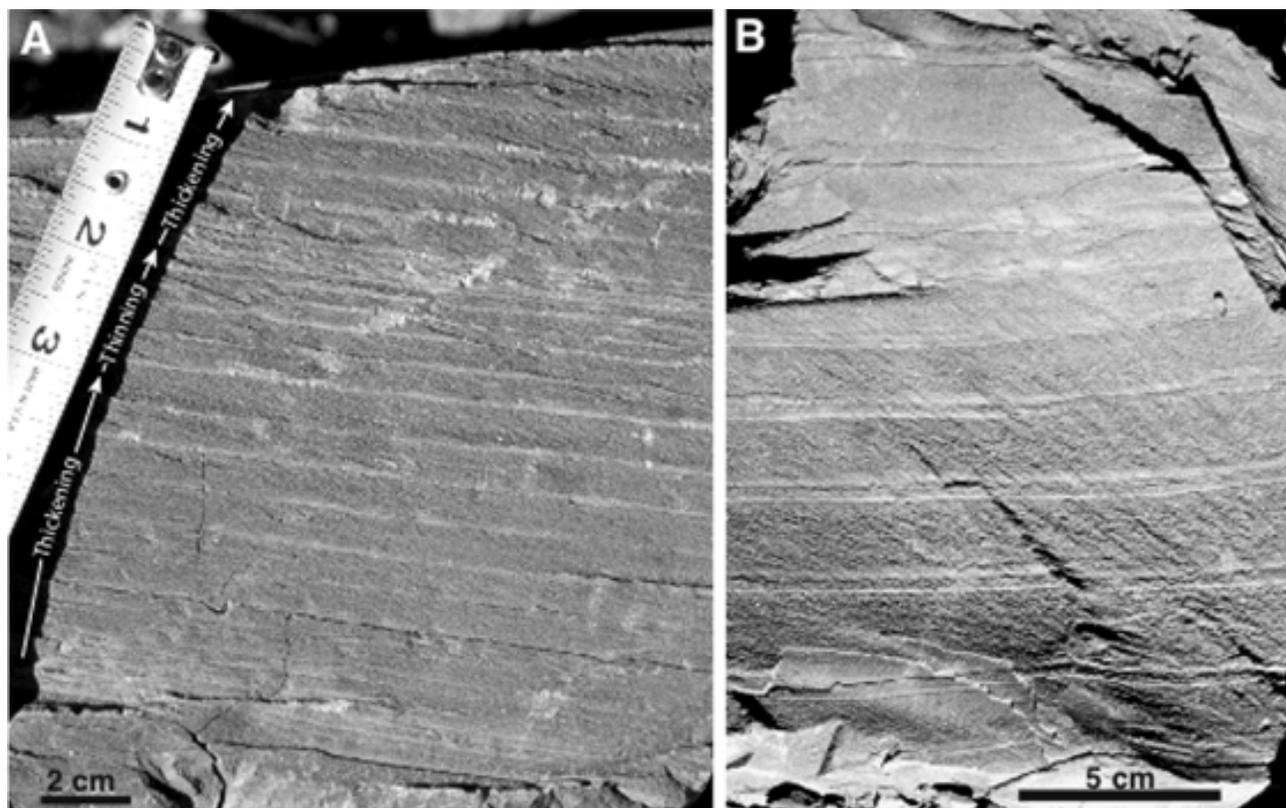


FIGURE 13. Graded siltstone-shale layers in the *Cincosaurus* beds at the Union Chapel Mine. Siltstone is lighter in color than shale. A, Progressive thickening and thinning of bedding. B, Paired thick and thin graded beds in oblique section.

fur content is markedly higher at 1.5 percent. In other mines in the Cordova area, sulfur content of the New Castle bed is as high as 5 percent (Tolson, 1986; Bragg et al., 1998).

The flora of the New Castle coal is similar to that in the Mary Lee coal, and coal balls from the New Castle bed in western Walker County, Alabama, provide a unique view of Pottsville floras (Winston and Phillips, 1991). Coal balls are limestone (calcium carbonate;  $\text{CaCO}_3$ ) concretions that form in peat before deep burial and compaction, and the New Castle coal balls are significant because they are the oldest known from Pennsylvanian-age rocks in North America. Because coal balls form so early, they preserve the cell structure of ancient plants, and thus provide detailed information on the biology of ancient swamp forests. The New Castle coal balls preserve a diverse flora, with lycopods forming 82 percent of the biovolume, fern-like plants forming 4 percent, and a range of other plant types forming the remainder.

*Interpretation.* The New Castle coal signifies a return to lycopod-dominated peat swamp environments similar to those discussed earlier in the section on the Mary Lee coal. A lack of shaly partings plus ash content similar to that in the Mary Lee coal indicate that New Castle peat in the Union Chapel area accumulated in the interior of a low-lying swamp. The New Castle peat accu-

mulation was thin compared to the Mary Lee bed and, based on the 10:1 peat-to-coal compaction ratio discussed earlier, original thickness of the New Castle peat was only about 3 m.

The relatively high sulfur content and local preservation of coal balls in the New Castle bed indicate that marine waters influenced coal quality. Coal balls are known exclusively from coal beds with marine or brackish roof strata, as is the case where the New Castle coal balls were discovered in northwestern Walker County, Alabama (Gastaldo et al., 1990; Winston and Phillips, 1991). Coal balls form as carbonate-saturated sea water infiltrates peat, and some of the carbonate may be derived directly from decaying plant material (Stopes and Watson, 1909; Scott and Rex, 1985). The high sulfur content of the New Castle bed in much of the Cordova area provides evidence for bacterial sulfate reduction as marine water infiltrated peat. However, the sulfur content of the New Castle bed at the Union Chapel Mine is low for the Cordova area, and the key to determining why the sulfur content is low is to examine the roof strata.

### New Castle Roof Shale

*Characteristics.* Above the New Castle coal bed is about 2.7 m of gray, silty shale with sparse, reddish siderite nodules (Fig. 11). The shale forms the top of the Mary

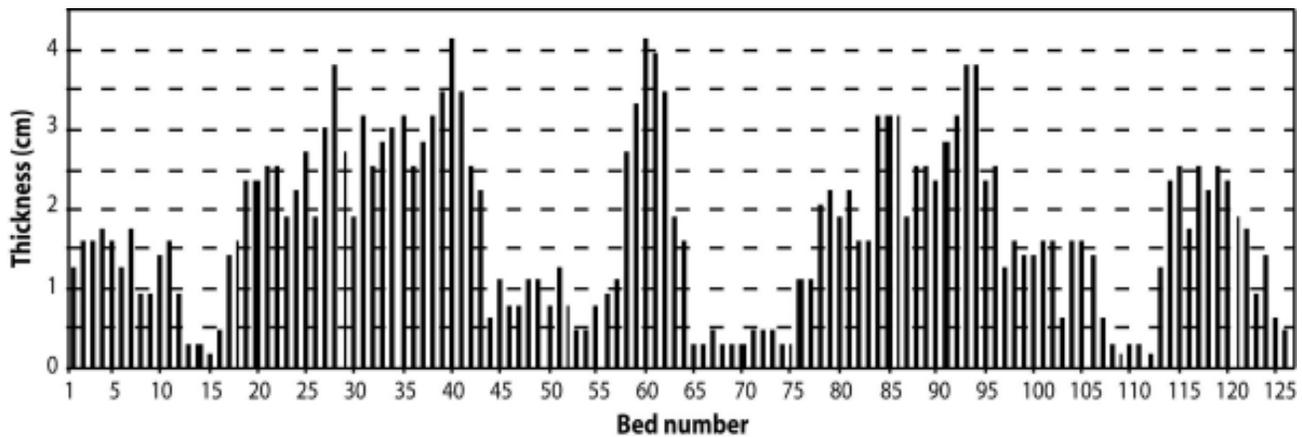


FIGURE 14. Bar chart showing variation of bedding thickness in the *Cincosaurus* beds at the Union Chapel Mine.

Lee coal zone and contains abundant plant fossils. This shale is typical of the roof strata above economic coal beds in the Appalachian region. The New Castle roof shale is poorly bedded compared to the *Cincosaurus* beds, and the presence of siderite nodules is another distinguishing feature. In contrast to the low-diversity flora of the *Cincosaurus* beds, the New Castle roof shale contains a rich and diverse plant assemblage. Indeed, most collectable plant fossils at the Union Chapel Mine come from this bed. Included in the assemblage are lycopods (*Lepidodendron*, *Lepidophloios*), sphenophytes (*Calamites*, *Sphenophyllum*), and several genera of fernlike foliage (*Neuropteris*, *Sphenopteris*, *Alethopteris*, and *Mariopteris*) (Dilcher et al., 2005).

Among the most distinctive features of the roof shale are erect lycopod and sphenophyte axes that are filled with shale. The lycopods can be distinguished from other erect plants because they have broad, flared bases. Careful examination of the shale indicates that the erect plants have root systems, including *Stigmaria*, preserved in at least two separate stratigraphic levels. Several layers contain abundant fern-like foliage as well as leaf and branch litter from lycopods. Similar stratigraphic relationships have been identified in plant-bearing intervals of the Mary Lee coal zone at other locations (Gastaldo et al., 1989; Demko and Gastaldo, 1992).

**Interpretation.** Abundant plants, including lycopods and sphenophytes fossilized in life position, indicate that the New Castle roof shale was deposited in a terrestrial setting. The diverse flora suggests analogy with the swamp forests that formed the Mary Lee and New Castle coal beds, and the flared bases of the lycopods are reminiscent of cypress trees in present-day low-lying wetlands of the southeastern United States. But the preservation of plant fossils in shale indicates that the New Castle roof shale represents a swamp that was prone to influxes of mud, perhaps by overbank flooding. These non-marine roof strata help explain why the sulfur content of the New Castle coal is below 2 percent at the Union Chapel Mine, because the mud protected the peat from direct infiltration of sea water. However, the elevated sulfur content of the New Castle coal relative to the Mary Lee coal suggests that some sea water and sulfur-reduc-

ing bacteria may have migrated laterally within the peat from nearby areas with marine roof strata.

The floral characteristics of different layers in terrestrial roof shale provide evidence of the ecological dynamics of swamp forests (Gastaldo et al., 1989; Demko and Gastaldo, 1992). Concentration of root systems and erect plant axes in distinct layers indicates that the roof shale does not represent a single swamp forest that grew for a sustained period, but represents multiple forests that were established at different times. Layers bearing fern-like foliage and leaf-branch litter just above the root layers may be the product of forest litter that accumulated during a time of relative stability. Major floods and associated influxes of mud, by comparison, are thought to have disturbed the swamp ecosystem, causing the plants to die and the forest canopy to drop to the surface. These events are thought to result in extensive layers of fossil plant litter and erect stumps.

### Nodular Limestone

**Characteristics.** Above the roof shale is a bed of nodular (i.e., knobby) limestone that is about 15 cm thick (Fig. 11). The limestone is argillaceous, is dark gray, and contains abundant macerated fossils; it weathers with a dark red cast. Erect plant axes in the upper part of the New Castle roof shale are truncated at the base of the limestone. The lower contact of the limestone marks the top of the Mary Lee coal zone, and both contacts of the limestone are gradational and intensely burrowed. The nodular character of the limestone also is the product of burrowing.

Most fossil material in the nodular limestone has been broken, but some identifiable remains are present. The dominant types of fossils are productid brachiopods and bivalves. Gibson (1990) illustrated several fossils from this same bed in western Walker County, Alabama. Two species of strophomenid brachiopods were observed at the Union Chapel Mine, specifically *Antiquatonia portlockiana* (Norwood and Pratten) and *Desmoinesia muracatina* (Dunbar and Conrad). Also identified was the bivalve *Astartella concentrica* (Conrad). Gibson (1990) noted that marine faunas atop the Mary Lee coal zone in Walker County vary from

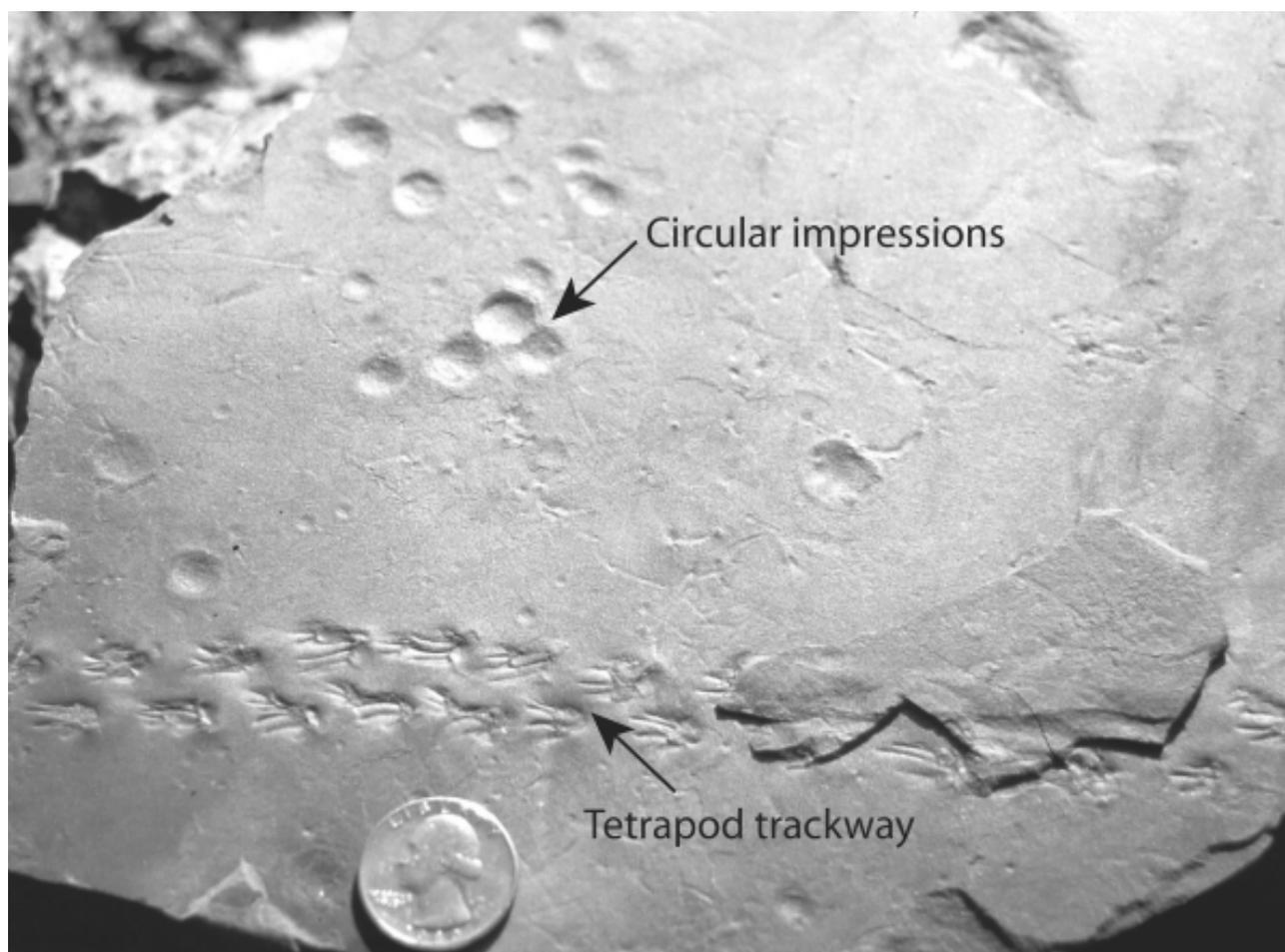


FIGURE 15. Small *trackway* (*Cincosaurus*) with crater-like gas-escape structures or raindrop impressions. Specimen collected by T. Prescott Atkinson.

outcrop to outcrop and in places include echinoderms, gastropods, and other types of molluscs.

*Interpretation.* The nodular limestone marks a change from terrestrial to marine sedimentation. Truncation of erect plants at the base of the limestone indicates that an episode of exposure or erosion predated marine deposition. Evidence of erosion is common at the base of the thin limy units atop the Pottsville coal zones, and this erosion is thought to be caused by current action (shoreface erosion) as the sea onlaps the coastal plain (Liu and Gastaldo, 1992). The predominance of productid brachiopods and bivalves in the limestone suggests that environmental conditions were stressed compared to other locations where echinoderms indicate more normal, open-marine sedimentation. The nodular texture of the limestone bed is the product of intense burrowing, which apparently caused maceration and disorientation of the shells.

Thin limestone units overlying transgressive surfaces of erosion are characteristic of condensed sections, which form when relative sea-level rise reaches a maximum rate (Vail, 1987; Posamentier and Vail, 1988) (Fig. 6). Condensed sections are thin but can represent large spans of geologic time because they form as mud and sand are

held inshore by the transgressing sea. Indeed, the erosional surface below the limestone formed near the shoreline, whereas the top of the limestone represents the deepest water recorded in the Union Chapel section. Although the maximum water depth recorded in the Union Chapel section is unknown, absolute sea level changes during Early Pennsylvanian time are thought to have been greater than 40 m in magnitude (Maynard and Leeder, 1992).

### Marine Shale and Sandstone

*Characteristics.* The upper part of the section in the Union Chapel Mine consists of gray shale that coarsens upward into thickly interbedded sandstone and shale (Fig. 11). This part of the section is the coarsening-upward shale-sandstone interval separating the Mary Lee and Gillespy coal zones (Fig. 2). The lower part of this interval consists of gray, silty shale with weak to moderate fissility. This shale is distinguished from older clay-rich beds in the Union Chapel Mine because it contains thin (~2 cm) bands of red-weathering siderite. No body fossils were recovered from this bed, but the shale is intensely burrowed, and careful examination reveals an abundance of horizontal tubular burrows ranging from

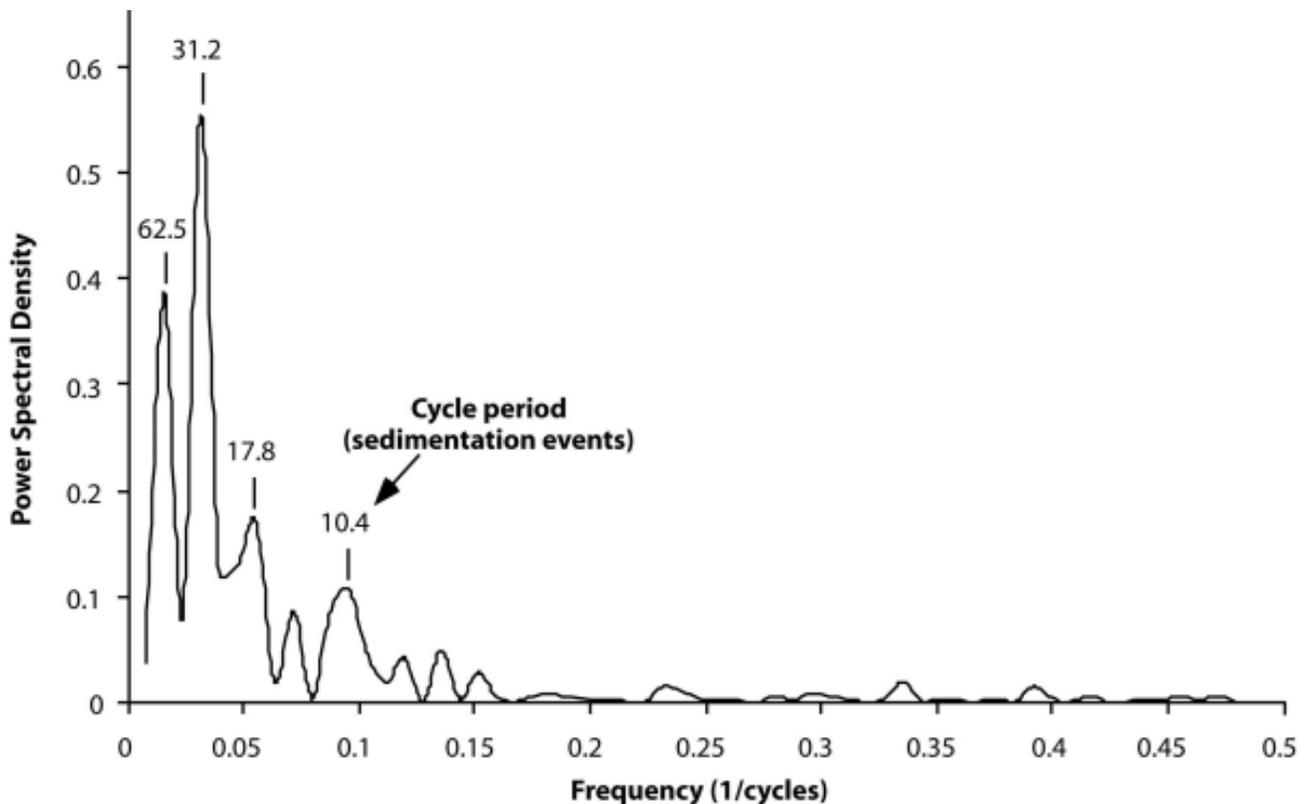


FIGURE 16. Results of Fourier transform analysis showing periodicity of bedding thickness cycles in the *Cincosaurus* beds (courtesy of E. P. Kvale).

about 1 to 3 mm in diameter.

About 12 m of interbedded gray shale and sandstone is accessible in the upper part of the highwall (Fig. 11). Shale is exposed in laminae to thick beds and is similar in character to that described above. Sandstone is very fine to fine grained, is light gray to medium gray, and forms laminae to thick beds. The sandstone beds have sharp bases and gradational tops. Abundant sole markings distinguish graded beds in the marine shale and sandstone from those in the *Cincosaurus* beds, and the sole marks mainly constitute prod marks, load casts, and horizontal burrow casts. Shale pebbles are locally present in the lower parts of the thick sandstone beds. Sedimentary structures within thin sandstone beds include horizontal laminae and current ripples. Within the thick sandstone beds, by comparison, sedimentary structure is dominated by horizontal laminae. Trace fossils are common in the interbedded shale and sandstone, and care must be taken to distinguish them from those in the *Cincosaurus* beds. The most common trace fossils in the marine shale and sandstone are horizontal tubular burrows. Other trace fossils include *Nereites* isp., which is a sinuous feeding trace of unknown affinity (Rindsberg, 1994).

The upper part of the highwall is inaccessible, but blocks in the mine talus indicate that the main rock types are dark gray, silty shale and medium gray, fine- to medium-grained sandstone. Shale and sandstone in the upper part of the section are thickly interbedded, and a variety of sedimentary structures are developed. In ad-

dition to current ripples and horizontal laminae like those identified near the top of the accessible section, thick sandstone beds contain crossbeds. Bedding becomes increasingly irregular and lensoid upward in section, and a broad, shallow channel filled with sandstone and shale is developed near the top of the highwall. Trace fossils, including abundant specimens of the horseshoe crab resting trace, *Arborichnus* isp. are common in the shale talus.

*Interpretation:* This interval is typical of major marine shale-sandstone units in the Pottsville Formation and was deposited in prodelta and delta-front environments (Figs. 6, 7). Prodelta areas are the muddy areas seaward of delta systems, and the lower, shale-dominated part of the interval apparently was deposited in this environment. Delta-front environments include sandy and muddy marine slopes near river mouths, and the thickly interbedded shale and sandstone near the top of the Union Chapel exposure are typical of delta-front deposits in the Pottsville Formation (e.g., Rheams and Benson, 1982; Pashin, 1994a). Trace fossils like *Nereites* confirm the marine origin of the mudstone (Seilacher, 1967; Rindsberg, 1994), although local conditions were not conducive to preservation of the shelly fauna that is common elsewhere at this stratigraphic level (Gibson, 1990).

Graded bedding indicates that sedimentation was episodic like in the *Cincosaurus* beds. However, graded sandstone layers in the marine shale and sandstone interval are irregularly distributed and thus represent rela-

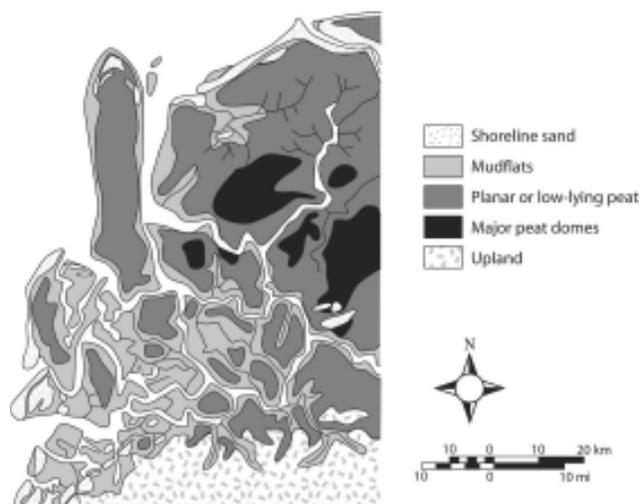


FIGURE 17. Possible modern analog for the Pottsville Formation, including the *Cincosaurus* beds, in the Rajang Delta of Indonesia (after Staub and Esterle, 1994).

tively rare depositional events. In delta-front environments, graded beds commonly are deposited as sediment-laden currents move downslope during episodes of high river discharge stimulated by heavy rainfall in the drainage basin (Martinsen, 1990). Graded beds also can be formed during local storm events in which sediment is eroded in proximal parts of the delta and is redeposited farther downslope. Crossbedding and channel fills near the top of the section are suggestive of delta-front environments close to the mouths of stream channels. In contrast to the episodic flows that formed graded beds lower in section, the flow of water was probably persistent close to the stream mouths. Crossbedding in the sandstone indicates that the flow was at times highly turbulent, and the channel fill is a testament to the erosive power in the shallow marine parts of delta systems.

## SUMMARY AND CONCLUSIONS

The Union Chapel trace fossil assemblage is a fossil lagerstätte that can be considered in the context of the global, regional, and local events that shaped the world during Pennsylvanian time. The Union Chapel lagerstätte is in the Mary Lee coal zone of the Pottsville Formation, which is of Morrowan (Early Pennsylvanian) age and is an important source of coal and coalbed methane. The Early Pennsylvanian was a time of major tectonic and climatic changes associated with assembly of the supercontinent Pangaea, and the Pottsville Formation is a direct reflection of those changes.

The Black Warrior Basin formed at the juncture of the Appalachian and Ouachita orogenic belts, which provided most of the sediment that fills the basin. Pottsville strata were deposited in the humid tropics just south of the paleoequator and, at the same time, a major continental ice sheet existed in the south polar realm. Waxing and waning of the ice sheet resulted in lowering and raising of sea level that is expressed as marine-nonmarine depositional cyclicity in the Pottsville Formation. Climatic fluctuations controlling ice volume and sea level

are thought to have been controlled by perturbations of the earth's orbit around the sun, specifically the long (0.4 Ma) and short (0.1 Ma) orbital eccentricity cycles. Most Pottsville depositional cycles were apparently deposited in the long eccentricity band, and stratigraphic variation within the cycles can be explained in part by sea level changes in the short eccentricity band.

Strata at the Union Chapel Mine are exposed from the upper part of the Mary Lee coal zone through the lower part of the Gillespy coal zone, and each bed exposed in the mine contains a different fossil assemblage reflecting different environments of deposition. The Mary Lee coal bed was the principal mining objective at the Union Chapel Mine and represents a widespread, low-lying peat swamp that was dominated by lycopods. The *Cincosaurus* beds overlie the Mary Lee coal and contain all the amphibian trackways recovered from the Union Chapel Mine, as well as a variety of other locomotion and resting trace fossils. The *Cincosaurus* beds evidently were deposited by tidal currents on a freshwater, estuarine mud flat that formed as the Mary Lee swamp was inundated. Rapid sedimentation in the *Cincosaurus* beds apparently reflects rapid compaction of Mary Lee peat, as well as rising sea level in the short eccentricity band. The trackways provide evidence for animals that were in transit, perhaps scouring the mudflat for food at low tide. At the top of the *Cincosaurus* beds is an underclay that provides evidence for widespread soil development, which may have been stimulated in response to a relative lowering of sea level.

As sea level rose again, a high water table formed, which was conducive to wetland development and gleying of the muddy soil horizon represented by the underclay. This episode culminated in renewed peat accumulation and formation of the New Castle coal. Roof strata above the New Castle bed record inundation of the swamp by marine water in much of Walker County, Alabama, but roof strata at the Union Chapel Mine indicate that persistent terrestrial wetland sedimentation protected the New Castle peat from degradation by sulfur-reducing bacteria. These strata preserve standing forests at multiple stratigraphic levels and contain diverse and well-preserved compression floras.

Erect plant fossils in the New Castle roof shale are truncated below a nodular limestone bed, which records a major (i.e., long eccentricity) marine flooding event that marks the top of the Mary Lee coal zone. The limestone contains a condensed brachiopod-mollusc assemblage that formed during the most rapid phase of sea-level rise. The upper part of the Union Chapel highwall contains a coarsening-upward shale-sandstone interval that was deposited in prodelta and delta-front environments during a major highstand of relative sea level. This event set the stage for deposition of younger Pottsville strata in which yet other Fossil-Lagerstätten may await discovery.

## ACKNOWLEDGMENTS

This manuscript was reviewed by M. A. Gibson and J. R. Lowery, who made many useful suggestions that improved the quality of this contribution. E. P. Kvale of

the Indiana Geological Survey kindly performed a Fourier transform analysis of bedding in the *Cincosaurus* beds using the maximum entropy method.

## REFERENCES

- Aldrich, T. H., Sr. and Jones, W. B., 1930, Footprints from the coal measures of Alabama: Alabama Museum of Natural History, Museum Paper 9, 64 p.
- Anderson, J. A. R., 1964, Structure and development of the peat swamps of Sarawak and Brunei: *Journal of Tropical Geography*, v. 18, p. 7-16.
- Archer, A. W., 1991, Modeling of tidal rhythmites using modern tidal periodicities and implications for short-term sedimentation rates: *Kansas Geological Survey Bulletin*, no. 233, p. 185-194.
- Berger, A. L., and Loutre, M. F., 1991, Insolation values for the climate of the last 10 million years: *Quaternary Science Review*, v. 10, p. 297-317.
- Bragg, L. J., Oman, J. K., Tewalt, S. J., Oman, C. L., Rega, N. H., Washington, P. M., and Finkelman, R. B., 1998, U.S. Geological Survey coal quality database (COALQUAL), version 2.0: U.S. Geological Survey Open-File Report 97-134 (CD-ROM).
- Buta, R. J., Kopaska-Merkel, D. C., Rindsberg, A. K., and Martin, A. J., 2005, Atlas of Union Chapel Mine invertebrate trackways and other traces; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 277-337.
- Butts, C., 1910, Description of the Birmingham Quadrangle, Alabama: U.S. Geological Survey Geologic Atlas of the United States, Folio 175, 24 p.
- Butts, C., 1926, The Paleozoic rocks; in Adams, G. I., Butts, C., Stephenson, L. W. and Cooke, C. W., *Geology of Alabama*: Alabama Geological Survey Special Report 14, p. 41-230.
- Caputo, M. V. and Crowell, J. C., 1985, Migration of glacial centers across Gondwana during Paleozoic Era: *Geological Society of America Bulletin*, v. 96, p. 1020-1036.
- Carroll, R. E., 1997, Alabama coal data for 1994: *Alabama Geological Survey Information Series 58P*, 132 p.
- Carroll, R. E., Pashin, J. C. and Kugler, R. L., 1995, Burial history and source-rock characteristics of Upper Devonian through Pennsylvanian strata, Black Warrior basin, Alabama: *Alabama Geological Survey Circular 187*, 29 p.
- Casagrande, D. J., 1987, Sulphur in peat and coal; in Scott, A. C., ed., *Coal and coal-bearing strata: recent advances*: Geological Society of London Special Publication no. 32, p. 87-105.
- Cecil, C. B., 1990, Paleoclimate controls on stratigraphic repetition of chemical and siliciclastic rocks: *Geology*, v. 18, p. 533-536.
- Cobb, J. C., Chesnut, D. R., Hester, N. C. and Hower, J. C., 1981, Coal and coal-bearing rocks of eastern Kentucky. Lexington, Kentucky, Kentucky Geological Survey, Annual Geological Society of America Coal Division Field Trip Guidebook, 169 p.
- Cohen, A. D., 1974, Petrography and paleoecology of Holocene peats from the Okefenokee swamp-marsh complex of Georgia: *Journal of Sedimentary Petrology*, v. 44, p. 716-726.
- Culbertson, W. C., 1964, Geology and coal resources of the coal-bearing rocks of Alabama: U.S. Geological Survey Bulletin 1182-B, 79 p.
- Demko, T. M. and Gastaldo, R. A., 1992, Paludal environments of the Lower Mary Lee coal zone, Pottsville Formation, Alabama: Stacked clastic swamps and peat mires: *International Journal of Coal Geology*, v. 20, p. 23-47.
- Demko, T. M. and Gastaldo, R. A., 1996, Eustatic and autocyclic influences on deposition of the Lower Pennsylvanian Mary Lee coal zone, Warrior Basin, Alabama: *International Journal of Coal Geology*, v. 31, p. 3-19.
- Eble, C. F., Gastaldo, R. A., Demko, T. M., and Liu, Y., 1994, Coal compositional changes along a swamp interior to swamp margin transect in the Mary Lee Coal bed, Warrior Basin, Alabama, U.S.A: *International Journal of Coal Geology*, v. 26, p. 43-62.
- Eble, C. F. and Gillespie, W. H., 1989, Palynology of selected coal beds from the central and southern Appalachian basin: correlation and stratigraphic implications: Washington, D.C., 28th International Geological Congress, Guidebook T352, p. 61-66.
- Eble, C. F., Gillespie, W. H. and Henry, T. W., 1991, Palynology, paleobotany, and invertebrate paleontology of Pennsylvanian coal beds and associated strata in the Warrior and Cahaba coal fields; in Thomas, W.A., and Osborne, W. E., eds., *Mississippian-Pennsylvanian tectonic history of the Cahaba synclinorium*: Alabama Geological Society Guidebook, 28th Annual Field Trip, p. 119-132.
- Elder, C. H. and Deul, M., 1974, Degasification of the Mary Lee coalbed near Oak Grove, Jefferson County, Alabama, by vertical borehole in advance of mining: U.S. Bureau of Mines Report of Investigations 7968, 21 p.
- Ferm, J. C., Ehrlich, R. and Neathery, T. L., 1967, A field guide to Carboniferous detrital rocks in northern Alabama: Geological Society of America, 1967 Coal Division Field Trip Guidebook, 101 p.
- Ferm, J. C. and Weisenfluh, G. A., 1989, Evolution of some depositional models in Late Carboniferous rocks of the Appalachian coal fields: *International Journal of Coal Geology*, v. 12, p. 259-292.
- Frakes, L. A., Francis, J. E. and Syktus, J. I., 1992, *Climate modes of the Phanerozoic*. Cambridge, Cambridge Press, 274 p.
- Galloway, W. E., 1989, Genetic stratigraphic sequences in basin analysis I: architecture and genesis of flooding-surface bounded depositional units: *American Association of Petroleum Geologists Bulletin*, v. 73, p. 125-142.
- Gardner, T. W., Williams, E. G. and Holbrook, P. W., 1988, Pedogenesis of some Pennsylvanian underclays: ground-water, topographic, and tectonic controls: *Geological Society of America, Special Paper*, no. 216, p. 81-101.
- Gastaldo, R. A., Demko, T. M., and Liu, Y. eds., 1990, Carboniferous coastal environments and paleocommunities of the Mary Lee coal zone, Marion and Walker Counties, Alabama: *Alabama Geological Survey Guidebook Series VI*, 139 p.
- Gastaldo, R. A., Demko, T. M. and Liu, Y., 1993, Application of sequence and genetic stratigraphic concepts to Carboniferous coal-bearing strata: an example from the Black Warrior Basin, USA: *Geologische Rundschau*, v. 82, p. 212-226.
- Gastaldo, R. A., Demko, T. M., Liu, Y., Keefer, W. D., and Abston, S. L., 1989, Biostratigraphic processes for the development of mud-cast logs in Carboniferous and Holocene swamps: *Palaios*, v. 4, p. 356-365.
- Gentzis, T., 2000, Subsurface sequestration of carbon dioxide: an overview from an Alberta (Canada) perspective: *International Journal of Coal Geology*, v. 43, p. 287-305.
- Gibson, M. A., 1990, Common macroinvertebrates associated with the Mary Lee coal zone (Pennsylvanian, upper Pottsville Formation), northern Alabama; in Gastaldo, R. A., Demko, T. M., and Liu, Y., eds., *Carboniferous coastal environments and paleocommunities of the Mary Lee coal zone, Marion and Walker Counties, Alabama*: Alabama Geological Survey Guidebook Series VI, p. 97-104.
- Gillespie, W. H., Clendening, J. A. and Pfefferkorn, H. W., 1978, Plant fossils of West Virginia: *West Virginia Geological and Economic Survey Educational Series*, ED-3A, 172 p.
- Heckel, P. H., 1986, Sea-level curve for Pennsylvanian eustatic

- transgressive-regressive depositional cycles along midcontinent outcrop belt, North America: *Geology*, v. 14, p. 330-334.
- Heckel, P. H., 1994, Evaluation of evidence for glacio-eustatic control over marine Pennsylvanian cyclothems in North America and consideration of possible tectonic effects; in Dennison, J. M., and Etensohn, F. R. eds., *Tectonic and Eustatic Controls on Sedimentary Cycles: Society for sedimentology, Concepts in Sedimentology and Paleontology*, no. 4, p. 89-105.
- Hewitt, J. L., 1984, Geologic overview, coal, and coal bed methane resources of the Warrior basin — Alabama and Mississippi; in Rightmire, C. T., Eddy, G. E., and Kirr, J. N., eds., *Coal bed methane resources of the United States: American Association of Petroleum Geologists, Studies in Geology*, no. 17, p. 73-104.
- Hobday, D. K., 1974, Beach and barrier island facies in the Upper Carboniferous of northern Alabama: *Geological Society of America Special Paper*, no. 148, p. 209-224.
- Horne, J. C., 1979, The effects of Carboniferous shoreline geometry on paleocurrent distribution; in Ferm, J. C. and Horne, J. C., eds., *Carboniferous depositional environments in the Appalachian region: Carolina Coal Group, University of South Carolina, Columbia, South Carolina*, p. 509-516.
- Horsey, C. A., 1981, Depositional environments of the Pennsylvanian Pottsville Formation in the Black Warrior basin of Alabama: *Journal of Sedimentary Petrology*, v. 51, p. 799-806.
- Imbrie, J., 1985, A theoretical framework for the Pleistocene ice ages: *Journal of the Geological Society of London*, v. 142, p. 417-432.
- Imbrie, J. and Imbrie, J. Z., 1980, Modeling the climatic response to orbital variations: *Science*, v. 207, p. 943-953.
- Klein, G. deV., 1977, *Clastic Tidal Facies: Dordrecht, D. Reidel Publishing*, 119 p.
- Kvale, E. P., Archer, A. W. and Johnson, H. R., 1989, Daily, monthly, and yearly tidal cycles within laminated siltstones of the Mansfield Formation (Pennsylvanian) of Indiana: *Geology*, v. 17, p. 365-368.
- Kvale, E. P. and Mastalerz, M., 1998, Evidence of ancient freshwater tidal deposits; in Alexander, C. R., Davis, R. A., and Henry, V. J., eds., *Tidalites: Processes and Products: Society for Sedimentology Special Publication*, no. 61, p. 95-107.
- Lahee, F. H., 1961, *Field geology (6th edition): New York, McGraw Hill*, 926 p.
- Liu, Y. and Gastaldo, R. A., 1992, Characteristics of a Pennsylvanian ravinement surface: *Sedimentary Geology*, v. 77, p. 197-213.
- Mack, G. H., James, W. C. and Monger, H. C., 1993, Classification of paleosols: *Geological Society of America Bulletin*, v. 105, p. 129-136.
- Martinsen, O. J., 1990, Fluvial, inertia-dominated deltaic deposition in the Namurian (Carboniferous) of northern England: *Sedimentology*, v. 37, p. 1099-1113.
- Maynard, J. R. and Leeder, M. R., 1992, On the periodicity and magnitude of Late Carboniferous glacio-eustatic sea-level changes: *Journal of the Geological Society of London*, v. 149, p. 303-311.
- McCabe, P. J., 1984, Depositional environments of coal and coal-bearing strata; in Rahmani, R. A., and Flores, R. M., eds., *Sedimentology of coal and coal-bearing strata: International Association of Sedimentologists Special Publication*, no. 7, p. 13-42.
- McCalley, H., 1886, On the Warrior coal field: *Alabama Geological Survey Special Report 1*, 571 p.
- McCalley, H., 1900, Report on the Warrior coal basin: *Alabama Geological Survey Special Report 10*, 327 p.
- McFall, K. S., Wicks, D. E., and Kuuskraa, V. A., 1986, A geological assessment of natural gas from coal seams in the Warrior basin, Alabama — topical report (September 1985-September 1986). Lewin and Associates, Inc., Washington, D. C., Gas Research Institute contract no. 5084-214-1066, 80 p.
- Mellen, F. F., 1947, Black Warrior basin, Alabama and Mississippi: *American Association of Petroleum Geologists Bulletin*, v. 31, p. 1801-1816.
- Metzger, W. J., 1965, Pennsylvanian stratigraphy of the Warrior basin, Alabama: *Alabama Geological Survey Circular 30*, 80 p.
- Nadon, G. C., 1998, Magnitude and timing of peat-to-coal compaction: *Geology*, v. 26, p. 727-730.
- Pashin, J. C., 1994a, Cycles and stacking patterns in Carboniferous rocks of the Black Warrior foreland basin: *Gulf Coast Association of Geological Societies, Transactions*, v. 44, p. 555-563.
- Pashin, J. C., 1994b, Flexurally influenced eustatic cycles in the Pottsville Formation (Lower Pennsylvanian), Black Warrior basin, Alabama; in Dennison, J. M. and Etensohn, F. R. eds., *Tectonic and Eustatic Controls on Sedimentary Cycles: Society for Sedimentology, Concepts in Sedimentology and Paleontology*, no. 4, p. 89-105.
- Pashin, J. C., 1994c, Coal-body geometry and synsedimentary detachment folding in Oak Grove coalbed-methane field, Black Warrior basin, Alabama: *American Association of Petroleum Geologists Bulletin*, v. 78, p. 960-980.
- Pashin, J. C., 1998, Stratigraphy and structure of coalbed methane reservoirs in the United States: an overview: *International Journal of Coal Geology*, v. 35, p. 207-238.
- Pashin J. C. and Carroll, R. E., eds., 1998, *Geology of the Cahaba coalfield: Alabama Geological Society, 36th Annual Field Trip Guidebook*, 98 p.
- Pashin, J. C., Carroll, R. E., Barnett, R. L. and Beg, M. A., 1995, *Geology and coal resources of the Cahaba coal field: Alabama Geological Survey Bulletin 163*, 49 p.
- Pashin, J. C., Carroll, R. E., Groshong, R. H., Jr., Raymond, D. E., McIntyre, M. and Payton, W. J., 2003, Geologic screening criteria for sequestration of CO<sub>2</sub> in coal: quantifying potential of the Black Warrior coalbed methane fairway, Alabama: *Annual Technical Progress Report, U.S. Department of Energy, National Technology Laboratory, contract DE-FC-00NT40927*, 190 p.
- Pashin, J. C., Groshong, R. H., Jr. and Carroll, R. E., 2001, Carbon sequestration potential of coalbed methane reservoirs in the Black Warrior basin: a preliminary look. Tuscaloosa, Alabama, University of Alabama, College of Continuing Studies, 2001 International Coalbed Methane Symposium, Proceedings, p. 51-62.
- Pashin, J. C. and Hinkle, F., 1997, Coal bed methane in Alabama. *Alabama Geological Survey Circular 192*, 71 p.
- Pashin, J. C., Ward, W. E., II, Winston, R. B., Chandler, R. V., Bolin, D. E., Richter, K. E., Osborne, W. E. and Sarnecki, J., C. 1991, Regional analysis of the Black Creek-Cobb coalbed-methane target interval, Black Warrior basin, Alabama: *Alabama Geological Survey Bulletin 145*, 127 p.
- Posamentier, H. W. and Vail, P. R., 1988, Eustatic controls on clastic deposition, II. Sequence and systems tract models: *Society of Economic Paleontologists and Mineralogists Special Publication*, no. 42, p. 125-154.
- Reichle, D., Houghton, J., Kane, B. and Ekmann, J., 1999, Carbon sequestration: State of the science. U.S. Department of Energy, Offices of Science and Fossil Energy, unpaginated PDF document.
- Reineck, H.-E., 1955, Marken, Spuren, und Fährten in den Waderner Schichten (ro) bei Martinstein/Nahe: *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, v. 101, p. 75-90.
- Renton, J. J. and Cecil, C. B., 1979, The origin of mineral matter in coal; in Donaldson, A. C., Presley, M. W., and Renton, J.

- J., eds., Carboniferous Coal Guidebook, v. 1: West Virginia Geologic and Economic Survey Bulletin 37-1, p. 206-233.
- Rheams, L. J. and Benson, D. J., 1982, Depositional setting of the Pottsville Formation in the Black Warrior basin: Alabama Geological Society 19th Annual Field Trip Guidebook, 94 p.
- Rial, J. A., 1999, Pacemaking the ice ages by frequency modulation of Earth's orbital eccentricity: *Science*, v. 285, p. 564-568.
- Rindsberg, A. K., 1990, Freshwater to marine trace fossils of the Mary Lee coal zone and overlying strata (Westphalian A), Pottsville Formation of northern Alabama; in Gastaldo, R. A., Demko, T. M., and Liu, Y., eds., Carboniferous coastal environments and paleocommunities of the Mary Lee coal zone, Marion and Walker Counties, Alabama: Alabama Geological Survey Guidebook Series VI, p. 82-95.
- Rindsberg, A. K., 1994, Ichnology of the Upper Mississippian Hartselle Sandstone of Alabama, with notes on other Carboniferous formations: Alabama Geological Survey Bulletin 158, 107 p.
- Scotese, C. R., 1990, Atlas of Phanerozoic plate tectonic reconstructions: International Lithosphere Program (IUGG-IUGS), Paleomap Project Technical Report 10-90-1, 54 p.
- Scotese, C. R., Golonka, J., and Ross, M. J., 1994, Phanerozoic paleogeographic and paleoclimatic modeling maps; in Embry, A. F., Beauchamp, B. and Glass, D. J., eds., Pangea, global environments and resources: Canadian Society of Petroleum Geologists, Memoir, no. 17, p. 1-47.
- Scott, A. C. and Rex, G., 1985, The formation and significance of Carboniferous coal balls: *Philosophical Transactions of the Royal Society of London*, v. 311B, p. 123-137.
- Seilacher, A., 1967, Bathymetry of trace fossils: *Marine Geology*, v. 5, p. 413-428.
- Seilacher, A., 1990, Taphonomy of Fossil-Lagerstätten; in Briggs, D. E. G. and Crowther, P. R., eds., *Palaeobiology: a synthesis*. London, Blackwell, p. 266-270.
- Sestak, H. M., 1984, Stratigraphy and depositional environments of the Pennsylvanian Pottsville Formation in the Black Warrior basin, Alabama and Mississippi: Tuscaloosa, University of Alabama, M. S. Thesis, 184 p.
- Shrock, R. R., 1948, *Sequence in layered rocks*. New York, McGraw-Hill, 507 p.
- Spears, D. A., 1987, Mineral matter in coals, with special reference to the Pennine Coalfields; in Scott, A. C., (ed.), *Coal and coal-bearing strata: recent advances*: Geological Society of London Special Publication, no. 32, p. 171-185.
- Staub, J. R. and Esterle, J. S., 1994, Peat-accumulating depositional systems of Sarawak, eastern Malaysia: *Sedimentary Geology*, v. 89, p. 91-106.
- Stopes, M. C. and Watson, D. M. S., 1909, On the present distribution and origin of the calcareous concretions in coal seams, known as coal balls: *Philosophical Transactions of the Royal Society of London*, ser. B, v. 200, p. 167-218.
- Telle, W. R., Thompson, D. A., Lottman, L. K. and Malone, P. G., 1987, Preliminary burial-thermal history investigations of the Black Warrior basin: implications for coal bed methane and conventional hydrocarbon development: Tuscaloosa, University of Alabama, College of Continuing Studies, 1987 Coalbed Methane Symposium Proceedings, p. 37-50.
- Thomas, W. A., 1974, Converging clastic wedges in the Mississippian of Alabama: Geological Society of America, Special Paper, no. 148, p. 187-207.
- Thomas, W. A., 1976, Evolution of the Appalachian-Ouachita continental margin: *Journal of Geology*, v. 84, p. 323-342.
- Thomas, W. A., 1977, Evolution of Appalachian-Ouachita salients and recesses from reentrants and promontories in the continental margin: *American Journal of Science*, v. 277, p. 1233-1278.
- Thomas, W. A., 1985, The Appalachian-Ouachita connection: Paleozoic orogenic belt at the southern margin of North America: *Annual Reviews of Earth and Planetary Sciences*, v. 13, p. 175-199.
- Thomas, W. A., 1988, The Black Warrior Basin; in Sloss, L. L., ed., *Sedimentary cover — North American craton*: Geological Society of America, *The Geology of North America*, v. D-2, p. 471-492.
- Thomas, W. A. and Womack, S. H., 1983, Coal stratigraphy of the deeper part of the Black Warrior Basin in Alabama: *Gulf Coast Association of Geological Societies, Transactions*, v. 33, p. 439-446.
- Tolson, J. S., 1986, Coal occurrence and general geology in the Cordova 7.5-Minute Quadrangle, Walker County, Alabama: Alabama Geological Survey Open File Report, 15 p.
- Vail, P. R., 1987, Seismic stratigraphy interpretation procedure: *American Association of Petroleum Geologists Studies in Geology*, no. 27 (1), p. 1-10.
- van Straaten, L. J. M. U., 1954, Sedimentology of Recent tidal flat deposits and the Psammites du Condroz (Devonian): *Geologie en Mijnbouw*, v. 15, p. 1-11.
- Wanless, H. R. and Shepard, F. P., 1936, Sea level and climatic changes related to late Paleozoic cycles: *Geological Society of America Bulletin*, v. 47, p. 1177-1206.
- Ward, W. E., II, 1984, Reserve base of bituminous coal and lignite in Alabama: Alabama Geological Survey Circular 118, 102 p.
- Weller, S., 1930, Cyclic sedimentation of the Pennsylvanian Period and its significance: *Journal of Geology*, v. 38, p. 97-135.
- Williams, E. G. and Keith, M. L., 1963, Relationship between sulfur in coals and the occurrence of marine roof beds: *Economic Geology*, v. 58, p. 720-729.
- Winston, R. B., 1990, Coal-paleobotany of the Mary Lee coal bed of the Pennsylvanian Pottsville Formation near Carbon Hill, Walker County, Alabama; in Gastaldo, R. A., Demko, T. M. and Liu, Y., eds., Carboniferous coastal environments and paleocommunities of the Mary Lee coal zone, Marion and Walker Counties, Alabama: Alabama Geological Survey Guidebook Series VI, p. 55-64.
- Winston, R. B. and Phillips, T. L., 1991, A structurally preserved, Lower Pennsylvanian flora from the New Castle coal bed of Alabama: Alabama Geological Survey Circular 157, 21 p.

#### AUTHOR'S E-MAIL ADDRESS

jpashin@gsa.state.al.us

## BEHAVIORAL SIGNIFICANCE OF VERTEBRATE TRACE FOSSILS FROM THE UNION CHAPEL SITE

ANTHONY J. MARTIN

Department of Environmental Studies, Emory University, Atlanta, Georgia 30322, USA

NICHOLAS D. PYENSON

Department of Integrative Biology, University of California at Berkeley, Berkeley, California 94720, USA

**ABSTRACT:** The Union Chapel site is one of the world's most important for Early Pennsylvanian vertebrate trace fossils. Most of these vertebrate trace fossils consist of tracks made by temnospondyl amphibians and other tetrapods, but some are trails left by the fins of swimming fish. The exceptional quality and quantity of the traces provide for a unique opportunity to interpret behavioral nuances of vertebrates from this time interval. Tracks were likely made on emergent muddy, freshwater-dominated estuarine tidal flats during low tides, whereas fish swimming traces were probably formed in very shallow water during either falling or rising tides. Fish trace fossils, identified as the ichnogenus *Undichna*, are the result of caudal and anal fins that dragged along muddy surfaces. These trails, which have wave-like forms with low amplitudes and long wavelengths, indicate relatively small fish (10-15 cm long). Some *Undichna* provide evidence of changes in swimming speed, abrupt turns, and possible schooling. Vertebrate tracks, most assignable to the ichnogenus *Cincosaurus*, indicate animals that ranged from about 10 cm to 1.5 m long and most may have represented growth stages of a single species of tracemaker. The trackways are most significant for the array of behaviors they reveal: shifts in speed and direction, lateral movements, obstacle avoidances, and possible group movement, all of which are rarely reported from the fossil record from any time, let alone from the Early Pennsylvanian. In short, vertebrate trace fossils from the Union Chapel site give paleontologically noteworthy insights into Early Pennsylvanian vertebrate behavior unknown from body fossils or most other trace fossils from rocks of this age.

### INTRODUCTION

Fossil vertebrate tracks from strata in the immediate area of the Union Chapel site were recognized more than 70 years ago, when Aldrich and Jones (1930) first described a number of these tracks and attempted to classify them. Little was done to study these tracks any more until 2000, when members of the Alabama Paleontological Society (then known as the Birmingham Paleontological Society) investigated them. The rediscovery of this motherlode of vertebrate tracks was the main motivating force behind subsequent and laudable cooperation between amateur paleontologists, state agencies, and universities in efforts to document and preserve the site and the tracks (Rindsberg et al., 2001; Buta and Minkin, 2005). Of course, vertebrate tracks are not the only fossils that occur in this deposit; in total, the invertebrate burrow *Treptichnus* is probably the most commonly encountered fossil (Rindsberg et al., 2004). However, the vertebrate tracks were the main draw for attention from the amateur collectors and garnered the lion's share of media focus (Bourne, 2003; Toner, 2003; Sever, 2003). Although a thorough examination of the reasons for this admitted bias is beyond the range of this report, we can suggest two explanations: (1) most people, whether they have training in paleontology or not, easily recognize fossil vertebrate tracks as representative by-products of animal behavior; and (2) the quantity and quality of the vertebrate tracks from this site are exceptional and likely exceed those of any known deposit of the same age anywhere in the world.

While keeping in mind this foundation of interest in

the tracks, we felt that other vertebrate trace fossils, represented by fish swimming trails, are also important to consider because no fish body fossils have been found from this deposit or others of the same age in the southeastern United States. Nonetheless, track-bearing slabs are far more abundant than slabs with fish trails: out of more than 1200 slabs cataloged in the first three "track meets" held by the Alabama Paleontological Society (Rindsberg et al., 2001; Buta and Minkin, 2005), most of which have tracks, only 36 are known to have such trails. (Admittedly, this may be an artifact of the aforementioned collecting bias that favors an overrepresentation of tracks, and more *Undichna* have been found since.) Because of the large numbers of tracks and extensive trackways, we were able to make some population estimates of the trackmakers (as indicated by size ranges of track parameters), a study that would have been much more limited with the fish trace fossils. Such a population analysis was first done by Pyenson and Martin (2001) and followed up with a more quantitative assessment that modeled specific parameters of the Union Chapel tracks and trackways (Pyenson, 2002; Pyenson and Martin, 2002).

In this article, we will mention some information about the quantitative aspects of the Union Chapel fish trails and vertebrate tracks, but will focus more on interpreting the behaviors of their tracemakers. The Union Chapel material quite likely represents the best preserved and most abundant record of vertebrate populations and behavior from this time, meaning that it can provide a window to better understanding vertebrate evolution that otherwise would not be available to paleontologists. Moreover, some of the behaviors we report here are sel-

dom interpreted from the geologic record, highlighting the scientific importance of the Union Chapel site for vertebrate paleontology.

### DESCRIPTION OF UNION CHAPEL MINE VERTEBRATE TRACE FOSSILS AND POSSIBLE TRACEMAKERS

Fish trails and vertebrate tracks are preserved in a 2-3 m thick interval of gray, laminated, silty shale of the Pottsville Formation (Early Pennsylvanian) that was probably formed in the upper reaches of an estuarine tidal flat (Pashin, 2005). Interestingly, fish trails rarely occur on the same surfaces as the tracks, which may mean that each type of trace fossil represents different environmental and preservational conditions. For example, the trails were certainly made by swimming fish (elaborated later), so the water depths must have been at least the heights of the fish making the trails. However, vertebrate trackways show no evidence of being made underwater and, rather, point toward formation on emergent mudflats. For example, some of the smallest trackways have drag marks of both the ventral abdominal surfaces and tails, which would have been unlikely in a submerged environment where the tracemakers would have been more buoyant. Depositional rates in this environment were relatively high (Pashin, 2005), which probably aided the preservation of the trails and tracks. This happenstance combination of quick burial and fine-grained material in a quiet-water environment caused ideal conditions for preserving the excellent detail seen in the Union Chapel specimens (Martin and Rindsberg, 2004). Although Haubold et al. (2005a) interpret the majority of Union Chapel tracks as undertracks and we agree with this assessment, tracks are three-dimensional entities (Brown, 1999) and thus the undertracks should not be treated as inferior simply because they do not represent original top surfaces.

Fish trails occur as wave-like traces on bedding planes, showing both negative-relief (grooves) and positive-relief (casts of grooves), with the grooves on bed tops and casts on bed bottoms, respectively. Trails are invariably quite narrow and shallow, only 2-3 mm wide and 2-4 mm deep in most instances. Trail lengths often vary according to the size of collected slabs, in that some originate and end off the slabs, but some are at least 40 cm long. Amplitudes are typically low, varying from 1 to 4 cm, and when viewed in conjunction with wavelengths suggest that relatively small fish (mostly 10-15 cm long) were responsible for the traces. Trails can be placed into four categories based on form: (1) regularly spaced but discontinuous parts of single or coupled waveforms; (2) single waveforms, with some showing different amplitudes and wavelengths; (3) slightly offset and overlapping coupled waveforms, with one waveform of slightly lower amplitude; (4) completely out-of-phase overlapping and coupled waveforms, again with one waveform of slightly lower amplitude than the other (Fig. 1). In some instances, fish trails are evenly spaced and parallel to one another, and in other cases multiple trails overlap along the same trend (Fig. 2).

All fish trails are assignable to the ichnogenus

*Undichna* (Anderson, 1976), a trace fossil commonly reported from Early Pennsylvanian strata in other parts of the world (Archer and Maples, 1984; Turek, 1989, 1996; Buatois and Mángano, 1994; Buatois et al., 1997; Soler-Gijón and Moratalla, 2001). We currently have too little information to infer whether more than one species of fish caused the various forms of *Undichna* in this deposit, but because they are so limited in size, they represent either juveniles of different species, juveniles and small adults of different species, or adults of one small-sized species. We do know that the majority of these fish had both caudal and anal fins and were likely jawed fish because of their swimming movements, as explained later.

The vast majority of the thousands of Union Chapel vertebrate tracks documented thus far are relatively small (less than 2 cm wide), but a few large tracks are as much as 12 cm wide. Based on the range of track sizes, trackway widths, and glenoacetabular distances (the distance between successive front-foot tracks on the same side), trackmakers were probably about 10 cm to 1.5 m long (Pyenson, 2002). Front-foot (manus) tracks typically show four toes, whereas hind-foot (pes) tracks normally show five toes; pes tracks are also distinguishable because they are significantly larger (about 60%) than manus tracks (Fig. 3). Although track preservation certainly varied enough that not all toes were impressed in every track, the most consistently observed number of toes on the manus and pes were four and five, respectively (Pyenson, 2002). Relatively small tracks not only demonstrate this same arrangement, but also show greater morphological detail, such as an elongated fourth toe on the pes (Fig. 4). Toe lengths are otherwise nearly equal in the manus and pes tracks examined in this study. The first three toes of the manus and pes are the most parallel to the direction the trackmaker was traveling, whereas the fourth and fifth digits tend to diverge toward the outside of the trackways.

Most track forms are assignable to the ichnogenus *Cincosaurus*, which was named by Aldrich (in Aldrich and Jones 1930) based on material from the same deposit near the UCM site. The sum of these characteristics coupled with the known body fossil record for vertebrates strongly suggest that most of the trackmakers were temnospondyl amphibians, a group originally recognized by Zittel (1888) and updated by Steyer (2000). Temnospondyls are amphibians that were common during the Early Pennsylvanian (Carroll, 1988; Benton, 1997). The age estimated for the formation of the Union Chapel deposit is about 308 million years (Pashin, 2005), which is at the beginning of the known evolutionary history for egg-bearing vertebrates (amniotes), such as reptiles (Carroll, 1988; Benton, 1997). Although our study did not delve into the details of identifying all trackmakers, others have concluded that a lesser number of amniotes may have been present as well (Aldrich and Jones, 1930; Lucas et al., 2004; Haubold et al., 2005a).

The hypothesis that most tracks were made by temnospondyls is supported foremost by the common association of four-digit manus and five-digit pes in trackways, which are characteristic of that group of

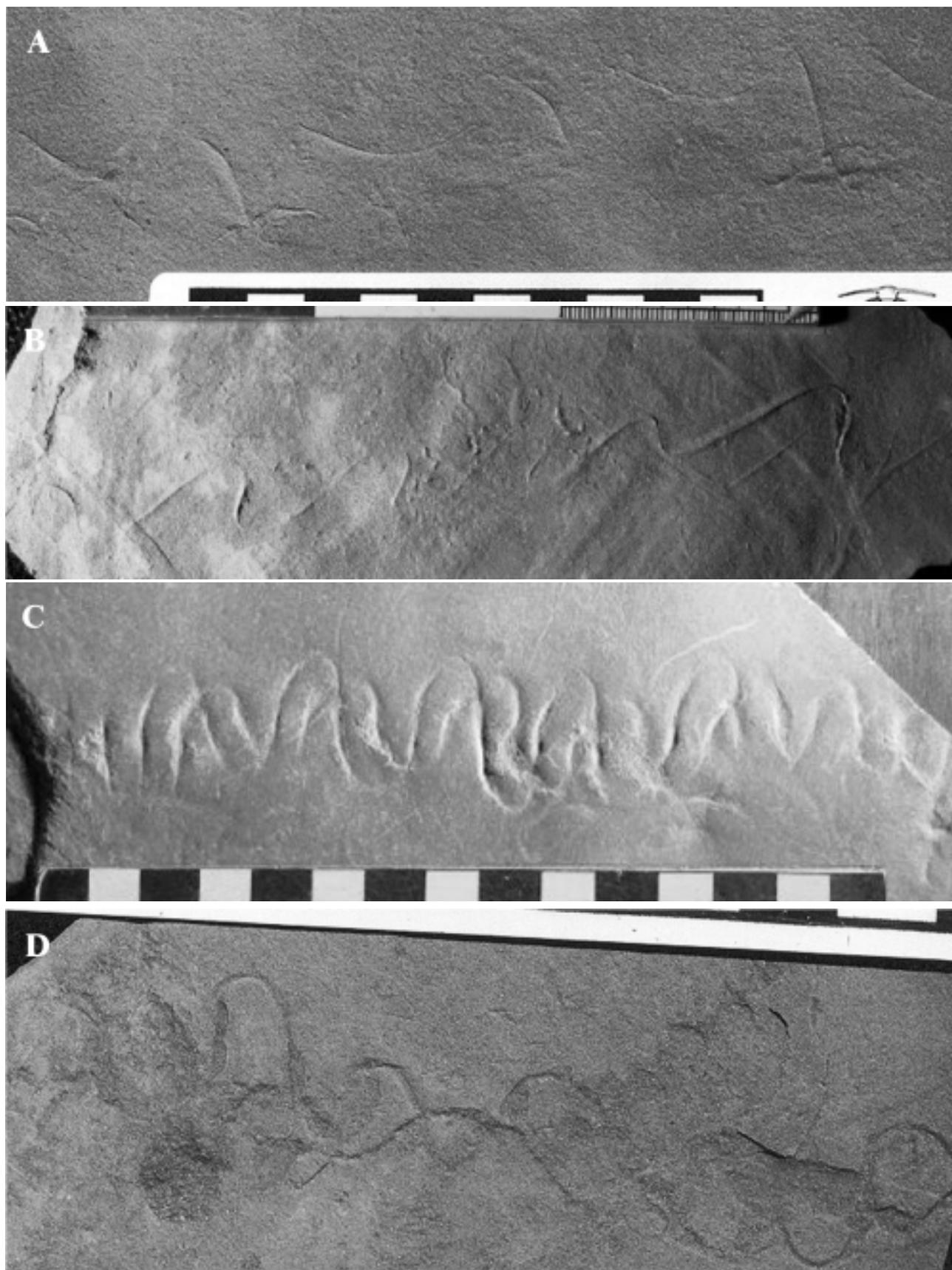


FIGURE 1. Categories of fish trails (*Undichna*) in the UCM deposit based on morphology. A - Discontinuous waveforms (UCM 455); B - single waveforms (UCM 1734); C - Slightly offset and overlapping waveforms (UCM number not identified); D - completely out of phase overlapping and coupled waveforms (UCM 728).

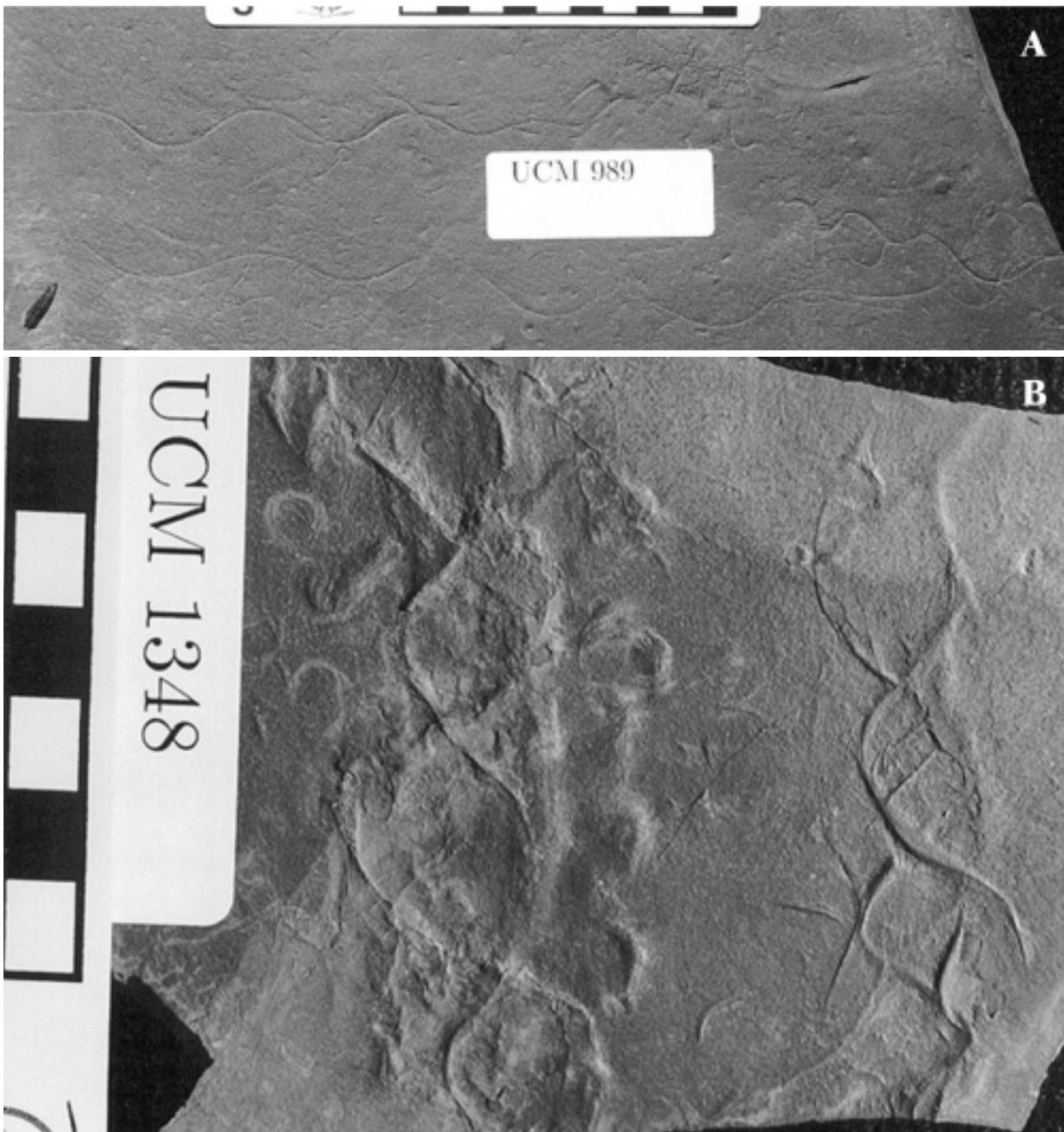


FIGURE 2. Multiple *Undichna* on same slabs. A - *Undichna* showing parallelism (UCM 989); B - *Undichna* showing both parallelism and overlapping (UCM 1348).

amphibians (M. Coates, personal commun. to Pyenson, 2002). Size-frequency distributions of track widths also approximate population curves of modern amphibians (Duellman and Trueb, 1994), which are skewed so that the majority of the tracks fall into smaller size ranges and comparatively fewer are in the larger size ranges (Pyenson, 2002; Pyenson and Martin, 2002). Furthermore, statistical methods applied to 94 Union Chapel trackways showed very high positive correlations ( $r^2 > 0.85$ ) between all paired comparisons of manus width, pes width, trackway width, and glenoacetabular distance,

an expected outcome for a population of the same or similar species (Pyenson, 2002; Pyenson and Martin, 2002). Tracks with different forms, like many other trace fossil forms, might be ascribed to various combinations of sediment quality and behavioral interactions with the sediment, and not necessarily different species of trackmakers (Bromley, 1996).

In terms of feeding habits, all modern adult amphibians are carnivores, although some juvenile amphibians eat plant material and invertebrates (Duellman and Trueb, 1994), but no evidence pertinent to feeding hab-



FIGURE 3. Left-side manus-pes pair of amphibian tracks (*Cincosaurus cobbi*), displaying significant size difference between smaller manus and larger pes (UCM number not identified).

its of the Union Chapel tetrapods is known. The deposit contains much allochthonous plant material (Dilcher et al., 2005) and trace fossil evidence for many invertebrates in and on the mud flats (Rindsberg and Martin, 2004; Rindsberg et al., 2004), which conceivably could have sustained a large population of juvenile amphibians or amniotes.

Fortunately, many of the tracks do not occur as isolated examples but are associated with definite trackways, which for our purposes are defined as any sequence of more than two steps by opposite sides of the trackmaker (i.e., left-right-left or right-left-right). These trackways show important parameters needed for interpreting populations and behavior: pace, stride, straddle, pace angulation, glenoacetabular distance, and any deviations that trackways might take from a straight line, all of which are measurable in well-preserved trackways (Figure 5). All trackways show clear evidence of vertebrates walking on four legs (quadrupedalism) and most consist of same-side manus-pes pairs that alternate in a diagonal pattern (Fig. 3). A few trackways have only pes impressions, which gives a false appearance of bipedalism; we are certain that such occurrences represent undertracks of more deeply impressed pes tracks, where the more shallowly impressed manus tracks were recorded in overlying layers. This conclusion is also supported by a few examples of shallow manus prints paired with deep pes prints in the same trackways. Moreover, the larger-sized pes also could have obliterated any preceding smaller-sized manus print if the trackmaker directly registered its pes onto the manus print, thus leaving only pes prints to see.

Some of the trackways are remarkable for their con-

tinuity and epitomize why the Union Chapel specimens are exceptional when compared to tetrapod trace fossils in similarly aged rocks. For example, one slab (UCM 76 and its counterpart UCM 84) has more than 200 tracks on it, with one trackway showing 76 measurable and continuous paces in an unbroken sequence (Fig. 6). The small sizes of most tracks were surely advantageous for collectors, who were able to carry away entire trackways (rather than just individual tracks), which in turn were amenable for professionals to conduct detailed studies on amphibian behavior.

### INTERPRETATIONS OF VERTEBRATE BEHAVIOR

In terms of behavior, Union Chapel vertebrate trace fossils most fundamentally provide convincing evidence of fish swimming and quadrupedal walking by amphibians. Furthermore, swimming or walking at relatively low speeds is seemingly the norm represented by Union Chapel trace fossils, although both fish trails and trackways contain evidence of variations in speed.

Relative fish swimming speeds can be estimated by looking at their wavelengths versus amplitudes; for example, *Undichna* that have high amplitudes with short wavelengths (i.e., high frequencies) imply that the fish were moving their tails faster than normal in the given distance traveled (Gilbert et al., 1999). Fish swimming can be categorized on the basis of their primary mode of propulsion, such as whether it is provided by full-body, fin, or tail movement (Sfakiotakis et al., 1999). Tail-based propulsion, which is typical of jawed fishes, causes a wave-like movement of the caudal and anal fins on

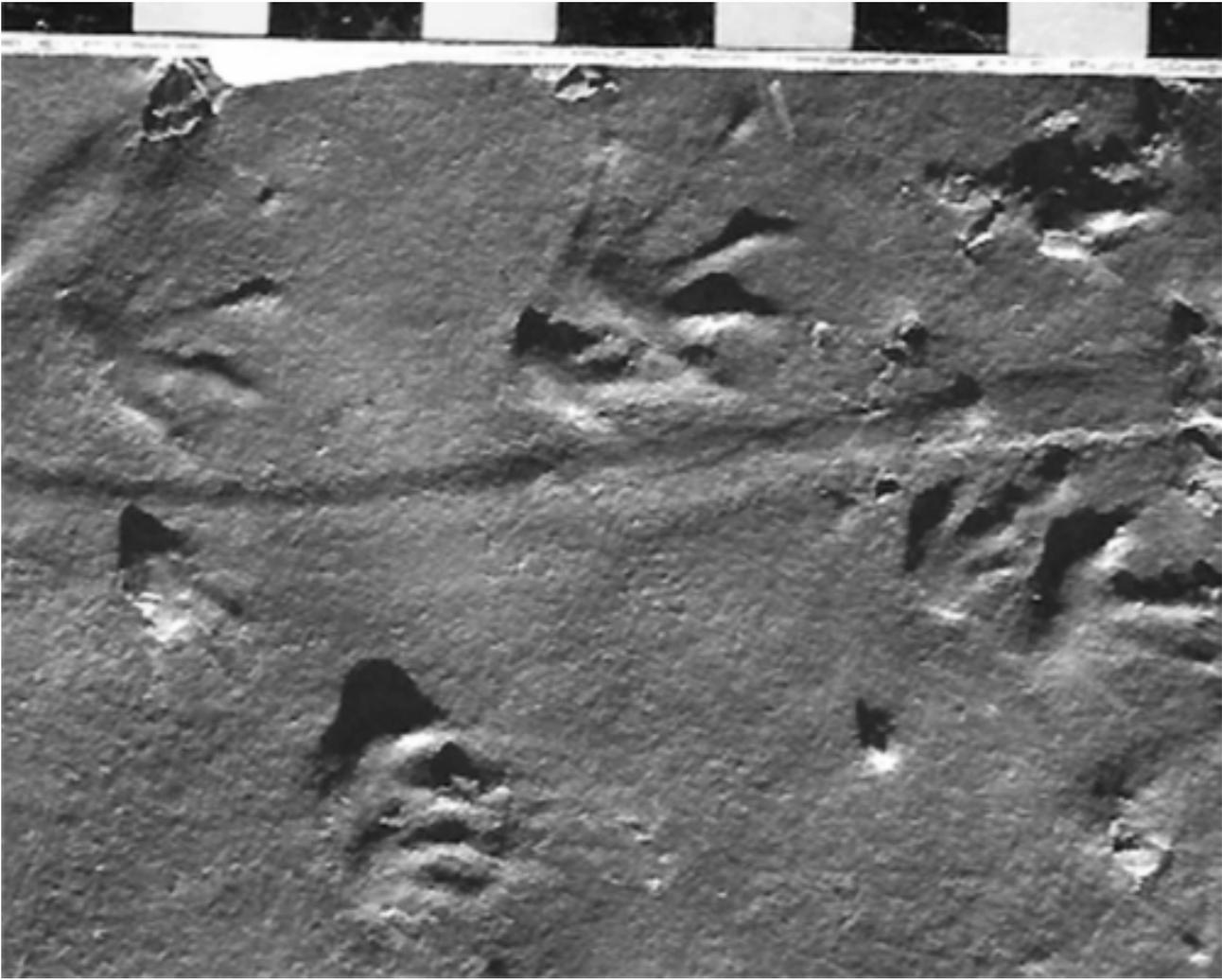


FIGURE 4. Foot morphology of manus and pes from specimen UCM 469, with larger pes overlapping manus; pes has elongated digit IV and bulbous tips to distal parts of toes. Note the sinuous tail drag mark in the middle of the trackway.

fish, so we conclude that in Union Chapel *Undichna* the lower ends of these two fins cut through the sediment, thus making the double undulating lines seen in most specimens. Moreover, because the caudal fin represents a greater range of movement in tail-based propulsion, its trace must be the higher amplitude waveform, whereas the lower amplitude one belongs to the anal fin. Using this principle and knowing that most fish swimming motion should be forward, the anal fin trace should be cross-cut by the caudal fin trace. Indeed, this supposition is borne out by the lower amplitude waveforms being cross-cut by the higher-amplitude ones in all UCM *Undichna* where double waveforms were seen.

Regardless of which fin made the traces, the larger-amplitude waveforms represent greater amounts of movement, so shorter wavelengths along a single trail should correlate generally to greater speed. Several specimens of Union Chapel *Undichna* (e.g., UCM 1304 and UCM 1729; Fig. 7) show just such variations along the length of their trails, where high-amplitude waveforms are succeeded by low-amplitude waveforms or vice versa. This behavior can be demonstrated by watching

some aquarium fish beat their tails rapidly to increase their speed, followed by less rapid beats and smaller movements of the tail once the fish reach their desired speeds.

A fish behavior related to changes in speed is abrupt turning, which is indicated by a few Union Chapel *Undichna* specimens. Abrupt turns are inferred from specimens with sharp bends (nearly 60°) to their trails accompanied by double lines that parallel one another and then converge (Fig. 8A). The double lines are probably from the caudal and anal fins, which at their widest separation represent their anatomical distance from one another on the tracemaking fish. These traces would have been made as the fish turned and then started to straighten out its path, which would have caused the caudal fin to align with the anal fin and thus make the two converge. In some cases these parallel lines then merge into a “normal” *Undichna* with a coupled waveform (Fig. 8B).

Some slabs containing multiple specimens of Union Chapel *Undichna* also suggest group behaviors, such as schooling and following. Schooling behavior, the tandem movement of fish of the same species in a group

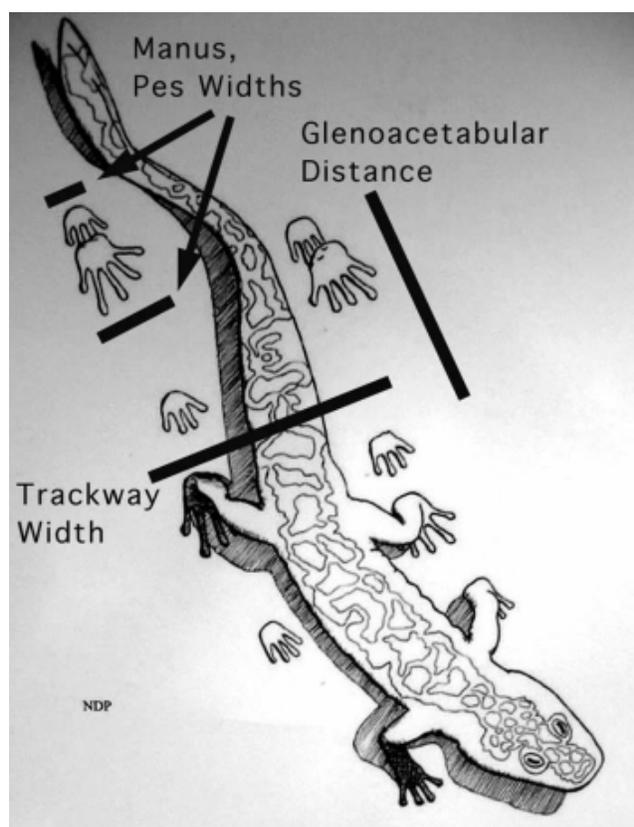


FIGURE 5. Schematic diagram of trackmaking temnospondyl and various measurements that can be made from a well-preserved trackway.

(“school”), is interpretable from slabs that show more than one *Undichna* of similar size that parallel one another (Fig. 2A). Schooling fish often space themselves regularly to decrease the effects of turbulence (Sfakiotakis et al., 1999), thus trails left by schooling fish should show even spacing as well.

Following behavior, where one fish follows the path of another fish, should cause overlapping multiple trails: two such compound trails are observed in one Union Chapel specimen (UCM 1348: Fig. 2B). Following can happen in schooling but also could be caused by predation, when a predatory fish pursues a prey fish. However, if the waveforms of overlapping trails show very similar amplitudes and wavelengths, then a reasonable conclusion is that these are from similar-sized fish, which is atypical for a predator-prey situation. Furthermore, UCM 1348 also shows the same parallelism and spacing of trails postulated for schooling. Consequently, where fish followed and swam next to one another, these trails were made by a school of the same species of fish where following and swimming next to one another occurred. As far as we are aware, this is the oldest known evidence for group behavior in fish from the geologic record.

Amphibian trackway patterns are typical of diagonal walkers, where the manus print is either in front of or indirectly registered by the pes print and left-right and right-left alternations of these pairs form a diagonal pattern (Brown and Morgan, 1983; Rezendes, 2002).

Pace angulation, which is the angle between left-right or right-left steps, is often less than  $150^\circ$  in Union Chapel trackways, which suggests a more sprawling posture; in contrast, upright postures tend to form trackway patterns with angulations closer to  $180^\circ$ , or like walking a “tightrope” (Schult and Farlow, 1992). Variations in speed are also demonstrated by trackways that show differences in pes paces, which show up as slight “understeps” or “oversteps” by the pes as it was placed slightly behind or in front of the manus, respectively (e.g., Fig. 3 for the latter). Based on our observations of Union Chapel trackways, “understeps” are represented by the majority of manus-pes placements and thus designate a normal walking gait, whereas “oversteps” indicate a faster than normal gait, and direct register is in between. However, Peabody (1959) noted that differences in torso lengths can affect the placement of a manus and pes; for example, a temnospondyl with a very long torso would have always had its pes register far behind the manus. Nevertheless, torso lengths of most trackmakers, as definable from glenoacetabular distances, were probably not abnormally long (Pyenson, 2002). As a result, we attribute most variations in manus-pes placement to behavior and not so much anatomical differences. Sprawling postures caused somewhat sinuous movements to the trackmakers, which is corroborated by wave-like traces of occasional tail drags evident midway between the tracks (Fig. 4). However, no trackways display any evidence of trotting, galloping, bounding, or other major variations of four-legged locomotion.

Perhaps most significantly for tracks of this age, more detailed information regarding behavior is indicated by the tracks. For example, changes in speed, sideways movements, abrupt turns, tail and belly drags, and obstacle avoidances are all inferrable from Union Chapel trackways. One bedding plane also shows as many as five similarly sized individuals moving in the same direction, which suggests group behavior.

Changes in speed can be easily detected by observing the manus-pes placement in a trackway, as mentioned previously. One of the outstanding attributes of the Union Chapel trackways is that so many of them show continuous sequences of manus-pes tracks, providing an opportunity to see step-by-step nuances in locomotion. For example, as mentioned before, two trackways on UCM 76 (and its counterpart UCM 84) made by similarly sized individuals have more than 200 manus and pes impressions preserved. As a result, careful measurements of the pes paces for one of the trackways revealed subtle variations in speed over the course of the trackway, but also showed an overall “moving average” for the trackmaker indicating that it gradually slowed down (Pyenson, 2002, Fig. 18). Sideways movement off the straightforward trend of a trackway is also a product of changes in speed, and several trackways accordingly display manus and pes impressions that register both to the inside and outside of a trackway (Fig. 4). Of course, abrupt turns in trackways also represent changes in speed because the trackmaker had to either stop or otherwise slow its movement to make turns that in some cases are almost  $90^\circ$ . As men-

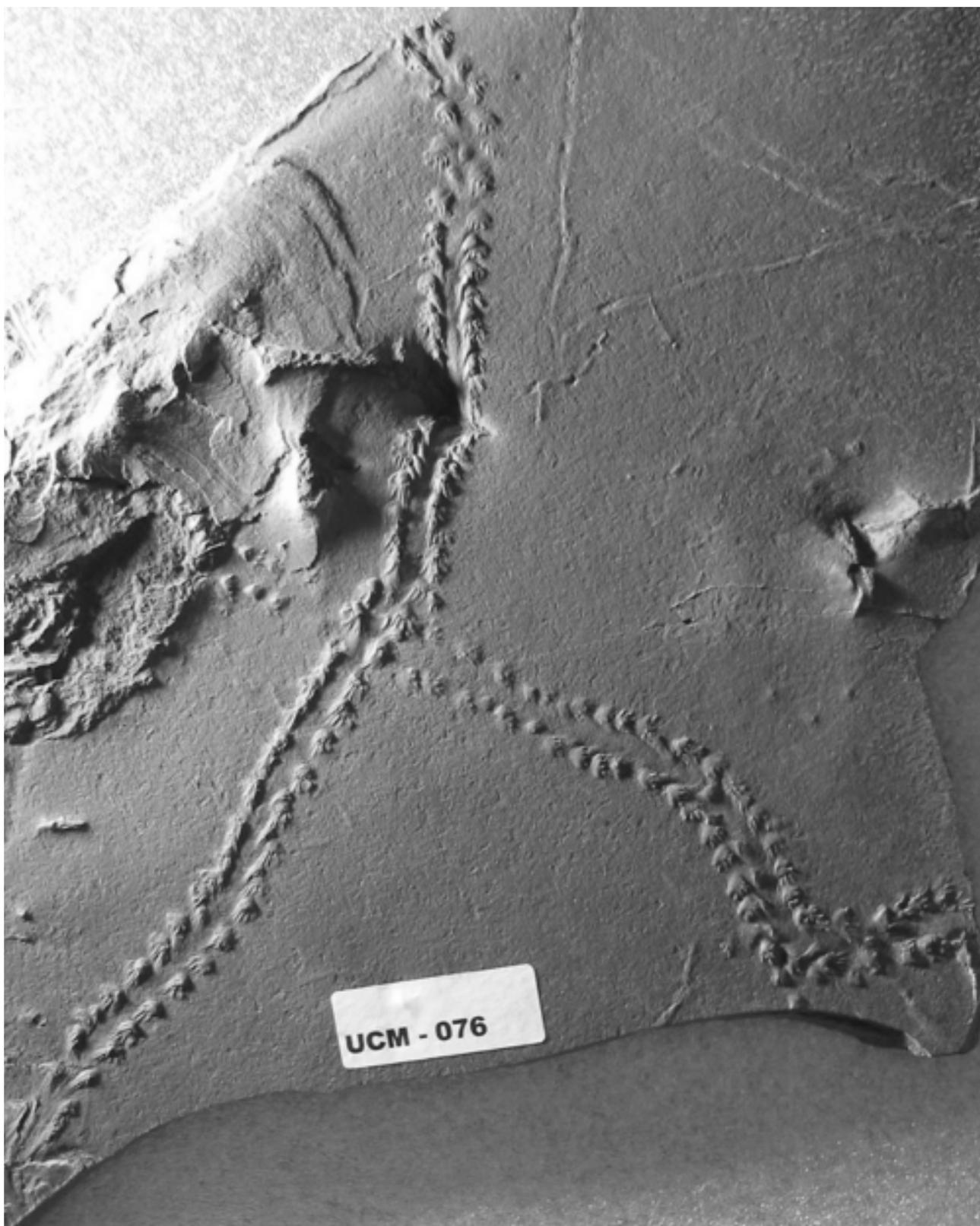


FIGURE 6. Two cross-cutting and lengthy temnospondyl trackways in UCM 76.



FIGURE 7. Variations in wavelength along a fish trail (*Undichna*), indicating changes in speed. A - UCM 1304; B - UCM 1729.

tioned previously, “belly”-drag marks also show up in a few trackways, which indirectly indicate a slowly moving animal on a sediment surface (Fig. 9). The reasons for these abrupt turns are unclear in a few examples, but two specimens have remarkable evidence for why the trackmakers turned: they were avoiding obstacles. In one example, a small trackmaker apparently bumped into and then walked around a buried xiphosuran (“horseshoe crab”), and in another example, a small trackmaker walked around a large buried plant fragment (Fig. 10). Such “stimulus-response” behaviors are rarely preserved in fossil vertebrate trackways from any geologic period, let alone in the Pennsylvanian Period (Lockley and Hunt, 1994).

Finally, one slab (UCM 1075) provides persuasive evidence for group behavior in tetrapods. On this slab are numerous shallowly impressed and overlapping medium-sized (pes about 4 cm wide, manus about 3 cm wide) tracks that were formed by at least four (perhaps five) similarly sized individuals (Fig. 11). The tracks all point in the same direction, which prompts several hypotheses: (1) multiple individuals, probably of the same species and age range, walked together or after one another on the same surface in this area at about the same time; (2) multiple individuals at different times walked through the area in a narrow landscape-induced pathway; (3) different individuals walked through the same area at different times and on different surfaces (where undertracks reached older surfaces); and (4) one individual trackmaker was repeating the same pathway in a loop. Of these, the first is the most probable because of the very similar morphology, size, direction, spacing,

depth, and preservation of the tracks on what is apparently the same surface. With regard to the latter, the high sedimentation rate inferred for the Union Chapel deposit means that track formation had to have been in a relatively narrow time span (i.e., between low tide and high tide in a given cycle). If the first hypothesis is the best fit for now, it constitutes the oldest evidence for gregarious behavior in amphibians known from the geologic record. In fact, vertebrate trackways in general rarely provide convincing support of group behavior (such as herding and pack hunting), although it has been interpreted from some Permian reptile and Mesozoic dinosaur trackways (Lockley and Hunt, 1994; MacDonald, 1994).

## SUMMARY

The Union Chapel site is quantitatively and qualitatively the most important in the world for vertebrate trace fossils from the Early Pennsylvanian Period. These trace fossils, which consist of numerous well-preserved fish trails (*Undichna*) and amphibian tracks (*Cincosaurus*), provide evidence for detailed interpretations of vertebrate behavior from 308 million years ago. Both fish trails and tracks were formed on mud flats of a freshwater-dominated estuary with high enough sedimentation rates that both types of trace fossils were buried quickly and preserved with considerable detail. Fish trails were likely made by relatively small, jawed fishes in shallow water (either during rising or falling tides), whereas tracks were probably made by temnospondyl amphibians during low tides, when mud flats were emergent.

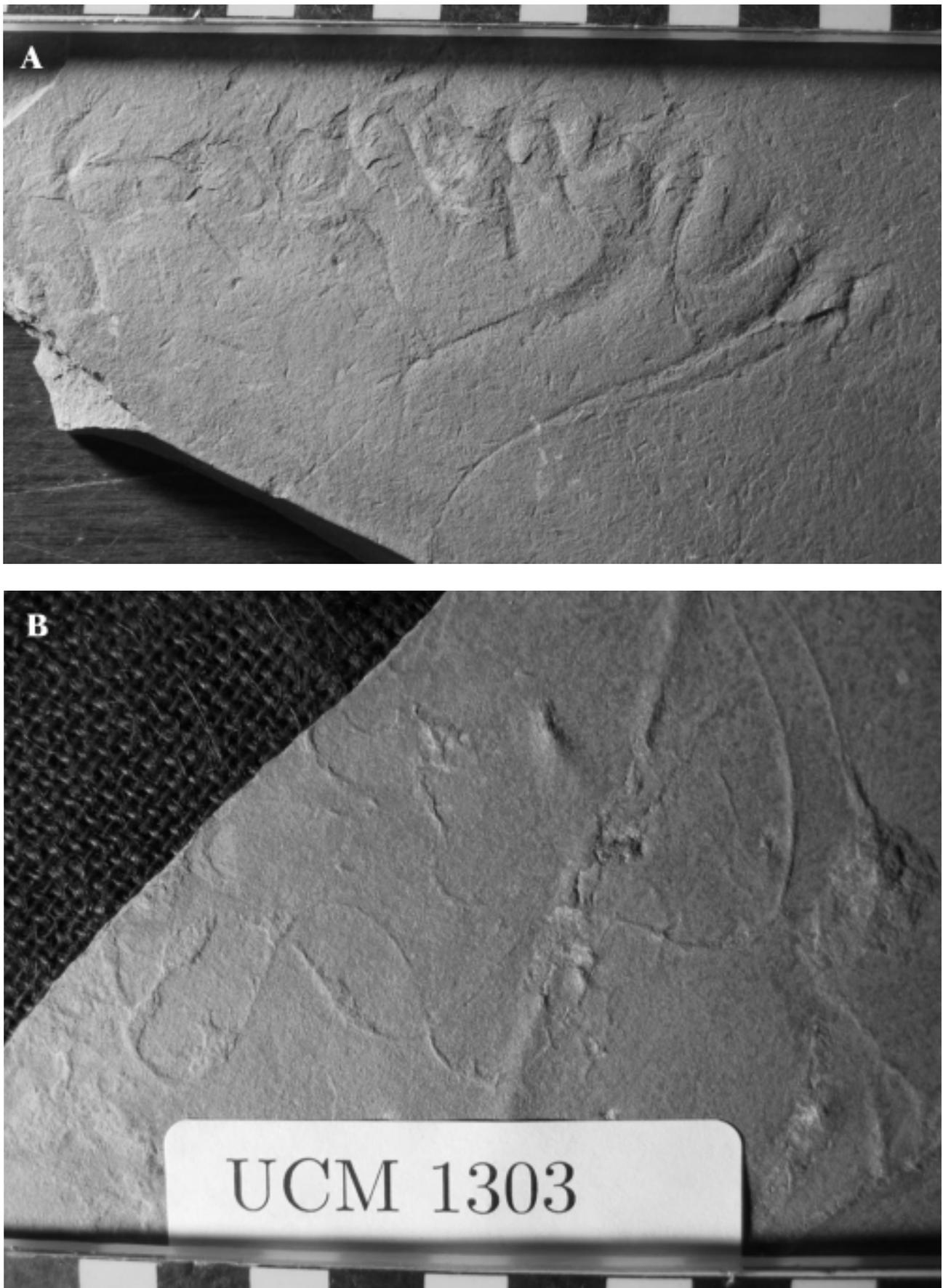


FIGURE 8. Evidence for abrupt turns of swimming fish indicated by UCM *Undichna* specimens. A - UCM; B - UCM 1303



Figure 9. Evidence for abrupt turns by trackmaker in UCM 76. Note “belly”-drag caused by trackmaking animal.

Although the number of fish species responsible for the *Undichna* specimens is unknown, we postulate that only a few species of tetrapods in various stages of its growth (juvenile to adult) made the wide size range of tracks observed in the Union Chapel deposit.

*Undichna* in the Union Chapel deposit are the result of caudal and anal fins that dragged along the top surfaces of mud flats, which is indicated by commonly coupled waveforms that have low amplitudes and long wavelengths. Changes in these wavelengths and sharp angles along individual trails indicate corresponding changes in swimming speed and abrupt turns, respectively. Group behavior (“schooling”) is strongly suggested by parallel and overlapping fish trails on the same surfaces. These latter interpretations constitute the oldest known such behavior for fish in the fossil record.

*Cincosaurus* and other tracks in the Union Chapel deposit are the result of quadrupedal locomotion and show diagonal walking patterns made by a relatively sprawling gait. Trackways oftentimes have well-preserved manus and pes impressions that show varied placement in the course of any given trackway; tail-drag and “belly”-drag marks were also occasionally preserved. These traces collectively give nuanced clues about movement of the trackmakers, which include changes in speed and direction, lateral movements, obstacle avoidances, and possible group movement. Just as in the case of *Undichna* specimens, the evidence for group behavior is perhaps the oldest interpreted from the geologic record, highlighting the significance of the Union Chapel deposit for better understanding vertebrate behavior and evolution. We also hope that this study is

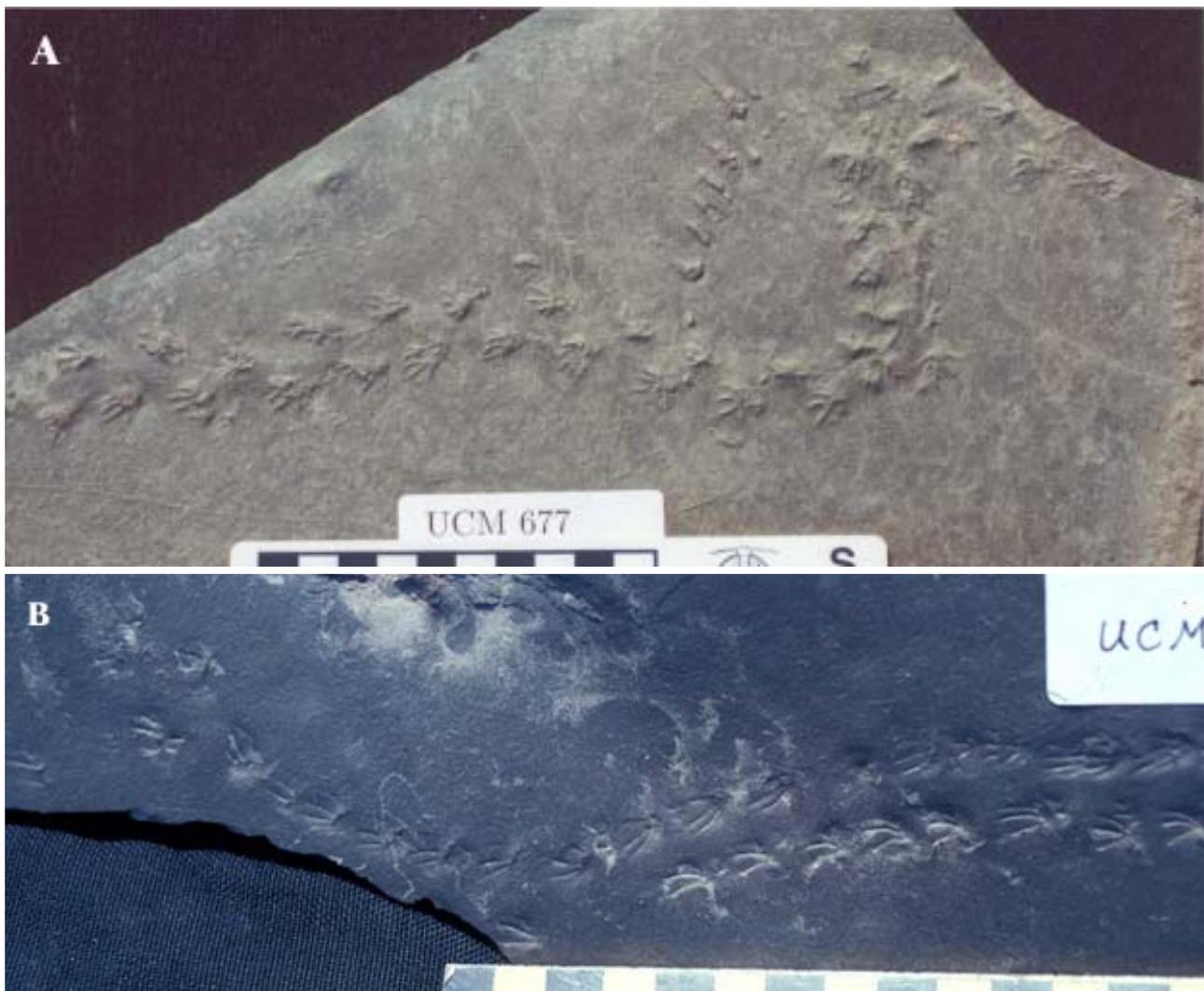


FIGURE 10. Evidence for abrupt turns by trackmakers as a result of obstacle avoidance. A - Avoiding a buried xiphosuran (UCM 677); B - Avoiding a plant fragment (UCM 484).

simply a beginning for further work that attempts to better understand vertebrate behavior as represented by Union Chapel trace fossils.

*Editors' note: For additional photographs of vertebrate traces (both tetrapod trackways and Undichna) from the Union Chapel Mine, see Haubold et al. (2005b).*

#### ACKNOWLEDGMENTS

So many people helped with advice, feedback (some as formal reviews of the manuscript), supplying access to specimens, and all-around good humor in association with the long, drawn-out process of putting together this paper that they are almost impossible to list. However, a good sample of these wonderful people consists of the following: Ashley Allen, Prescott Atkinson, Ron Buta, Jim Lacefield, Steve Minkin, Kathy Twieg, and Bruce Relihan of the Alabama Paleontological Society; David Kopaska-Merkel, Jack Pashin, and Andy Rindsberg of

the Geological Survey of Alabama; Ed Hooks, formerly of the Alabama Museum of Natural History; Chris Beck, Jon Kingston, Pat Marsteller, Don Shure, William Size, Lance Waller, and John Wegner of Emory University; Julie Bartley of the State University of West Georgia; Richard Bromley of the University of Copenhagen; Alfred Uchman of the Jagiellonian University; Jerry MacDonald of the Paleozoic Trackways Project; and Spencer Lucas and Adrian Hunt of the New Mexico Museum of Natural History and Science; and Lauren Tucker of the University of Birmingham, UK. However, as the primary author, Martin takes responsibility for any errors, misjudgments, or outright slanderous allegations about the ancestry of temnospondyls or otherwise that might have crept into the final manuscript. Funding for Pyenson was provided in part by the Howard Hughes Medical Institute under Grant No. 52003071, the University of California Board of Regents, and the Faculty Science Council of Emory University.

Finally, we dedicate this paper to the paleontological legacy of Steve Minkin, who through his relentless

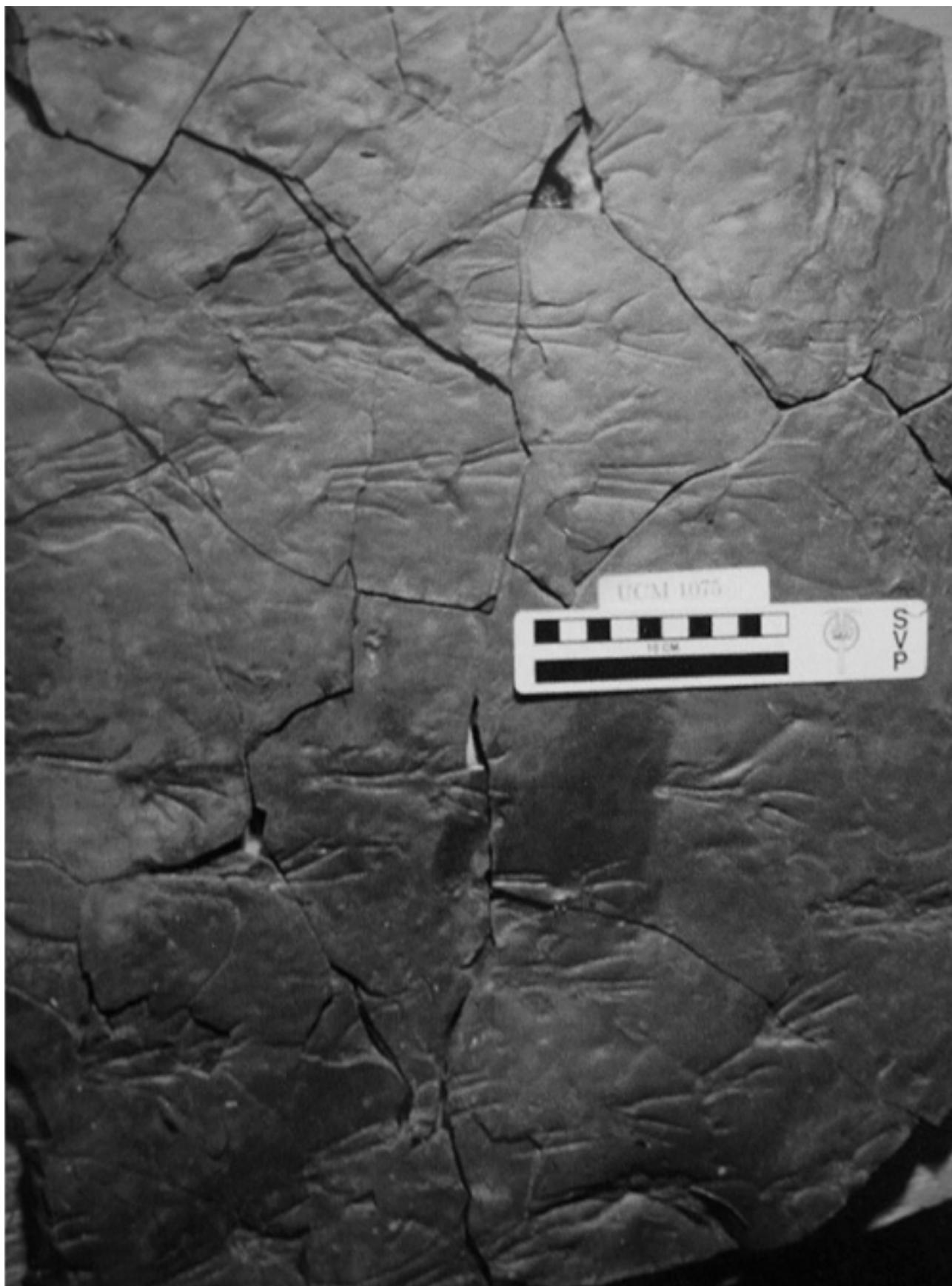


FIGURE 11. Evidence for group behavior in temnospondyls, showing multiple trackways with similarly sized tracks pointing in the same direction (UCM 1075).

scouting, collecting, cataloging, and networking provided the sparks responsible for much of the excellent science that emerged from the UCM site. We will miss him dearly but his tracks will live on.

## REFERENCES

- Aldrich, T. H. Sr., and Jones, W. B., 1930, Footprints from the Coal Measures of Alabama: Alabama Natural History Museum Museum Paper No. 9, 64 p.
- Anderson, A. M., 1976, Fish trails from the Early Permian of South Africa: *Palaentology*, v. 19, p. 397-409.
- Archer, A. W. and Maples, C. G., 1984, Trace-fossil distribution across a marine-to-nonmarine gradient in the Pennsylvanian of southwest Indiana: *Journal of Paleontology*, v. 48(2), p. 661-669.
- Benton, M. J., 1997, *Vertebrate palaeontology [Second Edition]*: Blackwell Publishing, London, 452 p.
- Bourne, C., 2003, Filling of Alabama coal mine endangers key fossil field: *USA Today*, July 31, 2003.
- Bromley, R. G., 1996, *Trace Fossils: Biology, Taphonomy and Applications [Second Edition]*: London, Chapman & Hall, 361 p.
- Brown, T., Jr., 1999, *The Science and Art of Tracking*: New York, Berkeley Books, 240 p.
- Brown, T., Jr. and Morgan, B., 1983, *Tom Brown's Field Guide to Nature Observation and Tracking*: Berkley Books, New York, 288 p.
- Buatois, L. A. and Mángano, M. G., 1994, Pistas de peces en el Carbonífero de la Cuenca Paganzo (Argentina): su significado estratigráfico y paleoambiental [Fish ichnofossils from the Carboniferous of the Paganzo Basin (Argentina): their stratigraphic and paleoenvironmental significance]: *Ameghiniana*, v. 31(1), p. 33-40.
- Buatois, L. A., Mángano, M. G. and Maples, C. G., 1997, The paradox of nonmarine ichnofaunas in tidal rhythmites: integrating sedimentologic and ichnologic data from the Late Cretaceous of eastern Kansas, USA: *Palaios*, v. 12(5), p. 467-481.
- Buta, R. J. and Minkin, S. C., 2005, The salvaging and documentation of trace fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 19-27.
- Carroll, R., 1988, *Vertebrate paleontology and evolution*: New York, W. H. Freeman and Co., 698 p.
- Dilcher, D., Lott, T. A. and Axsmith, B. J., 2005, Fossil plants from the Union Chapel Mine, Alabama; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 153-168.
- Duellman, W. and Trueb, L. E., 1994, *The Biology of Amphibians*: Baltimore, Maryland, Johns Hopkins University Press, 670 p.
- Gibert, J. M. d., Buatois, L. A., Fregenal-Martínez, M. A., Mángano, M. G., Ortega, F., Poyato-Ariza, F. J. and Wenz, S., 1999, The fish trace fossil *Undichna* from the Cretaceous of Spain: *Palaentology*, v. 42 (3), p. 409-427.
- Haubold, H., Allen, A., Atkinson, T. P., Buta, R. J., Lacefield, J. A., Minkin, S. C. and Relihan, B. A., 2005a, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 75-111.
- Haubold, H., Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, Atlas of Union Chapel Mine vertebrate trackways and swimming traces; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*, Alabama Paleontological Society Monograph no. 1, p. 207-276.
- Hunt, A. P., Lucas, S. G. and Lockley, M. G., 2004, Large pelycosaur footprints from the Lower Pennsylvanian of Alabama, USA: *Ichnos*, v. 11, p. 39-44.
- Lockley, M. and Hunt, A., 1995, *Dinosaur Tracks and other Fossil Tracks of the Western US*: Columbia University Press, New York, 388 p.
- Lucas, S. G., Lerner, A. J., Bruner, M. and Shipman, P., 2004, Middle Pennsylvanian ichnofauna from eastern Oklahoma, USA: *Ichnos*, v. 11, p. 45-55.
- MacDonald, J., 1994, *Earth's First Steps: Tracking Life before the Dinosaurs*: Boulder, Colorado, Johnson Books, 220 pp.
- Martin, A. J. and Rindsberg, A. K., 2004, Insights from the Union Chapel Mine, Alabama (USA) on Carboniferous vertebrate behavior; in Buatois, L. A. and Mángano, M. G., eds., *Ichnia 2004: First International Congress on Ichnology*, Abstract Book, Museo Paleontológico Egidio Feruglio, Trelew, Argentina: 52.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R.J., Rindsberg, A.K. and Kopaska-Merkel, D.C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 39-58.
- Peabody, F. E., 1959, *Trackways of living and fossil salamanders*: University of California Publications in Zoology, no. 63, 48 p.
- Pyenson, N. D., 2002, Temnospondyl amphibians from the Union Chapel Mine, Pennsylvanian (Westphalian A), Alabama: Predicting body size and estimating population size structure using paleoichnology: Department of Biology, Emory University, Senior Honors Thesis, Atlanta, Georgia, 72 p.
- Pyenson, N. D. and Martin, A. J., 2002, Quantified approach for predicting tracemaker size: applications in tetrapod ichnology using Carboniferous temnospondyl trackways from the Union Chapel Mine site, Alabama: *Journal of Vertebrate Paleontology*, v. 22 [Supplement to No. 3], p. 97A.
- Pyenson, N. D. and Martin, A. J., 2001, Uses of amphibian trackways from the Union Chapel Mine (Lower Pennsylvanian: Westphalian A) of Alabama for estimating amphibian population compositions: *Journal of Vertebrate Paleontology*, v. 21 (Supplement to no. 3), p. 91A.
- Rezendes, P., 2002, *Tracking and the Art of Seeing: How to Read Animal Tracks and Sign [Second Edition]*: New York, Harper Resource, 336 pp.
- Rindsberg, A. K. and Martin, A. J., 2004, Invertebrate trace fossils from the Union Chapel Mine of Alabama (Early Pennsylvanian: Langsetian); in Buatois, L. A. and Mángano, M. G., eds., *Ichnia 2004: First International Congress on Ichnology* Abstract Book, Museo Paleontológico Egidio Feruglio, Trelew, Argentina, p. 68-69.
- Rindsberg, A. K., Uchman, A. and Kopaska-Merkel, D. C., 2004, *Treptichnus* made by insect larvae in the Pennsylvanian of Alabama (USA); in Buatois, L. A. and Mángano, M. G., eds., *Ichnia 2004: First International Congress on Ichnology* Abstract Book, Museo Paleontológico Egidio Feruglio, Trelew, Argentina, p. 69.
- Rindsberg, A. K., Martin, A. J. and Pyenson, N. D., 2001, Cooperation among amateurs and professionals to salvage a new Lower Pennsylvanian tracksite in Alabama: *Geological Society of America, Abstracts with Programs*, v. 33 (2), p. 57.
- Schult, M.F. and Farlow, J. O., 1992, Vertebrate trace fossils; in Maples, C. G. and West, R. R., eds., *Trace Fossils: The Paleontological Society, Short Course in Paleontology*, no. 5, p. 34-66.

- Sever, M. G., 2003, Mine reclamation threatens tracksite: *Geotimes*, v. 48 (10), p. 6-7.
- Sfakiotakis, M., Lane, D. M. and Davies, J. B., 1999, Review of fish swimming modes for aquatic locomotion: *IEEE Journal of Oceanic Engineering*, v. 24, p. 237-252.
- Soler-Gijón, R. and Moratalla, J. J., 2001, Fish and tetrapod trace fossils from the Upper Carboniferous of Puertollano, Spain: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 171(1-2), p. 1-28.
- Steyer, J. S., 2000, Ontogeny and phylogeny of temnospondyl amphibians, a new method of analysis: *Zoological Journal of the Linnean Society*, v. 130, p. 449-467.
- Toner, M., 2003, Ancient footprints in peril: Mine reclamation may bury history: *Atlanta Journal-Constitution*, Home Edition, September 9, p. 1A.
- Turek, V., 1989, Fish and amphibian trace fossils from Westphalian sediments of Bohemia: *Palaeontology*, v. 32(3), p. 623-643.
- Turek, V., 1996, Fish trace fossil interpreted as a food gathering swimming trail from the Upper Carboniferous (Westphalian) of Bohemia: *Casopis Narodního Muzea Rada Prirodovedna*, v. 165(1-4), p. 5-8.
- Zittel, K. von., 1888, *Handbuch der Paläontologie: Abteilung 1. Paläozoologie Band III. Vertebrata (Pisces, Amphibia, Reptilia, Aves)*: Oldenbourg, Munich and Leipzig, 900 p.

#### **AUTHORS' E-MAIL ADDRESSES**

Anthony J. Martin: [geoam@learnlink.emory.edu](mailto:geoam@learnlink.emory.edu)  
 Nicholas D. Pyenson: [pyenson@berkeley.edu](mailto:pyenson@berkeley.edu)



Hartmut Haubold prepares a trackway specimen for photography during his visit to Tuscaloosa, Alabama, in February 2003. Photo taken at Mary Harmon Bryant Hall, Geological Survey of Alabama, by Ron Buta.

## INTERPRETATION OF THE TETRAPOD FOOTPRINTS FROM THE EARLY PENNSYLVANIAN OF ALABAMA

HARTMUT HAUBOLD<sup>1</sup>, ASHLEY ALLEN<sup>2</sup>, T. PRESCOTT ATKINSON<sup>3</sup>, RONALD J. BUTA<sup>4</sup>,  
JAMES A. LACEFIELD<sup>5</sup>, STEVEN C. MINKIN<sup>6</sup>, and BRUCE A. RELIHAN<sup>7</sup>

<sup>1</sup> Institute of Geological Sciences, Martin-Luther-University, Von-Seckendorff-Platz 3, D-06120 Halle, Germany

<sup>2</sup> Oneonta High School, Oneonta, Alabama 35121, USA

<sup>3</sup> Children's Hospital CHT 752M, 1600 Seventh Avenue South, Birmingham, Alabama 35233, USA

<sup>4</sup> Department of Physics and Astronomy, University of Alabama, Tuscaloosa, Alabama 35487, USA

<sup>5</sup> Adjunct Professor of Biology and Earth Science, University of North Alabama, Florence, Alabama 35632, USA

<sup>6</sup> Anniston, Alabama, USA (deceased February 20, 2004)

<sup>7</sup> 3216 Daphne Lane, Hoover, Alabama 35216, USA

**ABSTRACT:** Discoveries of tetrapod footprints from the lower part of the upper Pottsville Formation in Alabama (USA) from the 1990s to the present constitute the most representative record, both in quality and quantity, hitherto known from the Early Pennsylvanian (Westphalian A age). These discoveries succeed and considerably broaden the first finds published by Aldrich (1930) from the roofrock of the Jagger coal seam near Carbon Hill, Walker County. The recent investigation of the available material from several sites near Carbon Hill and Jasper concerns, first and foremost, specimens from the Union Chapel Mine, and, in addition, those from the Kansas and Fern Springs Mines, as well as the surviving specimens remaining in the Alabama Museum of Natural History described by Aldrich, which were presumably collected from the Holly Grove Mine near Carbon Hill. After a detailed investigation of several hundred specimens we are able to identify a significant ichnofauna of the following content:

**Temnospondyl trackways:** *Nanopus reidia* n. isp., *Matthewichnus caudifer* Kohl & Bryan, 1994;

**Anthracosaur trackways:** *Attenosaurus subulensis* Aldrich, 1930;

**Amniote trackways:** *Cincosaurus cobbi* Aldrich, 1930, and *Notalacerta missouriensis* Butts, 1891.

The identification and determination of these ichnotaxa can be established because of the exceptionally large sample size from the Union Chapel Mine in combination with the evidence known from other localities. All are related stratigraphically to the Mary Lee coal zone at the base of the upper Pottsville Formation. The preservation of the footprints is related to the environment of estuarine tidal flat deposits. The so-called *Cincosaurus* beds above the Mary Lee coal are exposed at the Union Chapel Mine. The Fern Springs Mine and Kansas sites presumably belong to the lower horizon of the Jagger coal.

## INTRODUCTION

### The Knowledge of Carboniferous Tetrapod Footprints

The scientific description of Carboniferous tetrapod footprints, in particular those from the Pennsylvanian, begins with King (1845, 1846), who named *Ornithichnithes* and *Thenaropus* and changed the latter into *Spheropezium*. These forms remained problematic until Lea (1849) next introduced *Sauropus* as a common form of tracks of the Coal Measures, and Dawson (1863, 1868, 1872, 1882) applied this name to footprints from the Paleozoic. Dawson (1882) used the form of the impression for classification and distinguished digitigrade (*Hylopus*) and plantigrade (*Sauropus*) morphs. This procedure related tracks that had been separated by other students. Other criteria of classification are the number of toes, a chirotherian pattern of *S. unguifer*, and an elephantine tread of *S. sydnensis*. Butts (1891)

summarized under *Notalacerta* digitigrade, plantigrade, pentadactyl and tetradactyl tracks. Hay (1902) recognized that the name *Sauropus* was first used for tracks from the Triassic (preoccupied by Hitchcock), and substituted *Palaeosauropus* for all Carboniferous tracks called *Sauropus* by former authors.

Previously Matthew (1903b: p. 109f.) argued that the Carboniferous forms encompassed under the name *Sauropus/Palaeosauropus* appear quite diverse from each other. Therefore, they cannot be unified under a single generic name. *Sauropus primaevus* Lea is quite different from *S. sydnensis* Dawson, and several other ichnospecies included under *Palaeosauropus* by Hay (1902) can be included under generic names of previous authors. As Matthew (1903b) stated, for the type of footprint represented by *S. primaevus*, several generic names have been used — *Thenaropus/Theranopus*, *Notalacerta*, *Anthracopus*, and *Sauropus* — with as many different species. A similar number of generic names and species can be found in other groups of these

footprints. By 1903 it was clear how difficult it was to determine a common basis for the classification of footprints. Matthew stated that tail marks and drag marks of the belly are less significant as the basis for a classification; instead, he used the number of toes, and as subordinate characters the “weight” and “strength” of the impression.

Marsh (1894) noted the morphological variation in the footprints he described under certain generic names. This was, from the modern point of view, one of the first realistic, well-founded classification *caveats*. The arguments of Marsh suggest that the main reason for the apparent diversity in Permo-Carboniferous track genera is that authors of this time described only one or a few prints, and gave each separate, new generic names. The paper by Matthew (1903b, p. 110) was intended to reduce this redundancy of names, divide the footmarks into related groups under generic names, and present a tentative arrangement. The numbers of toe marks of manus and pes are the primary criteria used for the classification of batrachian tracks from North America. Of secondary value are slenderness or stoutness of the toes, the weight of the heel, etc. Unfortunately, Matthew used the recorded number of toe marks without regard to the potential incompleteness of the record; e.g. *Dromopus agilis* appears in group 4 with a pentadactyl manus, and *Nanopus caudatus* represents group 9 with a pentadactyl pes and tridactyl manus. Matthew classified 11 groups represented by the following genera:

1. *Notalacerta* Butts, 1891
2. *Hylopus* Dawson, 1882
3. *Pseudobradypus* Matthew, 1903
4. *Dromopus* Marsh, 1894
5. *Batrachichnus* Woodworth, 1900
6. *Thenaropus* King, 1845
7. *Limnopus* Marsh, 1894
8. *Baropus* Marsh, 1894
9. *Nanopus* Marsh, 1894
10. “*Apatichnus*”? with *Hylopus ? trifidus* Dawson, 1895
11. “*Ornithichnites*” King, 1845.

Matthew (1903b, p. 111) astutely emphasized that the method of representing tracks by drawings “is wide scope for the exercise of imagination.” Thereafter, photography became the principal standard for objective determination. The ultimate goal is to be able to compare the footprints to the animals which made them, and this must await discovery of their skeletons.

The framework formulated by Matthew (1903a,b,c, 1905) has been continued by Baird (1952) and Haubold (1970, 1971). However, over the following 100 years there was no significant progress or solution, as shown in the attempt at a revision by Haubold (1970, 1971) and the overviews by Cotton et al. (1995) and Hunt et al. (1995). At present we are confronted with 56 generic names primarily introduced for tetrapod footprints of the Carboniferous (Table 1), and an additional 10 generic names related first to Permian finds. The number of primary ichnospecies introduced for Carboniferous

specimens totals 97, with 43 later binominal combinations. As shown by the origin of generic and species names, the majority of tetrapod footprints were found in North America: 42 ichnogenera and 75 ichnospecies were first described from Carboniferous formations in North America. The remaining 12 ichnogenera and 24 ichnospecies were introduced by studies in western Europe.

Now, one century after Matthew’s attempt at a unified classification scheme, it seems possible to correlate at least some tracks, or some ichnotaxa with the foot skeletal structures of tetrapods known from Permo-Carboniferous deposits. This is due to the remarkable accumulation of knowledge concerning skeletons of terrestrial tetrapods from the Carboniferous and to the discoveries of footprints in the Pottsville Formation in Alabama in hitherto unequalled quantities. This large sample size allows critical insights into the modes of origin and preservation that control the recorded morphology of footprints. The detailed investigation and comparison of the specimens from the Union Chapel Mine, and the delamination of several footprints layer by layer, together with an objective documentation by photographs as proposed by Matthew (1903b), creates an optimal chance to establish an understanding of Carboniferous footprints free from imagination, and free from taxonomic oversplitting or oversimplified lumping.

### Occurrences in Alabama

The tetrapod footprints investigated for this paper come from the Mary Lee coal zone of the basal upper Pottsville Formation. This is the interval from the Jagger to the New Castle coal beds (see Pashin, 2005). All sites (Union Chapel Mine, Holly Grove Mine, Fern Springs Mine, and Kansas) are located near Carbon Hill, Walker County, Alabama.

### Material

**UCM** - Union Chapel Mine, with suffix identifying the collectors: AA - Ashley Allen, TPA - T. Prescott Atkinson, SM - Steven C. Minkin, RB - Ronald J. Buta, BR - Bruce A. Relihan, JT - Jay Tucker, JL - James A. Lacefield, DA - David Ausmus, GB - Gerald Badger.

**FSM** - Fern Springs Mine, specimens collected recently by members of the Alabama Paleontological Society are not yet cataloged.

**Kansas** - Specimens from the outcrops near Kansas collected by J. Lacefield in 1993. The remaining specimens are not yet cataloged.

**AMNH** - Alabama Museum of Natural History, Tuscaloosa, houses the surviving specimens described by Aldrich (1930) and holds a portion of the UCM specimens.

**HH** - specimens in the collection of Hartmut Haubold from UCM and FSM.

**RM** - Redpath Museum, McGill University, Montreal. Casts of some specimens from Joggins, Nova Scotia, originals of Matthew (1905).

TABLE 1. The 56 primary ichnogenera introduced for tetrapod footprints and trackways of Carboniferous formations (asterisks refer to names related to discoveries from North America)

<p>*<i>Allopus</i> Marsh, 1894          "Acripes" Langiaux &amp; Sotty, 1975 (praeocc.)          *<i>Ancylopus</i> Carman, 1927          *<i>Anomoeichnus</i> Carman, 1927          *<i>Anthracosaurus</i> Leidy, 1880          *<i>Anticheiropus</i> Sarjeant &amp; Mossman, 1979 (praeocc.)          *<i>Asperipes</i> Matthew, 1903          *<i>Attenosaurus</i> Aldrich, 1930          *<i>Barillopus</i> Matthew, 1903          *<i>Baropezia</i> Matthew, 1904          *<i>Baropus</i> Marsh, 1894          *<i>Batrachichnus</i> Woodworth, 1900          *<i>Bipedes</i> Aldrich, 1930          *<i>Cincosaurus</i> Aldrich, 1930          *<i>Collettosaurus</i> Cox, 1874          *<i>Ctenerpeton</i> Aldrich, 1930          *<i>Crucipes</i> Butts, 1891          *<i>Cursipes</i> Matthew, 1903          *<i>Dromillopus</i> Matthew, 1905          *<i>Dromopus</i> Marsh, 1894,          *<i>Hydromedichnus</i> Kuhn, 1963 for <i>Hydromeda</i> Aldrich, 1930          *<i>Hylopus</i> Dawson, 1881, 1895  <i>Leptopus</i> Langiaux &amp; Sotty, 1975          *<i>Limnopus</i> Marsh, 1894          *<i>Limnosauripus</i> Kuhn, 1959 for <i>Limnosaurus</i> Aldrich, 1930          *<i>Matthewichnus</i> Haubold, 1970          *<i>Megabaropus</i> Baird, 1952          *<i>Megapaezia</i> Matthew, 1903          *<i>Nanopus</i> Marsh, 1894          *<i>Notalacerta</i>, Butts 1891          *<i>Notamphibia</i> Butts, 1891  <i>Okypes</i> Langiaux &amp; Sotty, 1975          *<i>Onychopus</i> Martin, 1922          *<i>Ornithoidipus</i> Sternberg, 1933          *<i>Ornithoides</i> Matthew, 1903          *<i>Palaeosauropus</i> Hay, 1902 for <i>Sauropus</i> Lea, 1849          *<i>Parvives</i> Willard &amp; Cleaves, 1930          *<i>Peratodactylopus</i> Sarjeant &amp; Mossman, 1979  <i>Pinguipes</i> Langiaux &amp; Sotty, 1975 [= <i>Stephanopus</i> syn. of same year]  <i>Platytherium</i> Barkas, 1873  <i>Prolacertipes</i> Dolle et al., 1970          *<i>Pseudobradypus</i> Matthew, 1903          *<i>Quadropedia</i> Aldrich, 1930  <i>Salichnium</i> Müller, 1962  <i>Schmidtopus</i> Haubold, 1970  <i>Sormiensipes</i> Langiaux &amp; Sotty, 1975 [= <i>Stephanopus</i> syn. of same year]          *<i>Sphaeropezium</i> King, 1845 (replaced <i>Thenaropus</i> King, 1844)          *<i>Steganoposaurus</i> Branson &amp; Mehl, 1932  <i>Stephanopus</i> Gand, 1975  <i>Tenuipes</i> Langiaux &amp; Sotty, 1975          *<i>Thenaropus</i> King, 1844  <i>Tridactylosaurus</i> Barkas, 1883          *<i>Trisaurus</i> Aldrich, 1930</p>
---

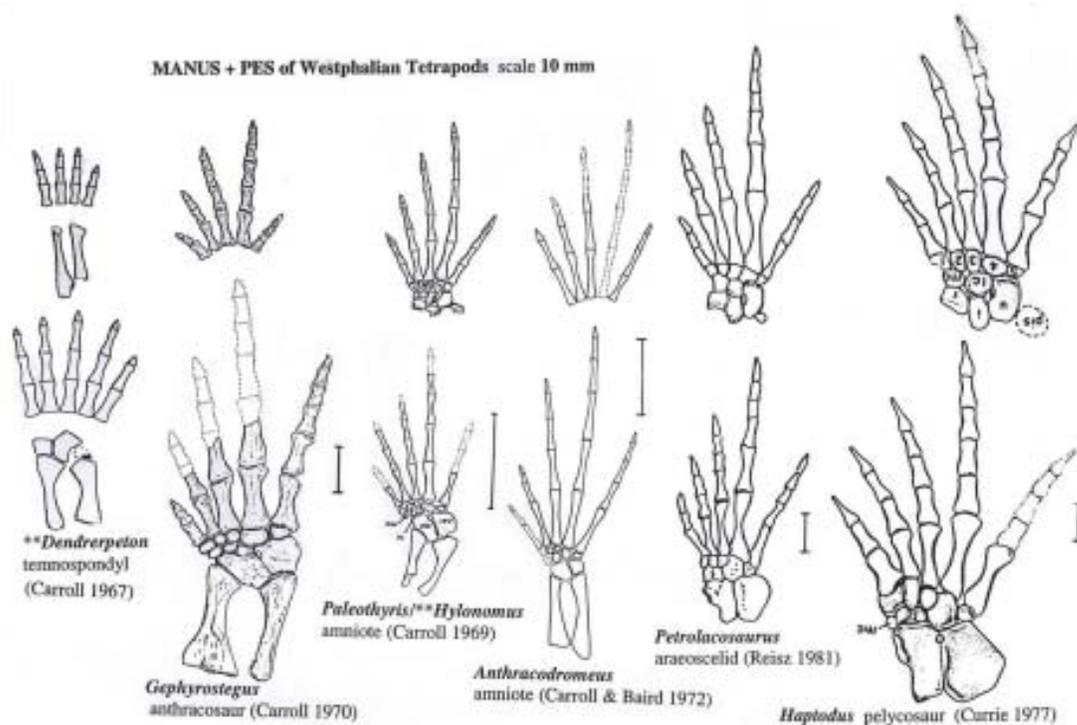


FIGURE 1. Manus and pes skeletons of Westphalian terrestrial tetrapods. Scale 10 mm. *Dendrerpeton* after Carroll (1967 a), *Gephyrostegus* after Carroll, (1970), *Paleothyris* (manus) and *Hylonomus* (pes) after Carroll (1969b), *Anthracodromeus* after Carroll and Baird (1972), *Petrolacosaurus* after Reisz (1981), and *Haptodus* after Currie (1977).

## PRINCIPLES OF INTERPRETATION

### Skeletal record

The interpretation of tetrapod footprints presented below follows the principle of correlating footprint and skeletal evidence known from the Pennsylvanian in general and from the Westphalian A in particular. Terrestrial tetrapods have been recorded from the Westphalian (\*genera known from the Westphalian A of Joggins, Nova Scotia); most of the other forms are known from the late Westphalian, localities including Florence, Nova Scotia, Linton, Ohio, and Nyraný, Czech Republic. The following list includes terrestrial groups known by certain genera (assembled from Carroll, 1964a, b, 1967a, b, 1969a, b, 1970, 1982, 1986; Carroll and Baird, 1968, 1970; Currie, 1977; Holmes et al., 1998; Reisz, 1975).

**TEMNOSPONDYLI:** *Dendrerpeton*\*, *Amphibamus*

**MICROSAURIA** (Tuditanomorpha): *Asaphestra*\*,  
*Archerpeton*\*, *Tuditanus*

### REPTILIOMORPHA

Anthracosauria: *Gephyrostegus*

Diadectomorpha: *Diadectes*, *Limnoscelis*

### AMNIOTA

Anapsida, Protorothyrididae: *Hylonomus*\*

*Palaeothyris*, *Anthracodromeus*, *Cephalerpeton*

Synnapsida: *Protoclepsyrops*\*

Ophiacodontidae: *Archaeothyris*, *Clepsyrops*,

*Ophiacodon*

Haptodontidae: *Haptodus*, *Macromerion*

In deciphering the tetrapod footprints from the Alabama localities, we can use a well-established record of terrestrial tetrapods representing temnospondyls, microsauria, anthracosaurs, and amniotes. Several taxa are represented by rather complete skeletons. In some cases we have sufficient Westphalian skeletal material inclusive of the manus and pes: *Dendrerpeton*, *Gephyrostegus*, *Hylonomus* in combination with *Palaeothyris*, *Anthracodromeus* and *Haptodus* (Fig. 1). Added to this assemblage is the manus and pes skeleton of the first diapsid *Petrolacosaurus* (Reisz, 1981) from the Stephanian (Missourian) of Garnett, Kansas, to show that the fully developed lacertoid foot and track pattern of diapsid amniotes, well known with the ichnotaxon *Dromopus*, is not yet recorded from Westphalian time.

### Ichnotaxonomy

The footprint record itself, and also its analysis and interpretation, are intriguing in many respects. Part of the complex of problems includes standardizing the methodology of describing and distinguishing tetrapod footprints, the meaning of an ichnotaxon, relationships between the original imprint and the potential undertracks in general and the observed undertracks in the Westphalian *Cincosaurus* beds in particular. Due to the extraordinarily large sample size originating from UCM, we are confronted with an excellent opportunity to understand the distinction of original tracks from undertracks. This is of prime importance in reducing the potential for misinterpretation in the ichnotaxonomy

of Permo-Carboniferous tetrapod footprints.

In the case of the Union Chapel site and the Westphalian A tracks from Alabama, we must deal with opposing positions taken by others in their efforts to recognize extramorphology and avoid the creation of phantom taxa — the approaches of the so-called “lumpers” and “splitters”. On one side is the separation of every track morph as described by Aldrich (1930), and at the other side the unification of all track morphs under *Cincosaurus cobbi* as proposed by Pyenson and Martin (2001, 2002; see also Martin and Pyenson, 2005). We propose a middle road, utilizing the experience of so-called extramorphology in tetrapod footprints. Extramorphology may be simply explained using the following observation: through influences other than those relating to foot shape, the trackways and tracks of any tetrapod may appear identical or quite different. When measuring all tracks, one usually gets a range of variation that might suggest high diversity. When the sample size is as large and close to complete as that from the UCM, the measurements of high diversity might be instead interpreted as evidence of low diversity.

This apparent contradiction results from the fact that, in a large amount of specimens, all potential variants of preservation may be documented, and the record is thus a continuum. In contrast, where only a few specimens are known, some may represent extreme morphs in size and preservation. Therefore, each morph might be given separate taxonomic status because transitional morphs are unknown or unavailable, as done by Aldrich (1930). (This can be expressed simply in a statement: The larger the sample size, the lower the diversity, and vice versa, the lower the sample size, the larger the diversity.) A consequence of the very extensive record at UCM is the conclusion that all footprints from Westphalian formations might be identified as *Cincosaurus cobbi*. This means all tracks from 5 mm up to 25 cm of any aspect or preservation. And indeed, the diversity of UCM tracks, identified by Pyenson and Martin (2001, 2002) as a single ichnotaxon, might be attributed to such an effect of large ichnological sample size.

There is a solution that lies between both positions. To better reflect objective reality in identifying the tetrapods that produced the ichnofauna, one must follow a different line. This strategy for interpreting diversity utilizes only those imprints that record the anatomy of the manus and pes without, or nearly without, extramorphological deformation. Such deformation may be due to gait, substrate qualities and differences, and the downward diminution of foot pressure that results in undertracks. In undertracks, in particular, a gradational change or loss of anatomical control related to morphology can be observed. In undertrack layers, track digits may appear shorter or longer than the digits that made them, or may disappear completely because strongly impressed digits and body impressions may dominate over lightly impressed digits. Such modifications are facies- and substrate-controlled and might cause morphologically disparate imprints to appear similar. Some impressions may appear significant but in reality represent extramorphological phantoms.

Here is the definition of *extramorphology* formulated by Peabody (1948, p. 296-7), and Haubold et al. (1995, p. 136): “In the study of trackways recorded by any living tetrapod it is possible to distinguish trackway characters which portray the anatomy of the animal from those which tend to obscure the portrayal. The latter kind may be termed ‘extramorphologic’ and include characters arising from the type of recording material and from the gait and variable speed of the animal. If a trackway exhibits a mixture of morphologic, sedimentary, and dynamic characters that are not clearly differentiated from the others, the trackway has little significance. The only trackways to be described (*determined and named*) are those which are clearly impressed and are as free as possible from extramorphological characters. Considerable effort was made to obtain a large number of consecutive footprints so that their composite detail would provide a picture of the pedal morphology, and in the trackway would clearly demonstrate the gait and general body from their arrangement.”

In continuing this line of argument, Haubold (1996, p. 35) formulated the term *phantom taxon*: Ichnogenera and ichnospecies introduced by footprints or trackways that exhibit a mixture of morphologic, sedimentary, and dynamic characters are not clearly differentiated from one another, and are, therefore, considered phantom taxa. If the significant traits are so deformed that the anatomy of the manus and pes prints are not recorded, the footprints and trackways cannot be correctly identified and interpreted. The “fingerprint of the architect” is lost. A common basis for introducing phantom taxa are footprints and trackways preserved as undertracks, because their high potential for producing variation may lead to an artificially high number of ichnotaxa. In summary, the experience of observing extramorphology and phantom tracks clearly suggests that individuals of a single species of animals may produce very different deformed tracks (phantoms), and vice versa — similar phantom tracks might be produced by different animals.

The extensive examination by the authors of specimens from the Westphalian A of Alabama cannot be presented here at length. Instead this paper’s systematics section relies only upon those specimens that display an optimal anatomically controlled record. In other words, we focus on specimens that clearly preserve manus and pes imprints along trackways recorded at surfaces at or very close to the layer of track origin. In these cases extramorphological influences can be excluded so far as possible, and the observed morphology gives an anatomical basis for characterizing certain ichnotaxa. The evidence of original surfaces includes the composition of several layers as well as telltale characteristics recorded in the slab’s surface, such as rounded digit impressions. In contrast, undertracks show digit imprints sharpened by the transfer of weight through the sedimentary layers. Also indicative of an original layer can be the presence of a tail or body impression, which usually disappear at undertrack levels within a few millimeters. One surprising and remarkable observation was made during investigation of UCM specimens: that the imprints recorded at undertrack levels are usually sharper at depth than those at the original surface. This is caus-

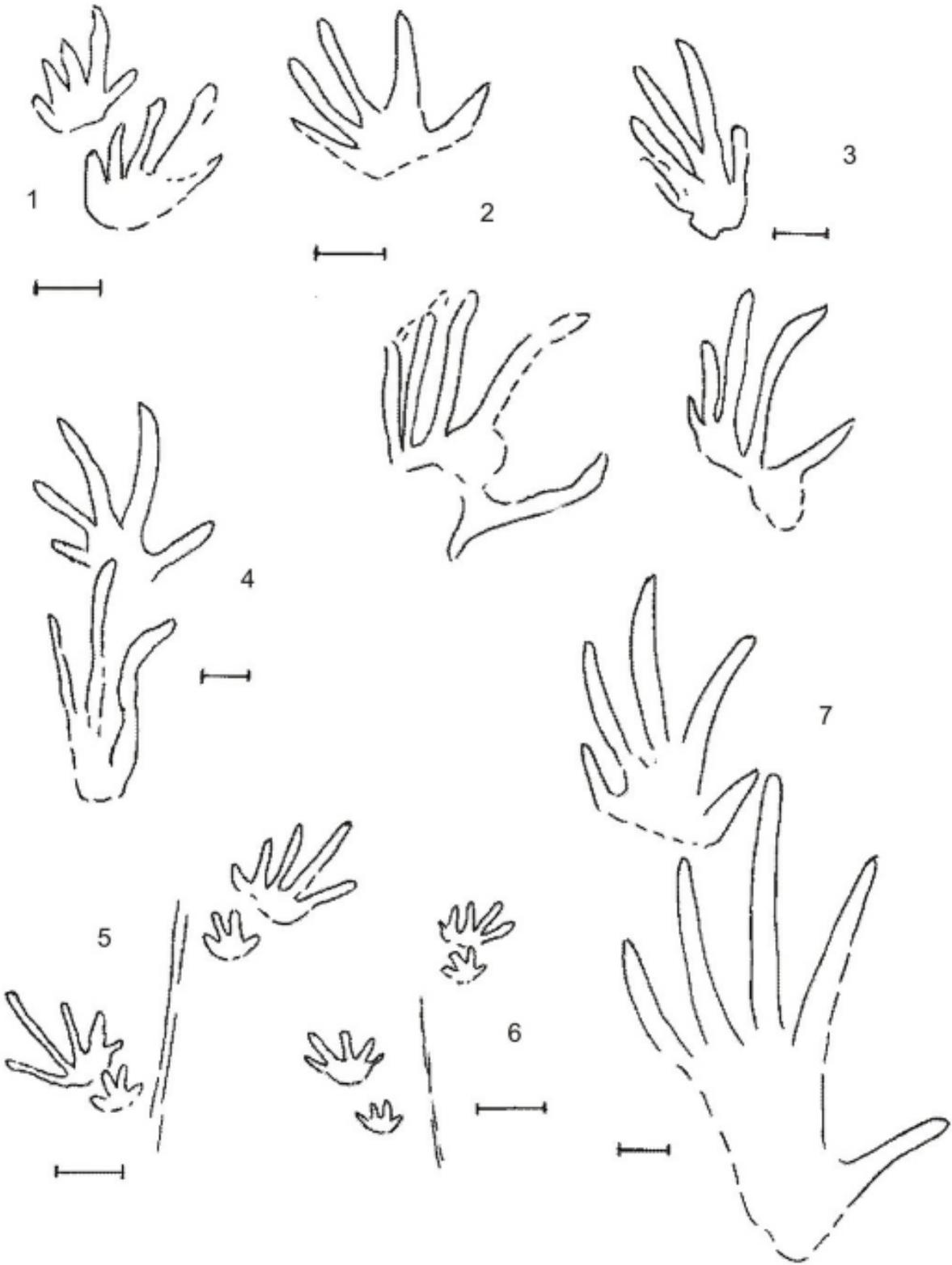


FIGURE 2. The five principal ichnotaxa of the Mary Lee coal zone, outline drawings of significant manus-pes sets: 1 *Notalacerta missouriensis* specimen from Kansas JL. 2 - 4: *Cincosaurus cobbi*. 2: specimen plate 6/7 in Aldrich 1930. 3: UCM 174/175 BR. 4: UCM 263 JT. 5: *Matthewichnus caudifer* UCM 469 BR. 6: *Nanopus reidia* UCM 1141/1142 TPA (holotype). 7: *Attenosaurus subulensis* assembled from specimens UCM 205, 242, 1214 and 1216 SM. Scale: 1 cm.

ally related to the mechanisms of the origin of tetrapod footprints and the sedimentological conditions controlling their record. These aspects have not been analyzed sufficiently for Permo-Carboniferous track beds. Some examples are discussed below. Due to the greater distinctness of imprints or of their central parts at depth, undertracks might have been preferred to original surfaces when tracks were being collected and selected for exhibition and education. However, as noted by Buta and Minkin (2005), all UCM material was taken seriously by some collectors, and this bias is not as important a problem as it might be in other collections.

## SYSTEMATIC PALEONTOLOGY

### Trackways Attributed to Temnospondyls

Based upon the published record (Aldrich, 1930) the small track types from specimens collected in the *Cincosaurus* beds of the Union Chapel Mine and the layers of Fern Springs Mine, presumably of temnospondyl origin and here described as *Matthewichnus* and *Nanopus*, are new for the Pottsville Formation in Alabama. In particular, from the UCM surfaces, undertracks of these small tracemakers are very common and look attractive, some surfaces displaying extensive trackways. Only a few specimens are preserved at or close to the original surfaces and, therefore, record an actual, anatomically controlled foot morphology and trackway pattern that might be useful for determination, differentiation, and interpretation. The unquestionably tetradactyl manus imprints suggest temnospondyl origins for both types.

#### *Matthewichnus* Haubold, 1970

*Dromopus*, Matthew, 1905: 86 (*D. velox*).  
*Matthewichnus* Haubold, 1970: 107.  
*Matthewichnus*, Kohl and Bryan, 1994: 661.

The ichnogenus was introduced based on type *Dromopus velox* Matthew, 1905 from the Westphalian of Joggins, Nova Scotia, by Haubold (1970). The elongate digits and plantigrade imprints distinguish this ichnogenus from others. But because knowledge of the trackways is incomplete, this ichnogenus remains problematic. A substantial contribution was the description of a trackway from the Cross Mountain Formation, Westphalian A, of Tennessee, by Kohl and Bryan (1994) as a new ichnospecies of *Matthewichnus* that shows plantigrade imprints with elongated digits. The species name *caudifer* ("tail-bearer") should not be confused with the previously described *Palaeosauropus (Hylopus) caudifer* (Dawson, 1882). It is also different from *Nanopus caudatus* Marsh, 1894 (see below).

#### *Matthewichnus caudifer* Kohl and Bryan, 1994

Figures 2 (5), 3A-C

*Matthewichnus caudifer* Kohl and Bryan, 1994: 661, figs. 3 - 6.

The identity of the UCM material with *Matthewichnus caudifer* Kohl and Bryan, 1994 from the Westphalian of Tennessee is confirmed by specimen UCM 469 BR with footprints in original surface preservation at several layers. Additional evidence of *M. caudifer* is known from uncataloged specimens from the Fern Springs Mine; one trackway in the collection of BR shows along a length of 60 cm about 120 manus-pes sets.

**Known distribution.** Cross Mountain Formation, Westphalian B, Campbell County, Tennessee, and basal upper Pottsville Formation, Westphalian A, Union Chapel Mine and Fern Springs Mine, Walker County, Alabama.

**Diagnosis.** Manus tetradactyl, roughly as wide as long. Digits II and III of roughly equal length, slightly more than half the length of the entire print. Digits I and IV also subequal, approximately one-third the length of the entire print. Pes pentadactyl, larger than manus, with digits of increasing length from I to IV, digits III and V subequal. (condensed from Kohl and Bryan, 1994).

**Material from Walker Co. Alabama.** UCM 469 BR (several surfaces), UCM 969 BR, UCM (H002) BR, UCM 652 TPA, UCM 285 AA; Fern Springs Mine — one unnumbered specimen BR, four specimens in the collection of HH.

**Description and discussion.** With extensive evidence, knowledge of the characters of these ichnospecies becomes more precise. Most significant is the comparison with other small pes prints having an elongate digit IV, usually directed outward. The axis of pes digit III is directed slightly outward; the smaller manus imprints are placed closer to the midline and directed inward. The presence of a tail impression, and the dimensions of imprints and trackway parameters mentioned in the original diagnosis of Kohl and Bryan (1994), must be modified to include the UCM specimens or, like the tail impression, are not diagnostically significant. The value of the tail impression, as with other ichnotaxa from the Pottsville Formation, lies in the demonstration of a track record at the original surface. This is the optimal, anatomically controlled record of the manus and pes morphology, sometimes with plantigrade imprints (Figs. 3 A-C). All the determinable specimens therefore show the tail impression. A long trackway with at least 120 manus-pes sets along 60 cm from Fern Springs Mine shows the smallest manus size, about 5 mm long; the pes is about 8 mm long. In other trackways collected by HH from the FSM, the pes length is greater than 20 mm. In trackways from the UCM, the known pes length does not exceed 15 mm. Due to different lithofacies of the UCM and FSM surfaces, the tracks' preservation shows some variation in morphology that might be quantified by further studies.

#### *Nanopus* Marsh, 1894

*Nanopus* Marsh, 1894: 82.  
*Nanopus*, Matthew, 1905: 98.  
*Nanopus*, Haubold, 1970: 96.  
*Anthichnium*, Haubold, 1970: 89 (*partim*).

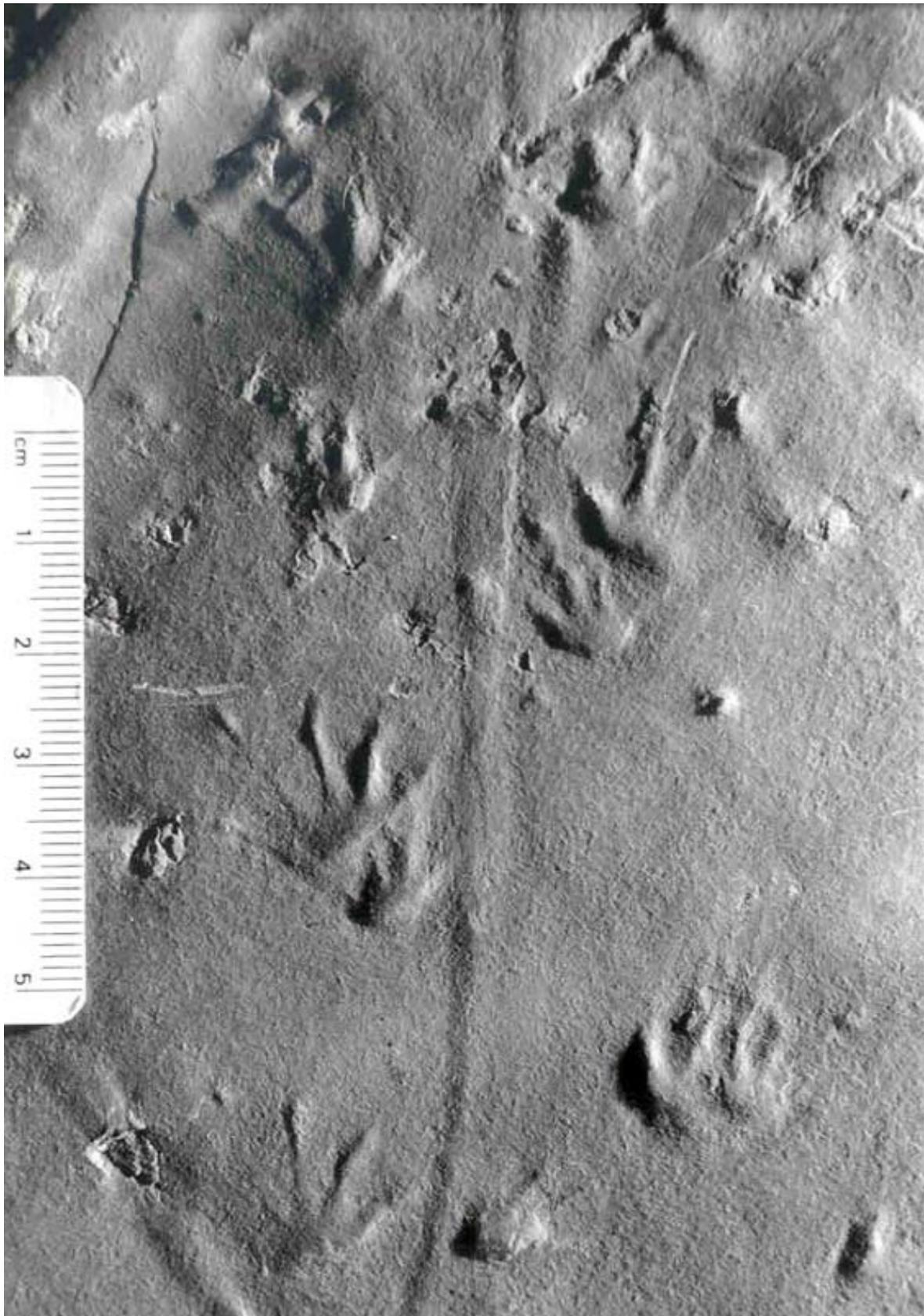


FIGURE 3A. UCM 469 BR.

FIGURE 3. *Matthewichnus caudifer* Kohl and Bryan, 1994 (photographs, scale mm and cm). A: UCM 469 BR. B: UCM 652 TPA. C: specimen from Fern Springs Mine, segment of a long trackway, coll. BR.



FIGURE 3B. UCM 652 TPA.

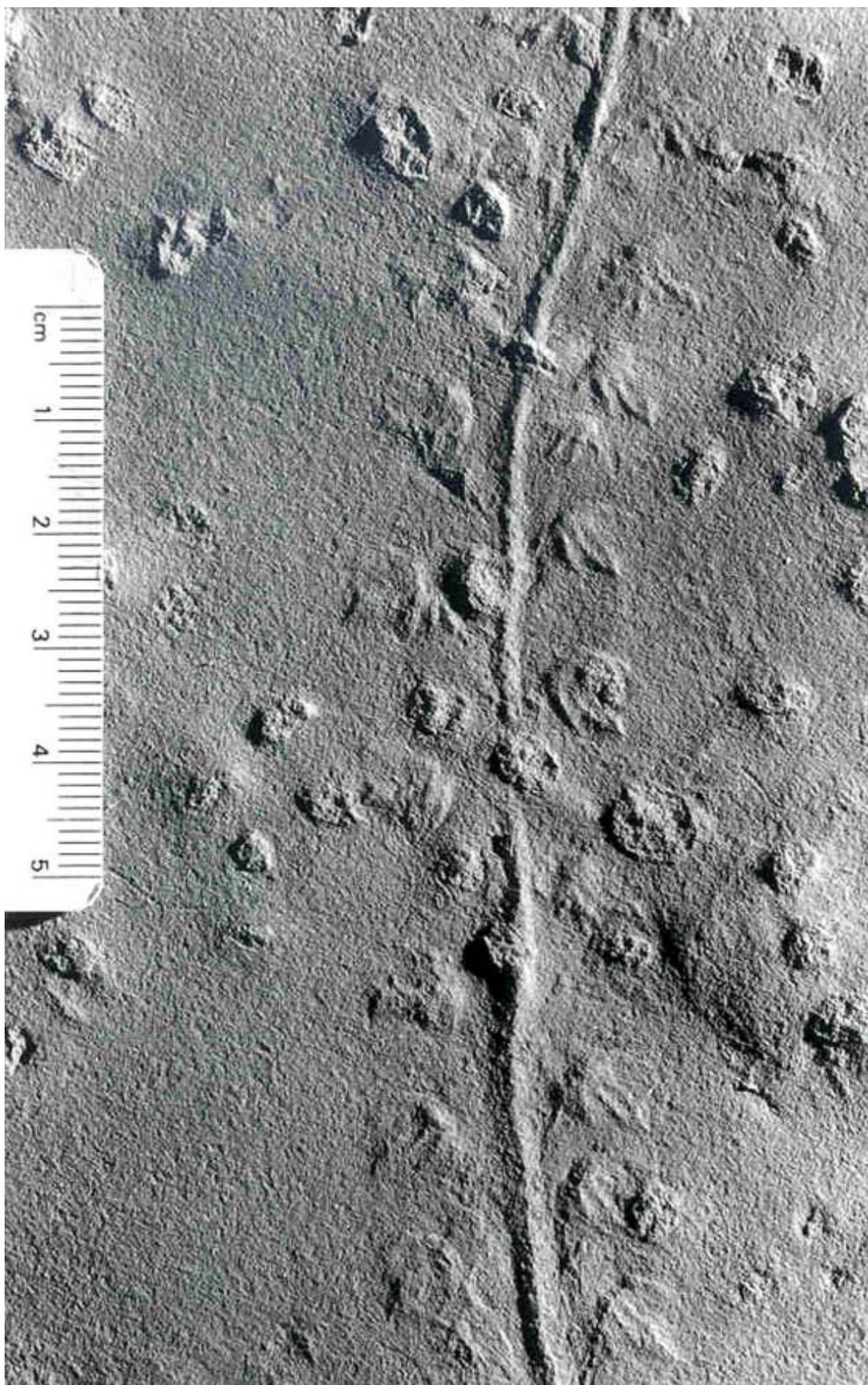


FIGURE 3C. UCM (H002) BR.

The ichnogenus was introduced by Marsh (1894) with *Nanopus caudatus* as type, for a relatively long trackway found in the Upper Pennsylvanian Wabaunsee Group of Kansas. Under *Nanopus quadratus* and *N. obtusus*, Matthew (1905: 98) named similar salamander-like tracks and trackways from the Westphalian A of Joggins. Haubold (1970, 1971) synonymized the *Nanopus* specimens from Joggins erroneously with *Anthrichnium*. At this time several data points were not available, such as the knowledge of *Batrachichnus*, type species *B. plainvillensis*. After the investigation of specimens from Lower Permian Red Beds the validity of *Batrachichnus* was recommended (Haubold, 1996), and after inspection by HH of the cast of the holotype from the Missourian of Massachusetts in the collection of Don Baird, the validity of *Batrachichnus* is confirmed. In common with *Batrachichnus*, *Nanopus* from Joggins has a pentadactyl manus, but the proportions of the digits and imprints are different from those of *Batrachichnus plainvillensis* and *B. delicatulus/salamandroides*. The number of digits in the species of the genus described by Marsh (1894) is obviously incomplete in most impressions. However, some imprints of the type specimen (Yale Peabody Museum 539) show a tetradactyl manus. Together with the information from the specimens of *N. quadratus* and *N. obtusus* from Joggins (RM 2.1134, 2.1134a, 2.1135, and 12.59 studied in casts) and the evidence from UCM, the ichnogenus *Nanopus* can be reestablished with a separate, new ichnospecies.

***Nanopus reidiai* n. isp.**

Figs. 2(6), 4A-F

**Holotype.** UCM 1141/1142 TPA.

**Paratypes** (referred material). UCM 311 AA, UCM 159 BR, UCM 196 BR, UCM 629-TPA, UCM 364 AA, UCM 60 GB, UCM 649 TPA. All specimens listed as paratypes allow in regard to their preservation at the original surface a sufficient identification of the manus and pes proportions, in particular of the digit length and arrangement, which is the main character in which it differs from *Matthewichnus caudifer*.

**Etymology.** The species is named in honor of Mrs. Dolores Reid, the owner of UCM when the initial specimens were recovered. Her generosity is arguably the single most important factor in the salvage of this large collection of tracks from the elements and from eventual destruction during reclamation.

**Locality and Horizon.** Union Chapel Mine, Walker County, Alabama, *Cincosaurus* beds above the Mary Lee coal bed, lower part of the upper Pottsville Formation.

**Diagnosis.** Footprints of tetrapods with tetradactyl manus and pentadactyl pes imprints. The length of pes digits I to V are nearly equal, pes digit III parallels the midline (direction of trackway), and digits I to V are outspread at an angle of 90°. The manus imprints are smaller, only 60% of the size of the pes imprints. Along a trackway manus and pes imprints appear close together in sets with a changing pattern. The manus is usually positioned behind the pes, but sometimes it is partially overstepped by the pes or may occasionally

appear in front of the pes. Where the trackway curves, the manus imprints may face outward from the middle line (axis) of the trackway. This points to a somewhat elongated trunk of the trackmaker; the coupling value (ratio of the length of trunk to the length of front + hind limb) might be more than 1:1.5. Observed pes lengths are about 10 mm or greater. In trackways associated with tail impressions the manus and pes imprints become increasingly plantigrade. The closely related *N. caudatus* and *N. quadratus* show an imprint pattern of shorter and broader digits.

**Description and discussion.** Within the spectrum of related ichnotaxa of small presumed temnospondyls, the most significant characters for *Nanopus* are those mentioned in the diagnosis: digit proportions and the orientation of the pes within the trackway. This is important for the differentiation to other small ichnogenera including the type *Matthewichnus* from the Westphalian A, and from *Batrachichnus* from younger beds of the Permian Carboniferous. A more objective characteristic in differentiation of *Nanopus* and *Matthewichnus* is possible by comparing the photographs (Figs. 3 and 4) with some helpful assistance from the added line drawings (Fig. 2).

The vast majority of the small tracks found at UCM may belong as well to *Nanopus*, but because of the preservation as undertracks the determination cannot be established definitely for all specimens. Examples of such undertracks are: UCM 2 SM, 4 SM, 11 SM, 140 BR, 167 BR, 177 BR, 191 BR, 195 BR, 281 AA, 302 AA, 312 AA, 313 AA, 318 AA, 357 AA, 447/8 TPA, 833/1031 AA, 973 BR. Long trackways, each with about 100 manus/pes sets, are 76/84 TPA, 249 JT, and 571 DA, providing evidence of the potential for change and variation during undertrack preservation. The list of specimens might be expanded considerably. Those mentioned are only a few representative specimens that have been studied and documented recently in detail.

In contrast to the specimens referred to as *holotype* and *paratypes*, undertrack specimens look more attractive and are rather easy to recognize during field work in the *Cincosaurus* beds at UCM. However, they are not significant for ichnotaxonomy, for shedding light on the behavior of the trackmaker, or for understanding the environment in which they were laid down. They are highly variable extramorphologically disguised impressions, a result of the action of sedimentological mechanics during the preservation of these tracks in the *Cincosaurus* beds at UCM and in many other Permian Carboniferous formations. This phenomenon of preservation is the reason for the apparent uniformity of small and large tracks in the Pottsville Formation. Indeed, the undertracks of the small *Nanopus*, the medium-sized *Cincosaurus* and the large *Attenosaurus* look alike. However, with the knowledge of sedimentology, track preservation and extramorphology, such similarity is nothing more than an illusion (see earlier under ichnotaxonomy). Moreover, such undertracks are named very differently and interpreted in every possible way from most Permian Carboniferous footprint formations in North America and Europe.

This context is the background in using names of



FIGURE 4A. UCM 1141 TPA.

FIGURE 4. *Nanopus reidia* n.isp. (photographs, scale cm and mm). A: UCM 1141 TPA, holotype specimen. B: UCM 311 AA. C: UCM 060 GB. D: UCM (H003) BR, trackway preserved at original surface and in the following part at a 1 mm deeper undertrack surface. E: UCM 973 BR the undertracks of manus and pes are reduced to a record of three digits. F: UCM 357 AA, one example of the attractive *Nanopus* trackways, the “little gems” of the Union Chapel Mine *Cincosaurus* beds. These undertracks display manus and pes partially complete.

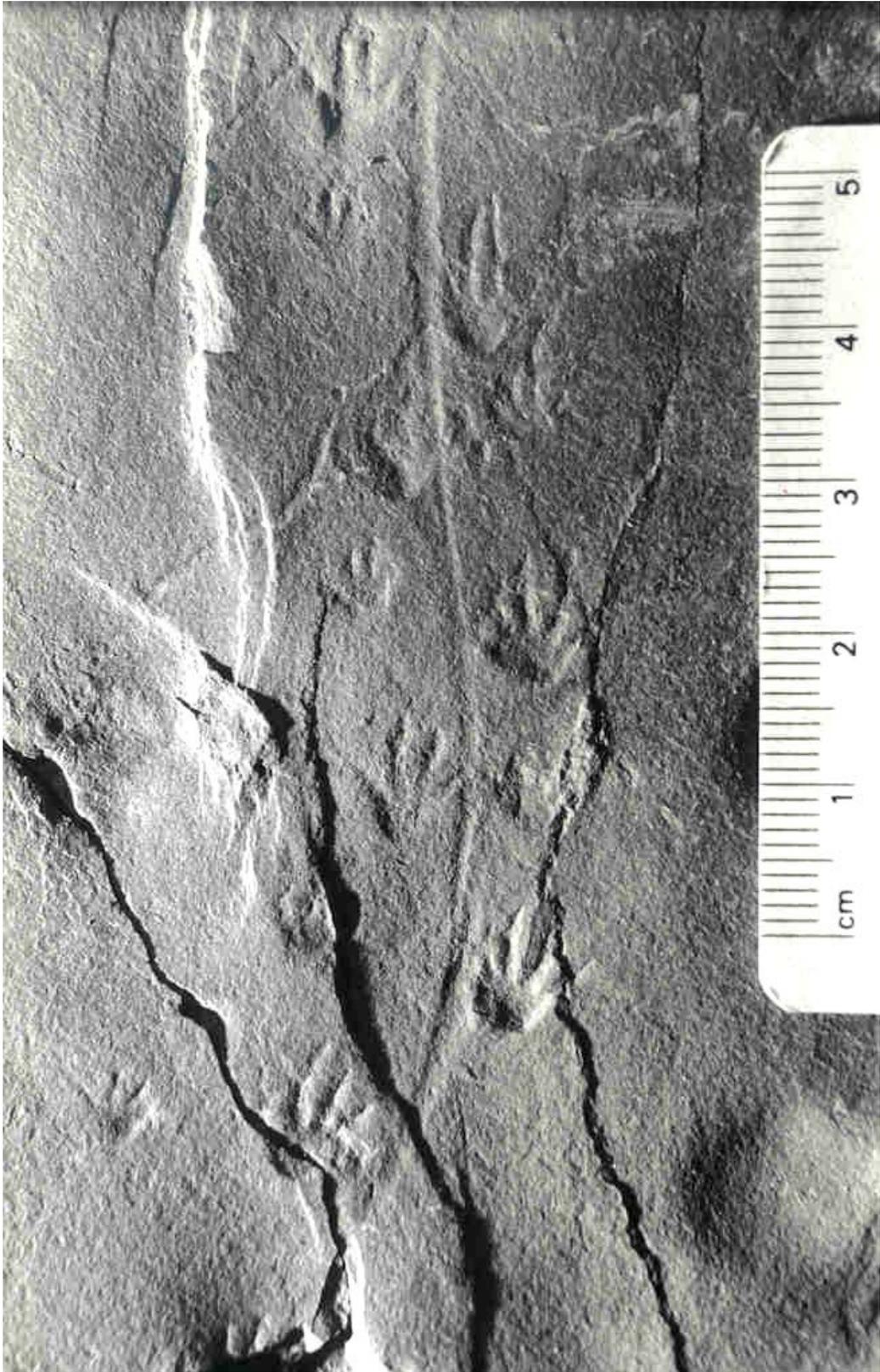


FIGURE 4B. UCM 311 AA.



FIGURE 4C. UCM 60 GB.



FIGURE 4D. UCM (H003) BR.



FIGURE 4E. UCM 973 BR.



FIGURE 4F. UCM 357 AA.



FIGURE 5. UCM 26 SM, cf *Matthewichnus caudifer*, the trackway started from a possible resting or aestivation trace, or some kind of hatching event.

Aldrich (1930) by Schult (1995) for the determination of several footprints from the Robledo Mountain Formation in New Mexico. The partial, apparently bipedal trackways called *Salichnium* — the name points to the hitherto enigmatic phenomenon of apparent leaping traces — first named by Müller (1962; cf. Haubold, 1970, p. 86; 1971, p. 11) from the Westphalian D of Zwickau, Germany, are simply undertracks identical to many specimens from the *Cincosaurus* beds. The number of examples is endless, like the synonymy of *Batrachichnus* (Haubold, 1996). The taxonomic establishment and comparison of the ichnospecies unified under *Nanopus* — *N. caudatus*, *N. obtusus*, *N. quadrifidus*, and *N. reidiaie* — must be elaborated in detail later. Aside from UCM, there are some finds (TPA collection) from the Birmingham region that resemble the imprint pattern with short broad digits known from *N. caudatus* and *N. quadratus*. The description and differentiation of these ichnotaxa have to be investigated later; here we concentrate on the evidence characterizing *N. reidiaie*.

Specimens UCM 949 BR and UCM (H003) BR are significant in proving the change in the preservation between tracks at the original surface and undertracks at surfaces a few millimeters below. In UCM 949 BR the original surface displays an extended trace of the tail and body beside rather few manus and pes imprints. Following our observations, this appearance is, in most cases, characteristic for the record of *N. reidiaie* at or close to the primary surface. In contrast, some 3 mm to 5 mm below the surface of UCM 949 BR, undertracks display medially sharpened and elongated digit impressions of manus and pes that are related to the record from the original surface. Much more instructive is specimen UCM (H003) BR (Fig. 4D). A segment of the track-

way is preserved along the original surface with tail impression and other imprints, a few of which allow determination as *N. reidiaie*; the trackway continues into a segment of undertracks exposed on a layer only 1 mm deeper, visible because the layer above has delaminated. These undertracks show sharp, elongate and pointed digits; the tail impression is lacking.

The manus imprints in both *Matthewichnus* and *Nanopus* are tetradactyl and significantly smaller than those of the pes. *Nanopus* shows pes digits of rather similar length; this proportion might be comparable with the pattern known from the temnospondyl *Dendroperon* (Fig. 1) of Joggins. In *Matthewichnus* the length of the pes digits increases strongly from I to IV, IV is the longest, and digit V is as long as digit III. No comparable foot morphology is yet known from temnospondyls of Westphalian age. The trackway pattern of both ichnospecies points, along with a coupling value between 1 and 1.5, to an elongated trunk region. This may allow as well a correlation with microsaur. However, the foot morphology and the tetradactyl manus have the standard morphology of several other kinds of Permo-Carboniferous tracks that are interpreted as having been made by temnospondyls.

An extraordinary and enigmatic record is displayed in specimen UCM 26 SM (Figure 5). The first interpretation in the UCM database argued for an act of predation, because the trackway apparently ends here. Instead, this is where the trackway of a small tetrapod begins and moves away. There are two potential interpretations. It is 1) a resting or aestivating situation, or 2) indicative of some kind of hatching event. Concerning the first argument there are no traces in the surrounding sediment. The second argument corresponds with the trace situation; however, it is highly speculative, especially because

it points to the absence of an “amphibian larval stage” in the temnospondyl trackmaker, and the idea should be attributed to the senior author alone. Still, in this case a temnospondyl origin should not necessarily be excluded. The reproductive strategies of terrestrial temnospondyls must not necessarily be the same as those of amphibians in a strict sense. Moreover, in view of some current discussions concerning a modified amphibian status of microsaur (Carroll, 2001), the hatching trace associated with a trackway of cf. *Matthewichnus* could argue for an origin of this group of early tetrapods as well. At present there are only preliminary ideas regarding specimen UCM-026 SM. Any further discussion and interpretation must consider the surface in relation to the environment of the track-bearing layers at UCM.

## TRACKWAYS ATTRIBUTED TO ANTHRACOSAURS

### *Attenosaurus* Aldrich, 1930 *Attenosaurus subulensis* Aldrich, 1930 Figures 2 (7), 6A-B

*Attenosaurus subulensis* Aldrich, 1930, p. 13, pl. 2.

The largest form, already introduced as an ichnotaxon by Aldrich (1930), is *Attenosaurus subulensis*. It is known from Holly Grove Mine and Union Chapel Mine. Although the original specimen described by Aldrich is lost, the ichnotaxon can be well established by reference to the UCM samples. By dimension (up to 25 cm pes length), trackway pattern, and digit proportions (the pentadactyl manus and pes imprints IV is shorter than III), the manus and pes morphology of *Attenosaurus* is therefore different from that of *Cincosaurus*. However, it might be possible in view of the restricted undertrack record, and from a more generalized formal point of view, to understand *Attenosaurus* and *Cincosaurus* as size-controlled extremes of a single ichnotaxon. In particular, under the spectrum of *Cincosaurus*, e.g., with taxa named as separate by Aldrich that are synonymized below under *Cincosaurus*, we apparently have evidence of transitional forms from *C. jonesii* to *A. subulensis*. This is, again, one example of the intriguing information of undertracks. If the ichnotaxonomy concerns the optimal recorded specimens, figured by Aldrich (1930, pl. 2 and 6, 7), together with specimens from UCM, these are separate ichnotaxa, not only in dimension but also, particularly, in foot morphology. An extended record of the large forms might allow a further ichnotaxonomic differentiation of specimens assigned to *Attenosaurus*. As long as we are dependent on undertracks, further detailed discrimination of certain forms remains premature.

In this context and in the forefront of taxonomical problems of tetrapod footprints of the Pennsylvanian in principle, the generic splitting of *Attenosaurus* tracks into three ichnogenera as proposed by Hunt et al. (2004) needs to be briefly discussed. The interpretation as pelycosaur concerns only two or three specimens assigned to *Dimetropus*, and tentatively identified as *Dimetropus* isp. This rather formal argumentation surpasses the re-

ality in interpreting tetrapod footprints of Pennsylvanian age in particular. And although the limitations of undertracks and extramorphological elongations and shortenings of digits are noted by Hunt et al. (2004) repeatedly, such characters are used for the ichnogenic discrimination. Above all, the extended record of several hundred footprints of large animals within the the UCM specimens contradicts the generic separation presented by Hunt et al. The mentioned specimens UCM 24 (“*Alabamasauripus*”), UCM 21 (“*Dimetropus*”), and UCM 199/200, UCM 270 (“*Attenosaurus*”) are a fragmentary selection from an extended number of specimens that record all possible morphological-extramorphological transitions. Before any future ichnotaxonomical conclusions, the undertrack phenomena of the footprint-bearing formation in Alabama and other occurrences in North America should be analyzed. The understanding of larger tetrapod tracks of the Carboniferous is too incomplete yet, and there are enough ichnogenic names available that need to be revised before new names should be introduced.

The most plausible interpretation of *Attenosaurus* points to anthracosaurs as represented by *Gephyrostegus* (Fig. 1) from the later Westphalian deposits. However, the huge size of *Attenosaurus* appears in principle rather enigmatic within the hitherto known skeletal record of terrestrial tetrapods of the early Westphalian. An origin by pelycosaur, respectively early synapsids, is excluded by the large size of *Attenosaurus*, although it may appear only as a relative argument. At first sight, a transition in size and, therefore, in origin appears possible. However, the wide trackway pattern of *Attenosaurus* is different from the very narrow pattern of the pelycosaurian *Cincosaurus*. In all known specimens *Attenosaurus* is recorded as undertracks, and digits II, III, IV and sometimes V, belonging mainly to the pes, appear very elongate in the undertracks. Some prints pushed through several centimeters of sediment and the number of visible digits is reduced, a phenomenon already reported by Aldrich (1930, pl. 1) as *A. indistinctus*. In some cases only the imprints of the larger foot, presumed to represent the pes, are recorded. Due to its large size, the knowledge of the trackway pattern is limited. The blocks of roof shale slabs or surfaces of larger extent, such as the uncataloged slab in the Aldrich collection at the ALMNH from the Aldrich collection (Fig. 6 B) and UCM 645/1074 TPA, are the exception. The stride was measured from UCM 270 AA with 420 mm related to a pes length of 130 mm. Some additional significant selected specimens representing *Attenosaurus* from Union Chapel Mine are 9, 16, 24/25, 205, 219, 242, 1206 and 1216 (all SM) as well as 270, 282 AA, and 1470-72 (all RB). Several additional specimens are documented in Haubold et al. (2005).

Although in most aspects the restricted preservation of *Attenosaurus* does not allow a clear description, and it may have a status of a phantom taxon, this significant and comparable gigantic element of the Pottsville ichnofauna should be accepted at present as valid. The missing type material of *A. subulensis* is a formal problem in the nomenclature. But this not a substantial argument against a distinct tetrapod ichnotaxon.



FIGURE 6A. UCM 645 TPA.

FIGURE 6. *Attenosaurus subulensis* Aldrich, 1930 (photographs scale in cm). A: UCM 645 TPA trackway segment with two manus and pes imprints. B: ALMNH uncataloged from Holly Grove Mine; the trackway displays pes-undertracks only.



FIGURE 6B. ALMNH specimen.

## TRACKWAYS ATTRIBUTED TO AMNIOTES

The amniote interpretation of ichnotaxa *Cincosaurus* and *Notalacerta* is supported by the pentadactyl manus and by the trackway pattern, which shows a more advanced, less sprawling gait that reflects the progress in terrestrial abilities of early amniotes. *Notalacerta* can be optimally correlated in accordance with Chesnut et al. (1994) to protorothyridid anapsids such as *Hylonomus* (Fig. 1) known from the Westphalian A of Joggins. In contrast, *Cincosaurus* might be represented, in view of its digit proportions and remarkable high pace angulation pattern, by early synapsids resembling *Haptodus* (Fig. 1), although such skeletal evidence is known only from the late Westphalian onward.

### *Notalacerta* Butts, 1891

#### *Notalacerta missouriensis* Butts, 1891

Figs. 2 (1), 7A-D

*Notalacerta missouriensis* Butts, 1891: 18, Fig.  
*Notalacerta missouriensis*, Chesnut et al., 1994: 155,  
Fig. 3-6  
footprints from Kansas, Alabama, Lacefield 2000:  
Figs. on p. 68 and 69.

**Known distribution.** Top of Cement City Limestone, Chanute Formation, Missourian of Kansas City, Missouri (original locality); Rock Lake Member of Stanton Formation near Garnett, Kansas (Chesnut et al. 1994); Rockcastle Sandstone Member (Westphalian A) of the Le Formation, McCreary County, Kentucky (Chesnut et al., 1994); Mary Lee Coal Zone, Kansas, Holly Grove Mine and Union Chapel Mine, Walker County, Alabama.

This hitherto problematic ichnotaxon was reestablished by the description of a new find in the Westphalian A of Kentucky by Chesnut et al. (1994). Their paper contains several important comments that originated from the experience of Don Baird (1982). Besides the description of a new specimen, Chesnut et al. (1994) presented a composite sketched from topotypes and photographs of the lost types.

Exceptionally preserved additions to *N. missouriensis* are specimens collected by JL in 1993 near Kansas, west of Carbon Hill, Alabama. Along several trackways with tail mark are recorded imprints of the pentadactyl manus about 18 mm long, and pes about 22 mm long. The manus is directed inward, and the pes outward along trackways with a stride of 50 mm to 65 mm, and manus pace angulation of 90°. This relatively wide trackway pattern is significant and allows the tentative identification of specimens displaying trackways with undertracks of manus imprints not only from Kansas, Alabama, but also trackways with fragmentary imprints in the pattern of *N. missouriensis* from the Union Chapel Mine (UCM 223, 229 and 1209 SM) and two trackways on slabs of Aldrich's collection from the Holly Grove Mine (ALMNH P.985.1.15 and 17). The relatively wide trackway pattern, together with the digit

proportions of the manus, are important for the differentiation of *N. missouriensis* from *Cincosaurus cobbi*.

### *Cincosaurus* Aldrich, 1930

*Cincosaurus* Aldrich, 1930: 27

#### *Cincosaurus cobbi* Aldrich, 1930

Figs. 2 (2-4), 8A-H

*Cincosaurus cobbi* Aldrich, 1930: 27, pl. 6, 7  
cf. *C. fisheri* Aldrich, 1930: 27, pl. 8  
cf. *C. jaggerensis* Aldrich, 1930: 28, pl. 9 (ALMNH P 985.1.8)  
cf. *C. jonesii* Aldrich, 1930: 28, pl. 10 (ALMNH P 985.1.9), pl. 11  
cf. *Quadropedia prima* Aldrich, 1930: pl. 15 (ALMNH P 985.1.7)  
cf. *Limnosaurus alabamensis* Aldrich, 1930: 49, pl. 14 (ALMNH P 985.1.5)  
cf. *Hydromeda fimbriata* Aldrich, 1930: 45, pl. 13 (ALMNH P 985.1.1)  
cf. *Trisaurus secundus* Aldrich, 1930: pl. 17 (ALMNH P 985.1.14)

**Known distribution.** Mary Lee coal zone, lower part of the upper Pottsville Formation, Holly Grove Mine, Union Chapel Mine, and Kansas, all in Walker County, Alabama. There is no correct determined record known from outside Alabama.

**Diagnosis.** Tetrapod trackways with pentadactyl imprints of manus and pes, both in reptilian-like arrangement, the length of digits increases from I to IV, and V is shorter and positioned backward and outward. The known size range measured for the manus is 15 mm to 35 or even 40 mm in length. The pes is slightly larger than the manus. The majority of average trackways show the manus directed inward, and the pes parallels the midline, each related to the orientation of digit III. The trackway pattern is narrow with a pace angulation of succeeding manus imprints usually higher than 100° and up to 120°.

**Discussion.** The proof of the tentative synonymy above is given by the record from UCM specimens 17 SM, 18 SM, 87 TPA, 174/175 BR, 208 SM, 237 SM, 250 to 263 JT, 1075 TPA, and 1476 RB. Together, they may show transitions comparable to the types separated by Aldrich. After more detailed inspection of these tracks, the concept of transitional preservation may come under question, but the observed differences might, in part, have derived from the somewhat different substrate consistency of the Holly Grove samples in comparison to the thin laminated mudstones of the UCM layers. The best agreement with *C. cobbi* is given for the type specimen of *Quadropedia prima*: along the trackway segment, inward-directed manus imprints are visible, and from the pes are recorded short and shallow marks of only two digits. This corresponds with undertrack modifications; in most trackways of *C. cobbi* only the inward-directed pentadactyl manus imprints are completely recorded. This is identical to a specimen from Kansas, Alabama, collected by JL that displays a pace angula-

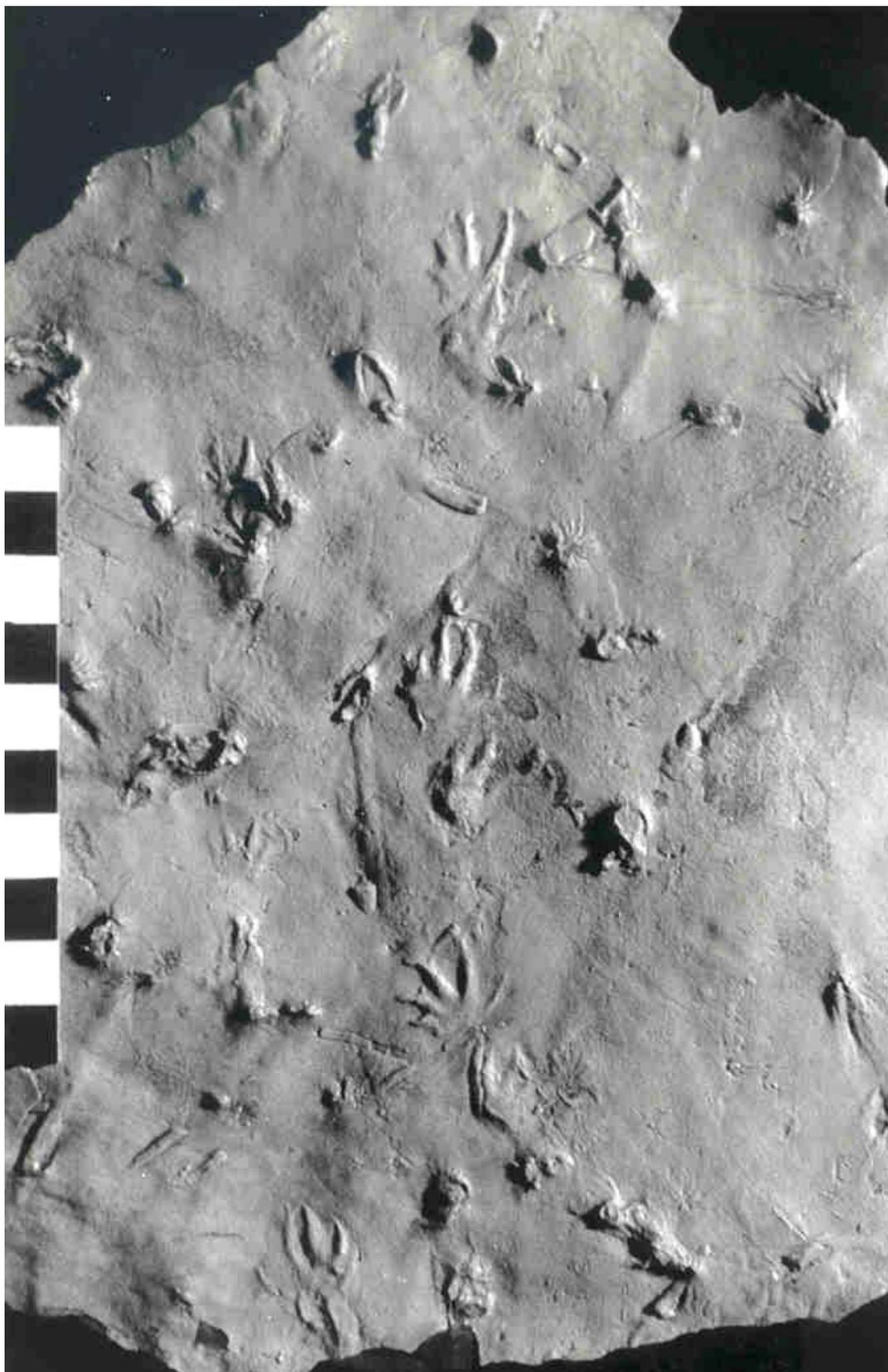


FIGURE 7A. Unnumbered specimen from Kansas, Alabama.

FIGURE 7. *Notalacerta missouriensis* Butts, 1891 (photographs, scale in cm). A: Trackway with 6 manus-pes sets, unnumbered specimen from Kansas, coll. JL. B: two subparallel trackways, unnumbered specimen from Kansas, coll. JL. C: ALMNH P.985.1.15 from Holly Grove Mine. D: UCM 229 SM, specimen with undertracks displaying the trackway pattern of *N. missouriensis*.

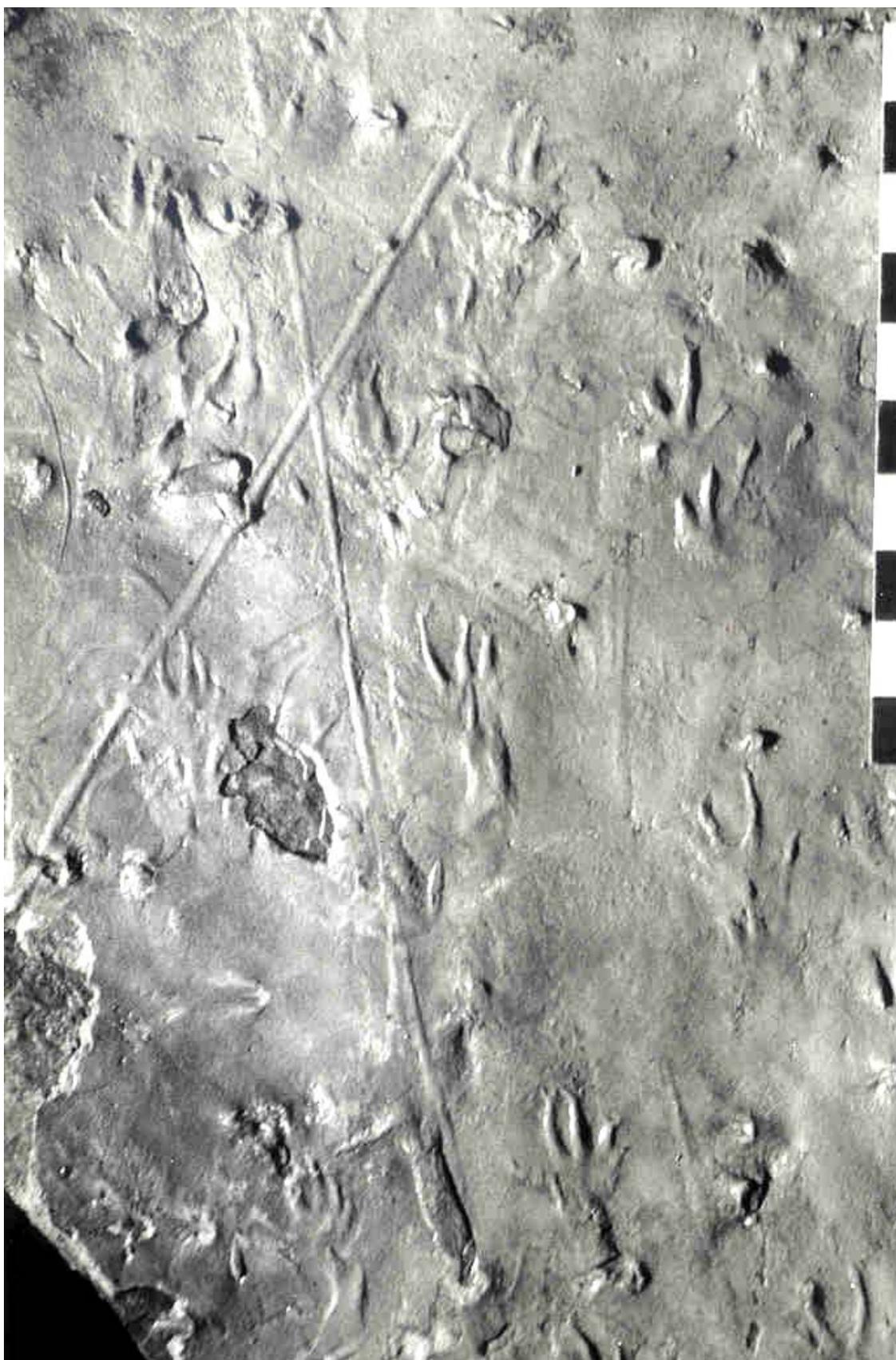


FIGURE 7B. Unnumbered specimen from Kansas, Alabama.



FIGURE 7C. ALMNH P.985.1.15.



FIGURE 7D. UCM 229 SM.

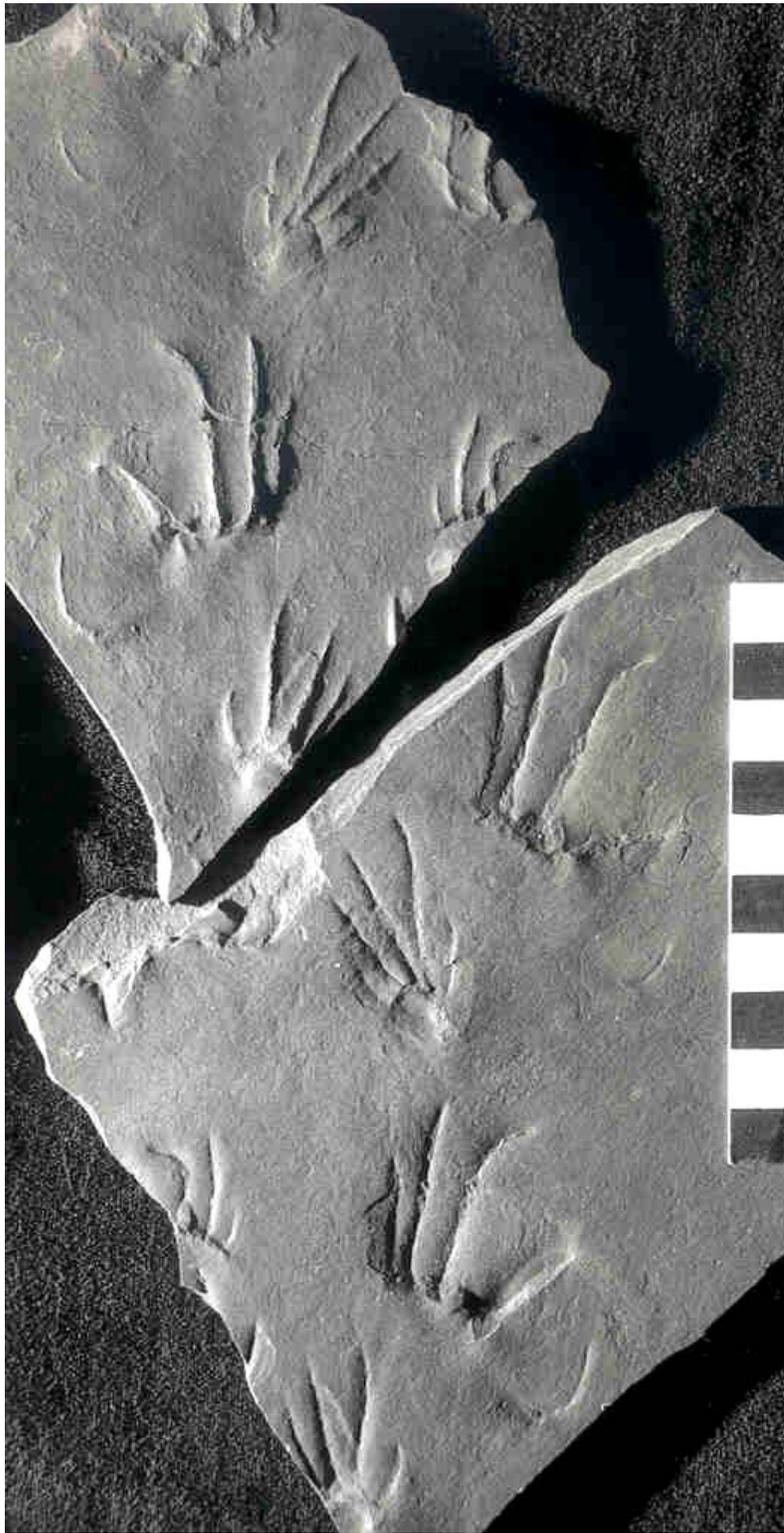


FIGURE 8A. UCM 174/175 BR.

FIGURE 8. *Cincosaurus cobbi* Aldrich, 1930 (photographs, scale cm). A: UCM 174/175 BR, manus and pes are recorded with five digits each, and narrow digit ankles. B: UCM 263 JT, the common undertrack preservation with incomplete pes and pentadactyl inward directed manus imprints. C: UCM 1075 TPA, subparallel trackways, with elongated digit imprints. D: ALMNH P.985.1.16 Holly Grove Mine. E + F: UCM 1476/1477 RB undertrack surface with sharp manus imprints and original surface of the same trackway with confused marks and significant lateral impressions of the fifth digits. G: UCM 17 SM, undertracks of manus imprints close together due to slow gait. H: ALMNH P.985.1.7 holotype of "*Quadropedia prima*"; the trackway segment shows complete manus imprints besides few marks of two pes digits.



FIGURE 8B. UCM 263 JT.



FIGURE 8C. UCM 1075 TPA.



FIGURE 8D. ALMNH P.985.1.16.



FIGURE 8E. UCM 1476 RB.

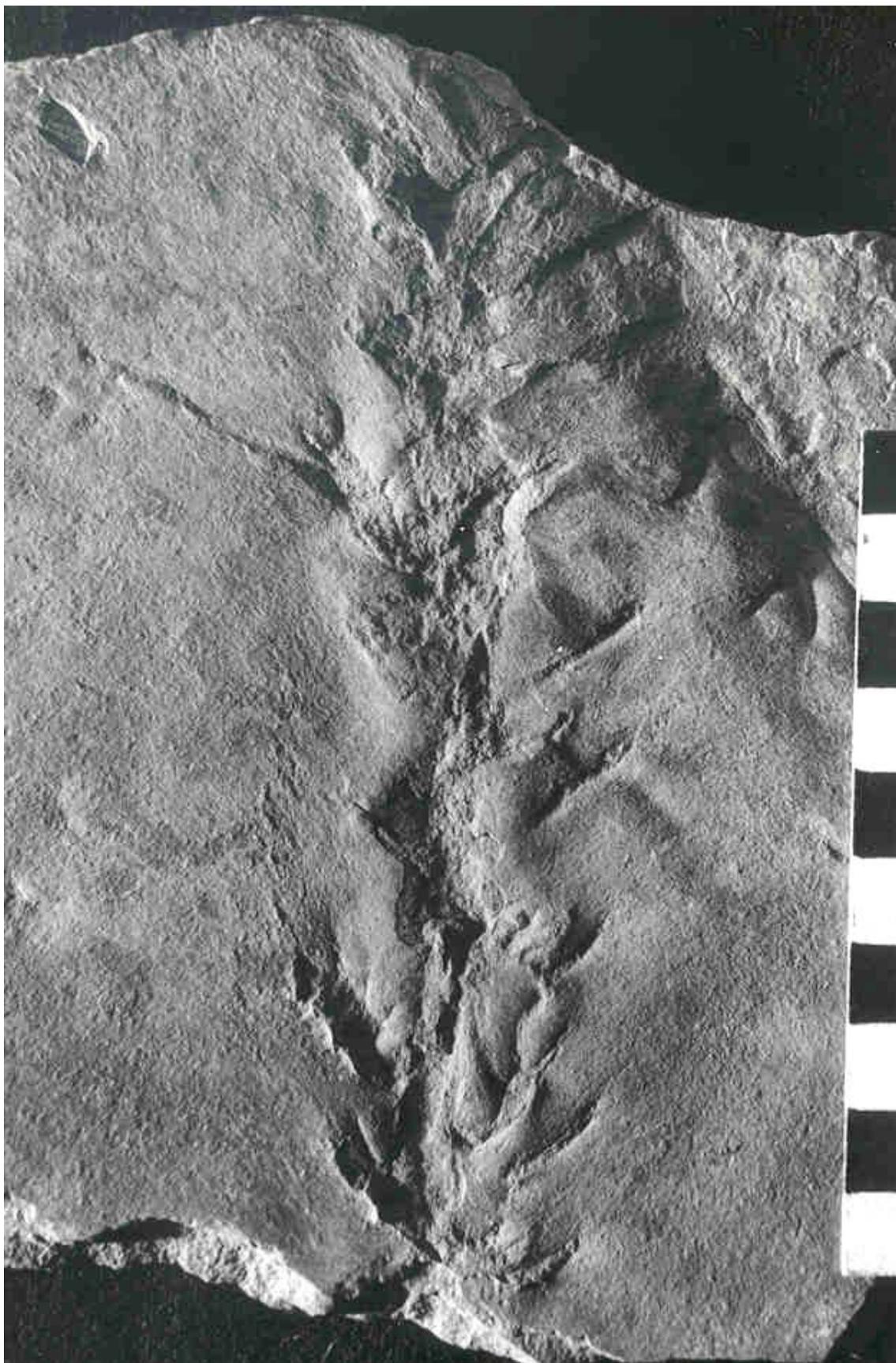


FIGURE 8F. UCM 1476 RB.

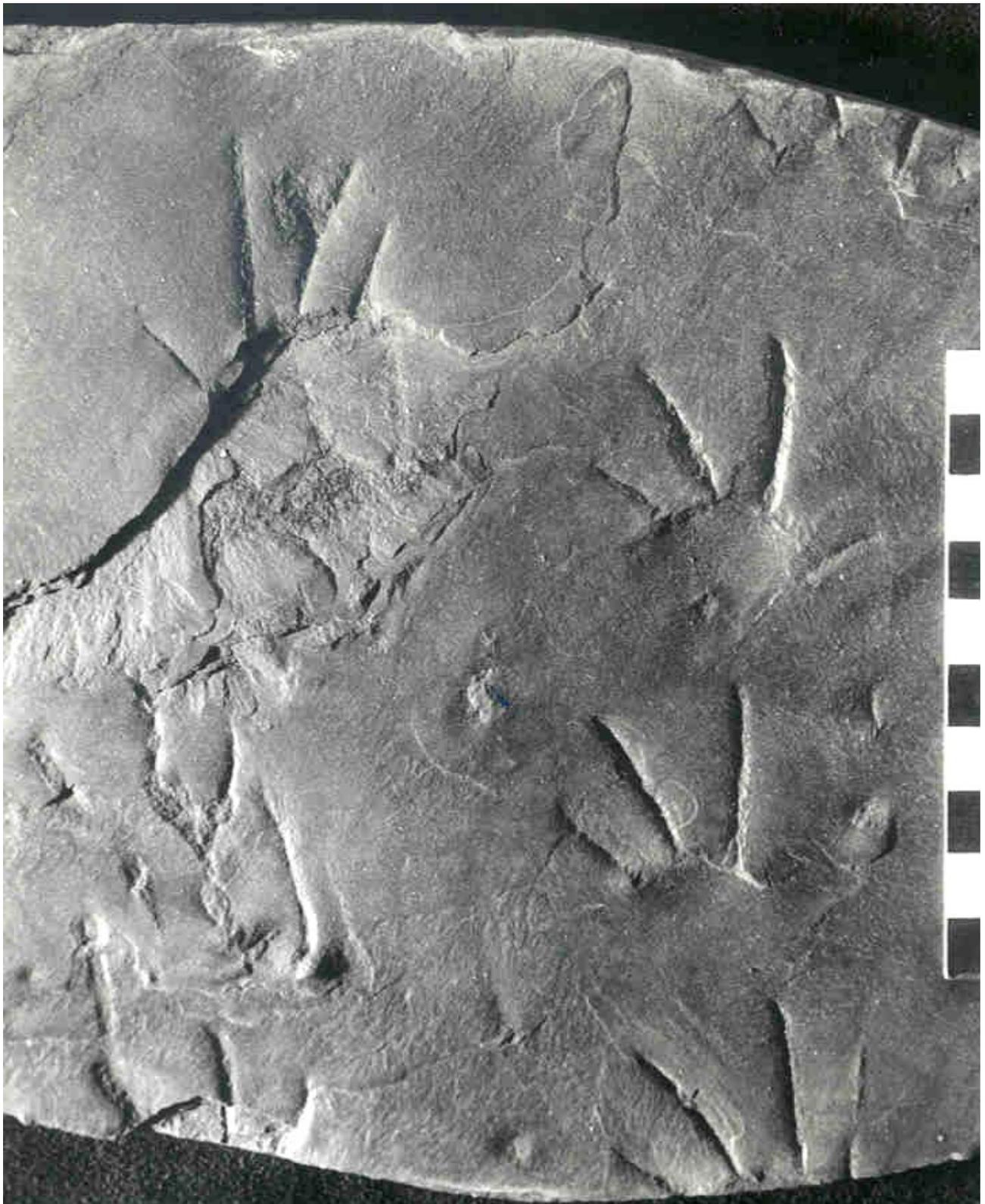


FIGURE 8G. UCM 17 SM.



FIGURE 8H. ALMNH P.985.1.7.

tion of about 110° of manus undertracks — the narrow trackway pattern of *C. cobbi*. In other examples there is a very slow gait with pace angulation of less than 50°, as present on specimen UCM 17 SM, but the visible manus imprints belong unquestionably to *C. cobbi*. Pes imprints can be incomplete or missing along the trackways. A representative record is given with the excellent original specimen, the nondesignated type specimen, of Aldrich. Although this specimen is lost, the figures (Aldrich 1930, pl. 6 and 7) show many significant features of this ichnotaxon. Specimen UCM 174/175 BR shows a comparable degree of completeness to Aldrich's original, but it has a comparably narrow degree of digit divarication. This might be due to a gait controlled pattern of the digits' ankles which is not of ichnotaxonomic value.

The majority of *C. cobbi* specimens from UCM show the manus complete and pentadactyl, whereas impressions of the pes are in general incomplete due to undertrack preservation, recording only two or three digit imprints. Because of both gait as well as undertrack preservation, track digits range from short (UCM 253/256 JT and UCM 1068 TPA) to very elongate (UCM 1075 TPA). Digits IV in manus and pes appear variable in length. Therefore digit IV might appear shorter or longer in several imprints along the trackways than digit III. A remarkable example of *C. cobbi* at the original layer is preserved in UCM 1477 RB. A rather confused trackway can be shown at the surface of the next layer, 4.5 mm deeper, which possesses the characteristic undertrack morphology. This evidence represents the key for the identification of some other enigmatic trackways, e.g., specimens UCM 331 AA, UCM 67 RB, that can now be recognized as *C. cobbi*. These hitherto rare cases of *C. cobbi* tracks from the original layer appear confused in a characteristic way, whereas a much larger proportion of the tracks are visible in undertracks only. However, one significant character that is indicative of both original and undertrack level might be the outward impression of pes digit tip V. In consequence the knowledge of *C. cobbi* remains incomplete, and imprints close to the anatomical manus and pes structure have yet to be confirmed, preferably by additional finds.

*Cincosaurus cobbi* is presented here as a definite and significant ichnotaxon. We underscore the possibility of misunderstanding when *Cincosaurus* is used in a wide sense, containing all hitherto known footprints from the Mary Lee coal zone. In this case all fossil footprints discovered in Carboniferous formations could be called "*Cincosaurus*". This is without question an untenable position in light of our observations presented here. It should be pointed out that there are no known clearly preserved imprints of *C. cobbi*. Because of this deficiency, this significant type, the most famous one from the Pottsville Formation, is of questionable taxonomic status. The validity of *Cincosaurus cobbi* must be tested by comparative studies of similar tetrapod footprints from related Pennsylvanian formations. However, the only previous description of *C. cobbi* outside the Black Warrior Basin, by Schneck and Fritz (1985) in the Early Pennsylvanian of Georgia, does not show a sufficient morphological relation to the specimens of *C. cobbi*

known from Alabama. The same questionable status caused by the restriction of undertrack record might be noted for *Attenosaurus*.

## CONCLUSIONS

The five described tetrapod ichnotaxa might be seen as standard elements of the Mary Lee coal zone and in particular of the so-called *Cincosaurus* beds. However, the documented distribution is not uniform for the known sites. From the Union Chapel Mine, within the *Cincosaurus* beds above the Mary Lee coal we recognize the presence of *Nanopus reidiae*, *Matthewichnus caudifer*, *Attenosaurus subulensis*, *Cincosaurus cobbi*, and cf. *Notalacerta missouriensis*.

All the other sites in Walker County may belong stratigraphically to footprint horizons close to the lower Jagger coal. We can list: Kansas: *Notalacerta missouriensis* and *Cincosaurus cobbi*; Fern Springs Mine: *Matthewichnus caudifer*; the Aldrich collection (presumably from the Holly Grove Mine near Carbon Hill): *Cincosaurus cobbi*, *Attenosaurus subulensis* and cf. *Notalacerta missouriensis*.

Indicative of possible additional ichnotaxa or hitherto not understandable types of preservational variations are, for example, specimens UCM 78 TPA, UCM 125 JL, UCM 267 AA, UCM 340 AA, UCM 945 BR. Resolution of the status of these types will presumably not be possible alone by additional samples collected at UCM but by specimens to be collected in the future elsewhere in the Pottsville Formation.

It is apparent that the UCM specimens will play a definitive role in clarifying the ichnotaxonomy of Permo-Carboniferous tracks. One aspect of the extraordinary value of the discoveries from the Union Chapel Mine is the evidence of hundreds of specimens that help to illuminate the mechanics of the preservational variations of tetrapod footprints and trackways. Globally, there is no other occurrence in the Permo-Carboniferous where the intriguing variation of undertrack preservation can be better understood than from the Union Chapel Mine. The UCM specimens are one of the basic keys for the revision of Permo-Carboniferous tetrapod footprints. If this key is used correctly in future investigations, it will open the door for a more realistic understanding of the rather enigmatic fossil footprints of Carboniferous age and their interpretation in correlation with the tetrapod skeletal record. The Carboniferous is the crucial period in the early evolution of terrestrial tetrapods. Therefore, the footprints and trackways found in Carboniferous formations are an authentic proof of the standard in locomotion realized by tetrapods, and the early differentiation in pattern of tetrapod locomotion. *The pattern of fossil trackways gives principal insight into locomotion, which is not available from the skeletal record.*

Last but not least, it should be noted: The present attempt to interpret the tetrapod footprints from some strata of the Pottsville in Alabama is not a revision of the ichnofauna from the Westphalian of North America as a whole. This might be underscored by a few personal words: "When I (HH) began my first studies on footprints from Carboniferous formations in the 1960s,

I got some helpful and warning arguments from Don Baird. In a letter dated March 19, 1969, Don wrote, 'I knew I would regret the day you were born! And you, too, will regret the day you first set foot in the field of Carboniferous ichnology.' I always kept this sentence in mind since I became aware of the discoveries at the Union Chapel Mine in 2002. The extraordinarily large sample size of footprints discovered by the engaged and open-minded paleontological community in Alabama motivated me to leave the former conservative principles regarding the rather restricted scientific value of Carboniferous tetrapod ichnofossils. Beyond question, following this contribution there will be much more to do in the future, and whether we come to a sufficient understanding of Carboniferous ichnology remains open."

*For additional photographs of vertebrate traces (both tetrapod trackways and fish swimming traces) from the Union Chapel Mine, see Haubold et al. (2005).*

### ACKNOWLEDGMENTS

Special thanks are extended to all members of the Alabama Paleontological Society, and to A. Rindsberg and J. Pashin for stimulating discussions. The group of authors of this contribution came together during the visit of HH in February 2003 in Alabama. The observations presented in this paper were made during detailed investigations of the specimens and discussions during this visit. HH thanks D. Baird, now in Pittsburgh, for his skeptical advice decades ago and during a personal meeting in 1999 concerning Carboniferous tetrapod ichnology. HH is also grateful to R. L. Carroll, Montreal, for making casts available from Joggins, Nova Scotia, during the late 1960s, which aided greatly in comparisons of the ichnotaxa presented here. Helpful for the final version of this paper were some critical and constructive remarks of S. G. Lucas, D. Gillette, R. McCrea, A. Rindsberg, and D. Kopaska-Merkel.

### REFERENCES

- Aldrich, T. H., Sr., 1930, Description of tracks, in Aldrich, T. H., Sr. and Jones, W. B., 1930. Footprints from the Coal Measures of Alabama: Alabama Museum of Natural History, Museum Paper, no. 9, p. 13-64, 17 pl.
- Baird, D., 1952, Revision of the Pennsylvanian and Permian footprints *Limnopus*, *Allopus* and *Baropus*: Journal of Paleontology, v. 26, p. 832-840.
- Baird, D., 1982, Upper Pennsylvanian ichnology of Kansas City, Missouri: Ichnology Newsletter, v. 13, p. 11.
- Buta, R. J. and Minkin, S. C., 2005, The salvaging and documentation of trace fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 19-27.
- Butts, E., 1891, Recently discovered foot-prints of the Amphibian age in the Upper Coal Measure Group of Kansas City, Missouri: Kansas City Scientist, v. 5, p. 17-19, 44.
- Carroll, R. L., 1964a, Early evolution of the dissorophid amphibians: Bulletin of the Museum of Comparative Zoology, v. 131, p. 161-250.
- Carroll, R. L., 1964b, The earliest reptiles: Journal of the Linnean Society (Zoology), v. 45, p. 61-83.
- Carroll, R. L., 1967a, Labyrinthodonts from the Joggins Formation. Journal of Paleontology, v. 41, p. 111-142.
- Carroll, R. L., 1967b, A limnoscelid reptile from the Middle Pennsylvanian: Journal of Paleontology, v. 41, p. 1256-1261.
- Carroll, R. L., 1969a, Problems of the origin of reptiles: Biological Reviews, v. 44, p. 393-432.
- Carroll, R. L., 1969 b, The Middle Pennsylvanian captorhinomorph, and the interrelationships of primitive reptiles: Journal of Paleontology, v. 43, p. 151-170.
- Carroll, R. L., 1970, The ancestry of reptiles: Philosophical Transactions of the Royal Society of London, Biological Sciences, v. 257, p. 267-308.
- Carroll, R. L., 1982, Early evolution of reptiles: Annual Reviews of Ecological Systematics, v. 13, p. 87-103.
- Carroll, R. L., 1986, The skeletal anatomy and some aspects of the physiology of primitive reptiles; in Hotton, N. III et al., eds., The Ecology and Biology of Mammal-Like Reptiles: Washington, Smithsonian Institution Press, p. 25-45.
- Carroll, R. L., 2001, The origin and early radiation of terrestrial vertebrates: Journal of Paleontology, v. 75, p. 1202-1213.
- Carroll, R. L. and Baird, D., 1968, The Carboniferous amphibian *Tuditanus (Eosauravus)* and the distinction between microsaur and reptiles: American Museum Novitates, no. 2337, 50 p.
- Carroll, R. L. and Baird, D., 1970, Carboniferous stem-reptiles of the family Romeriidae: Bulletin of the Museum of Comparative Zoology, v. 143, p. 3212-364.
- Chesnut, D. R., Baird, D., Smith, J. H., and Lewis, R. Q., 1994, Reptile trackways from the Lee Formation (Lower Pennsylvanian) of south-central Kentucky: Journal of Paleontology, v. 68, p. 154-158.
- Cotton, W. D., Hunt, A. P., and Cotton, J. E., 1995, Paleozoic vertebrate tracksites in eastern North America; in Lucas, S. G. and Heckert, A. B., eds., Early Permian footprints and facies: New Mexico Museum of Natural History and Science, Bulletin, no. 6, p. 189-211.
- Currie, P. J., 1977, A new haptodontine sphenacodont (Reptilia: Pelycosauria) from the Upper Pennsylvanian of North America: Journal of Paleontology, v. 51, p. 927-942.
- Dawson, J. W., 1863, The air breathers of the Coal Period of Nova Scotia. I: Canadian Naturalist and Geologist, v. 8, p. 1-12.
- Dawson, J. W., 1868, The Carboniferous System. Land animals of the Coal Period: Acadian Geology, p. 353-358.
- Dawson, J. W., 1872, Note on footprints from the Carboniferous of Nova Scotia in the collection of the Geological Survey of Canada: Geological Magazine, v. 9, p. 251-253.
- Dawson, J. W., 1882, On the footprints of batrachians observed in the Carboniferous rocks of Nova Scotia: Philosophical Transactions of the Royal Society London, v. 173, p. 651-654.
- Dawson, J. W., 1895, Synopsis of the air-breathing animals of the Paleozoic in Canada, up to 1894: Transactions of the Royal Society of Canada, v. 12, p. 71-88.
- Haubold, H., 1970, Versuch der Revision der Amphibien-Fährten des Karbon und Perm: Freiburger Forschungs-Hefte, ser. C, v. 260, p. 83-117.
- Haubold, H., 1971, Ichnia Amphibiorum et Reptiliorum fossilium: Encyclopedia of Paleoherpetology, v. 18, p. 1-124.
- Haubold, H., 1996, Ichnotaxonomie und Klassifikation von Tetrapodenfährten aus dem Perm: Hallesches Jahrbuch Geowissenschaften, ser. B, v. 18, p. 23-88.
- Haubold, H., Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, Atlas of Union Chapel Mine vertebrate trackways and swimming traces; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama, Alabama Paleontological Society Monograph no. 1, p. 207-276.

- Haubold, H., Hunt, A. P., Lucas, S. G. and Lockley, M. G., 1995, Wolfcampian (Early Permian) vertebrate tracks from Arizona and New Mexico; in Lucas, S. G. and Heckert, A. B., eds., Early Permian footprints and facies: New Mexico Museum of Natural History and Science Bulletin, no. 6, p. 135-165.
- Haubold, H., Lacefield, J. and Minkin, S., 2003, A presumed egg and hatching trace of a temnospondyl from the Early Pennsylvanian *Cincosaurus* beds of the Union Chapel Mine, Walker County, Alabama; in Martin, A. J., ed., Workshop on Permo-Carboniferous Ichnology, University of Alabama, May 2-4, 2003, Abstracts, p. 7-8.
- Hay, O. P., 1902, Bibliography and catalogue of fossil vertebrates of North America: U.S. Geological Survey Bulletin 179, 868 p.
- Holmes, R., Carroll, R. L. and Reisz, R. R., 1998, The first articulated skeleton of *Dendroperpeton acadianaum* (Temnospondyli, Dendroperpetontidae) from the Lower Pennsylvanian locality Joggins, Nova Scotia, and a review of its relationships: Journal of Vertebrate Paleontology, v. 18, p. 64-79.
- Hunt, A. P., Lucas, S. G. and Lockley, M. G., 1995, Palaeozoic tracksites of the western United States; in Lucas, S. G. and Heckert, A. B., eds., Early Permian footprints and facies: New Mexico Museum of Natural History and Science Bulletin, no. 6, p. 213-217.
- Hunt, A. P., Lucas, S. G., and Lockley, M. G., 2004, Large pelycosaur footprints from the Lower Pennsylvanian of Alabama: Ichnos, v. 11 (1-2), p. 39-44.
- King, A. T., 1845, Description of fossil footmarks found in the Carboniferous series in Westmoreland Co., Pa.: American Journal of Science, ser. 4, v. 48, p. 343-352.
- King, A. T., 1846, Description of fossil footmarks, supposed to be referable to the classes Birds, Reptilia and Mammalia, found in the Carboniferous series, in Westmoreland Co., Pa: Proceedings of the Academy of Natural Science of Philadelphia, v. 2, p. 175-180.
- Kohl, M. S. and Bryan, J. R., 1994, A new Middle Pennsylvanian (Westphalian) amphibian trackway from the Cross Mountain Formation, east Tennessee Cumberlands: Journal of Paleontology, v. 68, p. 655-663.
- Lacefield, J., 2000, Lost worlds in Alabama rocks: a guide to the state's ancient life and landscapes. Tuscaloosa, Alabama, Alabama Geological Society, iv + 124 pp.
- Lea, I., 1849, On reptilian footmarks found in the gorge of Sharp Mountain near Pottsville, Pa.: Proceedings of the American Philosophical Society, v. 5, p. 91-94.
- Marsh, O. C., 1894, Footprints of vertebrates in the Coal Measures of Kansas: American Journal of Science, ser. 4, v. 48, p. 81-84.
- Martin, A. J. and Pyenson, N. D., 2005, Behavioral significance of vertebrate trace fossils from the Union Chapel site; in Buta, R.J., Rindsberg, A.K. and Kopaska-Merkel, D.C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 59-73.
- Matthew, G. F., 1903a, On batrachian and other footprints from the Coal Measures of Joggins, N.S.: Bulletin of the Natural History Society of New Brunswick, 5, p. 103-108.
- Matthew, G. F., 1903b, An attempt to classify Paleozoic batrachian footprints: Transactions of the Royal Society of Canada, ser. 2, v. 9, sect. 4, p. 109-121.
- Matthew, G. F., 1903c, New genera of batrachian footprints of the Carboniferous system in eastern Canada: Canadian Record of Science, v. 9, p. 99-111.
- Matthew, G. F., 1905, New species and new genus of batrachian footprints of the Carboniferous System in Eastern Canada: Transactions of the Royal Society of Canada, ser. 2, v. 10, sect. 4, p. 77-122.
- Müller, A. H., 1962, Zur Ichnologie, Taxiologie und Ökologie fossiler Tiere, I. Freiburger Forschungs-Hefte, ser. C, v. 151, p. 5-30.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R.J., Rindsberg, A.K. and Kopaska-Merkel, D.C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 39-58.
- Peabody, F. E., 1948, Reptile and amphibian trackways from the Moenkopi Formation of Arizona and Utah: University of California Publications, Bulletin of the Department of Geological Sciences, v. 27, p. 295-468.
- Pyenson, N. D. and Martin, A. J., 2001, Uses of amphibian trackways from the Union Chapel Mine (Lower Pennsylvanian: Westphalian A) of Alabama for estimating amphibian population compositions: Journal of Vertebrate Paleontology, v. 21 (3), p. 91A.
- Pyenson, N. D. and Martin, A. J., 2002, Quantified approach for predicting tracemaker size: applications in tetrapod ichnology using Carboniferous temnospondyl trackways from Union Chapel Mine site, Alabama: Journal of Vertebrate Paleontology, v. 22 (3), p. 97A-98A.
- Reisz, R., 1975, Pennsylvanian pelycosaur from Linton, Ohio, and Nyirany, Czechoslovakia: Journal of Paleontology, v. 49, p. 522-527.
- Reisz, R., 1981, A diapsid reptile from the Pennsylvanian of Kansas: Special Publications of the Museum of Natural History, no. 7, 74 p.
- Schneck, W. M. and Fritz, W. J., 1985, An amphibian trackway (*Cincosaurus cobbii*) from Lower Pennsylvanian ("Pottsville") of Lockout Mountain, Georgia: Journal of Paleontology, v. 59, p. 1243-1250.
- Schult, M. F., 1995, Vertebrate trackways from the Robledo Mountains Member of the Hueco Formation, south-central New Mexico; in Lucas, S. G. and Heckert, A. B., eds., Early Permian footprints and facies: New Mexico Museum of Natural History and Science Bulletin, no. 6, p. 115-126.
- Woodworth, J. B., 1900, Vertebrate footprints from Carboniferous shales of Plainville, Massachusetts: Bulletin of the Geological Society of America, v. 11, p. 449-454.

#### AUTHORS' E-MAIL ADDRESSES

Hartmut Haubold: haubold@geologie.uni-halle.de  
 T. Prescott Atkinson: patkinson@peds.uab.edu  
 Ronald J. Buta: rbuta@bama.ua.edu  
 James A. Lacefield: lacefiel@hiwaay.net



Jerry MacDonald, discoverer of major Permian trackways in the Robledo Mountains of New Mexico and author of *Earth's First Steps: Tracking Life Before the Dinosaurs*, inspects Union Chapel Mine and other fossil trackways stored in vaults in Mary Harmon Bryant Hall, on the campus of the University of Alabama, during his visit in April, 2002. Ed Hooks, former Curator of Vertebrate Paleontology, Alabama Museum of Natural History, and Pearl MacDonald look on. Photo credit: Ron Buta.

## TETRAPOD ICHNOFACIES AND THEIR UTILITY IN THE PALEOZOIC

ADRIAN P. HUNT and SPENCER G. LUCAS

New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, New Mexico 87104-1375, USA

**ABSTRACT:** Two distinct traditions exist in the study of ancient ichnofaunas, which may be termed the ethological (invertebrate ichnology) and the biotaxonomic (tetrapod ichnology). Consequently, there are two different kinds of ichnofacies, each peculiar to one tradition, and we term them ethoichnofacies (invertebrate ichnofacies) and biotaxonichnofacies (tetrapod ichnofacies). In the Paleozoic, the *Chelichnus* and *Batrachichnus* (named herein) biotaxonichnofacies encompass all Carboniferous-Permian tetrapod ichnofaunas. Nevertheless, the concept of tetrapod ethoichnofacies in the Paleozoic merits further development. Recognition of two tetrapod biotaxonichnofacies in the Paleozoic has important bearing on biochronologic and facies analysis.

### INTRODUCTION

More than two centuries ago, tetrapod tracks were the first trace fossils recognized by scientists (Steinbock, 1989). However, for most of the next two centuries, the study of tetrapod trace fossils lagged behind that of invertebrate trace fossils in both volume and complexity. This situation changed in 1986 with the catalyzing "First International Symposium on Dinosaur Tracks and Traces," held in Albuquerque, New Mexico. Prior to this meeting, there had been little intellectual exchange between the tetrapod ichnologists scattered around the world. This meeting and the subsequent publication of its proceedings (Gillette and Lockley, 1989) sparked a renaissance of interest in tetrapod trace fossils.

Invertebrate ichnologists have long realized that recurrent assemblages of trace fossils can be discriminated. For example, Seilacher (1964a, 1964b, 1967) recognized recurring associations of trace fossils through much of the Phanerozoic, and these associations became the basis of the concept of ichnofacies. Invertebrate ichnologists now use the term ichnofacies in three different ways (Bromley, 1990, 1996): (1) large-scale "Seilacherian ichnofacies" that can be traced through the Phanerozoic; (2) medium-scale ichnofacies that have a widespread distribution in space and time and can be considered subsets of the "Seilacherian ichnofacies"; and (3) small-scale ichnofacies for individual units in a particular rock sequence. We concur with Bromley (1990, 1996) in his reservations about the third usage since it does not refer to any recurrence in space or time.

Lockley et al. (1994) first synthesized information on tetrapod ichnofacies. They recognized the concepts of an ichnocoenosis for a single assemblage of tracks preserved on a single horizon (Leonardi, 1987) and an ichnofacies for multiple ichnocoenoses that are similar in ichnotaxonomic composition and show recurrent association with particular (paleo)environments. This concept of the ichnofacies is equivalent to the medium scale ichnofacies of the invertebrate ichnologist. We employ this concept of tetrapod ichnofacies here.

The purpose of this paper is to discuss the importance and utility of tetrapod ichnofacies in the Paleo-

zoic tetrapod footprint record. However, this requires some discussion of the two different traditions of ichnology evident in invertebrate and tetrapod paleontology.

### THE DIFFERENT TRADITIONS OF INVERTEBRATE AND TETRAPOD ICHNOLOGY

Two distinct traditions can be identified in the study of ancient ichnofaunas, and we term them the ethological and the biotaxonomic. Invertebrate paleontologists mostly use an ethological approach to ichnology by describing and naming behavioral interactions between an organism and the substrate. In contrast, vertebrate paleontologists have principally applied a biotaxonomic approach by attempting to relate tracks and traces to the taxonomy of the producer. In other words, vertebrate ichnologists treat vertebrate ichnotaxa as proxies of biotaxa. Thus, vertebrate ichnofaunas are dominantly used to reconstruct evidence about the biotaxonomic composition of track assemblages ("faunas") that is useful for paleoecology, biostratigraphy and biogeography, whereas invertebrate ichnofaunas are utilized more for environmental reconstruction and paleogeographic analysis.

Ichnofacies can be described as associations of ichnotaxa recurrent in time and space. Obviously, there must be two different kinds of ichnofacies, one peculiar to each ichnological tradition. They may be termed ethoichnofacies for invertebrate ichnology and biotaxonichnofacies for tetrapod ichnology.

### TWO LATE PALEOZOIC BIOTAXONICHNOFACIES

Among Paleozoic tetrapod footprint assemblages (Fig. 1), recurrent associations of ichnotaxa allow the recognition of two medium-level biotaxonichnofacies (Fig. 2). Baird (1965) first emphasized that in the American West, the differences between the Permian ichnofaunas of the redbeds and those of eolianites might be the result of facies differences. Subsequently, Lockley

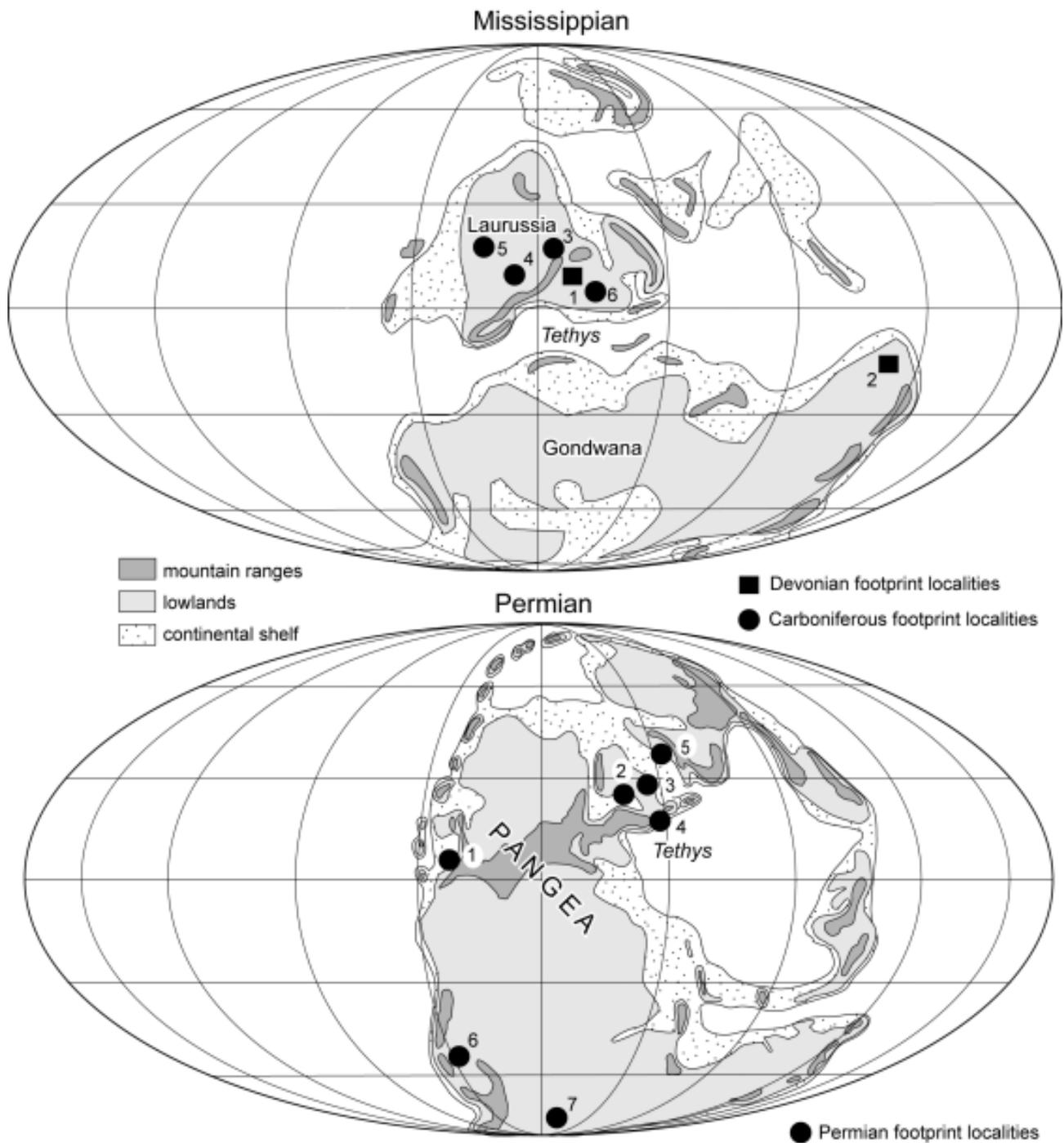


FIGURE 1. Global map of Paleozoic tetrapod ichnofaunas. Upper map shows distribution of principal Devonian-Carboniferous tetrapod tracksites. Devonian sites are: 1, Ireland and Scotland, 2, eastern Australia. Carboniferous sites are: 3, Nova Scotia, 4, eastern United States, 5, western United States, 6, western Europe. Lower map shows distribution of principal Permian tetrapod tracksites on Permian Pangea. Locations are: 1, western United States, 2, France, 3, Germany, 4, Italy, 5, Russia, 6, Argentina, 7, South Africa. Base maps after DiMichele and Hook (1992).

et al. (1994), in the context of an overview of the utility of the ichnofacies concept for tetrapod tracks, recognized a *Laoporus* ichnofacies for Permian eolian ichnofaunas of the United States. This ichnofacies was later amended to the *Chelichnus* ichnofacies because of synonymy (*Chelichnus* = *Laoporus*), and it is also

present in Europe and South America (e.g., Lockley et al., 1995; Morales and Haubold, 1995; McKeever and Haubold, 1996; Hunt and Santucci, 1998; Hunt and Lucas, 1998a; Lockley and Meyer, 2000; Melchor, 2001). Since 1995, various articles have addressed Paleozoic tetrapod ichnofacies (e.g., Hunt et al., 1995c;

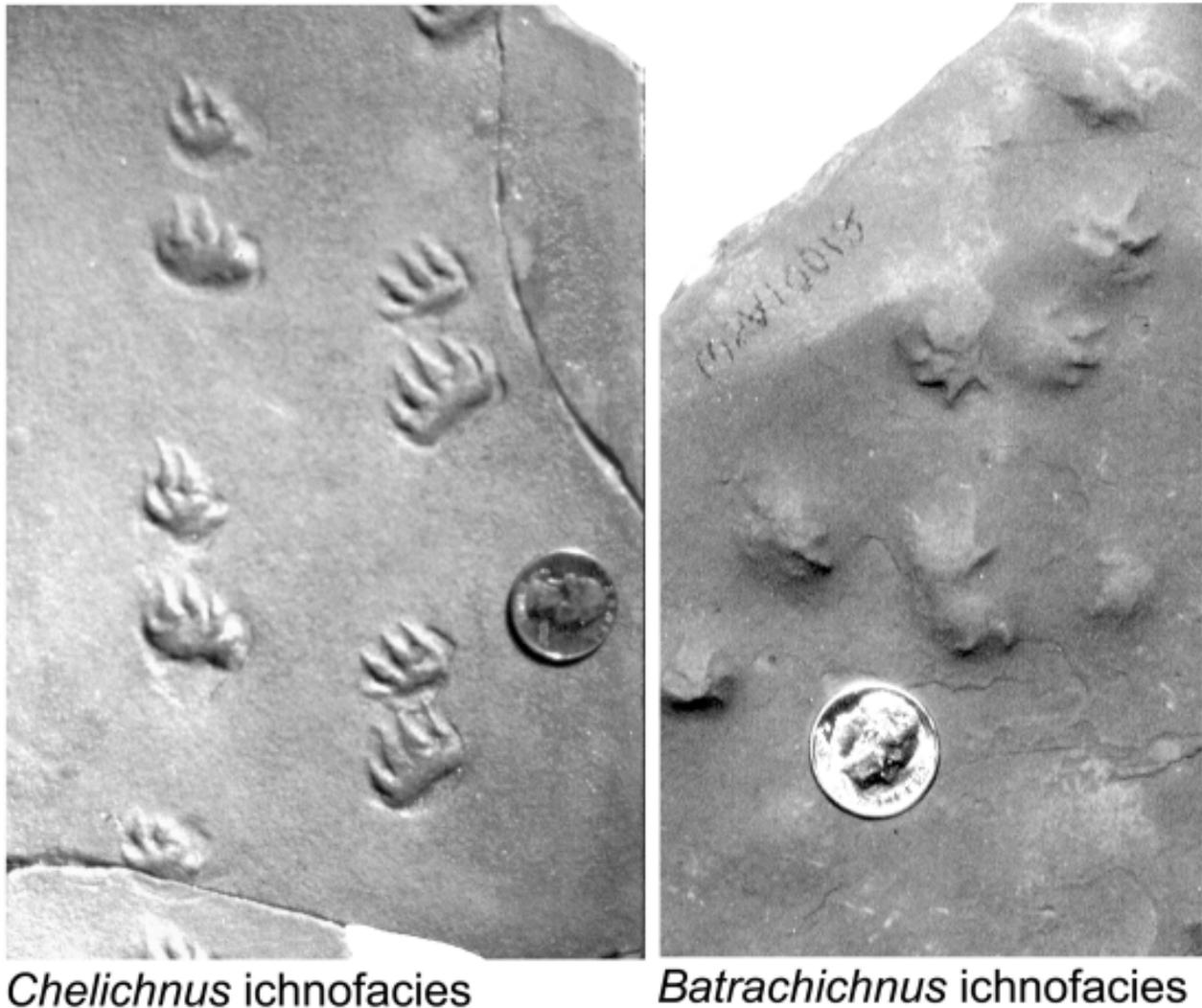


FIGURE 2. Representative tracks of the two Paleozoic tetrapod ichnofacies: left, the *Chelichnus* ichnofacies (eolian) represented by *Chelichnus duncani* (scale is coin with diameter of 24 mm); and right, the *Batrachichnus* ichnofacies (water-laid, including red beds) represented by *Batrachichnus delicatulus* (scale is coin with diameter of 18 mm).

Haubold, 1996; Hunt and Lucas, 1998a, b, 2003, 2004b; Lockley and Meyer, 2000; Lucas et al., 2004a,b; Melchor and Sarjeant, 2004).

Clearly, another widespread Paleozoic biotaxonichnofacies is present in water-laid non-marine strata, and it has generally been referred to as the red-bed ichnofacies (e.g., Hunt and Lucas, 1998a). Lockley and Meyer (2000) named this the *Anthichnium-Limnopus* assemblage, and we formalize this as the *Batrachichnus* ichnofacies for the cosmopolitan ichnogenus (trackmaker = small temnospondyls) that extends from the ?Early Mississippian to the Early Permian. The type ichnofaunas of this biotaxonichnofacies is from the Robledo Mountains Formation of the Hueco Group in southern New Mexico (Hunt et al., 1995a, b; Lucas et al., 1995, 2002, 2004b).

Among the ichnofaunas that can be assigned to this biotaxonichnofacies are: (1) in Europe, Permian tetra-

pod tracks from England, Pennsylvanian-Permian footprints from Germany (Haubold et al., 1995; the Rotliegendes *sensu lato*) and correlative strata in Germany, France and Italy, and in other countries such as Poland (e.g., Haubold, 1971); (2) tetrapod tracks of Mississippian-Permian age from the American Southwest (principally Arizona, Utah, Colorado, New Mexico and Texas), the southeastern and eastern United States (primarily West Virginia, Ohio and Alabama) and eastern Canada (Nova Scotia and Prince Edward Island) (e.g., Cotton et al., 1995; Hunt et al., 1995a); (3) in South America, redbed ichnofaunas from the Permian of Argentina (Melchor and Poiré 1992; Melchor, 1997; Melchor and Sarjeant, 2004); and (4) redbeds of the northern Caucasus, Russia (Lucas et al., 1999).

The *Batrachichnus* biotaxonichnofacies, thus, is widespread temporally and geographically (Hunt and Lucas, 1998a). The *Chelichnus* and *Batrachichnus*

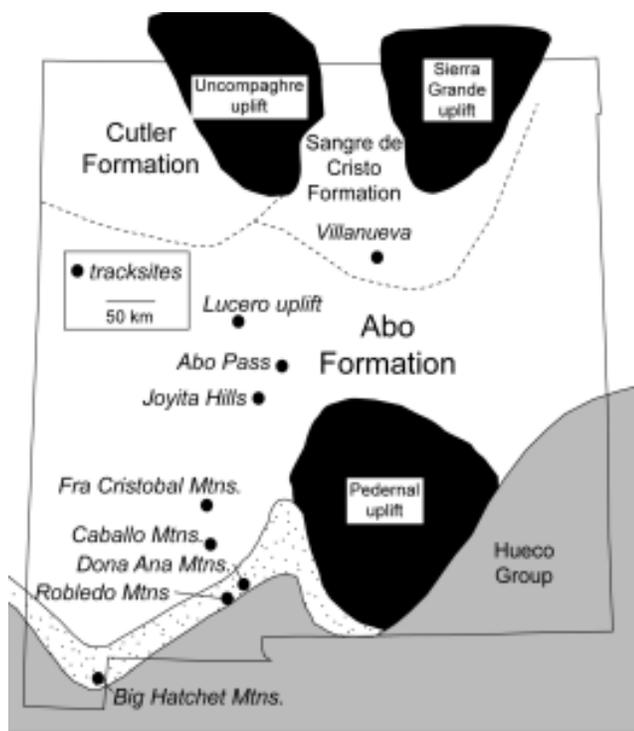


FIGURE 3. Paleogeographic map of New Mexico during the Early Permian.

ichnofacies encompass all Carboniferous-Permian tetrapod footprint ichnofaunas. Thus, tetrapods define only two non-marine ichnofacies in the late Paleozoic, in contrast to the more numerous invertebrate ichnofacies in coeval marine strata. Paleozoic tetrapods thus provide less precision than invertebrates in defining ichnofacies, but it is important to consider that tetrapods are vagrant organisms that are not substrate dependent, although they are environment dependent (Hunt et al., 1995c). Therefore, they should provide much less specificity in the identification of substrates. However, it is also important to realize that we are comparing unlike entities because invertebrate ichnofacies are ethoichnofacies and tetrapod ichnofacies are biotaxonichnofacies.

### ECOLOGICAL GRADIENTS AND SUBDIVISIONS

Permian strata of the American Southwest represent a variety of non-marine environments. In New Mexico, it is possible to reconstruct an ecological transect from tidal flat through distal alluvial fan (Figs. 3-4). The ichnofaunas from these ecosystems contain the common Late Pennsylvanian-Early Permian ichnotaxa *Batrachichnus*, *Limnopus*, *Amphisauropus*, *Dromopus*, *Dimetropus* and *Gilmoreichnus* and represent the *Batrachichnus* biotaxonichnofacies.

Hunt et al. (1995c) recognized three subdivisions of this biotaxonichnofacies, and further work has confirmed this trichotomy (Fig. 4): (1) inland/distal alluvial fan settings characterized by the presence of *Ichniotherium* and a paucity of *Dimetropus*; (2) allu-

vial plain settings characterized by the presence of *Amphisauropus*; and (3) coastal/tidal flat settings characterized by the relative abundance of *Batrachichnus* and *Dimetropus*. These subdivisions of the *Batrachichnus* biotaxonichnofacies provide a basis for discriminating environments in other areas in Upper Pennsylvanian-Lower Permian strata (e.g., Lucas et al., 2004a, b).

### TETRAPOD ETHOICHNOFACIES?

Vertebrate paleontologists have published little on ethoichnofacies. However, certain preserved tetrapod behaviors (interactions between organism and substrate) may have implications for ethoichnofacies recognition using tetrapod trace fossils.

For example, oblique up-dune progression with downslope sand crescents is well documented in the Permian ichnogenus *Chelichnus*. This response to progression over an unstable substrate on a steep slope may be recognizable throughout the Phanerozoic in eolian sediments. Indeed, there are clear similarities in eolian tetrapod ichnofaunas throughout the Phanerozoic that bear more study. For example, Lockley et al. (1994) noted the similarity in foot structure of tracks from eolian environments of the Permian and Jurassic that suggest the continuity of the *Chelichnus* (or a *Chelichnus*-like) ichnofacies into the Jurassic.

Another example of the potential for tetrapod ethoichnofacies is provided by tidal flat environments such as the Permian Robledo Mountains Formation in New Mexico, which preserve more tail drags in tetrapod trackways than do other environments; this presumably reflects the slipperiness of the muddy substrate. Hunt and Lucas (2004a) demonstrated a similar abundance of tail drag marks in dinosaur trackways in a Cretaceous coastal plain setting.

Clearly, there are features of tetrapod tracks from the Paleozoic (e.g., oblique progression and associated sand crescents, tail drag marks) that are, thus far, not utilized in ichnofacies analysis. This is largely because of the philosophy of vertebrate paleontologists, but these features may have utility throughout the Phanerozoic for the recognition of paleoenvironments and in paleogeographic analysis. There is thus a need for much more study of the concept of tetrapod ethoichnofacies, particularly in the Paleozoic.

### BIOCHRONOLOGICAL AND FACIES APPLICATIONS

The construction of biochronologies using trace fossils requires a clear understanding of ichnofacies. Several European workers have constructed complex biochronologies of the Permian based on tetrapod tracks (e.g., Haubold, 1971; Holub and Kozur, 1981; Boy and Fichter, 1988). These studies virtually ignored ichnofacies concerns. Thus, for example, the *Harpagnichnus* zone of Boy and Fichter (1988) is based on tracks from an eolian (Cornberg Sandstein) unit, whereas their other Permian footprint zones are based on tracks from redbeds.

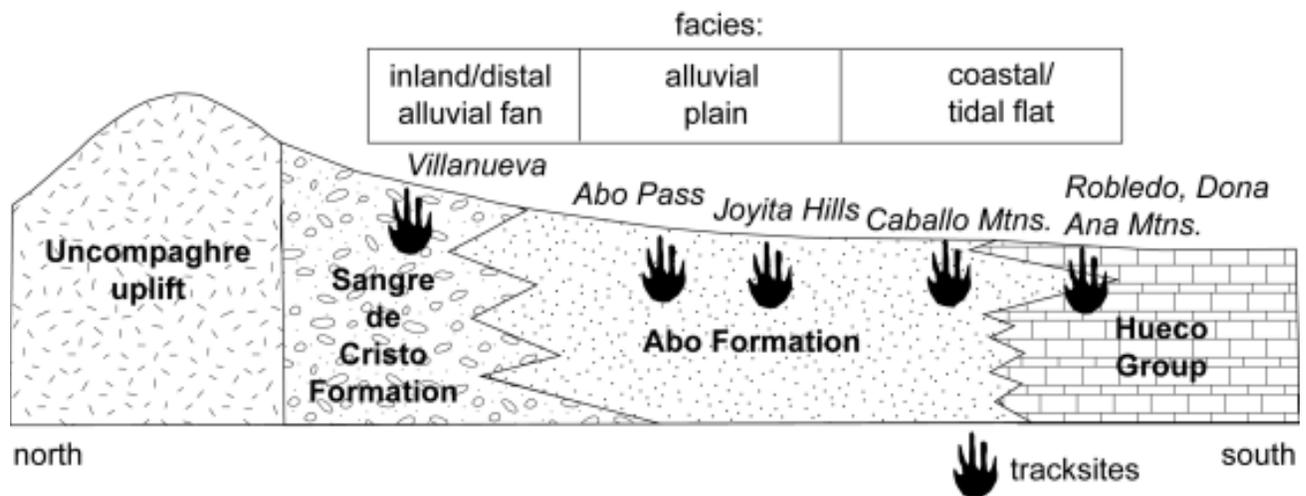


FIGURE 4. North-south transect of Early Permian redbeds in New Mexico showing distribution of ichnofaunas of the *Batrachichnus* biotaxonichnofacies.

Gilmore (1927) first noted the close similarity between Permian ichnofaunas from the eolian Coconino Sandstone of Arizona and from the Corncockle, Lochabriggs and Hopeman Sandstone formations of Scotland. Lockley et al. (1994) and McKeever and Haubold (1996) subsequently recognized a widespread eolian ichnofacies that characterizes these units as well as the Permian DeChelly Sandstone of Arizona, Lyons Sandstone of Colorado and the Cornberg Sandstein of Germany. This ichnofacies is also present in the Permian Yacimiento Los Reyunos Formation of Argentina (Melchor, 1997) and is characterized by low diversity ichnofaunas consisting almost exclusively of species of *Chelichnus* with rare occurrences of *Dromopus* and *Dimetropus*. It is distinctive, widespread and reflects a persistent facies rather than a biostratigraphic datum. Clearly, any biochronology utilizing the ichnofaunas of the *Chelichnus* biotaxonichnofacies is, at least in part, reflecting temporal changes in environment as much as evolutionary patterns.

Recognition of tetrapod biotaxonichnofacies in the Paleozoic also elucidates some apparent problems of facies analysis. For example, the distinctive Early Permian tetrapod ichnotaxon *Ichniotherium* has an unusual distribution. It is well known from some European ichnofaunas (e. g., Tambach Sandstein), but until relatively recently it was unknown in contemporaneous ichnofaunas in the American Southwest. Haubold (1971) first identified this ichnogenus from the Hermit Shale of Arizona, and Hunt et al. (1995c) documented it in the Sangre de Cristo Formation of New Mexico.

One significant aspect of the tetrapod ichnofaunas from the Permian of New Mexico, with respect to ichnofacies, is that they occur along an environmental transect from alluvial fans in the north to coastal plains in the south (Figs. 3-4). Hunt et al. (1995c) presented an initial hypothesis that the northern ichnofaunas would be more similar to those from the intermontane deposits of the Rotliegendes of Europe than to the ichnofaunas

from the coastal plains of southern New Mexico. *Ichniotherium* in New Mexico is restricted to the northern Sangre de Cristo Formation, which was deposited near the base of the mountain front (Fig. 3). Thus, the rarity of *Ichniotherium* in North America may be facies controlled. Only in northern New Mexico and possibly in northern Arizona (Hermit Shale) are ichnofaunas preserved in depositional environments broadly similar to those of Europe. Thus, the distribution of *Ichniotherium* can be explained if it is a facies fossil restricted to more "intermontane" or "inland" environments

This hypothesis is bolstered by the distribution of the amphibian track *Limnopus*. *Limnopus* is relatively uncommon in North America, but is known from abundant specimens from Europe (Gand, 1985; Haubold et al., 1995). In the Lower Permian of New Mexico, *Limnopus* becomes increasingly common in ichnofaunas to the north, away from the coastal plain. It thus appears that *Limnopus* is relatively common in more "inland" ichnofaunas, and this could explain the gross differences between its frequency in Europe and North America.

## CONCLUSIONS

1. There are two distinct traditions in the study of ancient ichnofaunas, which may be termed the ethological and the biotaxonomic.

2. There are, thus, two different kinds of ichnofacies, each peculiar to each tradition, and we term them ethoichnofacies (invertebrate ichnology) and biotaxonichnofacies (tetrapod ichnology).

3. The *Chelichnus* and *Batrachichnus* ichnofacies encompass all Carboniferous-Permian tetrapod ichnofaunas.

4. There is need for much more study of the concept of tetrapod ethoichnofacies, particularly in the Paleozoic.

5. Recognition of Paleozoic tetrapod

biotaxonomic facies has potentially important applications to problems of biochronology and facies analysis.

### ACKNOWLEDGMENTS

We thank Hartmut Haubold, David C. Kopaska-Merkel, Martin G. Lockley, Robert B. MacNaughton, Emma Rainforth and Andy Rindsberg for helpful reviews.

### REFERENCES

- Baird, D., 1965, Footprints from the Cutler Formation: U. S. Geological Survey Professional Paper 503C, p. C47-C50.
- Boy, J. A. and Fichter, J., 1988, Zur Stratigraphie des höheren Rotliegenden im Saar-Nahe-Becken (Unter Perm: SW Deutschland) und seiner Korrelation mit anderen Gebieten: Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, v. 176, p. 331-394.
- Bromley, R. G., 1990, Trace fossils: biology and taphonomy: London, Unwin Hyman, 250 p.
- Bromley, R. G., 1996, Trace fossils: biology and taphonomy (second edition): London, Unwin Hyman, 361 p.
- Cotton, W. D., Hunt, A. P. and Cotton, J. E., 1995, Paleozoic vertebrate tracksites in eastern North America: New Mexico Museum of Natural History and Science Bulletin, no. 6, p. 189-211.
- DiMichele, W. A. and Hook, R. W., 1992, Paleozoic terrestrial ecosystems; in Behrensmeyer, A. K., Damuth, J. D., DiMichele, W. A., Potts, R., Sues, H-D. and Wing, S. L., (eds.), Terrestrial ecosystems through time: Chicago, University of Chicago Press, p. 205-325.
- Gand, G., 1985, Significations paléobiologique et stratigraphique de *Limnopus zelleri* dans le partie nord du bassin Permien de Saint-Affrique (Aveyron, France): Geobios, v. 18, p. 215-227.
- Gillette, D. D. and Lockley, M. G., 1989, eds, Dinosaur Tracks and Traces: Cambridge, Cambridge University Press, 454 pp.
- Gilmore, C. W., 1927, Fossil footprints from the Grand Canyon: second contribution: Smithsonian Miscellaneous Collections, v. 80(3), 78 p.
- Haubold, H., 1971, Ichnia amphibiorum et reptiliorum fossilium: Handbuch der Paläohierpetologie, Teil 18: Stuttgart, Gustav Fischer Verlag, 124 p.
- Haubold, H., 1996, Ichnotaxonomie und Klassifikation von Tetrapodenfährten aus dem Perm: Hallesches Jahrbuch für Geowissenschaften, ser. B., v. 18, p. 23-88.
- Haubold, H., Hunt, A. P., Lucas, S. G. and Lockley, M. G., 1995, Wolfcampian (Early Permian) vertebrate tracks from Arizona and New Mexico. Bulletin of New Mexico Museum of Natural History and Science, v. 6, p. 135-165.
- Holub, V. and Kozur, H., 1981, Revision einiger Tetrapodenfährten des Rotliegenden und biostratigraphische Auswertung der Tetrapodfährten des obersten Karbon und Perm: Geologische Paläontologische Mitteilungen Innsbruck, v. 11, p. 149-193.
- Hunt, A. P. and Lucas, S. G., 1998a, Implications of the cosmopolitanism of Permian tetrapod ichnofaunas: New Mexico Museum of Natural History and Science Bulletin, no. 12, p. 55-57.
- Hunt, A. P. and Lucas, S. G., 1998b, Vertebrate ichnofaunas of New Mexico and their bearing on Lower Permian vertebrate ichnofacies: New Mexico Museum of Natural History and Science Bulletin, no. 12, p. 63-65.
- Hunt, A. P. and Lucas, S. G., 2003, Tetrapod ichnofacies in the Paleozoic; in Martin, A. J., ed., Workshop on Permo-Carboniferous Ichnology, Program and Abstracts, Alabama Museum of Natural History, Geological Survey of Alabama, p. 8-11.
- Hunt, A. P. and Lucas, S. G., 2004a, Multiple, parallel, dinosaur tail drags from the Early Cretaceous of New Mexico. Journal of Vertebrate Paleontology, v. 24 (supplement to no. 3), p. 73A.
- Hunt, A. P. and Lucas, S. G., 2004b, Tetrapod ichnofacies in the Paleozoic: 32nd International Geological Congress Italia 2004 Abstracts Part 1. International Union of Geological Sciences, p. 600.
- Hunt, A. P. and Santucci, V. L., 1998, Taxonomy and ichnofacies of Permian tetrapod tracks from Grand Canyon National Park, Arizona; in Santucci, V. L. and McClelland, L., eds., National Park Service Paleontological Research. National Park Service Geological Resources Division Technical Report NPS/NRGRD/GRDTR-98/01, p. 94-96.
- Hunt, A. P., Lucas, S. G. and Lockley, M. G., 1995a, Paleozoic tracksites of the western United States: New Mexico Museum of Natural History and Science Bulletin, no. 6, p. 213-217.
- Hunt, A. P., Lucas, S. G., Haubold, H. and Lockley, M. G., 1995b, Early Permian (late Wolfcampian) tetrapod tracks from the Robledo Mountains, south-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin no. 6, p. 167-180.
- Hunt, A. P., Lucas, S. G., Lockley, M. G., Haubold, H. and Braddy, S., 1995c, Tetrapod ichnofacies in Early Permian red beds of the American Southwest: New Mexico Museum of Natural History and Science Bulletin, no. 6, p. 295-301.
- Leonardi, G., ed., 1987, Glossary and manual of tetrapod footprint palaeoichnology: Departamento Nacional da Produção Mineral, Brasilia, 75 p.
- Lockley, M. G. and Meyer, C., 2000, Dinosaur tracks and other fossil footprints of Europe: New York, Columbia University Press, 323 p.
- Lockley, M. G., Hunt, A. P. and Meyer, C., 1994, Vertebrate tracks and the ichnofacies concept: implications for paleoecology and palichnostratigraphy; in Donovan, S., ed., The palaeobiology of trace fossils: London, John Wiley, p. 241-268.
- Lockley, M. G., Hunt, A. P., Haubold, H. and Lucas, S. G., 1995, Fossil footprints in the DeChelly Sandstone of Arizona: with paleoecological observations on the ichnology of dune facies. Bulletin of New Mexico Museum of Natural History and Science, v. 6, p. 225-233.
- Lucas, S. G., Krainer, K. and Kues, B. S., 2002, Stratigraphy and correlation of the Lower Permian Hueco Group in the southern San Andres Mountains, Doña Ana County, New Mexico: New Mexico Geological Society Guidebook, no. 53, p. 223-240.
- Lucas, S. G., Lerner, A. J. and Hunt, A. P., 2004, Permian tetrapod footprints from the Lucero uplift, central New Mexico, and Permian footprint biostratigraphy: New Mexico Museum of Natural History and Science Bulletin, no. 25, p. 291-300.
- Lucas, S. G., Lozovsky, V. R. and Shishkin, M. A., 1999, Tetrapod footprints from the Early Permian redbeds of the northern Caucasus, Russia: Ichnos, v. 6, p. 277-281.
- Lucas, S. G., Anderson, O. J., Heckert, A. B. and Hunt, A. P., 1995, Geology of Early Permian track sites, Robledo Mountains, south-central New Mexico: New Mexico Museum of Natural History and Science Bulletin, no. 6, p. 13-32.
- Lucas, S. G., Lerner, A. J., Bruner, M. and Shipman, P., 2004a, Middle Pennsylvanian ichnofauna from eastern Oklahoma, USA: Ichnos, v. 11, p. 45-55.
- McKeever, P. J. and Haubold, H., 1996, Reclassification of vertebrate trackways from the Permian of Scotland and related forms from Arizona and Germany: Journal of Paleontology, v. 70, p. 1011-1022.
- Melchor, R. N., 1997, Permian tetrapod ichnofaunas from Argentina: further evidence of redbed shallow lacustrine and aeolian vertebrate ichnofacies: Abstracts and papers of Workshop on

- the Ichnofacies and Ichnotaxonomy of the Terrestrial Permian, Halle, p. 59-60.
- Melchor, R. N., 2001, Permian tetrapod footprints from Argentina. *Hallesches Jahrbuch für Geowissenschaften*, ser. B, v. 23, p. 35-43.
- Melchor, R. N. and Poiré, D., 1992, Sedimentological and paleoecological implications of invertebrate and tetrapod ichnocoenosis from a Permian fluvial/lacustrine sequence: Carapacha Formation, La Pampa Province, Argentina: *Cuarta Reunión Argentina de Sedimentología*, Actas III, p. 247-257.
- Melchor, R. N. and Sarjeant, W. A. S., 2004, Small amphibian and reptile footprints from the Permian Carapacha Basin, Argentina: *Ichnos*, v. 11, p. 57-78.
- Morales, M. and Haubold, H., 1995, Tetrapod tracks from the Lower Permian DeChelly Sandstone of Arizona: systematic description: *New Mexico Museum of Natural History and Science Bulletin*, no. 6, p. 251-261.
- Seilacher, A., 1964a, Biogenic sedimentary structures; in Imbrie, J. and Newell, N., eds., *Approaches to Paleoecology*: New York, Wiley, p. 296-316.
- Seilacher, A., 1964b, Sedimentary classification and nomenclature of trace fossils: *Sedimentology*, v. 3, p. 253-256.
- Seilacher, A., 1967, Bathymetry of trace fossils: *Marine Geology*, v. 5, p. 413-428.
- Steinbock, R. T., 1989, Ichnology of the Connecticut Valley: a vignette of American science in the early nineteenth century; in Gillette, D. D. and Lockley, M. G., eds., *Dinosaur Tracks and Traces*: Cambridge, Cambridge University Press, p. 27-36.

#### **AUTHORS' E-MAIL ADDRESSES**

Adrian P. Hunt: ahunt@nmmnh.state.nm.us  
 Spencer G. Lucas: slucas@nmmnh.state.al.us



Tony Martin (Department of Environmental Studies, Emory University) welcomes attendees at the beginning of the Workshop on Permo-Carboniferous Ichnology, held at Smith Hall (Alabama Museum of Natural History) on May 2, 2003. Photo credit: Ron Buta.

## **TREPTICHNUS AND ARENICOLITES FROM THE STEVEN C. MINKIN PALEOZOIC FOOTPRINT SITE (LANGSETTIAN, ALABAMA, USA)**

ANDREW K. RINDSBERG and DAVID C. KOPASKA-MERKEL

Geological Survey of Alabama, P.O. Box 869999, Tuscaloosa, Alabama 35486-6999, USA

**ABSTRACT:** U-shaped burrows (Arenicolitidae: *Arenicolites longistriatus* n.isp.) and connected series of similar U-shaped burrows (*Treptichnus apsorum* n.isp.) are common at the Steven C. Minkin Paleozoic Footprint Site near Union Chapel, Alabama. Both kinds of burrows share a similar *bioprint* (new term), that is, characters that allow recognition of the maker. In this case, shallow U-shaped burrows and longitudinal striation comprise the bioprint of larval insects, or possibly other arthropods, having similar behavior and growth patterns to that of modern dipteran (fly) larvae. *Haplotichnus*, including *H. ornatus* n.isp., may have been made by very small insect larvae and other arthropods.

Ichnogenus *Treptichnus* is confined to *T. bifurcus* (the type ichnospecies), *T. apsorum*, and *T. pollardi*. Ichnofamily Arenicolitidae is revised.

### **INTRODUCTION**

The most abundant trace fossils of the Steven C. Minkin Paleozoic Footprint Site near Union Chapel, Alabama, are insect burrows: zigzag burrows *Treptichnus apsorum* n.isp. and shallow U-shaped burrows *Arenicolites longistriatus* n.isp. Many slabs are covered on both sides with these trace fossils, which are commonly preserved in exquisite detail. These trace fossils are valuable keys to the paleoenvironment of the Steven C. Minkin Site. *Arenicolites* and *Treptichnus* are considered together here because they have similar size range and morphologic features. As will be shown, *Treptichnus* can be considered as a string of *Arenicolites* connected together in a particular pattern. Intergradational trace fossils consisting of only a few connected *Arenicolites* are considered to be incipient *Treptichnus*.

### **Setting**

More than 25 m of Lower Pennsylvanian strata are exposed at the Steven C. Minkin Paleozoic Footprint Site near Carbon Hill, Walker County, Alabama, and about 7 m consist of the abundantly ichnofossiliferous *Cincosaurus* beds (Pashin, 2005). The site, about 13.4 hectares (33 acres) in area, is a small part of the Union Chapel Mine operated by the New Acton Coal Mining Company. Beginning in December 1999, amateur paleontologists conducted an extensive weekend salvage operation with the cooperation of coal company and state officials. In 2004, the site was acquired by the Alabama Department of Conservation and Natural Resources, and on March 12, 2005, the site was dedicated to the memory of deceased collector Steven C. Minkin.

The Steven C. Minkin Site has yielded a spectacular abundance of well-preserved tetrapod trackways (Haubold et al., 2005; Martin and Pyenson, 2005). Similar trace fossils occur elsewhere in the Black Warrior

basin, though in smaller numbers (Rindsberg, 1990). Hundreds of slabs have been recovered from the spoil piles at the Steven C. Minkin Site, especially from the *Cincosaurus* beds underlying the Newcastle coal seam.

### **Paleoenvironment**

Although previous workers suggested a floodplain to lacustrine environment for the Indiana *Treptichnus* (Archer and Maples, 1984), and a brackish tidal-flat environment for Alabama *Treptichnus* (Rindsberg, 1990), in both cases these are now recognized as freshwater tidal-flat environments (Kvale et al., 1989; Archer, 1998; Pashin, 2005). This is the result of a rapid and exciting increase in knowledge about such systems. *Treptichnus* has also been reported from marine paleoenvironments, but, as will be shown, these examples are morphologically distinct from the type species, tending to have relatively short segments and a relatively regular pattern (Buatois and Mángano, 1993a).

The *Cincosaurus* beds were deposited as silty mud in a freshwater tidal setting, evidently at the head of an estuary near a delta (Pashin, 2005). As shown by Pashin, the evidence for very rapid tidal deposition includes couplets of laminae up to 0.5 cm thick, each representing one diurnal tidal cycle. Freshwater conditions are suggested by the presence of amphibian trace fossils, as well as the absence of brackish and marine indicators such as siderite or stenohaline fauna. However, J. Clack (personal commun., 2005) indicates that some Carboniferous temnospondyls may have tolerated brackish water. There is no evidence of desiccation; mudcracks and rainprints are absent. Gas-escape structures are very common, suggesting, along with the dark color of the shale and the preservation of plant debris, that the organic content of the mud was very high (Rindsberg, 2005).

The shale has probably been compacted to some



FIGURE 1. Tetrapod trackway with *Treptichnus apsorum* and gas-escape structures. UCM 788, lower surface. The scale in all figures is in centimeters.

degree, perhaps to one-third of the original thickness (J. C. Pashin, personal commun., 2005).

In slabs from the Union Chapel *Cincosaurus* beds, *Treptichnus* and U-burrows may occur alone or together, and may also accompany any of the other ichnotaxa known from the same beds, including tetrapod trackways. In contrast, at Galloway Mine no. 11, from which Aldrich's (1930) specimens were collected, slabs with tetrapod trackways generally lack invertebrate burrows, though the horseshoe crab trackway *Kouphichnium aspodon* (Aldrich, 1930) is present. The reasons for this difference are unknown, but it is clear that the Union Chapel Mine represents only one snapshot from a whole album of paleoenvironments represented in other exposures within the Black Warrior Basin, for the ranges of ichnotaxa overlap in a gradient from freshwater to quiet-water marine shelf deposits (Rindsberg, 1990). Tetrapod trackways, *Treptichnus*, and *Undichna* are characteristic of the freshwater end of this continuum.

#### Trace fossil assemblage of the *Cincosaurus* beds

Trace fossils in the *Cincosaurus* beds are primarily preserved in full relief within laminated shale, and are

exposed on laminar surfaces as hypichnia and epichnia. Most are very shallow and not clearly visible in cross section. Among the most common ichnotaxa from the *Cincosaurus* beds, other than tetrapod trackways, are *Treptichnus*, *Arenicolites*, *Kouphichnium*, and *Undichna* (Rindsberg et al., 2001, 2004; Rindsberg and Kopaska-Merkel, 2003). Surfaces having tetrapod trackways at Union Chapel generally also contain invertebrate traces (Fig. 1). Because the field relations must be deduced from broken spoil, it is important to note that each pair of these ichnotaxa has been found in close association on single slabs, confirming that they belong to one assemblage.

#### Bioprint

The characters that allow recognition of the maker are called a trace's *signature* or *bioprint*. The Union Chapel *Arenicolites* has a distinctive bioprint that is shared with the local *Treptichnus*, with which it occurs. Both are evidently the burrows of the same or similar animals.

In the following sections, the focus is on the ethology and possible makers of *Arenicolites* and *Treptichnus*.

The formal, morphologically-based classification of *Arenicolites*, *Treptichnus*, and similar trace fossils is dealt with under "Systematic Ichnology."

### **ARENICOLITES** **The Alabama *Arenicolites***

*Arenicolites* Salter, 1857 consists of simple, vertical, U-shaped, open holes with distinct walls; the burrows extend upward to two apertures at the surface of the substrate. In modern examples, the tracemaker generally lives within the U-burrow, rarely leaving it; feeding is accomplished by circulating water through the burrow (a process called irrigation or bioirrigation) and filtering particles from the water. This dwelling-burrow (domichnial) strategy favors animals that live in water having a high flux of food particles, for example, in intertidal and nearshore environments having reliably strong currents. Dense populations of filter-feeders are possible in such environments, which are unsuitable for most other species.

Many kinds of living animals can excavate vertical dwelling burrows of various kinds; certain polychaete worms, amphipod crustaceans, and insects are among those that make modern examples of *Arenicolites* (Chamberlain, 1977). In contrast, the makers of most fossil *Arenicolites* are unknown because the burrows lack sufficiently diagnostic characters, or because the significance of those characters is not understood. However, the makers of *Arenicolites* from the Steven C. Minkin Site have a distinctive bioprint.

The Union Chapel U-burrows, *Arenicolites longistriatus* n.sp., are shallow, 2.5 to 11 mm wide at the ends and 11 to 84 mm long, but generally less than 8 mm deep (Fig. 2). Compaction of shale has probably flattened the traces somewhat, possibly to a fraction of the original depth. Some are simple, but others have a shallow spreite consisting of only a few laminae (Figs. 2, 3), which can be discounted for the purposes of classification. The U-burrows' most distinctive feature is their longitudinal striation, with striae scored into the floor of the burrow (Figs. 2, 3). As shown by Uchman (2005), this bioprint makes it possible to relate the burrows to those of the larvae of modern dipterans (true flies), including chironomids (midges) and tipulids (craneflies), in fresh water.

#### ***Arenicolites longistriatus* as an insect burrow**

Chironomids are abundant in modern freshwater to brackish aquatic environments; some species are even marine. Their habits are as diverse as their habitats. The larvae generally build silken tubes on or within the substrate, and in some species the tube is modified as a case that protects the larva as it travels on the substrate. Some forms spin silken nets to use as filters for gathering food particles; others graze on the substrate or burrow within it; still others are carnivorous. The group includes many species that are tolerant of low-oxygen and high-organic conditions.

Tipulids occur in moist to wet terrestrial, freshwater and brackish environments, where the larvae eat roots

or organic debris such as leaf litter. Unlike the chironomids, they have a rather low tolerance of high-organic conditions.

It should be noted that the fossil record of the Diptera goes back only to the Late Triassic (Evenhuis, 2004). Although Pennsylvanian trace fossils that appear to be made by dipterans may in fact have been made by otherwise unrecorded, early dipterans, it is also possible that the burrows were made by other insects, or possibly other arthropods, having similar behavior.

### **TREPTICHNUS** **The Alabama *Treptichnus***

*Treptichnus* Miller, 1889 is a burrow consisting of segments connected at their ends, each one to the next, characteristically but not invariably in a zigzag pattern. The Alabama ichnospecies, *T. apsorum* n.sp., is similar to Miller's type ichnospecies, *T. bifurcus*, but, like *Arenicolites longistriatus*, is longitudinally striate (Fig. 4). Several other zigzag burrows have been included in *Treptichnus*, but represent such different behavior that they are considered here as belonging to other ichnogenera, as suggested by Buatois and Mángano (1993a) and discussed further in "Systematic Ichnology."

The Alabama *Treptichnus* consists of shallow U-shaped segments of similar dimensions and sculpture to the U-burrows described here, but connected in a zigzag pattern (Figs. 4-9), suggesting that they were made by the same or similar species. The U-shaped components can be arranged in any pattern from a regular zigzag to an irregular zigzag to a nearly straight line, though most are irregularly zigzag (Figs. 5, 7). The U's are branched not at their ends, but just before (Fig. 8), so that at the original sediment surface, only a series of alternating apertures would have been visible. Each U-shaped segment within a specimen has a relatively constant width, ranging overall from 1 to 3.5 mm, but segment length may vary threefold within a specimen, from 2.5 to 60 mm overall. At depth within the substrate, the zigzag pattern in some cases is smoothed out to form a gently curved to nearly straight *Planolites*-like burrow (Fig. 9).

The burrows are longitudinally striate, a bioprint that points to an arthropod maker. More than one lamina of mud may be preserved within a burrow, and each can be striate, suggesting that the maker could adjust the burrow upward to some degree as a response to partial filling of the burrow owing to rapid deposition. The burrows show no sign of having been filled by the maker after use, but instead were allowed to collapse. As will be shown, these features, which are significant in interpreting the makers of these burrows, are different from those of burrows ascribed to *Treptichnus* from truly marine settings.

#### ***Treptichnus bifurcus* and *T. apsorum* as insect burrows**

Miller (1889) based *Treptichnus* and two similar trace fossils, *Plangtichnus* and *Haplotichnus*, on specimens he found in the Lower Pennsylvanian Hindostan

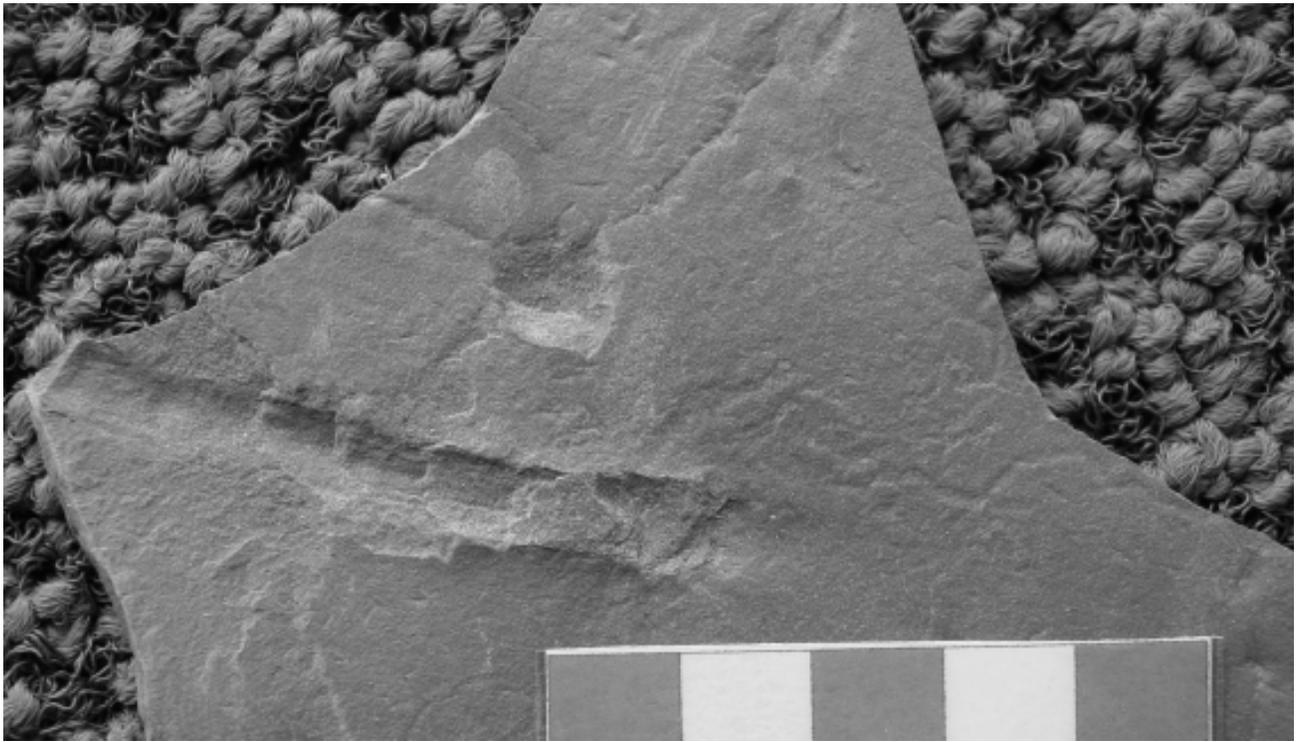


FIGURE 2. *Arenicolites longistriatus* showing the longitudinal striation for which it is named, scored into the floor of the burrow. Striation is evident in four different laminae within a rudimentary spreite. A (Top): Holotype, UCM 2038, upper surface. B (Bottom): Upper surface.

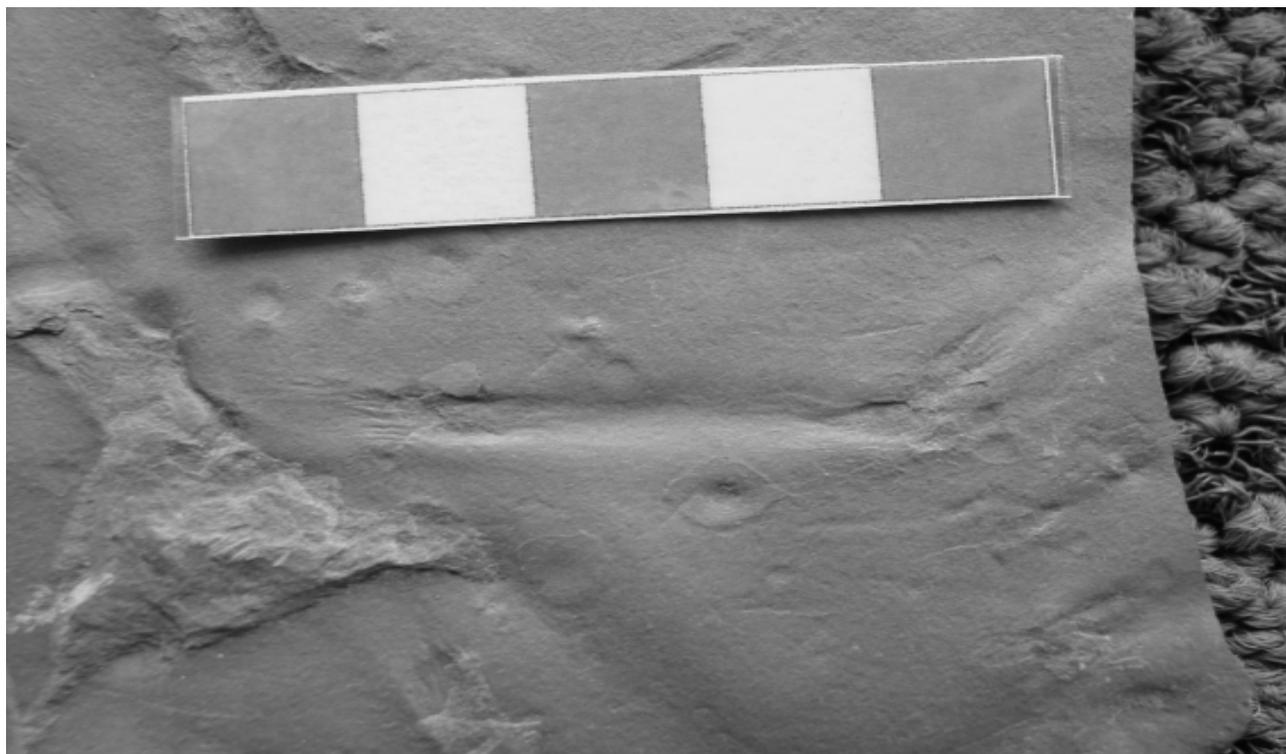


FIGURE 3. *Arenicolites longistriatus* showing collapse of sediment over shallow gallery. Upper surface. The shallow spreite can be discounted for the purposes of classification.

whetstone beds (Mansfield Formation) of Orange County, Indiana (Figs. 10-12). The original descriptions were embedded and forgotten in the section on fossil insects in a book-sized catalog of all the North American Paleozoic fossils known at that time, but the ichnogenera were rediscovered by Häntzschel (1975) and revised by Maples and Archer (1987) and Buatois and Mángano (1993a).

Miller (1889) attributed the burrows to insect larvae, and guessed that they might be the larvae of palaeodictyopterans, which were similar to dragonflies (Atkinson, 2005) and occur in both the Hindostan beds of Indiana and the *Cincosaurus* beds of Alabama. Although there is no need to read the Hindostan rock record so literally, Miller's attribution of the burrows to insect larvae was sound. If he had documented the modern analogs, it would have left a firm basis for recognition of *Treptichnus* elsewhere, but he did not. Eventually, however, *Treptichnus* of probable insect origin was discovered in Carboniferous strata in much of the Americas (Table 1). Tessier et al. (1995) and Archer et al. (1995) reported similar insect burrows on freshwater to brackish fluviotidal flats on the coast of northern France. Recent work by Uchman (2005) confirms that dipteran fly larvae are at least one of the makers of striate zigzag burrows in modern alluvial mud in Poland.

#### **Ontogeny of the makers of *Treptichnus***

Evidence is seen for the ontogeny (growth) of the tracemakers of *Treptichnus*. In his Indiana specimens,

which are of nearly the same age as the Alabama specimens and are found in similar kinds of rocks, Miller (1889) distinguished very small zigzags as *Haplotichnus*, medium ones as *Treptichnus*, and large ones as *Plangtichnus*, and some morphologic differences can be picked out between these forms. Because intermediate forms exist from *Haplotichnus* to *Treptichnus* to *Plangtichnus*, it seems possible that Miller named three stages in the behavior of one species as it progressed through life.

As shown in "Systematic Ichnology," *Haplotichnus indianensis* may be the work of very young larvae of the same species as made *Treptichnus bifurcus*, but their morphology is different enough to inspire caution about synonymizing these ichnotaxa.

In Alabama, similar relationships hold, except that *Haplotichnus* is present only at other Pottsville sites and not at Union Chapel. At any one horizon on a piece of broken spoil, each population of *Treptichnus* generally ranges only narrowly in size (Fig. 5), suggesting that tracemaker populations consisted of cohorts of the same age. However, the overall size range shows no clear evidence for separation into instars.

At some horizons, the size range is bimodal (Fig. 1). In this case, traces made at different times may be superposed, apparently accounting for the bimodality at least of U-shaped burrows and *Treptichnus*. The great overall size range suggests that deposition of the *Cincosaurus* beds encompassed at least one season, during which insect larvae had time to grow to maturity.



FIGURE 4. Longitudinal striation in a short but well-preserved specimen of *Treptichnus apsorum*. Upper surface.

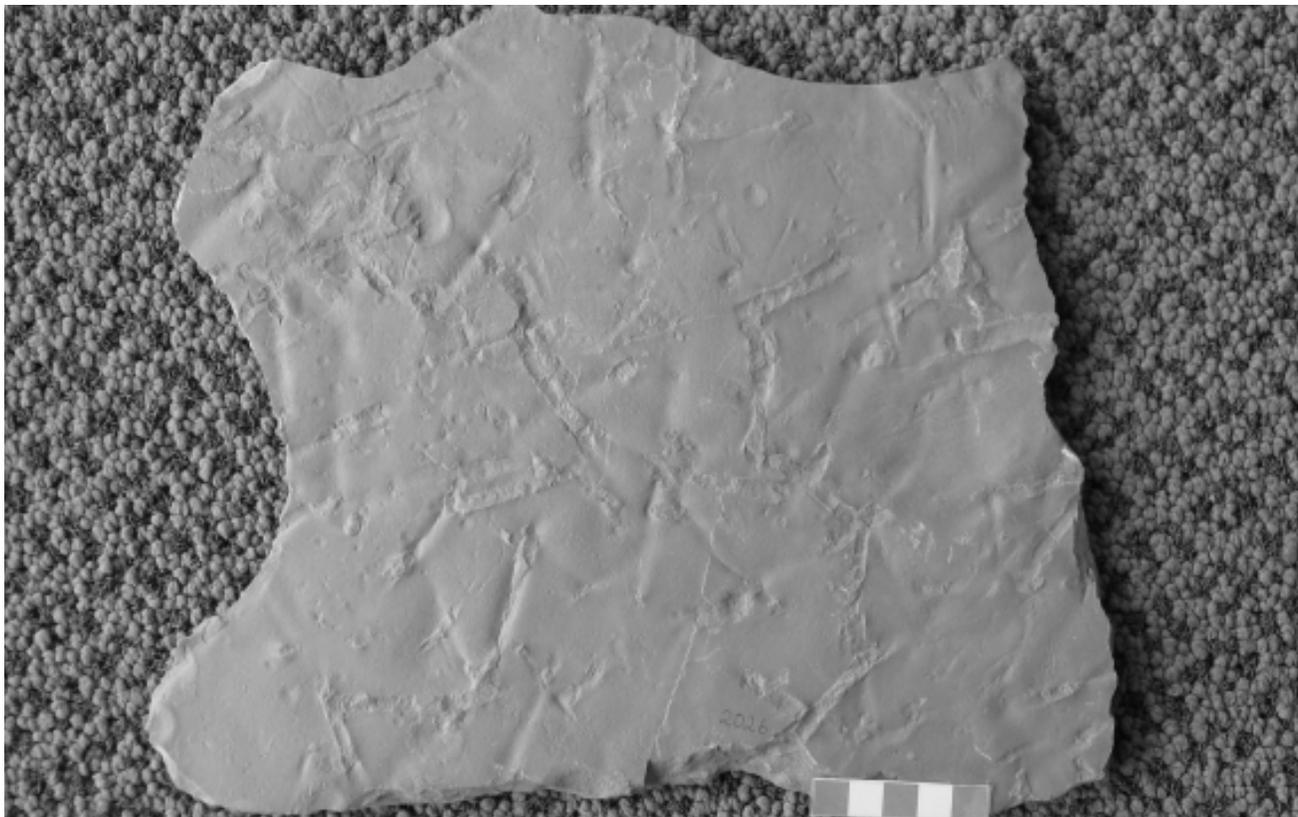


FIGURE 5. *Treptichnus apsorum* consisting of shallow, U-shaped segments of similar dimensions and sculpture to *Arenicolites longistriatus* (also present) but connected in a zigzag pattern. UCM 2026, upper surface. For closer view of holotype, see Fig. 6.

TABLE 1. Distribution of *Treptichnus bifurcus* and similar forms.

Age	Location	Ichnospecies	Reference
Oligocene	Switzerland	<i>T. pollardi</i>	Uchman et al., 2004
Late Triassic	Pennsylvania, USA	<i>T. pollardi</i>	Metz, 2000
Late Pennsylvanian-Early Permian	Santa Catarina, Brazil	<i>T. pollardi</i>	Balistieri et al., 2002
Late Pennsylvanian	Kansas, USA	<i>T. bifurcus</i>	Buatois et al., 1998a,b
		<i>T. pollardi</i>	
Pennsylvanian	Catamarca, Argentina	<i>T. pollardi</i>	Buatois & Mángano, 1993b
Early Pennsylvanian	Alabama, USA	<i>T. apsorum</i>	this study
Early Pennsylvanian	Alabama, USA	<i>T. bifurcus</i>	Rindsberg, 1990
Early Pennsylvanian	Indiana, USA	<i>T. bifurcus</i>	Miller, 1889
			Archer & Maples, 1984
			Maples & Archer, 1987
Early Pennsylvanian	Nova Scotia, Canada	<i>T. pollardi</i>	Archer et al., 1995
Middle Pennsylvanian	Oklahoma, USA	<i>T. bifurcus</i>	Lucas et al., 2004
Late Mississippian	Alabama, USA	<i>T. bifurcus</i>	Rindsberg, 1991

### RELATIONSHIP BETWEEN *ARENICOLITES* AND *TREPTICHNUS* IN ALABAMA

Burrows assigned to these ichnogenera are among the most common at Union Chapel. They occur on the same slabs as tetrapod trackways and the swimming trace *Undichna*, so their makers are all presumed to have lived together. Although they appear at first glance to be distinct, it is likely that *Arenicolites longistriatus* and *Treptichnus apsorum* were made by one species or at least a group of species of insect, as will be shown.

*Arenicolites* and *Treptichnus* from Union Chapel occur together (Fig. 5) and are built of similar U-shaped components: one in *Arenicolites*, two or more in *Treptichnus*. Segment width is 2.5 to 11 mm in *Arenicolites* and 1 to 3.5 mm in *Treptichnus*; segment length is 11 to 84 mm in *Arenicolites* and 2.5 to 60 mm in *Treptichnus*. Both are shallow U-burrows, with the greatest observed depth being 8 mm in a single specimen of *Arenicolites* in relatively coarse-grained, hence probably uncompressed, sediment. Tellingly, parallel longitudinal striation is found in both the Alabama forms despite this feature being rarely reported in either ichnogenus elsewhere. These similarities are so close, and so unusual, that they probably indicate that both types of burrows were made by the same kind of animals — possibly different species, but very likely belonging to the same group of insects or other arthropods. In more technical terms, similarities in bioprint (size and sculpture of components) as well as co-occurrence are evidence for a similar or identical maker (Rindsberg and Martin, 2003).

### SYSTEMATIC ICHNOLOGY

Because the taxonomy of *Arenicolites* and *Treptichnus* is bound to that of other ichnogenera, the

systematic ichnology includes discussion of some trace fossils that are not found at the Steven C. Minkin Site, especially *Treptichnus bifurcus* and *Haplotichnus indianensis*. These are based on examination of Miller's Indiana holotypes as well as observations on hundreds of specimens from the Steven C. Minkin Paleozoic Footprint Site.

#### Ichnofamily Arenicolitidae Richter, 1926

- \* 1926 Arenicolitidae Richter, p. 212.
- 1929 Arenicolitidae, Bentz, p. 1180-1181.
- 1932 Arenicolitidae, Mägdefrau, p. 158.
- 1941 Arenicolitidae, Hundt, p. 63.
- 1956 Arenicolitidae, Lessertisseur, p. 61.
- 1961 Arenicolitidae, Vialov, Table 1.
- 1975 Arenicolitidae, Häntzschel, p. W17.

*Original diagnosis.* "U-Röhre ohne Spreite. [Nicht "U in U"]." (U-tubes without spreite. [Not "U-in-U."]") (Richter, 1926, p. 212).

*Emended diagnosis.* Simple, unspiraled, U-shaped burrows without spreite, and systems consisting of J-shaped burrow segments with only one topologic U open at a time; plane of U normal or oblique to bedding; U oriented upward to include two apertures.

*Type genus.* *Arenicolites* Salter, 1857 by original designation.

*Remarks.* Richter (1926) contrasted U-shaped burrows with and without spreite, naming the U-burrows with spreite as Rhizocorallidae (properly Rhizocoralliidae, *nom. correct.*) and the U-burrows without spreite as Arenicolitidae. Believing that *Diplocraterion* lacks a

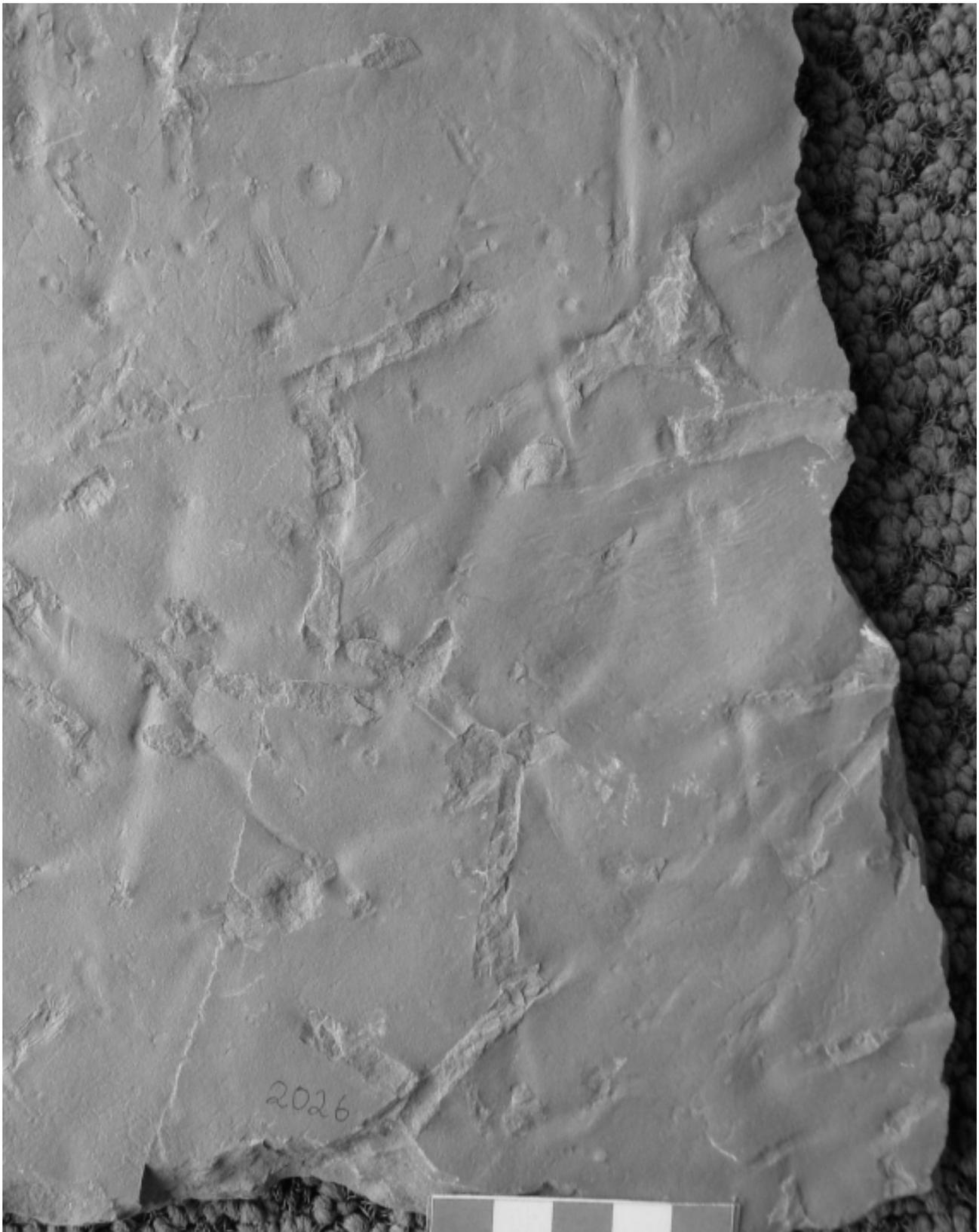


FIGURE 6. Holotype of *Treptichnus apsorum*. UCM 2026, upper surface.

spreite, Richter (1926) included it together with *Arenicolites* and perhaps *Arthraria* in Arenicolitidae. The Rhizocoralliidae included the spreite-bearing U-burrows *Rhizocorallium* and *Corophioides* (now considered to be a junior synonym of *Diplocraterion*; Fürsich, 1974). Bentz (1929) added his new ichnogenus, *Cavernaecola*, which is now considered as a synonym of *Rhizocorallium* with an obscure spreite (Häntzschel, 1975). Later revisions of ichnogenera make it necessary to rearrange the ichnogenera but not the basic diagnoses of the ichnofamilies.

As currently defined, arenicolitids include *Tisoa* Serres, 1840, *Arthraria* Billings, 1872, and perhaps *Lanicoidichna* Chamberlain, 1971 as well as *Arenicolites*.

*Palaeophycus* Hall, 1847 is currently rather broadly defined (Pemberton and Frey, 1982), and includes some species of U-burrows such as *P. triadicus* (Fliche, 1906), and *P. alternatus* Pemberton and Frey, 1982. As described by Pollard (1981, p. 573) based on specimens from the Triassic of England, *Palaeophycus triadicus* consists of short, subhorizontal, fusiform burrows having a sculpture of anastomosing longitudinal striae. *P. alternatus*, from the Upper Ordovician of the Cincinnati Arch, consists of short, subhorizontal burrows having a sculpture of both longitudinal and transverse striae (Osgood, 1970, pl. 76, fig. 9; Pemberton and Frey, 1982). *P. striatus* might be added to this list, as Hall (1852) emphasized its originally open character and lack of branching, but the types are incomplete so the full burrow morphology is unknown (Osgood, 1970; Pemberton and Frey, 1982). U-shaped burrows described from modern sediments may have long horizontal components compared to gallery width (e.g., MacGinitie and MacGinitie, 1968). The simple, U-shaped forms of *Palaeophycus* should be reassigned to another ichnogenus such as *Arenicolites*; further work on topotypes is needed before *P. striatus* can be understood.

*Trichophycus* Miller and Dyer, 1878 is another ichnogenus that includes simple, branched, and even spreite-bearing U-burrows and networks made of such components. Osgood (1970, p. 347) suspected that the simple form "*Palaeophycus*" *virgatus* Hall, 1847 is an older synonym of *Trichophycus venosus* Miller, 1879, and he was probably correct. In the best preserved specimens of *Trichophycus venosus*, the bioprint includes the inconstant diameter of the gallery, which has nodes that bear biradial sets of striae that are consistent with a trilobite maker (Seilacher and Meischner, 1964). The type species, *T. lanosus* Miller and Dyer, 1878, is more irregular than most and shows the striate pattern well (Osgood, 1970, pl. 68, figs. 2, 8). These features are more important to the taxonomy of *Trichophycus* than the branching pattern, which is labile. *Trichophycus* can thus be diagnosed as a mainly subhorizontal burrow or burrow system composed of one or more broad, originally open, U-shaped burrows, characteristically having a nodose gallery, and in exceptionally well preserved cases, with biradial striation on the walls of nodes. These features distinguish *Trichophycus* from *Treptichnus*.

In classifying U-burrows, one should keep in mind that the burrow must accommodate the growth of the

animal that lives within it. For example, the spreite of *Diplocraterion* is a way of increasing the length and diameter of the burrow while utilizing part of it. The U can also be lengthened in other ways. In the simplest case, the tracemaker can abandon the burrow and dig a new one, but this leads to waste and the risk of predation.

The marine polychaete *Chaetopterus variopedatus* lives in a U-burrow with a tough, parchment-like lining; the animal's body occupies only about a third of the burrow (Enders, 1908). To enlarge its burrow, the worm cuts through the lining, digs a new burrow segment to the surface, and blocks off the old passage. For practical purposes such as bioirrigation, the resulting burrow is still U-shaped and oriented in one vertical plane to take advantage of prevailing currents. However, a fossilized example including the whole history of the burrow would be W-shaped, and the Carboniferous type species of *Arenicolites*, *A. carbonarius* Salter, 1856, is now recognized as having this pattern (Pollard, 1999). The key to recognition is the maker's preference for keeping all the burrow segments in one plane; systems that are built of J-shaped segments in different planes are not *Arenicolites*.

#### **Ichnogenus *Arenicolites* Salter, 1857**

- \* 1857 *Arenicolites* Salter, p. 204.
- 1977 *Arenicolites*, Chamberlain, p. 8.

*Original diagnosis.* "*Arenicolites* might stand for all worm-burrows with double openings" (Salter, 1857, p. 204).

*Emended diagnosis.* Simple, vertical U-shaped burrows with two apertures above.

*Type ichnospecies.* *Arenicola carbonaria* Binney, 1852, p. 192, by subsequent designation of Richter (1924, p. 137).

*Remarks.* Chamberlain (1977, p. 8) briefly delineated the differences of several ichnospecies of *Arenicolites*, only some of which are mentioned here. The ichnogenus has an unresolved taxonomic problem: The type ichnospecies, *A. carbonarius*, is now known to be branched (Pollard, 1999), though probably only two apertures were open at any one time. The most characteristic species is *A. sparsus* Salter, 1856, a simple, regular U-shaped burrow having vertical limbs and lacking a thick lining. *A. curvatus* Goldring, 1962 has inclined limbs. The new ichnospecies, *A. longistriatus*, is subhorizontal, at least after compaction, and is longitudinally striate.

Makers of modern *Arenicolites* include polychaetes, crustaceans, and insects (Chamberlain, 1977).

#### ***Arenicolites longistriatus* n.isp.**

Figs. 2, 3, 5

*Etymology.* Latin *longus*, long, and *striatus*, furrowed, striate.

*Description.* Unbranched, subhorizontal U-shaped burrows with parallel longitudinal striae all of approximately even depth.

*Remarks.* Comparisons to other species of *Arenicolites* are given under the ichnogenus. In addition, *Palaeophycus* includes ichnospecies with very shallow, originally open U-shaped burrows. *P. striatus* Hall, 1852 has parallel longitudinal striae, commonly with the median stria particularly deep; its complete burrow morphology is unknown (Osgood, 1970; Pemberton and Frey, 1982). *P. triadicus* (Fliche, 1906) is similar to *P. striatus*, but has a fusiform outline and anastomosing striae (Pollard, 1981, p. 573). *P. alternatus* Pemberton and Frey, 1982 has transverse as well as longitudinal striation.

*Holotype.* Geological Survey of Alabama Paleontological Collection, UCM 2038.

#### **Ichnofamily incertae sedis**

#### **Ichnogenus *Treptichnus* Miller, 1889**

- \* 1889 *Plangtichnus* Miller, p. 580.
- \* 1889 *Treptichnus* Miller, p. 581.
- non 1948 Feather-stitch trail, Wilson, p. 57.
- 1975 *Plangtichnus*, Häntzschel, p. W95.
- partim 1975 *Treptichnus*, Häntzschel, p. W117-118, figs. 68(5a-c).
- 1984 *Trepticynus*, Archer and Maples, p. 455 [nom. null.].
- partim 1993a *Treptichnus*, Buatois and Mángano, p. 220-221.
- non 1997 *Treptichnus*, Wetzel and Uchman, p. 151 [cf. *Belorhaphé*].
- partim 1998 *Treptichnus*, Uchman et al., p. 272-273.
- partim 1998b *Treptichnus*, Buatois et al., p. 157-158.
- non 2000 *Treptichnus*, Schlirf, 2000, p. 156-157 [cf. *Belorhaphé*].
- 2002 *Treptichnus*, Balistieri et al., p. 20.

*Type species.* *Treptichnus bifurcus* Miller, 1889 by original diagnosis.

*Original diagnoses.* *Treptichnus*: “A zigzag, half-cylindrical, continuous trail, forked at each angle, and running in any direction; each line is prolonged in the direction in which the animal moved, at the angle, so as to form a short fork or projection” (Miller, 1889, p. 581).

*Plangtichnus*: “A zigzag, half-cylindrical, broken trail, running in any and every direction; sometimes dotted or sunk deeper at the angles than at other places, or most depressed between the angles in some cases” (Miller, 1889, p. 580).

*Emended diagnosis.* Subhorizontal burrow consisting of one series of downbowed or J- to U-shaped segments joined near or at their ends in a uniserial pattern that may be irregular, zigzag, or arcuate. Segments extending to sediment-water interface with at least one aperture originally open; very gently downbowed or nearly

straight; fill passive, commonly by collapse.

*Remarks.* Not all zigzag burrows were made by the same animals or in the same way. In ichnotaxonomy, behavior is the basis of classification. Each trace represents major and minor modes of behavior, but usually one can be recognized as the major function of the trace, such as locomotion, resting or hiding, deposit-feeding, grazing, or dwelling (Seilacher, 1953). If the zigzag burrows from different times and places represent fundamentally different behaviors as recognized morphologically, then they should be separated into distinct ichnogenera, as previously suggested by Buatois and Mángano (1993a).

The history of ichnogenus *Treptichnus* has so far been one of including more and more kinds of zigzag burrows, three of whose strategies are described here: (1) deposit-feeding, with narrow older segments abandoned to collapse (*Treptichnus* in a strict sense), (2) farming with all segments in simultaneous use (cf. *Belorhaphé*), and (3) deposit-feeding with broad older segments passively filled under a biomark (unnamed ichnogenus). Each of these requires a separate ichnogenic name — a position that may seem radical, but was previously articulated in very similar form by Buatois and Mángano (1993a).

*Treptichnus* and *Plangtichnus* consist of zigzag burrows that were originally described by Miller (1889) from Lower Pennsylvanian freshwater tidal flat deposits in Indiana. *Haplotichnus* Miller, 1889 is a smaller burrow having a rather angular path within a looping or wandering course. In their revision of Miller’s Hindostan ichnogenera based on type and new material, Maples and Archer (1987) showed that *Plangtichnus* is a preservational aspect of *Treptichnus* in which the uppermost part of the burrow system is absent, but left the question open whether *Plangtichnus* should be maintained as a separate ichnogenus. Buatois and Mángano (1993b) formally placed *Plangtichnus* as a synonym of *Treptichnus*, and most subsequent workers have accepted this (though not all; Archer et al., 1995).

Miller’s *Treptichnus bifurcus* and similar Carboniferous forms were poorly understood until Archer and Maples (1984) and Maples and Archer (1987) reinvestigated the Hindostan beds and their trace fossils. Buatois and Mángano (1993a) revised ichnogenus *Treptichnus* further. Figures of modern insect-made analogs were published in the paleontologic literature even later (Uchman, 2005; Rindsberg et al., 2004). It is now clear that these burrows represent deposit-feeding in a zigzag or other segmented, serial pattern, with older segments abandoned after use. Segments extended to the sediment-water interface but only one or two may have been open at any one time, the others probably being allowed to collapse.

Häntzschel (1975) broadened the concept of *Treptichnus* to include the zigzag or “feather-stitch trails” described by Wilson (1948) and Seilacher and Hemleben (1966) from Ordovician and Devonian strata. Häntzschel illustrated Paleozoic marine examples that differ from the type species in having relatively thin and deep galleries, which branched at a relatively deep level and ap-

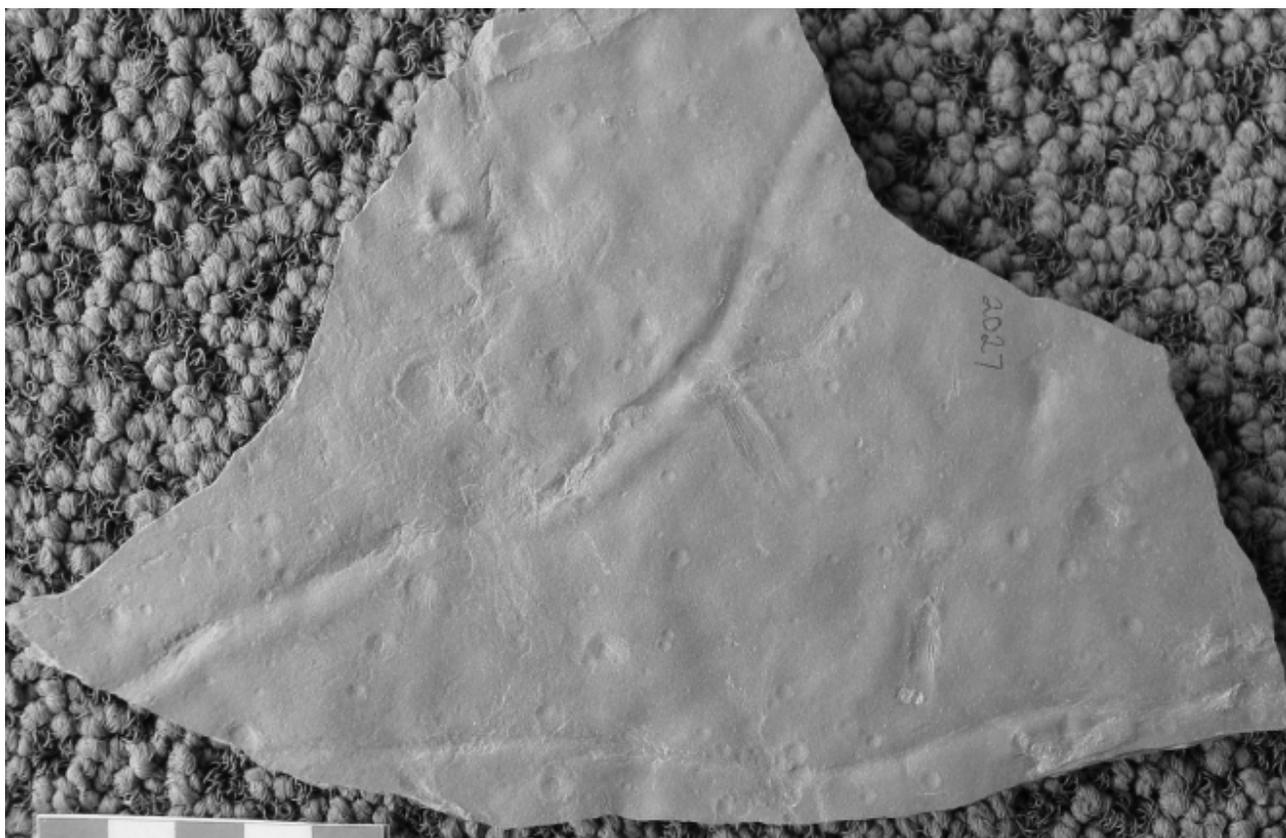


FIGURE 7. Obscure *Treptichnus apsorum* with nearly straight pattern. UCM 2027, upper surface. (For a closer view of the striate *Treptichnus* near the center, see Fig. 4.)

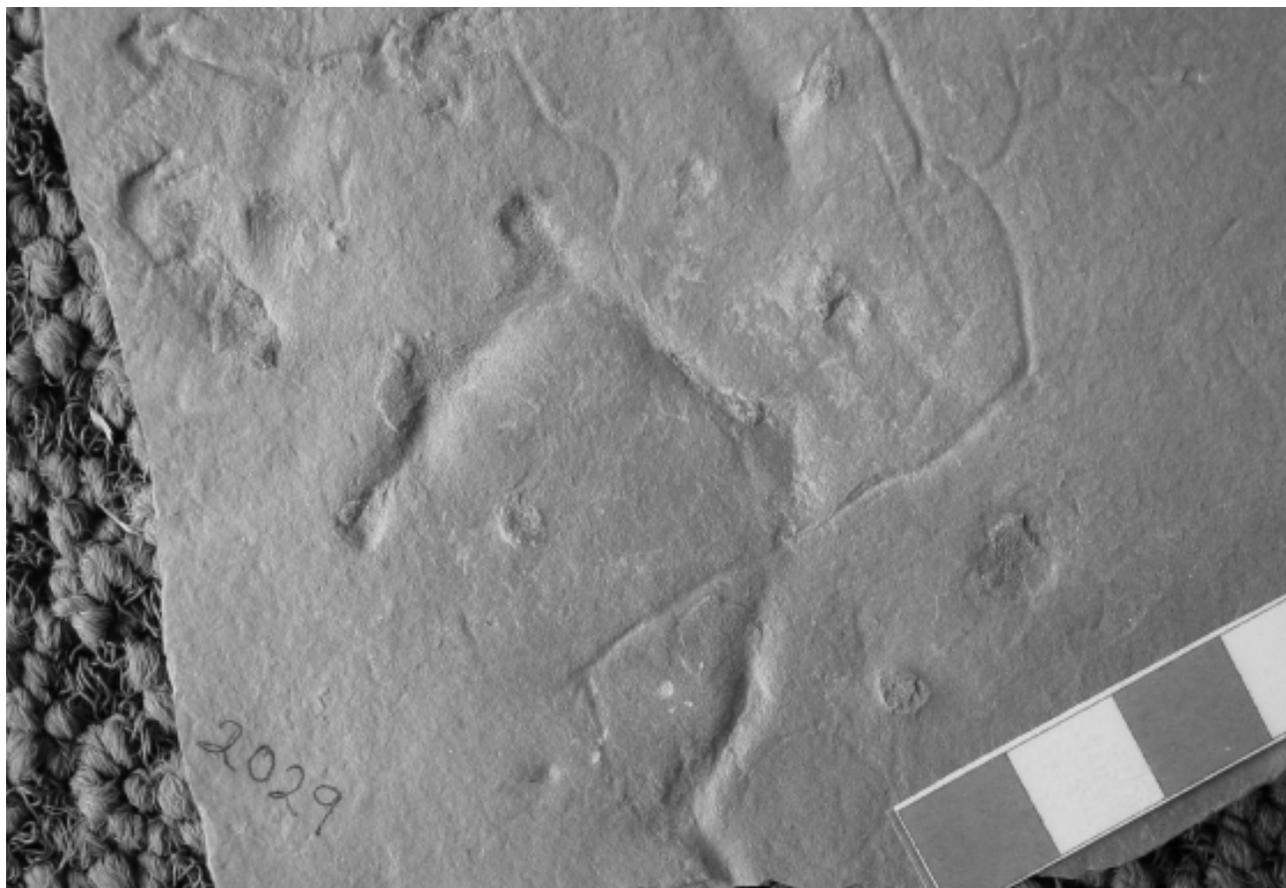


FIGURE 8. *Treptichnus apsorum* showing branching near ends of segments. UCM 2029, upper surface.

parently were all open at the same time (Schlirf, 2000). Häntzschel thus presented a misleading search image. Similar forms were later found in the Eocene flysch of Poland (Uchman et al., 1998) and in other deposits scattered through the Phanerozoic (Schlirf, 2000). These burrows were originally open, with several apertures and no backfill, characteristics more consistent with an agrichnial interpretation than with a deposit-feeding interpretation (Schlirf, 2000); Buatois and Mángano (1993a) questioned whether these burrows belonged in *Treptichnus*, and they are rejected here. The “feather-stitch” *Treptichnus* shows similarities with *Belorhapha*, as pointed out by Buatois and Mángano (1993a).

Jensen (1997, p. 91), and other researchers expanded the concept of *Treptichnus* still further to include the Lower Cambrian trace fossil that Seilacher (1955) named *Phycodes pedum*. Because “*Treptichnus*” *pedum* is now used to define the Precambrian-Cambrian boundary (Brasier et al., 1994), its taxonomy, paleoecology, and stratigraphy are matters of broad interest. *T. pedum* and similar ichnospecies differ from *T. bifurcus* in several respects. This “*pedum* group” has much thicker and more irregular branches whose ends are blunt, although they apparently did extend to the surface as in *T. bifurcus*, as shown in Seilacher’s reconstruction (1955, fig. 4b). In well-preserved examples such as those described by Jensen (1997, fig. 62B), branches were evidently filled passively rather than allowed to collapse as in Carboniferous examples. This is clearly the work of deposit-feeders, but the makers are unknown.

Devonian specimens attributed to *Treptichnus pedum* from the Wapske Formation of New Brunswick have a distinctive bioprint. The tips of the branches are smooth and conical, distinctly separate from the main part of the branches, which have an annulate sculpture (Han and Pickerill, 1995). These specimens may be better placed in still a fourth ichnogenus and species.

Thus, if the overall zigzag shape is set aside, then nearly all the forms attributed to *Treptichnus* fall into three groups (Table 2): (1) *T. pedum* and similar forms that branch irregularly and have relatively broad branches (latest Precambrian to Cambrian, shallow marine); (2) *Belorhapha*-like “feather-stitch” burrows that branch regularly deep in the sediment and whose branches are relatively narrow and constant in diameter, but with extensions that probably reached the surface (Phanerozoic, shallow to deep marine); and (3) *T. bifurcus* and similar forms that branch irregularly just below the sediment-water interface, at or near apertures, and have relatively narrow branches of fairly constant diameter (Carboniferous and recent, freshwater to brackish). Groups 1 and 2 have unknown makers but group 3 is made by insect larvae today. In such cases, it is preferable to choose morphologic criteria that shed light on the maker, behavior, paleoenvironment, or stratigraphy of the trace fossils, rather than adhere to a strictly geometric approach that groups all zigzag burrows together based on a single feature that is conspicuous to the human eye.

The zigzag configuration supports either a deposit-feeding (fodinichnial) or a farming and trapping (agrichnial) life strategy. In the fodinichnial strategy, an

animal shifts from one segment to the next as it feeds on the sediment, perhaps maintaining the last segment as a bioirrigated open hole. In the agrichnial strategy, the animal keeps all the segments open as a trap to catch meiofauna, or alternatively as a farm for microbes that are periodically scraped from the walls. Because behavior, not a human geometric ideal, is the touchstone of ichnotaxonomy, it is desirable to distinguish these very different strategies at the ichnogenetic level despite their superficial similarity in form. In principle, fodinichnial zigzag burrows should have relatively indistinct walls compared to agrichnial ones, because deposit-feeding would have been followed by only a brief period of dwelling before older segments filled or collapsed, whereas farming or trapping would have required maintenance of an open hole for a long time. However, this aspect has not yet been investigated for the marine examples.

### *Treptichnus apsorum* n. isp.

Figs. 1, 4-8

*Etymology.* The name honors the collective effort of the Alabama Paleontological Society (APS), and accordingly is given a plural genitive suffix in the masculine (general) gender. It should be pronounced in three syllables as *ap-sorum*, not as *A-P-S-orum*.

*Diagnosis.* *Treptichnus* consisting of shallow, U-shaped segments serially connected in a zigzag, irregular, or other pattern near their ends, and, where well preserved, having longitudinal striae on at least the lower surface of the burrow, or on each of several laminae flooring the burrow, or in some cases on the sediment beyond the apertures.

*Description.* Subhorizontal burrow consisting of uniserial segments arranged in zigzag or irregular fashion, with shallow, U-shaped segments curving upward into shafts near junctions; parallel longitudinal striation on floor of well-preserved galleries; some galleries with a minimal spreite of a few laminae. Preservation as full-relief epichnia and hypichnia. Longitudinal sections may show anything from the zigzag lower portion to a series of dots for the upper portion. Measurements: gallery width, 1 to 3.5 mm, nearly constant in individual; segment length ranging as much as threefold within an individual, 2.5 to 60 mm; shaft width, about 2 mm; maximum observed length, 9.5 cm.

*Remarks.* In *Treptichnus bifurcus* Miller, 1889, branching is predominantly zigzag, but topotypes include a broad range of forms, including systems branching nearly in a straight line or branched consistently to one side to form an arc. Burrow diameter bulges toward the center or is nearly constant in this ichnogenus, and the burrow segments presumably curved upward to reach the sediment-water interface.

*Treptichnus apsorum* resembles *T. bifurcus* in most respects. However, well-preserved specimens of *T. apsorum* have distinctive longitudinal striation, in some cases on each of several laminae on the floor of the burrow. Also, *T. apsorum* has a relatively great size range

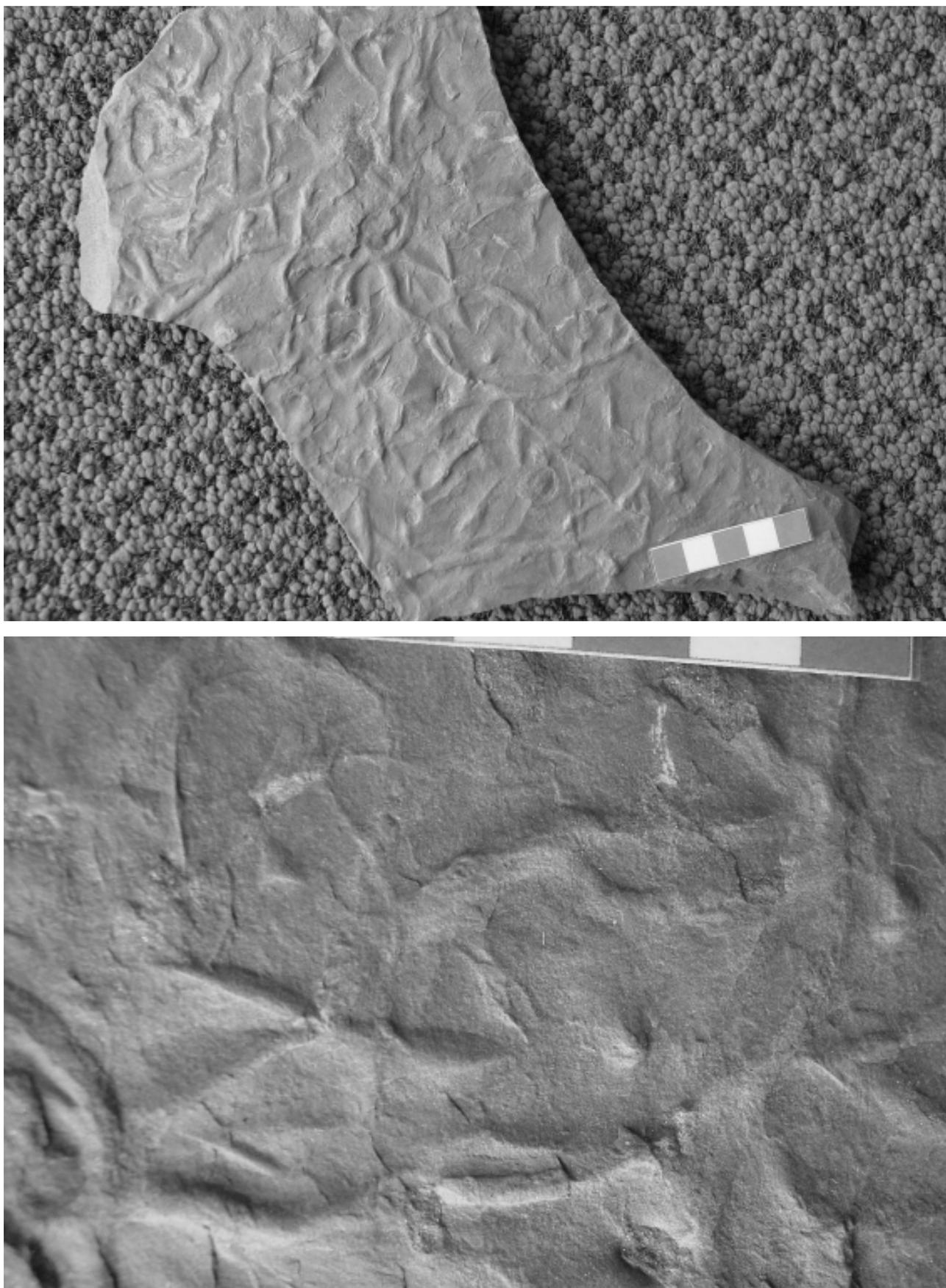


FIGURE 9. A (top). *Treptichnus apsorum* with relatively straight, smooth pattern (reminiscent of *Planolites*) at depth within the substrate. Note the angularity of the burrows' course. Lower surface. B (bottom): Closer view.

TABLE 2. Species attributed to *Treptichnus* Miller, 1889 by various authors.

Mostly Carboniferous freshwater or marginal-marine forms: *Treptichnus sensu stricto*

*Treptichnus bifurcus* Miller, 1889 = *T. bifurcus* (type species)  
*Plangtichnus erraticus* Miller, 1889 = *T. bifurcus*  
*Spirodesmos interruptus* Andre, 1920, *sensu* Archer & Maples, 1984 = *T. bifurcus*  
*Treptichnus pollardi* Buatois & Mángano, 1993a = *T. pollardi*  
*Treptichnus apsorum* n.isp.

Post-Cambrian marine forms: cf. *Belorhappe* Fuchs, 1895

“Feather-stitch trail”, Wilson, 1948  
*Treptichnus aequalternus* Schlirf, 2000  
*Treptichnus meandrinus*, Uchman et al., 1998  
*Treptichnus pedum*, *sensu* Han & Pickerill, 1995  
*Belorhappe protopalaeodictyum* Bandel, 1973

Cambrian marine forms (*pedum* group): unnamed ichnogenus

*Treptichnus coronatum* MacNaughton & Narbonne, 1999  
*Treptichnus lublinensis* Paczeńska, 1996  
*Phycodes pedum* Seilacher, 1955  
*Treptichnus rectangularis* Orlowski & Żylińska, 1996  
*Treptichnus triplex* Palij, 1976

compared to *T. bifurcus*, whose segments in its type area range from 2.0 to 8.4 mm long (Maples and Archer, 1987).

*Range in Alabama.* Lower Pennsylvanian Pottsville Formation, Steven C. Minkin Paleozoic Footprint Site near Union Chapel, Walker County, Alabama.

*Holotype.* UCM 2026.

***Treptichnus bifurcus* Miller, 1889**  
 Figs. 10, 11

- |   |      |   |     |              |   |
|---|------|---|-----|--------------|---|
| * | 1889 | <i>Treptichnus bifurcus</i> Miller, p. 581, fig. 1095 [Lower Pennsylvanian, Indiana].                           | ?   | 1985         | Archer and Maples, p. 455, fig. 5B [Lower Pennsylvanian, Indiana].<br>? <i>Thalassinoides</i> Ehrenberg, Miller and Knox, p. 89, pl. 1A [Pennsylvanian, Tennessee]. |
| * | 1889 | <i>Plangtichnus erraticus</i> Miller, p. 580, fig. 1093 [Lower Pennsylvanian, Indiana].                         | ?   | 1990         | <i>Treptichnus</i> , Rindsberg, p. VI-95, fig. VI-39e [Lower Pennsylvanian, Alabama].   |
|   | 1977 | <i>Treptichnus bifurcus</i> , Forney et al., p. 32 [Lower Pennsylvanian, Indiana].                              |     | 1991         | <i>Treptichnus bifurcus</i> , Rindsberg, p. 141, pl. 2, fig. 6 [Upper Mississippian, Alabama].  |
|   | 1977 | <i>Plangtichnus erraticus</i> , Forney et al., p. 30 [Lower Pennsylvanian, Indiana].                            |     | partim 1993a | <i>Treptichnus bifurcus</i> , Buatois and Mángano, p. 221, figs. 2A-D [Lower Pennsylvanian, Indiana].   |
|   | 1984 | <i>Plangtichnus erraticus</i> , Archer and Maples, p. 452, figs. 5C, E, G, 6A-D [Lower Pennsylvanian, Indiana]. | ?   | 1995         | <i>Plangtichnus erraticus</i> , Archer et al., p. 2034, figs. 7a-c [Carboniferous, Nova Scotia].  |
|   | 1984 | <i>Treptichnus bifurcus</i> , Archer and Maples, p. 455, figs. 5B, D, F, I [Lower Pennsylvanian, Indiana].      | ?   | 1995         | <i>Plangtichnus</i> sp., Greb and Archer, p. 99, fig. 9B [Middle Pennsylvanian, Kentucky].  |
|   | 1984 | <i>Spirodesmos interruptus</i> Andrée,  | non | 1997         | <i>Treptichnus bifurcus</i> , Buatois et al., figs. 5B, 7D [Upper Pennsylvanian, Kansas].   |
|   |      |   |     | 1997         | <i>Treptichnus bifurcus</i> , Jensen, p. 91, fig. 62A [Lower Cambrian, Sweden].   |
|   |      |   |     | 1998         | Insect trackways, Archer, fig. [1] [Lower Pennsylvanian, Indiana].  |
|   |      |   |     | 1998a        | <i>Treptichnus bifurcus</i> , Buatois et al., figs. 21, 24 [Upper Pennsylvanian, Kansas].   |

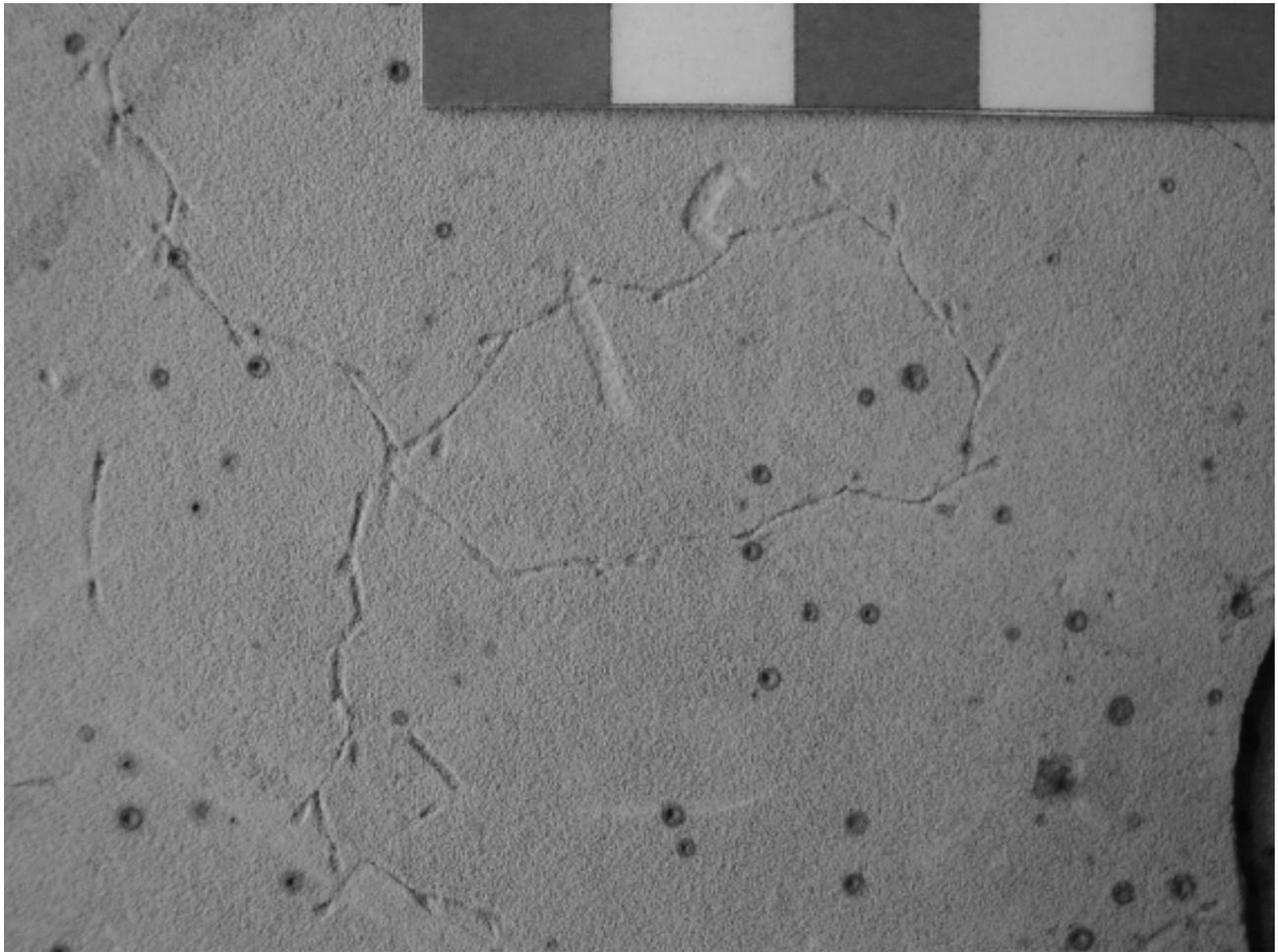


FIGURE 10. Holotype of *Treptichnus bifurcus* from the Lower Pennsylvanian Hindostan whetstone beds (Mansfield Formation) of Orange County, Indiana. Field Museum of Natural History, UC 54099, upper surface.

- 1998b *Treptichnus bifurcus*, Buatois et al., p. 158, fig. 4.6 [Upper Pennsylvanian, Kansas].
- ? 1998a Irregular networks, Buatois et al., fig. 21 [Pennsylvanian, Kansas].
- non 1998 *Treptichnus bifurcus*, Uchman et al., p. 273-274 [Eocene, Poland] [cf. *Belorhapse*].
- non 2000 *Treptichnus bifurcus*, Schlirf, p. 157-158, figs. 12A, B, pl. 2, figs. 7, 8, 10 [Upper Jurassic, France] [cf. *Belorhapse*].
- 2004 *Treptichnus* isp., Uchman et al., p. 140, figs. 5C, 6F, 9B [Oligocene, Switzerland].

*Original diagnoses. Treptichnus bifurcus*: “A zigzag, half-cylindrical, continuous trail, quite evenly depressed, and forked at each angle; the bifurcation takes place in the direction in which the animal moved, but generally is less sunken than the trail, and sometimes shows simply a dot disconnected with the angle” (Miller, 1889, p. 581).

*Plangtichnus erraticus*: “A simple, irregularly zigzag, half-cylindrical, broken trail, running in any and every direction; depressed in spots deeper than the general trail” (Miller, 1889, p. 580).

*Emended diagnosis.* Subhorizontal burrow consisting of a series of U-shaped segments joined angularly at or near their ends; burrow commonly but not invariably zigzag; surface of burrow smooth.

*Remarks.* *Plangtichnus erraticus* is a preservational aspect of *Treptichnus bifurcus* (Maples and Archer, 1987; Buatois and Mángano, 1993a). *Treptichnus pollardi* Buatois and Mángano, 1995 differs from *T. bifurcus* in having shafts extending upward from segment junctions rather than as part of the segments themselves.

*Range in Alabama. T. bifurcus?*: Upper Mississippian lower Parkwood Formation, Irondale, Jefferson County, Alabama (Rindsberg, 1991); Lower Pennsylvanian Pottsville Formation (Mary Lee coal zone), Walker County, Alabama (Rindsberg, 1990).

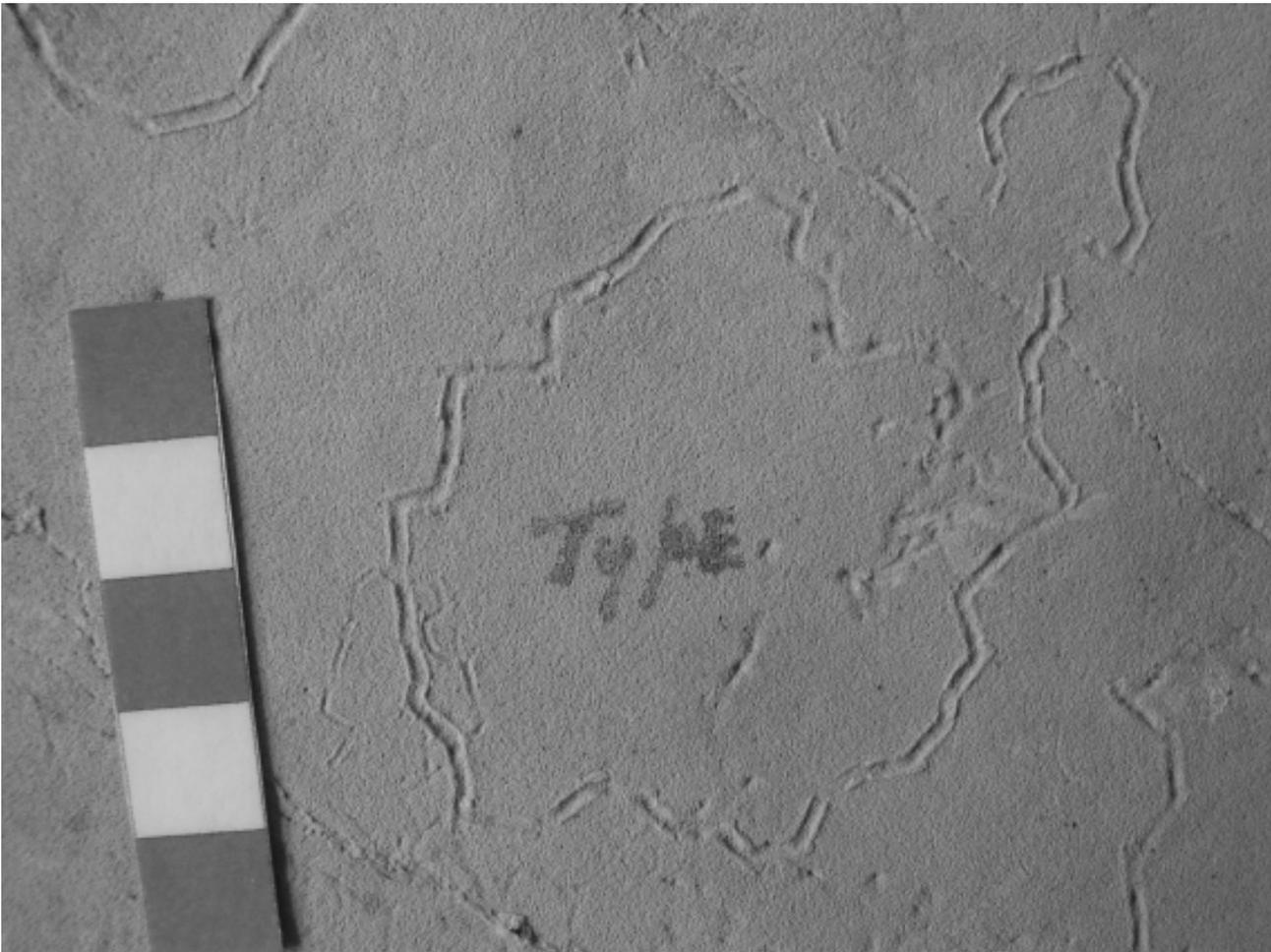


FIGURE 11. Holotype of *Plangtichnus erraticus* from the Lower Pennsylvanian Hindostan whetstone beds (Mansfield Formation) of Orange County, Indiana. Field Museum of Natural History, UC 36077, upper surface.

### **Ichnogenus *Haplotichnus* Miller, 1889**

- \* 1889 *Haplotichnus* Miller, p. 578, fig. 1086 [Lower Pennsylvanian, Indiana].
- 1984 *Haplotichnus*, Archer and Maples, p. 450, fig. 4F [Lower Pennsylvanian, Indiana].
- ? 1985 *Gordia* Emmons, Miller and Knox, p. 84, pl. 2E [Pennsylvanian, Tennessee].
- 1987 *Haplotichnus*, Maples and Archer, p. 890 [Lower Pennsylvanian, Indiana].
- 1994 *Haplotichnus*, Rindsberg, p. 59 [Upper Mississippian, Alabama].
- partim* 1998b *Gordia*, Buatois et al., p. 155 [*G. indianensis* only].

*Original diagnosis.* “Simple, small, half-cylindrical trails running in any direction” (Miller, 1889, p. 578).

*Diagnosis.* Simple trail, straight to curved, commonly in a self-penetrating “scribbled” pattern; path turned smoothly or sharply.

*Type Species.* *Haplotichnus indianensis* Miller, 1889

by original designation.

*Remarks.* *Haplotichnus* differs from the superficially similar *Gordia* in two ways. First, *Gordia* is apparently a burrow, whereas *Haplotichnus* is a trail or at most a very shallow burrow. Second, as pointed out by Maples and Archer (1987) and Buatois et al. (1997), *Haplotichnus* has relatively angular turns as compared to *Gordia*. The sharp turns are significant because short-bodied animals such as arthropods can change direction more easily than long-bodied worms (Rindsberg and Martin, 2003). Thus, *Gordia* may be the work of polychaetes, oligochaetes, and other vermiform animals; *Haplotichnus* is evidently the work of insects and other arthropods, as recognized by Miller (1889).

### ***Haplotichnus indianensis* Miller, 1889**

Fig. 12

- 1889 *Haplotichnus indianensis* Miller, p. 578, fig. 1086 [Lower Pennsylvanian, Indiana].
- 1977 *Haplotichnus indianensis*, Forney et al., p. 28-29 [Lower Pennsylvanian,

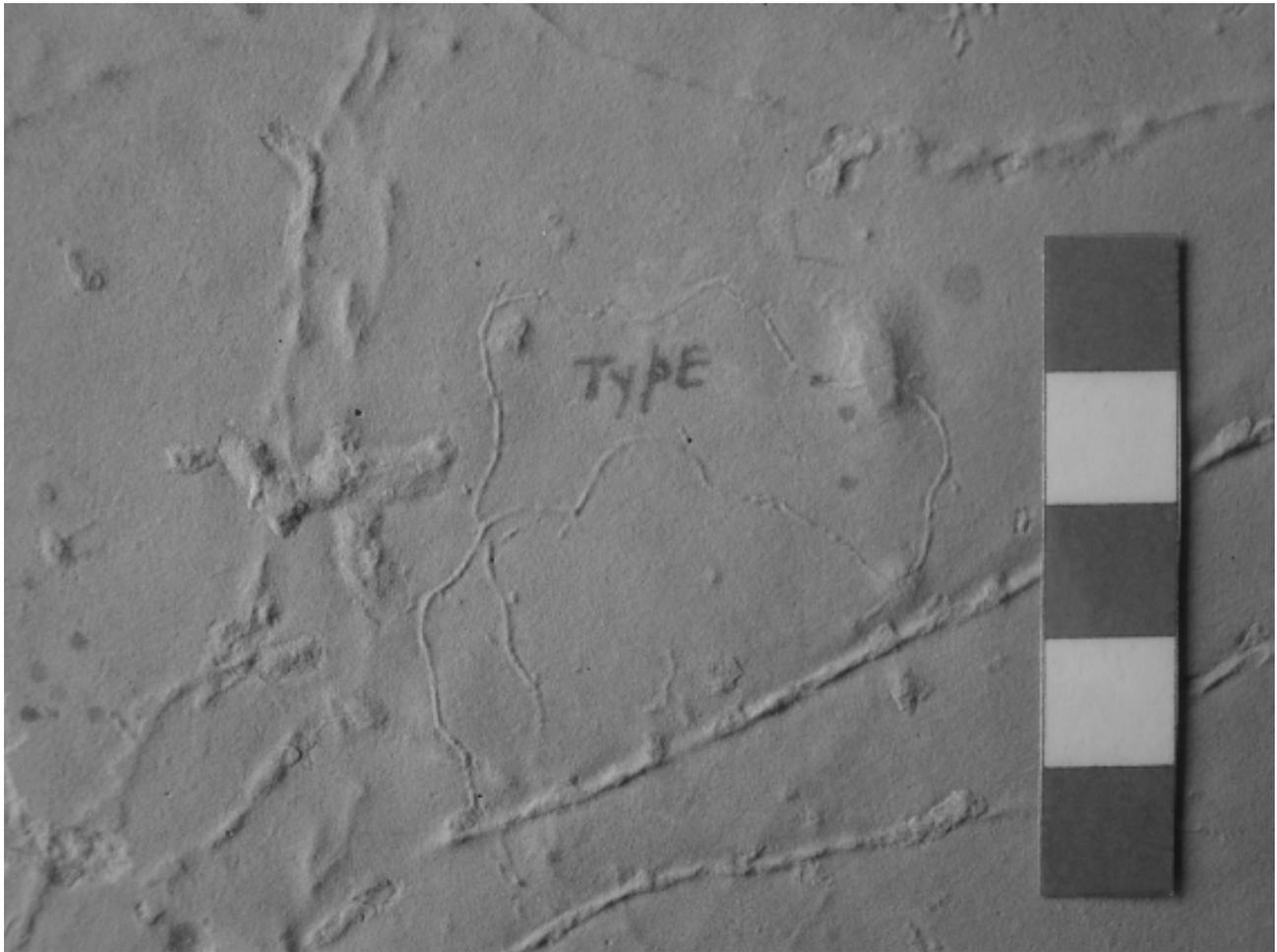


FIGURE 12. Holotype of *Haplotichnus indianensis* from the Lower Pennsylvanian Hindostan whetstone beds (Mansfield Formation) of Orange County, Indiana. Field Museum of Natural History, UC 36076, upper surface. Straight *Treptichnus bifurcus* is also present.

- Indiana].
- 1984 *Haplotichnus indianensis*, Archer and Maples, p. 450, fig. 4F [Lower Pennsylvanian, Indiana].
- 1987 *Haplotichnus indianensis*, Maples and Archer, p. 890-891, fig. 2.1 [Lower Pennsylvanian, Indiana].
- ? 1993b *Haplotichnus indianensis*, Buatois and Mángano, p. 242, fig. 3E [Upper Carboniferous, Catamarca, Argentina].
- ? 1995 *Haplotichnus?* sp., Archer et al., p. 2031-2034, fig. 6e [Lower Pennsylvanian, Nova Scotia].
- 1997 Irregular networks, Buatois et al., fig. 8D [Upper Pennsylvanian, Kansas].
- 1997 *Gordia indianaensis*, Buatois et al., fig. 8B [*nom. null.*] [Upper Pennsylvanian, Kansas].
- 1998a *Gordia indianaensis*, Buatois et al., fig. 17 [*nom. null.*] [Upper Pennsylvanian, Kansas].
- 1998b *Gordia indianaensis*, Buatois et al., p. 155, fig. 4.2 [*nom. null.*] [Upper Pennsylvanian, Kansas].
- Original diagnosis*: “A simple half-cylindrical trail, needle-like in size, running in straight or crooked lines, or crossing itself” (Miller, 1889, p. 578).
- Haplotichnus ornatus* n.isp.**  
Fig. 13
- 1990 *Haplotichnus*, Rindsberg, fig. VI-41I [Lower Pennsylvanian, Alabama].
- 1994 *Haplotichnus* isp., Rindsberg, p. 59, pls. 18D, E [Upper Mississippian, Alabama].
- Etymology*. Latin *ornatus*, ornate.
- Diagnosis*. *Haplotichnus* consisting of a steep-sided groove flanked by pads of sediment.
- Description*. Trail irregularly meandering, tending to concentrate on particular areas of sediment. Trails may penetrate themselves and even retrace older segments, but do not truly branch. Trails may dive into the sub-



FIGURE 13. Holotype of *Haplotichnus ornatus*. Upper Mississippian Hartselle Sandstone, Fielder Ridge, Colbert County, Alabama (Rindsberg, 1994, pl. 18E). GSA 1052-245.

strate for short segments. Pads nearly normal to the axis, distinct only in siltstone to fine-grained sandstone.

*Remarks.* These trails are very similar to *H. indianensis* Miller, 1889 in morphologic details and overall course, differing in sculpture. *H. indianensis* is smooth (C.G. Maples, oral communication, 1989; Buatois et al., 1998b). The sculpture of *Oniscoidichnus filiciformis* (Brady, 1947) is similar to that of *H. ornatus*, and is supposed to be the work of isopods similar to recent *Oniscus*.

*Haplotichnus ornatus* is not known at the Steven C. Minkin Site, but is one of the commonest trace fossils of the freshwater ichnocoenose at other Lower Pennsylvanian sites in Walker County, Alabama (Rindsberg, 1990). The makers are probably arthropods. It also occurs in the Upper Mississippian Hartselle Sandstone, where it is associated with shallow-marine traces such as *Asteriacites* as well as plant debris (Rindsberg, 1994).

*Holotype.* Geological Survey of Alabama Paleontological Collection, GSA 1052-245. Upper Mississippian Hartselle Sandstone, Fielder Ridge, Colbert County, Alabama (Rindsberg, 1994, pl. 18E).

## CONCLUSIONS

Two common, longitudinally striate trace fossils found at the Union Chapel Mine are assigned to new ichnospecies: *Treptichnus apsorum* and *Arenicolites longistriatus*. *Treptichnus apsorum* consists of two or

more connected U-shaped burrows that commonly combine to approximate a zigzag form. *Arenicolites longistriatus* consists of a single U-shaped burrow. On the basis of co-occurrence, similar size range, similar U-shaped burrow building blocks, and similar sculpture (longitudinal striae in well-preserved specimens), we argue that both ichnospecies were made by the same organisms. Comparison to modern traces with known makers indicates that *T. apsorum* and *A. longistriatus* were made by arthropods with behavior similar to modern dipteran larvae.

Both *T. apsorum* and *A. longistriatus* co-occur with *Undichna* (a fish swimming trace) and with invertebrate trackways (not undertracks) that were made on wet muddy surfaces but with no signs of desiccation. Hence, the makers of *T. apsorum* and *A. longistriatus* were certainly active on sediment surfaces underneath shallow water, and possibly also briefly exposed to the air at low tide. *T. apsorum* varies greatly in size, but not on any one slab, suggesting that tracemaker populations consisted of same-aged cohorts. Slabs with bimodal size ranges may indicate superposition of traces made at different times. The great overall size range suggests that deposition of the *Cincosaurus* beds encompassed at least one season: time for insect larvae to grow to maturity.

*Haplotichnus indianensis* may have been made by small insect larvae; in contrast, *Haplotichnus ornatus* from other Alabama Carboniferous units was more likely made by marine arthropods. Ichnogenus *Treptichnus* is confined to *T. bifurcus* (the type ichnospecies), *T. apsorum*, and *T. pollardi*. Ichnofamily Arenicolitidae is

revised.

*For additional photographs of invertebrate trackways and other traces from the Union Chapel Mine, see Buta et al. (2005).*

### ACKNOWLEDGMENTS

We thank with pleasure those who shared their knowledge of *Treptichnus* and *Arenicolites* with us. The list only begins with Alfred Uchman (Jagiellonian University), Sören Jensen (Universidad de Extremadura), Jordi M. de Gibert (Universitat de Barcelona), and Luis A. Buatois and M. Gabriela Mángano (University of Saskatchewan). We also thank the many collectors who selflessly donated specimens to preserve them for the public. W. Edward Osborne (Geological Survey of Alabama) reviewed the manuscript.

### REFERENCES

- Aldrich, T. H., Sr., 1930, Description of tracks; in Aldrich, T.H., Sr. and Jones, W.B., Footprints from the Coal Measures of Alabama: Alabama Museum of Natural History, Museum Paper, 9, p. 13-64, 17 pls.
- Andrée, K., 1920, Über einige fossile Problematika, I. Ein Problematikum aus dem Paläozoikum von Battenberg an der Eder und das dasselbe beherbergende Gestein: Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, 1920(1), p. 55-88, 1 pl.
- Archer, A. W., 1998, Implications of Carboniferous cyclic rhythmites. *Geotimes*, v. 43(5), p. 23-26.
- Archer, A. W., Calder, J. H., Gibling, M. R., Naylor, R. D., Reid, D. R. and Wightman, W. G., 1995, Invertebrate trace fossils and agglutinated foraminifera as indicators of marine influence within the classic Carboniferous section at Joggins, Nova Scotia, Canada: *Canadian Journal of Earth Sciences*, v. 32(12), p. 2027-2039.
- Archer, A. W. and Maples, C. G., 1984, Trace-fossil distribution across a marine-to-nonmarine gradient in the Pennsylvanian of southwest Indiana: *Journal of Paleontology*, v. 48(2), p. 448-466.
- Atkinson, T. P., 2005, Arthropod body fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian footprints in the Black Warrior basin of Alabama: Alabama Paleontological Society, Monograph, no. 1, p. 169-176.
- Balastieri, P., Netto, R. G. and Lavina, E. L. C., 2002, Ichnofauna from the Upper Carboniferous-Lower Permian rhythmites from Mafra, Santa Catarina State, Brazil: ichnotaxonomy: *Revista Brasileira de Paleontologia*, v. 4, p. 13-26.
- Bandel, K., 1973, Trace fossils from the Upper Devonian Nehden siltstone of Wuppertal-Barmen (Nordrhein-Westfalen, Germany): *Palaeontographica*, ser. A, v. 174, p. 157-176, pls. 37-39.
- Bentz, A., 1929, Fossile Röhrenbauten im Unterneokom des Isterbergs bei Bentheim. Prussia, Preussische Geologische Landesanstalt und Bergakademie, Jahrbuch, v. 49(2 [for 1928]): p. 1173-1183, pl. 74.
- Billings, E., 1872, On some fossils from the primordial rocks of Newfoundland: *Canadian Naturalist*, n.ser., v. 6, 465-479.
- Binney, E. W., 1852, On some trails and holes found in rocks of the carboniferous strata, with remarks on the *Microconchus carbonarius*: Manchester Literary and Philosophical Society, *Memoirs and Proceedings*, (2) 10(6), p. 181-201, pls. 1-2.
- Brady, L. F., 1947, Invertebrate tracks from the Coconino sandstone of northern Arizona: *Journal of Paleontology*, v. 21, p. 466-472, pls. 66-69.
- Brasier, M., Cowie, J. and Taylor, M., 1994, Decision on the Precambrian-Cambrian boundary stratotype: *Episodes*, v. 17(1-2):, p. 3-8.
- Buatois, L. A. and Mángano, M. G., 1993a, The ichnotaxonomic status of *Plangtichnus* and *Treptichnus*: *Ichnos*, v. 2(3), p. 217-224.
- Buatois, L. A. and Mángano, M. G., 1993b, Trace fossils from a Carboniferous turbiditic lake: implications for the recognition of additional non-marine ichnofacies: *Ichnos*, v. 2(3), p. 237-258.
- Buatois, L. A., Mángano, M. G. and Maples, C. G., 1997, The paradox of non-marine ichnofaunas in tidal rhythmites: integrating sedimentologic and ichnologic data from the Late Cretaceous of eastern Kansas, USA: *Palaios*, v. 12(5), p. 467-481.
- Buatois, L. A., Mángano, M. G., Maples, C. G. and Lanier, W. P., 1998a, Allostratigraphic and sedimentologic applications of trace fossils to the study of incised estuarine valleys: an example from the Virgilian Tonganoxie Sandstone Member of eastern Kansas: *Kansas Geological Survey, Current Research in Earth Sciences*, no. 241(1), p. 1-27.
- Buatois, L. A., Mángano, M. G., Maples, C. G. and Lanier, W. P., 1998b, Ichnology of an Upper Carboniferous fluvio-estuarine paleovalley: the Tonganoxie Sandstone, Buildex Quarry, eastern Kansas, USA: *Journal of Paleontology*, v. 72(1), p. 152-180.
- Buta, R. J., Kopaska-Merkel, D. C., Rindsberg, A. K., and Martin, A. J., 2005, Atlas of Union Chapel Mine invertebrate trackways and other traces; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 277-337.
- Chamberlain, C. K., 1971, Morphology and ethology of trace fossils from the Ouachita Mountains, southeastern Oklahoma: *Journal of Paleontology*, v. 45(2), p. 212-246, pls. 29-32.
- Chamberlain, C. K., 1977, Ordovician and Devonian trace fossils from Nevada: Nevada Bureau of Mines and Geology, Bulletin 90, 24 pp.
- Droser, M. L., Jensen, S. and Gehling, J. G., 2002, Trace fossils and substrates of the terminal Proterozoic-Cambrian transition: implications for the record of early bilaterians and sediment mixing: *Proceedings of the National Academy of Sciences of the United States of America*, v. 99(20), p. 12572-12576.
- Enders, H. E., 1908, Observations on the formation and enlargement of the tubes of the marine annelid, (*Chaetopterus variopedatus*): *Proceedings of the Indiana Academy of Science*, v. 1907, p. 128-135, 2 pls.
- Evenhuis, N. L., 2004, Catalogue of the fossil flies of the world (Insecta: Diptera). URL <http://hbsbishopmuseum.org/fossilcat>, accessed March 9, 2005. Originally published 1994, Leiden, Backhuys Publishers.
- Fliche, P., 1906, Flore fossile du Trias en Lorraine et en Franche-Comté Société des Sciences de Nancy: *Bulletin des Séances*, (3) 6 (1905), p. 1-66, pls. 1-5.
- Forney, G. G., Jenkins, D. T. and Nitecki, M. H., 1977, Type fossil *Miscellanea* (worms, problematica, conoidal shells, trace fossils) in Field Museum: *Fieldiana, Geology*, v. 37(1), p. 1-41.
- Fuchs, T., 1895, Studien über Fucoiden und Hieroglyphen: Akademie der Wissenschaften zu Wien, mathematisch-naturwissenschaftliche Classe, *Denkschriften*, v. 62, p. 369-448, 1 pl.
- Fnrnsich, F. T., 1974, On *Diplocraterion* Torell 1870 and the significance of morphological features in vertical, spreiten-bearing, U-shaped trace fossils: *Journal of Paleontology*, v. 48(5),

- p. 952-962.
- Goldring, R., 1962, The trace fossils of the Baggy Beds (Upper Devonian) of north Devon, England: *Paläontologische Zeitschrift*, v. 36, p. 232-251, pls. 22-23.
- Greb, S. F. and Archer, A. W., 1995, Rhythmic sedimentation in a mixed tide and wave deposit, Hazel Patch sandstone (Pennsylvanian), Eastern Kentucky Coal Field: *Journal of Sedimentary Research*, v. B65(1), p. 96-106.
- Häntzschel, W., 1975, Trace fossils and problematica; in Teichert, C., ed., *Treatise on invertebrate paleontology*, part W. Miscellaneous, supplement 1, W269 pp. Boulder, Colorado, Geological Society of America and Lawrence, Kansas, University of Kansas Press.
- Hall, J., 1847, *Palaeontology of New-York*, v. 1. Containing descriptions of the organic remains of the lower division of the New-York System, (equivalent in part to the Lower Silurian rocks of Europe). *Natural History of New York*. Albany, C. van Benthuyzen, xxiii + 338, 87 + 1 pls.
- Hall, J., 1852, *Palaeontology of New York*, v. 2. Containing descriptions of the lower Middle Devonian of the New York System (equivalent in part to the Middle Silurian rocks of Europe). *Natural History of New York*. Albany, C. van Benthuyzen, viii + 363 p., '85' [101] pls.
- Han, Y. and Pickerill, R. K., 1995, Palichnology of the Lower Devonian Wapske Formation, Perth-Andover-Mount Carleton region, northwestern New Brunswick, eastern Canada: *Atlantic Geology*, v. 30(for 1994), p. 217-245.
- Haubold, H., Allen, A., Atkinson, T. P., Buta, R. J., Minkin, S. and Relihan, B., 2005, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society, Monograph no. 1, p. 75-111.
- Hundt, R., 1941, *Das mitteldeutsche Phycodesmeer*. Gustav Fischer, Jena, 136 pp.
- Jensen, S., 1997, Trace fossils from the Lower Cambrian Mickwitzia sandstone, south-central Sweden: *Fossils and Strata*, v. 42, 111 pp.
- Kvale, E. P., Archer, A. W. and Johnson, H. R., 1989, Daily, monthly and yearly tidal cycles within laminated siltstones of the Mansfield Formation (Pennsylvanian) of Indiana: *Geology*, v. 17(4), p. 365-368.
- Lessertisseur, J., 1956, Traces fossiles d'activité animale et leur signification paléobiologique: *Mémoires de la Société Géologique de France*, n.ser., v. 74, p. 1-150.
- Lucas, S. G., Lerner, A. J., Bruner, M. and Shipman, P., 2004, Middle Pennsylvanian ichnofauna from eastern Oklahoma, USA: *Ichnos*, v. 11(1-2), p. 45-55.
- MacGinitie, G.E. and MacGinitie, N., 1968, *Natural history of marine animals* (2nd edition). New York, McGraw-Hill, 523 pp.
- MacNaughton, R. B. and Narbonne, G. M., 1999, Evolutionary and environmental controls on Neoproterozoic-Early Cambrian ichnofossils, NW Canada: *Palaio*, v. 14(2), p. 97-115.
- Mägdefrau, K., 1932, Über einige Bohrgänge aus dem unteren Muschelkalk von Jena: *Paläontologische Zeitschrift*, v. 14, p. 150-160, pl. 5.
- Maples, C. G. and Archer, A. W., 1987, Redescription of Early Pennsylvanian trace-fossil holotypes from the nonmarine Hindostan whetstone beds of Indiana: *Journal of Paleontology*, v. 61(5), p. 890-897.
- Martin, A. J. and Pyenson, N. D., 2005, Behavioral significance of vertebrate trace fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society, Monograph no. 1, p. 59-73.
- Metz, R., 2000, Triassic trace fossils from lacustrine shoreline deposits of the Passaic Formation, Douglassville, Pennsylvania: *Ichnos*, v. 7(4), p. 253-266.
- Miller, M. F. and Knox, L., W. 1985, Biogenic structures and depositional environments of a Lower Pennsylvanian coal-bearing sequence, northern Cumberland Plateau, Tennessee, U.S.A; in Curran, H. A., ed., *Biogenic structures: their use in interpreting depositional environments*. Society of Economic Paleontologists and Mineralogists, Special Publication, v. 35, p. 67-97.
- Miller, S. A., 1879, Description of twelve new fossil species, and remarks upon others: *Journal of the Cincinnati Society of Natural History*, v. 2(2), p. 104-118, pls. 9-10.
- Miller, S. A., 1889, *North American geology and paleontology for the use of amateurs, students and scientists*: Cincinnati, Ohio, Western Methodist Book Concern, 664 pp.
- Miller, S. A. and Dyer, C. B., 1878, Contributions to paleontology [no. 1]: *Journal of the Cincinnati Society of Natural History*, v. 1, p. 24-39, pls. 1-2.
- Orlowski, S. and Zylinska, A., 1996, Non-arthropod burrows from the Middle and Late Cambrian of the Holy Cross Mountains, Poland. *Acta Palaeontologica Polonica*, v. 41(4), p. 385-409.
- Osgood, R. G., 1970, Trace fossils of the Cincinnati area. *Palaeontographica Americana*, v. 6(41), p. 277-444, pls. 57-83.
- Paczerna, J., 1996, The Vendian and Cambrian ichnocoenoses from the Polish part of the East-European Platform: *Prace Panstwowego Instytutu Geologicznego*, v. 152, p. 1-77.
- Palij, V. M., 1976, Ostatki besskieletnoiy fauny i sledy zhiznedelatelnosti iz otlozheniy vierhnoho dokembria i nizhneho kembria Podolii; in *Paleontologia i stratigrafia vostokneho dokembria i nizhneho paleozoya yugo-zapada Vostochno-Evropeskoj platformy*. Naukova Dumka, Kiev, p. 63-77.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel lagerstätte; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian footprints in the Black Warrior basin of Alabama*: Alabama Paleontological Society, Monograph no. 1, p. 39-58.
- Pemberton, S. G. and Frey, R. W. 1982, Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma: *Journal of Paleontology*, v. 56(4), p. 843-881, 5 pls.
- Pollard, J. E., 1981, A comparison between the Triassic trace fossils of Cheshire and south Germany: *Palaeontology*, v. 24(3), p. 555-588, pls. 86-90.
- Pollard, J. E., 1999, *Arenicolites carbonarius* in the Manchester region: ichnofabrics of a deltaic opportunist. In Pollard, J. and Taylor, A., eds. *Fifth International Ichnofabric Workshop IHW5*, Manchester University, 12th-14th July 1999, Abstract volume, unpaginated.
- Richter, R., 1924, Flachseebeobachtungen zur Paläontologie und Geologie, VII. *Arenicola* von Heute und "*Arenicoloides*," eine Rhizocorallide des Buntsandsteins, als Vertreter verschiedener Lebensweise: *Senckenbergiana*, v. 6, p. 119-140.
- Richter, R., 1926, Flachseebeobachtungen zur Paläontologie und Geologie XII. Bau, Begriff und paläogeographische Bedeutung von *Corophioides luniformis* (BLANCKENHORN, 1917): *Senckenbergiana*, 8: 200-219, pl. 3.
- Rindsberg, A. K., 1990, Freshwater to marine trace fossils of the Mary Lee coal zone and overlying strata (Westphalian A, Pottsville Formation of northern Alabama); in Gastaldo, R. A., Demko, T. M. & Liu, Y., eds., *Carboniferous coastal environments and paleocommunities of the Mary Lee coal zone, Marion and Walker Counties, Alabama*: Geological Society of America, Southeastern Section, Field Trip 6, Alabama Geological Survey, Guidebook Series, 3-6: VI-82 to VI-95.
- Rindsberg, A. K., 1991, Ichnology of the Carboniferous Parkwood Formation in the Cahaba synclinorium near Birmingham, Alabama; In Thomas, W.A. and Osborne, W.E., eds. *Missis-*

- sippian-Pennsylvanian tectonic history of the Cahaba synclinorium: Alabama Geological Society, Annual Field Trip, Guidebook, v. 28, p. 133-147, 2 pls.
- Rindsberg, A. K., 1994, Ichnology of the Upper Mississippian Hartselle Sandstone of Alabama, with notes on other Carboniferous formations: Geological Survey of Alabama, Bulletin 158, 107 pp., 22 pls.
- Rindsberg, A. K., 2005, Gas-escape structures and their paleoenvironmental significance at the Steven C. Minkin Paleozoic Footprint Site (Early Pennsylvanian, Alabama); in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society, Monograph no. 1, p. 177-183.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2003, *Treptichnus* and related trace fossils from the Union Chapel Mine (Langsettian, Alabama, USA): Workshop on Permo-Carboniferous Ichnology, Tuscaloosa, Alabama, p. 27-28.
- Rindsberg, A. K. and Martin, A. J., 2003, *Arthropycus* in the Silurian of Alabama (USA) and the problem of compound trace fossils: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 192, p. 187-219.
- Rindsberg, A. K., Martin, A. J. and Pyenson, N. D., 2001, Ichnofossil-Lagerstätte in Alabama: a world-class Carboniferous (Westphalian A) tracksite. Program and Abstracts; NAPC 2001, North American paleontological convention 2001, Paleontology in the new millennium. University of California, Museum of Paleontology, Berkeley, California: PaleoBios, v. 21(2, Suppl.), p. 109.
- Rindsberg, A. K., Uchman, A. and Kopaska-Merkel, D. C., 2004, *Treptichnus* made by insect larvae in the Pennsylvanian of Alabama (USA): First International Congress on Ichnology, April 19-23, 2004, Trelew, Patagonia Argentina, Museo Paleontológico Egidio Feruglio, p. 70.
- Salter, J. W., 1856, On fossil remains in the Cambrian rocks of the Longmynd and north Wales: Quarterly Journal of the Geological Society of London, v. 12, p. 246-252, pl. 4.
- Salter, J. W., 1857, On annelide-burrows and surface-markings from the Cambrian rocks of the Longmynd, No. 2: Quarterly Journal of the Geological Society of London, v. 13, p. 199-206, pl. 5.
- Schlirf, M., 2000, Upper Jurassic trace fossils from the Boulonnais (northern France): Geologica and Palaeontologica, v. 34, p. 145-213.
- Seilacher, A., 1953, Studien zur Paläichnologie. I. Über die Methoden der Paläichnologie: Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, v. 96(3), p. 421-452, pl. 14.
- Seilacher, A., 1955, Spuren und Fazies im Unterkambrium; in Schindewolf, O. H. and Seilacher, A., Beiträge zur Kenntnis des Kambriums in der Salt Range (Pakistan): Akademie der Wissenschaften und der Literatur zu Mainz, mathematisch-naturwissenschaftliche Klasse, Abhandlungen, v. 10, p. 373-399.
- Seilacher, A. and Hemleben, C., 1966, Beiträge zur Sedimentation und Fossil-führung des Hunrückschiefers, Teil 14, Spurenfaua und Bildungstiefe des Hunrückschiefers: Notizblatt des Hessisches Landesmat für Bodenforschung, v. 94, p. 40-53, pls. 2-4.
- Seilacher, A. and Meischner, D., 1965, Fazies-Analyse im Paläozoikum des Oslo-Gebeites: Geologische Rundschau, v. 54 (for 1964), p. 596-619.
- Serres, M. de, 1840, Description de quelques mollusques fossiles nouveaux des terrains infra-jurassiques et de craie compacte inférieure du Midi de la France: Annales des Sciences Naturelles, Zoologie, (2) v. 14, p. 5-25, pls. 1, 2.
- Tessier, B., Archer, A. W., Lanier, W. P. and Feldman, H. R., 1995, Comparison of ancient tidal rhythmites (Carboniferous of Kansas and Indiana, USA) with modern analogues (the Bay of Mont-Saint-Michel, France); in Fleming, B. W. and Bartholomä, A., eds., Tidal signatures in modern and ancient sediments: International Association of Sedimentologists, Special Publication, v. 24, p. 259-271.
- Uchman, A., 2005, *Treptichnus*-like traces produced by insect larvae (Diptera: Chironomidae, Tipulidae); in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society, Monograph no. 1, p. 143-146.
- Uchman, A., Bromley, R. G. and Leszczynski, S., 1998, Ichnogenus *Treptichnus* in Eocene flysch, Carpathians, Poland: taxonomy and preservation: Ichnos, v. 5(4), p. 269-275.
- Uchman, A., Pika-Biolzi, M. and Hochuli, P. A., 2004, Oligocene trace fossils from temporary fluvial plain ponds: an example from the Freshwater Molasse of Switzerland: Eclogae Geologicae Helvetiae, v. 97, p. 133-148.
- Vialov, O. S., 1961, Materialy k klassifikatsii iskopaemykh sledov i sledov zhiznedeyatelnosti organizmov: Paleontologicheskii Sbornik, v. 1(5), p. 125-129.
- Wetzel, A. and Uchman, A., 1997, Ichnology of deep-sea fan overbank deposits of the Ganei Slates (Eocene, Switzerland) — a classical flysch trace fossils locality studied first by Oswald Heer: Ichnos, v. 5(2), p. 139-162.
- Wilson, A. E., 1948, Miscellaneous classes of fossils, Ottawa Formation, Ottawa-St. Lawrence Valley. Geological Survey of Canada, Department of Mines and Resources, Bulletin, 11, 116 pp., 28 pls.

#### AUTHORS' E-MAIL ADDRESSES

Andrew K. Rindsberg: arindsberg@gsa.state.al.us  
 David C. Kopaska-Merkel: davidkm@gsa.state.al.us



Finding trackways in the field: (left to right) Ron Buta, Jimmy Baldwin, Jr., and Ashley Allen pose with a large rock containing numerous criss-crossing invertebrate trackways (*Kouphichnium*), found during a field trip to the Union Chapel Mine in May, 2003. Photo credit: another attendee.

## **TREPTICHNUS-LIKE TRACES MADE BY INSECT LARVAE (DIPTERA: CHIRONOMIDAE, TIPULIDAE)**

ALFRED UCHMAN

Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, 30-063 Kraków, Poland

**ABSTRACT:** It is shown that the abundant traces of *Treptichnus* found at the Union Chapel Mine closely resemble those made by dipteran larvae collected from temporary ponds on recent flood plains and from point bars of muddy sand exposed along rivers.

Tracemakers of most ichnotaxa remain unknown. This is ichnology's Achilles tendon, despite great effort made in this matter (e.g., Bromley, 1996). Even in terrestrial environments, where neoichnologic research is relatively easy, and some research has been done (e.g., Chamberlain, 1975; Ratcliffe and Fagerstrom, 1980; Metz 1987a, 1987b; Mángano et al., 1996), large gaps in our knowledge of tracemakers still exist. One solution is simple experimentation with animals, an example of which is illustrated in this article.

A few taxa of dipteran larvae were collected from temporary ponds on recent flood plains and from point bars of muddy sand exposed along rivers in southern Poland. The larvae were kept in tanks filled with fresh, plastic mud that was allowed to dry out. They produced several kinds of traces, which show morphologic changes according to the changing consistency of the mud.

One of the most characteristic traces is made by chironomid (midge) larvae collected from sandy mud along a river bank. They produce shallow tunnels whose roof protrudes over the mud surface. Periodically, a characteristic "knot" is produced that marks where the larva communicated directly to the surface. The knots subdivide the trace into straight to somewhat curved segments (Fig. 1). Short side branches protrude from some of the knots. The trace locally displays loops and coils (Fig. 2). This trace is no more than 1 mm wide. The morphology of the trace is very similar to the trace fossil *Treptichnus* (Rindsberg and Kopaska-Merkel, 2005). The chironomid larvae are detritus or algae feeders or carnivores. More information about their life habits is available in Oliver (1971).

The *Treptichnus*-like pattern can also be seen in larger traces produced by larvae of crane flies (Tipulidae). These are also subsurface tunnels and show the characteristic side protrusions (Fig. 3). The larvae produce mostly different furrows and subsurface tunnels, which are 2-3 mm wide. Within a certain range of mud consistency, fine, longitudinal striae can be seen in the furrows. Striae are produced by dragging the lobes and papillae around the posterior spiracle (Fig. 4). Longitudinal striation is also seen in fossil material. Tipulid larvae are efficient deposit feeders, responsible for bioturbation of mud and sandy mud along rivers as observed by the author.

*Treptichnus* has already been considered the product of dipteran larvae. *Treptichnus bifurcus* Miller has been compared with tabanid larvae traces (Buatois et al., 1998), based on modern subsurface tunnels illustrated by Bajard (1966, fig. 36). Taking into account

the similarities outlined above, it can be hypothesized that insect larvae produced *Treptichnus* from the Union Chapel Mine. According to body fossil data, the *Diptera* range from the Permian onward (Labandeira, 1999), but the Union Chapel Mine trace fossils are dated as Late Carboniferous. It is not out of the question either that dipteran insects already existed in the Carboniferous, or that the trace fossils were produced by insect larvae of similar behavior but belonging to some other, maybe related, systematic group. The first possibility is strengthened by the fact that trace fossils have larger preservational potential than body fossils.

### ACKNOWLEDGMENTS

A. K. Rindsberg and D. C. Kopaska-Merkel (Alabama) improved the English and provided helpful comments. G. Mángano (Saskatchewan) provided further helpful comments and pointed to useful papers. Andrzej Palaczyk (Kraków) provided information on the larvae.

### REFERENCES

- Bajard, J., 1966, Figures et structures sédimentaires dans la zone intertidale de la partie orientale de la Baie du Mont-Saint-Michel: *Revue de Géographie Physique et de Géologie Dynamique*, v. 8, p. 39-111.
- Bromley, R. G., 1996, *Trace Fossils: Biology, Taphonomy and Applications* (second edition): London, Chapman and Hall, 361 pp.
- Buatois, L. A., Mángano, M. G., Maples, C. G. and Lanier, W. P., 1998, Ichnology of an Upper Carboniferous fluvio-estuarine paleovalley: The Tonganoxie Sandstone, Buildex Quarry, eastern Kansas, USA: *Journal of Paleontology*, v. 72, p. 152-180.
- Chamberlain, C. K. 1975. Recent lebensspuren in non-marine environments; in Frey, R. W., ed., *The Study of Trace Fossils*: New York, Springer Verlag, p. 431-458.
- Labandeira, C. C., 1999, Insects and other hexapods; in Singer, R., ed., *Encyclopedia of Paleontology*, v. 1 (A-L), p. 603-624.
- Mángano, M. G., Buatois, L. A. and Clips, G. L., 1996, Grazing trails formed by soldier fly larvae (Diptera: Stratiomyidae) and their paleoenvironmental and paleoecological implications for the fossil record: *Ichnos*, v. 4, p. 163-167.
- Metz, R., 1987a, Insect traces from non-marine ephemeral puddles: *Boreas*, v. 16, p. 189-195.
- Metz, R., 1987b, Recent traces by invertebrates in aquatic non-marine environments: *Bulletin of the New Jersey Academy of Sciences*, v. 32, p. 19-24.
- Oliver, D. R., 1971, Life history of the Chironomidae: *Annual Review of Entomology*, v. 16, p. 211-230.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, *Treptichnus* and *Arenicolites* from the Steven C. Minkin Paleozoic Footprint site (Langsettian, Alabama, USA); in Buta, R. J.,

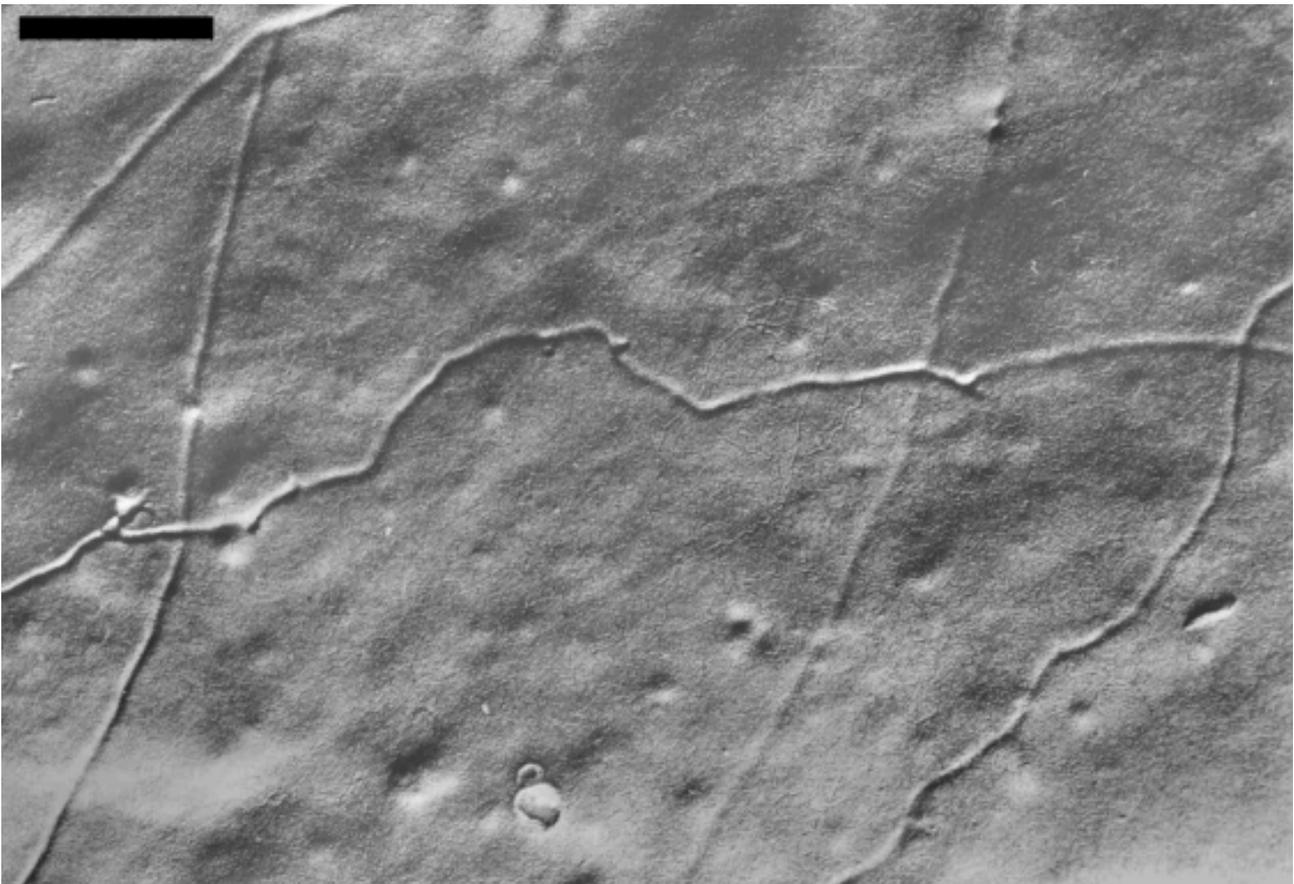


FIGURE 1. Traces produced by Chironomidae larvae in a plastic mud. The traces are subsurface tunnels. Scale bar is 1 cm long.

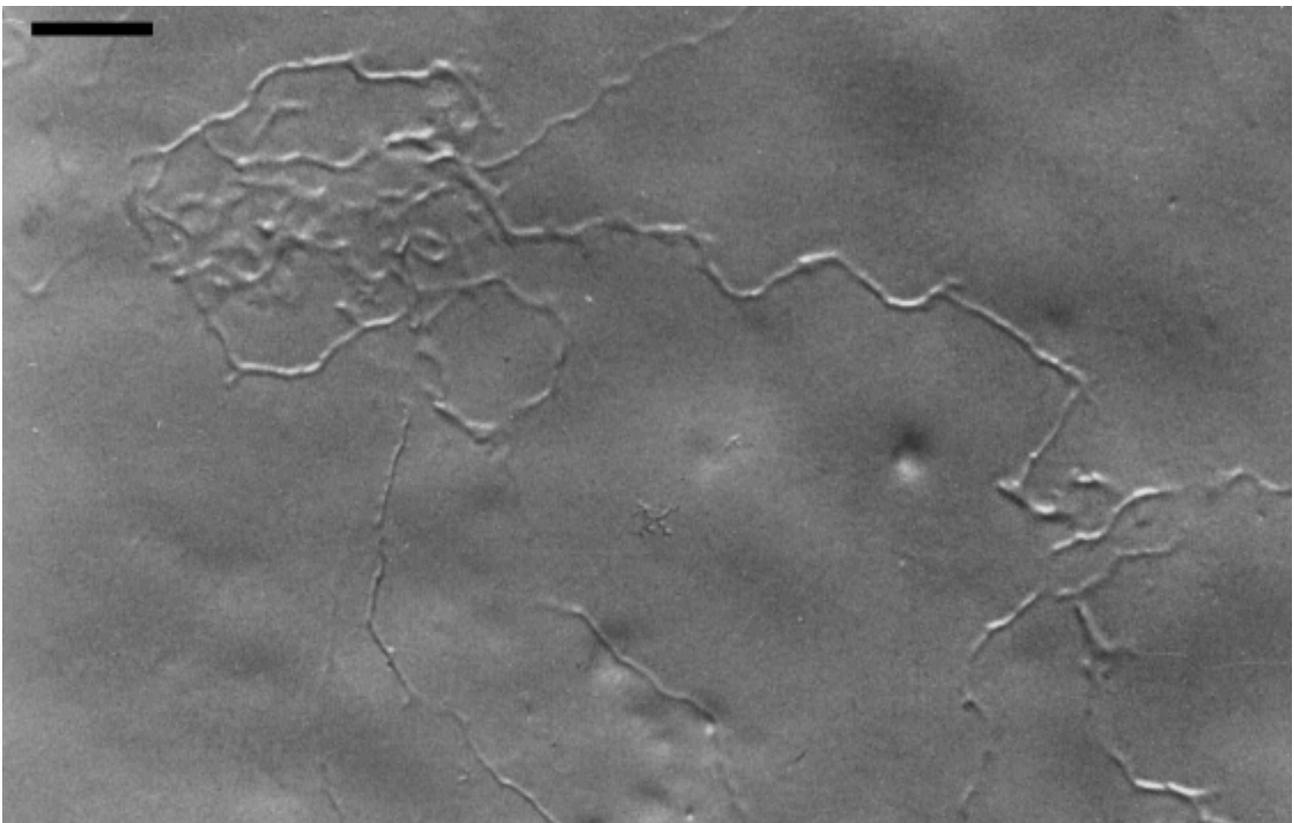


FIGURE 2. Traces produced by a chironomid larva in a plastic mud as in Fig. 1. Scale bar is 1 cm long. Note the characteristic side protrusions and coiling typical of *Treptichnus* from the Union Chapel Mine.

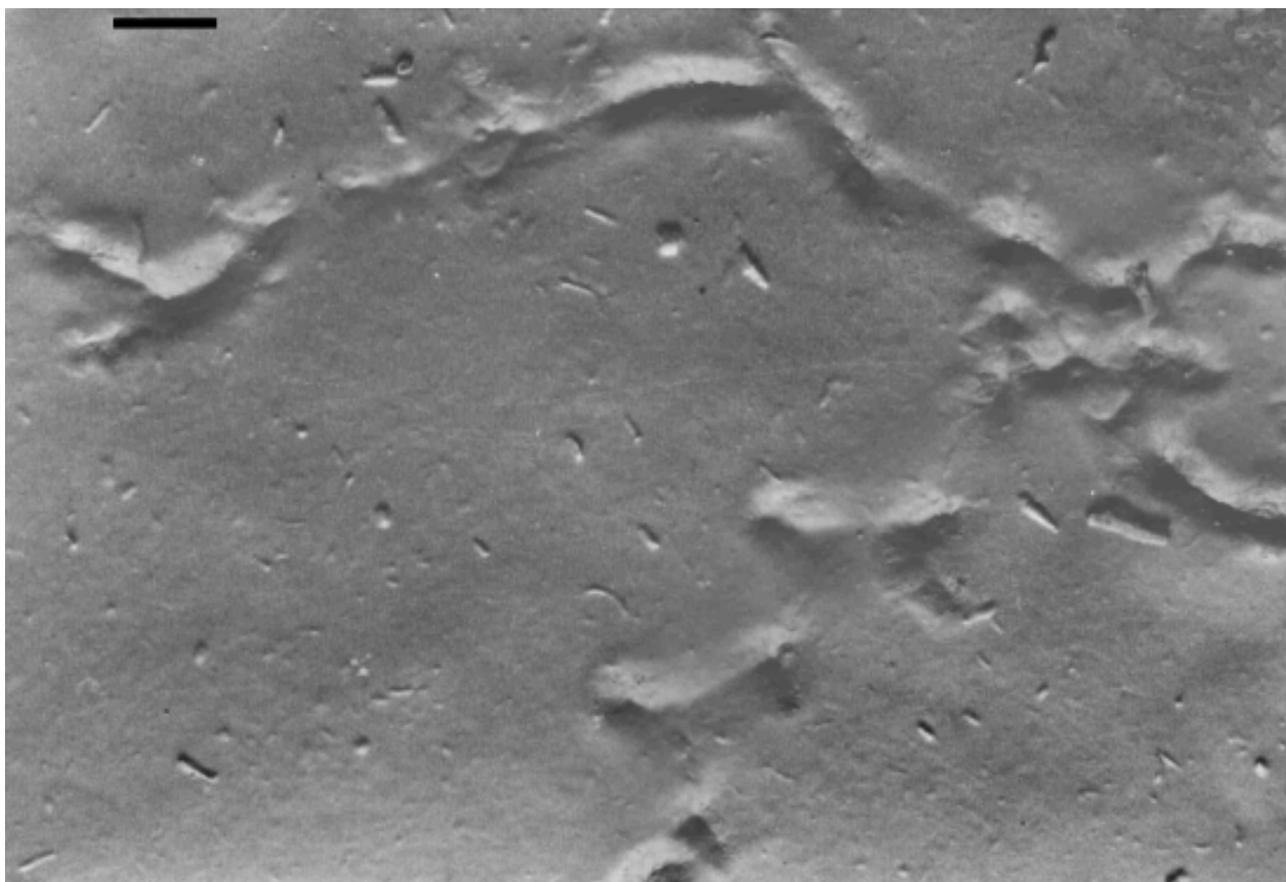


FIGURE 3. Traces produced by a tipulid larva in a plastic, low-cohesive mud. The traces are subsurface tunnels. Scale bar is 1 cm long.

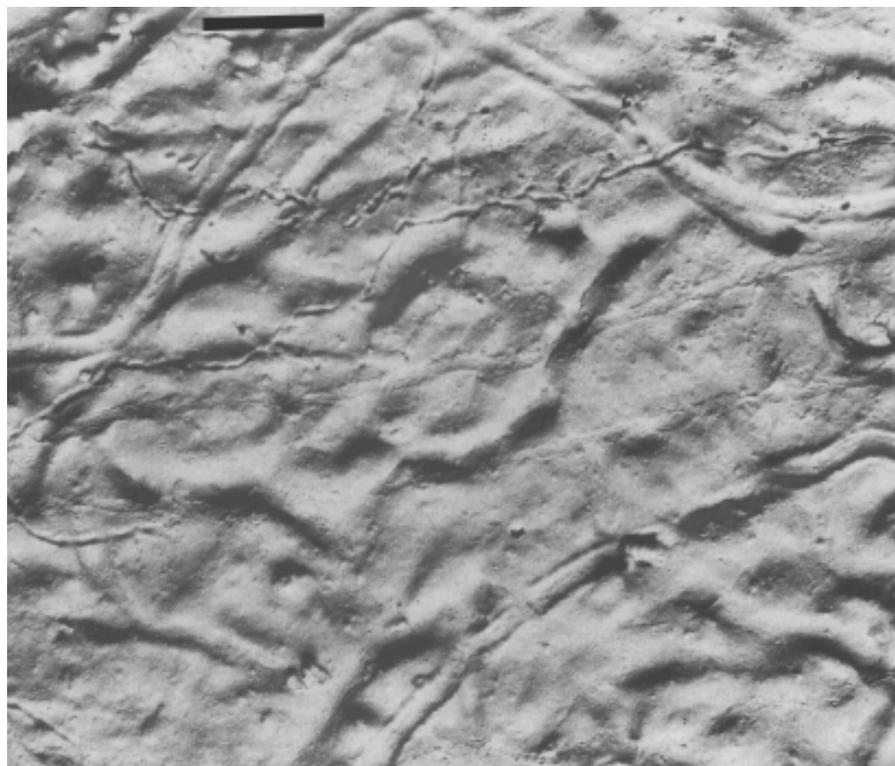


FIGURE 4. Smaller traces produced by chironomid larvae and larger traces produced by tipulid larvae. Note longitudinal striation along some of the Tipulidae traces, produced by dragging of the lobes and papillae around the posterior spiracle in relatively cohesive mud. Scale bar is 1 cm long.

Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 121-141.

Ratcliffe, B. C. and Fagerstrom, J. A., 1980, Invertebrate lebensspuren of Holocene floodplains: their morphology, origin, and paleoecological significance. *Journal of Paleontology*, v. 54, p. 614-630.

#### **AUTHOR'S E-MAIL ADDRESS**

fred@ing.uj.edu.pl

## LOWER PENNSYLVANIAN INVERTEBRATE ICHNOFOSSILS FROM THE UNION CHAPEL MINE, ALABAMA: A PRELIMINARY ASSESSMENT

SPENCER G. LUCAS and ALLAN J LERNER

New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, New Mexico 87104, USA

**ABSTRACT:** A preliminary assessment of the invertebrate ichnofossil assemblage from the Union Chapel Mine (Lower Pennsylvanian, Pottsville Formation, Alabama) indicates that the assemblage is dominated by *Kouphichnium* isp., *Arborichnus repetita*, and *Treptichnus bifurcus*. *Selenichnites*, *Cochlichnus*, *Protovirgularia*, *Palaeophycus*, and *Diplichnites gouldi* are rare elements of the assemblage. The Union Chapel Mine invertebrate ichnofossil assemblage is characteristic of an estuarine tidal flat ichnofauna in being dominated by arthropod trackways, grazing traces, and subsurface feeding traces.

### INTRODUCTION

Aldrich and Jones (1930) first documented the presence of extensive assemblages of tetrapod footprints found in coal mines developed in Lower Pennsylvanian strata of the Warrior basin coal field of Alabama. Until recently, this remained essentially all that was known of these footprint assemblages. However, the discovery of tetrapod footprints at the Union Chapel Mine in Walker County, Alabama (Fig. 1), by Ashley Allen in the 1990s, initiated new interest in the Pennsylvanian tetrapod footprint record in Alabama that was culminated by a recent symposium on the footprints held by the University of Alabama, and by the publication of this volume. These tetrapod footprints are part of an extensive trace fossil assemblage that includes numerous invertebrate ichnofossils (see <http://bama.ua.edu/~rbuta/monograph/database/database.html>, as well as Rindsberg, 1990; Buta et al., 2005). Our purpose here is to provide a preliminary assessment of the invertebrate ichnofossils from the Union Chapel Mine pending more detailed studies. In this article, UCM = Union Chapel Mine collection, stored at various sites (mostly private collections) in Alabama.

### GEOLOGICAL CONTEXT

The Union Chapel Mine is near Jasper, Alabama, and the track-bearing strata at the Union Chapel Mine are in the Mary Lee coal zone (Fig. 1). The track-bearing interval at the Union Chapel Mine is in sandstone-shale couplets interpreted as tidal rhythmites (Pashin, 2003). Invertebrate ichnotaxa in these strata include abundant xiphosuran trails and resting traces (*Kouphichnium*, etc.) and insect feeding traces (*Treptichnus*), as well as less common walking and feeding traces (Rindsberg and Kopaska-Merkel, 2003) that are discussed here. Elsewhere in this volume, Rindsberg and Kopaska-Merkel (2005) document the specimens of *Treptichnus* from the Union Chapel Mine (also see Uchman, 2005). Fish swimming traces (*Undichna*) are

also present, as are the tracks of small amphibians (*Batrachichnus*), small captorinomorphic reptiles (*Notalacerta* and *Cincosaurus*) and larger tetrapods (*Attenosaurus*, *Alabamasauripus*, *Dimetropus*; Haubold et al., 2005; Martin, 2003; Hunt et al., 2004). Indeed, tracks assigned to *Cincosaurus* so dominate the footprint assemblage that local collectors refer to the trace-fossil-bearing strata at the Union Chapel Mine as the “*Cincosaurus* beds.”

### SYSTEMATIC ICHNOLOGY

#### *Cochlichnus* Hitchcock, 1858 *Cochlichnus* isp.

Fig. 2A

**Description:** These specimens are smooth, thin, unbranched, unlined, unornamented, horizontal burrows. Preservation is in positive hyporelief. The assigned burrows display regular courses that resemble sine waves. Some of these small burrows are in close proximity and overcross. The burrow diameters are approximately 1 mm, and the average burrow length is between 30 and 50 mm.

**Discussion:** The specimens are contained on a single block (UCM 1650) that has an extensively worked surface of relatively small and large horizontal burrows (Fig. 2A). The smaller burrows are tentatively assigned to *Cochlichnus*, and are found in association with larger burrows tentatively assigned to *Palaeophycus*. Both ichnotaxa are seen to overcross. Some of the smaller burrows on this slab display a less regularly sinusoidal course than is seen in *Cochlichnus*, and they more closely resemble *Helminthopsis*.

Insect larvae and nematodes are thought to have been the producers of *Cochlichnus* in this type of nonmarine assemblage (Buatois et al., 1997a; Metz, 1998). *Cochlichnus* ranges in age from Precambrian to Holocene and has a wide facies range, including fluvial (Mermia ichnofacies) and marginal marine (*Cruziana* ichnofacies) settings (e.g., Häntzschel, 1975; Fillion and



FIGURE 1. Index map of Alabama and simplified stratigraphic section of part of the Pottsville Formation (after Metzger, 1965), showing geographic location and stratigraphic position in Mary Lee coal zone of Union Chapel Mine ichnofossil assemblage.

Pickerill, 1990; Buatois and Mángano, 1993).

***Palaeophycus* Hall, 1847**

***Palaeophycus* isp.**

Fig. 2A

**Description:** These specimens consist of horizontal burrows that are generally smooth and subcylindrical. Preservation is in positive hyporelief. They display variable courses that are alternately straight to loosely winding. There is frequent touching and overcrossing between burrows. The burrow widths are generally constant and are approximately 5 mm in diameter. The average burrow lengths approach 50 mm.

**Discussion:** These larger burrows, which are found on UCM 1650 in association with *Cochlichnus* and *Helminthopsis*-like trails are assigned to *Palaeophycus* largely because the burrow fill is identical to the surrounding matrix (cf. Lucas and Lerner, 2004). *Palaeophycus* is a facies-crossing ichnospecies that ranges in age from Proterozoic to Holocene, and is generally thought to have been produced by worms or worm-like organisms (Lucas and Lerner, 2004).

**Ichnogenus *Protovirgularia* M<sup>c</sup>Coy, 1850**

***Protovirgularia* isp.**

Fig. 2B

**Description:** The illustrated specimen is a horizontal, unbranched trace with a narrow central furrow and regularly-spaced, lateral, chevron-shaped elevations.

Width is up to 20 mm.

**Discussion:** We assign this specimen to *Protovirgularia* based on Han and Pickerill's (1994) emended diagnosis of the ichnogenus (also see Lucas and Lerner, 2004). *Protovirgularia* is the locomotion trace of a cleft-foot bivalve. It has been recorded from a variety of facies, including tidal flats, that range in age from Ordovician to Holocene. It is rare in the UCM collection.

**Ichnogenus *Diplichnites* Dawson, 1873**

***Diplichnites* *gouldi* Gevers et al., 1971**

Fig. 2D

**Description:** UCM 154 is a single slab that contains three trackways composed of simple, biserial track rows. The trackway courses are straight to curving. There is one section in which two of the trails overcross. Trackway length extends to 100 mm, and the width is about 10 mm. The imprints are small and mostly ellipsoidal in shape. A few imprints appear as short, elongated scratches that are perpendicular to the trackway axis. All three trackways are of similar imprint morphology and dimensions, suggesting that they were made by a single animal.

**Discussion:** These trails are assigned to *Diplichnites* *gouldi*, based on their having simple track rows and closely spaced imprints (Buatois et al., 1998). These specimens appear similar to other reports of this ichnotaxon (e.g., Buatois et al., 1997b, 1998; Lucas et al., 2004). Specimens of *Diplichnites* *gouldi* are commonly thought to have been produced by myriapods, which are infrequently preserved as body fossils.

**Ichnogenus *Kouphichnium* Nopsca, 1923**

***Kouphichnium* isp.**

Fig. 2E

**Description:** The Union Chapel ichnofauna includes numerous epirelief and hyporelief trackways that are assigned to this well-known ichnogenus. Specimens commonly show two rows of symmetrically arranged heteropodous imprints bordering medial drag marks. Imprint shapes generally consist of elongate scratches, small bifid scratches and ellipsoidal marks but show considerable variation. Characteristic digitate "pusher" tracks, oriented parallel to the central axis, are commonly seen. External drag marks are rare. Trackway courses meander and frequently intersect. External trackway widths average 30 to 40 mm.

**Discussion:** The Union Chapel Mine invertebrate ichnofauna is notable for having an abundance of well-preserved *Kouphichnium* trackways. These trackways provide a large sample of the preservational variation and undertrack fallout that has often been noted for *Kouphichnium*, and which has complicated its ichnotaxonomy. Buatois et al. (1998) stated that a taxonomic review of *Kouphichnium* ichnospecies is needed, and we wholeheartedly concur. The UCM ichnofauna has great potential for utility in this regard, and should be a pivotal sample in resolving the ichnospecies-level taxonomy of *Kouphichnium*.

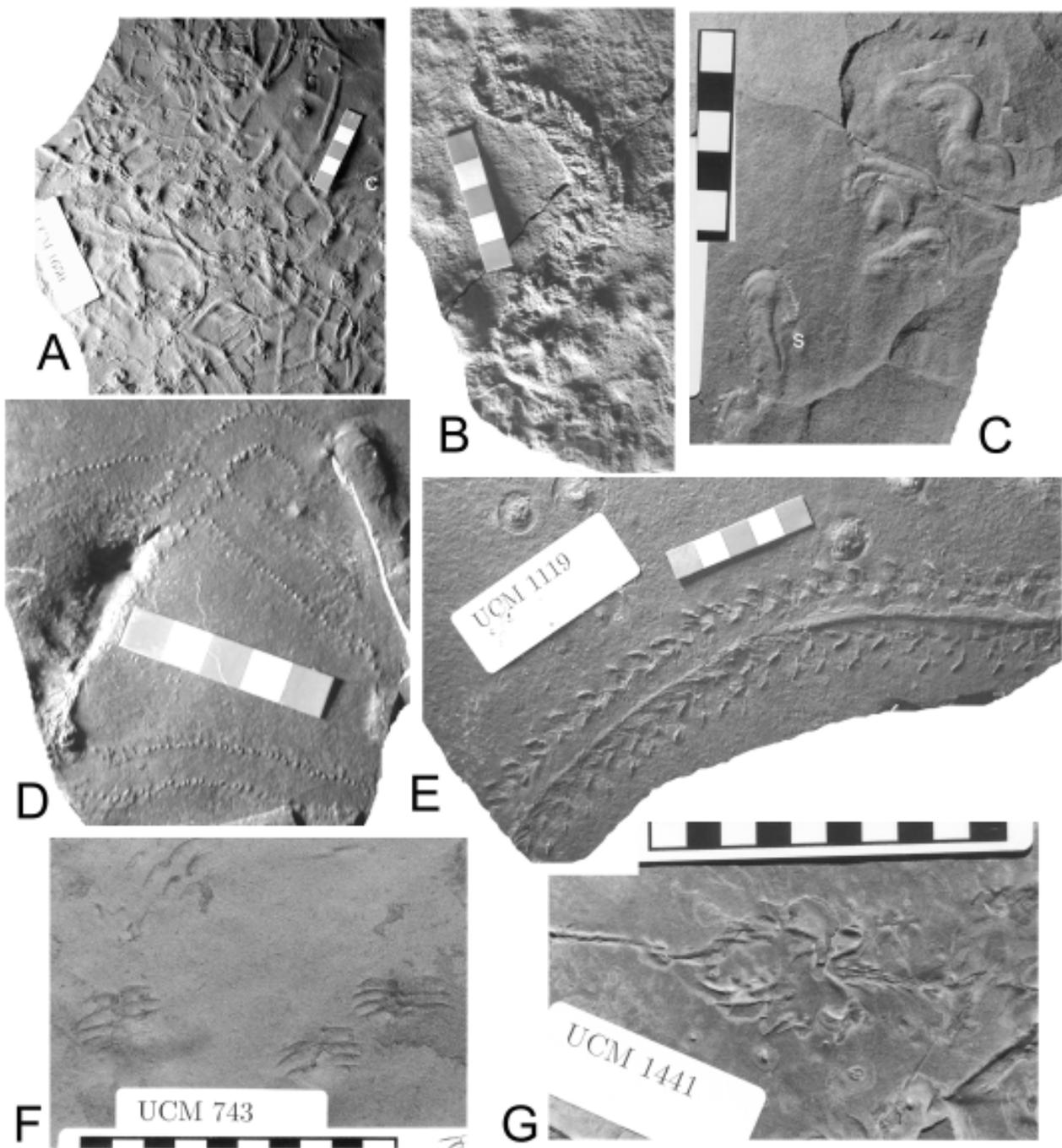


FIGURE 2. Representative invertebrate ichnofossils from the Union Chapel Mine. All scale bars are in cm. A, UCM 1650, *Cochlichnus* isp. and *Paleophycus* isp. A good example of *Cochlichnus* is to the immediate left of the "c." B, UCM uncatalogued, *Protovirgularia* isp. C, UCM 107, *Selenichnites* isp. Note the shallow angle imprint to the left of the "s." D, UCM 154, *Diplichnites gouldi*. E, UCM 1119, *Kouphichnium* isp. F, UCM 743, *Arborichnus repetita*. G, UCM 1441, xiphosuran resting trace.

***Selenichnites* Romano and Whyte, 1987*****Selenichnites* isp.**

Fig. 2C

**Description:** UCM 107 is preserved as a part and an incomplete counterpart. The part contains a series of repeated crescentic impressions that are preserved in convex hyporelief. The entire group of crescentic impressions is aligned in a similar direction. An interval of 30 mm typically separates these impressions, although several intervening impressions are seen to overlap. The crescents range from 15 to 20 mm wide, and are highest anteriorly. The lateral lobes of the crescents range from 10 to 15 mm long and are arranged anterolaterally to the median line (where best seen). A single well-preserved impression appears to have been less steeply dug than the others (Fig. 2C, marked with a "s"). It shows an anterior crescent with a centralized posterior ridge that is 20 mm long. A faint, shallow furrow is medially present along the ridge, which separates it into pairs. Several closely spaced, convex, lateral scratch marks are preserved along one side of the ridge. The other side of the ridge is mostly smooth, gently curved, and preserves few scratch marks. The anterior of the crescent preserves a clear outline of a thin prosoma in ventral aspect. Similar outlines are faintly preserved on several of the other crescents. However, none of the other crescents show a centralized posterior ridge.

**Discussion:** These traces are assigned to *Selenichnites* based on the distinctive crescent shaped morphology that readily conforms to the ichnogenetic diagnosis. There are five recorded ichnospecies of *Selenichnites*, as well as two known occurrences of *Selenichnites* isp. (Draganits et al., 2001). UCM 107 is most similar in shape to *S. langridgei*, although the absence of a characteristic medial trefoil shape precludes ichnospecific assignment. The Union Chapel specimens are smaller than the average width given for *S. langridgei*, although they are within the range reported by Trewin and McNamara (1995). Xiphosurans are generally thought to have produced *Kouphichnium*, as well as some *Selenichnites*. The width of the Union Chapel *Selenichnites* is noticeably smaller than *Kouphichnium* from the same ichnofauna. Thus, if a xiphosuran did produce the UCM *Selenichnites*, a juvenile individual probably made it. Other possible trace makers include eurypterids, trilobites, or crustaceans. *Selenichnites* that shows repeated digging behavior is thought to be a feeding trace, a behavior akin to that of modern *Limulus* (Trewin and McNamara, 1995).

***Ichnogenus Arborichnus* Romano and Meléndez, 1985*****Arborichnus repetita* Romano and Meléndez, 1985**

Fig. 2F

**Description:** Numerous UCM specimens, preserved in both epirelief and hyporelief, are confidently assigned to this ichnospecies. These distinctive traces closely resemble the original diagnosis, being sets of short, symmetrical scratch marks and characteristic alignment, and with repeat distance between sets being approximately

equal to the length of the set.

**Discussion:** *Arborichnus* was not formally described until Romano and Meléndez (1985), although it had been known for a considerable time (see Caster, 1938, fig. 1, plate 9, figs. 3, 4). Other than Romano and Meléndez's type descriptions from the Carboniferous of Spain, there are few recent reports of this ichnotaxon in the literature. The large number of UCM *A. repetita* specimens, which number in the hundreds, provides an extensive sample with which to broaden our understanding of xiphosuran behavior and further clarify the taxonomy of this ichnogenus.

**Unassigned xiphosuran traces**

Fig. 2G

**Description:** A variety of specimens (e.g., UCM 487, 1051, 1053, 1058, 1060, 1061, 1437, 1441, 1568, 1752, 1755, 1762) record the linear and serial repetition of telson drags, opistosomal and genal spine imprints. Prosomal marks are occasionally present. Walking appendage imprints are absent or minimally present in the majority of specimens. Preservation is in both epirelief and hyporelief.

**Discussion:** The UCM specimens record behavior that is also documented by *Kouphichnium rossendalensis* Hardy, 1970, later transferred to *Selenichnites* by Romano and Whyte (1987). However, there are significant differences between the UCM specimens and these ichnotaxa. Hardy interpreted *S. rossendalensis* as having been formed when swimming xiphosurans briefly touched down on the sediment surface, dragged their telson and appendages, and retracted them before implanting lunate casts. The lunate casts of *S. rossendalensis* are deepest anteriorly and shallow posteriorly, and thought to represent burrowing for concealment or resting. The UCM traces show similar behavior in that swimming xiphosurans serially touched down on the substrate, which in this case recorded aspects of their posterior ventral surfaces. However, distinctively crescentic marks are absent from the UCM specimens, which precludes their assignment to *Selenichnites*.

The UCM specimens were most likely made with the xiphosuran's anterior inclined away from the bedding plane, as evidenced by the presence of genal spine and telson marks, and the relative absence of prosomal impressions. However, Hardy (1970) stated that in a few examples of *S. rossendalensis* the convex end (anterior) forms a cloven hoof mark. Similar anterior morphology is seen in several UCM specimens (Fig. 2G), which suggests that they may be undertracks of *S. rossendalensis* or extra-morphological variations due to substrate conditions. The UCM specimens also differ significantly from *Limulicubichnus* Miller, 1982, erected for limulid resting traces, in which the imprint of the prosoma is prominent.

The morphologic characteristics of these traces, which record general body and prosomal outlines, genal spines impressions, and telson marks, provide strong evidence of their having been produced by xiphosurans. Whatever the eventual outcome of their ichnotaxic as-

signment, it is highly probable that a closer examination of their size and shape, when compared to Upper Carboniferous xiphosurans known from body fossils, will reveal the identity of the xiphosuran producer.

## DISCUSSION

The paleoenvironment of the *Cincosaurus* beds at the Union Chapel Mine has been described as an estuarine tidal flat in a coastal lowland region near the Early Pennsylvanian paleoequator (Minkin, 2005; Pashin, 2005). The trace-fossil-bearing interval at the mine is about 4 meters thick, and the trace fossils generally occur at the tops of graded couplets of siltstone-shale or sandstone-shale interpreted as tidal rhythmites (Pashin, 2005). The footprints and other traces were apparently made on the tidal flats at times of low tides.

The invertebrate ichnofossil assemblage at the Union Chapel mine is dominated by xiphosuran locomotion and resting traces, which comprise more than 90% of the assemblage. The next most common invertebrate ichnotaxon is *Treptichnus bifurcus*, and all other invertebrate ichnotaxa are rare, being known from one or a few specimens. In general, the Union Chapel Mine invertebrate ichnofossil assemblage is of low diversity, dominated by epifaunal trails and lacks any significant infaunal traces. It thus is a characteristic estuarine tidal flat ichnofossil assemblage in being dominated by arthropod trackways (*Kouphichnium*, *Diplichnites*), grazing traces (*Palaeophycus*, *Cochlichnus*) and subsurface feeding traces (*Treptichnus*), and is accompanied by fish traces (*Undichna*) and abundant tetrapod footprints (cf. Buatois et al., 1998; Mángano and Buatois, 2003, 2004; Lucas et al., 2004).

*Editors' note: For additional photographs of invertebrate traces from the Union Chapel Mine, see Buta et al. (2005).*

## ACKNOWLEDGMENTS

We are grateful for the generosity and assistance of Prescott Atkinson, Ron Buta, Adrian Hunt, and Steve Minkin, which made this paper possible. Comments on the manuscript by L. A. Buatois and M. G. Mángano improved its content and presentation.

## REFERENCES

- Aldrich, T. H., Sr. and Jones, W. B., 1930, Footprints from the coal measures of Alabama: Geological Survey of Alabama, Museum Paper 9, 64 p.
- Buatois, L. A. and Mángano, M. G., 1993, The ichnotaxonomic status of *Plangtichnus* and *Treptichnus*: *Ichnos*, v. 2, p. 217-224.
- Buatois, L. A., Jalfin, G. and Aceñolaza, F. G., 1997a, Permian non-marine invertebrate trace fossils from southern Patagonia, Argentina: Ichnologic signatures of substrate consolidation and colonization sequences: *Journal of Paleontology*, v. 71, p. 324-336.
- Buatois, L. A., Mángano, M. G., Maples, C. G. and Lanier, W. P., 1997b, The paradox of non-marine ichnofaunas in tidal rhythmites: Integrating sedimentologic and ichnologic data from the Late Carboniferous of eastern Kansas, USA: *Palaios*, v. 12, p. 467-481.
- Buatois, L. A., Mángano, M. G., Maples, C. G. and Lanier, W. P., 1998, Ichnology of an Upper Carboniferous fluvio-estuarine paleovalley: The Tonganoxie Sandstone, Buildex Quarry, eastern Kansas, USA: *Journal of Paleontology*, v. 72, p. 152-180.
- Buta, R. J., Kopaska-Merkel, D. C., Rindsberg, A. K., and Martin, A. J., 2005, Atlas of Union Chapel Mine invertebrate trackways and other traces; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 277-337.
- Caster, K. E., 1938, A restudy of the tracks of *Paramphibius*: *Journal of Paleontology*, v. 12, p. 3-60.
- Dawson, J. W., 1873, Impressions and footprints of aquatic animals and imitative markings on Carboniferous rocks: *American Journal of Science and Arts*, v. 105, p. 16-24.
- Draganits, E., Braddy, S., and Briggs, D.E.G., 2001, A Gondwanan coastal arthropod ichnofauna from the Muth Formation (Lower Devonian, northern India): *Paleoenvironment and tracemaker behavior: Palaios*, v. 16, p. 126-147.
- Fillion, D. and Pickerill, R. K., 1990, Ichnology of the Lower Ordovician Bell Island and Wabana Groups of eastern Newfoundland: *Palaeontographica Canadiana*, v. 7, p. 1-119.
- Gevers, T. W., Frakes, L. A., Edwards, L. N. and Marzolf, J. E., 1971, Trace fossils from the Lower Beacon sediments (Devonian), Darwin Mountains, southern Victoria Land, Antarctica: *Journal of Paleontology*, v. 45, p. 81-94.
- Hall, J., 1847, *Paleontology of New York*, v. 1: Albany, C. van Benthuysen, 338 p.
- Han, Y. and Pickerill, R. K., 1994, Taxonomic reassessment of *Protovirgularia* McCoy, 1850 with new examples from the Paleozoic of New Brunswick, eastern Canada: *Ichnos*, v. 3, p. 203-212.
- Häntzschel, W., 1975, Trace fossils and problematica; in Teichert, C., ed., *Treatise on Invertebrate Paleontology, Part W, Miscellaneous, Supplement I: Boulder and Lawrence*, Geological Society of America and University of Kansas Press, p. 1-269.
- Hardy, P. G., 1970, New xiphosurid trails from the Upper Carboniferous of northern England: *Palaeontology*, v. 13, p. 188-190.
- Haubold, H., Allen, A., Atkinson, T. P., Buta, R. J., Lacefield, J. A., Minkin, S. C. and Relihan, B. A., 2005, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 75-111.
- Hitchcock, E., 1858, *Ichnology of New England: A report on the sandstone of the Connecticut Valley, especially its footprints*: Boston, W. White, 220 p.
- Hunt, A. P., Lucas, S. G. and Lockley, M. G., 2004, Large pelycosaur footprints from the Lower Pennsylvanian of Alabama, USA: *Ichnos*, v. 11, p. 39-44.
- Lucas, S. G., and Lerner, A. J., 2004, Extensive ichnofossil assemblage at the base of the Permian Abo Formation, Carrizo Arroyo, New Mexico: *New Mexico Museum of Natural History and Science, Bulletin no. 25*, p. 285-289.
- Lucas, S. G., Lerner, A. J., Bruner, M. and Shipman, P., 2004, Middle Pennsylvanian Ichnofauna from Eastern Oklahoma, USA: *Ichnos*, v.11, p.1-11.
- Mángano, M. G. and Buatois, L. A., 2003, Comparative ichnologic analysis of Pennsylvanian tidal flats of the North American midcontinent; in Martin, A. J., ed., *Workshop on Permian-Carboniferous Ichnology, Program and Abstracts*: Tuscaloosa, Alabama Museum of Natural History, p. 18-19.
- Mángano, M. G. and Buatois, L. A., 2004, Reconstructing early Phanerozoic intertidal ecosystems: Ichnology of the Cambrian Campanario Formation in northwest Argentina; in Webby, B.

- D., Mángano, M. G. and Buatois, L. A., eds., Trace fossils in evolutionary palaeoecology: *Fossils and Strata*, v. 51, p. 17-38.
- Martin, A. J., 2003, *Undichna*: A trace fossil bridging the gap between fish and tetrapods; in Martin, A. J., ed., Workshop on Permo-Carboniferous Ichnology, Program and Abstracts: Tuscaloosa, Alabama Museum of Natural History, p. 19-21.
- McCoy, F., 1850, On some genera and species of Silurian Radiata in the collection of the University of Cambridge: *Annals and Magazine of Natural History*, ser. 2, v. 6, p. 270-290.
- Metz, R., 1998, Nematode trails from the Late Triassic of Pennsylvania: *Ichnos*, v. 5, p. 303-308.
- Metzger, W. J., 1965, Pennsylvanian stratigraphy of the Warrior basin, Alabama: Geological Survey of Alabama, Circular 30, 80 p.
- Miller, M. F., 1982, *Limulicubichnus*: A new ichnogenus of limulid resting traces: *Journal of Paleontology*, v. 56, p. 429-433.
- Minkin, S. C., 2005, Paleoenvironment of the *Cincosaurus* beds, Walker County, Alabama; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 31-38.
- Nopsca, F. B., 1923, Die Familien der Reptilien: *Fortschritte in der Geologie und Paläontologie*, v. 2, p. 1-210.
- Pashin, J., 2003, Stratigraphy of the Union Chapel Mine in its regional context; in Martin, A. J., ed., Workshop on Permo-Carboniferous Ichnology, Program and Abstracts: Tuscaloosa, Alabama Museum of Natural History, p. 25-26.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 39-58.
- Rindsberg, A. K., 1990, Freshwater to marine trace fossils of the Mary Lee Coal zone and overlying strata (Westphalian A), Pottsville Formation of northern Alabama; in Gastaldo, R. A., Demko, T. M. and Liu, Y., eds., Carboniferous coastal environments and paleocommunities of the Mary Lee Coal zone, Marion and Walker counties, Alabama. A guidebook for field trip VI, Southeastern Section, Geological Society of America. Tuscaloosa, Geological Survey of Alabama, p. 82-95.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2003, *Treptichnus* and related trace fossils from the Union Chapel Mine (Langsettian, Alabama, USA); in Martin, A. J., ed., Workshop on Permo-Carboniferous Ichnology, Program and Abstracts: Tuscaloosa, University of Alabama, p. 27-28.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, *Treptichnus* and *Arenicolites* from the Steven C. Minkin Paleozoic Footprint Site (Langsettian, Alabama, USA); in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 121-141.
- Romano, M. and Mélenlez, B., 1985, An arthropod (merostome) ichnocoenosis from the Carboniferous of northwest Spain: Ninth International Geological Congress, Urbana, Illinois, v. 5, p. 317-325.
- Romano, M. and Whyte, M. A., 1987, A limulid trace fossil from the Scarborough Formation (Jurassic) of Yorkshire; its occurrence, taxonomy and interpretation: *Proceedings of the Yorkshire Geological Society*, v. 46, p. 85-95.
- Trewin, N. H., and McNamara, K. J., 1995, Arthropods invade the land: Trace fossils and palaeoenvironments of the Tumblagooda Sandstone (?Late Silurian) of Kalbarri, Western Australia: *Transactions of the Royal Society of Edinburgh, Earth Sciences*, v. 85, p. 77-210.
- Uchman, A., 2005, *Treptichnus*-like traces made by insect larvae

(Diptera: Chironomidae: Tipulidae); in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 143-146.

#### AUTHORS' E-MAIL ADDRESSES

Spencer G. Lucas: slucas@nmmnh.state.nm.us  
Allan J Lerner: hanallaine@aol.com

## FOSSIL PLANTS FROM THE UNION CHAPEL MINE, ALABAMA

DAVID L. DILCHER<sup>1</sup>, TERRY A. LOTT<sup>1</sup> and BRIAN J. AXSMITH<sup>2</sup>

<sup>1</sup>Florida Museum of Natural History, University of Florida, Gainesville, Florida 32611-7800, USA.

<sup>2</sup>Department of Biological Sciences, LSCB 124, University of South Alabama, Mobile, Alabama 36688, USA.

**ABSTRACT:** The vertebrate tracks of the Union Chapel Mine are associated with a rich Early Pennsylvanian impression/compression and petrified flora. The flora appears to be dominated by arborescent lycopods (Lepidodendrales) including bark impressions of *Lepidophloios* and *Lepidodendron*. Lepidodendralean reproductive structures include intact cones (*Lepidostrobus*) and isolated cone scales (*Lepidostrobophyllum*). Several examples of lepidodendralean detached leaves (*Lepidophylloides*) have been recovered. Additional non-seed-bearing plants are represented by numerous arborescent horsetail (sphenophyte) remains including pith and stem casts of *Calamites*, a cone of *Calamostachys* and leafy stems (*Asterophyllites charaeformis*). Seed plants such as the pteridosperm foliage genera *Sphenopteris* and *Neuraethopteris* are common at the Union Chapel locality. Seed plant reproductive structures include excellently-preserved specimens of the pteridosperm seed *Trigonocarpus ampulliforme*, and the pollen organ *Whittleseyia elegans*. The fine preservation and high degree of articulation of the Union Chapel plants indicates that they were not transported far before burial. This suggests that the trackmaking animals were living in, or at least visiting, tidal influenced environments. This paleoecological setting stands in sharp contrast to the extensive late Paleozoic (Early Permian) vertebrate track sites of the Hueco Formation in New Mexico, which are associated with a walcchian conifer-dominated plant community. Numerous illustrations of the fossil plants are included in this chapter to document the nature of the flora associated with the tracks presented elsewhere in this volume.

### INTRODUCTION

The fossil plants preserved with the trackways in the Union Chapel Mine of Walker County, Alabama present an opportunity to associate plants and animals in a unique taphonomic setting. The animals that wandered among the plants living on or near these Pennsylvanian age mud flats are of great interest. However, the plants also have an interesting and unique story to tell about the life in this place and time. It is with this need to present a record of the abundant plant material associated with the trackways that we document the floristic elements present in these Lower Pennsylvanian sediments.

The plants of the Union Chapel Mine occur in the Lower Pennsylvanian, Pottsville Formation. Joseph Wood (1963) described a Pottsville flora, the Stanley Cemetery Flora, from west central Indiana. These two floras contain similar elements indicating that floristic elements extended from one North American coal basin to another. During the Early Pennsylvanian a large Northern Hemisphere land mass, Laurasia, consisted of much of North America, Europe, and parts of Asia. Low and swampy areas extended from the American mid-west into western Europe. Consequently, certain species of land plants that make up the famous Carboniferous coal swamp forests are found in Asia, Europe, and North America. Changes in species composition in these floras occurred throughout the Carboniferous (DiMichele and Phillips, 1995).

Carboniferous basins contained peat-accumulating

swamps of coastal lowlands that accumulated fine-grained silts from floods (Gastaldo, 1990) forming mud flats. In these wet areas many species of land plants shed their various organs such as cones, seeds or large branches, and these were dispersed in a forest or swamp, much as plant organs are dispersed today. Major groups represented in the Early Pennsylvanian include the lycopods, sphenopsids, ferns, seed ferns and cordaites. Examples of these major groups are still living today except for the seed ferns and the cordaites (which may be considered only very distantly related to conifers today). Most of this flora consists of long extinct swamp inhabiting trees. As various organs were shed, they fell adjacent to the parent plants, onto the mud or into the shallow water of the swamp. As trees died their branches and stems dropped to the forest floor. Some have a natural hollow cavity (*Calamites*) while the stems of lycophytes and most seed plants lack a hollow cavity. With the subsequent decay of plant material and infilling of sediment, a cast is formed (Gastaldo et al., 1989). Some of the trees had special tissues and morphological features to facilitate their life in the swamp environment (Phillips et al., 1976).

Plant megafossils from the Alabama coal fields are noted in Bunbury (1846), Lyell (1846a, b), Lesquereux (1879, 1880, 1884, 1888), McCalley (1896, 1900), White (1900, 1943), Smith (1903), Rothrock (1949), Mamay (1955), Read and Mamay (1964), Metzger (1965), Gastaldo (1984, 1985, 1988, 1990), Gastaldo and Boersma (1983a, b), Gillespie and Rheams (1985), and Lacefield (2000). Similar Pennsylvanian plants from

TABLE 1. List of Fossil Plants in the Union Chapel Mine, Alabama

Name	Number of described specimens
Order LEPIDODENDRALES	
Family LEPIDODENDRACEAE	
<i>Lepidodendron aculeatum</i> Sternberg	1
<i>Lepidodendron obovatum</i> Sternberg	1
<i>Lepidophloios laricinus</i> (Sternberg) Goldenberg	1
<i>Aspidiopsis</i> sp.	1
<i>Lepidophylloides intermedium</i> Lindley & Hutton	2
<i>Lepidostrobos</i> sp. A	3
<i>Lepidostrobos</i> sp. B	3
<i>Lepidostrobophyllum</i> cf <i>majus</i> (Brongniart) Hirmer	3
Family SIGILLARIACEAE	
<i>Syringodendron</i> sp.	2
Order EQUISETALES	
Family CALAMITACEAE	
<i>Asterophyllites charaeformis</i> (Sternberg) Goeppert in Wimmer	3
<i>Calamites suckowii</i> Brongniart	2
<i>Calamites undulatus</i> Sternberg	2
<i>Calamites goepperti</i> Ettingshausen	2
<i>Calamostachys</i> sp.	1
Order MEDULLOSALES	
PTERIDOSPERMS	
ALETHOPTERIDS	
<i>Alethopteris valida</i> Boulay	1
SPHENOPTERIDS	
<i>Sphenopteris elegans</i> (Brongniart) Sternberg	1
<i>Sphenopteris pottsvillea</i> (D. White) Gastaldo and Boersma	1
<i>Lyginopteris hoeninghausi</i> (Brongniart) H. Potonié	2
NEUROPTERIDS	
<i>Cyclopteris</i> sp.	1
<i>Neuralethopteris pocahontas</i> (White) Goubet et al.	1
<i>Neuralethopteris biformis</i> (Lesquereux) Goubet et al.	4
MISC. PTERIDOSPERMS	
<i>Myeloxylon</i> sp.	1
<i>Whittleseya elegans</i> Newberry	1
<i>Holcospermum</i> sp.	1
<i>Trigonocarpus ampulliforme</i> Lesquereux	1
<i>Trigonocarpus</i> sp.	1
<i>Carpolithes</i> sp.	1
CORDAITALES	
<i>Artisia</i> sp.	1
<i>Cordaicarpon</i> sp.	1
<i>Cordaites</i> sp.	1

elsewhere in the United States were listed by Newberry (1853), Lesquereux (1866), Noe (1925), Janssen (1939), Langford (1958), Canright (1959), Wood (1963), Darrah (1969), Gillespie and Crawford (1985), Gillespie et al. (1978, 1989), and Goubet et al. (2000). Comparative studies with the European flora are found in Schlotheim (1820), Sternberg (1820-1838), Brongniart (1822, 1828, 1828-1834, 1849, 1881), Martius (1822), Lindley and Hutton (1831-1833), Goeppert (1844), Unger (1850), Ettingshausen (1854), Goldenberg (1857), Geinitz (1862), Boulay (1876), Stur (1877), Kidston (1889, 1894), Cremer (1893), Potonié (1897-1899), Nathorst (1914), Hirmer (1927), Crookall (1955, 1966), Laveine (1967), Remy and Remy (1977), Josten (1991), and Kvacek and Straková (1997). This is one of the few documented impression/compression megafossil assemblages from Alabama.

### MATERIAL, SOURCE STRATA, AND METHODS

All of the fossil plants presented in this paper were collected and donated by amateur paleontologists who have an interest in fossil plants and trackways preserved in the Warrior Basin coal field, Pottsville Formation, Lower Pennsylvanian, Union Chapel Mine, Walker County, Alabama, sec. 21, T. 14. S, R. 6. W, Cordova 7.5-Minute Quadrangle. They were collected from the spoils of the coal mine and in some cases are closely associated with trackways preserved on the same surface. This study of floral diversity is based on over 125 fossil plant specimens. The relative abundance of individual taxa in the collection may reflect original composition of the flora. More likely, however, the attractiveness of particular plant species to collectors in the field, the dispersal and differential preservation of particular plant species, or a combination of these factors, bias the collection of some species over others. Regardless, because many different species are present, some represented by only one or two examples, it is likely that much of the total systematic diversity of species is represented in this small collection of plant fossils. The specimens are housed in the collections of the Paleobotanical/Palynological Section of the Florida Museum of Natural History, University of Florida, Gainesville, Florida. All specimens are labeled with a locality number of UF18902 followed by specific specimen numbers. Systematic organization and taxonomic terminology in this paper are based on Harrington and Durrell (1957), Andrews (1970), Radford et al. (1974), Remy and Remy (1977), and Taylor and Taylor (1993).

### SYSTEMATIC PALEOBOTANY

The Union Chapel flora contains many elements typical of the Early Pennsylvanian of the northern hemisphere (Table 1). The original forests probably consisted of a mixture of tall trees such as *Lepidodendron*, *Lepidophloios* and *Sigillaria*, some of which may have reached heights of over 100 feet (Phillips et al., 1976). These were mixed with shorter trees of *Calamites* (up to 50 feet tall) and *Psaronius* (about 30 to 40 feet tall).

All of these plants reproduced by spores, some of which may have been dispersed in the shallow water of the swamp. *Medullosa*, a seed fern up to 30 feet tall, may have had *Neuralethopteris* foliage, bore *Trigonocarpus* seeds and *Whittleseya* pollen organs. Other seed ferns may have been shorter or even vine-like plants. An early conifer-like fossil plant is represented by *Cordaites*.

In this chapter we present as complete a description of the flora and illustrate each of these genera and/or species. It is important to remember that each individual plant usually falls into many pieces and each of the pieces is given a separate form generic name. Thus many different names go together to make up one individual plant.

### Family LEPIDODENDRACEAE Genus LEPIDODENDRON Sternberg, 1820

This genus accommodates stem impressions with leaf cushions of bark in spiral arrangement, rhomboidal to narrowly rhomboidal, acute at both ends. Central leaf scars are rhomboidal and perpendicular to the long axis of the leaf cushion. The leaf cushions bear a medial line separating two parichnos scars.

#### LEPIDODENDRON ACULEATUM Sternberg, 1820

Figures 1.1, 1.2

*Lepidodendron aculeatum* STERNBERG, 1820, p. 20, 23, pl. 6, fig. 2; pl. 8, figs. 1Ba,b.

**Description:** Leaf cushions in spiral arrangement, narrowly rhomboidal. Central leaf scars near middle, obtuse at apex, acute at sides and base. Medial line distinct, with depressions at both ends.

**Discussion:** The leaf cushions of this specimen are similar to those figured in Darrah (1969, pl. 30, fig. 1) and Gillespie et al. (1989, pl. 2, fig. 11) but lack the transverse wrinkles on the medial line as in Sternberg (1820), Lesquereux (1879, 1880), Langford (1958), Gillespie et al. (1978), and Kvacek and Straková (1997). This species was listed from Alabama by Lesquereux (1888) and Gillespie and Rheams (1985).

**Material examined:** UF 18902-34014.

#### LEPIDODENDRON OBOVATUM Sternberg, 1820

Figures 1.3, 1.4

*Lepidodendron obovatum* STERNBERG, 1820, p. 20, 23, pl. 6, fig. 1, pl. 8, figs. 1Aa,b; tent. 10.

**Description:** Leaf cushions in spiral arrangement, rhomboidal (obovate). Central leaf scars at top, obtuse at apex and base, acute at sides. Medial line distinct from scar to base, with depression at base.

**Discussion:** The leaf cushions of this specimen are similar to those figured in Gillespie et al. (1978, pl. 11, fig. 5) but lack the quadratic rhombic shape as in Gillespie and Rheams (1985) and Gillespie et al. (1989).

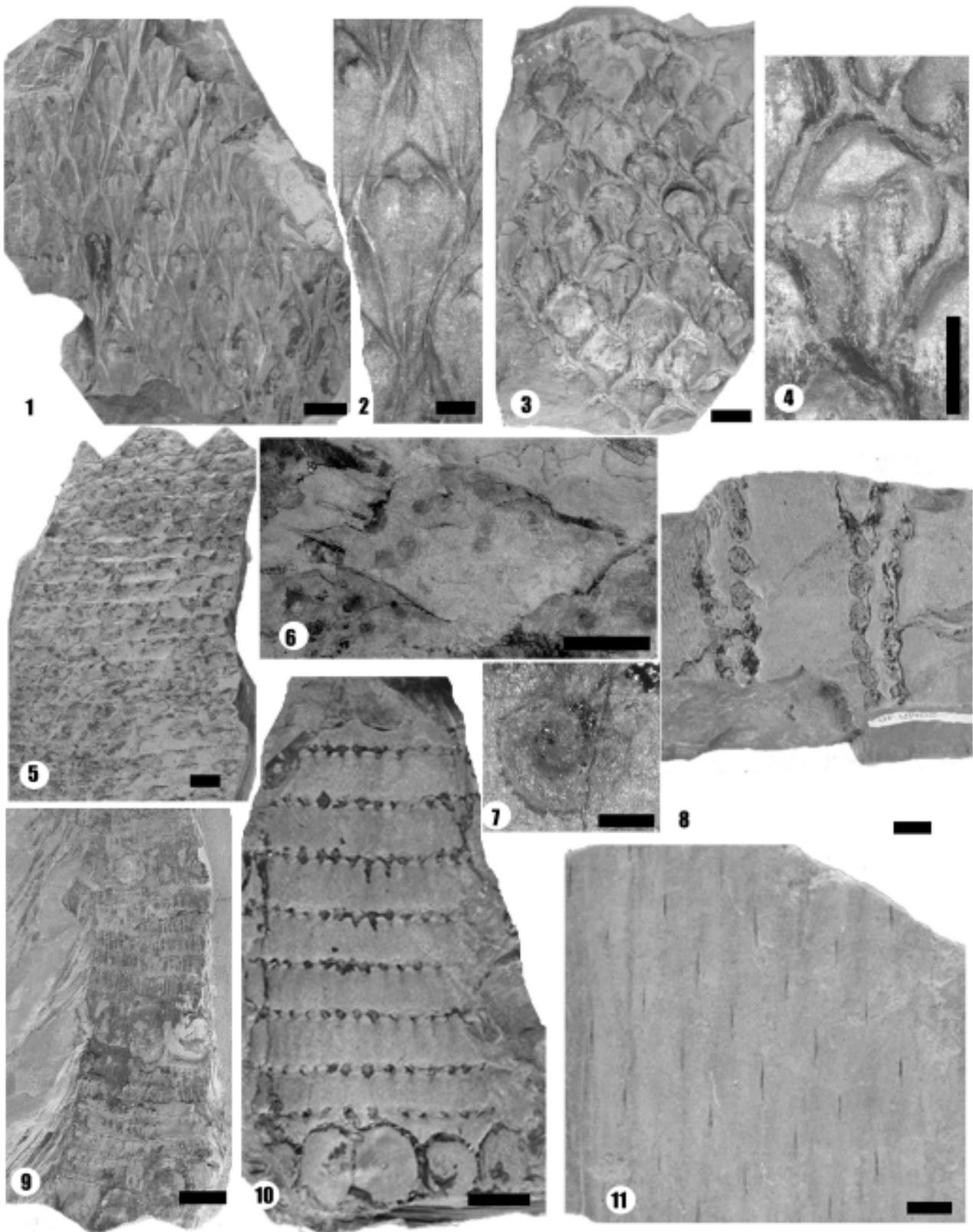


FIGURE 1.1, 2, UF 34014, *Lepidodendron aculeatum*; 1, Bark; 2, Leaf scar; 3, 4, UF 34008, *Lepidodendron obovatum*; 3, Bark; 4, Leaf scar; 5-7, UF 34371, *Lepidophloios laricinus*; 5, Bark; 6, Leaf scar, 7, Snail on leaf scars; 8, UF 34016, *Syringodendron* sp.; 9, 10, *Calamites goeppertii*; 9, UF 33994; 10, UF 33992; 11, UF 34013, *Aspidiopsis* sp. UF loc. 18902. Bar-1 mm (7), 5 mm (2, 4, 6, 10), 10 mm (1, 3, 5, 8, 9, 11).

This species was listed from Alabama by Gillespie and Rheams (1985).

**Material examined:** UF 18902-34008.

**Genus LEPIDOPHLOIOS Sternberg, 1825**  
**LEPIDOPHLOIOS LARICINUS (Sternberg)**  
**Goldenberg, 1857**  
 Figures 1.5-1.7

*Lepidodendron laricinum* STERNBERG, 1820, p. 22, tent. 23, pl. 11, figs. 2-4.

*Lychnophorites laricinum* (STERNBERG) MARTIUS, 1822, p. 144.

*Lepidofloyos laricinum* (STERNBERG) STERNBERG, 1825, p. 4, tent. 13.

*Lepidophloios laricinus* (STERNBERG) GOLDENBERG, 1857, p. 30, pl. 3, fig. 14, pl. 15, figs. 11-13, pl. 16, figs. 1-8.

**Description:** Leaf cushions overlapping in spiral arrangement, rhomboidal, acute at both ends. Central leaf scars horizontal to long axis of leaf cushion, and in lower portion of leaf cushion. Central leaf scars bilobed at apex, acute at the sides, and rounded at the base.

**Discussion:** The leaf cushions of this specimen are similar to those figured in Gillespie and Crawford (1985, pl. 1, fig. 5), and Gillespie and Rheams (1985, pl. 3, fig. 7), but lack the clearly visible central leaf scars as in Sternberg (1820), Gillespie et al. (1978, 1989), and Kvacek and Straková (1997). This species was listed from Alabama in Lesquereux (1880, 1884) and Gillespie and Rheams (1985). Numerous worm tubes on the leaf cushions (Fig. 1.7) are similar to those identified by Lesquereux (1866, pl. 38, fig. 6) as shells of a spirorbid polychaete, *Spirorbis carbonarius*.

**Material examined:** UF 18902-34371.

**Genus ASPIDIOPSIS H. Potonié, 1893**  
**ASPIDIOPSIS sp.**  
 Figure 1.11

**Description:** Sub-surface bark. Short, narrow longitudinal scars in spiral arrangement.

**Discussion:** This sub-surface portion of a *Lepidodendron* is very similar to the specimen figured by Janssen (1939, fig. 29).

**Material examined:** UF 18902-34013.

**Genus LEPIDOPHYLLOIDES Snigirevskaya, 1958**  
**LEPIDOPHYLLOIDES INTERMEDIUM**  
**Lindley & Hutton, 1831**  
 Figure 2.7

*Lepidophyllum intermedium* LINDLEY AND HUTTON, 1831, p. 125, pl. 43, fig. 3.

*Cyperites bicarinata* LINDLEY AND HUTTON, 1831, p. 123-124, pl. 43, fig. 1.2.

**Description:** Fragments of linear leaves with midvein and two thinner longitudinal veins on each side

of midvein, interspersed among numerous minute striations. Leaf width tapers apically.

**Discussion:** These leaves are similar to those figured by Lindley & Hutton (1831, pl. 43, figs. 1, 2), Janssen (1939, fig. 47), and Gillespie et al. (1978, pl. 13, fig. 2). This type of leaf was listed from Alabama by Lacefield (2000). Snigirevskaya (1958) proposed the new genus *Lepidophylloides* for detached leaves due to previous use of *Lepidophyllum* (Taylor & Taylor, 1993).

**Material examined:** UF 18902-34378, 18902-34373b.

**Genus LEPIDOSTROBUS Brongniart, 1828**

This genus accommodates elliptic to linear lycopod cones. Sporangia and cone scales are in spiral arrangement. We recognize two types in the Union Chapel flora.

**LEPIDOSTROBUS sp. A**  
 Figures 2.3, 2.4, 2.6

*Lepidostrobus* BRONGNIART, 1828, p. 87.

**Description:** Strobili linear, length 3-6x width. Sporangia and cone scales in spiral arrangement. Sporangia transversely rhombic, a few scales near apex lanceolate with medial longitudinal ridge.

**Discussion:** These narrow cones are similar to those figured by Gillespie et al. (1978, pl. 15, fig. 6) and Lacefield (2000) and were listed from Alabama by Lesquereux (1880) and Lacefield (2000).

**Material examined:** UF 18902-33993, 18902-34007, 18902-34372.

**LEPIDOSTROBUS sp. B**  
 Figures 2.1, 2.2

**Description:** Strobili elliptic, length 2x width, with pedicel. Scales spiral, with distinct bulges, lanceolate with attachment of entire base.

**Material examined:** UF 18902-34042, 18902-34365, 18902-34375.

**Genus LEPIDOSTROBOPHYLLUM Hirmer, 1927**  
**LEPIDOSTROBOPHYLLUM cf. MAJUS**  
**(Brongniart) Hirmer, 1927**  
 Figures 3.3, 3.12.1

*Lepidophyllum majus* BRONGNIART, 1828, p. 87.

*Lepidostrobophyllum majus* (BRONGNIART) HIRMER, 1927, p. 193, 231, fig. 213.

**Description:** Cone scales lanceolate, widest near middle, sloping slightly towards base, sloping sharply towards apex. Scales with numerous longitudinal striations. Midvein wide, lateral striations narrow.

**Discussion:** These scales are similar to those figured by Lesquereux (1879, pl. 69, fig. 37, 1880), Langford (1958, fig. 183), and Darrah (1969, pl. 29, figs. 6, 7) but lack an obvious triple-nerved aspect.

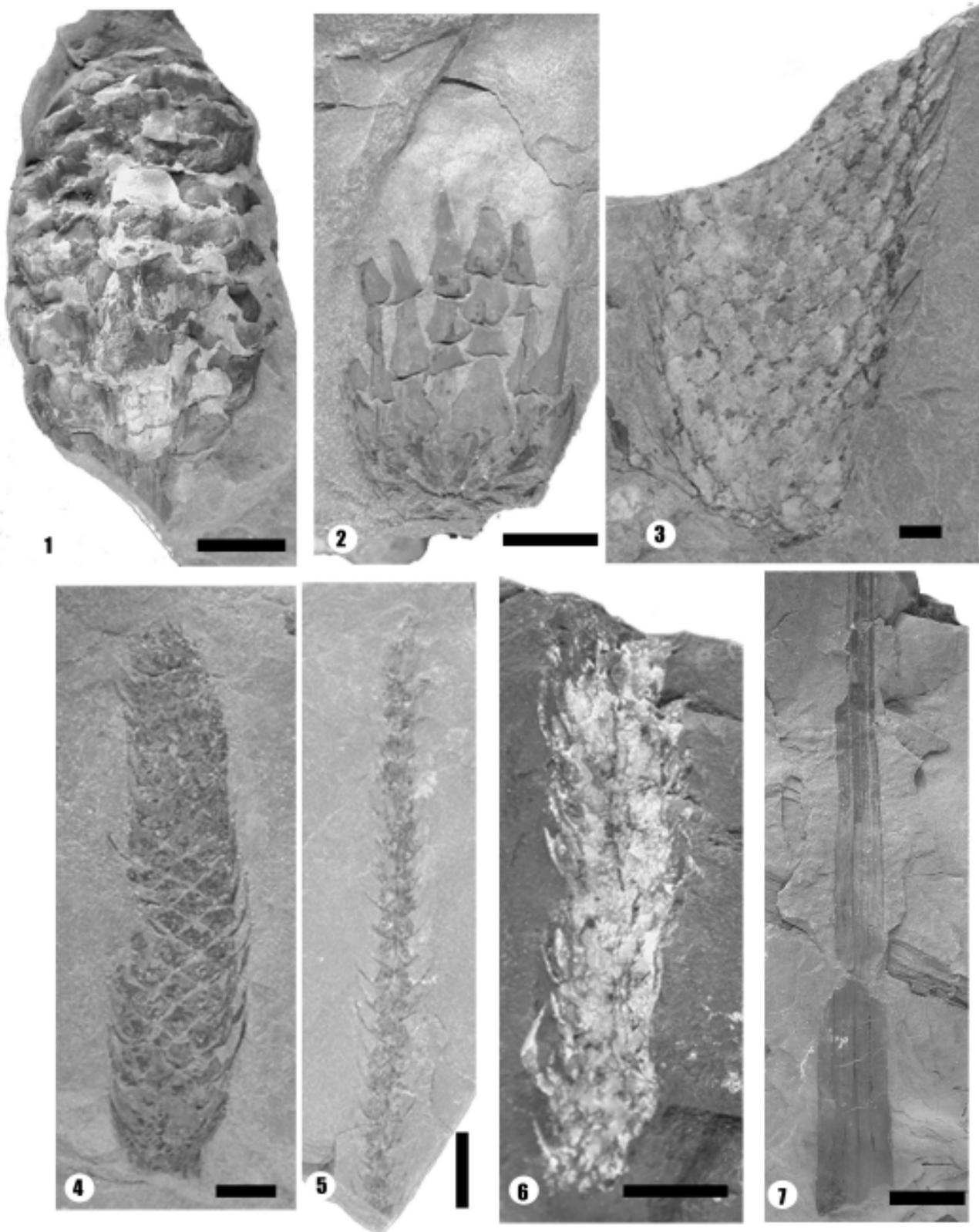


FIGURE 2.1, 2, *Lepidostrobus* sp. B.: 1, UF 34042; 2, UF 34365; 3, 4, *Lepidostrobus* sp. A.: 3, UF 33993; 4, UF 34007; 5, UF 34011, *Calamostachys* sp.; 6, UF 34372, *Lepidostrobus* sp. A.; 7, UF 34378, *Lepidophylloides intermedium*. UF loc. 18902. Bar-5 mm (2-6), 10 mm (1, 7).

Hirmer (1927) proposed the new genus *Lepidostrobophyllum* for detached cone scales (sporophylls).

**Material examined:** UF 18902-34369a, 18902-34374, 18902-34377.

**Family SIGILLARIACEAE**

**Genus SYRINGODENDRON Sternberg, 1820**  
**SYRINGODENDRON sp.**

Figures 1.8, 3.9, 3.11

*Syringodendron* STERNBERG, 1820, p. 22, 24.

**Description:** Lower decorticated stem. Ribs lacking. Subcortical surface striate. Subcortical scars double, elliptic, and in vertical rows. Scars with rough, broken cross striations. Upper decorticated stem large (Figs. 3.9, 3.11), 19 cm in diameter. Surface with straight to wavy longitudinal parallel striations formed into bands of ridges and furrows. Predominantly oval scars in spiral arrangement, elevated above the surface. Long axis of scars parallel to striations.

**Discussion:** The few morphological characters available for decorticated stem impressions make it difficult to place this in any particular species.

**Material examined:** UF 18902-34016, 18902-34379.

**Family CALAMITACEAE**

**Genus ASTEROPHYLLITES Brongniart, 1822**  
**ASTEROPHYLLITES CHARAEFORMIS**

(Sternberg) Goepfert in Wimmer, 1844

Figures 3.8, 3.10

*Bechera charaeformis* STERNBERG, 1825, p. 45, tent. 30, pl. 55, figs. 3, 5.

*Asterophyllites charaeformis* (STERNBERG) GOEPPERT in WIMMER, 1844, p. 198.

**Description:** Branching opposite. Stems with thin longitudinal striations. Leaves narrow and whorled, 4 or more per whorl. Leaves arch upward or basal portion horizontal to stem axis and distal portion arching upwards. Tip of leaves overlapping base of superadjacent whorl.

**Discussion:** These specimens are similar to those figured by Gillespie and Rheams (1985, pl. 2, fig. 5), Gillespie et al. (1978, pl. 25, figs. 1, 4, 1989, pl. 1, fig. 8), and Kvacek and Straková (1997, pl. 13, fig. 1). This species was reported from Alabama by Gillespie and Rheams (1985).

**Material examined:** UF 18902-33986, 18902-34373a, 18902-33990.

**Genus CALAMITES Brongniart, 1828**

This genus accommodates pith cast with internodes of longitudinal ribs and furrows. The internodes are wider than long and the longitudinal ribs are straight to undulate. The nodal areas possess or lack leaf/branch scars.

**CALAMITES SUCKOWII Brongniart, 1828**

Figures 3.4, 3.5

*Calamites suckowii* BRONGNIART, 1828, p. 124, pl. 14, fig. 6; pl. 15, figs. 1-6; pl. 16.

**Description:** Pith cast with internodes of longitudinal ribs and furrows. Internodes wider than long. Longitudinal ribs with straight sides and rounded to acute apices.

**Discussion:** The pith cast is similar to those figured by Lesquereux (1879, pl. 1, fig. 3, 1880) and Gillespie et al. (1989, pl. 2, fig. 1), but lack the basal constriction described by Langford (1958) and Darrah (1969). This species was reported from Alabama by Lesquereux (1884).

**Material examined:** UF 18902-34043, 18902-34366.

**CALAMITES UNDULATUS Sternberg, 1825**

Figures 3.1, 3.2

*Calamites undulatus* STERNBERG, 1825, tent. 26.

*Stylocalamites undulatus* (STERNBERG) KIDSTON, 1889, p. 401.

*Calamitina undulata* (STERNBERG) KIDSTON, 1894, p. 580.

*Calamites undulatus* STERNBERG; CROOKALL, 1966, p. 555, pl. 121, figs. 2, 3, pl. 122, figs. 1-3, pl. 124, figs. 1, 2, pl. 125, fig. 1, pl. 126, figs. 2, 3, pl. 127, figs. 1-4, pl. 128, fig. 1.

**Description:** Pith cast with internodes of longitudinal ribs and furrows. Internodes wider than long. Longitudinal ribs with undulate sides and squared apices.

**Discussion:** The pith cast is similar to those figured by Langford (1958, fig. 28), Gillespie et al. (1978, pl. 23, fig. 3), and Kvacek and Straková (1997, pl. 58, fig. 5) but the undulations are smoother.

**Material examined:** UF 18902-34047, 18902-34018.

**CALAMITES GOEPPERTI Ettingshausen, 1854**

Figures 1.9, 1.10

*Calamites goepperti* ETTINGSHAUSEN, 1854.

**Description:** Stem pattern with internodes filled with longitudinal ribs and furrows. Internodes wider than long. The longitudinal ribs are straight and end in small leaf scars. Nodal areas consist of small leaf scars and occasional larger branch scars. The branch scars are packed close together with flattened sides and a square-like outline. Linear leaf-like structures extend from stems. These appear to be leaves.

**Discussion:** These specimens are similar to those figured by Janssen (1939, fig. 65), Langford (1958, fig. 25), and Gillespie et al. (1978, pl. 24 fig. 4).

**Material examined:** UF 18902-33992, 18902-33994.

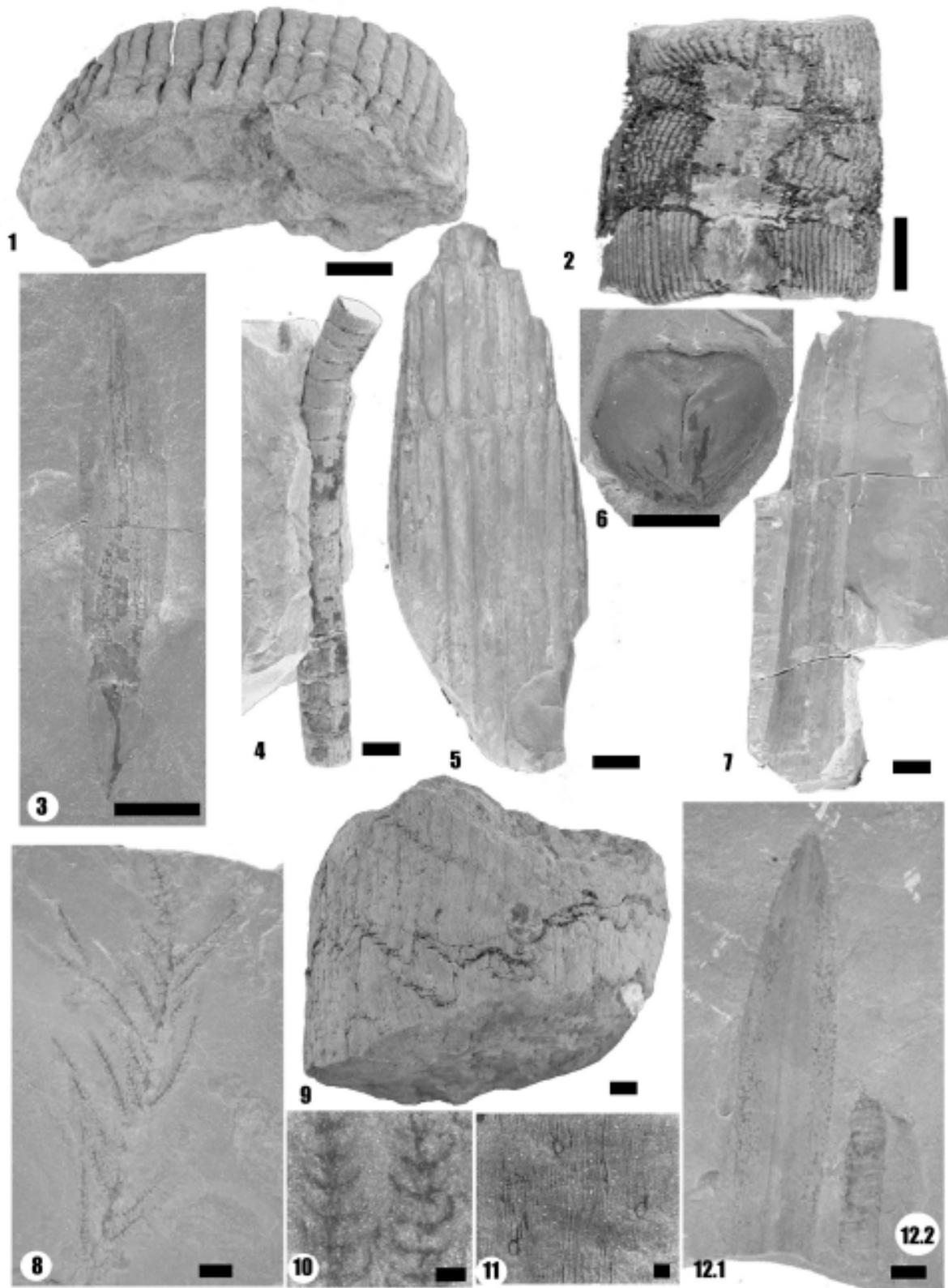


FIGURE 3.1, 2, *Calamites undulatus*; 1, UF 34047; 2, UF 34018; 3, UF 34374, *Lepidostrobophyllum* cf. *majus*; 4, 5, *C. suckowii*; 4, UF 34043; 5, UF 34366; 6, UF 34368, *Cordaicarpon* sp.; 7, UF 33989, *Cordaites* sp.; 8, 10, UF 34373a, *Asterophyllites charaeformis*; 9, 11, UF 34379, *Syringodendron* sp.; 10, Enlargement of 8 showing whorled leaves; 11, Enlargement of 9; 12.1, UF 34369a, *Lepidostrobophyllum* cf. *majus*; 12.2, UF 34369b, *Artisia* sp. UF loc. 18902. Bar: 1 mm (10, 11), 5 mm (6, 8, 12.1, 12.2), 10 mm (1, 3, 4, 5, 9), 20 mm (2), 3 cm (7).

**Genus CALAMOSTACHYS Schimper, 1869**  
**CALAMOSTACHYS sp.**

Figure 2.5

**Description:** Stroboli linear, length 50 mm, width 5-7 mm. Sporangia midway between whorls of sterile bracts. Internode length 2 mm, bract length 2-4 mm. Basal portion of bracts perpendicular to main axis, then arch apically.

**Material examined:** UF 18902-34011.

**MEDULLOSALES**  
**PTERIDOSPERMS**  
**ALETHOPTERIDS**

**Genus ALETHOPTERIS Sternberg, 1825**  
**ALETHOPTERIS VALIDA Boulay, 1876**

Figure 4.3

**Description:** Frond fragment. Pinnae opposite, lanceolate, pinnatifid. Pinnules alternate, broadly attached to rachis, connate, oblong, obtuse apex. Pinnules of lower to midsection of pinnae 2-3 mm wide, 5-7 mm long. Pinnules reducing upward to elongate apical pinule with crenate margin. Midvein of pinnules fork near apex. Lateral veinlets in pairs of 5-7, divide 1-2 times ending at margins at acute to right angles. Basal pinules with some veinlets arising from rachis.

**Discussion:** The frond is similar to specimens with more obtuse apex of pinnules figured by Crookall (1955, Pl. 1, fig. 3) and Josten (1991, Pl. 167, figs. 2, 3).

**Material examined:** UF 18902-34036.

**SPHENOPTERIDS**

**Genus SPHENOPTERIS (Brongniart) Sternberg, 1825**

This genus accommodates pinna which are alternate and narrowly attached to the rachis. The pinna are lobed to pinnatifid, and the pinnules are broad to narrowly attached to the rachis.

**SPHENOPTERIS ELEGANS (Brongniart)**  
**Sternberg, 1825**

Figure 4.8

*Filicites elegans* BRONGNIART, 1822, p. 33, pl. 2, fig. 2.

*Sphenopteris elegans* (BRONGNIART) STERNBERG, 1825, tent. 15.

**Description:** Pinna fragment. Pinnules alternate, tri-pinnate, and ovate in outline. Pinnules with narrow attachment. Primary lobes alternate, secondary and tertiary lobes with rounded apex. Single veins entering terminal lobes.

**Discussion:** The pinna is similar to those figured by Lesquereux (1879, pl. 55, fig. 6, 1880), Gillespie et al. (1978, pl. 8, fig. 1), and Gillespie and Rheams (1985, pl. 3, fig. 3). This species was reported from Alabama by Gillespie and Rheams (1985). Our specimen is different from the Alabama species of *Eremopteris*

(Lesquereux, 1879, 1880; White, 1900, 1943) due to narrow secondary and tertiary lobes, and single veins entering the terminal lobes.

**Material examined:** UF 18902-34030.

**SPHENOPTERIS POTTSVILLEA (D. White)**  
**Gastaldo and Boersma, 1983**

Figure 4.2

*Mariopteris pottsvillea* D. WHITE, 1900, p. 874, pl. 190, figs. 6 (non pl. 190, figs. 3-5).

*Sphenopteris pottsvillea* (D. WHITE) GASTALDO AND BOERSMA, 1983, p. 223, pl. 8, pl. 9, pl. 10, figs. 6, 7.

**Description:** Pinna alternate, narrowly attached and somewhat decurrent to axis. Pinna lobed to pinnatifid. Pinnatifid state with basal lobe separate. Pinna apex obtuse to acute. Pinnules alternate, ovate and obtuse, broad attachment to rachis. Pinnules confluent towards top of pinna. Parallel veins originating low at an acute angle continuing straight or arching out to apex. Veins forking 1-3 times.

**Discussion:** The pinna is similar to those figured by White (1900, pl. 190, figs. 3-6, 1943, pls. 8-10), Read and Mamay (1964, pl. 5, fig. 1), Gastaldo and Boersma (1983a, pls. 8-10), Gillespie and Rheams (1985, pl. 1, fig. 5), Gillespie and Crawford (1985, pl. 1, fig. 7), Gastaldo (1988, fig. 2), and Gillespie et al. (1989, pl. 1, fig. 7). This species was reported from Alabama by White (1900, 1943), Gastaldo and Boersma (1983a), Gillespie and Rheams (1985), and Gastaldo (1988).

**Material examined:** UF 18902-34033.

**Genus LYGINOPTERIS H. Potonié, 1897**  
**LYGINOPTERIS HOENINGHAUSI (Brongniart)**

**H. Potonié, 1897**

Figures 4.4, 4.7

*Sphenopteris hoeninghausi* BRONGNIART, 1830, p. 199, pl. 52.

*Dadoxylon oldhamium* Binney, 1866, p. 115.

*Lyginopteris oldhamia* (Binney) H. Potonié, 1897, p. 170.

*Lyginopteris hoeninghausi* Gothan, 1931, p. 71-79, pl. 21, figs. 1, 2, pl. 22, figs. 1, 2, pl. 23, figs. 4, 5.

**Description:** Fragment of frond. Secondary pinna alternate. Tertiary pinna alternate with narrow attachment. Pinna lobed to pinnatifid with obtuse apex. Pinnules alternate, ovate to shallow lobed, broadly attached and decurrent to rachis. Pinnules confluent towards top of pinna. Veins parallel, emerging from rachis, forking 1-2 times.

**Discussion:** The frond is similar to those figured by Gillespie and Rheams (1985, pl. 2, fig. 6), Gillespie and Crawford (1985, pl. 3, fig. 1) and Gillespie et al. (1989, pl. 1, fig. 14) but the pinnules are broadly attached to rachis and slightly lobed. This species was reported from Alabama by Gillespie and Rheams (1985).

**Material examined:** UF 18902-34038, 34039.

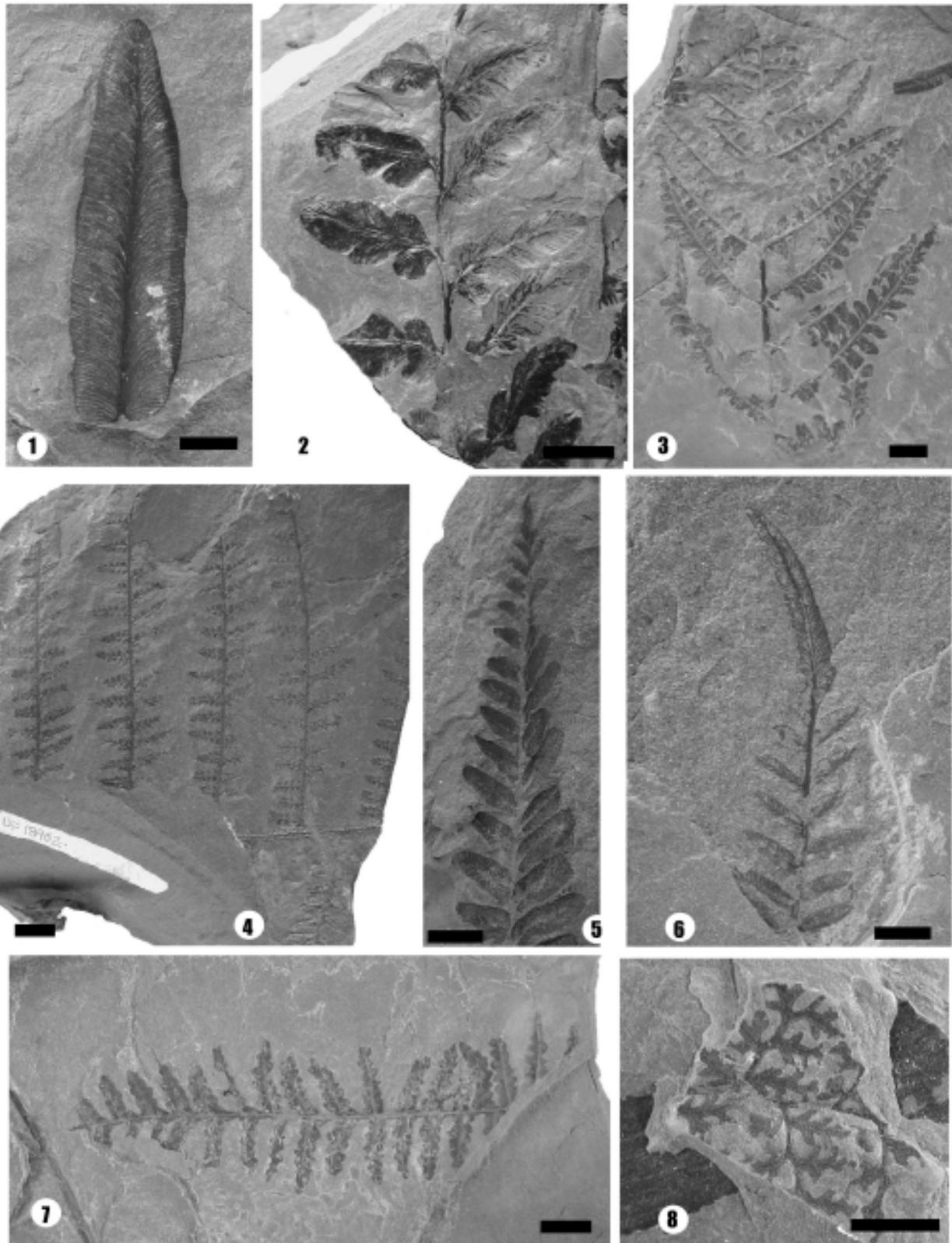


FIGURE 4.1, UF 34029, *Neuralethopteris biformis*; 2, UF 34033, *Sphenopteris pottsvillea*; 3, UF 34036, *Alethopteris valida*; 4, UF 34039, *Lyginopteris hoeninghausi*; 5, UF 34025, *Neuralethopteris pocahontas*; 6, UF 34023, *Neuralethopteris biformis*; 7, UF 34038, *Lyginopteris hoeninghausi*; 8, UF 34030, *Sphenopteris elegans*. UF loc. 18902. Bar: 5 mm (1, 6, 8), 10 mm (2-5, 7).

## NEUROPTERIDS

Genus *CYCLOPTERIS* Brongniart, 1831*CYCLOPTERIS* sp.

Figure 5.3

*Cyclopteris* BRONGNIART, 1831, p. 215

**Description:** Leaf oval, broad base 5 cm wide, upper portion 11 cm wide. Convex on upper surface. Veins flabellate, parallel, arched, thin and all the same size.

**Discussion:** Could not verify if the veins forked or dichotomize, but the leaf is similar to *Neuropteris inflata* Lx. illustrated by Lesquereux (1866, pl. 37, fig. 2).

**Material examined:** UF 18902-34046, 18902-34046'.

Genus *NEURALETHOPTERIS* Cremer ex Laveine 1967

This genus accommodates pinnae that are lanceolate with a single terminal pinnule. Pinnules are alternate and lanceolate to ovate. Pinnules are narrowly attached at the middle with a short pedicel and are rounded to cordate. Pinnules have a prominent midvein. The lateral veins divide once near the midvein, then a second time half way to margin and then meet at the margin at a 45-90° angle.

*NEURALETHOPTERIS* POCAHONTAS (White)

## Goubet et al., 2000

Figure 4.5

*Neuropteris pocahontas* D. WHITE, 1900, p. 888-890, pl. 189, figs. 4, 4a, pl. 191, figs. 5, 5a.

**Description:** Pinna fragment, lanceolate. Pinnules alternate and ovate, with narrow attachment. Base round to slightly cordate, obtuse to rounded apex. Prominent midrib to near apex then divides. Lateral veins prominent, arise from midrib at acute angle then arch out to margin dividing 2-3 times. First division near midrib, veins meet margin at or near 90° angle. Terminal pinnule narrow and oblong, with basal lobes.

**Discussion:** The pinna is similar to those figured by Lesquereux (1879, 1880), White (1900, pl. 190, figs. 7, 8), Gillespie et al. (1978, pl. 44, fig. 1), and Gillespie and Rheams (1985, pl. 2, fig. 7). This species was reported from Alabama by White (1900), and Gillespie and Rheams (1985).

**Material examined:** UF 18902-34025.

*NEURALETHOPTERIS* BIFORMIS

(Lesquereux)

## Goubet et al., 2000

Figures 4.1, 4.6

*Neuropteris biformis* Lesquereux, Atlas 1879, pl. 13, fig. 7; 1880, p. 121.

**Description:** Pinna fragment lanceolate with single terminal pinnule. Pinnules alternate, lanceolate, and not overlapping. Pinnule base rounded to slightly cordate,

narrow attachment at middle with short pedicel. Prominent midvein to near acute apex. Lateral veins divide 2 times meeting margin at 45-90° angle. Terminal pinnule elongate, acute apex and slightly bulging base. Isolated pinnule lanceolate, 3.2 cm long by 0.8 cm wide. Apex acute, base cordate. Strong midvein reaches nearly to apex. Secondary veins angle upward from midvein then running straight out to margin, divide 2-3 times. Average count is 42-45 per centimeter of margin.

**Discussion:** The pinnules are similar to specimens figured by Goubet et al. (2000, figs. 12.7, 13) and Gillespie and Rheams (1985, pl. 2, figs. 9, 10).

**Material examined:** UF 18902-34023, 18902-34350, 18902-34351, 18902-34029.

## MISCELLANEOUS PTERIDOSPERMS

Genus *MYELOXYLON* Brongniart, 1849*MYELOXYLON* sp.

Figure 5.7

*Myeloxylon* BRONGNIART, 1849.

**Description:** Fragment of branched stem, with presence of vascular strands.

**Discussion:** The stem is similar to a specimen figured by Darrah (1969, pl. 80, fig. 2).

**Material examined:** UF 18902-33988.

Genus *WHITTLESEYA* Newberry, 1853*WHITTLESEYA* ELEGANS Newberry, 1853

Figure 5.6

*Whittleseya elegans* NEWBERRY, 1853, p. 106, figs. 1-2b.

**Description:** Campanulate structure with parallel longitudinal striations, radiating out from base and ending in dentate apex. Base rounded with peduncle, apex truncate with dentate teeth.

**Discussion:** The structure is similar to those figured by Lesquereux (1879, pl. 4, fig. 1, 1880) and Darrah (1969, pl. 71, fig. 2).

**Material examined:** UF 18902-34364, 18902-34364'.

Genus *HOLCOSPERMUM* Nathorst, 1914*HOLCOSPERMUM* sp.

Figure 5.5

*Holcospermum* NATHORST, 1914, p. 28.

**Description:** Seed ovate, rounded at base and narrowed upward. Longitudinal striations radiating from base and converging near apex.

**Discussion:** The seed is similar to *Holcospermum multistriatus* figured by Lesquereux (1879, pl. 85, figs. 22, 23, 1880) and Darrah (1969, pl. 68, figs. 2, 3), *H. mammillatus* by Lesquereux (1884, pl. 110, figs. 39-42), plus *H. maizeretense* Stockmans & Williere in Gillespie and Rheams (1985, pl. 1, fig. 4) and Gillespie et al. (1989, pl. 1, fig. 4). This species is reported from Alabama by Gillespie and Rheams (1985).

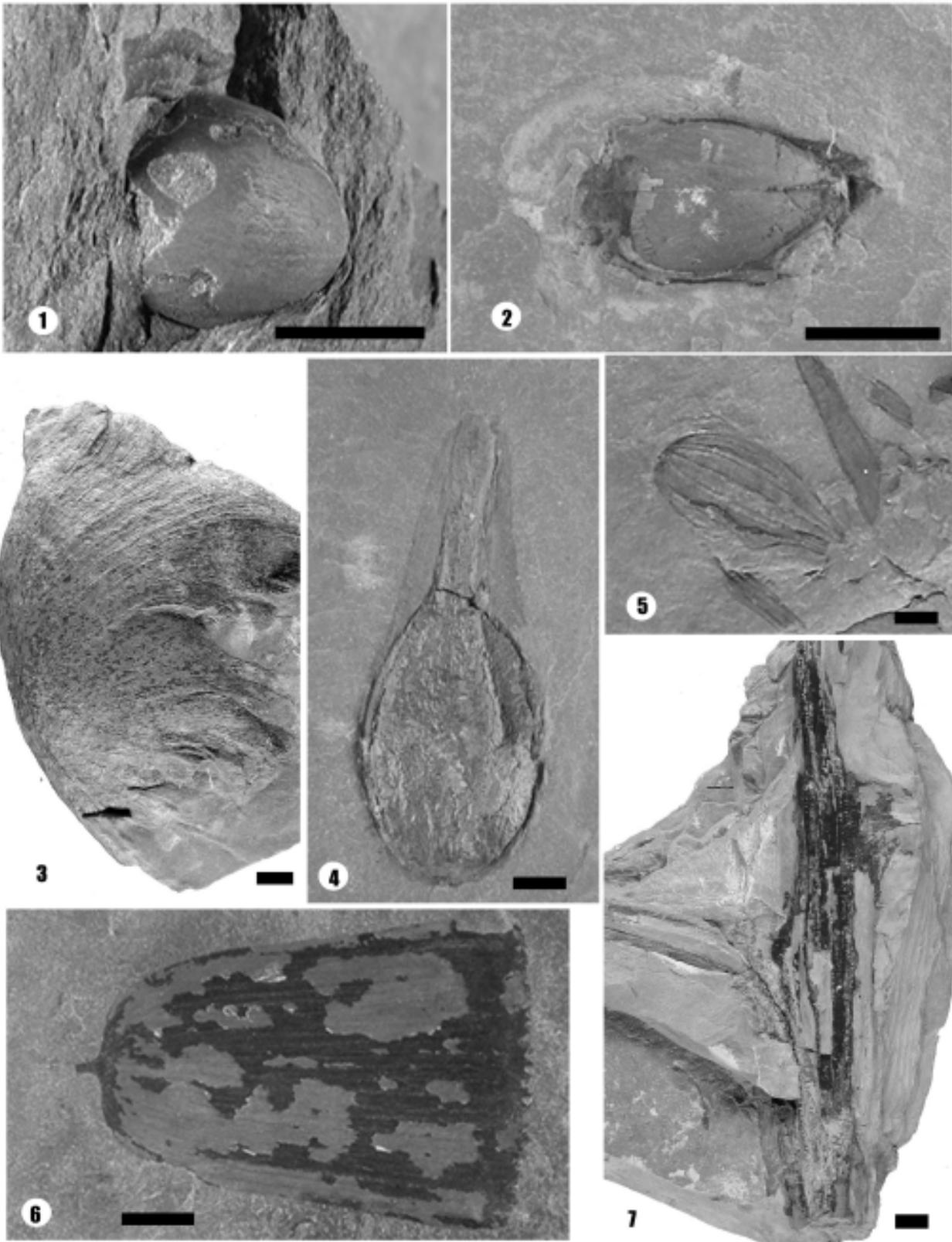


FIGURE 5.1, UF 34041, *Carpolithes* sp.; 2, UF 34040, *Trigonocarpus* sp.; 3, UF 34046, *Cyclopteris* sp.; 4, UF 34362, *T. ampulliforme*; 5, UF 34370, *Holcospermum* sp.; 6, UF 34364', *Whittleseya elegans*. 7, UF 33988, *Myeloxylon* sp. UF loc. 18902. Bar: 5 mm (4-6), 10 mm (1, 2, 3, 7).

**Material examined:** UF 18902-34370.

**Genus TRIGONOCARPUS Brongniart, 1828**  
**TRIGONOCARPUS AMPULLIFORME**  
**Lesquereux, 1884**  
 Figure 5.4

*Trigonocarpus ampulliforme* LESQUEREUX, 1884, p. 823, pl. 109, figs. 18-20.

**Description:** Seeds ovate, narrowed upward to a tubular neck. Base rounded with small circular depression. Sclerotesta surrounding nucellus and microphyte extension. Faint ribs on sclerotesta.

**Discussion:** The seeds are similar to those figured by Lesquereux (1884, pl. 109, figs. 18-20), White (1900, pl. 191, fig. 8), Gillespie and Crawford (1985, pl. 3, fig. 6), and Gillespie and Rheams (1985, pl. 2, fig. 1). This species is reported from Alabama by Gillespie and Rheams (1985).

**Material examined:** UF 18902-34362, 18902-34362'.

**TRIGONOCARPUS sp.**  
 Figure 5.2

*Trigonocarpum* BRONGNIART, 1828, p. 137.  
*Trigonocarpus* BRONGNIART, 1881, p. 39.

**Description:** Seed that is three valved, ovate, and sclerotesta with faint ribs. Short, acute apex and rounded base.

**Material examined:** UF 18902-34040, 34040'.

**Genus CARPOLITHES Schlotheim, 1820**  
**CARPOLITHES sp.**  
 Figure 5.1

*Carpolithes* SCHLOTHEIM, 1820.

**Description:** Seed ovate, surface smooth, with obtuse apex and rounded base. Possible ribs present.

**Material examined:** UF 18902-34041.

**CORDAITALES**  
**Family CORDAITACEAE**  
**Genus ARTISIA Sternberg, 1838**  
**ARTISIA sp.**  
 Figure 3.12.2

*Artisia* STERNBERG, 1838, p. 192.

**Description:** Central pith cast with transverse, irregular spaced septations.

**Discussion:** This pith cast is similar to ones figured by Janssen (1939, fig. 56), Langford (1958, fig. 224), Canright (1959, pl. 5, fig. 10), Wood (1963, pl. 11, fig. 8), and Gillespie et al. (1978, pl. 53, figs. 1, 2).

**Material examined:** UF 18902-34369b.

**Genus CORDAICARPON H. B. Geinitz, 1862**  
**CORDAICARPON sp.**  
 Figure 3.6

*Cordaicarpus* GEINITZ, 1862, p. 150.

**Description:** Seed obovate with an apical protruding flange overriding an obtuse notch, base truncate. Medial longitudinal ridge flanked by broadly undulating smooth surface.

**Discussion:** This seed is similar to those of Langford (1958, fig. 625) but our specimen has a medial longitudinal line. It is also similar to those of Wood (1963, pl. 12, fig. 7), but our specimen has a depression flanking the obtuse apical notch.

**Material examined:** UF 18902-34368.

**Genus CORDAITES Unger, 1850**  
**CORDAITES sp.**  
 Figure 3.7

*Cordaites* UNGER, 1850, p. 277.

**Description:** Linear fragment of leaf, entire margin. Length 50 cm, basal width 4 cm, apical width 6 cm. Numerous closely packed parallel longitudinal veins (30-40 per cm).

**Discussion:** This leaf is similar to *C. mansfieldi* figured by Lesquereux (1879, pl. 76, fig. 4, 1880), and *C. grandifolius* figured by Noe (1925, pl. 45, fig. 2) and Darrah (1969, pl. 48, fig. 3).

**Material examined:** UF 18902-33989.

**DISCUSSION**

The Union Chapel flora is characterized as a coastal lowland swamp forest dominated by large arborescent lycophytes of the Lepidodendrales. Different organs of essentially the same type of lycophyte trees are well preserved. This includes bark impressions of *Lepidodendron* and *Lepidophloios*, subsurface bark *Aspidiopsis*, detached leaves *Lepidophylloides*, intact cones *Lepidostrobus*, and isolated cone scales *Lepidostrobophyllum*. Of particular interest are the association of annelids and the bark of *Lepidophloios* recorded from leaves and stems of various coal plants (Lesquereux, 1866). A minor constituent of large trees is *Sigillaria*, represented by highly eroded stem cast and impressions of *Syringodendron*. Smaller trees are represented by a cone of *Calamostachys*, stem and pith casts of *Calamites* and associated foliage of *Asterophyllites*. Understory plants are made up mainly of seed ferns, or pteridosperms, which includes foliage of *Neuraethopteris*, *Sphenopteris*, and *Cyclopteris*, stems of *Myeloxylon*, seeds of *Trigonocarpus*, and pre-pollen organs of *Whittleseya*. A minor group of understory plants includes *Alethopteris*, isolated seeds of *Holcospermum*, and of *Carpolithes*. A possibly riparian, tree-sized plant (Lacefield, 2000) includes isolated leaves of *Cordaites*, pith casts of *Artisia*, and seeds of *Cordaicarpus*. Figure 6 illustrates what a view of the

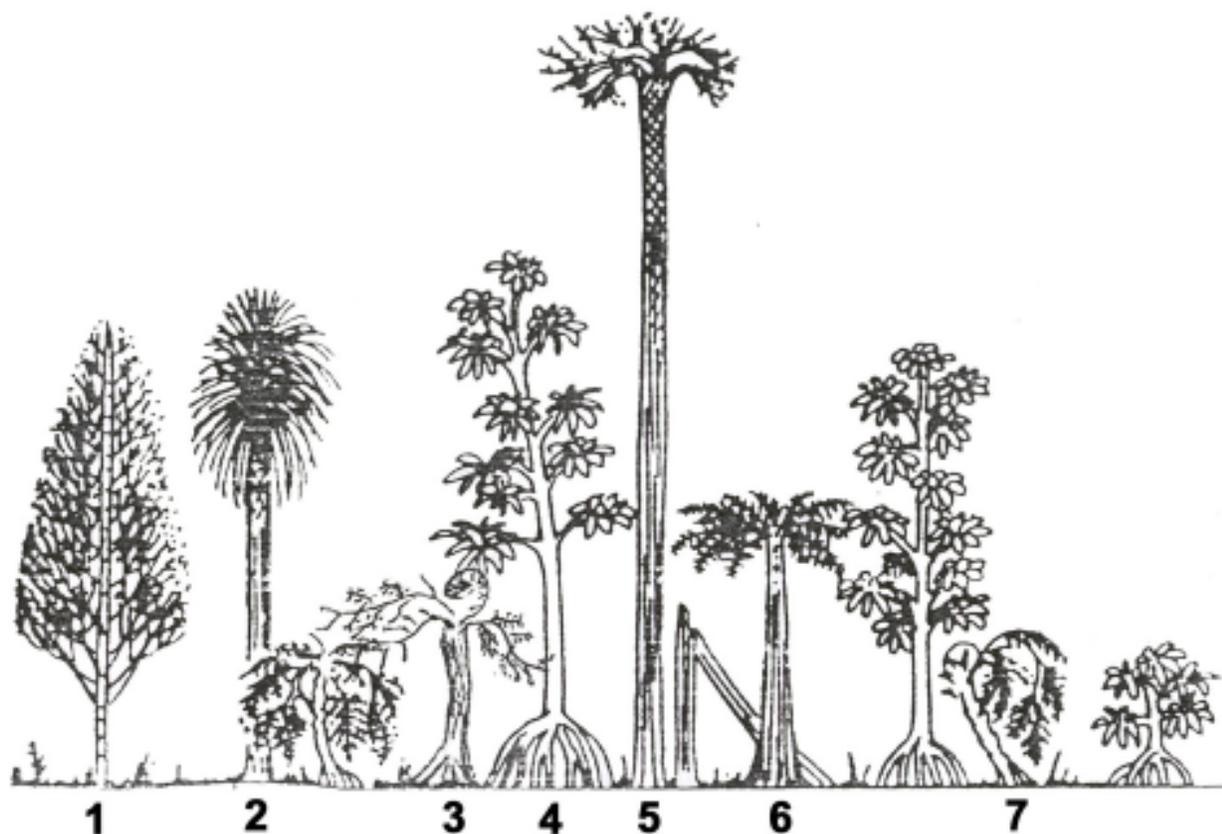


FIGURE 6. Reconstruction of coal swamp trees. 1, *Calamites*; 2, *Sigillaria*; 3, *Medullosa* (seed fern); 4, *Cordaites*; 5, *Lepidodendron/Lepidophloios*; 6, *Psaronius*; 7, seed fern. Modified from Phillips et al. (1976).

swamp forest might have looked like.

*For additional photographs of fossil plants from the Union Chapel Mine, see Dilcher and Lott (2005).*

#### ACKNOWLEDGMENTS

We would like to thank the members of the Alabama Paleontological Society, Inc. and the Birmingham Paleontological Society, especially Steve Minkin and Prescott Atkinson, for the donation of specimens to the Paleobotany/Palynology Collection. We also would like to thank Ron Buta, David Kopaska-Merkel, Robert Gastaldo and Steven Manchester for their valuable comments and suggestions. This study was supported by the Becker/Dilcher Endowment for Paleobotany of the University of Florida Foundation. This paper is University of Florida Contribution to Paleobiology publication number 548.

#### REFERENCES

- Andrews, H. N., Jr., 1970, Index of generic names of fossil plants, 1820-1965: U.S. Geological Survey Bulletin, no. 1300, p. 1-354.
- Binney, E. W., 1866, On fossil wood found in calcareous nodules in the lower coal seam of Lancashire and Yorkshire: Manchester Literary and Philosophical Society Proceedings, v. 5, p. 61-64, 113-115
- Boulay, N., 1876, Le terrain houiller du Nord de la France et ses végétaux fossiles: Université de Caen, Thèse de géologie, 74 p.
- Brongniart, A. T., 1822, Sur la classification et la distribution des végétaux fossiles en général, et sur des terrains de sédiment supérieur en particulier. Reprinted from: Mémoires du Muséum d'Histoire Naturelle, v. 8, Imprimerie de A. Belin, Paris, 91 p.
- Brongniart, A. T., 1828, Prodrome d'une histoire des végétaux fossiles: F. G. Levrault, Paris, 223 p.
- Brongniart, A. T., 1828-1834, Histoire des végétaux fossiles, ou recherches botaniques et géologiques sur les végétaux renfermés dans les diverses couches du globe. v. 1, no. 1 (1828), p. 1-80; v. 1, no. 4 (1830), p. 169-208.; v. 1, no. 5 (1831), p. 209-248; v. 1, no. 6 (1831), p. 249-264; v. 1, 9 (1834), p. 313-336.
- Brongniart, A. T., 1849, Tableau des genres de végétaux fossiles considérés sous le point de vue de leur classification botanique et de leur distribution géologique; in d'Orbigny, A. C. V. D., ed., Dictionnaire Universel d'Histoire Naturelle, v. 13, 52-176 (1-127).
- Brongniart, A. T., 1881, Recherches sur les graines fossiles silicifiées: Paris, G. Masson, 93 p.
- Bunbury, C. T. F., 1846, Description of Alabama coal plants: American Journal of Science and Arts, ser. 2, v. 2, p. 230-

- 233.
- Canright, J. E., 1959, Fossil plants of Indiana: Indiana Department of Conservation Geological Survey Report of Progress, no. 14, p. 1-45.
- Cremer, L., 1893, Über die fossilen Farne des westfälischen Carbons und ihre Bedeutung für eine Gliederung des Letzteren: Universität Marburg, Dissertation, 49 p.
- Crookall, R., 1955, Fossil plants of the Carboniferous rocks of Great Britain [Second Section]. Part 1: Memoirs of the Geological Survey of Great Britain, Palaeontology, v. 4, p. 1-84.
- Crookall, R., 1966, Fossil plants of the Carboniferous rocks of Great Britain, II: Memoirs of the Geological Survey of Great Britain, Palaeontology, v. 4, p. 355-572.
- Darrah, W. C., 1969, A critical review of the Upper Pennsylvanian floras of eastern United States with notes on the Mazon Creek Flora of Illinois, Pennsylvania, Gettysburg College, 220 p.
- Dilcher, D. L. and Tott, T. A., 2005, Atlas of Union Chapel Mine fossil plants; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 339-365.
- DiMichelle, W. A. and Phillips, T. L., 1995, The response of hierarchially-structured ecosystems to long-term climatic change: a case study using tropical peat swamps of Pennsylvanian age, p. 134-155; in Stanley, S. M. et al., eds., Effect of Past Global Change on Life: National Research Council Studies on Geophysics.
- Ettingshausen, C., 1854, Die Steinkohlenflora von Radnitz in Böhmen: Abhandlungen der Kaiserlich-königlichen geologischen Reichsanstalt, Abt. 3, v. 2, p. 1-74.
- Gastaldo, R. A., 1984, Studies on North American pecopterids. III. *Pecopteris buttsii* D. White from the Early Pennsylvanian of Alabama: Journal of Paleontology, v. 58, p. 63-77.
- Gastaldo, R. A., 1985, Upper Carboniferous paleoecological reconstructions: observations and reconsiderations: Compte Rendu, Tenth International Congress of Carboniferous Stratigraphy and Geology, Madrid, Spain, v. 2, p. 281-296.
- Gastaldo, R. A., 1988, The frond architecture of *Sphenopteris pottsvillea* (White) Gastaldo and Boersma: Journal of Paleontology, v. 62, p. 982-988.
- Gastaldo, R. A., 1990, Early Pennsylvanian swamp forests in the Mary Lee Coal Zone, Warrior Basin, Alabama; in Gastaldo, R. A. et al., eds., Carboniferous coastal environments and paleocommunities of the Mary Lee Coal Zone, Marion and Walker Counties, Alabama: Geological Survey of Alabama, Tuscaloosa, Alabama, p. 1-54.
- Gastaldo, R. A. and Boersma, M., 1983a, A reinvestigation of early Pennsylvanian species of *Mariopteris* from the Appalachian regions. I. *Karinopteris*, *Mariopteris* and the "Pottsville complex": Review of Palaeobotany and Palynology, v. 38, p. 185-226.
- Gastaldo, R. A. and Boersma, M., 1983b, A reinvestigation of early Pennsylvanian species of *Mariopteris* from the Appalachian Region. II. *Eusphenopteris* and *Sphenopteris*: Review of Palaeobotany and Palynology, v. 38, p. 227-247.
- Gastaldo, R. A., Demko, T. M., Liu, Y., Keefer, W. D. and Abston, S. L., 1989, Biostratigraphic processes for the development of mud-cast logs in Carboniferous and Holocene swamps: Palaios, v. 4, p. 356-365.
- Geinitz, H. B., 1862, Dyas oder die Zechsteinformation und das Rothliegende, II, Die Pflanzen der Dyas und Geologisches. W. Engelmann, Leipzig, 342 p.
- Gillespie, W. H., Clendening, J. A. and Pfefferkorn, H. W., 1978, Plant fossils of West Virginia: West Virginia Geological and Economic Survey, Educational Series ED-3A, p. 1-172.
- Gillespie, W. H. and Crawford, T. J., 1985, Plant megafossils from the Carboniferous of Georgia, USA: Compte Rendu, Tenth International Congress of Carboniferous Stratigraphy and Geology, Madrid, Spain, v. 2, p. 247-256.
- Gillespie, W. H., Crawford, T. J. and Waters, J. A., 1989, Plant fossils of the Pennsylvanian system of Georgia: Guidebook Addendum, 38th Annual Meeting Southeastern Section, Geological Society of America, Atlanta, Georgia, April 3-5, p. 2-13.
- Gillespie, W. H. and Rheams, L. J., 1985, Plant megafossils from the Carboniferous of Alabama, USA: Compte Rendu, Tenth International Congress of Carboniferous Stratigraphy and Geology, Madrid, Spain, v. 2, p. 191-202.
- Goeppert, H. R., 1844, Uebersicht der fossilen Flora Schlesiens; in Wimmer, F., ed., Flora von Schlesien preussischen und österreichischen Antheils: Breslau, F. Hirt, vol. 2, edition 2., p. 159-225.
- Goldenberg, F., 1857, Flora Saraepontana fossilis: Die Pflanzenversteinerungen des Steinkohlen Gebirges von Saarbrücken, vol. 2, Neumann'sche Buchhandlung, Saarbrücken, 60 p.
- Gothan, W., 1931, Die Steinkohlenflora der westlichen paralischen Carbonreviere Deutschlands, Lfg. 2: Arbeiten Institut Paläobotany u Petrogr. Brennsteine, v. 1, p. 49-96.
- Goubet, P., Pfefferkorn, H. W., and Gillespie, W. H., 2000, Neuraethopterids (trigonocarpalean pteridosperms) from the Early Pennsylvanian of eastern North America: PaleoBios, v. 20, p. 11-37.
- Harrington, H. D. and Durrell, L. W., 1957, How to identify plants. Ohio, Swallow Press, 203 p.
- Hirmer, M., 1927, Handbuch der Paläobotanik, Band I: Thallophyta- Bryophyta-Pteridophyta: Berlin, R. Oldenbourg, 708 p.
- Janssen, R. E., 1939, Leaves and stems from fossil forests: Illinois State Museum Popular Science Series, no. 1, p. 1-190.
- Josten, K.H., 1991, Die Steinkohlen-Floren Nordwestdeutschlands: Fortschritte in der Geologie von Rheinland und Westfalen, 36, p. 1-434.
- Kidston, R., 1889, On the fossil plants in the Ravenhead Collection in the Free Library and Museum, Liverpool: Transactions of the Royal Society of Edinburgh, v. 35, p. 391-428.
- Kidston, R., 1894, Fossil flora of the South Wales Coal Field, and the relationship of its strata to the Somerset and Bristol Coal Field: Transactions of the Royal Society of Edinburgh, v. 37, p. 565-614.
- Kvacek, J. and Straková, M., 1997, Catalogue of Fossil Plants Described in Works of Kaspar M. Sternberg: Prague, National Museum, 201 p.
- Lacefield, J., 2000, Lost Worlds in Alabama Rocks: A Guide to the State's Ancient Life and Landscapes: Tuscaloosa, Alabama Geological Society, 123 p.
- Langford, G., 1958, The Wilmington Coal Flora from a Pennsylvanian deposit in Will County, Illinois: Esconi Associates, Illinois, 360 p.
- Laveine, J.-P., 1967, Contribution à l'étude de la flore du terrain houiller. Les Neuroptéridées du Nord de la France: I- Flore fossile, 5e fascicule. Etudes Géologiques Atlas de Topographie Souterraine, Houillères du Bassin du Nord et du Pas-de-Calais, 344 p.
- Lesquereux, L., 1866, Report of the fossil plants of Illinois: Illinois Geological Survey, Volume 2, Palaeontology, p. 427-470.
- Lesquereux, L., 1879-1884, Description of the coal flora of the Carboniferous Formation in Pennsylvania and throughout the United States: Second Pennsylvania Geological Survey, 3 vols. Atlas (1879), p. 1-18, 85 pls; v. 1-2 (1880), p. 1-694. v. 3 (1884), p. 695-975.
- Lesquereux, L., 1888, List of fossil plants collected by Mr. I. C. Russell, at Black Creek, near Gadsden, Ala., with descriptions of several new species: Proceedings of the United States National Museum, v. 11, p. 83-87.

- Lindley, J. and Hutton, W., 1831-1833, The fossil flora of Great Britain, or figures and descriptions of the vegetable remains found in a fossil state in this country, v. I, London, James Ridgway, 218 p.
- Lyell, C., 1846a, Coal field of Tuscaloosa, Alabama: American Journal of Science and Arts, ser. 2, v. 1, p. 371-376.
- Lyell, C., 1846b, Observations on the fossil plants of the coal field of Tuscaloosa, Alabama: American Journal of Science and Arts, ser. 2, v. 2, p. 228-230.
- Mamay, S. H., 1955, *Acrangiophyllum*, a new genus of Pennsylvanian Pteropsida based on fertile foliage: American Journal of Botany, v. 42, p. 177-183.
- Martius, D. C., 1822, De plantis nonnullis antediluvianis ope specierum inter tropicos viventium illustrandis: Denkschriften der königlichen bayerischen botanischen Gesellschaft, v. 2, p. 121-147.
- Metzger, W. J., 1965, Pennsylvanian stratigraphy of the Warrior basin, Alabama: Alabama Geological Survey Circular, no. 30, p. 1-80.
- McCalley, H., 1896, Report on the valley regions of Alabama (Paleozoic strata) pt. 2: Alabama Geological Survey Special Report, no. 8, p. 1-436.
- McCalley, H., 1900, Report on the Warrior coal basin: Geological Survey of Alabama Special Report, no. 10, p. 1-327.
- Nathorst, A. G., 1914, Nachträge zur paläozoischen Flora Spitzbergens zur fossilen Flora der Polarländer: Stockholm, 110 p.
- Newberry, J. S., 1853, Fossil plants from the Ohio coal basin: Annals of Science, v. 1, p. 95-97, 106-108, 116-117.
- Noe, A. C., 1925, Pennsylvanian flora of northern Illinois: Illinois State Geological Survey Bulletin, no. 52, p. 1-113.
- Phillips, T. L., Avcin, M. J. and Berggren, D., 1976, Fossil peat from the Illinois Basin: a guide to the study of coal balls of Pennsylvanian age: Illinois State Geological Survey Educational Series no. 11, p. 1-39.
- Potonié, H., 1893, Die Flora des Rothliegenden von Thüringen Preussische geol. Landesanst. Abh., v. 9, pt. 2, p. 1-298.
- Potonié, H., 1897-1899, Lehrbuch der Pflanzenpalaeontologie: Berlin, pt. 1-2, p. 1-208 (1897); pt. 3, p. 209-288 (1898); pt. 4, p. 289-402 (1899).
- Radford, A. E., Dickison, W. C., Massey, J. R. and Bell, C. R., 1974, Vascular Plant Systematics: New York, Harper & Row, 891 p.
- Read, C. B. and Mamay, S. H., 1964, Upper Paleozoic floral zones and floral provinces of the United States: United States Geological Survey, Professional Paper 454K, p. K1-K35.
- Remy, W. and Remy, R., 1977, Die Floren des Erdaltertums: Verlag Glückauf GmbH, Germany, 468 p.
- Rothrock, H. E., 1949, Geology and coal resources of the north-east part of the Coosa coal field, St. Clair County: Alabama Geological Survey, Bulletin 61, p. 1-163.
- Schimper, W. P., 1869, Traité de paléontologie végétale ou la flore du monde primitif: Paris, Bailliè et fils, 740 p.
- Schlotheim, E. F., 1820, Die Petrefactenkunde auf ihrem jetzigen Standpunkte durch die Beschreibung seiner Sammlung versteinerter und fossiler Überreste des Thier- und Pflanzenreiches der Vorwelt erläutert: Gotha, Beckersche Buchhandlung, 435 p.
- Smith, E. A., 1903, Carboniferous fossils in Ocoee slates in Alabama: Science, v. 18, p. 244-246.
- Snigirevskaya, N. S., 1958, An anatomical study of the leaves (phylloids) of some lycopsids in the Donets basin coal balls: Akademiya Nauk SSR, Bot. Jour., v. 43, p. 106-112.
- Sternberg, K. M., 1820-1838, Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt: v. I, 1 (1820) F. Fleischer, Leipzig, 1-24 p.; v. I, 4 (1825) Ernst Brenck's Wittwe, Regensburg, 1-48 p.; v. II, 7/8 (1838) (Presl, C. B. and Corda, A. J., coauthors) Gotlieb Häse Söhne, Prague, 81-220 p.
- Stur, D., 1877, Die Culm-flora der Ostrauer und Waldenburger Schichten: Beiträge zur Kenntniss der Flora der Vorwelt, vol. II. Abhandlungen der Kaiserlich-königlichen geologischen Reichsanstalt, v. 7, 1-366.
- Taylor, T. N. and Taylor, E. L., 1993, The Biology and Evolution of Fossil Plants: New Jersey, Prentice Hall, 982 p.
- Unger, F., 1850, Genera et species plantarum fossilium: Wien, Wilhelm Braunmüller, 627 p.
- White, D., 1900, The stratigraphic succession of the fossil flora of the Pottsville formation in the Southern anthracite coal fields, Pennsylvania: United States Geological Survey, Annual Report 20, 1898-1899, pt. 2, p. 749-930.
- White, D., 1943, Lower Pennsylvanian species of *Mariopteris*, *Eremopteris*, *Diplothemema*, and *Aneimites* from the Appalachian region: United States Geological Survey Professional Paper 197C, p. C1-C140.
- Wood, J. M., 1963, The Stanley Cemetery Flora (Early Pennsylvanian) of Greene County, Indiana: Indiana Geological Survey Bulletin, 29, p. 1-73.

### AUTHORS' E-MAIL ADDRESSES

David L. Dilcher: dilcher@flmnh.ufl.edu

Terry A. Lott: lott@flmnh.ufl.edu

Brian J. Axsmith: baxsmith@jaguar1.usouthal.edu

## ARTHROPOD BODY FOSSILS FROM THE UNION CHAPEL MINE

T. PRESCOTT ATKINSON

Children's Hospital CHT 752M, 1600 Seventh Avenue South, Birmingham, Alabama 35233, USA

**ABSTRACT:** Arthropod body fossils are rare in the Pottsville formation. The assemblage of fossil material from the Union Chapel Mine, while containing a number of trackways which were made by arthropods or their larvae, includes, thus far, only two wing impressions and a possible arachnid body fossil. The fossils from the Union Chapel site were preserved only 15 million years after the oldest known winged insect. Thus, they represent relatively early and important representatives of this large and interesting group of animals. I will here attempt to review, first, the significance of insect body fossils from the Pennsylvanian in the fossil record of insects, followed by a description of the actual specimens. This report is intended to be a relatively superficial description of the arthropod finds to date at Union Chapel Mine with the hope of stimulating further, and more rigorous, future studies of these specimens.

### INTRODUCTION

The first insects developed some 415 to 390 million years ago in the Lower Devonian (Gradstein and Ogg, 1996). These earliest members of the group, such as the collembolan (springtail) *Rhyniella* precursor from Scotland (Ross and Jarzembowski, 1993), were wingless. Interestingly, recent information derived from the analysis of mitochondrial DNA suggests that the evolution of the primitive wingless collembolans may have taken place separately from that of later winged insects (Nardi et al., 2003). Unfortunately, fossil remains from the first 90 million years of insect evolution are very rare (Labandeira and Sepkoski, 1993), and because of this large gap, both the time and the manner in which wings first developed in insects are unclear. Also, the pace at which insect evolution proceeded following the development of wings is unknown. The earliest winged insect, *Delitzschala bitterfeldensis* (Palaeodictyoptera: Spilapteridae), dates from the end of the Lower Carboniferous of Germany (Brauckmann and Schneider, 1996). However, it is apparent that for some time preceding that point, approximately 325 million years ago, a period of radical diversification occurred in insect evolution coincident with the development of wings and no doubt due to the increase in the number of ecological niches that flight permitted. When they become well represented in the fossil record at the end of the Early Carboniferous, winged insects are already more diverse at the ordinal level than they are today (Shear and Kukalová-Peck, 1990; Dudley, 2000). The wing structure in more primitive orders is palaeopterous while that of more advanced insects is neopterous (palaeopterous = insects with wings not folded over abdomen, laterally outstretched with the exception of the Diaphanopteroidea; neopterous = insects with wings folded over abdomen.).

The selective pressure that favored the development of wings likely involved escape from predators as well

as the ability to gain access to new food sources. Two theories have been put forth regarding anatomic origins in the evolution of wings in insects: (1) modification of existing limb branches that probably were functioning as gills in the progenitor arthropod and (2) *de novo* outgrowths from the body wall. Recent genetic evidence supports the former hypothesis: crustacean genes homologous to two wing-specific insect genes are specifically expressed in distal epipodite cells, part of a dorsal limb branch with respiratory and osmoregulatory functions (Averof and Cohen, 1997). This genetic evidence agrees with a common pattern in evolution: modification of previous structures to serve new functions. The modified gills may first have functioned for swimming and then to permit short gliding movements prior to their further development for fully independent flight.

The Paleozoic peak of insect diversity was reached in the Late Carboniferous to Early Permian (Labandeira and Sepkowski, 1993); however, this diversity was present at the ordinal but not at the family level (Jarzembowski, 2001). Some of these insects were the largest that have ever lived. The giant Carboniferous dragonfly *Meganeura monyi* had a wingspan of 66 cm and a thoracic diameter of 2.8 cm, and some paleodictyopterans were not far behind with wingspans up to 56 cm (Graham et al., 1995). It has been speculated that the development of gigantism among insects during the latter half of the Carboniferous was permitted by increases in the atmospheric oxygen concentration, which by some estimates may have reached 35% (Berner, 2001; Dudley, 1998). The increase in the partial pressure of oxygen could have permitted an increase in the size of animals such as insects with diffusion-limited tracheal systems for gas exchange. In addition, the increased partial pressure of oxygen was likely accompanied by an increase in total atmospheric pressure, further augmenting diffusion rates as well as resulting in additional lift from aerodynamic forces produced by

wing movements (Dudley, 2000). Another change in ambient gas concentrations that could have facilitated rapid rates of cellular respiration was the tenfold decline in CO<sub>2</sub> levels from the late Silurian to Early Permian, eventually reaching levels comparable to those of today during the Middle to Late Pennsylvanian (Mora et al., 1996).

The importance of higher oxygen levels in the development of gigantism in Carboniferous arthropods has been questioned by some authorities. Bechly et al. (2001) suggest that gigantism and its disappearance correlates with the prior absence and later evolution of flying vertebrates. True giants make up only 1% of the fossil insects in the Coal Measures of southern England (E. Jarzembowski, written commun.); obviously, the level of preservation of insect fossils affects the ability to recognize smaller forms, for example, no blattoids (roach-like insects) have been recovered from the Union Chapel site to date, although they were likely very abundant. Other factors, such as drastically different predator-prey relationships than those of today, may have also played a role in the development of giant forms (Jarzembowski and Ross, 1996). It is interesting that by the close of the Permian, 5 of 32 orders of insects had become extinct, including two orders of the superorder Paleodictyopteroidea: Megasecoptera and Diaphanopteroidea (Ross and Jarzembowski, 1993; Jarzembowski and Ross, 1996). The Paleodictyoptera became much less abundant as well; Bechly (1997) demonstrated a surviving member of the Palaeodictyoptera from the Lower Triassic, but this is the only member of that order which is known beyond the Permian. The disappearance of these orders, including nearly all of the gigantic forms, coincided, probably not coincidentally, with a drop in atmospheric oxygen levels, which eventually reached about 15% at the end of the Permian (Graham et al., 1995).

As Shear and Kukalová-Peck (1990) point out in their review of Paleozoic arthropods, wings are by far the most frequently preserved insect fossils, being relatively inedible and decay-resistant. The presence of large wing impressions as the sole representative of Insecta thus far from the Union Chapel site suggests, first, that conditions for preservation of insect body fossils favored relatively large insects, presumably at least partly because of the tidal ebb and flow through the marshes, and, second, that among large insects in this locality, palaeopterans were among the more abundant (since the only three known insect body fossils from the Pottsville of Walker County are of that group). However, as noted above, although it has been estimated that the four orders of the Palaeodictyopteroidea together make up almost half of the late Paleozoic entomofauna preserved in coal swamp deposits (Shear and Kukalová-Peck, 1990), some bias of ascertainment is likely present, in other collections as well as this, since large insect parts are more likely to be preserved and more likely to be recognizable, especially to amateurs, than small ones.

The Union Chapel site is a surface coal mine in Walker County, Alabama. The fossil-bearing slabs were all recovered from spoil piles adjacent to the highwall, which represents the point at which, some two years

prior to the first collections from the site, excavation by the company had been halted due to the rising height of the overburden above the coal seams. The rocks at the site are characteristic of the Pottsville formation with cycles of coal-bearing shales alternating with sandstones and marine layers containing siderite nodules and brachiopods. Clear evidence of rapid tidal deposition of sediments can be found in the shales (Pashin, 2005). The track-bearing slabs appear to have derived from layers of shale adjacent to the coal seams. This is in accord with the previous observations in an underground mine in Walker County by Aldrich and Jones (1930); in that instance the tracks were found in shales within 76-107 cm (30-42 inches) above the Jagger coal seam. At the Union Chapel site the most detailed vertebrate tracks were found on slabs with a very fine particle size and surfaces bearing an almost polished appearance, suggesting that deposition of sediments occurred following the gentle withdrawal of the water, perhaps on a tidal mud flat relatively far from the coast. The particle composition of the shale bearing the wing impressions, while still quite fine as to permit considerable detail, is of a somewhat coarser grade, indicating a different local environment with higher depositional energy.

### THE UNION CHAPEL INSECT WINGS

The first set of wing impressions found at the Union Chapel Mine are illustrated in Figures 1 and 2. They consist of fore and hind wings from a palaeopterous insect (8.1 × 3.7 cm and 9.1 × 4.1 cm respectively) in a reasonably life-like orientation suggesting that at least some portion of the thorax may have been present in the original specimen. All major veins are present, but neither archidictyon nor crossveins can be discerned (see below). No other invertebrates were evident in the small slabs of shale that contained the impressions, but lycopod and seed fern leaves are present in the layers of shale immediately adjacent to the impressions. They were found in July 2000, surprisingly enough in the middle of a rough dirt access road that led down to the base of the highwall of the mine, having presumably tumbled down one side of the adjacent embankment. The edge bearing the proximal part of the impressions appeared freshly broken, but a careful search of the roadbed and the embankment over several visits to the site failed to yield the remainder of the fossil. The impression corresponding to the obverse (dorsal) view of the wings was intact, but the reverse impression corresponding to the ventral view was fractured into five pieces that were still, however, associated with one another in a more or less undisturbed fashion. The image of this pair of fragile impressions, lying open like a book in the middle of a roadbed, up and down which heavy machinery had moved, still stand vividly in the author's memory as a breathtaking example of how the unlikeliest of chance events may still come to pass.

The absence of critical features from the base of the wing and any other anatomical features make it less likely that any definite identification can be made in more thorough studies. After review of photographs, one authority has identified the impressions as most likely repre-



FIGURE 1A. Palaeopterous wings from the Union Chapel Mine: Reverse (ventral) impression. Scale in inches (left) and centimeters (right).

senting a member of the large extinct order Palaeodictyoptera, whose members have been reported from the Upper Carboniferous to the Upper Permian (Günter Bechly, written commun.). None of three other authorities in the field who reviewed this report took issue with this tentative assignment. The wing structure of the order Palaeodictyoptera is defined as follows: "Wings containing all main veins, including MA, MP, CUA, and CUP, with alternation of convexities and concavities; main veins usually without coalescence and always arising independently; area between veins with

a delicate, irregular network (archedictyon) or with true crossveins, or with a combination of both; intercalary veins present in a very few families (e.g., Syntonopteridae); fore and hind wings similar in form and venation in some families (e.g., Dictyoneuridae); in others (e.g., Spilapteridae) hind wings much broader than the fore pair with basic venational pattern remaining the same; in some others (e.g., Eugereonidae and Megaptilidae) hind wings only about half as long as fore wings; in one family (Diatthemidae) hind wings minute, in a related family (Permothemistidae) hind wings com-



FIGURE 1B. Palaeopteran wings from the Union Chapel Mine: Obverse (dorsal) impression.

pletely absent; front margin of wing commonly serrate, costa with or without setae; wings in some families with prominent pigment markings” (Carpenter, 1992). After review of the photographs Jarmila Kukalová-Peck disagreed with the identification as a member of the Palaeodictyoptera, preferring instead to assign the specimen to the Ephemeroptera (mayflies). The Paleozoic representatives of this latter order are mainly from the Permian, including nymphs and adults from five extinct families, although some members are known from the Upper Carboniferous. Further definitive assignment will have to await the day when the actual specimen can be studied by authorities on the subject.

Since no members of the Palaeodictyoptera are extant, a few words on what is known or surmised about the biology of these insects are appropriate. The development of wings in palaeodictyopterans occurred gradually as the animal passed through a series of nymphal stages, so evidently these insects were hemimetabolous, i.e., they underwent gradual or “incomplete” metamor-

phosis. When fully developed, the wings were permanently outstretched as seen in mayflies or dragonflies, an adaptation which facilitates gliding movements, useful in conserving energy while searching for food but making flight difficult in dense foliage and presenting difficulties in high winds (Figure 3). The mouthparts of palaeodictyopterans were adapted for piercing and sucking, forming a formidable beak up to 32 mm long (Shear and Kukalová-Peck, 1990). Depending on the species, those with more robust mouthparts likely fed on the vascular tissue of tree fern fronds and seed fern pollen organs and ovules of *Cordaites* (Labandeira, 1998; Labandeira and Phillips, 1996), the latter two plant types both found in abundance among the plant material from the Union Chapel Mine tailings (Dilcher et al., 2005). Fossil nymph specimens have been described with spores or pollen filling the gut (Kukalová-Peck, 1985). Some species may have been able to bore holes in seeds or megaspores and extract the contents. The nymphs of palaeodictyopterans were strictly terrestrial and fed on

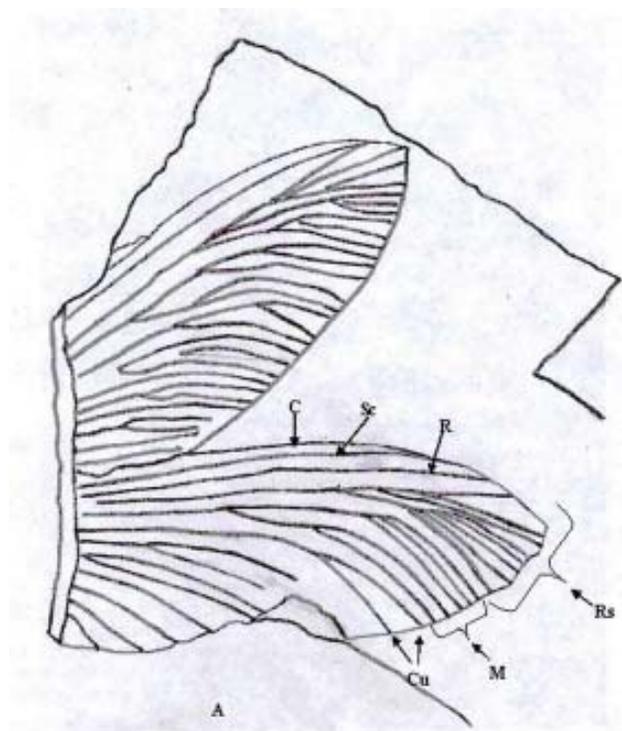


FIGURE 2. Line drawing detailing the venation of the wings. No archedictyon or crossvenation is evident. The venation is designated according to Tasch (1980). The costa is a heavy, unbranched vein forming the anterior margin of the wing. The subcosta is the next and is concave when viewed from the obverse (dorsal) aspect. The radius is commonly the heaviest vein in the wing and is convex in the obverse aspect. R branches into R1 and the Radial Sector which is then subdivided into four branches. Media is next, then cubitus, which branches to Cu1 (convex, often branched) and Cu2 (concave, unbranched). Anal veins (frequently unbranched) form a fan, generally set apart from Cu2 by the cubital furrow, along which the wing folds. C: Costa, Sc: Subcosta, R: Radius, Rs: Radial Sector, M: Media, Cu: Cubitus, A: Anal.

similar fructifications and probably vascular tissue. They were “peculiar, highly derived creatures ..... flattened, well-armored, and shaped like trilobites” (Shear and Kukalová-Peck, 1990), all obvious adaptations to escape predation. While these insects remained earthbound nymphs, such predators would have likely included a variety of insects and other arthropods, e.g. arachnids, as well as vertebrates, particularly land-dwelling amphibians and reptiles. Once the nymphs matured and became airworthy, they likely fell prey to the top predators of the Paleozoic skies: ancestral dragonflies similar to *Meganeura monyi* (although *M. monyi* is only described from the Late Pennsylvanian of Europe).

The abundance and diversity of invertebrate and vertebrate trace fossils and plant fossils in the Pottsville Formation (Westphalian A) at the Union Chapel site suggest that insects were probably well-represented in this ancient ecosystem. Insect trace fossils are abundant at the site (Rindsberg and Kopaska-Merkel, 2005). Arthro-



FIGURE 3. Restoration showing a paleodictyopteran insect (*Homaloneura* sp.) feeding on a *Cordaites* cone (Shear and Kukalová-Peck, 1990, with permission).

pod body fossils are rare in the Pottsville Formation. A large insect wing impression, discovered by James A. Lacefield in tailings from another Walker County surface coal mine, is included for comparison; the specimen now resides in the collection of the Alabama Museum of Natural History (Figure 4; Lacefield, 2000). This specimen has been identified by Dr. Kukalová-Peck (written commun.), again from a photograph, as Palaeodictyoptera, family Breyeriidae, genus *Breyeria*.

One definite arachnid body fossil has been recovered from the Pottsville of Alabama (J. C. Pashin, personal commun., 2003). A possible trigonotarbid arachnid was found in May 2003 at the Union Chapel site by the author. The specimen has been tentatively identified by C. Labandeira from photographs (Figure 5). Further work is needed to establish the authenticity of this specimen as well as its assignment to a more specific group. Their inclusion in this report is permitted in the hope that it will stimulate further scholarly work.

Finally, a second large insect wing impression was found during the final stages of preparation of this report (Figure 6). From a photograph Kukalová-Peck felt that it was most likely a petiolate wing from a member of the Megasecoptera. As with the other specimens, a more definitive description will require careful study of the actual specimen by authorities in paleoentomology.

## SUMMARY

Arthropod body fossils are present in the Union Chapel mine tailings and already comprise a considerable proportion of the scant total of such fossils recov-



FIGURE 4. Palaeodictyopteran wing impression from another surface coal mine on Alabama Highway 13 near its intersection with U.S. Highway 78, near Eldridge in Walker County, Alabama, collected in March 1993 by Jim Lacefield (Lacefield, 2000). Unlike the specimen from the Union Chapel site, in this impression a well-preserved archdictyon is present. This specimen was identified from photographs as a hind wing, order Palaeodictyoptera, family Breyeriidae, genus *Breyeria* (J. Kukulová-Peck, written commun.).

ered from the Pottsville of Alabama. One possible arachnid body fossil has been added to the UCM collection and awaits further study. The insect body fossils recovered to date consist of a pair of palaeopterous wings, likely representing either Palaeodictyoptera or possibly Ephemeroptera and another, more slender single wing, possibly from the Megasecoptera.

#### ACKNOWLEDGMENTS

The author is grateful for helpful suggestions and corrections from Drs. Andrew Rindsberg, David Kopaska-Merkel (Geological Survey of Alabama), Dr. Ron Buta (University of Alabama), and to Dr. Günter Bechly (Staatliches Museum für Naturkunde, Stuttgart) for review of photographs of the specimens. He extends particular thanks to Drs. Conrad C. Labandeira (Smithsonian Institution) and Ed Jarzembowski (University of Reading, UK) for careful review of the manuscript and correction of numerous factual errors. In addition, Dr. Kukulová-Peck (Carleton College) reviewed images of the wings and provided tentative identifications.

#### REFERENCES

- Aldrich, T. H., Sr. and Jones, W. B., 1930, Footprints from the Coal Measures of Alabama: Alabama Museum of Natural History, Museum Paper, no. 9, 64 p., 17 pl.
- Averof, M. and Cohen, S. M., 1997, Evolutionary origin of insect wings from ancestral gills: *Nature*, v. 385, p. 627-630.
- Bechly, G., 1997, New fossil odonates from the Upper Triassic of Italy, with a redescription of *Italophlebia gervasuttii*, and a reclassification of Triassic dragonflies (Insecta: Odonata): *Rivista del Museo Civico de Scienze Naturali 'E. Caffi'*, v. 19, p. 31-70.
- Bechly, G., Haas, F., Schawaller, W., Schmalzfuss, H., and Schmid, U. 2001. *Ur-Geziefen — Die faszinierende Evolution der Insekten: Stuttgarter Beiträge zur Naturkunde, ser. C, v. 49, 96 p.*
- Berner, R. A., 2001, Modeling atmospheric O<sub>2</sub> over Phanerozoic time: *Geochimica et Cosmochimica Acta*, v. 65, p. 685-694.
- Brauckmann, C. and Schneider, J., 1996, Ein unter-karbonisches Insekt aus dem Raum Bitterfeld/Delitzsch (Pterygota, Arnsbergium, Deutschland): *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, 1996(1), p. 17-30.
- Carpenter, F. M., 1992, Superclass Hexapoda; in v. 3, pt. R, Arthropoda 4 of *Treatise on Invertebrate Paleontology*: Boulder, Colorado, Geological Society of America and Lawrence, Kansas, University of Kansas Press.
- Dilcher, D., Lott, T. A. and Axsmith, B. J., 2005, Fossil plants from the Union Chapel Mine, Alabama; in Buta, R. J.,



FIGURE 5. Probable trigonotarbid arachnid (tentative identification by C. Labandeira, written commun.) collected by P. Atkinson, May 2003, Union Chapel Mine.



FIGURE 6. Single wing impression, probably from a member of the Megasecoptera (J. Kukulová-Peck, written commun.).

- Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 153-168.
- Dudley, R., 1998, Atmospheric oxygen, giant paleozoic insects, and the evolution of aerial locomotor performance: *Journal of Experimental Biology*, v. 201, p. 1043-1050.
- Dudley, R., 2000, The evolutionary physiology of animal flight: paleobiological and present perspectives: *Annual Reviews in Physiology*, v. 62, p. 135-155.
- Gradstein, F. M. and Ogg, J., 1996, A Phanerozoic time scale: *Episodes*, v. 19, p. 3-5.
- Graham, J. B., Dudley, R., Aguilar, N. M. and Gans, C., 1995, Implications of the late Palaeozoic oxygen pulse for physiology and evolution: *Nature*, v. 375, p. 117-120.
- Jarzewowski, E. A. and Ross, A. J. 1996, Insect origination and extinction in the Phanerozoic; in Hart, M. B., ed., *Biotic recovery from mass extinction events*: Geological Society of London, Special Publication, no. 102, p. 65-78.
- Jarzewowski, E. A., 2001, Review of early insects and palaeocommunities: *Annales de la Société Entomologique de France*, n. ser., v. 37, p. 11-19.
- Kukalová-Peck, J., 1985, Ephemeroïd wing venation based upon new gigantic Carboniferous mayflies and basic morphology, phylogeny, and metamorphosis of pterygote insects (Insecta, Ephemeroïda): *Canadian Journal of Zoology*, v. 63, p. 933-955.
- Labandeira, C. C. and Sepkoski, J. J., 1993, Insect diversity in the fossil record: *Science*, v. 261, p. 310-315.
- Labandeira, C. C. and Phillips, T. L., 1996, Insect fluid-feeding on Upper Pennsylvanian tree ferns (Palaeodictyoptera, Marattiales) and the early history of the piercing-and-sucking functional feeding group: *Annals of the Entomological Society of America*, v. 89(2), p. 157-183.
- Labandeira, C.C., 1998, The early history of arthropod and vascular plant associations: *Annual Reviews of Earth and Planetary Science*, v. 26, p. 329-377.
- Lacefield, J., 2000, *Lost Worlds in Alabama Rocks: A Guide to the State's Ancient Life and Landscapes*, (first edition): Tuscaloosa, Alabama Geological Society, 123 p.
- Mora, C. I., Driese, S. G. and Colarusso, L. A., 1996, Middle to late Paleozoic atmospheric CO<sub>2</sub> levels from soil carbonate and organic matter: *Science*, v. 271, p. 1105-1107.
- Nardi, F., Spinsanti, G., Boore J. L., Carapelli, A., Dallai, R. and Frati, F., 2003, Hexapod origins: monophyletic or paraphyletic? *Science*, v. 299, p.1854-1855.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 39-58.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, *Treptichnus* and *Arenicolites* from the Steven C. Minkin Paleozoic Footprint site (Langsettian, Alabama, USA); in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society Monograph no. 1, p. 121-141.
- Ross, A. J. and Jarzewowski, E. A., 1993, Arthropoda (Hexapoda; Insecta); in Benton, I. and Whyte, M. A., eds., *The fossil record*, (2nd edition): p. 363-426.
- Shear, W. A. and Kukalová-Peck, J., 1990, The ecology of Paleozoic terrestrial arthropods: the fossil evidence: *Canadian Journal of Zoology*, v. 68, p. 1807-1834.
- Tasch, P., 1980, The skeleton shedders (Arthropods - II); in *Paleobiology of the Invertebrates: Data Retrieval from the Fossil Record*, p. 500-626.

patkinson@peds.uab.edu

## **GAS-ESCAPE STRUCTURES AND THEIR PALEOENVIRONMENTAL SIGNIFICANCE AT THE STEVEN C. MINKIN PALEOZOIC FOOTPRINT SITE (EARLY PENNSYLVANIAN, ALABAMA)**

ANDREW K. RINDSBERG

Geological Survey of Alabama, P.O. Box 869999, Tuscaloosa, Alabama 35486-6999, USA

**ABSTRACT:** Small circular structures are common in shale at the Steven C. Minkin Paleozoic Footprint Site (Union Chapel tracksite). Researchers originally identified them as rainprints (and therefore indicators of subaerial exposure), but closer examination shows them to be gas-escape structures (which do not require subaerial exposure). Considering the lack of mudcracks or other evidence of desiccation, it seems likely that the Union Chapel trackways were made on wet or submerged surfaces.

### INTRODUCTION

During preliminary work on the Union Chapel tracksite, researchers were intrigued by numerous circular pits on track-bearing surfaces (Fig. 1). The pits are shallow and many have raised rims. Rainprints (or raindrop imprints) are commonly associated with trackways, and at first we uncritically identified them as rainprints and used them as evidence of subaerial exposure. In time, work by Pashin (2005) and others made it clear that the tracks were made on a freshwater intertidal flat, where raindrop imprints would not be surprising. However, other observations mounted against the interpretation of the circular pits as rainprints, and indeed against any subaerial drying of the beds. I now interpret the tracks to have been made either under water or on a very wet subaerial surface.

### THE STEVEN C. MINKIN PALEOZOIC FOOTPRINT SITE

The Steven C. Minkin tracksite has yielded the largest number of well-preserved vertebrate trackways of any Carboniferous site in the world (Pyenson et al., 2001; Haubold et al., 2005). The site is an inactive part of the Union Chapel Mine of the New Acton Coal Mining Company, near the community of Union Chapel in Walker County, Alabama (USA). As described by Pashin (2005), the track-bearing strata lie within about 1 to 6 meters below the Newcastle coal seam (Mary Lee coal group) in the upper Pottsville Formation (Lower Pennsylvanian, Westphalian A = Langsettian). The site was discovered in late 1999 and has been extensively collected since then, mainly by members of the Alabama Paleontological Society.

Trace and body fossils were collected from mine spoil, the vertical highwall being too dangerous to approach for intensive study. Thus, the detailed stratigraphy of trace fossils and other sedimentary structures is unknown, though some relationships can be inferred from the association of structures on single slabs.

### COMPARISON OF RAINPRINTS AND GAS-ESCAPE STRUCTURES

Researchers on both sides of the Atlantic realized from the first that vertebrate trackways are commonly associated with rainprints and mudcracks (Cunningham, 1839; Lyell, 1841, 1845, 1852; Buckland, 1842; Redfield, 1842; Vanuxem, 1842; Deane, 1844, 1845). Lyell (1845, v. 2, p. 167) wrote that William Buckland was the first to recognize rainprints as such during a lecture in 1838, creating a sensation in the "incredulous public." However, many so-called rainprints have been interpreted by others as gas-escape structures (Desor, 1850; Twenhofel, 1921, 1932; Moussa, 1974). Superficially, rainprints and gas-escape structures may look much alike (Figs. 1, 2), despite different processes of formation. Rainprints occur on subaerial surfaces, whereas gas-escape structures are made within both subaerial and submerged substrates. Both may form circular pits on a sedimentary surface, and distinguishing them requires close observation, as was recognized very early.

William Buckland (1842, p. 57) cautioned in regard to the Permian-Triassic New Red Sandstone near Birmingham, England,

The origin of these holes appeared to have been the rise of bubbles of air through the bottom of little partial shallow ponds of water on the mud, the general surface of which, from its convex form, had allowed no water to rest upon it ... a slab of new red sandstone ... from near Birmingham, containing a few impressions of vegetables, was covered with small tubercles in close contact with one another, and apparently caused by the deposition of sand in holes formed by the rise of bubbles of air from a subjacent bed of clay ... some of the cavities, and casts of cavities, ... which have been attributed to rain-drops, may have been due to the extrication of air-bubbles; care would therefore be necessary to distinguish between these two causes of phenomena, which have hitherto been exclusively attributed to rain.

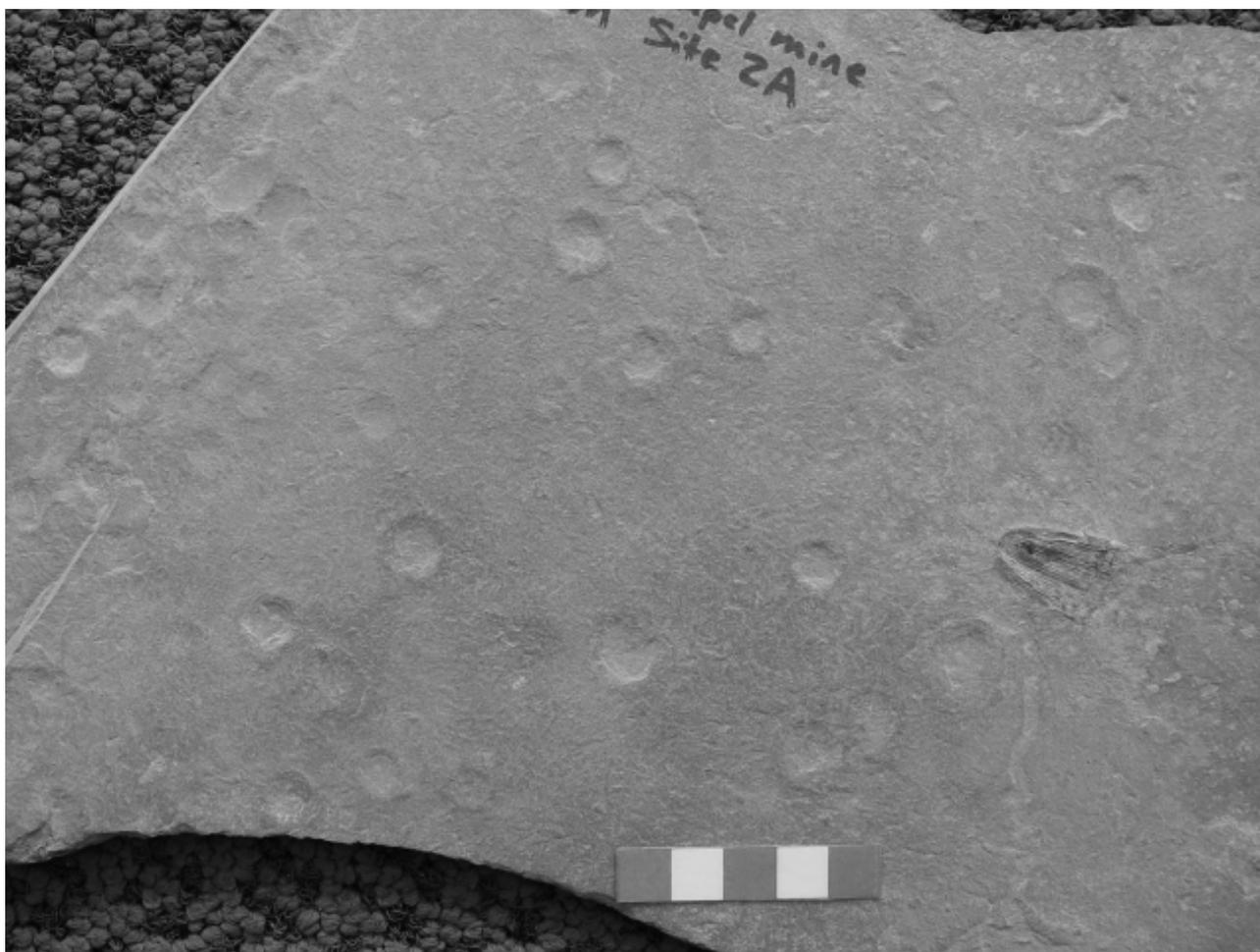


FIGURE 1. Gas-escape structures in shale from the Steven C. Minkin Footprint Site, Walker County, Alabama. UCM 2072, collected by David C. Kopaska-Merkel (Geological Survey of Alabama). The scale is in centimeters.

Desor (1850) repeated the warning. Lyell (1851, p. 241-242), studying Carboniferous trackways at Joggins, Nova Scotia, noted that rainprints were also present there, and compared them to marks made by falling rain, dripping water, and gas bubbles in the nearby Bay of Fundy tidal flats. Lyell even performed an experiment to clarify their distinction.

Being desirous of ascertaining whether air-bubbles, rising through mud and bursting as they reached the surface, could give rise to cavities similar to those caused by the fall of rain, I poured some pounded mud from Kentville on a small quantity of water, and shook the basin containing it, upon which numerous bubbles of entangled air rose through the mud, and, on bursting at the surface, left cavities resembling in size the ordinary rain-prints from Nova Scotia, but very different in character. Nearly all of them were perfectly circular, with a very sharp edge, and without any rim projecting above the general surface. In a few cases, however, there was a slight, narrow rim, sharper and more even than that of a rain-print. In no instance was this rim connected with a greater depression at one end of an oval concave depression. Most of the pits produced by these

air-bubbles were different also from rain-prints, in being deeper than they were wide. Their sides were very steep, and often over-arching, the cavity below the surface being wider than the opening at the top. The axis of some few of these deeper cavities was oblique to the surface of the mud. Where two bubbles had touched, a vertical thin parting wall of mud was left between them.

Later observations would show that there is considerable variation in the form both of rainprints and of gas-escape structures (Twenhofel, 1921), and authors continued to caution investigators about their superficial resemblance (Twenhofel, 1921; Lahee, 1941; Shrock, 1948; Moussa, 1974; Potter et al., 1980). Twenhofel (1921) noted that pits can be caused by raindrops, hailstones, dripping water, spray and splash, stranded bubbles, drifting bubbles, bubbles forming at the surface of a submerged substrate, and bubbles forming within the substrate and rising upward through it. All have a convex-downward form that can be used as an indicator of the top and bottom sides of a loose slab or a layer in complexly folded rock (Shrock, 1948).

Rainprints are impact structures (Fig. 2). Like meteorite craters, rainprints are formed by the impact of a

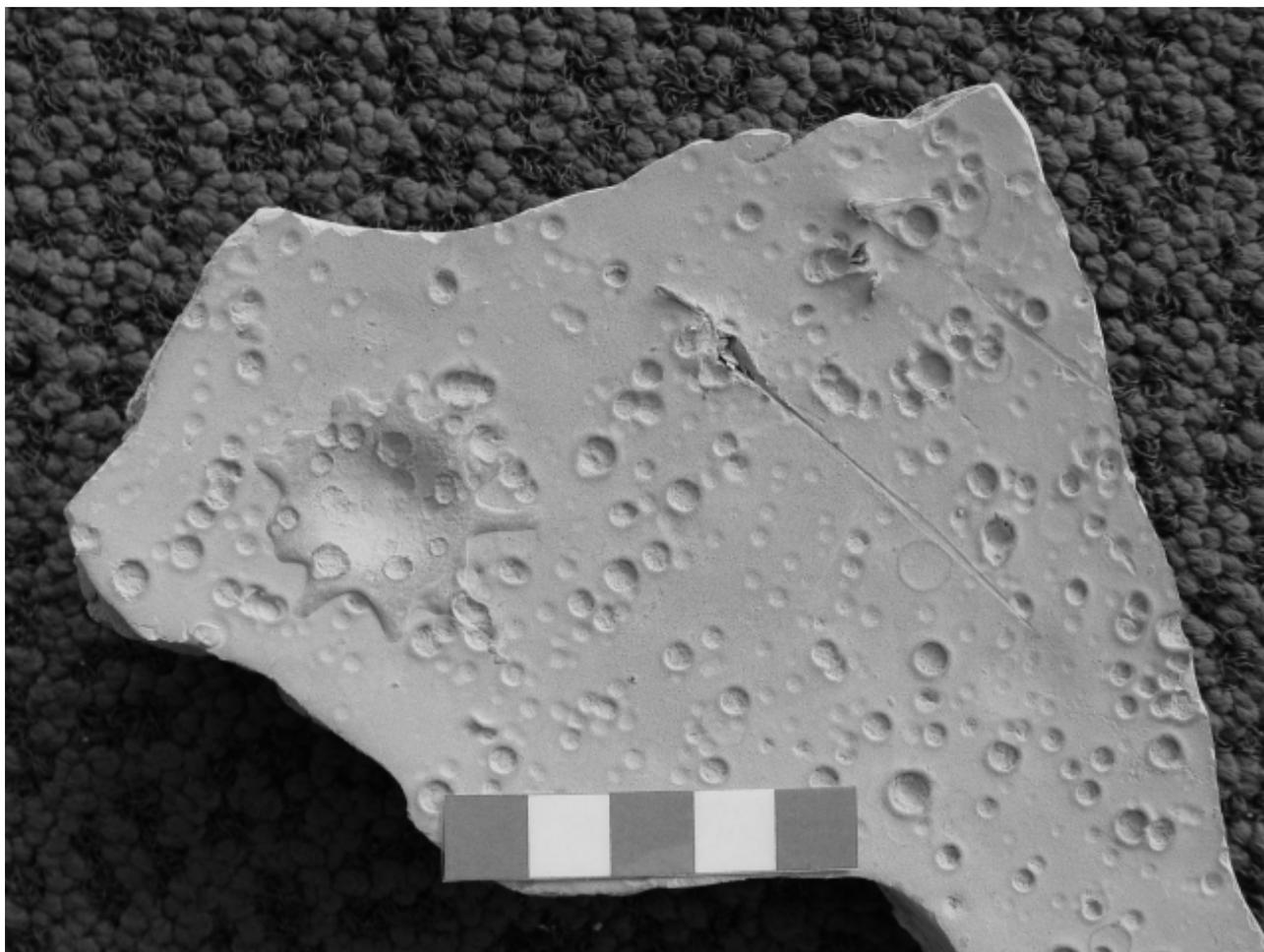


FIGURE 2. Modern rainprints in dried mud from Lehigh Portland Cement Quarry, Leeds, Alabama, collected by W. Edward Osborne (Geological Survey of Alabama). The scale is in centimeters. The largest print, showing a spattered rim, is too large to be the impression of a normal raindrop and may be the result of drip or hail. It is overlapped by the rainprints from subsequent raindrops. Some rainprints overlap one another as well.

falling body on the earth. The meteorite rapidly is converted to fluid, while the raindrop is already fluid; accordingly, each spreads outward in a roughly even manner, creating the familiar circular pit or crater with a raised rim. Unlike gas-escape structures, rainprints are limited in size and are generally 5 to 15 mm wide (Potter et al., 1980). Within a broad range, the angle of impact has little effect on the circularity of the pit, but wind-driven, obliquely falling raindrops may create elliptical imprints (Lahee, 1941, p. 54, fig. 30). The edges of the pit are raised and are commonly uneven due to spattering; in the case of water droplets, surface tension plays a role in shaping the impacting droplet, especially of larger droplets (Edgerton and Killian, 1939) (Fig. 2). Slurried or weakened sediment may fall back into the crater, shallowing it.

Conditions for producing and preserving rainprints are limited by the cohesiveness of the sedimentary surface upon which a raindrop falls (Blackwelder, 1941; McKee, 1945). If the sediment is too soft, then it will settle back into a flat surface after impact. If it is too hard, the impact will leave no imprint at all. The ideal

surface is one that is plastic enough to be distorted by impact, but firm enough to retain its shape afterward. Moreover, only a light rain will do. Heavy rain will create so many overlapping rainprints that only the last few could be distinguished, and the soaked sediment is unlikely to remain firm enough to hold their forms. Finally, the surface must be buried before the rainprints are erased, and by sediment whose deposition does not itself erase the record, such as wind-driven sand. The presence of rainprints should not be considered as evidence of a humid climate, but rather is suggestive of aridity.

Thus, it should not be surprising that rainprints are uncommon in the overall geologic record. However, they do occur at many tracksites; the preservation of footprints requires similar sedimentary coherence, neither too soft nor too firm. Rainprints are common, for example, in the famous Triassic-Jurassic tracksites of the Connecticut Valley (Shrock, 1948). In each of these occurrences, rainprints typically occur on the same bedding planes as mudcracks — further evidence of desiccation.

Gas-escape structures are not as familiar as rainprints, though they are common in the geologic record, and even now many questions remain. Most of the more recent studies have focused on gas-escape structures in carbonate rather than clastic sediment, in connection with porosity and petroleum geology. In general, gas is either trapped in rapidly deposited sediment, or is generated there by microbial processes (Hammond, 1978; Reineck and Singh, 1980, p. 66-67, 249-250). The gas may consist of air, oxygen, carbon dioxide, methane, or other fermentative gases. In each case, buried gas is less dense than surrounding sediment, and therefore tends to rise through it. In relatively coarse, permeable sediment, gas generally seeps upward through pores between sand or pebbles without moving them; but in relatively fine, impermeable sediment such as clay and algally laminated carbonate, the gas may build up as bubbles that push aside sediment as they rise, forming a vertical shaft that may widen into a pit at the top. In fine-grained carbonate sediments, gas bubbles may be trapped beneath the surface long enough for the sediment to become cemented; afterward, the pores may be filled with calcite cement (*fenestrae* or *birdseyes*). These may be indistinguishable in hand specimen from horizontal burrows.

Where gas bubbles pierce the substrate vertically, the surrounding sediment either falls back into the shafts, if it is very soft, or else retains the form of the shafts, if it is relatively firm. The shafts may closely resemble the vertical burrow *Skolithos*, but without the lining characteristic of that trace fossil. Unlike burrows, which are sometimes branched, the shafts of gas-escape structures should be unbranched. In soft sediment, where material has fallen back into the shaft, the result may be a series of convex-downward laminae shaped like a stack of saucers or cups. Material carried upward by released gas may form a cratered mound at the surface (Shrock, 1948; Reineck and Singh, 1980, p. 57).

Gas-escape structures are common in rapidly deposited sediments having a high organic carbon content, such as microbially laminated, fine-grained carbonate rocks. Bubbles of methane and other gases can result from the decomposition of buried organic matter (Goemann, 1939; Häntzschel, 1941; Hammond, 1978).

Although the descriptions of rainprints and gas-escape structures seem very different here, at the surfaces of beds, the circular pits can look much alike, and can even be confused with vertical burrows (Clarke, 1923). Some vertical burrows can be recognized as such by the presence of linings, which are particularly necessary in incohesive substrates. However, escape structures made by animals may not always be distinguishable from gas-escape structures.

### GAS-ESCAPE STRUCTURES AT UNION CHAPEL

Circular pits are very common on trace-fossil-bearing surfaces at the Steven C. Minkin Paleozoic Footprint Site. They are 4 to 11 mm wide and about 1 mm deep, and resemble rainprints, which are common at other tracksites. However, they are not rainprints, but gas-

escape structures, as shown by the following observations.

*The craters' rims show no sign of spattering.* Uneven rims would be evidence for impact (compare Fig. 2); instead, the rims are raised in some cases, but are even (Fig. 1).

*The circular pits occur on the same surfaces as undertracks* (Fig. 3). Haubold et al. (2005) and Martin and Pyenson (2005) agree that nearly all the Union Chapel tracks are undertracks, that is, the part of a footprint that formed as a series of distorted laminae beneath the surface on which the animal walked. Thus, if they were rainprints, the circular pits cannot have been made during the same tidal cycle as the footprints on the same laminae, because the raindrops would have impacted a layer that was already buried when the animal walked there. However, if the pits are gas-escape structures, then they could have been formed at any time with respect to the undertracks.

In a few cases where vertical sections are available, *the pits can be observed to be only part of a larger vertical structure like a stack of saucers and may even penetrate through several laminae* (Fig. 4). Raindrop impact cannot penetrate deeply enough to produce a vertical stack of disturbed laminae; upward gas escape followed by settling sediment can.

*The pits are not associated with mudcracks at Union Chapel.* In most other tracksites that have rainprints, mudcracks are common. As shown above, preservation of rainprints requires rather special conditions that also favor the preservation of tracks and mudcracks.

*Overlap of circular pits is unusual at Union Chapel* (Fig. 5). Raindrops fall at random, so overlap of craters is expected even in a light rain, just as meteor craters overlap on the lunar surface. At Union Chapel, overlap is uncommon even on surfaces bearing many pits. This would be expected of gas-escape structures, where gas bubbles would be expected to follow a previously existing zone of weakness rather than punching through in a new place.

*Some pits are associated with Undichna, a swimming trace.* These bedding planes must have been covered by at least several centimeters of water at the time when the fish swam over it (Martin and Pyenson, 2005).

*Circular pits commonly formed directly under tetrapod footprints.* Unless a small raincloud follows a tetrapod like Al Capp's cartoon character Joe Btfsplk (Kitchen, 2004), it seems impossible for raindrops to follow a tetrapod's footsteps. However, it is easy for a person walking through a marsh (i.e., increasing the pressure in buried layers) to induce gas-escape structures nearby, sometimes several centimeters to the side (Martin and Rindsberg, 2004).

### SIGNIFICANCE

The reinterpretation of "rainprints" as gas-escape structures makes sense in the Union Chapel context. The site was a freshwater intertidal flat within the delta of a large river, as shown by the presence of amphibian trackways, tidal lamination, and other clues (Pashin,

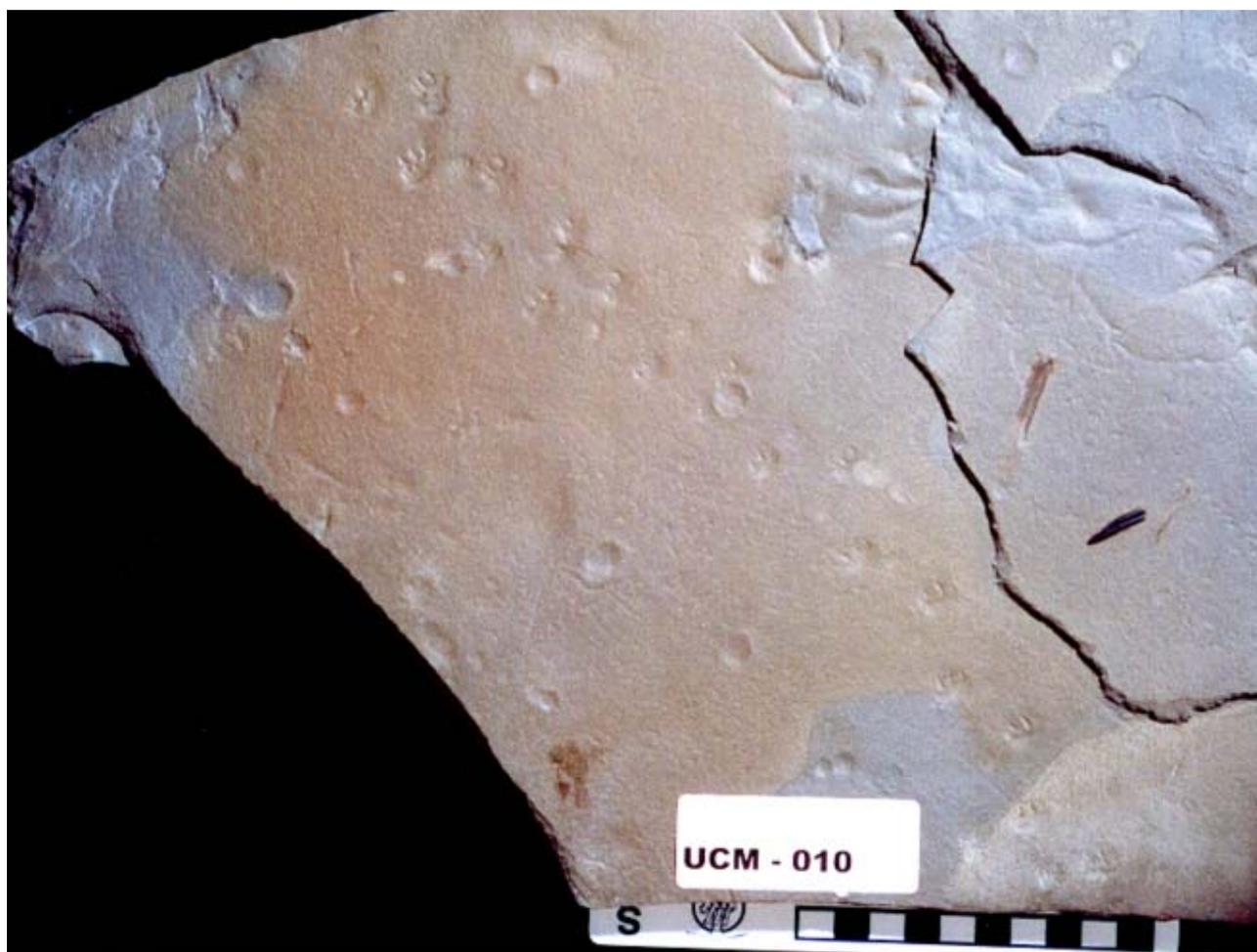


FIGURE 3. Gas-escape structures associated with vertebrate undertracks. UCM 10, collected by Steven C. Minkin.

2005). This is compatible with very rapid deposition in a humid climate. Plant debris is common and the shale is dark, probably due to high carbon content; the shale overlies a coal bed. There would have been ample nutrients to form gases of decomposition in muds that are known from their track taphonomy to have been soft, yet firm enough to hold a foot imprint (Martin and Pyenson, 2005).

Once the mind is cleared of illusory “rainprints,” a truer model of the Union Chapel paleoenvironment can be constructed. Without rainprints, there is no evidence of dry substrates in the track-bearing beds. Indeed, Haubold et al. (2005) have shown that tracks made at the substrate surface are so indistinct that the uppermost sediment must have been very soft; only the undertracks show sharp details. This is in keeping with the preference of modern amphibians for moist environments.

As “rainprints,” the circular pits were interesting but there was little reason to study them in detail with regard to trackways. As gas-escape structures, the pits are additional clues to sediment coherence, microbial activity, and maturation. Rainprints fall randomly, but

gas-escape structures are intimately connected with tetrapod locomotion, and can even be considered as part of their walking traces (Martin and Pyenson, 2005).

The relationships between trackways and gas-escape structures have never been studied in detail at any ancient or modern site. What are the relationships between animal weight and the size and distribution of gas-escape structures? Does it matter whether an animal is walking or running, and whether an animal treads softly or heavily? Can gas-escape structures be reactivated days later in natural environments, as seems likely? What determines the width of the pits? Some of these questions can be answered with Union Chapel material; others can be studied in modern terrestrial environments.

#### ACKNOWLEDGMENTS

Thanks to David C. Kopaska-Merkel, Jack C. Pashin (Geological Survey of Alabama), Ronald J. Buta (University of Alabama), and Anthony J. Martin (Emory University) for stimulating discussions, and to Ashley Allen (Oneonta High School) and W. Edward Osborne (Geological Survey of Alabama) for making specimens

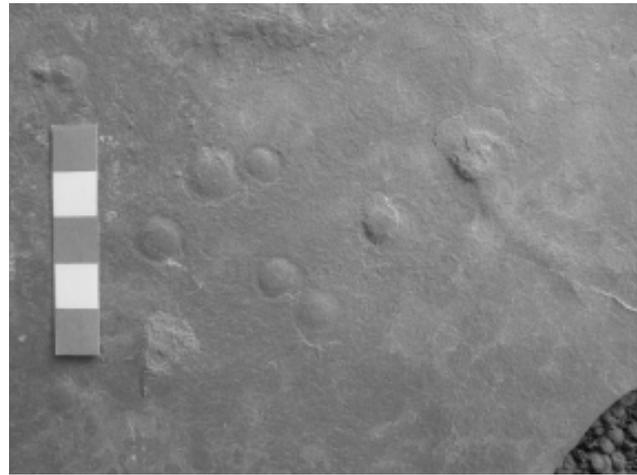
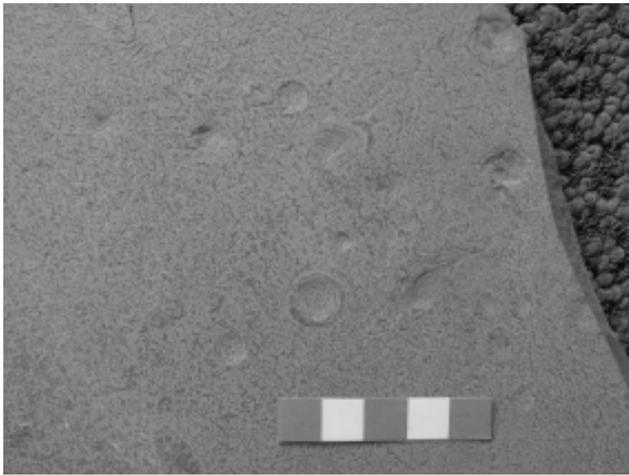


FIGURE 4. Gas-escape structures some of which penetrate several laminae of shale. UCM 1168, collected by David C. Kopaska-Merkel. A (left): Upper surface. B (right): Lower surface.

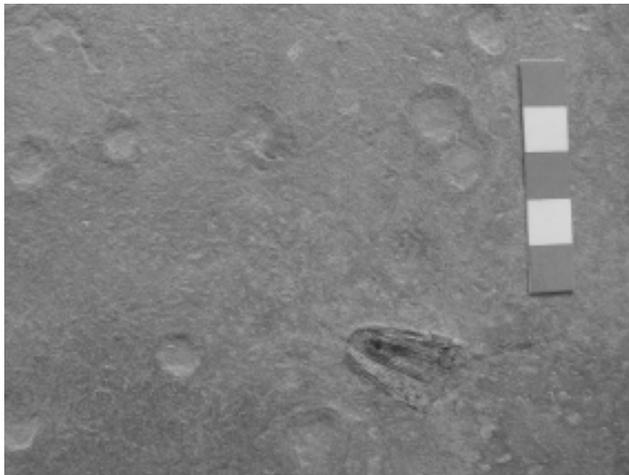


FIGURE 5. Partial overlap of gas-escape structures. Compare Lyell's comments quoted in the text. UCM 2072, upper surface; collected by David C. Kopaska-Merkel.

available. David C. Kopaska-Merkel and W. Edward Osborne reviewed the manuscript.

## REFERENCES

- Blackwelder, E., 1941, Significance of rain prints: Bulletin of the Geological Society of America, v. 52, p. 1944.
- Buckland, W., 1842, On recent and fossil semi-circular cavities caused by air-bubbles on the surface of soft clay, and resembling impressions of rain-drops: Report of the British Association for the Advancement of Science, Transactions of the Sections, v. 1842, p. 57-58 [not seen].
- Clarke, T. H., 1923, New fossils from the vicinity of Boston. 3. *Aspidella*-like markings from the Cambridge slate: Boston Society of Natural History, Proceedings, v. 36(8), p. 482-485.
- Cunningham, J., 1839, An account of the impressions and casts of drops of rain, discovered in the quarries at Storeton Hill, Cheshire: Geological Society of London, Proceedings, v. 3, p. 99-100.
- Deane, J., 1844, On the fossil footmarks of Turner's Falls, Massachusetts: American Journal of Science and Arts, v. 46(1):, p.73-77, pls. 1-2.
- Deane, J., 1845, Fossil footmarks and raindrops: American Journal of Science and Arts, v. 49(1), p. 213-215.
- Desor, E., 1850-52, Raindrop impressions, etc.: Boston Society of Natural History, Proceedings, v. 3, p. 200-203 (1850), v. 4, p. 131-133 (1852) [not seen].
- Egerton, H. E. and Killian, J. R., Jr., 1939, Flash! Seeing the unseen by ultra high-speed photography: Boston, Hale, Cushman and Flint, 203 p.
- Goemann, H. B., 1939, Entgasungs-Kuppen auf den Sedimente der Nieder-Weser: Natur und Volk, v. 69, p. 508-512.
- Häntzschel, W., 1941, Entgasungs-Krater im Wattenschlick: Natur und Volk, v. 71(6), p. 312-314.
- Hammond, D. E., 1978, Gases in sediments; in Fairbridge, R.W. and Bourgeois, J., eds., The encyclopedia of sedimentology: Stroudsburg, Pennsylvania, Dowden, Hutchinson and Ross, p. 346-348.
- Haubold, H., Allen, A., Atkinson, T.P., Buta, R., Laceyfield, J., Minkin, S. and Relihan, B., 2005, Interpretation of tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society, Monograph no. 1, p. 75-111.
- Kitchen, D., 2004, Al Capp's Joe Btfspk: URL [http://www.deniskitchen.com/thestore/bios\\_joe\\_btfspk.html](http://www.deniskitchen.com/thestore/bios_joe_btfspk.html), accessed March 10, 2005.
- Lahee, F. H., 1941, Field geology (fourth edition): New York, McGraw-Hill Book Company, 853 p.
- Lyell, C., 1841, The student's elements of geology: London [not seen].
- Lyell, C., 1845, Travels in North America; with geological observations on the United States, Canada, and Nova Scotia: London, John Murray, 1: 316 p., pls. 1, 3-5; 2: 272 p., pls. 2, 6, 7.
- Lyell, C., 1851, On fossil rain-marks of the recent, Triassic, and Carboniferous periods: Quarterly Journal of the Geological Society of London, v. 7, p. 238-247.
- Martin, A. J. and Rindsberg, A. K., 2004, Ichnological insights from the Union Chapel Mine, Alabama (USA) on Carboniferous vertebrate behaviour: Ichnia 2004, Abstracts.
- Martin, A. J. and Pyenson, N. D. 2005. Behavioral significance of vertebrate trace fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian footprints in the Black Warrior Basin of Ala-

- bama: Alabama Paleontological Society, Monograph no. 1, p. 59-73.
- McKee, E. D., 1945, Small-scale structures in the Coconino sandstone of northern Arizona: *Journal of Geology*, v. 53(5), p. 313-325.
- Moussa, M. T., 1974, Rain-drop impressions? *Journal of Sedimentary Petrology*, v. 44(4), p. 1118-1121.
- Pashin, J. C. 2005, Pottsville stratigraphy and the Union Chapel lagerstätte; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian footprints in the Black Warrior Basin of Alabama*: Alabama Paleontological Society, Monograph no. 1, p. 39-58.
- Potter, P. E., Maynard, J. B. and Pryor, W. A., 1980, *Sedimentology of shale: study guide and reference source*: New York, Heidelberg & Berlin, Springer-Verlag, 310 p.
- Pyenson, N. D., Martin, A. J. and Rindsberg, A. K., 2001, Ichnofossil-lagerstätte in Alabama: a world-class Carboniferous (Westphalian A) tracksite: 7th North American Paleontological Convention, Berkeley, California, June 26-July 1, Program and Abstracts: *PaleoBios*, v. 21(2, supplement), p. 109.
- Redfield, W. C., 1842, Notice of newly discovered fish beds and a fossil foot mark in the Red Sandstone formation of New Jersey: *American Journal of Science*, v. 44(1), p. 134-136.
- Reineck, H.-E. and Singh, I. B., 1980, *Depositional sedimentary environments with reference to terrigenous clastics* (second edition): Berlin, Heidelberg and New York, Springer-Verlag, 549 p.
- Shrock, R. R., 1948, *Sequence in layered rocks: a study of features and structures useful for determining top and bottom or order of succession in bedded and tabular rock bodies*: New York, Toronto and London, McGraw-Hill Book Co., 507 p.
- Twenhofel, W. E. 1921 [probably 1922], Impressions made by bubbles, rain-drops, and other agencies: *Bulletin of the Geological Society of America*, v. 32(4), p. 359-371.
- Twenhofel, W. E., et al., 1932, *Treatise on sedimentation*: Baltimore, Williams and Wilkins Company, 926 p. [not seen].
- Vanuxem, L., 1842, *Geology of New York. Part III, Comprising the survey of the Third Geological District*: Albany, 306 p. [not seen].

#### **AUTHOR'S E-MAIL ADDRESS**

arindsberg@gsa.state.al.us



## **Part III. Impact on Amateur and Professional Paleontology**



Long-time amateur paleontologist T. Prescott Atkinson (Children's Hospital, Birmingham, Alabama) speaks at the ceremony dedicating the Union Chapel Mine as the Steven C. Minkin Paleozoic Footprint Site, March 12, 2005. Jim Griggs, Director of the State Lands Division, Alabama Department of Conservation and Natural Resources, is seated behind the podium. Dr. Atkinson is credited with finding, at age 17, the only known dinosaur egg east of the Mississippi River, and has been a prolific and talented collector of Union Chapel Mine fossils. Photo credit: Andrew K. Rindsberg.

## THE IMPORTANCE OF THE AMATEUR PALEONTOLOGIST

G. E. HOOKS III

Department of Natural Sciences, Longwood University  
201 High Street, Farmville, Virginia 23909, USA

**ABSTRACT:** Amateurs make some of the most important contributions to paleontology, yet recognition for their contributions is scant and I am unaware of a single study which attempts to quantify the importance of their role to the science. Here I give some thoughts on this issue to place the Union Chapel Mine findings into perspective.

In the decade or so that I have been working in the field of paleontology, one of the things that has struck me is how often amateur paleontologists are mentioned. Seldom a day goes by when I am not working with, talking to, or talking about amateur paleontologists. There are few other scientific fields in which the amateur plays such an important role. As a scientist, I like to support my statements with hard data. You can understand then, my disappointment at not finding a single scientific study on the role of amateurs in paleontology. Past employment as a curator at a small natural history museum, the Alabama Museum of Natural History, certainly enlightened me to the vital role amateurs play in paleontology. This, along with information gleaned from communication with numerous colleagues both in the United States and abroad, provides the information for this article.

Readily apparent in discussions of amateurs in any field is the actual definition of an amateur. Webster's *Ninth New Collegiate Dictionary*, the one that allowed me to muddle through my undergraduate English composition classes and the one I still use, gives two possible definitions of an amateur: (1) "one who engages in a pursuit, study, science, or sport as a pastime rather than a profession," and (2) "one lacking in experience and competence in an art or science." The disparate nature of these definitions, one based on competency, the other on type of employment, helps to explain the difficulty in labeling someone an amateur. Jobs in paleontology are few and far between and there are numerous persons with adequate formal training in paleontology that cannot find employment in the field. There are also a significant number of persons with very little formal training that do find employment as paleontologists. To further confuse the definition of an amateur, there is, as with most fields, no guaranteed correlation between employment or unemployment as a paleontologist and competency. For the purposes of this article, I will consider an amateur to be a person who is not, or has not previously been, employed as a paleontologist or who has not received formal (college level) training in paleontology.

Probably the most obvious contribution of amateurs to the science of paleontology is the donation of important specimens to permanent collections where they can

be properly cared for and studied. Many amateurs are knowledgeable enough to recognize when they have made a find of importance and to understand the need to have it housed in an appropriate institution. Far outnumbering professionals, the participation of amateurs greatly increases the chance of making significant scientific finds. In fact, amateur finds comprise significant portions of most museum fossil collections. One example of this is the discovery of the only dinosaur egg ever found in eastern North America. The teenage amateur who found it recognized it as an important find and donated it to the Auburn University Museum of Paleontology.

In addition to finds of individual specimens, amateurs discover many important fossil collecting sites. Although professional paleontologists have training in locating sites, their limited numbers make checking all possible sites impossible. Amateur searches for collecting sites increase the possibility of important fossil finds that are associated with such sites. An obvious example is the discovery of the trace fossil site at the Union Chapel Mine by the Birmingham Paleontological Society.

No realm of science evokes more public interest than paleontology. Most persons, young and old alike, seem to have at least a passing interest in the science. The result is a never-ending torrent of public requests in matters paleontological. From giving talks in schools to identifying personal finds (some fossil, some not) the professional paleontologist becomes quickly overwhelmed. In most cases it is not that the paleontologist does not wish to respond to such requests; indeed most enjoy such activities and recognize their importance to the future of the science, but there simply is not enough time to handle them all. In the end the professional paleontologist must often adopt a policy of automatically refusing many public requests. Fortunately, the vast majority of these requests do not require the technical expertise of a professional paleontologist. An experienced amateur is often qualified to make presentations, fossil identifications, and conduct field trips for schools and other organizations. Once again amateur paleontologists are able to fill a large and important void in the science.

Few persons truly understand the tremendous

amount of time necessary to properly excavate and prepare the fossils that they see on display and in museum collections. Amateurs often play important roles in this area of paleontology. This is especially true at many smaller museums where there simply is not enough funding to pay professional preparators to handle the job. For example, while I supervised the paleontology program at the Alabama Museum of Natural History, a small museum located at the University of Alabama in Tuscaloosa, we spent approximately 600 hours on excavation and 1000 hours on preparation time each year. Of this time, amateur volunteers contributed approximately 400 hours of excavation and 300 hours of preparation, making a vital contribution to the museum's paleo program.

Over the last decade the public's interest in paleontology seems to have reached an all time high, as evidenced by the multitude of books, television programs, and movies that continue to flood the market, and increasing museum emphasis on fossil exhibits. Contrary to common public conceptions, these activities make only small, largely indirect contributions to the science of paleontology. Statistics on employment and funding in paleontology are few and very limited in scope; however, perusal of professional directories and discussion with colleagues consistently reveals two trends that have remained unchanged over the last few decades: (1) Finding work as a fulltime paleontologist is nearly impossible, and the majority of paleontology research is done as an aside pursuit by scientists paid primarily to fulfill other duties, and (2) Funding for paleontology research has remained largely unchanged. Interestingly enough, much of the limited funding for paleontology research comes from private individuals and groups, amateurs with an interest in paleontology. These contributions come in a variety of forms including donations of equipment and supplies and funding for positions from part-time student workers to endowed curatorships. Considering that the most any donor is likely to receive for their gift is a letter of thanks, his name on a plaque, or a tax deduction, his primary motivation is to further the science of paleontology. Without such generous benefactors the development of most paleontology programs would be highly restricted.

I experienced an example of this as Curator of Vertebrate Paleontology for the Alabama Museum of Natural History. Generally the museum had excellent offices, laboratories, and collection storage areas, but relied heavily on volunteer workers and lacked adequate equipment and supplies. Also, due to a lack of staff to adequately supervise operations, the labs only functioned for eight months of the year, with field work limited to the other four months of the year. The excellent facilities were largely due to the donations of private individuals during a fund raising campaign. Unfortunately, a similar strategy was not followed to provide funding for salaries, equipment, or supplies. The result was that only about 3% of the program's funding came from donations, severely limiting operations and failing to realize the potential of existing resources.

We now reach what might be called the penultimate contribution to paleontology, publication. While all other

contributions, by amateurs or professionals, are indispensable to the science, they all aim to achieve the final result of disseminating paleontological knowledge through publication of research findings. Much of their formal training having been spent on conducting research and writing papers, it is usually the professional paleontologists who produce the publications. Nevertheless, there are amateurs who, through self-study and experience, are able to conduct research and properly write up findings. In some cases they are able to obtain the hallmark of a professional paleontologist, authoring an article in a peer-reviewed scientific publication.

With the aforementioned amateur contributions to paleontology affecting paleontology programs, large and small, around the world, the importance of amateurs to paleontology is clearly evident. Also evident is the fact that, with no substantial increases in paleontology funding likely, the amateur will continue to play a vital role well into the foreseeable future.

#### **AUTHOR'S E-MAIL ADDRESS**

hooksge@longwood.edu

## ETHICS FOR COLLECTORS AND CURATORS OF FOSSILS

ANDREW K. RINDSBERG

Geological Survey of Alabama, P.O. Box 869999, Tuscaloosa, Alabama 35486-6999, USA

**ABSTRACT:** This article is a modified version of a lecture given at the Alabama Museum of Natural History on August 19, 2000.

Ethical behavior is not only the right way to act, but also the most practical way. Amateurs and professionals should aspire to an ethical standard higher than that required by the law. However, no one is perfect, so it important to retain the ability to forgive.

### INTRODUCTION

Ethics is the study of correct moral and professional behavior. While no one can act correctly all the time, maintaining a high personal standard gives a clean conscience and a sense of self-worth. Also, your life is easier when others can rely on your behavior. The problem is deciding what to do in ambiguous cases. Generally, to get along with people you will have to uphold higher standards than are strictly required by the law. Let's review a few cases, starting with an easy one.

### COLLECTING FOSSILS

Is it ethical to walk onto someone else's land and collect fossils there? Clearly not, because it is both wrong and illegal to trespass and to steal. In the United States, fossils on private land are the property of the landowner. (This is not the case in Alberta, Canada, where fossils are the property of the state.) But it certainly is acceptable to ask a landowner for permission to enter land to collect fossils.

Is it legal to ask a landowner for permission to collect a few fossils for your private collection, and then change your mind and sell them? Yes. Is it ethical? Yes, if you were sincere to begin with. Collecting fossils is a hobby for most people, not a contract to maintain a collection forever, and selling fossils is better than discarding them.

Is it legal to lease a landowner's property in order to collect fossils, then sell them? Yes. Is it ethical? Yes, though many would consider this procedure to be in poor taste if the lease prevents scientific research from being carried out. This leads us to the next question.

Is it ethical to lease all the known sites in a fossiliferous formation in order to collect fossils and exclude others? No. Is it legal? Yes.

### STORING FOSSILS

Does a collector have any obligation to label and store specimens properly? Legally, not at all; ethically, emphatically yes. The world supply of fossils is very large, but finite, and many specimens are unique records

of the earth's history — a heritage that belongs to all of us. It is not at all unusual for amateurs to discover important specimens, and every amateur should be aware that a unique specimen may turn up at any time. Thus, every amateur has an obligation to learn the basics of labeling and storing fossils (and curators have an obligation to teach amateurs). In practice, this is not a great burden, and raises the value of collected specimens. Specimens without labels generally have to be thrown out eventually.

### ETHICS FOR CURATORS

Is it legal for a museum curator to have a private collection of his or her own? Generally, yes. Is it ethical? Only if the collection does not overlap with the museum's. Otherwise, the curator may be tempted to keep the best specimens for the private collection. For this reason, some paleontologists dispose of their own collections when they get jobs as curators. Others stop adding material to their own collections.

Should a museum accept any donation, no matter the source? Legally and ethically, no. The specimens could have been stolen goods, for instance, as often happens in the art world (e.g., Nicholas, 1995). That's why museums use donor forms these days.

May curators appraise specimens? No. Curators can give a donor a receipt that can be used for tax purposes, but not with a dollar amount. A professional appraiser may be hired to assess a collection before donation.

### CONCLUSIONS

Now, I could continue to go through a series of special cases, but I think the general trends are evident. It is often legal to do something that is wrong — something that would lower you in your friends' esteem, and that also might get some landowners angry at all fossil collectors. It is also often hard to tell what is the right thing to do. But here are a few guidelines:

1. If you tell a landowner exactly what you want to do, and he or she agrees to it, and you then do what you said, then usually you will be in the clear ethically and

legally.

2. If you expect your hobby to make money, then it is not a hobby and you are not an amateur.

A final word on forgiveness. No one does the right thing every time, and people must be given the opportunity to change. If we continually condemn someone for a mistake made years ago without giving the person a chance to learn from that mistake, the result can be more improper behavior and ill feeling. But communication can lead to reconciliation.

### ACKNOWLEDGMENTS

James Lowery (University of Alabama at Birmingham) and Charles C. Smith (Geological Survey of Alabama) made helpful reviews of the manuscript.

### FURTHER READING

Note: URLs were accessed on April 11, 2005.

- Alabama Paleontological Society, 2003, Code of Ethics as of August 11, 2003, URL <http://bama.ua.edu/~rbuta/aps/ethics.html>.
- American Museum of Natural History, 2004a, Division of Paleontology loan policy: American Museum of Natural History. URL <http://paleo.amnh.org/about/loans.html>.
- \_\_\_\_\_, 2004b, Division of Paleontology. Visiting the collection: American Museum of Natural History. <http://paleo.amnh.org/about/visiting.html>.
- Association of Applied Paleontological Sciences, 2005, Code of ethics: Association of Applied Paleontological Sciences. URL <http://www.aaps.net/ethics.htm>.
- Brodie, N., and Tubb, K. W., eds., 2002, *Illicit antiquities: the theft of culture and the extinction of archaeology*: London and New York, Routledge, 308 p.
- Denver Museum of Nature and Science, 2004, *Certifications*: Denver Museum of Nature and Science. URL <http://www.dmns.org/main/en/general/education/adultprogram/certifications>.
- Eschberger, B., 2000, *Fossil collecting ethics I*: Suite University. URL <http://www.suite101.com/article.cfm/paleontology/36014>.
- Geological Survey of Alabama, not dated, *Paleontology in Alabama*: Geological Survey of Alabama. URL <http://www.gsa.state.al.us/gsa/Paleoweb/palpage.html>.
- Green, E. L., ed., 1984, *Ethics and values in archaeology*: New York, Free Press (Macmillan), 301 p.
- Kopaska-Merkel, D. C., Rindsberg, A. K., and DeJarnette, S. S., 2001, *A guidebook to the Mississippian rocks and fossils of north Alabama*: Alabama Geological Survey Educational Series 13, 57p., 8 pl. [Includes sections on Alabama law and conservation of fossils].
- MacFall, R. P., and Wollin, J. C., 1972, *Fossils for amateurs: a guide to collecting and preparing invertebrate fossils*: New York, Van Nostrand Reinhold, 341 p.
- Martin, A. J., 1997, *Fossil sales say much about ethics and future of paleontology*: Emory University, Emory Report, 50(12). URL [http://www.emory.edu/EMORY\\_REPORT/erarchive/1997/November/ernovember.10/11\\_10\\_97FirstPerson.html](http://www.emory.edu/EMORY_REPORT/erarchive/1997/November/ernovember.10/11_10_97FirstPerson.html).
- National Research Council, 1987, *Paleontological collecting*: Washington, DC, National Academy Press, 243 p. [Emphasizes legal and ethical issues, not techniques.]
- Nicholas, L. H., 1995, *The rape of Europa: the fate of Europe's*

*treasures in the Third Reich and the Second World War*: New York, Alfred A. Knopf, 498 p.

- North Coast Fossil Club, 1999-2000, *North Coast Fossil Club safety rules*: North Coast Fossil Club. URL <http://members.aol.com/fostrak/ncsafety.htm/>.
- Paleontological Society, 1993, *The Paleontological Society Code of Fossil Collecting*: Paleontological Society. URL <http://www.paleosoc.org/pscode.html>.
- San Diego Museum of Natural History, 2000, *Policies and protocols*: San Diego Museum of Natural History, Paleontology. URL <http://www.sdnhm.org/research/paleontology/policies.html>.
- Society of Vertebrate Paleontology, 2004, *By-law on ethics*: Society of Vertebrate Paleontology, Policy and position statements. URL <http://www.vertpaleo.org/policy/ethics.html>.
- Triebold, M., Siber, K., and Janke, P. R., 1997, *Commercial collectors in the 21st century*: Paleo21, Frankfurt 1997, Paleontology in the 21st century (an international Senckenberg conference and workshop). URL [http://www.nhm.ac.uk/hosted\\_sites/paleonet/paleo21/rr/cc21.html](http://www.nhm.ac.uk/hosted_sites/paleonet/paleo21/rr/cc21.html).
- Wolberg, D., and Reinard, P., 1991, *Collecting the natural world: legal requirements and personal liability for collecting plants, animals, rocks, minerals, fossils, and artifacts*: Tucson, Arizona, Geoscience Press, 330 p. [not seen].

### AUTHOR'S E-MAIL ADDRESS

arindsberg@gsa.state.al.us

## SAVING THE UNION CHAPEL MINE: HOW A GROUP OF DETERMINED AMATEURS TEAMED UP WITH PROFESSIONALS TO SAVE A WORLD-CLASS TRACKWAY SITE IN ALABAMA

T. PRESCOTT ATKINSON<sup>1</sup>, RONALD J. BUTA<sup>2</sup>, and DAVID C. KOPASKA-MERKEL<sup>3</sup>

<sup>1</sup>Children's Hospital CHT 752M, 1600 Seventh Avenue South, Birmingham, Alabama 35233, USA

<sup>2</sup>Department of Physics and Astronomy, University of Alabama, Box 870324, Tuscaloosa, Alabama 35487, USA

<sup>3</sup>Geological Survey of Alabama, PO Box 869999, Tuscaloosa, Alabama 35486, USA

**ABSTRACT:** In 2004, ownership of the Union Chapel Mine was transferred from the New Acton Coal Company to the State of Alabama, thus making it more likely that the site will be available for research and teaching for many years to come. This article describes how the Alabama Paleontological Society, Inc. (APS), together with the support of professional geologists and paleontologists, government officials, and the news media, were able to bring about the preservation of one of the most significant Carboniferous track sites in the world.

### INTRODUCTION

The discovery of rare fossil vertebrate trackways at the Union Chapel Mine in late 1999 was a pivotal event both for Alabama paleontology and for the group of amateurs who salvaged the trackways and brought them to the attention of professional paleontologists. For Alabama paleontology, the discovery brought back to light a 1930 Bulletin of the Alabama Museum of Natural History by T. H. Aldrich and W. B. Jones, who first described the tetrapod trackways discovered by miners in an underground coal mine in Carbon Hill, Alabama. Amazingly, the Alabama Museum of Natural History still had dozens of the old bulletins to sell to interested collectors — they had been stored in the basement for 70 years. This intriguing publication documented the occurrence of spectacular pre-dinosaur trackways in shale deposits associated with coal seams in Walker County but suggested there might be little scientific information to be derived from such trace fossils. Over the ensuing years, no further scholarly publications focussing on Carboniferous vertebrate trackways in Alabama emerged despite a very active coal mining industry. Other trackways must have come to light but been ignored or forgotten in private collections. No systematic mechanism, such as has been created for archaeological sites, exists for surveying excavations for possible fossils.

During the second half of the 20th century, particularly in the 1980s and 1990s, there was an explosion of interest in fossil tracks among paleontologists. This was fueled by the discovery of numerous dinosaur trackways in the American West and elsewhere and the realization that important scientific information could be derived from trace fossils. Trace fossils yield information about behavior that complements that obtained from the study of skeletal remains. In the case of the Alabama trackways, the identity of many of the track makers remains to be determined because skeletal remains from the Carboniferous are much less abundant

than are those from the era of the dinosaurs. Therefore, for some long extinct organisms, these trace fossils showing their activity in the coal swamps represent the only known record of their existence, pages from a lost book of early life preserved in thin layers of shale.

Despite the dearth of publications on trackways in Alabama, the Union Chapel Mine trackways were not the first to be discovered in Alabama since the work of Aldrich and Jones (Rindsberg, 1990; Lacefield and Relihan, 2005). Other sites, including the Fern Springs Road Mine near Eldridge, Alabama, and another mine near Kansas, Alabama, had yielded similar trackways before the Union Chapel Mine discovery. Jim Lacefield, author of *Lost Worlds in Alabama Rocks: A Guide to the State's Ancient Life and Landscape*, includes pictures of Kansas trackways in his book, and he once commented to the Birmingham Paleontological Society (BPS), the former designation of the Alabama Paleontological Society (APS) prior to its incorporation in 2002, that the Kansas site had a greater yield of tracks than the Union Chapel Mine. Nevertheless, no systematic research was conducted on the Fern Springs Road and Kansas fossils. Any material recovered from these sites is dispersed into private collections, and because the sites have now both been reclaimed, any further collecting has become impossible. The abandonment of surface coal mines after mining ceased, an all too frequent occurrence in the past, was prohibited by Congress in 1977 by the passage of the Surface Mining Control and Reclamation Act (U.S. Code Title 30, Chapter 25).

The discovery and documentation of Union Chapel Mine trackways by members of the BPS/APS is described elsewhere in this monograph (Allen, 2005; Buta and Minkin, 2005) and is summarized briefly below for the reader. The documentation effort alone was a remarkable achievement. All of the collectors involved remember how unusual it was to bring fossils collected independently during routine field trips to the "track meets" for photographic documentation. Thus, each member had an opportunity to see what the others had

found. But, even during the first track meet, the group did not have a full appreciation of the significance of the site. Eventually, it became clear that the Union Chapel Mine was an extraordinary fossil site, the kind that might be worth preserving for future studies and research. This chapter documents the strategy, ultimately successful against very long odds, in which the group pursued the seemingly impossible task of extricating the site from an exacting legal requirement that it be reclaimed and turned back into farmland or woodland.

### THE BEGINNING

It began in late 1999 at the monthly meeting of the Birmingham Paleontological Society (BPS), a group of amateur fossil collectors in north central Alabama. The BPS was founded in 1984 by Gordon Bell and James Lamb, two local paleontologists, to help support the newly established Red Mountain Museum. Fifteen years later the Society still existed, but the Red Mountain Museum had been subsumed as part of the newly created McWane Science Center, with much of the Museum's collection (still in packing crates at the time of this writing) moved to that center. Gordon Bell had taken a position with a museum in Texas, and James Lamb was working on his PhD in vertebrate paleontology at North Carolina State University. The BPS was now primarily a group of amateurs who enjoyed monthly academic presentations and field trips.

Ashley Allen brought to a BPS monthly meeting in December 1999 some trackways that he had recently found at a coal mine in Walker County. Ashley, a science teacher at Oneonta High School in Oneonta, Alabama, had learned of the site from one of his students, Jessie Burton (see Allen, 2005). Ashley always had been on the lookout for tetrapod trackways in his numerous visits to surface coal mines in the Warrior basin, and his first visit to the Union Chapel Mine (with permission from the mine owner, Dolores Reid) immediately yielded several beautiful specimens. Ashley recommended making the mine the site for an upcoming BPS field trip, and such an outing was scheduled for January 23, 2000. Mrs. Reid had granted permission for the BPS to collect without restriction at the site.

When that day arrived, the weather was cloudy and drizzly, and only eleven people attended the outing, about half the usual number. Ashley led the way in, and the group began to explore a series of large spoil piles in front of a high wall. People started finding trackways immediately, along with spectacular plant fossils (Fig. 1). Despite the rarity of trackways in other localities, the Union Chapel Mine seemed to have them in abundance. Members found tracks throughout the spoil piles, and, generally, had a grand time.

Initially, members simply collected tracks and took them home to their private collections according to the usual way such field trips are conducted in amateur fossil groups. Over the ensuing months, a core group of people kept making individual trips to the site. Steve Minkin, a geologist employed at the Army Chemical Weapons Incinerator in Anniston, took his mother out to the site one day. After a couple of hours of unproductive

searching, they sat down to rest on the side of one of a series of hillocks among the spoil piles. He immediately found that there were small, very high quality tracks right under his feet. That portion of the mine subsequently became the most productive part of the site, particularly for small to medium tetrapod tracks.

### THE DECISION

During the spring and summer of 2000, the BPS continued to collect at the Union Chapel Mine site. As specimens were accumulated by Society members, it became evident that the sheer number of specimens, as well as the size of some of the slabs, were greater than the occasional weekend collector could hope to store in a private collection. Discussions at the meetings began to turn to how much people were finding at the site. One evening it was decided, largely with Steve's urging, to arrange a session to create a photographic index of all the specimens collected to date. The name "Track Meet" was coined in emails between Steve and Ron Buta, a BPS member who is an astronomer at the University of Alabama. Steve largely organized the first Track Meet, held on August 19, 2000 at the Alabama Museum of Natural History, even arranging speakers. The roster included professional geologists and paleontologists from the Geological Survey of Alabama Museum and Emory University. These same professionals, including Andrew K. Rindsberg and Tony Martin, were instrumental to the effort to document and protect the mine. If it had not been for their initial professional opinions as to the tracks' significance, it is unlikely the amateurs would have gotten as far as they did.

The goal of the first Track Meet was to systematize and preserve the specimens so that they would not become casualties of site reclamation and the vicissitudes of the lives of amateur collectors. Ron took most of the photographs at this and the following three Track Meets which have been held to date. He placed digitized images of all the photos of the specimens on a website together with documentation regarding the collector, tentative identification of the specimen, and other pertinent data. As he had with BPS field trips in the past, Ron also began to document a rough history of events and publications related to these early activities at the Union Chapel Mine. The website's value to the preservation effort was serendipitous but crucial: *The instant availability of all these images via the internet to distant scientists, governmental officials, and media representatives turned out to be a key advantage when the decision was made the next summer to push for permanent protection for the site.* The intrinsic value of the discovery was of equal importance: *Its position at the beginning of the colonization of land by reptiles made it more important than ever to try and preserve the site for future research.* Even by the time of the first Track Meet, specimens recording some of the earliest known examples of specific animal behavior (such as schooling behavior; Martin and Pyenson, 2005) had already been found. The large number of well-preserved specimens allowed some exciting preliminary results on population dynamics.



FIGURE 1. Fossils found by BPS members who attended the first organized outing to the Union Chapel Mine on January 23, 2000. At left is a fine vertebrate trackway (UCM 125, tracks 1-2 cm in size) while at right is a beautiful arborescent lycopod bark impression. Photo credits: Larry A. Herr and Ron Buta

On October 14, 2000, a second Track Meet was held at the Oneonta High School, where Ashley was a science teacher. The event was, again, well attended, and hundreds more specimens were photographed. The weather was warm and sunny, and many of the tracks were laid out on the lawn after photography so that the ichnologists, Andy Rindsberg from the Geological Survey of Alabama (GSA) and Tony Martin and Nick Pyenson from Emory University, could go over them. They systematically moved through the array of slabs, picking them up and viewing them in various orientations in the rays of the sun to highlight the trace fossils on the surface.

During the summer and fall of 2000-2001, with over 1000 catalogued trackways in the database, some of them representing apparently undescribed ichnospecies, the BPS and its professional advisors at the GSA began to make plans for producing a monograph to lay out in detail all aspects of this unique site. By the time the third Track Meet was held on May 12, 2001, plans for the monograph were well underway. A "Great Track Layout" (GTL) was held on July 27, 2001 at the Alabama Museum of Natural History where the structure of the monograph was discussed and outlined (Fig. 2). In addition to original research papers, and papers concerning the discovery, documentation, and significance of the site, the monograph would include extensive atlas sections illustrating a selected subset of all the trackways found. For the atlas sections, all the photographs were laid out on large tables for inspection by professional ichnologists, and about 100 of the best were selected for inclusion. (Some of these are contained in the current atlases in Haubold et al., 2005 and Buta et al., 2005, but since these were produced more than 3 years later, they also include more recently collected specimens.) Even before the GTL, the BPS had contacted two paleobotanists, David Dilcher of the University of Florida and Brian Axsmith of the University of South Alabama, to write an article on the abundant and di-

verse fossil plants found at the Union Chapel Mine. (Coworker Terry A. Lott later contributed to this article.) David Dilcher made the long drive to Anniston for the third Track Meet and spent hours photographing plants for what would be a lavishly illustrated chapter on the diverse paleoflora from the mine (Dilcher et al., 2005).

It was early in the summer of 2001 when the daunting decision was made to mount a campaign to somehow stop the inevitable reclamation of the Union Chapel Mine. As Prescott Atkinson remembers:

I was out at the Union Chapel Mine site with Steve Minkin one sunny weekend day. It was pretty much just the two of us, and we had a great morning finding several slabs with the distinctive tracks of *Cincosaurus cobbi*, the most abundant vertebrate traces found at the site. The day was hot but not the furnace-like heat of mid-summer, which we had already discovered necessitated starting the day near dawn and leaving at mid-day. We were relaxing back at the cars, having some water and looking over our finds from the morning when Steve looked up at me and said, "We can't let this place go down without a fight. We've got to somehow get it preserved." His words crystallized a feeling that had been growing in me and other members of the group. We determined then and there that we had to get busy if we were serious. We knew that the hour was late. We had no idea how long the Surface Mining Commission in Jasper would permit the company to delay reclamation; it could start at any time.

In the fall of 2001, Ron traveled to South Africa to carry out a research collaboration with an astronomical colleague at the University of the Witwatersrand in Johannesburg. While there, he was able to visit the Bernard Price Institute for Paleontological Research on the same campus, and view some of the Institute's astounding Permian-Triassic vertebrate fossil collection from the Karoo Basin of South Africa. It was also there, ironi-



FIGURE 2. Several attendees at the “Great Track Layout” of 2001: (top left to right) Jim Lacefield, Ron Buta, Andy Rindsberg; (middle left to right) Bruce Relihan, Sam Hood, Nick Pyenson; (bottom left to right) Ashley Allen, Kathy Twieg, Steve Minkin. Photo credit: Deborah Crocker

cally enough, that he learned of a bulletin published by the New Mexico Museum of Natural History detailing an extensive set of Permian track sites in the Robledo Mountains near Las Cruces. In the late 1980s, a lone amateur named Jerry MacDonald had almost single-handedly brought the sites to the attention of professional paleontologists around the country and eventually had won the protection of the sites by the Federal Bureau of Land Management, which owned most of the localities. In an almost superhuman feat of endurance, Jerry had carried huge slabs of redbed sandstone strapped to his back over half a mile of rugged terrain, placed them in a truck, and reassembled them at his home. Many of these important trackways now reside in the collections of major museums across the country. Jerry recounted his experiences in a book, *Earth's First Steps: Tracking Life Before the Dinosaurs* (MacDonald, 1994), one of the greatest testaments to citizen science ever published. In his book, Jerry mentioned the influence the Aldrich and Jones paper had on his interest in seeking the source of fossil trackways in New Mexico, which up to 1987 had turned up mainly in private amateur collections, mysterious museum displays, and even in a restaurant and a local home. Jerry's book turned out to be a sort of roadmap for us, showing us at least some of the first steps we needed to take in our campaign to preserve an equally important site that predated the New Mexico Permian sites by 30 million years.

As we moved toward preserving the site, obviously we needed the support of the owner, in this case the New Acton Coal Mining Company. Any attempt to obtain the property without the cooperation of the company would probably be doomed. We needed support from professionals in the field to justify the need for preservation on a scientific basis; this was best obtained in the form of letters which could then be posted on Ron's website. We needed media attention to broadcast our campaign to save the site as widely as possible and to help gather support from nearby residents as well as scientists in other regions of the country and the world.



FIGURE 3. A group of BPS members meets with company representative Dennis Reid to discuss the early stages of the preservation effort. Left to right: Ashley Allen, Bruce Relihan, Steve Minkin, Prescott Atkinson, Kathy Twieg, Dennis Reid, Ken Hoyle, Don McDonald. Photo credit: Ron Buta

Finally, we needed the support of local, state, and national governmental officials to find some way around the seemingly insurmountable obstacle posed by the Surface Mining Control and Reclamation Act. The hurdle was significant, because no coal mine had ever been left unreclaimed to protect a fossil site before.

Fortunately, we had a good relationship with the mining company. In July 2001, we met with a company official to make known our newly-formed intention to fight for preservation of the site and to try to ascertain what kind of support we could expect (Fig. 3). The company representative, Dennis Reid, a relative of the owner Dolores Reid, was cautiously supportive. An unspoken but obvious advantage for the company lay in our efforts. If we were successful, the company might avoid tens of thousands of dollars in reclamation costs. At the same time, the company was anxious to avoid any appearance of conspiring to evade their responsibility to reclaim the mine. It should be stated here, in no uncertain terms, that the company always played a passive, though supportive, role in our campaign. In the end, after a lobbying effort that took four years, legal fees and payments to a local landowner who controlled an option to buy the site may have nearly equalled the amount of money the company saved in reclamation costs.

In September 2001, a delegation from the BPS met with Randy Johnson, the Alabama Surface Mining Commissioner, and the Commission's attorney Milton McCarthy at the SMC office in Jasper (Fig. 4). BPS members included club President Kathy Twieg, James Lowery, Steve, Ron, and Prescott. Andy Rindsberg was also there representing the Geological Survey of Alabama. They presented the Commissioner with a loose-leaf notebook filled with letters of support, clippings, and photographs that had been put together by Kathy. Kathy made several of these notebooks, which were a very useful way to present our case to officials. Amazingly, during the course of the meeting with the Commissioner, it became clear that no one seemed to know exactly how to go about exempting the site from reclamation. As we have noted, it had never been done before for scientific purposes. Although the Commissioner, who has a PhD in biology, recognized the significance



FIGURE 4. Meeting at the Alabama Surface Mining Commission, September 18, 2001. *Left to right:* Ron Buta, Kathy Twieg, Milton McCarthy (lawyer for Commission), Prescott Atkinson, Randy Johnson (Director, Alabama Surface Mining Commission), Billy Orick (Permits Manager, New Acton Coal Mining Company), Wendy Allen Jackson (Director of Land Acquisition, Black Warrior-Cahaba Rivers Land Trust), unidentified (commission official), Steve Minkin, Andy Rindsberg.

of the site and was sympathetic, he made it clear that he could do no more under the law than grant the company a little more time before they had to begin reclaiming the site. He indicated that in the search for a way out of the reclamation requirement, our steps would have to pass through Washington, DC, since the legislation mandating reclamation was a federal law.

Early in the campaign, the BPS members began to attract the attention of the press and articles began to appear, often centered around the Track Meets, detailing the remarkable fossils from the site and the problem posed by the impending reclamation. Steve, Prescott, and Bruce Relihan, another BPS member, met with Ed Howell, a reporter from the Jasper *Daily Mountain Eagle*, and showed him examples of the splendid tracks that were coming from the site in a display that covered a dozen tables. Ed's interest in the campaign as well as that of other reporters at local and regional newspapers was to play a key role in attracting local support for the effort to preserve the mine. In addition, to further spread the fame of the Union Chapel Mine trackways, Steve helped to prepare trackway displays at local museums, including the Anniston Museum of Natural History in Anniston, Alabama, and the Colburn Gem and Mineral Museum in Asheville, North Carolina. The latter museum carried, from March 16 to May 9, 2002, an exhibit titled "Tracks Through Time."

Another early strategy which the members employed was to involve conservation groups in the preservation effort. The enactment of the Surface Mining Control and Reclamation Act had not occurred without good reason. A large number of abandoned surface coal mines still litter the landscape of states in which the coal mining industry had been active, an unpleasant reminder of how necessary the legislation had been. The BPS wanted to make sure that there were no serious objections from an environmental standpoint. Fortunately, the track-bearing part of the Union Chapel Mine was a fairly small site, covering a total of 32 acres with only a small percentage of that representing unreclaimed spoil piles along a highwall about 150 yards in length. It did not lie close

to any bodies of water that might be contaminated by runoff. The highwall, which represents the point at which the excavation by the company stopped, is about 100 feet high, and the presence of this feature constituted both a potentially important scientific resource as well as a significant liability. It was the liability posed by the high wall that made the search for an organization that could accept custody of the site the most difficult aspect of its preservation. No small private organization could consider taking on the long-term risk that it represented without adequate insurance coverage. The potential scientific importance of this feature is also one of the most exciting aspects of the site. Buried beneath 75 feet of gray shale, interbedded shale and sandstone, and sandstone, and above the Mary Lee coal seam, lie layers of thin-bedded track-bearing shale (Pashin, 2005), more fragile than bone china, on which are inscribed traces of creatures long gone from the earth. These layers represent a potential gold mine of scientific information that may be the site of a controlled excavation sometime in the future if funding can be obtained.

As an initial move to assess the attitude of local environmentalists regarding the preservation of a valuable fossil site that happened to be located in a surface coal mine, Prescott made a presentation to Wendy Allen Jackson, the Director of the Black Warrior-Cahaba Rivers Land Trust, a local conservation group, at their Birmingham office. Wendy was immediately supportive and brought the matter up before the Board of the Land Trust, which was favorably impressed and even seriously considered offering to take temporary custody of the site. As an example of the depth of her interest in the project, Wendy even took the time to visit the site one weekend. On another occasion, Prescott and Steve met with Pete Conroy, another prominent Alabama conservationist, at Jacksonville State University and found him very supportive as well. Another conservation organization that proved very supportive of the campaign to preserve the mine was Cahaba-Warrior-Coosa Resource Conservation & Development (CaWaCo), an organization involved in ecologically sound land development and con-



FIGURE 5. April 24, 2002 meeting between Jerry MacDonald and members of the BPS and the Geological Survey of Alabama. *Left to right:* Prescott Atkinson, Jerry MacDonald, Jim Lacefield, David Kopaska-Merkel, Andy Rindsberg, Jack Pashin, Vicki Lais, Kathy Twieg, Richard Blake, Ron Buta. Photo credit: Pearl MacDonald.

servation in the watersheds of these three rivers in Walker, Shelby, Blount, Jefferson, and Chilton Counties. Paul Kennedy, the CaWaCo Project Coordinator, was especially interested, visiting the site on several occasions and even assisting in a site visit by the entire CaWaCo Board on one occasion. The support of these local environmental groups was essential to the ultimate success of the campaign; a failure to involve them and to explain the importance of the site to science might have resulted in inadvertent misunderstanding and opposition that could have crippled the preservation effort.

In April 2002, Jerry MacDonald and his wife, Pearl, made the long drive east to Birmingham from Las Cruces, New Mexico, on invitation from Ron representing the BPS (Fig. 5). Jerry spoke to the group both at one of their monthly meetings and at a reception hosted by Ron and his wife, Deb Crocker, at their home. Jerry also was able to visit the Union Chapel Mine site and see the area for himself despite health problems which were making it increasingly more difficult for him to walk long distances. Galvanized by Jerry's visit, Ron, Steve, and Prescott began to make a series of visits to local, state, and federal governmental officials to present the case for preservation. These included the staff in the Jasper office of the District 4 Congressman, Robert Aderholt, on May 25, 2002, and Bruce Hamrick, the Walker County Commissioner, on October 8, 2002. Ron had made a series of poster-sized photographic enlargements of tracks and plant impressions that helped a great deal in these sessions. Both of these officials offered their support in the effort. Later, Steve, Ron, and Prescott met with the Jasper Kiwanis Club to make a presentation, which was warmly received. The presence of a world-class fossil site in their back yard promised publicity and tourism, both welcomed in an area whose major traditional industry, coal mining, was in decline.

In July 2002, Congressman Aderholt made a site

visit to the Union Chapel Mine (Fig. 6). Under a blistering Alabama summer sun, he inspected a display of fossils from the site and looked at Ron's spectacular posters arranged as a backdrop for the tables. Several members of the BPS and the GSA made presentations to demonstrate to Mr. Aderholt how unusual the Union Chapel Mine fossils were and what a tragedy it would be if the site were reclaimed. The congressman was impressed with the depth of the scientific material and gave the preservation effort his support. In collaboration with the BPS, his staff submitted a bill entitled *The Union Chapel Fossil Footprint Site Preservation Act* under his sponsorship during the 1st Session of the 108th Congress. The bill was designed to exempt the site from the reclamation requirements and transfer it to the protection of a governmental agency, namely the Department of the Interior.

In September 2002, Kathy Twieg, the BPS President, and James Lowery, the Vice President, filed papers with the State incorporating both the BPS and a new, nonprofit corporation designated the Alabama Paleontological Society, Inc. (APS). The achievement of nonprofit status meant that the new 501(c)(3) organization, as an outgrowth of the former BPS, could potentially serve as a means to accept tax deductible donations for the educational purposes to which it was dedicated. This step simplified a financial problem that arose during the last days before the site was transferred to the State, which is described in some detail below.

In February 2003, the APS hosted Hartmut Haubold, Director of the Institute of Geological Sciences and Geiseltalmuseum, Martin-Luther-University, Halle-Wittenberg, Germany. Dr. Haubold is one of the most respected vertebrate ichnologists in the world. He spent two weeks looking at specimens that he had carefully catalogued from Ron Buta's website from his office in Halle, Germany. Dr. Haubold's evaluation of the importance of the site was a key element in the letters of



FIGURE 6. Congressman Robert Aderholt (left) listens to Andy Rindsberg discuss the remarkable finds from the Union Chapel Mine, during a site visit in July, 2002. Photo credit: Prescott Atkinson.

support from professional paleontologists that served to convince members of the press and governmental officials of the importance of the site. It is worth reproducing in part here: “My assessment: by quantity, by quality, and by geologic age, it is the most important discovery of Carboniferous tracks hitherto known.” He subsequently consented to contribute to the monograph a scholarly article with his analysis of the vertebrate trackways. Hartmut stayed in the homes of several of the APS members studying the tracks in their collections, and he spent a day at the site. He gave a talk at one of the APS monthly meetings and was hosted at a special dinner held at the home of Steve and Missy Minkin.

On May 3, 2003, the Geological Survey of Alabama hosted a workshop organized by Andy Rindsberg, Ed Hooks, David Kopaska-Merkel, Tony Martin, and others dedicated to the study of the fossils of the Union Chapel Mine (Fig. 7). The workshop was attended by paleontologists from all over the Southeast and even as far away as Birmingham, England. Adrian Hunt and Spencer Lucas flew in from the New Mexico Museum of Natural History in Albuquerque. Spencer, the New Mexico State Paleontologist, had been a very helpful supporter of the campaign, providing a letter of support as well as contacts in the Department of the Interior which was being considered by the APS as a possible governmental entity that could accept custody of the site. There was an organized program of lectures on all aspects of the Union Chapel Mine fossils (Martin, 2003), and classroom tables filled with specimens for examination. At times the discussions following the lectures became quite spirited when various controversial aspects of the trace fossils were considered. The workshop culminated with a site visit by the attendees at which they were able to see the mine for themselves and to collect samples.

In June 2003, two important events occurred. On

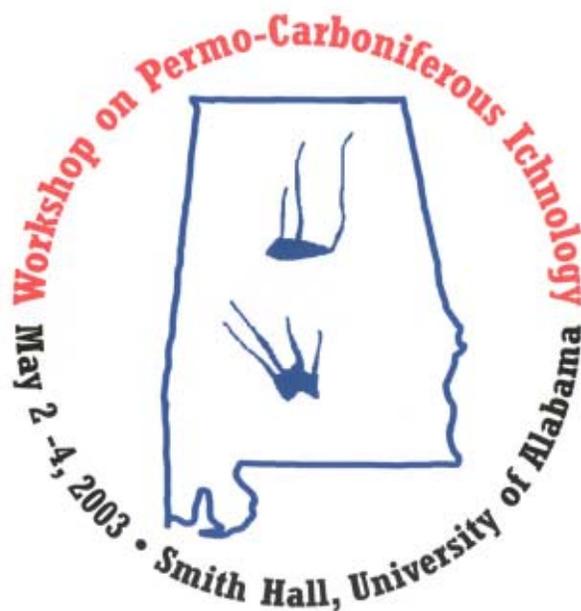


FIGURE 7. (Top) Logo used for the Workshop on Permo-Carboniferous Ichnology, held at the Alabama Museum of Natural History, May 2-4, 2003. Designed by Ron Buta and Deborah Crocker. (Bottom) Lauren Tucker, University of Birmingham, UK, speaks on the composition of early tetrapod communities at the Workshop.

Thursday, June 19, the monthly meeting of the Alabama Surface Mining Commission included a presentation by Prescott on the urgent need to preserve the Union Chapel Mine, an update on progress that was occurring to that end including the bill introduced by Congressman Aderholt, and a plea for more time so that the bill could move through Congress. On Tuesday June 24th, the site was visited by Randy Johnson, the Surface Mining Commissioner, Nick Tew, the newly appointed State Geologist and head of the Geological Survey of Alabama, and Jim Griggs (Fig. 8), the Director of the State Lands Division of the Alabama Department of Conservation and Natural Resources. Billy Orick, the permit manager from the New Acton Coal Mining Company was also in attendance as well as Prescott and Ron.

It was a sunny morning, and the group walked around the site finding several nice sets of tracks during the excursion. Afterwards they met at Uncle Mort's, a nearby restaurant, to discuss the possibility of preserv-

ing the site and the steps that would have to be taken. The APS had come to realize that an essential component of the preservation effort had to be a governmental agency that could accept it in perpetuity. Although the U.S. Department of the Interior had been considered, the most logical agency was the Alabama State Department of Conservation and Natural Resources, and so it was fortunate that Jim Griggs had been impressed by what he had seen at the site. He was a former attorney for the Geological Survey of Alabama and had a particular appreciation for the unique nature of the Union Chapel Mine fossils. What he could do towards preserving the site was unclear to those outside his office, but seeds had been planted that day that eventually bore fruit.

In late July 2003, the New Acton Coal Mining Company received a letter from the Surface Mining Commission informing them that time had run out and that reclamation must begin immediately. Billy Orick telephoned Prescott to inform him that APS access to the site was being withdrawn and that bulldozers would begin reclamation the following week. Although the company filed an appeal, all seemed lost. The attorneys agreed that an appeal might slow the order for reclamation but eventually would be denied because the law was clear. Prescott sent out a desperate email to everyone who had ever been involved in the preservation effort informing them of the end of the campaign but not really expecting anyone to offer any ideas for a last minute reprieve.

It was at this dismal point that Andy Rindsberg did something that galvanized the press, and they came riding in to the rescue. Everyone loves to read about an impending disaster — even on such a miniature scale — and the press took real notice of what was happening. When Andy put a notice of the impending doom of the fabulous fossil site on the Paleonet, Vertebrate Paleo, and Skolithos listservs, suddenly calls began coming in from big news organizations. It turned out that many of the bigger news media groups were monitoring the paleontology listservs for interesting news items. *USA Today* ran two stories, one quite extensive. *Science*, the premier scientific journal in America, ran a story in its *News and Views* section. *Geotimes*, the magazine published by the American Geological Institute, also ran an article. Perhaps the most helpful was a series of three front page articles by Ed Howell in the Jasper paper, *The Daily Mountain Eagle*. These voices, together with other articles and editorials in *The Birmingham News*, *The Huntsville Times*, and *The Tuscaloosa News*, won us a reprieve. In its August meeting, which also was attended by representatives from the County Commissioner's office and the Jasper office of Congressman Aderholt, the Surface Mining Commission decided that reclamation could be placed on hold until the company's appeal could be reviewed by an attorney from the Surface Mining Office in Birmingham.

On February 14, 2004, on a beautiful Saturday morning, Prescott and Steve visited the Union Chapel Mine for a morning of collecting. The fate of the mine was still unclear, but the two decided to enjoy what might be one of the last days collecting there. Although the

day was predicted to have showers, it was surprisingly sunny, and they passed a magical morning finding some spectacular trackways in the bright slanting winter rays of the sun. They also met with John Southard, the local neighboring landowner, and chatted at length with him at his breakfast table about the secrets of making homemade sauerkraut, and he sent them home with gifts from his pantry of home-canned vegetables. In less than a week, Steve suffered a fatal fall in his home in Anniston. At the time of his death, he had been busily planning a trip to Albuquerque to take Spencer Lucas a large sample of Union Chapel Mine fossils, a donation that he felt would spread the fame of the Union Chapel fossils far and wide. Steve's energy and imagination had been a driving force in the preservation effort, and the loss of his friendly smile and intellectual vigor was a shattering blow to his friends in the APS.

During the next three months, the machinery of the Department of Conservation and Natural Resources that had been set in motion by Jim Griggs, the Director of the State Lands Division, began to play a role in the gathering momentum to preserve the site. Over the months since he had visited the site, Mr. Griggs had quietly put in place the needed funds to assure eventual reclamation if the pending legislation failed to pass. In the spring of 2004, a meeting was convened at the Surface Mining Commission's office in Jasper. Present were the Surface Mining Commission's attorney Milton McCarthy, Prescott Atkinson representing the APS, company officials and their attorney, and the State Lands Division attorney. The State Lands Division agreed to take the site under its protection. However, a potential deal-killing complication had arisen. Before the BPS had made its intentions clear regarding a preservation effort, Mrs. Reid, the original owner of the New Acton Coal Mining Company, had signed a contract with a local land owner, to sell him the property after reclamation. It was agreed that some way to purchase his rights to the land would have to be found in order for the transfer to the State to take place. A lengthy series of negotiations ensued over the next three months, and eventually the landowner agreed to sell his rights to purchase the property for \$30,000. The purchase price was divided equally among the Company, the State, and private donations, which Prescott agreed to raise.

So it was that on June 18, 2004, the property known as the Union Chapel Mine passed into the keeping of the State of Alabama. A camel had been successfully passed through the eye of a needle. The book would not close on the Union Chapel Mine fossils. A new chapter, the first of many, had begun.

*Addendum:* In late July 2004, in honor of Steve's planned trip to New Mexico, Ron and Prescott drove a rental truck loaded with almost 200 Union Chapel Mine trackways, all duly photographed and indexed, as a donation to the New Mexico Museum of Natural History where the specimens joined the largest Permian trackway collection in North America and would serve as a resource for visiting scholars from around the world. This is only a small fraction of the specimens donated to museums by the collectors. Three large collections have also been established in Alabama, based on donations

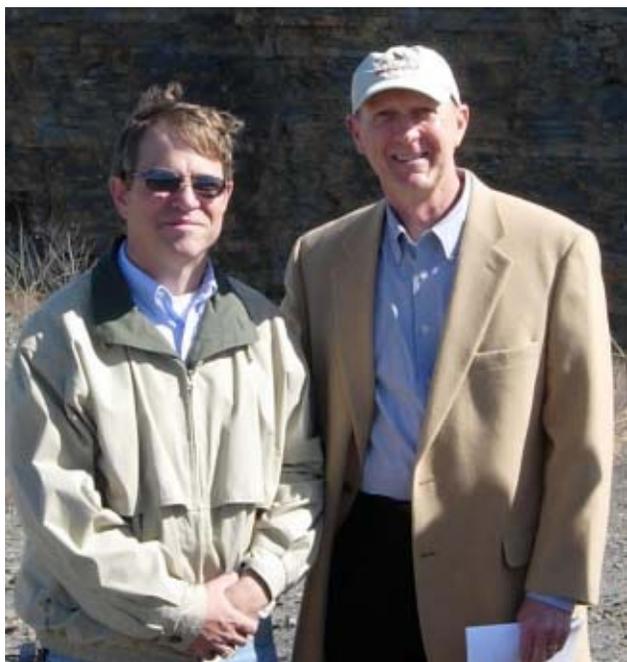


FIGURE 8. Jim Griggs (right), Director of the State Lands Division of the Alabama Department of Conservation and Natural Resources, and Prescott Atkinson pose before the dedication ceremony for the Steven C. Minkin Paleozoic Footprint Site. Photo credit: Ron Buta.

by Steve and others to the Alabama Museum of Natural History, the Anniston Museum of Natural History, and the McWane Science Center in Birmingham, Alabama. On March 12, 2005 the State Lands Division of the Alabama Department of Conservation and Natural Resources formally dedicated the Union Chapel Mine as the *Steven C. Minkin Paleozoic Footprint Site* (Figs. 8, 9).

#### ACKNOWLEDGMENTS

The APS is grateful to all those who helped make the preservation of the Union Chapel Mine a success: Congressman Robert Aderholt, Claire Bourne, Pete Conroy, Jim Griggs, Bruce Hamrick, Bill Harris, Hartmut Haubold, Ed Hooks, Ed Howell, Paul Housel, Wendy Allen Jackson, Randy Johnson, Paul Kennedy, James Lowery, Spencer Lucas, Jerry and Pearl MacDonald, Tony Martin, Milton McCarthy, Billy Orick, Nick Pyenson, Dennis Reid, Dolores Reid, Andrew K. Rindsberg, Berry H. (Nick) Tew, and Kathy Twieg. The following Institutions helped to preserve the site: the Alabama Museum of Natural History, the Anniston Museum of Natural History, the Geological Survey of Alabama, the Alabama Surface Mining Commission, and the Alabama Department of Conservation and Natural Resources. The APS is also grateful to all the trackway collectors who came together for the track meets and made the database available to the world. The authors wish to thank James Lowery, Rita Lueth and Andrew K. Rindsberg for their critical readings of the manuscript, and Andrew K. Rindsberg for a prelimi-

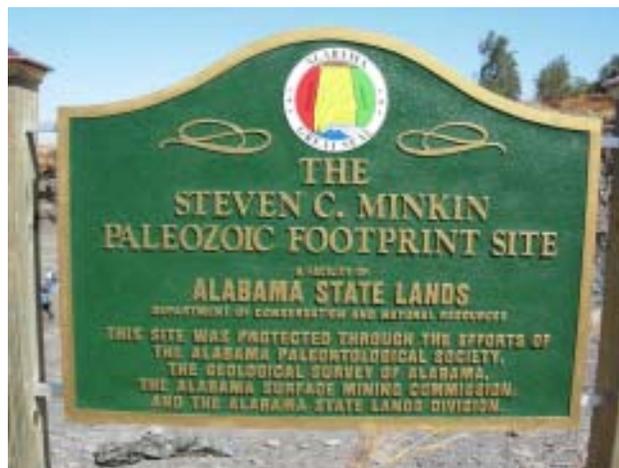


FIGURE 9. The sign dedicating the Union Chapel Mine as the Minkin Paleozoic Footprint Site, erected March 12, 2005. Photo credit: Ron Buta.

nary compilation of Union Chapel Mine articles.

#### BIBLIOGRAPHY OF UNION CHAPEL MINE NEWS ARTICLES

- Anderson, J., 2003, Law could cause rare fossil discovery to be lost to science: *The Huntsville Times*, November 2.
- Associated Press, 2004, Alabama agrees to buy acclaimed fossil site: *The Tuscaloosa News*, July 2.
- Associated Press, 2005, Fossil hunters will convene at dedication of prehistoric site: *The Tuscaloosa News*, March 12.
- Associated Press, 2005, Fossil hunters convene today at dedication of coal age site: *The Daily Mountain Eagle*, March 12.
- Atkinson, P., 2004, "This is a happy day...", quote: *The Birmingham News*, July 2.
- Bhattacharjee, Y., 2004, Saving ancient footprints. *Science*: 305, 473, July 23.
- Bourne, C., 2003, Major preservation effort digs in: *USA Today*, August 19.
- Bryant, J. D., 2000, Taking steps back in time: *The Crimson White*, August 25.
- Buta, R., 2003, Coal Mine should be preserved: *The Tuscaloosa News*, November 25 (response to November 17 editorial)
- DeWitt, R., 2000, Historical specimens represent one of state's largest finds: *The Tuscaloosa News*, August 20.
- Faulk, K., 2002, Ancient stories in stone face extinction: *The Birmingham News*, July 15.
- Faulk, K. 2004, Fossil-rich coal mine site saved from reclamation: *The Birmingham News*, July 2.
- Howell, E. 2003, Old mine one of world's best windows to the Coal age: *The Daily Mountain Eagle*, June 18.
- Howell, E., 2003, Mine shows county 300 million years ago: *The Daily Mountain Eagle*, June 19.
- Howell, E., 2004, Effort to preserve fossil find at local site may end: *The Daily Mountain Eagle*, February 16.
- Sever, M., 2003, Mine reclamation threatens tracksite: *Geotimes*, October.
- Spencer, T., 2000, Fossil hunters follow tracks to distant past: *The Birmingham News*, August 20.
- Spencer, T., 2003, Fossil-filled coal mine threatened: Activists try to save world-renowned site. *The Birmingham News*, June 5.
- Spencer, T. 2005, Walker fossils called rock-solid: *The Birmingham News*, July 2.

- ham News, March 11.
- Stokstad, E., 2003, Ancient trackways in strip mine threatened by reburial: *Science*, v. 301, p. 746, August 8.
- Toner, M., 2003, Ancient footprints in peril. Mine reclamation may bury history: *The Atlanta-Journal Constitution*, September 9.
- Tuscaloosa News, 2003, Natural resources not being protected: Editorial, November 17.
- Tuscaloosa News, 2004, Saving the past for the future: Editorial, July 4.
- USA Today, 2003, State news note: June 6.
- USA Today, 2003, Filling of Alabama coal mine endangers key fossil field: Short story, July 31.

for field trip VI, Southeastern Section, Geological Society of America. Tuscaloosa, Geological Survey of Alabama, p. 82-95.

#### AUTHORS' E-MAIL ADDRESSES

T. Prescott Atkinson: patkinson@peds.uab.edu  
 Ronald J. Buta: rbuta@bama.ua.edu  
 David C. Kopaska-Merkel: davidkm@gsa.state.al.us

#### REFERENCES

- Allen, A., 2005, Discovery of the Union Chapel Mine site; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 15-17.
- Buta, R. J., Kopaska-Merkel, D. C., Rindsberg, A. K., and Martin, A. J., 2005, Atlas of Union Chapel Mine invertebrate trackways and other traces; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 277-337.
- Dilcher, D., Lott, T. A., and Axsmith, B. J., 2005, Fossil plants from the Union Chapel Mine, Alabama; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 153-168.
- Haubold, H., Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, Atlas of Union Chapel Mine vertebrate trackways and swimming traces; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 207-276.
- Lacefield, J. A. and Relihan, B. R., 2005, The Significance of the Union Chapel Mine Project to Alabama Paleontology; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 201-204.
- Martin, A. J., ed., 2003, Workshop on Permo-Carboniferous ichnology, program and abstracts: University of Alabama, Tuscaloosa.
- Martin, A. J. and Pyenson, N. D., 2005, Behavioral significance of vertebrate trace fossils from the Union Chapel site; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 59-73.
- Minkin, S. C., 2000, Pennsylvanian vertebrate trackways, Walker County, Alabama: *Alabama Geological Society Newsletter*, v. 13 (4), p. 7-10.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 39-58.
- Rindsberg, A. K., 1990, Freshwater to marine trace fossils of the Mary Lee Coal zone and overlying strata (Westphalian A), Pottsville Formation of northern Alabama; in Gastaldo, R. A., Demko, T. M. and Liu, Y., eds., *Carboniferous coastal environments and paleocommunities of the Mary Lee Coal zone, Marion and Walker counties, Alabama. A guidebook*

## THE SIGNIFICANCE OF THE UNION CHAPEL MINE PROJECT TO ALABAMA PALEONTOLOGY

JAMES A. LACEFIELD<sup>1</sup> and BRUCE A. RELIHAN<sup>2</sup>

<sup>1</sup>Adjunct Professor of Biology and Earth Science, University of North Alabama, Florence, Alabama 35632, USA

<sup>2</sup>3216 Daphne Lane, Hoover, Alabama 35216, USA

**ABSTRACT:** The collection and cataloging of fossil trackway material from the Union Chapel Mine has provided a unique opportunity for the professional and amateur paleontological communities of Alabama to share in a scientifically significant undertaking. The UCM site has now been recognized as one of the most important Upper Carboniferous ichnofossil locales in North America. Determined efforts by members of the Alabama Paleontological Society to salvage the mine's rich and taxonomically diverse fossil vertebrate and invertebrate trackways before the impending reclamation of the site has resulted in a treasure trove of material that should provide important insights into the paleoecology of Coal Age Alabama for many years to come. The loss to science of fossil trackway material collected from Pennsylvanian sites in Alabama prior to the Union Chapel Mine preservation efforts stands in stark contrast to the success of the the Union Chapel Mine project. The ongoing planning to organize future use of the mine site for scientific study and educational purposes offers yet another opportunity for these diverse amateur, educational, and professional groups to combine efforts in a cooperative project of great significance to the scientific community and the state.

### INTRODUCTION

The collection and documentation of preserved trackways and other fossil material from the Union Chapel Mine by the Alabama Paleontological Society (APS), Inc. (formerly called the Birmingham Paleontological Society) during 1999-2005 has promoted the development of a unique partnership between the professional and amateur paleontological communities in Alabama. While cooperative efforts between amateurs and professionals are not unusual, and indeed have been an important part of paleontology since the discipline first became a science late in the 18th century, this particular association has many unique qualities about it. It is common practice for museums or other paleontological organizations to enlist the help of amateurs to carry out field work in excavations of paleontological sites, but it is unusual for amateurs to constitute the major driving force in the discovery and preservation of a new and potentially important site through actively soliciting the services of paleontological professionals.

The task of salvaging the exceptional fossil material from the Union Chapel Mine before its mandated reclamation was undertaken by members of the APS, who recognized the potential scientific value of the material they had uncovered at the site. The group saw early in their exploration of the mine that a major ethical and scientific responsibility facing them lay in determining how best to announce the site's discovery, assess the quality of fossils, and properly catalog the large body of accumulated fossil material. The inherent danger in any amateur exploitation of a significant fossil site lies in the potential for loss of important material into private collections before systematic study of the collected items is implemented. The loss to science resulting from significant fossil material disappearing into private collections before adequate evaluation by mem-

bers of the scientific community over the years has undoubtedly been enormous. Usually the task of preservation of an important fossil site is undertaken by professional paleontologists or personnel working with an established museum. The unique attribute of the UCM project lies in the fact that the major impetus toward recognition and preservation of the site has come from responsible action taken by amateurs.

Recognizing the importance of immediate and thorough documentation of the fossil material, members of the APS developed a method of systematically identifying and cataloguing the fossil trackways through hosting a series of "track meets" (Fig. 1; see also Buta and Minkin, 2005) held at different locations within the state. All noteworthy fossil material collected at the mine by members of the group was amassed for the purpose of cataloguing through identification number, identity of collector, location of temporary museum repository or private collection, and for the creation of a photographic database. Since the Alabama Museum of Natural History, the site of the first of these "track meets," had storage space for only a small portion of the thousands of fossil trackways salvaged from the mine, it was necessary to rely on private collectors to serve as temporary repositories for most of the trackway slabs. Prompt cataloguing and photographic documentation was seen by the group as the most viable method of ensuring that potentially significant material was made accessible to paleontological specialists and not placed prematurely out of scientific reach in uncataloged private collections. Researchers from a number of relevant fields of study were invited to these "track meets" to examine the fossil material as it was being catalogued and photographed. The APS members who organized the events anticipated that the large volume of fossil material displayed and the exceptional quality of preservation would likely prompt scientific professionals who attended the events



FIGURE 1.

to consider conducting research into various aspects of the material.

#### **FOSSIL TRACK COLLECTION IN WALKER COUNTY IN THE YEARS PRIOR TO THE UNION CHAPEL MINE PROJECT**

The success of the Union Chapel Mine preservation project stands in stark contrast to the fate of fossil vertebrate trackway material collected from the Black Warrior Basin of Alabama in the years just prior to the discovery of the UCM site. During the early to mid-1990s the first author of this essay was involved with similar recovery efforts of fossil trackway material from several mine sites in Walker County. As with the Union Chapel Mine project, attempts were made at these sites to salvage fossil trackway material before impending reclamation of the mine areas.

The first of these fossil track sites was an abandoned coal strip mine covering approximately ten acres near the community of Kansas, Alabama. During searches for fossil plant material at the unreclaimed mine, several sets of fossil trackways were found preserved in a distinctive, buff-colored, fine-grained sandstone facies. These track sets included tetrapod vertebrate prints, tracks of millipede-like creatures, and numerous traces thought to have been produced by insect larvae. The abandoned mine site was visited by a small group of collectors during the winter of 1992-93 for the purpose of searching for further trackway material. All members of the geology faculty of the University of North Alabama at the time accompanied the senior author in these collecting excursions. Graduate and undergraduate students also assisted in the search for fossil track material on several occasions. Attempts to engage paleontologists from the Alabama Museum of Natural History and the University of Alabama in the task of collection and identification of this trackway material were unsuccessful. Many of the less distinct track sets were discarded due to lack of appropriate storage space at the University of North Alabama. The best of the track sets were placed behind glass in a hallway exhibit on

Alabama Coal Age fossils in the geology department at the university. A small number of track slabs were set aside by this author for possible later study. These included a sampling of well-preserved primary tracks of vertebrate creatures later identified by Professor Haubold (Haubold et al., 2005) as those of *Notalacerta missouriensis* (Fig. 2), produced by a probable anapsid-type amniote animal.

A second fossil trackway site was discovered during the mid-1990s that was even richer in material than the Kansas track site. A University of North Alabama geology department collecting trip to the Cedrum Mine, operated by the Drummond Coal Company near the community of Townley in Walker County, led to the discovery of a number of fossil trackways. Many hundreds of track sets were eventually found, but most were of invertebrate creatures such as horseshoe crabs and millipedes. On three occasions collecting trips were organized to allow students and UNA faculty to participate in this collection of fossil trackways, as well as to gather specimens of the abundant fossil plant material found at the mine. In addition to the UNA geology faculty involved with track collecting at this site, two members of the UNA Biology faculty and two members of the UNA Chemistry Department accompanied the groups. Few vertebrate trackways were taken during this period of exploration at the Cedrum Mine, but several examples of *Cincosaur*-type prints were collected by this author

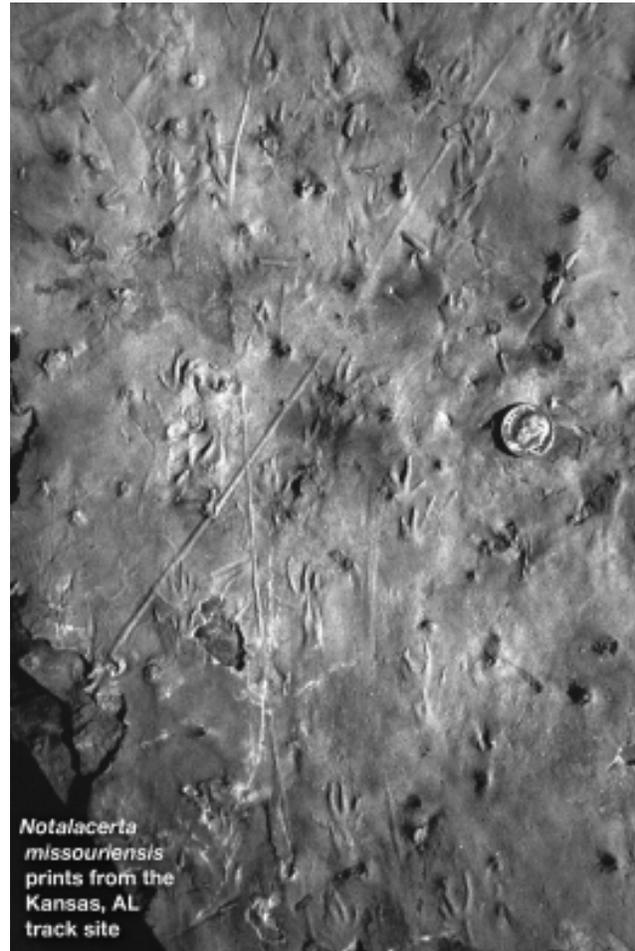


FIGURE 2.

near the far western end of the Cedrum Mine, where it bordered Yellow Jacket Road southeast of the town of Carbon Hill. The Cedrum Mine was an extensive excavation, covering several square miles, but only a small portion was examined for fossil trackways in the brief time the site was available for collecting.

Another abandoned mine area that produced fossil trackways in the years preceding the UCM discovery became known to collectors as the Fern Springs Mine, for its location on Fern Springs Road in far western Walker County. Active mining at this site had been completed several years previously, but it had not undergone reclamation due to the reported bankruptcy of the mining company involved. A number of vertebrate track sets were recovered from this location by the senior author and members of the APS over the course of several years. Fossil trackways later identified by Professor Haubold as those of *Notalacerta*, *Cincosaurus*, and two small, temnospondyl amphibians were taken from this mine site during this period of collection. Most track sets came from a light colored, fine-grained sandstone that lay stratigraphically above the Jagger coal seam. The track material had been strongly weathered from having been exposed for nearly ten years since the active mining at the site ceased, but the unreclaimed spoil piles were still producing recognizable track sets at the time of Professor Haubold's visit to the mine site in February of 2003 (Fig. 3). All of these three fossil track sites listed here have since been reclaimed.

The fate of fossil track material collected earlier from these Walker County sites offers a cautionary tale on the probable fate of the UCM material had the APS members not instituted their preservation efforts. During Professor Haubold's visit to Alabama in February of 2003 to study the UCM fossil material, an attempt was made to locate examples of trackway specimens collected at these older mine sites. Of the many dozens of fossil vertebrate trackways taken from the earlier Walker County sites during the 1990s, not a single track set outside of a handful kept by this author could be



FIGURE 3.

located for inspection by Professor Haubold during his visit. Reasons for the loss of these fossils were many. The UNA geology department had undergone major personnel changes since the tracks were first collected, students with some of the fossil track sets had graduated and left the area, and the department's display of the fossil trackways had been disassembled and the fossils discarded due to lack of storage space on campus. The loss of all these potentially significant fossil track sets collected prior to the UCM project highlights the importance of the APS members' preservation efforts. It is unlikely that any of this earlier material will re-surface with the necessary documentation that would allow them to have valid scientific context.

### THE FUTURE OF THE UNION CHAPEL MINE PROJECT

The initial phase of cooperative interaction between the professional paleontologists and the Alabama Paleontological Society was brought to fruition with the organization of a special *Workshop on Permo-Carboniferous Ichnology* that was held on the campus of the University of Alabama in May of 2003. At this workshop speakers presented papers on various aspects of the Union Chapel Mine and its ichnofauna, as well as on related topics of ichnology on a more general scale. These presentations were conducted by professional as well as by amateur paleontologists, and the diversity of workshop speakers and the topics on which they spoke symbolized well the unique spirit of cooperation that had been developed between the two groups.

The second important stage of cooperative effort related to the discovery and preservation of the fossil trackways from the Union Chapel Mine lies in the creation of this monograph, which summarizes the UCM project and its paleontological significance. Papers presented in this document include contributions from both research-level paleontologists as well as amateurs. Important developmental dynamics of the UCM project are described here by those most closely associated with the preservation efforts. The documentation of these efforts might provide a model for similar future successful preservation projects to be carried out elsewhere.

The most recent, and in many ways most important, task of the Union Chapel Mine project undertaken by APS members was to institute formal efforts to acquire the UCM site as a study area for future research. These efforts are chronicled in a separate paper (Atkinson et al., 2005). Members worked diligently to explore legal ways that the site might be saved from reclamation and preserved for future generations of researchers. After several years of uncertainty, these efforts finally succeeded in 2004 when the State of Alabama agreed to take possession of the mine site and preserve the unreclaimed portion for future scientific study as the Steven C. Minkin Paleozoic Footprint Site. The agreement by the State to accept responsibility for the site was unprecedented in the sense that no case of this kind had ever been ushered through the legislative and bureaucratic processes, let alone successfully.

It has been suggested that the Union Chapel Mine

might some day become the first publicly owned Alabama “paleopark”, an important paleontological site preserved solely for the purpose of ongoing research and education. While these efforts are not complete at the time of this writing (February, 2005), it is anticipated that a satisfactory arrangement can be finalized among all parties involved to dedicate the use of the site for these purposes. This final incarnation of the Union Chapel Mine project would certainly serve as a fitting culmination to the exceptional cooperative interaction that has taken place to bring about the recognition and development of this world-class Alabama Coal Age paleontological site.

### REFERENCES

- Atkinson, T. P., Buta, R. J. and Kopaska-Merkel, D. C., 2005, Saving the Union Chapel Mine: how a group of determined amateurs teamed up with professionals to save a world-class trackway site in Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 191-200.
- Buta, R. J. and Minkin, S. C., 2005, The salvaging and documentation of trace fossils from the Union Chapel Mine; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 19-27.
- Haubold, H., Allen, A., Atkinson, T. P., Buta, R. J., Lacefield, J. A., Minkin, S. C. and Relihan, B. A., 2005, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., *Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1*, p. 75-111.

### AUTHOR'S E-MAIL ADDRESS

James A. Lacefield: lacefiel@hiwaay.net

## **Part IV. Photographic Atlas of Union Chapel Mine Fossils**



# ATLAS OF UNION CHAPEL MINE VERTEBRATE TRACKWAYS AND SWIMMING TRACES

HARTMUT HAUBOLD,<sup>1</sup> RONALD J. BUTA,<sup>2</sup> ANDREW K. RINDSBERG,<sup>3</sup>  
and  
DAVID C. KOPASKA-MERKEL<sup>3</sup>

<sup>1</sup> Institute of Geological Sciences, Martin-Luther-University, Von-Seckendorff-Platz 3, D-06120 Halle, Germany

<sup>2</sup> Department of Physics and Astronomy, University of Alabama, Box 870324, Tuscaloosa, Alabama 35487, USA

<sup>3</sup> Geological Survey of Alabama, Box 869999, Tuscaloosa, Alabama 35486-6999, USA

This atlas is a compilation of 135 photographs of vertebrate trackway specimens (including parts and counterparts) and 28 fossil fish swimming traces salvaged from the Union Chapel Mine (Steven C. Minkin Paleozoic Footprint Site) in Walker County, Alabama, USA. Each specimen has a centimeter scale and is identified with a Union Chapel Mine (UCM) number followed by the initials of the collector (Table 1). All interpretations of vertebrate trackways are those of Haubold (Haubold et al., 2005), while interpretations of invertebrate traces and circular impressions on the same slabs are those of Rindsberg (Rindsberg and Kopaska-Merkel, 2005; Rindsberg, 2005). Plates 1-19 show examples of the small amphibian traces *Matthewichnus caudifer* and *Nanopus reidiai* n.sp. Plates 20-39 show examples of the large ichnospecies *Attenosaurus subulensis*. Plates 40-55 show examples of the amniote ichnospecies *Notalacerta missouriensis* and *Cincosaurus cobbi*. Finally, plates 56-63 show examples of the fish swimming trace *Undichna*. The atlas illustrates only a small fraction of the total number of slabs collected with vertebrate traces, which numbers over 1000. Tetrapod trackways and swimming traces from the Union Chapel Mine are discussed in detail by Haubold et al. (2005), Martin and Pyenson (2005), and Hunt et al. (2004, 2005). *Undichna* is discussed by Martin and Pyenson (2005). Table 2 provides an index of the illustrated specimens.

TABLE 1. Index to Collectors and Vertebrate Ichnotaxa

Code	Description
COLLECTORS	
AA	Ashley Allen
TPA	T. Prescott Atkinson
DA	David Ausmus
GB	Gerald Badger
RB	Ronald J. Buta
DC	David Claybourn
GD	Gary Dennison
EG	Enrique Gomez
DH	Daniel Hensley
JL	James A. Lacefield
BM	Bruce Minkin
SM	Steven C. Minkin
BR	Bruce A. Relihan
JT	Jay Tucker
GSA	Geological Survey of Alabama
VERTEBRATE ICHNOTAXA	
AS	<i>Attenosaurus subulensis</i>
CC	<i>Cincosaurus cobbi</i>
MC	<i>Matthewichnus caudifer</i>
NM	<i>Notalacerta missouriensis</i>
NR	<i>Nanopus reidiai</i>
UN	<i>Undichna</i> isp.

TABLE 2. Index to Illustrated Vertebrate Trace Fossil Specimens<sup>a</sup>

UCM No.	Collector	Plate No.	Taxon	UCM No.	Collector	Plate No.	Taxon
0002	SM	4B	NR	0281	AA	6A	NR
0004	SM	5A	NR	0285	AA	1A	MC
0011	SM	5B	NR	0287	AA	57A	UN
0017	SM	41A	CC	0300	AA	22B	AS
0018	SM	41B	CC	0302	AA	6B	NR
0024	SM	27A	AS	0312	AA	7A	NR
0025	SM	27A	AS	0313	AA	7B	NR
0060	GB	2B	NR	0318	AA	7C	NR
0064	DH	56C	UN	0331	AA	52C	CC
0067	RB	54A	CC	0357	AA	8B	NR
0068	RB	15A	NR	0364	AA	3A	NR
0071	RB	14A	NR	0447	TPA	8A	NR
0074	RB	56A	UN	0448	TPA	7D	NR
0076	TPA	9C	NR	0455	TPA	57D	UN
0076	TPA	10A	NR	0482	BR	51B	CC
0076	TPA	10B	NR	0507	DC	36B	AS
0076	TPA	10C	NR	0523	AA	19A	NR
0087	TPA	42A	CC	0553	RB	13C	NR
0093	TPA	56B	UN	0569	RB	39B	AS
0098	TPA	34B	AS	0571	DA	12A	NR
0124	JL	33B	AS	0624	TPA	6C	MC
0140	BR	3B	NR	0669	RB	17A	NR
0167	BR	4A	NR	0670	RB	50A	CC
0174	BR	43A	CC	0672	RB	50B	CC
0175	BR	43B	CC	0675	RB	50C	CC
0177	BR	3C	NR	0676	RB	18A	NR
0191	BR	2A	NR	0676	RB	18B	NR
0202	BR	22A	AS	0677	RB	18C	NR
0205	SM	23A	AS	0678	RB	57B	UN
0208	SM	44A	CC	0680	RB	17B	NR
0219	SM	23B	AS	0690	RB	54B	CC
0223	SM	40A	NM	0731	RB	58A	UN
0229	SM	40B	NM	0806	RB	63A	UN
0237	SM	44B	CC	0808	BM	9B	NR
0242	SM	24A	AS	0833	AA	8C	NR
0249	JT	11A	NR	0878	GD	14C	NR
0249	JT	11B	NR	0949	BR	12B	NR
0250	JT	45A	CC	0969	BR	1B	MC
0251	JT	45B	CC	0973	BR	9A	NR
0252	JT	46A	CC	0987	BR	63B	UN
0253	JT	46B	CC	0989	BR	57C	UN
0254	JT	45C	CC	1029	AA	58B	UN
0255	JT	47A	CC	1047	AA	58C	UN
0256	JT	47B	CC	1068	TPA	52B	CC
0257	JT	46C	CC	1074	TPA	20A	AS
0258	JT	48A	CC	1075	TPA	52A	CC
0259	JT	48B	CC	1088	TPA	14B	NR
0260	JT	49A	CC	1092	TPA	32B	AS
0261	JT	49B	CC	1093	TPA	28B	AS
0262	JT	49C	CC	1095	TPA	32A	AS
0270	AA	36C	AS	1096	TPA	42B	CC

TABLE 2 (cont.). Index to Illustrated Vertebrate Trace Fossil Specimens<sup>a</sup>

UCM No.	Collector	Plate No.	Taxon	UCM No.	Collector	Plate No.	Taxon
1142	TPA	16B	NR	1734	BR	60C	UN
1206	SM	24B	AS	1754	RB	21A	AS
1209	SM	40C	NM	1796	RB	21B	AS
1214	SM	38B	AS	1797	RB	13A	NR
1216	SM	25B	AS	1797	RB	13B	NR
1289	GSA	56D	UN	1798	RB	27B	AS
1300	EG	63D	UN	1814	DA	15B	NR
1304	GSA	63C	UN	1815	DA	55A	CC
1319	RB	39A	AS	1817	DA	31A	AS
1348	RB	59A	UN	1821	DA	16A	NR
1438	RB	26A	AS	1825	DA	51A	CC
1470	RB	25B	AS	1838	DA	15C	NR
1476	RB	53A	CC	1842	DA	55B	CC
1477	RB	53B	CC	1856	DA	5C	NR
1491	RB	28A	AS	1915	GB	38C	AS
1492	RB	28A	AS	1924	RB	37B	AS
1498	RB	26B	AS	2237	TPA	61A	UN
1589	TPA	16C	NR	2249	TPA	37A	AS
1621	TPA	29A	AS	2253	TPA	36A	AS
1622	TPA	30A	AS	2267	TPA	20B	AS
1623	TPA	33A	AS	2379	RB	29B	AS
1639	TPA	34A	AS	2380	RB	31B	AS
1679	TPA	60A	UN	2382	RB	62A	UN
1687	TPA	30B	AS	2446	RB	58D	UN
1692	TPA	38A	AS	2448	RB	59B	UN
1724	BR	19D	NR	2507	RB	19B	NR
1728	BR	60B	UN	2514	RB	19C	NR
1729	BR	59C	UN	2516	RB	62B	UN
1730	BR	62C	UN	2528	RB	35A	AS
1731	BR	61B	UN	2528	RB	35B	AS
1733	BR	61C	UN				

<sup>a</sup>Some specimens are tentatively assigned (cf.).

## REFERENCES

- Haubold, H., Allen, A., Atkinson, T. P., Buta, R. J., Laceyfield, J. A., Minkin, S. C. and Relihan, B. A., 2005, Interpretation of the tetrapod footprints from the Early Pennsylvanian of Alabama; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 75-111.
- Hunt, A. P., Lucas, S. G. and Lockley, M. G., 2004, Large pelycosaur footprints from the Lower Pennsylvanian of Alabama, USA: *Ichnos*, v. 11, p. 39-45.
- Hunt, A. P., Lucas, S. G., and Pyenson, N. D., 2005, The significance of the Union Chapel Mine site: a Lower Pennsylvanian (Westphalian A) ichnological Kozenrat-Lagerstätte, Alabama, USA; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 3-14.
- Martin, A. J. and Pyenson, N. D., 2005, Behavioral significance of vertebrate trace fossils from the Union Chapel site; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 59-73.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, *Treptichnus* and *Arenicolites* from the Steven C. Minkin Paleozoic Footprint site (Langsettian, Alabama, USA); in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 121-141.
- Rindsberg, A. K., 2005, Gas-escape structures and their paleoenvironmental significance at the Steven C. Minkin Paleozoic Footprint Site (Early Pennsylvanian, Alabama); in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian footprints in the Black Warrior basin of Alabama: Alabama Paleontological Society, Monograph no. 1, p. 177-183.

**AUTHORS' E-MAIL ADDRESSES**

Hartmut Haubold: haubold@geologie.uni-halle.de  
Ronald J. Buta: rbuta@bama.ua.edu  
Andrew K. Rindsberg: arindsberg@gsa.state.al.us  
David C. Kopaska-Merkel: davidkm@gsa.state.al.us

**SMALL AMPHIBIAN TRACKWAYS**

Ichnotaxa: *Matthewichnus caudifer*, *Nanopus reidiae*



Plate 1A. UCM 285 AA. *Matthewichnus caudifer*; trackway with undulating tail-mark.



Plate 1B. UCM 969 BR. *Matthewichnus caudifer*, with the invertebrate trace *Treptichnus apsorum* and a single fern pinnule.



Plate 2A. UCM 191 BR. *Nanopus reidiae*, undertracks, digits elongated; compare with other figured specimens UCM 2, 11, 140, 281, 447, 949.



Plate 2B. UCM 060 GB. *Nanopus reidiae*, paratype, with the invertebrate trace *Arenicolites longistriatus*.



Plate 3A. UCM 364 AA. *Nanopus reidiae*, paratype, trackway with tail-mark. Includes also the invertebrate trace *Treptichnus apsorum*.



Plate 3B. UCM 140 BR. *Nanopus reidiae*.



Plate 3C. UCM 177 BR. *Nanopus reidiae*.



Plate 4A. UCM 167 BR. *Nanopus reidia*.



Plate 4B. UCM 2 SM. *Nanopus reidia*.



Plate 5A. UCM 4 SM. *Nanopus reidiae*.



Plate 5B. UCM 11 SM. *Nanopus reidiae*.



Plate 5C. UCM 1856 DA. *Nanopus reidiae*.



PLate 6A. UCM 281 AA. *Nanopus reidiae*.



Plate 6B. UCM 302 AA. Cf. *Nanopus reidiae*, trackway displays short stride and undertracks; compared figured specimens UCM 318, 1797, and 1821.



Plate 6C. UCM 624 TPA. Cf. *Matthewichnus caudifer*.



Plate 7A. UCM312 AA *Nanopus reidia*, preserved with significant undertracks of manus and pes imprints; compare UCM 313, 357.



Plate 7B. UCM 313 AA. *Nanopus reidia*.



Plate 7C. UCM 318 AA. *Nanopus reidia*.



Plate 7D. UCM 448 TPA. *Nanopus reidia*.



Plate 8A. UCM 447 TPA. *Nanopus reidiae*.



Plate 8B. UCM 357 AA. *Nanopus reidiae*, with unidentified arthropod traces and *Treptichnus apsorum*.



Plate 8C. UCM 833 AA. Cf. *Nanopus reidiae*.



Plate 9A. UCM973 BR. *Nanopus reidiae*.



Plate 9B. UCM 808 BM. *Nanopus reidiae*.



Plate 9C. UCM 76 TPA. *Nanopus reidiae*, with the invertebrate trace *Treptichnus apsorum*. [To the right of the intersection of the two trackways, there is a large footprint made in later laminae — Rindsberg].



Plate 10A. UCM 76 TPA. Closeup of *Nanopus reidiae*.



Plate 10B. UCM 76 TPA. Closeup of *Nanopus reidiae*.



Plate 10C. UCM 76 TPA. Closeup of *Nanopus reidiae*.

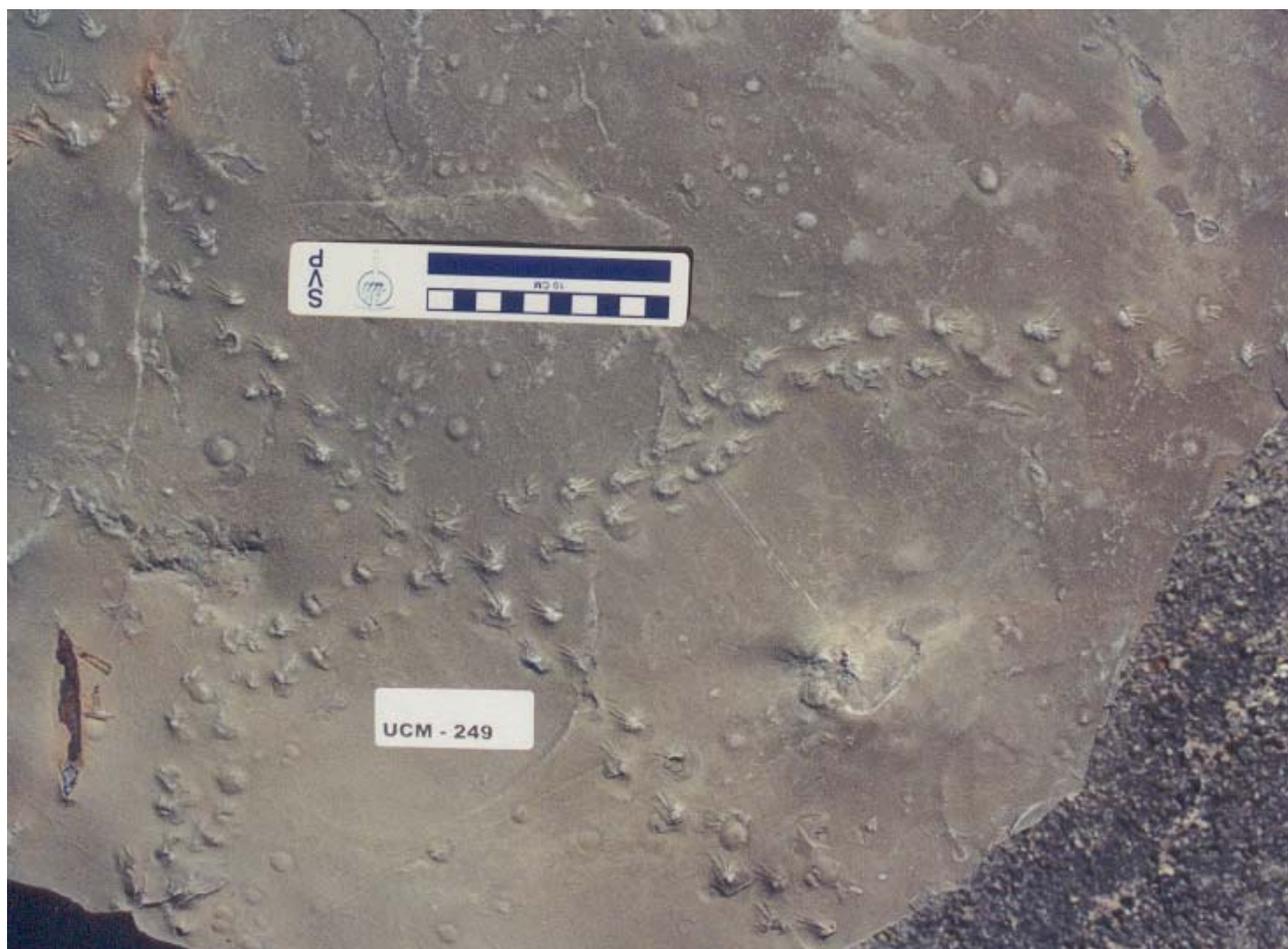


Plate 11A. UCM 249 JT. *Nanopus reidia*, with gas-escape structures.



Plate 11B. UCM 249 JT. Closeup of central intersection of two *Nanopus reidia*.

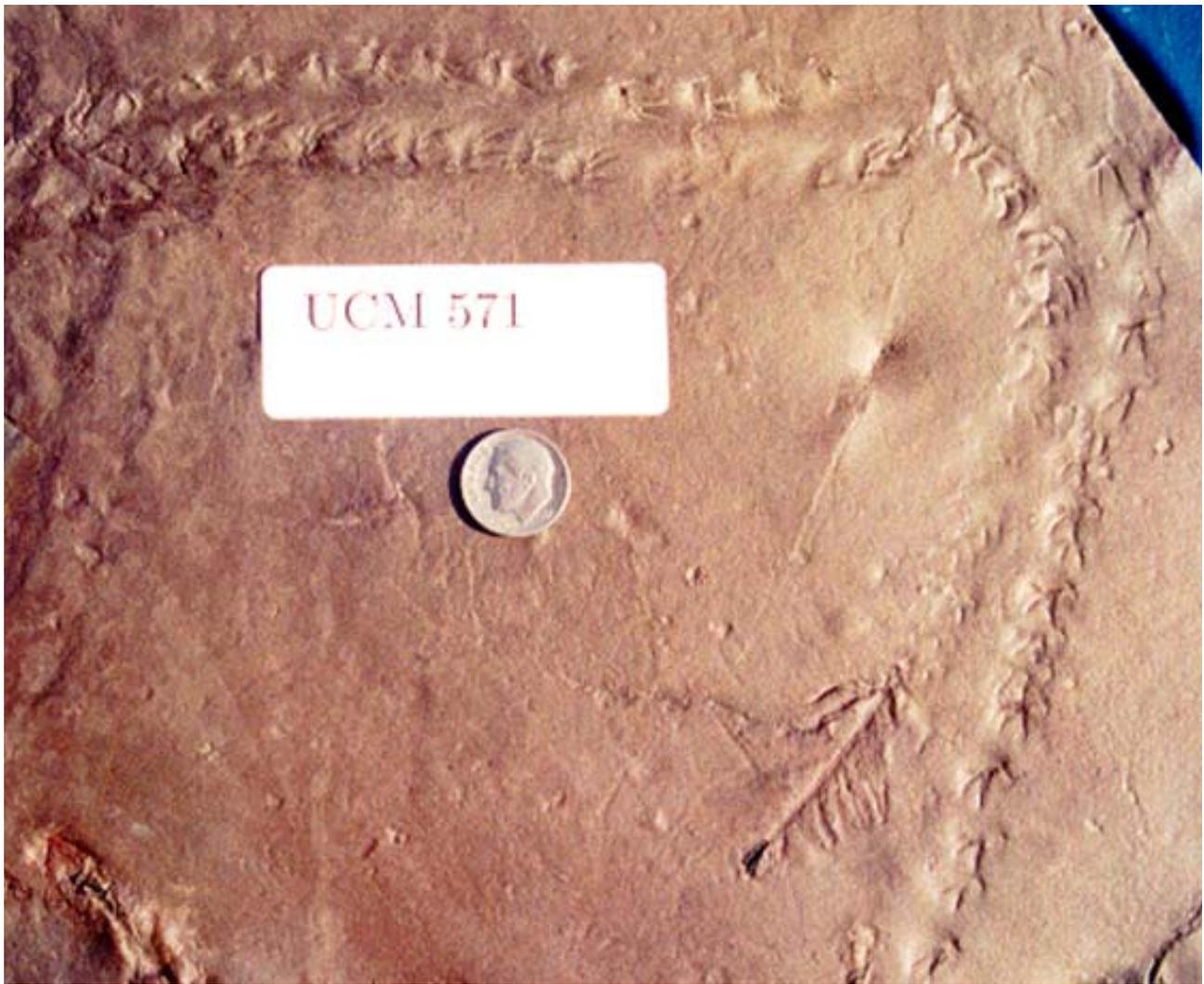


Plate 12A. UCM 571 DA. *Nanopus reidiae*.



Plate 12B. UCM 949 BR. *Nanopus reidiae*, compare page 81, Haubold et al. (2005).



Plates 13A,B. UCM 1797 RB. Cf. *Nanopus reidia* — both original (top, A) and clear undertrack (bottom, B). In B, two thin pieces of rock have been removed to reveal the undertrack.



Plate 13C. UCM 553 RB. Cf. *Nanopus reidia*, undertracks of a deeper level.



Plate 14A. UCM 71 RB. Cf. *Nanopus reidiae*, with unidentified possible invertebrate trace.



Plate 14B. UCM 1088 TPA. *Nanopus reidiae*.



Plate 14C. UCM 878 GD. Cf. *Nanopus reidiae*.

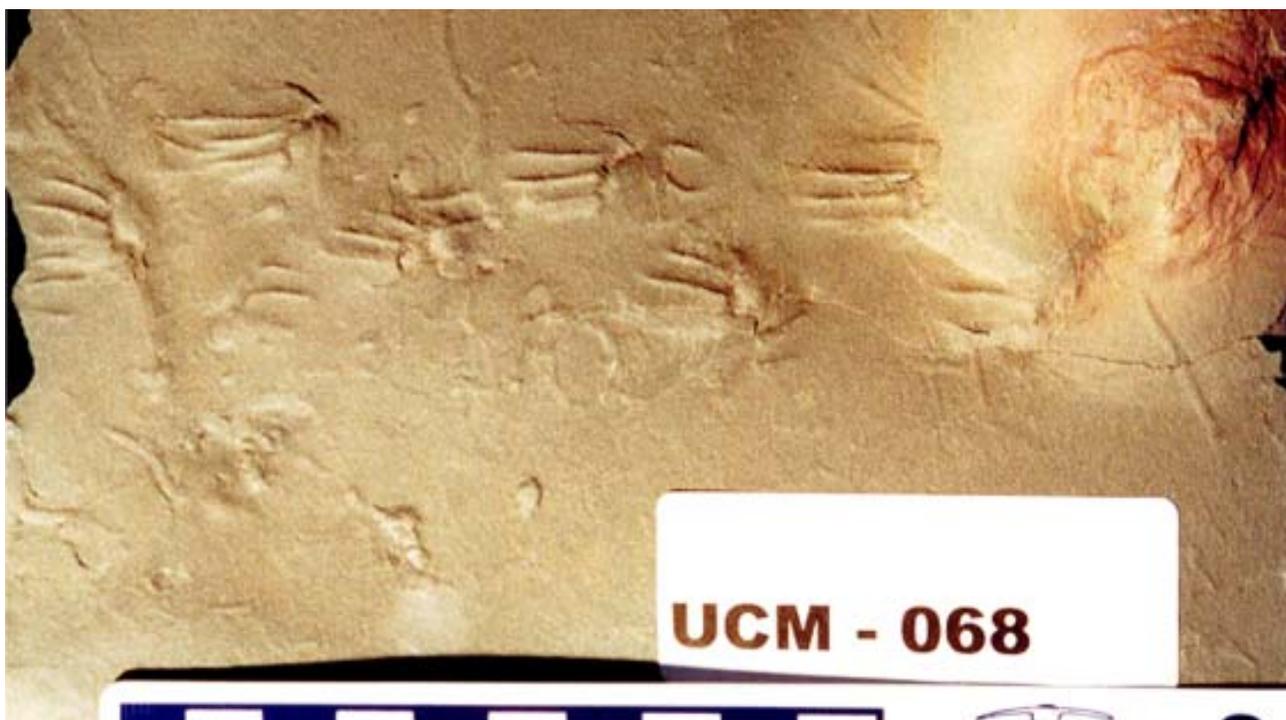


Plate 15A. UCM 68 RB. Cf. *Nanopus reidiae*.



Plate 15B. UCM 1814 DA. Cf. *Nanopus reidiae*, undertracks with outward curved digit imprints; compare UCM 833 AA.



Plate 15C. UCM 1838 DA. Cf. *Nanopus reidiae*, undertracks, mainly pes imprints.



Plate 16A. UCM 1821 DA. Cf. *Nanopus reidiae*, undertracks with short stride



Plate 16B. UCM 1142 TPA. *Nanopus reidiae*, holotype (see page 85, Haubold et al., 2005).



Plate 16C. UCM 1589 TPA. *Nanopus reidiae*.



Plate 17A. UCM 669 RB. Enigmatic situation, possible swimming traces with small amphibian tracks.



Plate 17B. UCM 680 RB. Trackway of *Nanopus reidia* with body trail and invertebrate traces.

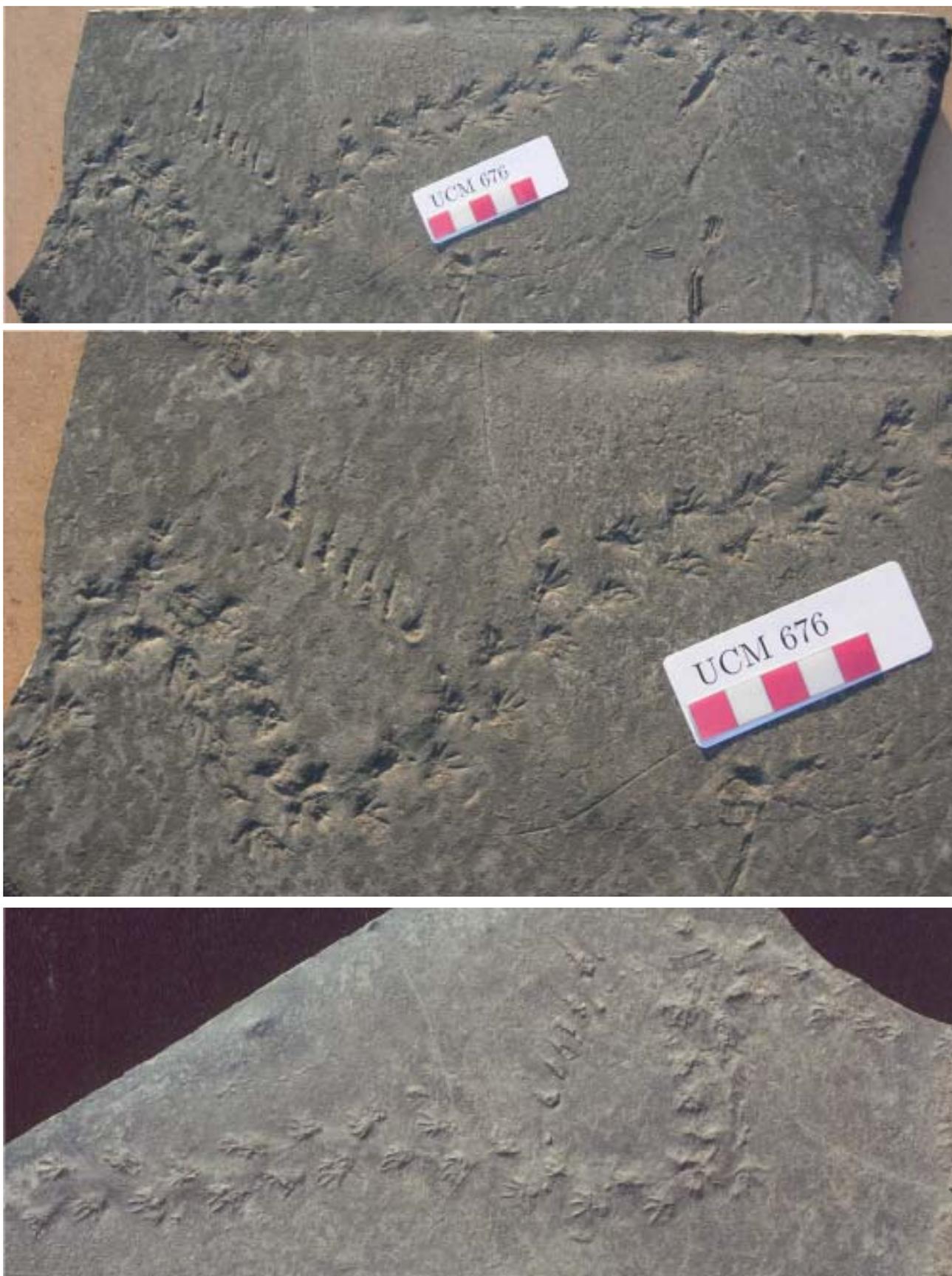


Plate 18ABC. UCM 676 (top, A; middle, B) and 677 (bottom, C) RB. Imprint and counterpart. Trackway of *Nanopus reidiae* with invertebrate trace (a partially buried xiphosuran; Martin and Pyenson, 2005). Excellent example of behavioral trackway.



Plate 19A. UCM 523 AA. Cf. *Nanopus reidiae*.



Plate 19B. UCM 2507 RB. Cf. *Nanopus reidiae*.



Plate 19C. UCM 2514 RB. Cf. *Nanopus reidiae*.



Plate 19D. UCM 1724 BR. Cf. *Nanopus reidiae*. Arthropod and tetrapod trackway on same slab.

**LARGE ANTHRACOSAUR TRACKS AND TRACKWAYS**  
Ichnotaxon: *Attenosaurus subulensis*



Plate 20A. UCM 1074 TPA. *Attenosaurus subulensis*, counterpart of UCM 645 TPA (see Haubold et al., 2005, page 94, Fig. 6A).



Plate 20B. UCM 2267 TPA. *Attenosaurus subulensis*.



Plate 21A. UCM1754 RB. *Attenosaurus subulensis*.



Plate 21B. UCM1796 RB. *Attenosaurus subulensis*, counterpart of right track in A.



Plate 22A. UCM 202 BR. *Attenosaurus subulensis*.



Plate 22B. UCM 300 AA. *Attenosaurus subulensis*.



Plate 23A. UCM 205 SM. *Attenosaurus subulensis*, imprint and counterpart.



Plate 23B. UCM 219 SM. *Attenosaurus subulensis*.



Plate 24A. UCM 242 SM. *Attenosaurus subulensis*.



Plate 24B. UCM 1206 SM. *Attenosaurus subulensis*.



Plate 25A. UCM 1216 SM. *Attenosaurus subulensis*. The invertebrate traces *Treptichnus apsorum* and *Arenicolites longistriatus* are also present.



Plate 25B. UCM 1470 RB. *Attenosaurus subulensis*.



Plate 26A. UCM 1438 RB. *Attenosaurus subulensis*.

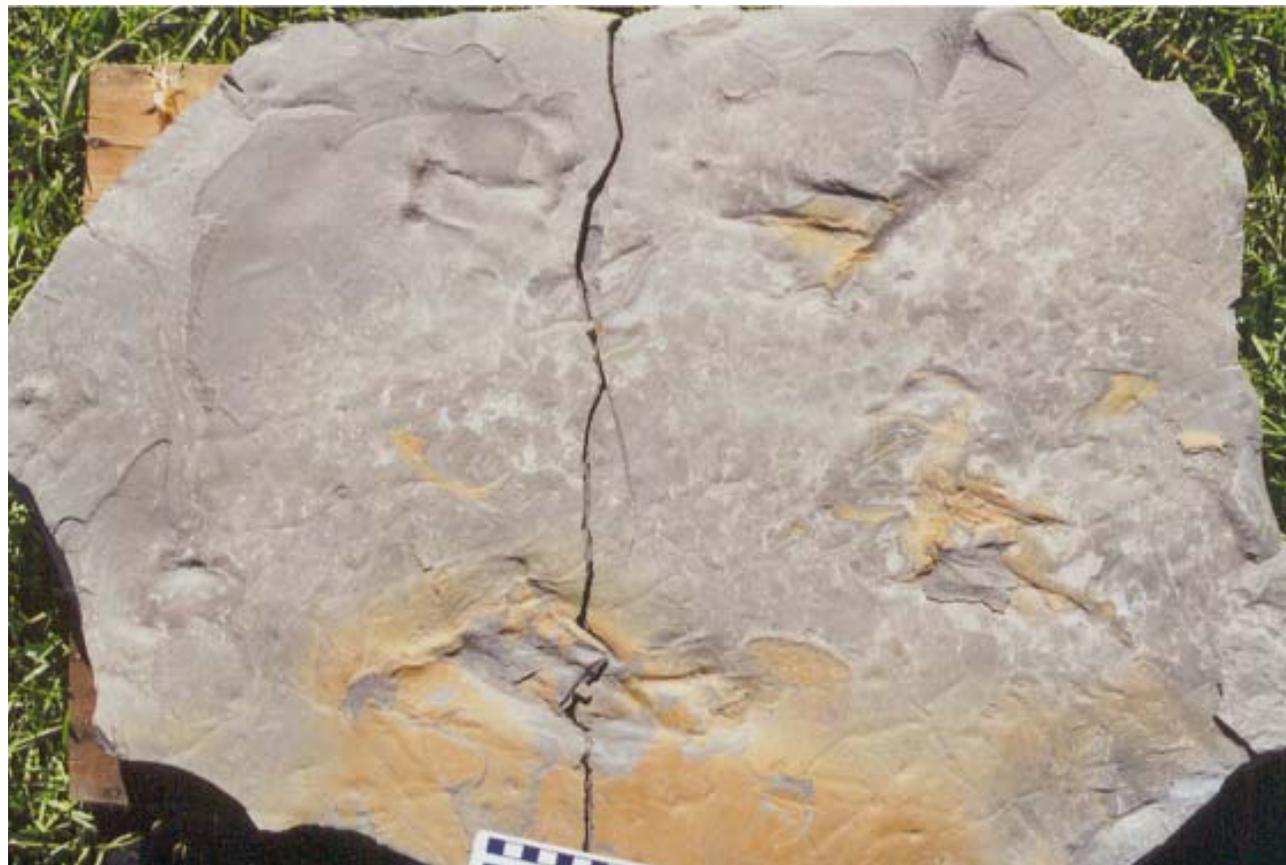


Plate 26B. UCM 1498 RB. *Attenosaurus subulensis*.



Plate 27A: UCM 24/25 SM. *Attenosaurus subulensis*, holotype of “*Alabamasauripus*” (see comment on p. 93 of Haubold et al., 2005).



Plate 27B. UCM 1798 RB. *Attenosaurus subulensis*.



Plate 28A. UCM 1491 and 1492 RB, imprint and counterpart. *Attenosaurus subulensis*.

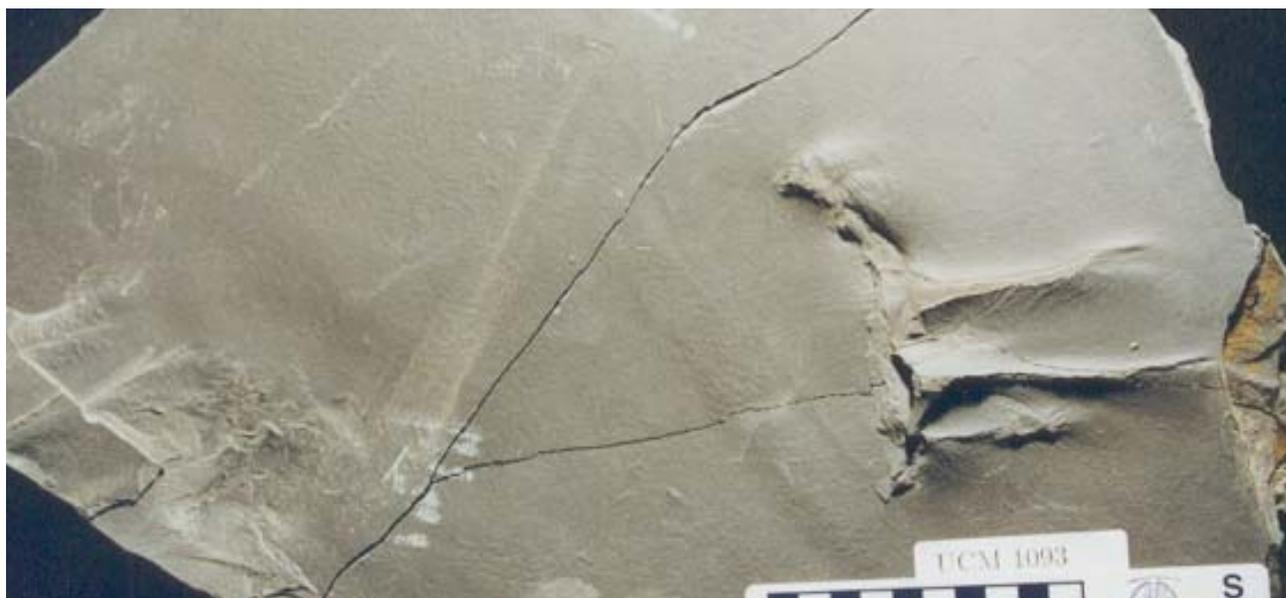


Plate 28B. UCM 1093 TPA. *Attenosaurus subulensis*.

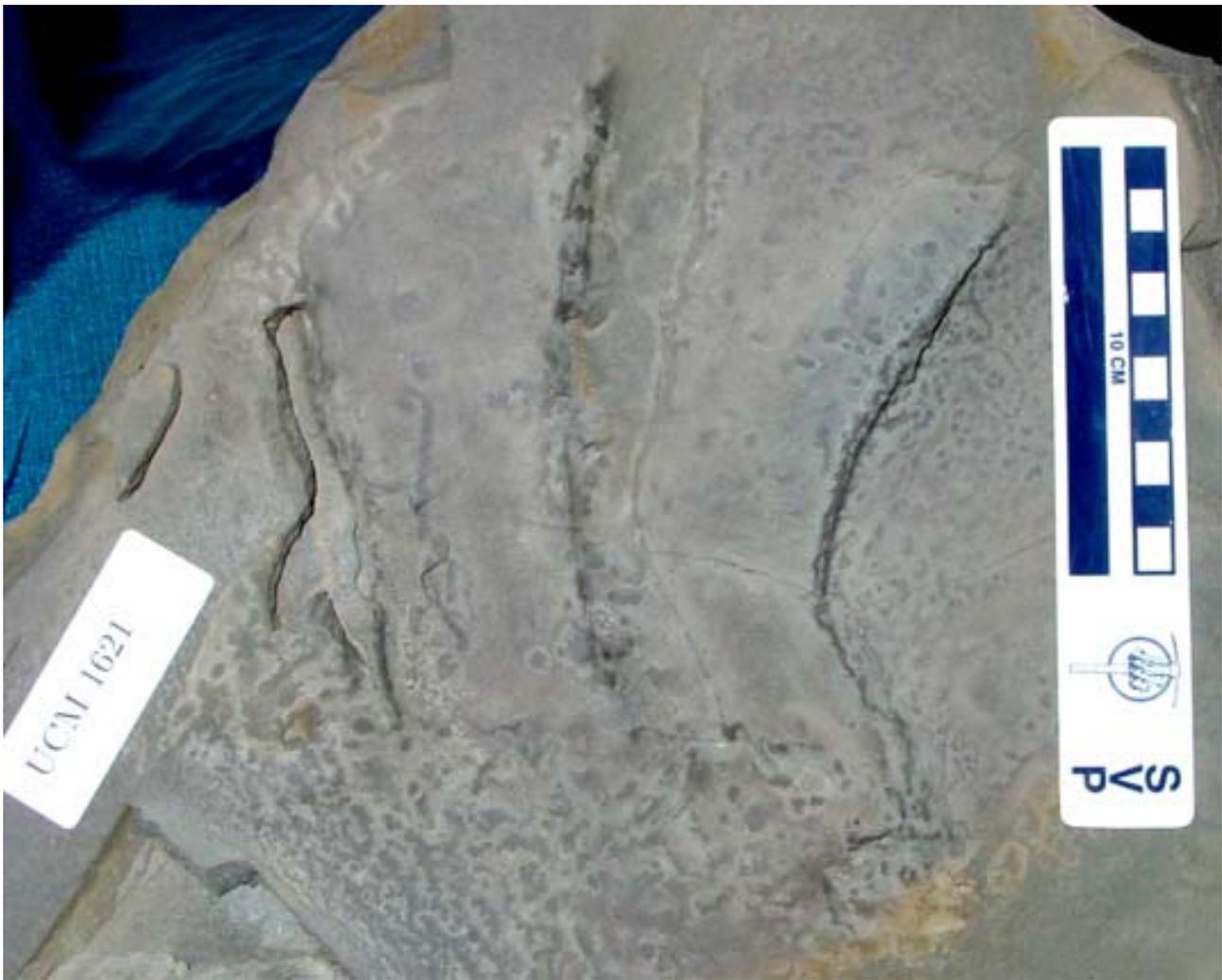


Plate 29A. UCM 1621 TPA. *Attenosaurus subulensis*, the largest track found at the Union Chapel Mine.



Plate 29B. UCM 2379 RB. *Attenosaurus subulensis*.



Plate 30A. UCM 1622 TPA. *Attenosaurus subulensis* (counterpart of UCM 1621, plate 29A, the largest track found at the Union Chapel Mine).



Plate 30B. UCM 1687 TPA. *Attenosaurus subulensis*.



Plate 31A. UCM 1817 DA. *Attenosaurus subulensis*.



Plate 31B. UCM 2380 RB. *Attenosaurus subulensis*.

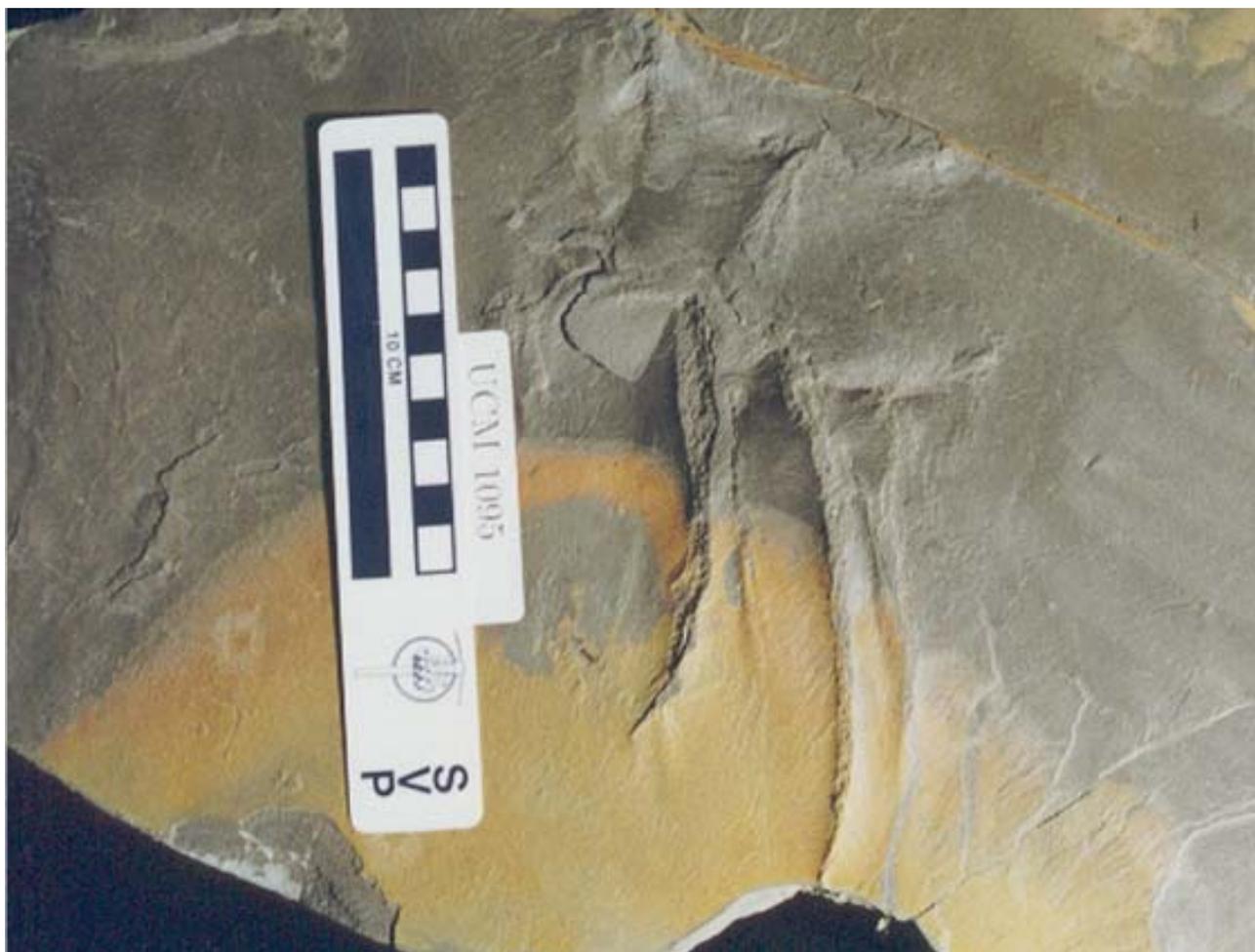


Plate 32A. UCM 1095 TPA. *Attenosaurus subulensis*.



Plate 32B. UCM 1092 TPA. *Attenosaurus subulensis*.



Plate 33A. UCM 1623 TPA. *Attenosaurus subulensis*.



Plate 33B. UCM 124 JL. *Attenosaurus subulensis*.



Plate 34A. UCM 1639 TPA. *Attenosaurus subulensis*.



Plate 34B. UCM 98 TPA. *Attenosaurus subulensis*.



Plate 35A. UCM 2528 RB. *Attenosaurus subulensis*, single track on same plane as invertebrate trail at upper right (see also plate 110C).



Plate 35B. UCM 2528 RB, closeup of single track, *Attenosaurus subulensis*.



Plate 36A. UCM 2253 TPA. *Attenosaurus subulensis*.



Plate 36B. UCM 507 DC. *Attenosaurus subulensis*.

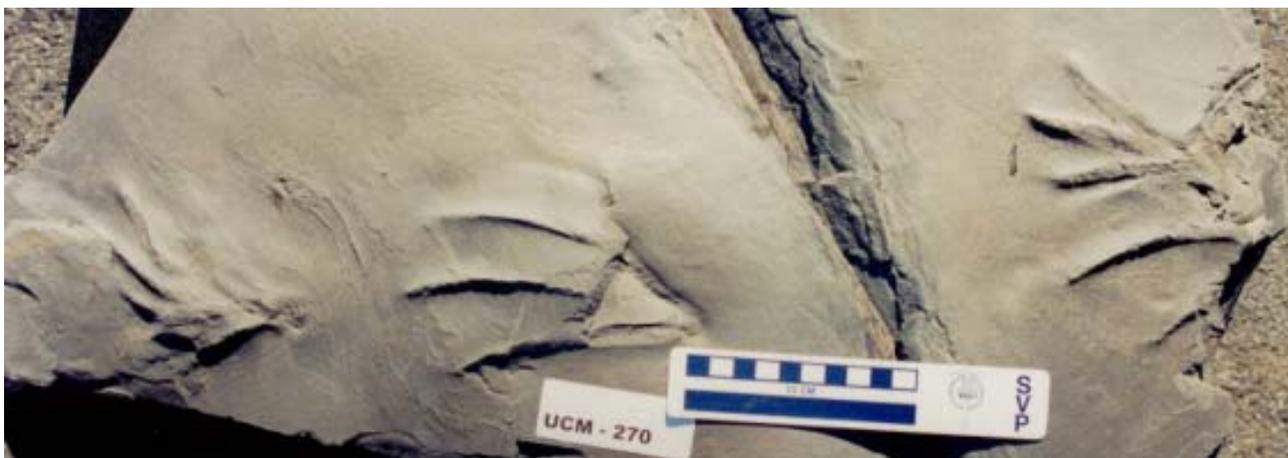


Plate 36C. UCM 270 AA. *Attenosaurus subulensis*.



Plate 37A. UCM 2249 TPA. *Attenosaurus subulensis*.

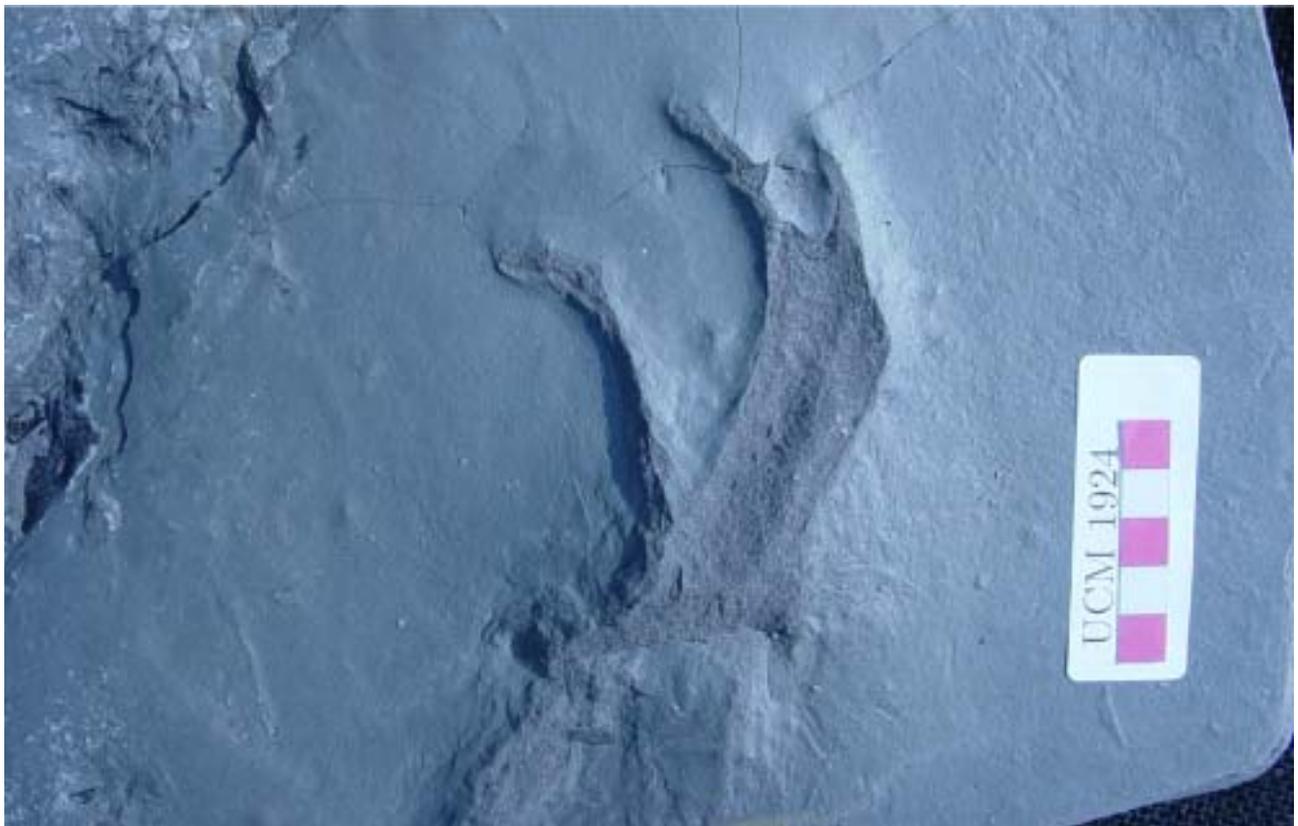


Plate 37B. UCM 1924 RB. *Attenosaurus subulensis*.



Plate 38A. UCM 1692 TPA. *Attenosaurus subulensis*.



Plate 38B. UCM 1214 SM. *Attenosaurus subulensis*.



Plate 38C. UCM 1915 GB . *Attenosaurus subulensis*.



Plate 39A. UCM 1319 RB. *Attenosaurus subulensis*.

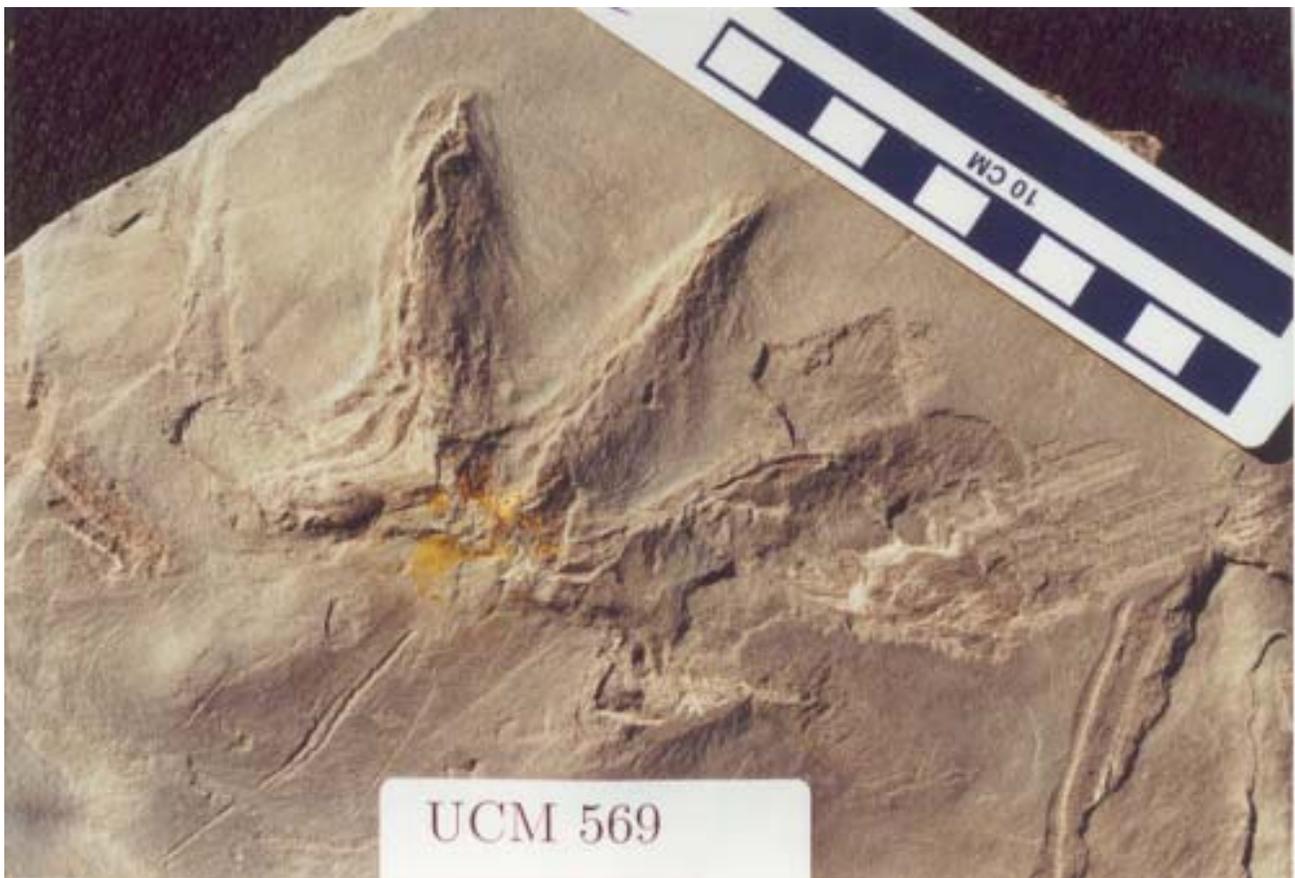


Plate 39B. UCM 569 RB. *Attenosaurus subulensis*.

**AMNIOTE TRACKWAYS**

Ichnotaxa: *Notalacerta missouriensis*, *Cincosaurus cobbi*



Plate 40A. UCM 223 SM. Cf. *Notalacerta missouriensis*.



Plate 40B. UCM 229 SM. Cf. *Notalacerta missouriensis* (see page 96 and Fig. 7D of Haubold et al., 2005).



Plate 40C. UCM 1209 SM. *Notalacerta missouriensis*.



Plate 41A. UCM 17 SM. *Cincosaurus cobbi*. Compare page 107, Fig. 8G, of Haubold et al. (2005). Specimen includes the invertebrate trace *Arenicolites longistriatus*.



Plate 41B. UCM 18 SM. *Cincosaurus cobbi*, with gas-escape structures.



Plate 42A. UCM 87 TPA. *Cincosaurus cobbi*.



Plate 42B. UCM 1096 TPA. *Cincosaurus cobbi*.



Plate 43A,B. UCM 174/175 BR. *Cincosaurus cobbi*, imprint and counterpart (see page 101, Fig. 8A, of Haubold et al., 2005).



Plate 44A. UCM 208 SM. *Cincosaurus cobbi*.



Plate 44B. UCM 237 SM. *Cincosaurus cobbi*.



Plate 45A. UCM 250 JT. *Cincosaurus cobbi*.



Plate 45B. UCM 251 JT. *Cincosaurus cobbi*, with gas-escape structures.



Plate 45C. UCM 254 JT *Cincosaurus cobbi*.



Plate 46A. UCM 252 JT. *Cincosaurus cobbi*.



Plate 46B. UCM 253 JT. *Cincosaurus cobbi*.



Plate 46C. UCM 257 JT. *Cincosaurus cobbi*, with gas-escape structures.



Plate 47A. UCM 255 JT. *Cincosaurus cobbi*.



Plate 47B. UCM 256 JT. *Cincosaurus cobbi*, with the invertebrate trace *Treptichnus apsorum*.



Plate 48A. UCM 258 JT. *Cincosaurus cobbi* .



Plate 48B. UCM 259 JT. *Cincosaurus cobbi*.



Plate 49A. UCM 260 JT. *Cincosaurus cobbi*.



Plate 49B. UCM 261 JT. *Cincosaurus cobbi*.



Plate 49C. UCM 262 JT. *Cincosaurus cobbi*, with invertebrate traces *Treptichnus apsorum* and *Arenicolites longistriatus*.



Plate 50A. UCM 670 RB. *Cincosaurus cobbi*, with the invertebrate trace *Arenicolites longistriatus*.



Plate 50B. UCM 672 RB. *Cincosaurus cobbi*, with the invertebrate trace *Arenicolites longistriatus*. Counterpart to UCM 670.



Plate 50C. UCM 675 RB. *Cincosaurus cobbi*.

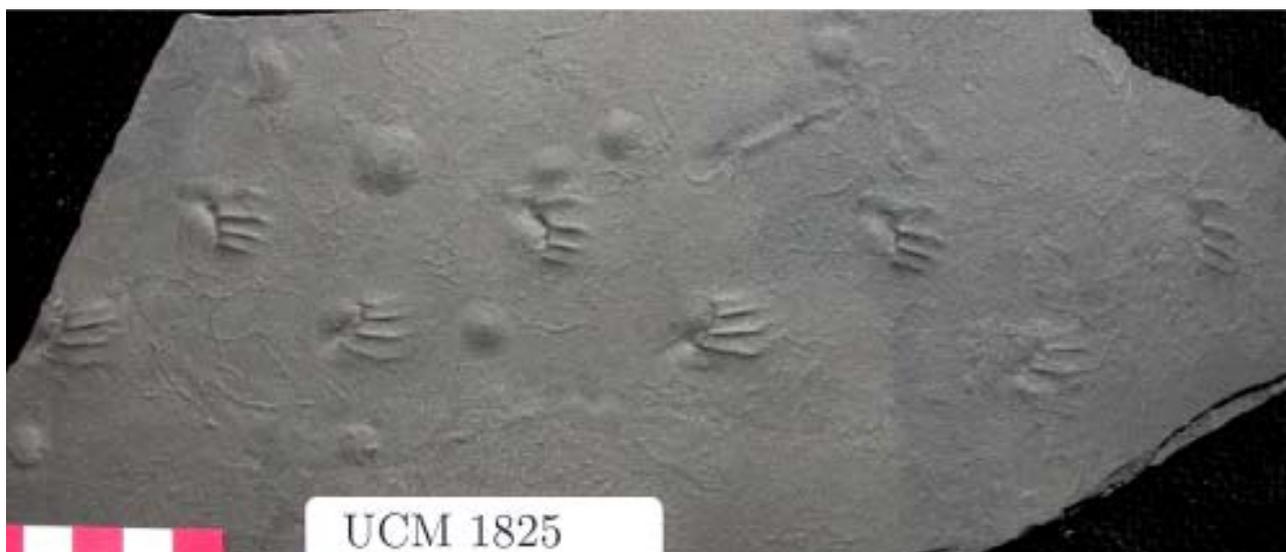


Plate 51A. UCM 1825 DA. Cf. *Cincosaurus cobbi*. Trackway displays undertracks of manus only. Numerous gas-escape structures are present also.



Plate 51B. UCM 482 BR. Cf. *Cincosaurus cobbi*. Digits secondary elongated and curved.



Plate 52A. UCM 1075 TPA. *Cincosaurus cobbi* (see p. 71 of Martin and Pyenson, 2005, and p. 96 of Hartmut et al., 2005).



Plate 52B. UCM 1068 TPA. *Cincosaurus cobbi*.



Plate 52C. UCM 331 AA. Cf. *Cincosaurus cobbi*, but compare with some specimens determined as *Kouphichnium* (see p. 109 of Haubold et al., 2005).



Plate 53A. UCM 1476 RB. *Cincosaurus cobbi*.



Plate 53B. UCM 1477 RB counterpart of UCM 1476; compare comment page 109, and Figs. 8E and 8F, of Haubold et al. (2005).

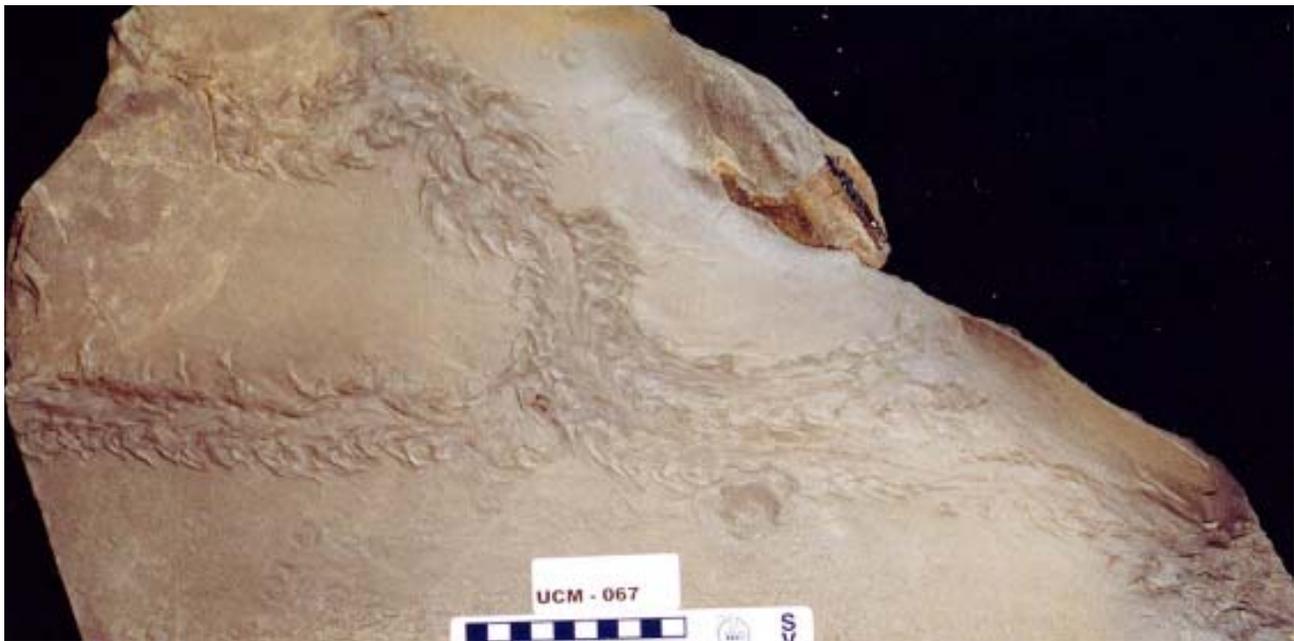


Plate 54A. UCM 67 RB. *Cincosaurus cobbi*.



Plate 54B. UCM 690 RB, counterpart of UCM 67. Two trackways preserved at the original surface; see comment, page 109, and Fig. 8F of Haubold et al. (2005).



Plate 55A. UCM 1815 DA. *Cincosaurus cobbi*.



Plate 55B. UCM 1842 DA. *Cincosaurus cobbi*.

**FISH SWIMMING TRACES**  
Ichnogenus: *Undichna*



Plate 56A. UCM 74 RB. *Undichna*.



Plate 56B. UCM 93 TPA. *Undichna*.



Plate 56C. UCM 64 DH. *Undichna*.



Plate 56D. UCM 1289 GSA. *Undichna*.



Plate 57A. UCM 287 AA. *Undichna*.



Plate 57B. UCM 678 RB. *Undichna*.



Plate 57C. UCM 989 BR. *Undichna*.



Plate 57D. UCM 455 TPA. *Undichna*.



Plate 58A. UCM 731 RB. *Undichna*.



Plate 58B. UCM 1029 AA. *Undichna*.



Plate 58C. UCM 1047 AA. *Undichna*.

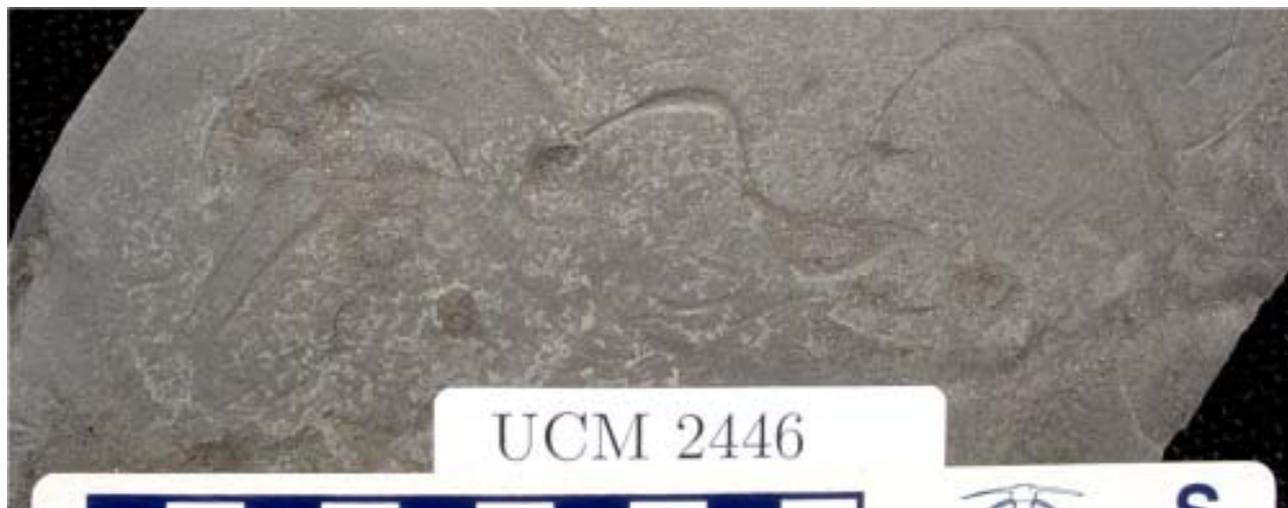


Plate 58D. UCM 2446 RB. *Undichna*.

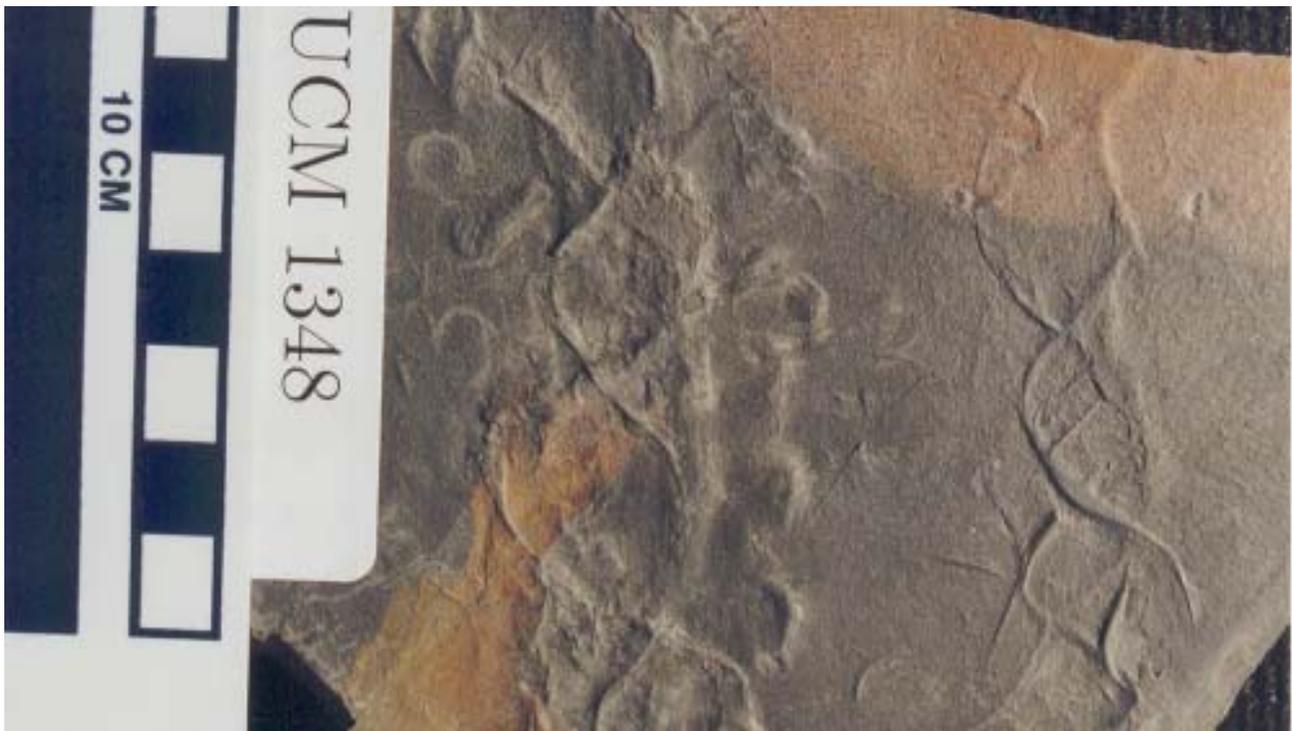


Plate 59A. UCM 1348 RB. *Undichna* (see page 62 of Martin and Pyenson, 2005).

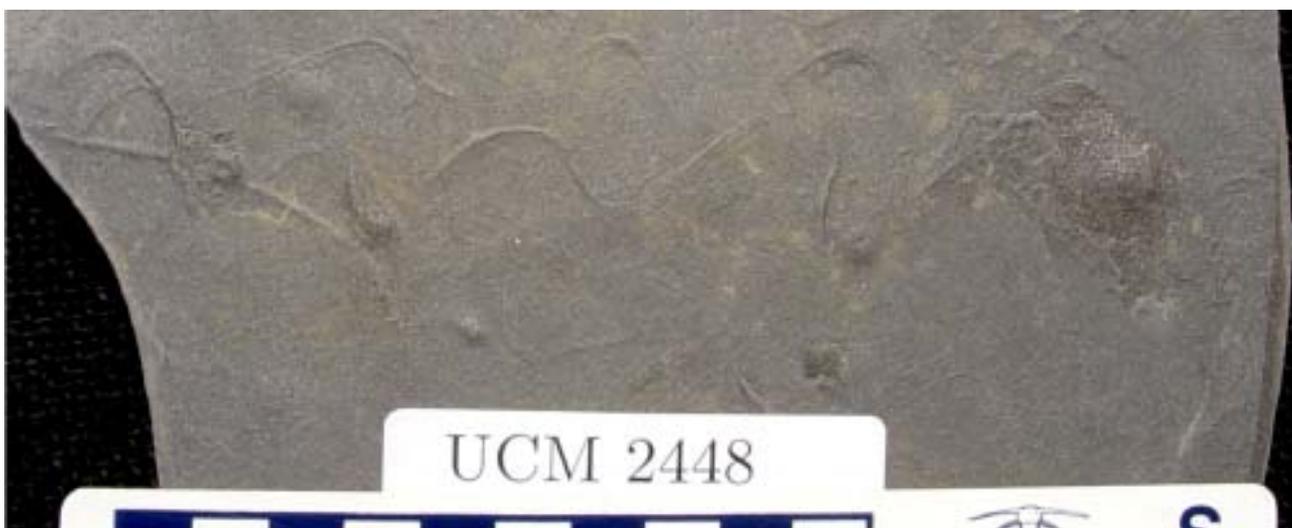


Plate 59B. UCM 2448 RB. *Undichna*.

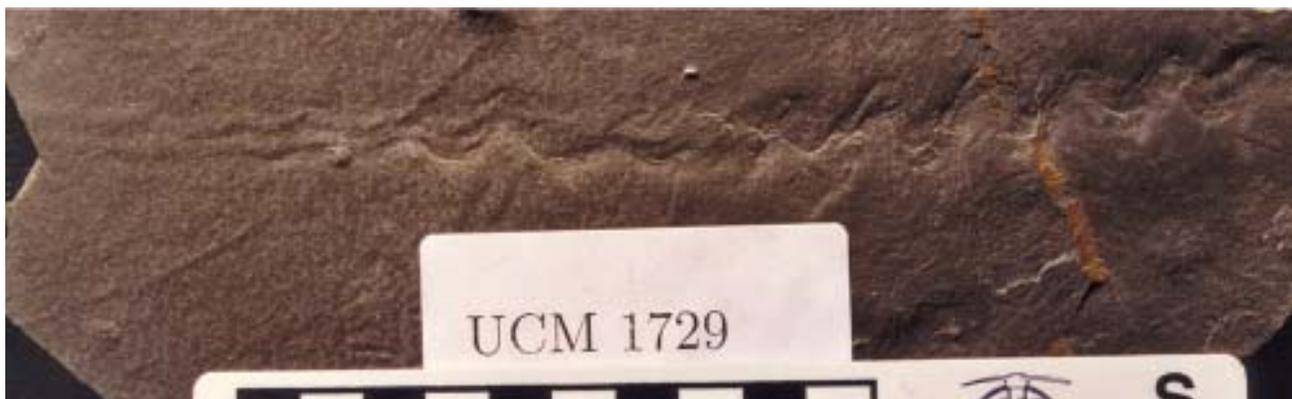


Plate 59C. UCM 1729 BR. *Undichna*.



Plate 60A. UCM 1670 TPA. *Undichna*.

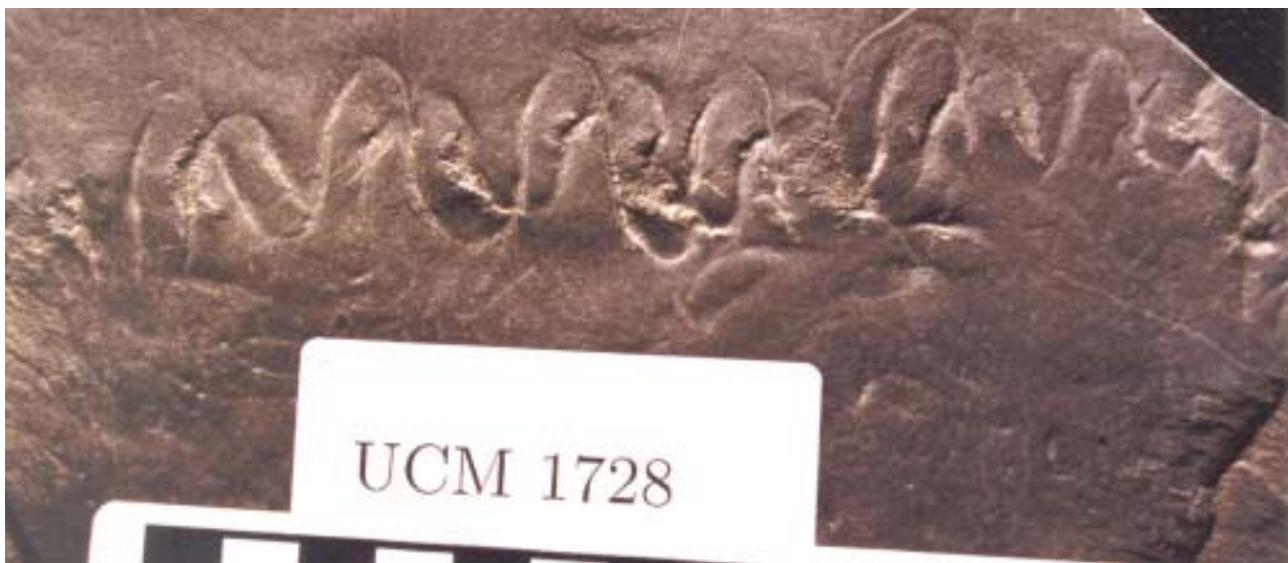


Plate 60B. UCM 1728 BR. *Undichna*.



Plate 60C. UCM 1734 BR. *Undichna*.



Plate 61A. UCM 2237 TPA. *Undichna*.



Plate 61B. UCM 1731 BR. *Undichna*.



Plate 61C. UCM 1733 BR. *Undichna*.



Plate 62A. UCM 2382 RB. *Undichna*.



Plate 62B. UCM 2516 RB. *Undichna*.

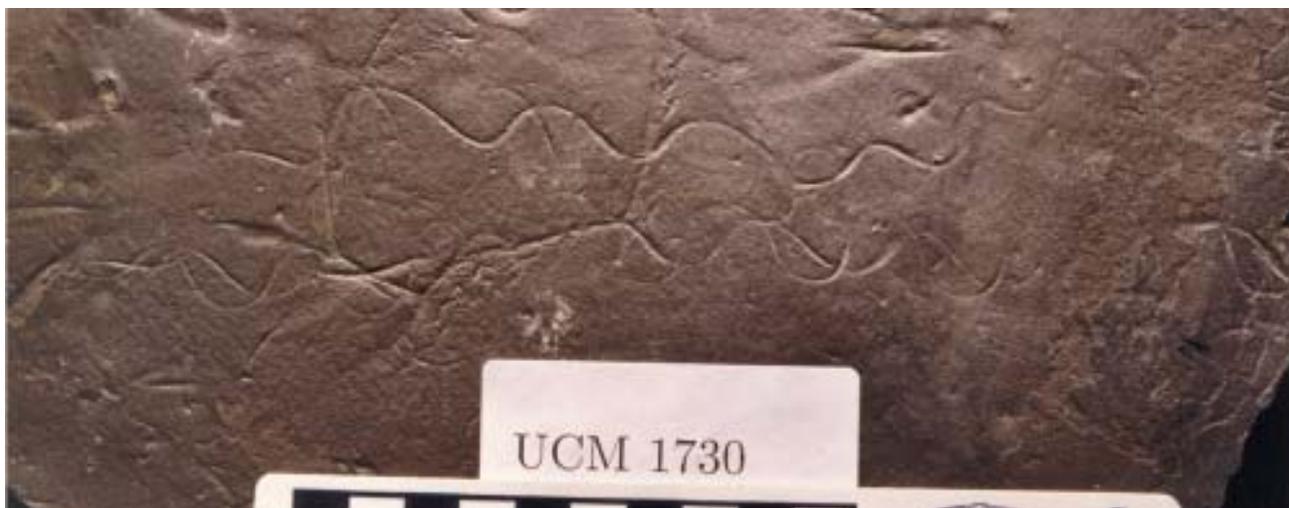


Plate 62C. UCM 1730 BR. *Undichna*.



Plate 63A. UCM 806 RB. *Undichna*.

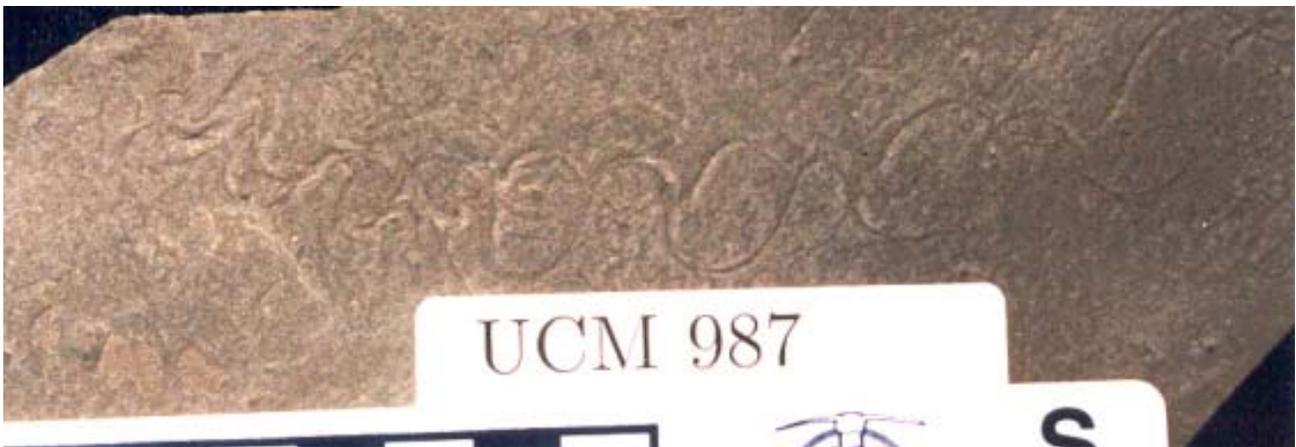


Plate 63B. UCM 987 BR. *Undichna*.



Plate 63C. UCM 1304 GSA. *Undichna*.



Plate 63D. UCM 1300 EG. *Undichna*.

## ATLAS OF UNION CHAPEL MINE INVERTEBRATE TRACKWAYS AND OTHER TRACES

RONALD J. BUTA,<sup>1</sup> DAVID C. KOPASKA-MERKEL,<sup>2</sup> ANDREW K. RINDSBERG,<sup>2</sup>  
and  
ANTHONY J. MARTIN<sup>3</sup>

<sup>1</sup> Department of Physics and Astronomy, University of Alabama, Box 870324, Tuscaloosa, 35487 Alabama, USA

<sup>2</sup> Geological Survey of Alabama, Box 869999, Tuscaloosa, Alabama 35486-6999, USA

<sup>3</sup> Department of Environmental Studies, Emory University, Atlanta, Georgia 30322, USA

This atlas is a compilation of 143 photographs of invertebrate trackways and other traces (including parts and counterparts in some cases) salvaged from the Union Chapel Mine (Steven C. Minkin Paleozoic Footprint Site) in Walker County, Alabama, USA. Each specimen has a centimeter scale and is identified with a Union Chapel Mine (UCM) number followed by the initials of the collector (Table 1). Plates 64-79 show xiphosuran locomotion traces, including the horseshoe crab trace *Kouphichnium* (Lucas and Lerner, 2005). Plates 80-84 show examples of an unassigned xiphosuran ichnogenus wherein the body outlines and other characteristics are recorded (Lucas and Lerner, 2005). Plates 85-89 (and also plate 64B) show undertracks which we tentatively assign to the ichnospecies *Kouphichnium aspodon* Aldrich, 1930. Plates 90-102 show xiphosuran traces collected from a single large boulder over many bedding planes. These slabs are dominated by high-density xiphosuran locomotion traces. Plates 103-106 show the xiphosuran resting traces *Arborichnus repetitus* (*Arborichnus repetita* of Lucas and Lerner, 2005); these unusual traces come from strata other than the *Cincosaurus* beds (Pashin, 2005, fig. 11). Plates 107-110 show examples of the myriapod trackway *Diplichnites gouldi*, an uncommon ichnotaxon at the site (Lucas and Lerner, 2005). Finally, Plates 111-116 show examples of the abundant insect burrows *Treptichnus aporum* and *Arenicolites longistriatus*, two newly identified ichnospecies (Rindsberg and Kopaska-Merkel, 2005; Uchman, 2005). The atlas illustrates only a small fraction of the total number of slabs collected with invertebrate traces, which exceeds 1000. Table 2 provides an index of the illustrated specimens.

TABLE 1. Index to Collectors and Invertebrate Ichnotaxa

Code	Description
COLLECTORS	
AA	Ashley Allen
TPA	T. Prescott Atkinson
DA	David Ausmus
GB	Gerald Badger
RB	Ronald J. Buta
KH	Kenneth Hoyle
DKM	David C. Kopaska-Merkel
DM	Donald McDonald
SM	Steven C. Minkin
BR	Bruce A. Relihan
INVERTEBRATE ICHNOTAXA	
AB	<i>Arborichnus repetitus</i>
TA	<i>Treptichnus aporum</i>
AL	<i>Arenicolites longistriatus</i>
DP	<i>Diplichnites gouldi</i>
KP	<i>Kouphichnium</i> isp.
KA	<i>Kouphichnium aspodon</i>

COLLECTORS

AA	Ashley Allen
TPA	T. Prescott Atkinson
DA	David Ausmus
GB	Gerald Badger
RB	Ronald J. Buta
KH	Kenneth Hoyle
DKM	David C. Kopaska-Merkel
DM	Donald McDonald
SM	Steven C. Minkin
BR	Bruce A. Relihan

INVERTEBRATE ICHNOTAXA

AB	<i>Arborichnus repetitus</i>
TA	<i>Treptichnus aporum</i>
AL	<i>Arenicolites longistriatus</i>
DP	<i>Diplichnites gouldi</i>
KP	<i>Kouphichnium</i> isp.
KA	<i>Kouphichnium aspodon</i>

TABLE 2. Index to Illustrated Invertebrate Trace Fossil Specimens<sup>a</sup>

UCM No.	Collector	Plate No.	Taxon	UCM No.	Collector	Plate No.	Taxon
0092	TPA	111A	TA	1030	AA	115C	TA
0118	KH	66A	KA	1051	TPA	81A	KP
0143	BR	111B	TA	1053	TPA	81B	KP
0147	BR	112A	TA	1057	TPA	81C	KP
0179	BR	112B	TA	1058	TPA	81D	KP
0180	BR	113A	TA	1060	TPA	82A	KP
0180	BR	113A	AL	1061	TPA	82B	KP
0214	SM	85A	KA	1070	TPA	64A	KA
0215	SM	85B	KA	1071	TPA	64B	KA
0227	SM	86A	KA	1072	TPA	65A	KA
0333	AA	76A	KP	1077	TPA	116A	TA
0370	AA	110A	DP	1117	TPA	70A	KP
0387	AA	77A	KP	1118	TPA	67C	KP
0388	AA	87D	KA	1119	TPA	70B	KP
0393	AA	107A	DP	1124	TPA	77B	KP
0394	AA	107B	DP	1152	RB	104A	AB
0417	AA	113B	TA	1153	RB	104B	AB
0419	AA	114A	TA	1154	RB	105A	AB
0419	AA	114A	AL	1156	RB	105B	AB
0421	AA	114B	TA	1157	RB	106A	AB
0426	GB	86B	KA	1207	SM	66B	KA
0430	GB	86C	KA	1220	BR	73B	KP
0437	TPA	87A	KA	1224	SM	69C	KP
0437	TPA	87B	KP	1264	RB	71A	KP
0477	BR	88A	KA	1265	RB	71B	KP
0479	BR	73A	KP	1267	RB	109C	DP
0487	BR	80A	KP	1268	RB	89A	KA
0489	BR	65B	KA	1281	RB	75A	KP
0490	BR	65C	KA	1345	RB	70C	KP
0546	RB	67A	KP	1349	RB	75B	KP
0556	RB	67B	KP	1368	RB	77C	KP
0602	TPA	80B	KP	1370	RB	108D	DP
0617	TPA	66C	KP	1370	RB	108E	DP
0620	TPA	68A	KP	1376	RB	78A	KP
0662	RB	65D	KA	1377	RB	78B	KP
0666	RB	107C	DP	1384	RB	78C	KP
0688	RB	115A	TA	1390	RB	79A	KP
0689	RB	68B	KP	1397	RB	76B	KP
0689	RB	68C	KP	1402	RB	72B	KP
0692	RB	73C	KP	1410	RB	74A	KP
0723	RB	69A	KP	1411	RB	74B	KP
0743	RB	103A	AB	1414	RB	72A	KP
0788	DKM	115B	TA	1437	RB	82C	KP
0788	DKM	115B	AL	1441	RB	83A	KP
0827	DM	88B	KA	1441	RB	83B	KP
0888	GD	106B	AB	1495	RB	103B	AB
0902	BR	88C	KA	1505	RB	89B	KA
0953	BR	108A	DP	1735	RB	91A	KP
0953	BR	108B	DP	1735	RB	91B	KP
0954	BR	108C	DP	1737	RB	90A	KP
0959	BR	69B	KP	1738	RB	90B	KP

TABLE 2 (cont.). Index to Illustrated Invertebrate Trace Fossil Specimens<sup>a</sup>

UCM No.	Collector	Plate No.	Taxon	UCM No.	Collector	Plate No.	Taxon
1740	RB	91C	KP	1777	RB	100A	KP
1742	RB	92A	KP	1780	RB	100B	KP
1742	RB	92B	KP	1781	RB	101A	KP
1744	RB	93A	KP	1786	RB	102A	KP
1748	RB	93B	KP	1788	RB	101B	KP
1749	RB	94A	KP	1794	RB	102B	KP
1749	RB	94B	KP	1801	RB	74C	KP
1749	RB	94C	KP	1805	RB	116B	TA
1752	RB	95A	KP	1820	DA	109A	DP
1755	RB	95B	KP	1820	DA	109B	DP
1757	RB	96A	KP	2461	RB	84A	KP
1757	RB	96B	KP	2466	RB	84B	KP
1758	RB	97A	KP	2466	RB	84C	KP
1761	RB	98A	KP	2466	RB	110B	DP
1761	RB	98B	KP	2495	RB	76C	KP
1762	RB	83C	KP	2495	RB	79B	KP
1762	RB	95C	KP	2497	RB	69D	KP
1764	RB	97B	KP	2497	RB	79C	KP
1767	RB	99A	KP	2518	RB	87C	KA
1771	RB	99B	KP	2528	RB	110C	DP
1772	RB	99C	KP				

<sup>a</sup>Some specimens are tentatively assigned.

## REFERENCES

- Aldrich, T. H., Sr., 1930, Description of tracks, in Aldrich, T. H., Sr., and Jones, W. B., 1930. Footprints from the Coal Measures of Alabama: Alabama Museum of Natural History, Museum Paper, no. 9, 64p.
- Lucas, S.G. and Lerner, A. J., 2005, Lower Pennsylvanian invertebrate ichnofossils from the Union Chapel Mine, Alabama: a preliminary assessment; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 147-152.
- Pashin, J. C., 2005, Pottsville stratigraphy and the Union Chapel Lagerstätte; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 39-58.
- Rindsberg, A. K. and Kopaska-Merkel, D. C., 2005, *Treptichnus* and *Arenicolites* from the Union Chapel Mine site; in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 121-141.
- Uchman, A., 2005, *Treptichnus*-like traces made by insect larvae (Diptera: Chironomidae: Tipulidae); in Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 143-146.

## AUTHORS' E-MAIL ADDRESSES

Ronald J. Buta: rbuta@bama.ua.edu  
 Andrew K. Rindsberg: arindsberg@gsa.state.al.us  
 David C. Kopaska-Merkel: davidkm@gsa.state.al.us  
 Anthony J. Martin: geoam@learnlink.emory.edu

**XIPHOSURAN TRACES**

Locomotion traces: *Kouphichnium* isp., *Kouphichnium aspodon*  
Other traces unassigned.



Plate 64A. UCM 1070 TPA. *Kouphichnium aspodon*



Plate 64B. UCM 1071 TPA. *Kouphichnium aspodon*. This is the same trackway as UCM 1070, seen at a different horizon.



Plate 65A. UCM 1072 TPA. *Kouphichnium aspodon*. Counterpart of UCM 1070 TPA, showing the whole track-way and several gas-escape structures.

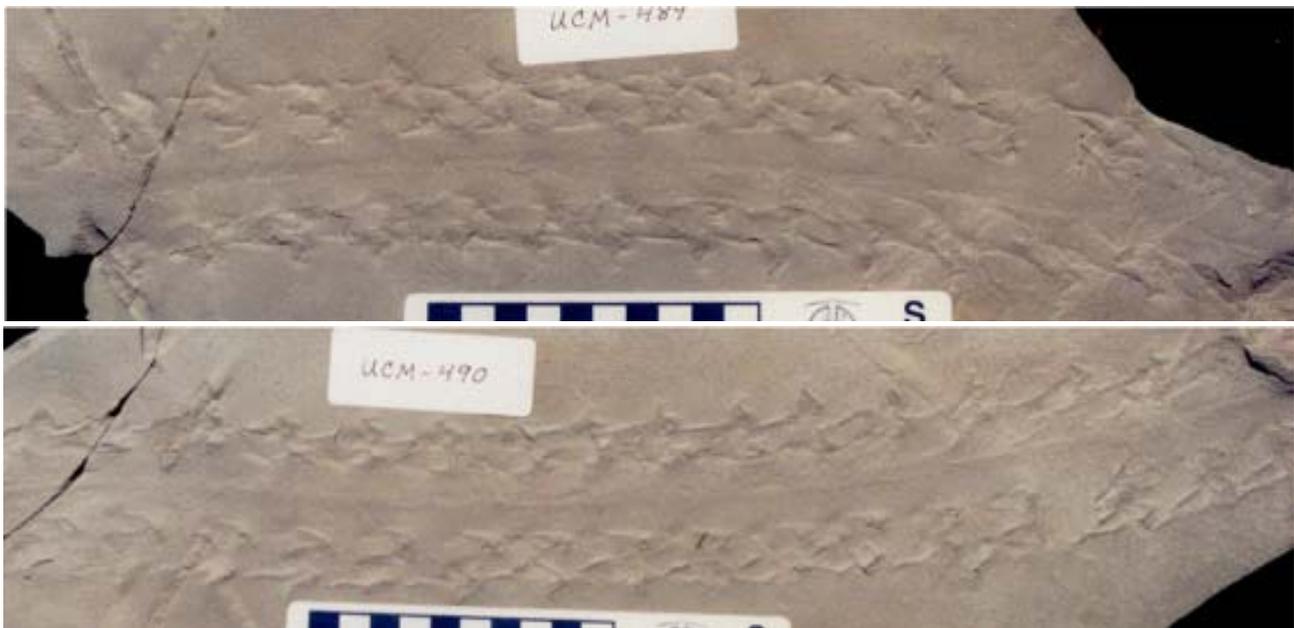


Plate 65B,C. UCM 489 (B), 490 (C) BR. *Kouphichnium aspodon*, imprint and counterpart.



Plate 65D. UCM 662 RB. *Kouphichnium aspodon*.

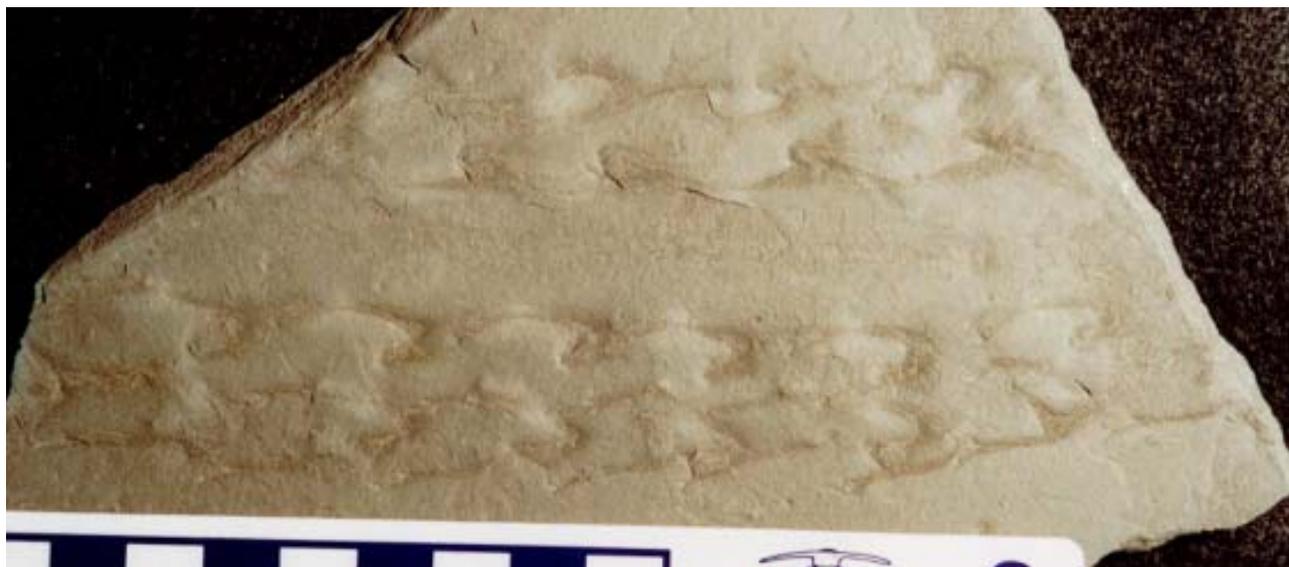


Plate 66A. UCM 118 KH. *Kouphichnium aspodon*.



Plate 66B. UCM 1207 SM. *Kouphichnium aspodon*.



Plate 66C. UCM 617 TPA. *Kouphichnium* isp.



Plate 67A. UCM 546 RB. Probable arthropod trackway resembling *Kouphichnium*.



Plate 67B. UCM 556 RB. *Kouphichnium* isp.

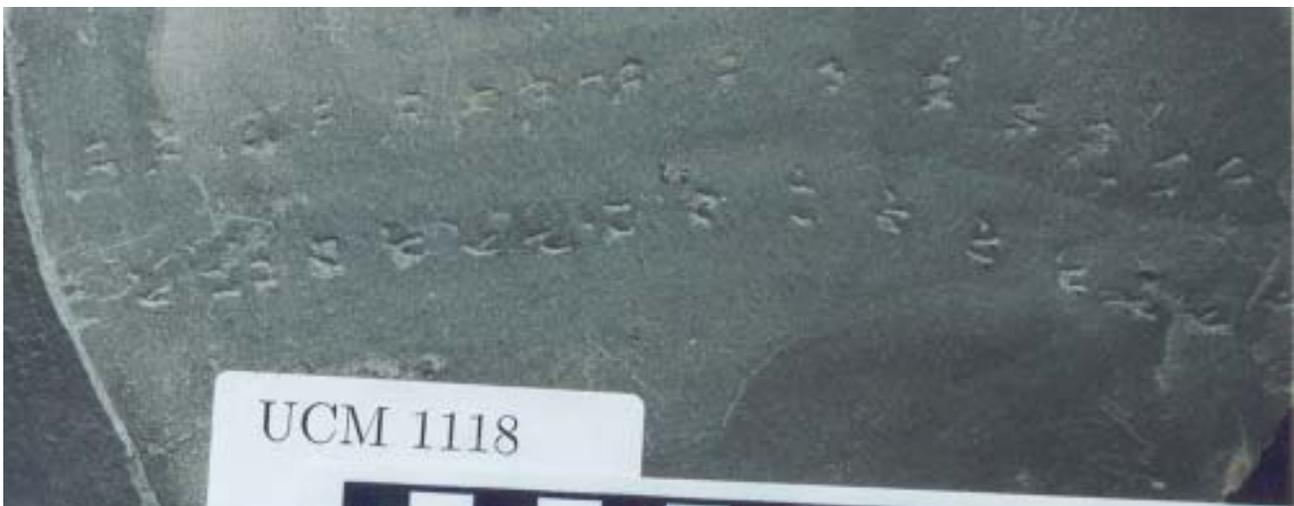


Plate 67C. UCM 1118 TPA. Probable arthropod trackway resembling *Kouphichnium*.



Plate 68A. UCM 620 TPA. *Kouphichnium* isp., with gas-escape structures.



Plate 68B. UCM 689 RB *Kouphichnium* isp. Many criss-crossing trackways of same type.

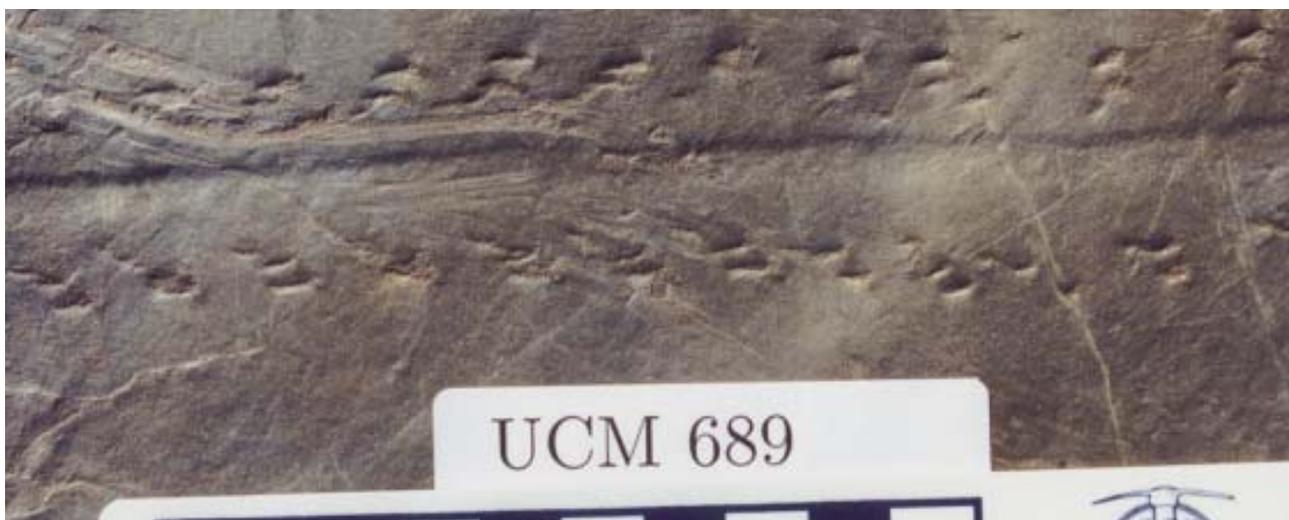


Plate 68C. UCM 689 RB. *Kouphichnium* isp., closeup of part of one trackway.



Plate 69A. UCM 723RB. *Kouphichnium* isp.



Plate 69B. UCM 959 BR. *Kouphichnium* isp.



Plate 69C. UCM 1224 SM. *Kouphichnium* isp.



Plate 69D. UCM 2497 RB. *Kouphichnium* isp.

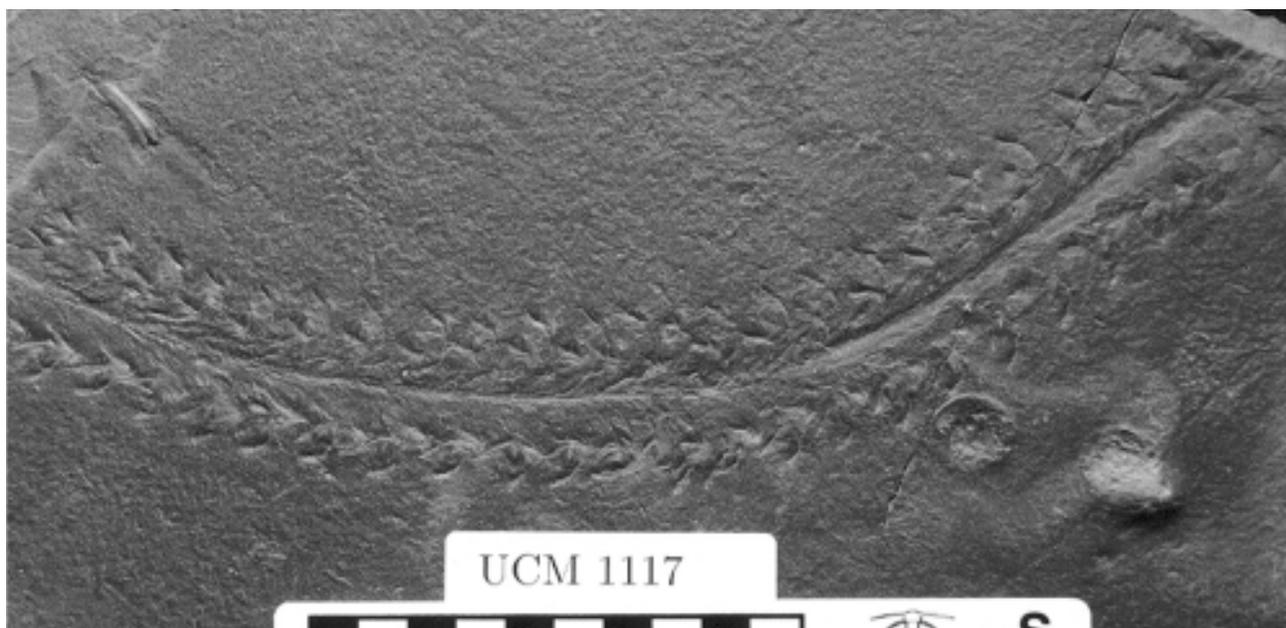


Plate 70A, B. UCM 1117 (A), 1119 (B) TPA. *Kouphichnium* isp., imprint and counterpart.

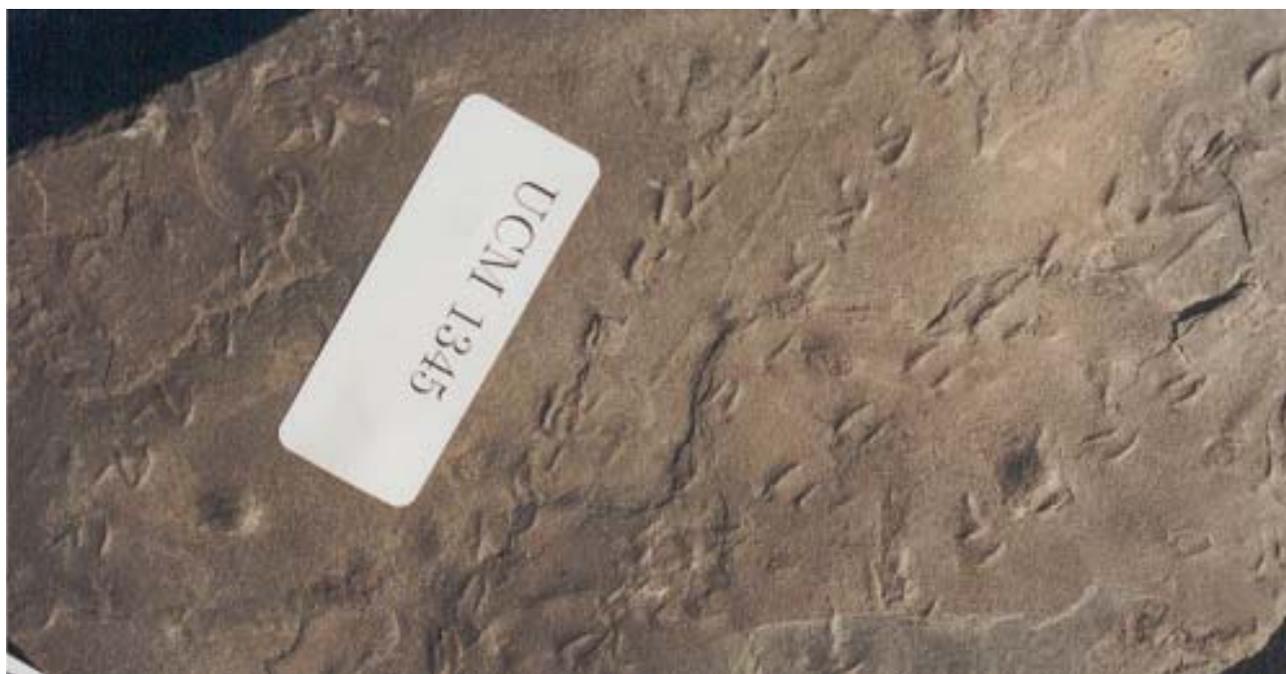


Plate 70C. UCM 1345 RB. *Kouphichnium* isp.



Plate 71A. UCM 1264 RB. *Kouphichnium* isp.



Plate 71B. UCM 1265 RB. *Kouphichnium* isp.



Plate 72A. UCM 1414 RB. *Koupichnium* isp.

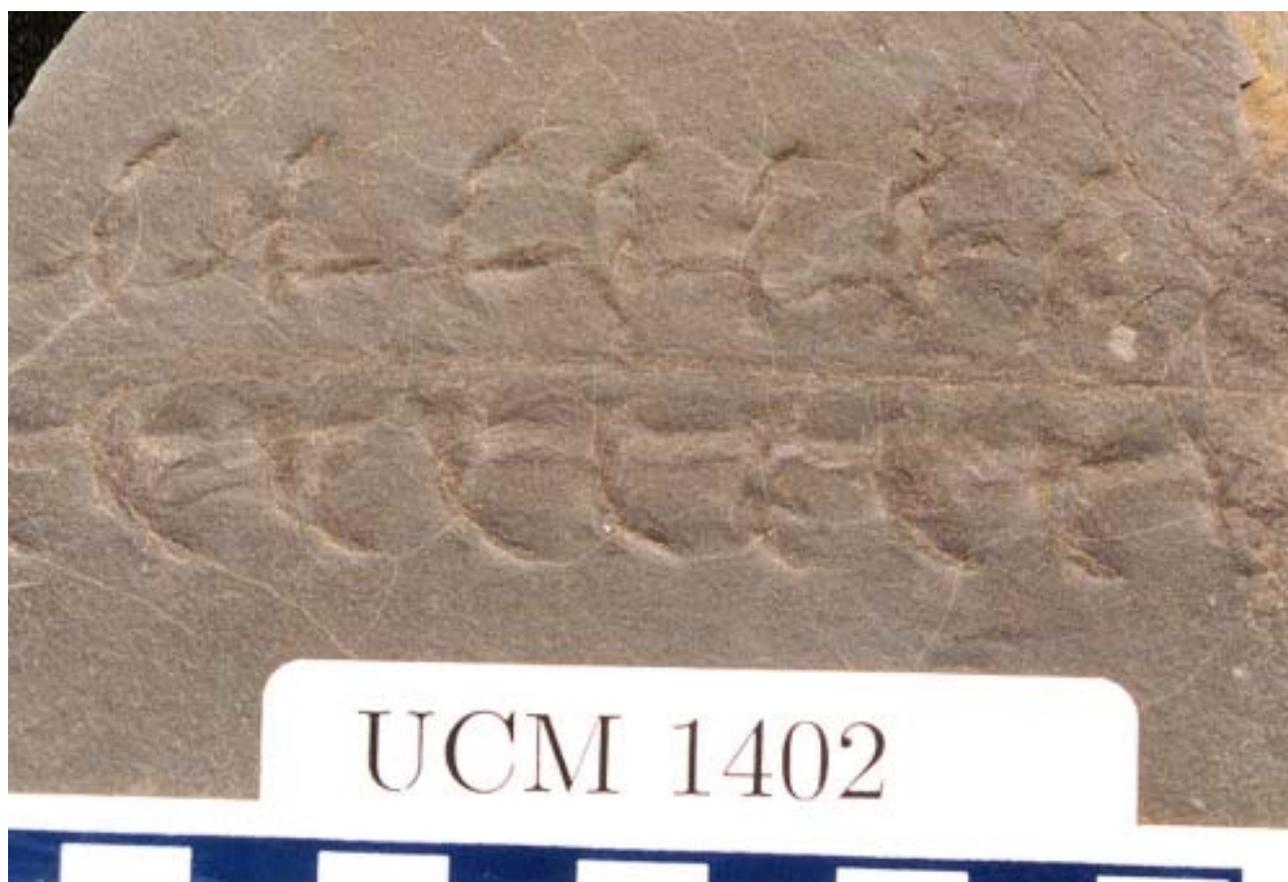


Plate 72B. UCM 1402 RB. Xiphosuran trackway with prosomal imprints.



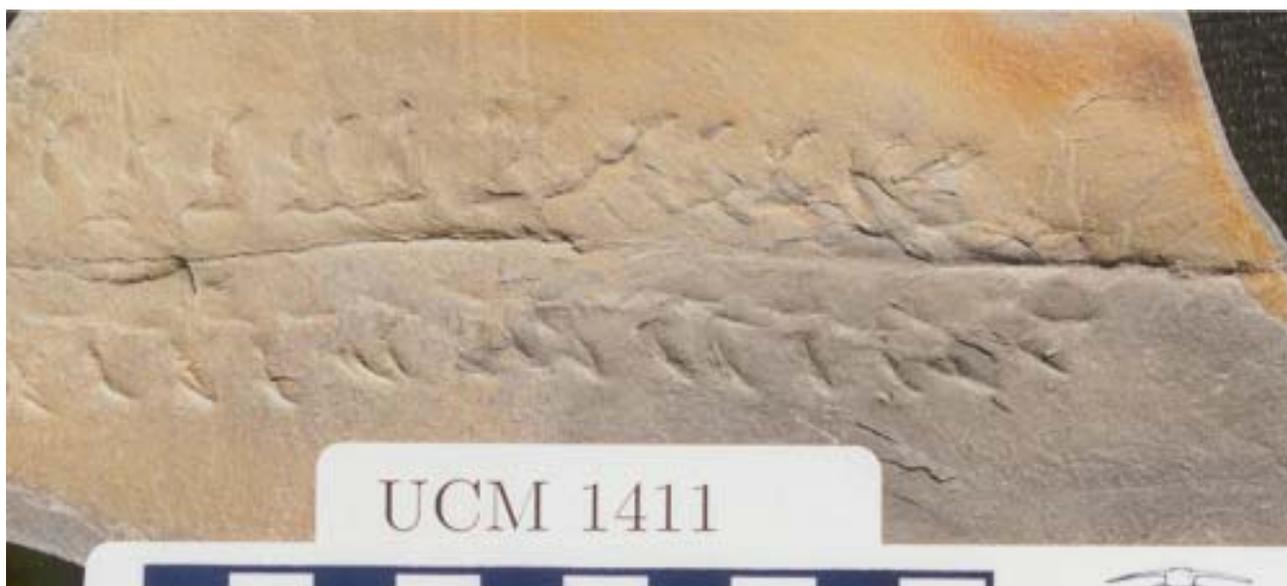
Plate 73A. UCM 479 BR. *Kouphichnium* isp.



Plate 73B. UCM 1220 SM. *Kouphichnium* isp.



Plate 73C. UCM 692 RB. *Kouphichnium* isp.



Plates 74A, B. UCM 1410 (A), 1411 (B) RB. *Kouphichnium* isp., imprint and counterpart.



Plate 74C. UCM 1801 RB. Probable arthropod trackway resembling *Kouphichnium*, but without the telson groove.



Plate 75A. UCM 1281 RB. *Kouphichnium* isp.



Plate 75B. UCM 1349 RB. *Kouphichnium* isp.



Plate 76A. UCM 333 AA. *Kouphichnium* isp.



Plate 76B. UCM 1397 RB. *Kouphichnium* isp.



Plate 76C. UCM 2495 RB. Xiphosuran trackway with prosomal imprints.



Plate 77A. UCM 387 AA. *Kouphichnium* isp.



Plate 77B. UCM 1124 TPA. *Kouphichnium* isp.



Plate 77C. UCM 1368 RB. *Kouphichnium* isp.

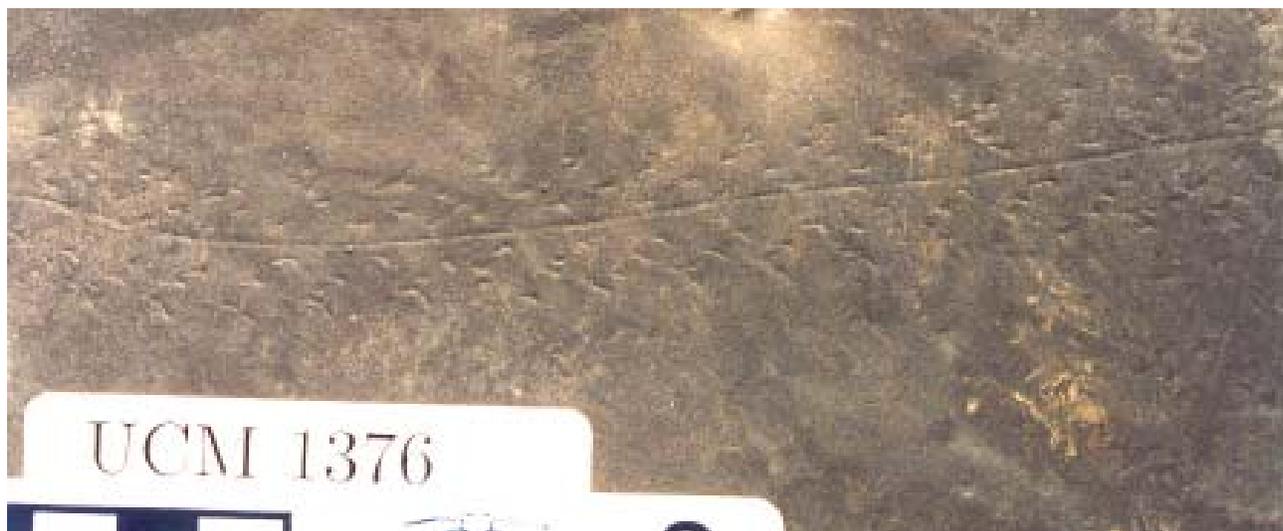


Plate 78A. UCM 1376 RB. *Kouphichnium* isp.

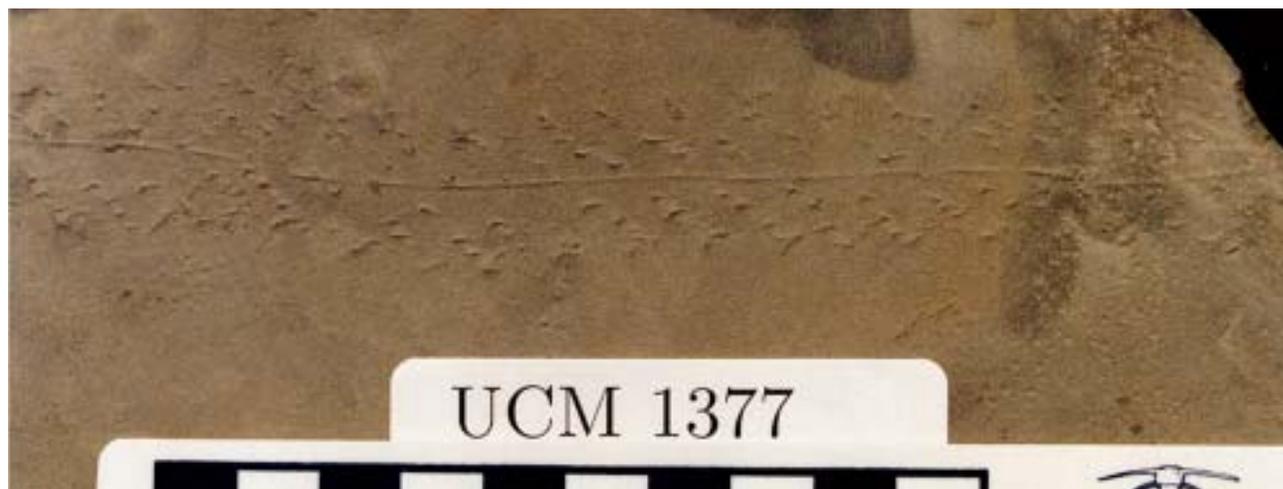


Plate 78B. UCM 1377 RB. *Kouphichnium* isp.



Plate 78C. UCM 1384 RB. *Kouphichnium* isp.

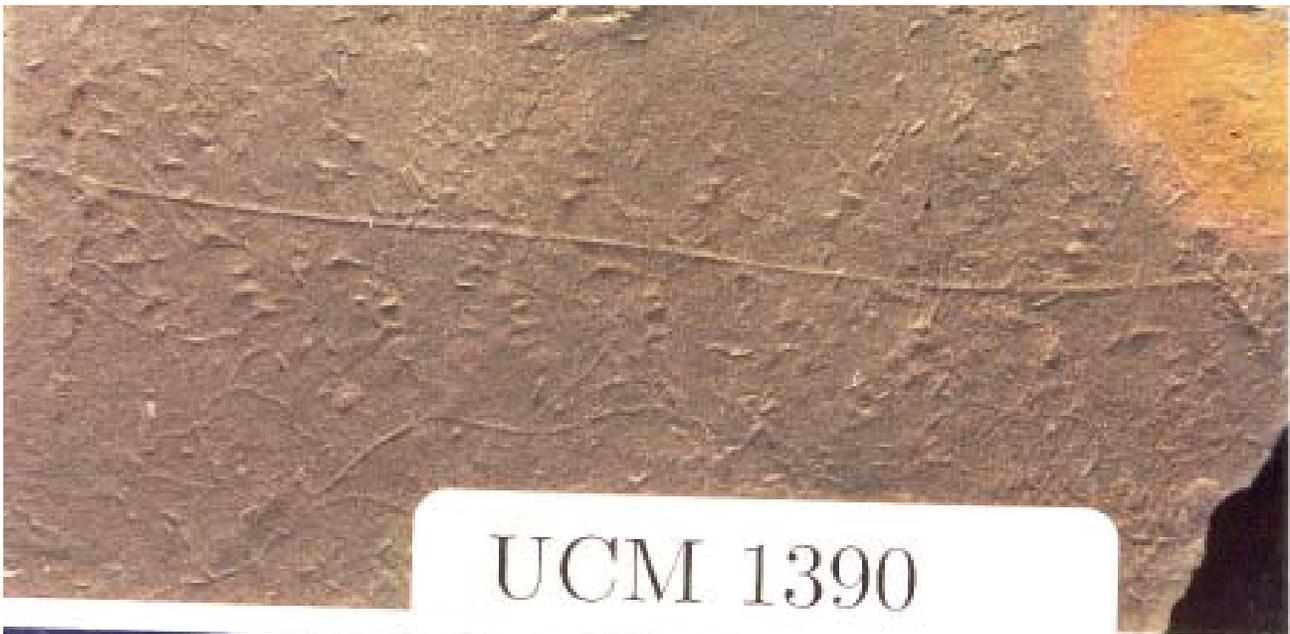


Plate 79A. UCM 1390 RB. *Kouphichnium* isp.

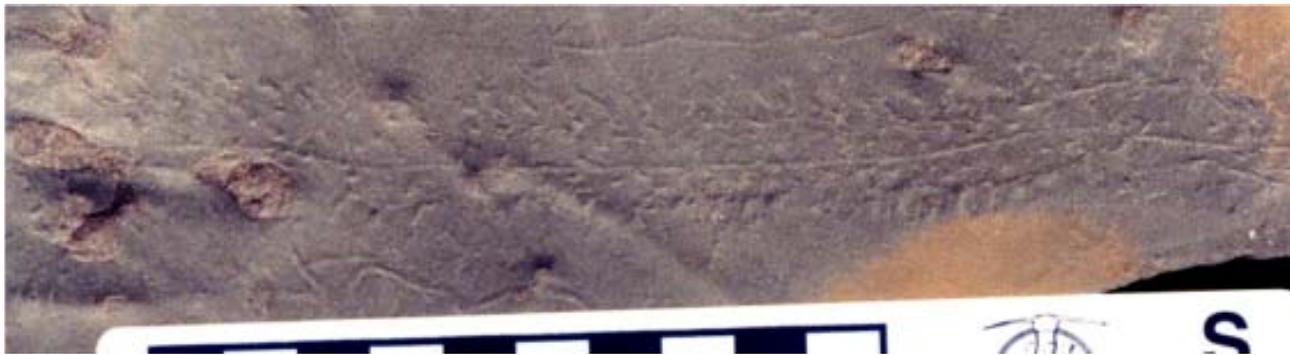


Plate 79B. UCM 485A BR. *Kouphichnium* isp.



Plate 79C. UCM 2469 RB. *Kouphichnium* isp.

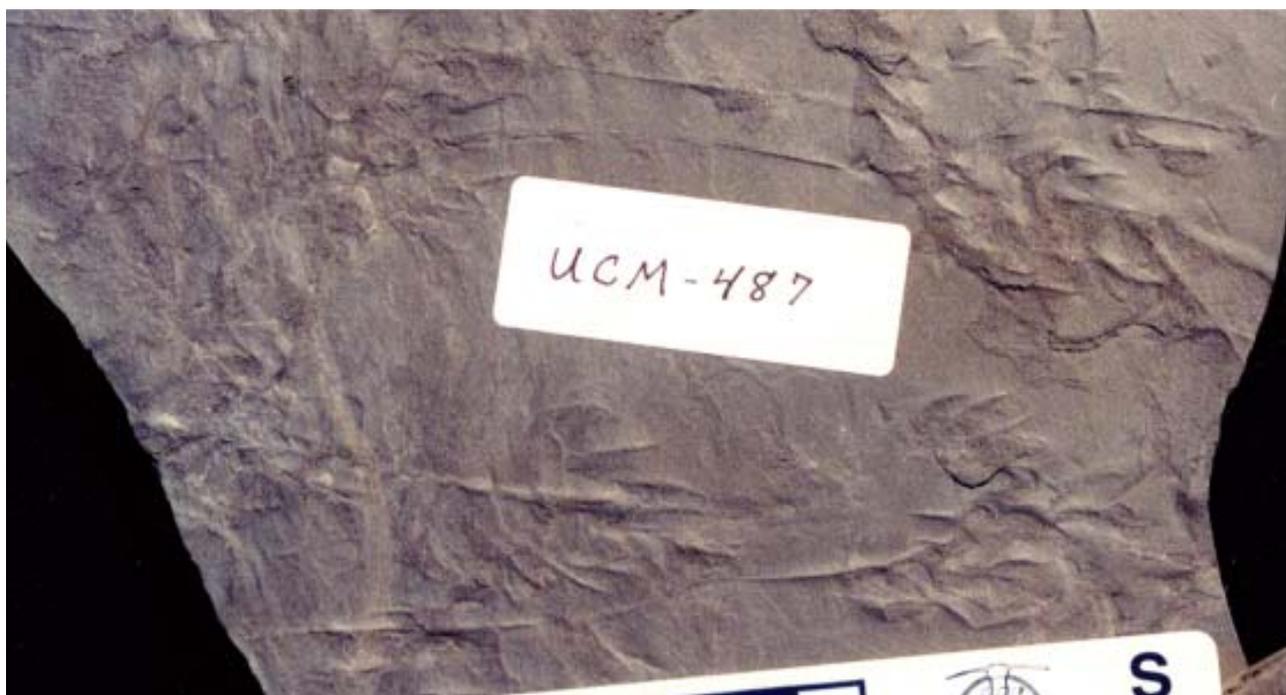


Plate 80A. UCM 487 BR. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 80B. UCM 602 TPA. Unassigned xiphosuran resting trace, with *Kouphichnium* isp. trackway.



Plate 81A. UCM 1051 TPA. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 81B. UCM 1053 TPA. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 81C. UCM 1057 TPA. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 81D. UCM 1058 TPA. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 82A. UCM 1060 TPA. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 82B. UCM 1061 TPA. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 82C. UCM 1437 RB. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plates 83A, B. UCM 1441 RB. Unassigned ichnotaxon. Full view (A) and closeup of one resting trace (B).



Plate 83C. UCM 1762 RB. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 84A. UCM 2461 RB. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 84B. UCM 2466 RB. Surface with several invertebrate traces, including *Diplichnites gouldi* (see Plate 110B), *Kouphichnium* isp., and several of the unassigned resting traces.



Plate 84C. UCM 2466 RB. Closeup of the resting traces on the same surface as shown in Plate 84B.



Plate 85A. UCM 214 SM. *Kouphichnium aspodon*, with *Treptichnus apsorum*.



Plate 85B. UCM 215 SM. *Kouphichnium aspodon*.

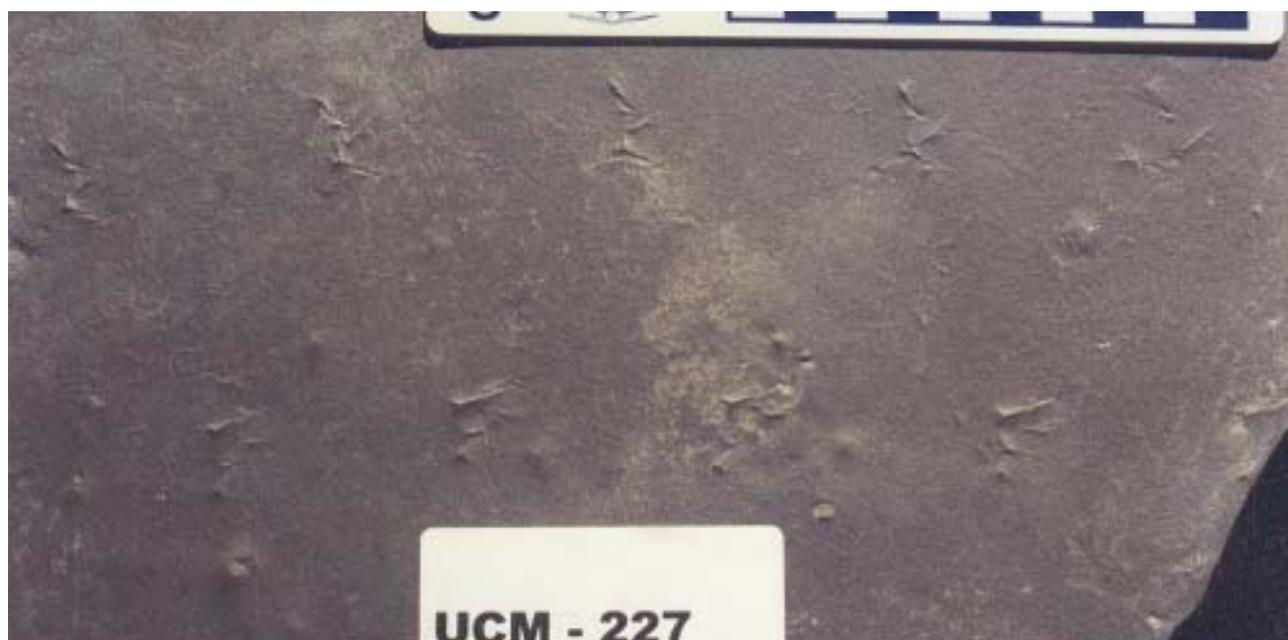


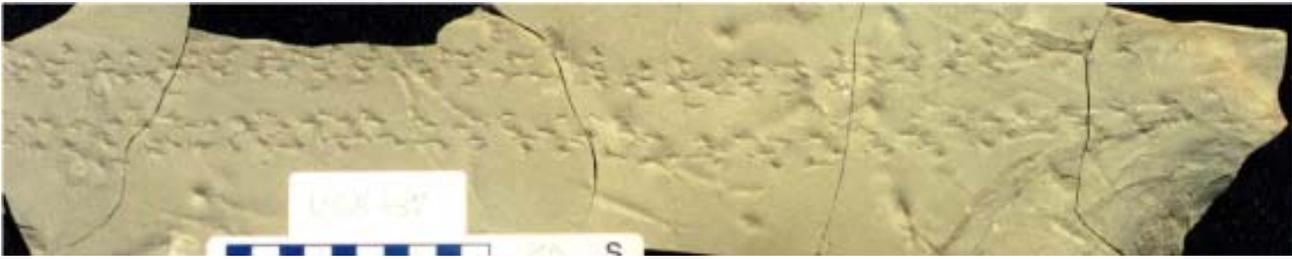
Plate 86A. UCM 227 SM. *Kouphichnium aspodon*.



Plate 86B. UCM 426 GB. *Kouphichnium aspodon*.



Plate 86C. UCM 430 GB. *Kouphichnium aspodon*.



Plates 87A, B. UCM 437 TPA. *Kouphichnium aspodon*, full view (A) and closeup (B)



Plate 87C. UCM 2518 RB. *Kouphichnium aspodon*.



Plate 87D. UCM 388 AA. *Kouphichnium aspodon*.



Plate 88A. UCM 477 BR. *Kouphichnium aspodon*.



Plate 88B. UCM 827 DM. *Kouphichnium aspodon*.



Plate 88C. UCM 902 BR. *Kouphichnium aspodon*.

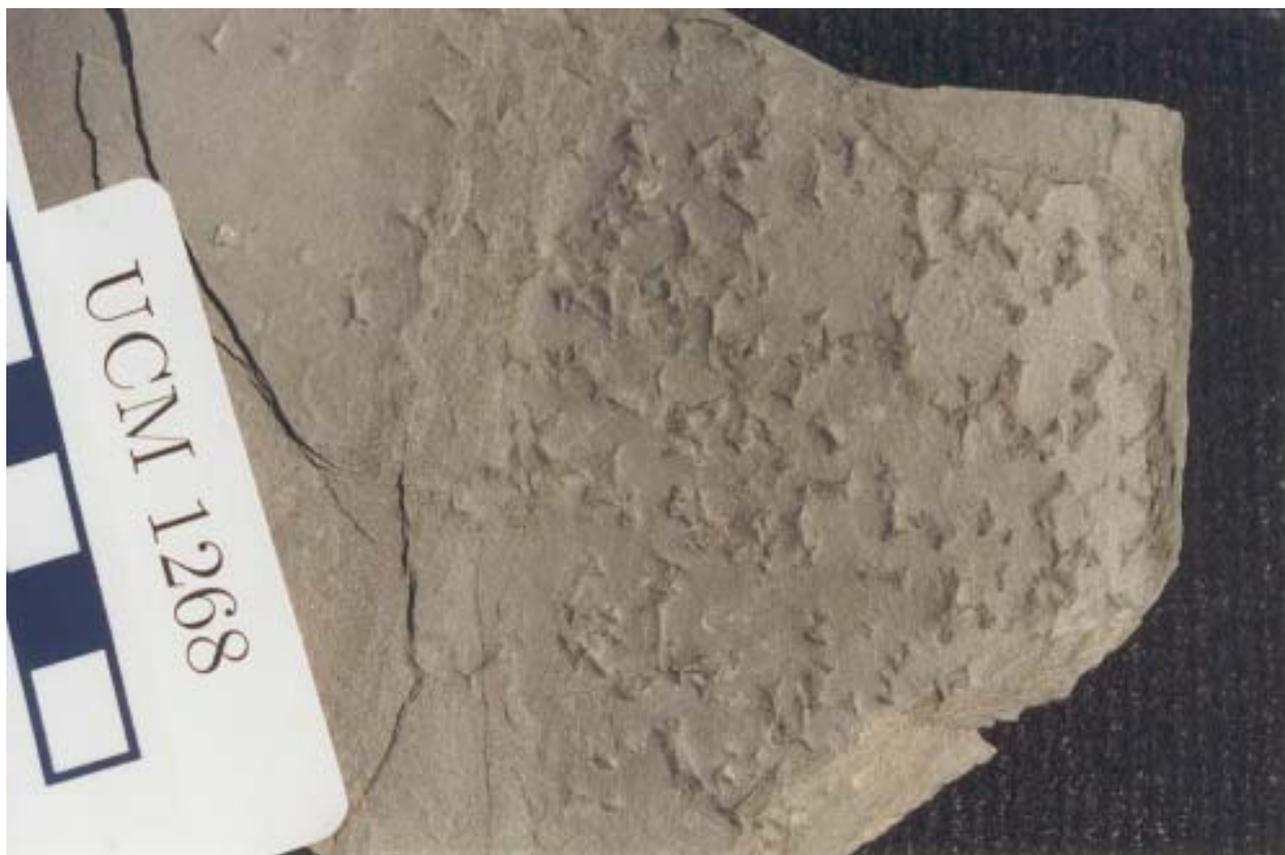


Plate 89A. UCM 1268 RB. *Kouphichnium aspodon*, multiple trackways.



Plate 89B. UCM 1505 RB. *Kouphichnium aspodon*.

**CASE STUDY OF INVERTEBRATE TRACE FOSSILS FROM A SINGLE BOULDER:  
HIGH DENSITY XIPHOSURAN TRACKWAYS AND RESTING TRACES**

All of the slabs in this section came from a single large boulder 0.3-0.5m thick. Included with the invertebrate tracks, but at a different horizon, were the tetrapod tracks shown in Plate 21.



Plate 90A. UCM 1737 RB. *Kouphichnium* isp.



Plate 90B. UCM 1738 RB. *Kouphichnium* isp., with gas-escape structures.



Plate 91A. UCM 1735 RB. *Kouphichnium* isp., with gas-escape structures.



Plate 91B. UCM 1735 RB. *Kouphichnium* isp., closeup of central imprint, rotated with respect to Plate 91A.



Plate 91C. UCM 1740 RB. *Kouphichnium* isp., with gas-escape structures.



Plate 92A. UCM 1742 RB. *Kouphichnium* isp.



Plate 92B. UCM 1742 RB. *Kouphichnium* isp., closeup of Plate 92A.



Plate 93A. UCM 1744 RB. *Kouphichnium* isp.



Plate 93B. UCM 1748 RB. *Kouphichnium* isp., with gas-escape structures.



Plate 94A. UCM 1749 RB. *Kouphichnium* isp.



Plate 94B. UCM1749 RB. *Kouphichnium* isp., closeup of right part of Plate 94A.



Plate 94C. UCM1749 RB. *Kouphichnium* isp., closeup of left part of Plate 94A.

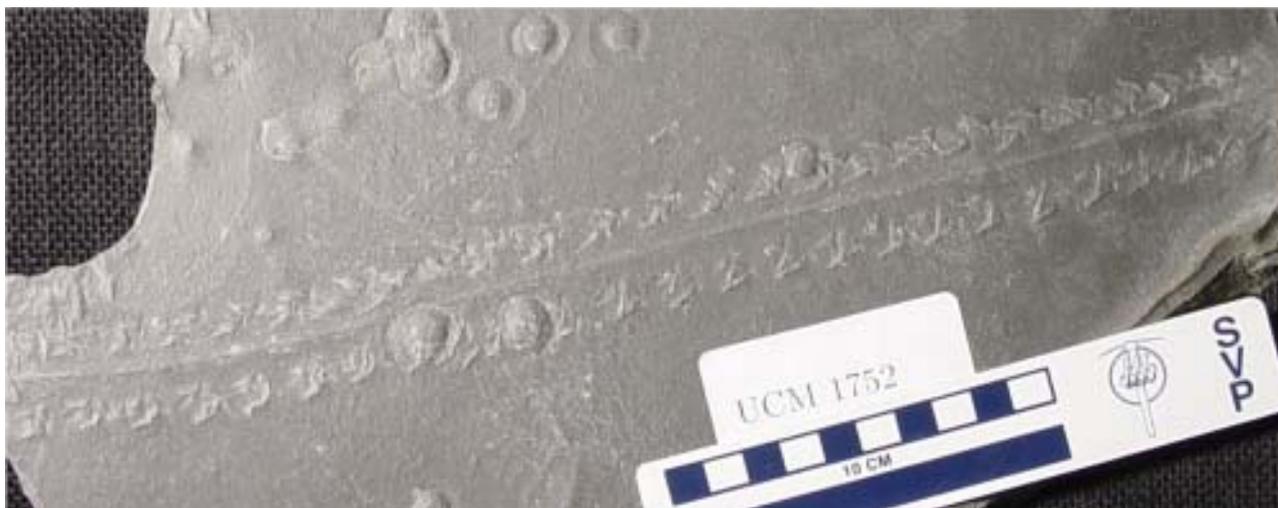


Plate 95A. UCM 1752 RB. *Kouphichnium* isp., with gas-escape structures.



Plate 95B. UCM 1755 RB. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 95C. UCM 1762 RB. Unassigned ichnotaxon, showing repeated xiphosuran resting traces.



Plate 96A. UCM 1757 RB. *Kouphichnium* isp.



Plate 96B. UCM 1757 RB. *Kouphichnium* isp., closeup of Plate 96A.

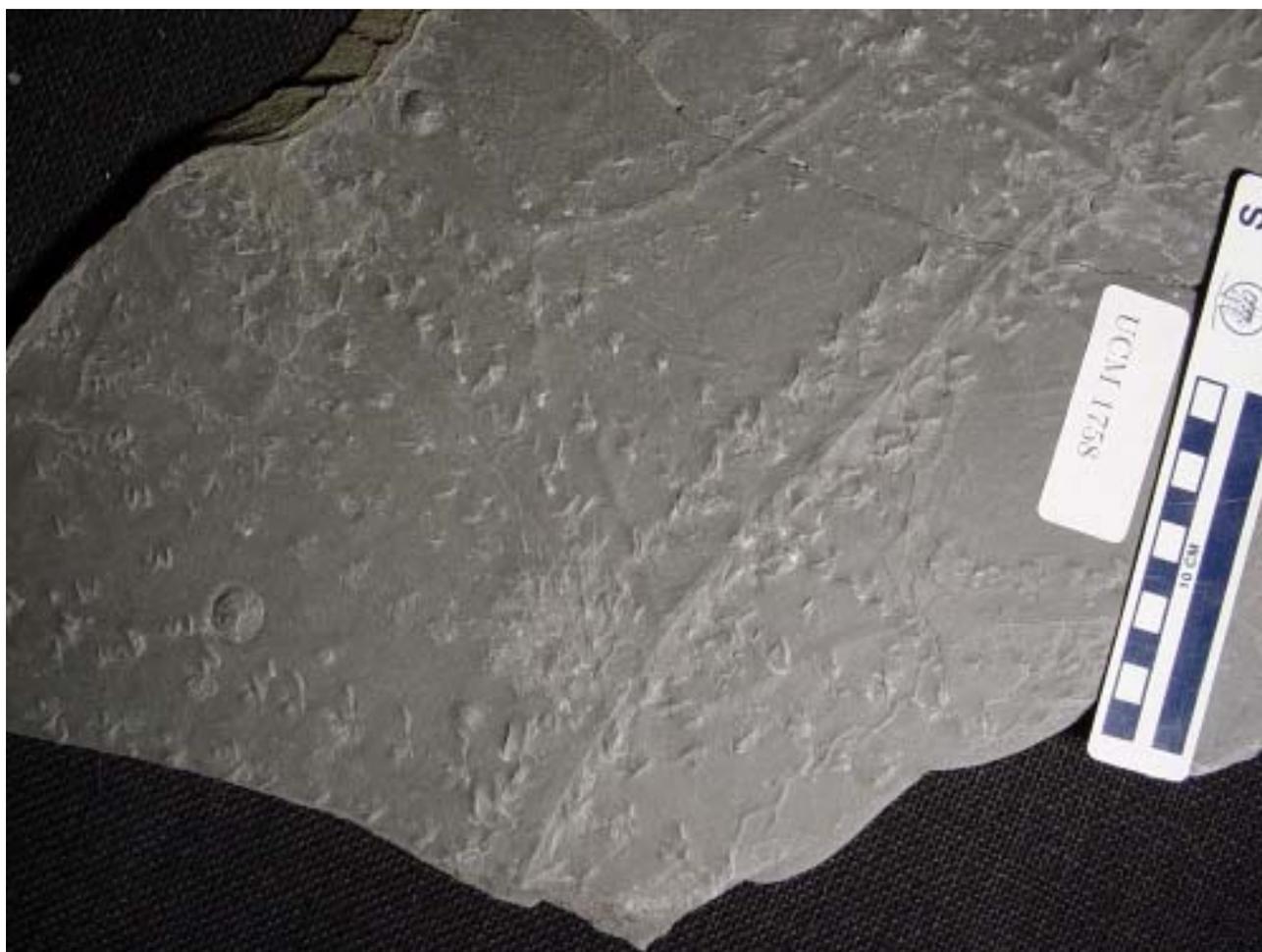


Plate 97A. UCM 1758 RB. *Kouphichnium* isp.

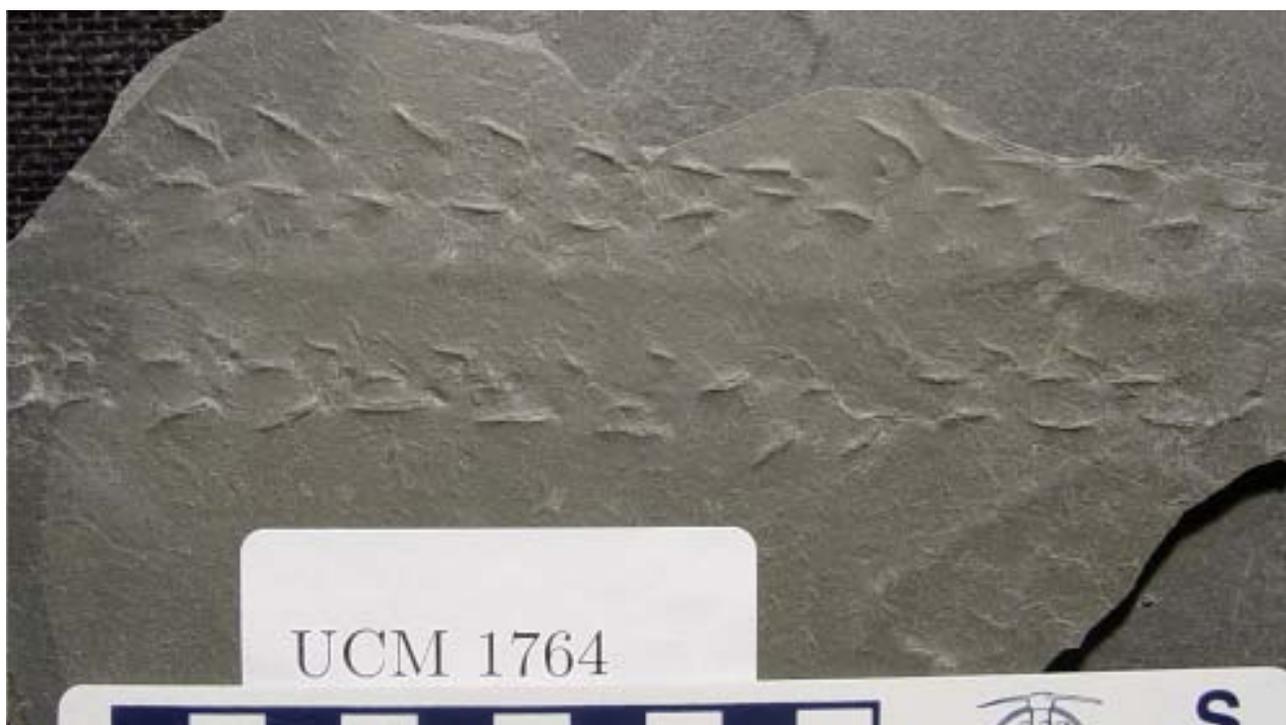


Plate 97B. UCM 1764 RB. *Kouphichnium* isp.



Plate 98A. UCM 1761 RB. *Koupichnium* isp., with *Treptichnus apsorum* and gas-escape structures.

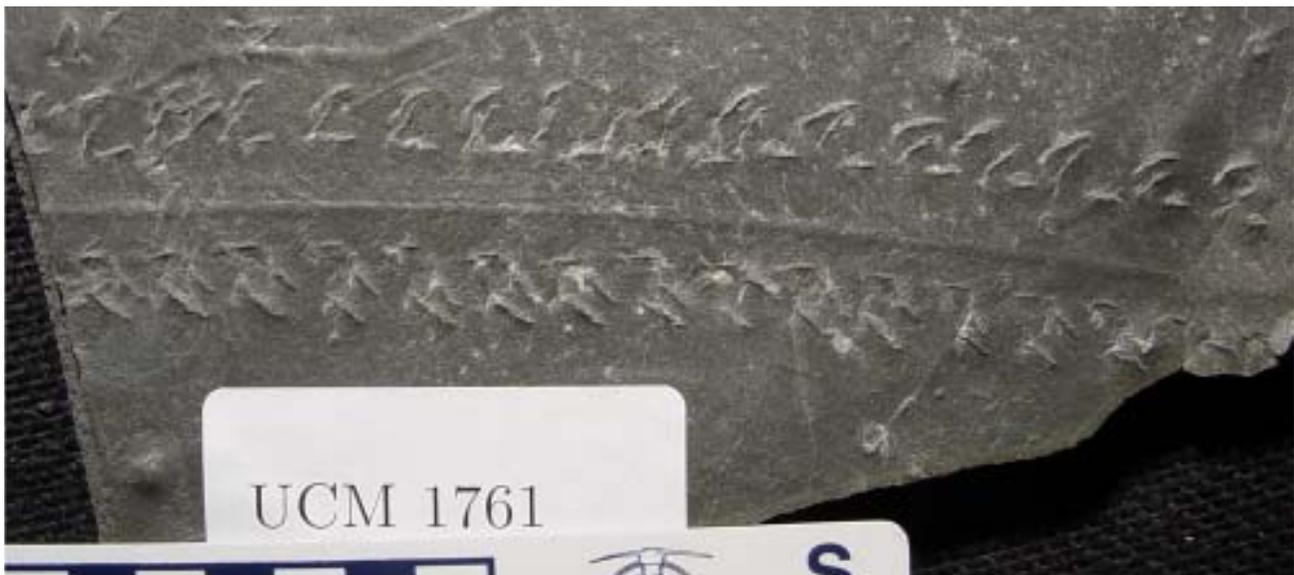


Plate 98B. UCM 1761 RB. *Koupichnium* isp., closeup of Plate 98A.



Plate 99A. UCM 1767 RB. *Kouphichnium* isp., with unassigned resting traces.

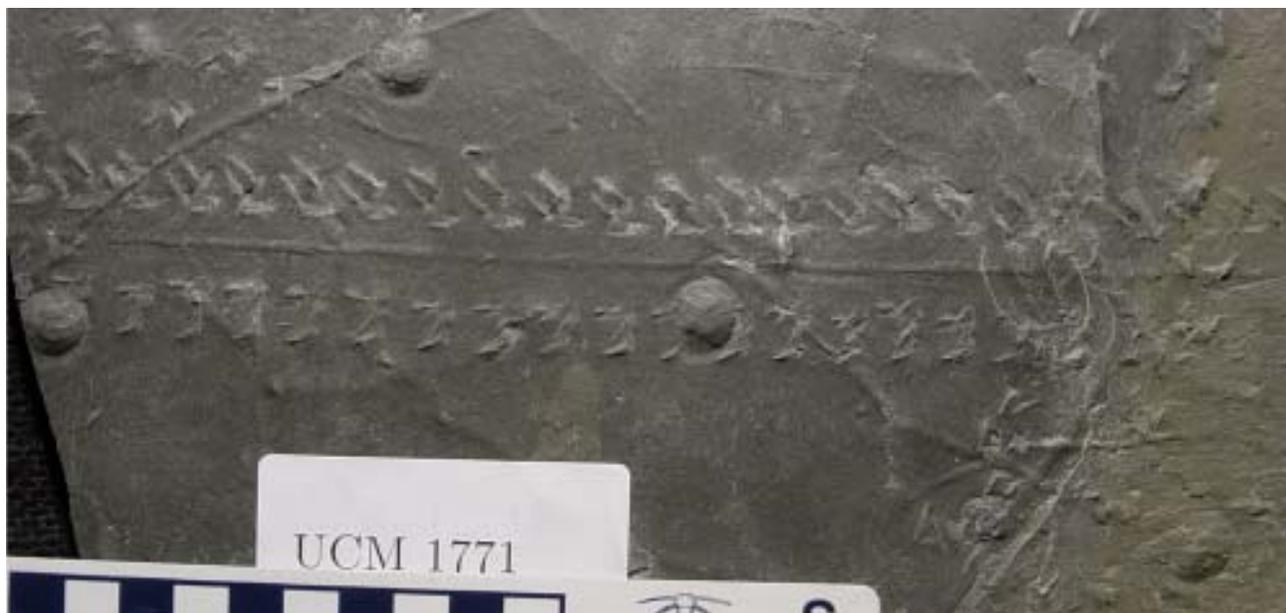


Plate 99B. UCM 1771 RB. *Kouphichnium* isp., with *Treptichnus apsorum* and gas-escape structures.



Plate 99C. UCM 1772 RB. *Kouphichnium* isp.

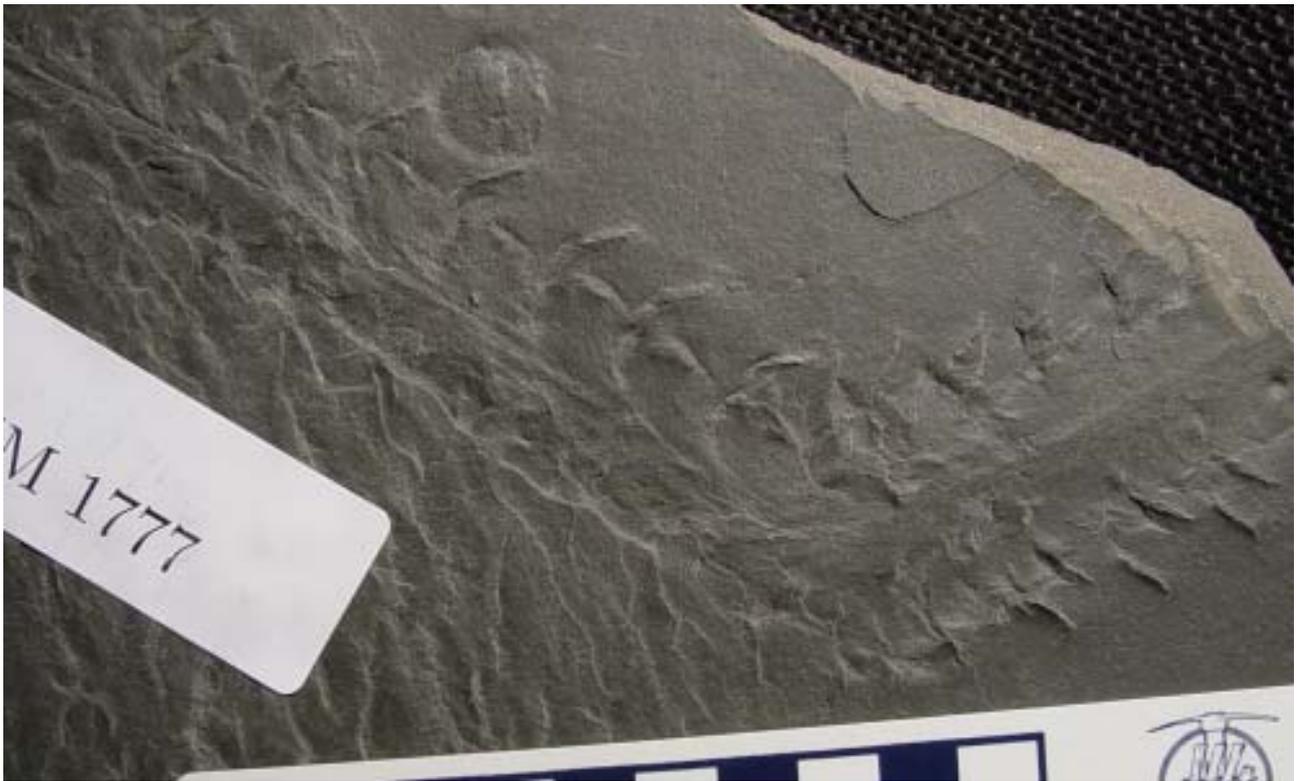


Plate 100A. UCM 1777 RB. *Kouphichnium* isp.



Plate 100B. UCM 1780 RB. *Kouphichnium* isp.

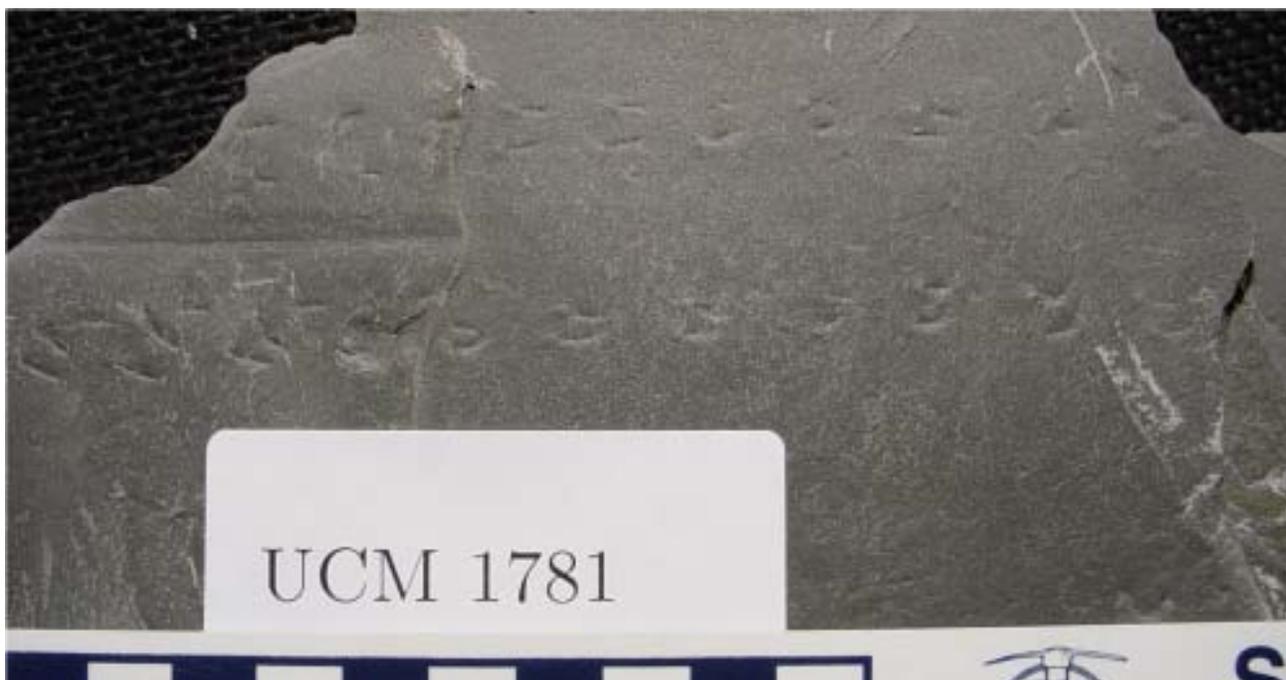


Plate 101A. UCM 1781 RB. *Kouphichnium* isp., the same trackway seen on two laminae.

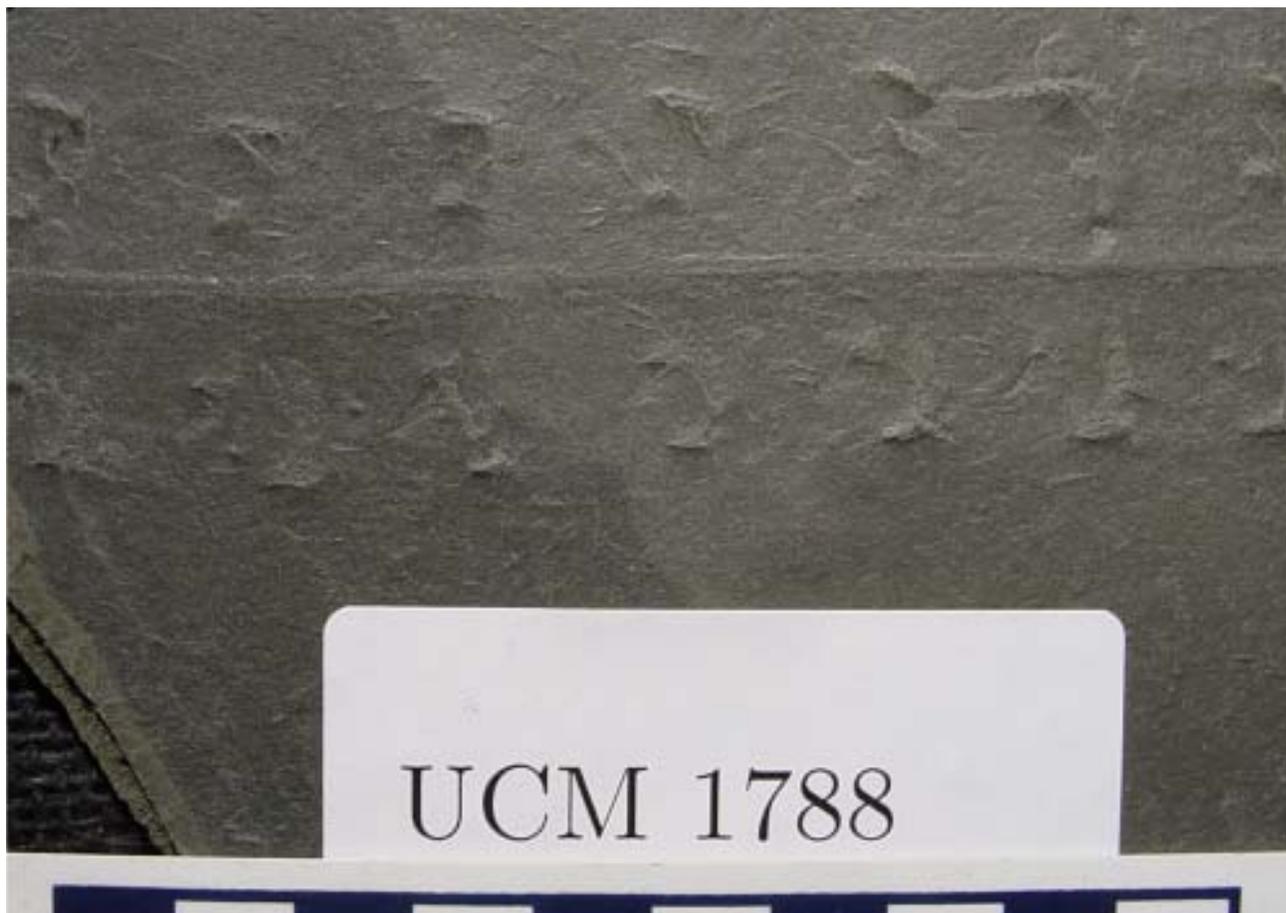


Plate 101B. UCM 1788 RB. *Kouphichnium* isp.

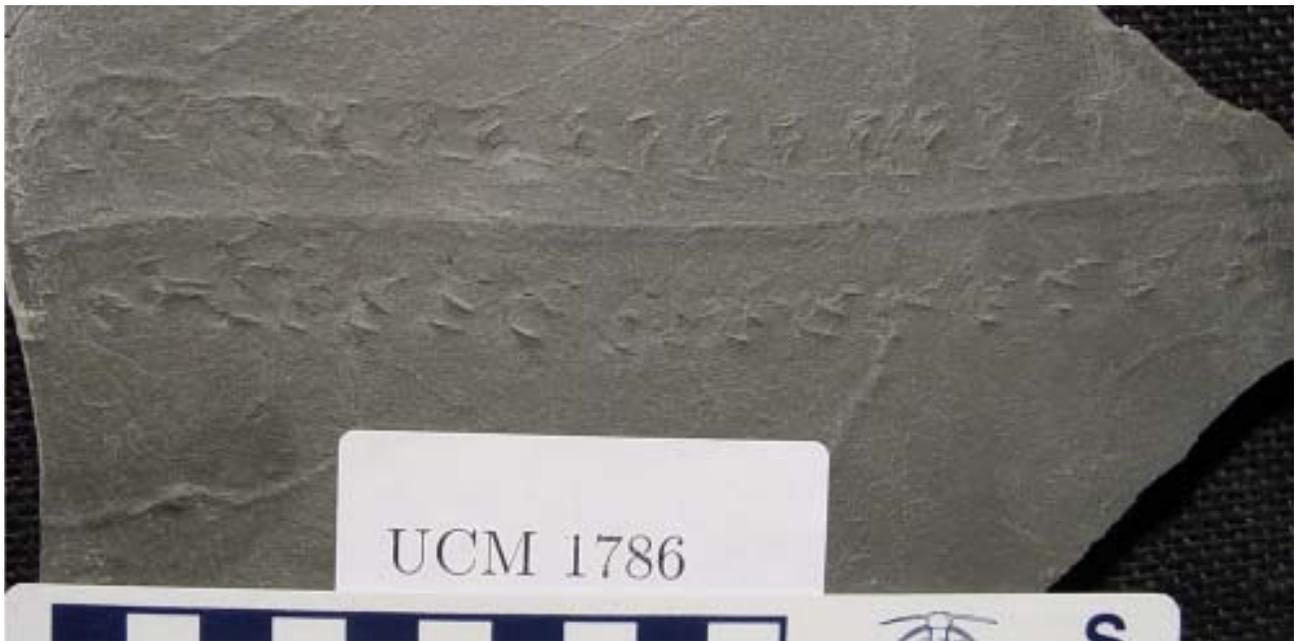


Plate 102A. UCM 1786 RB. *Kouphichnium* isp.

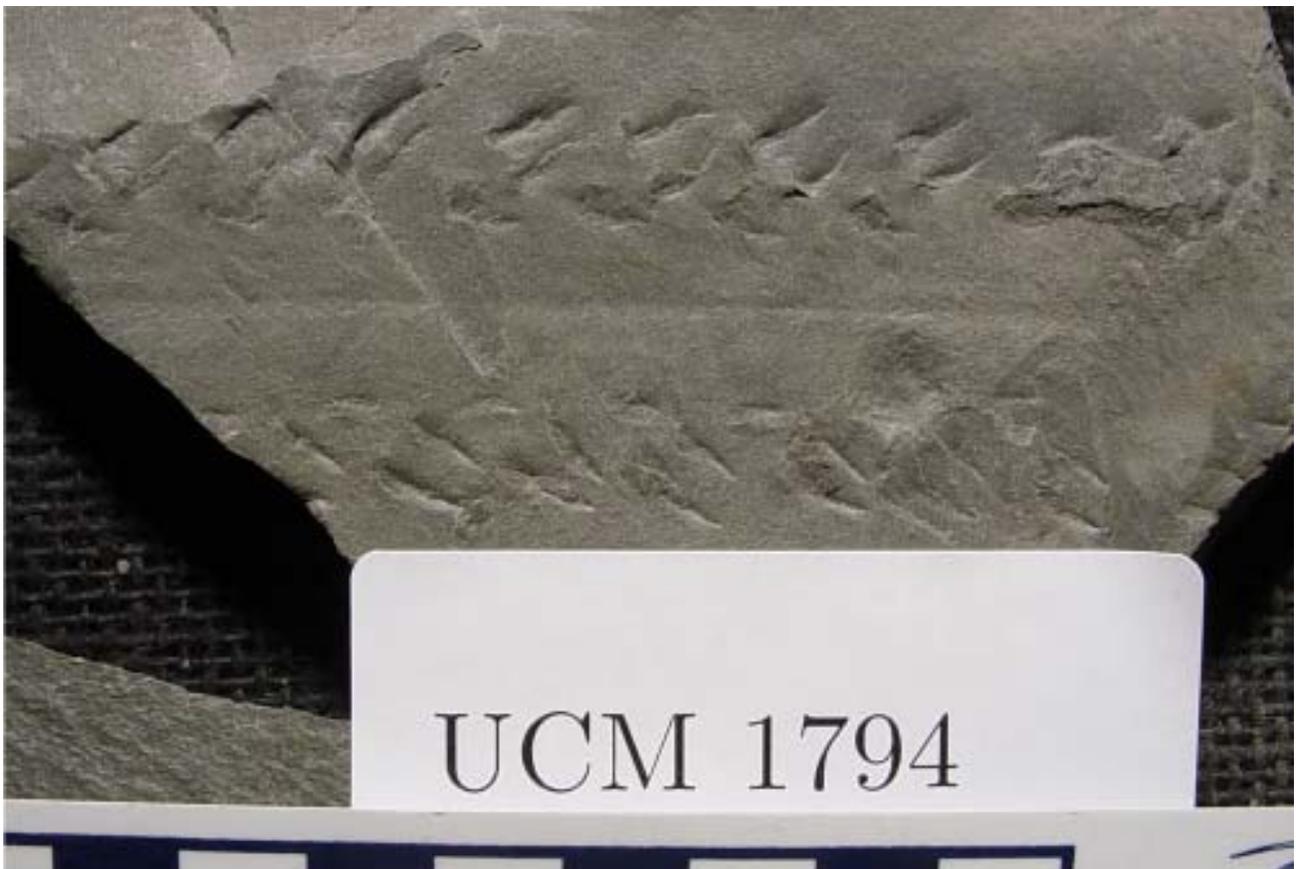


Plate 102B. UCM 1794 RB. *Kouphichnium* isp.

**XIPHOSURAN RESTING TRACES**  
Ichnotaxon: *Arborichnus repetitus*



Plate 103A. UCM 743 RB. *Arborichnus repetitus*.



Plate 103B. UCM 1495 RB. *Arborichnus repetitus*.



Plate 104A. UCM 1152 RB. *Arborichnus repetitus*.



Plate 104B. UCM 1153 RB. *Arborichnus repetitus*.



Plate 105A. UCM 1154 RB. *Arborichnus repetitus*.



Plate 105B. UCM 1156 RB. *Arborichnus repetitus*.



Plate 106A. UCM 1157 RB. *Arborichnus repetitus*.



Plate 106B. UCM 888 GD. *Arborichnus repetitus*.

**MYRIAPOD TRACES**  
Ichnotaxon: *Diplichnites gouldi*



Plate 107A. UCM 393 AA. *Diplichnites gouldi*.



Plate 107B. UCM 394 AA. *Diplichnites gouldi*.



Plate 107C. UCM 666 RB. *Diplichnites gouldi*.



Plates 108A, B. UCM 953 BR. *Diplichnites gouldi*, trackway (A) and closeup (B). Counterpart of UCM 954 BR shown in Plate 108C.



Plate 108C. UCM 954 BR. *Diplichnites gouldi*.



Plate 108D. UCM 1370 RB. *Diplichnites gouldi*.



Plate 108E. UCM 1370 RB. *Diplichnites gouldi*, closeup of left part shown in Plate 108D.



Plates 109A, B. UCM 1820 DA. *Diplichnites gouldi*, full view (A) and closeup of central section (B).



Plate 109C. UCM 1267 RB. cf. *Diplichnites*.



Plate 110A. UCM 370 AA. *Diplichnites gouldi*.



Plate 110B. UCM 2466 RB. *Diplichnites gouldi*, on same surface as other invertebrate traces (plate 84B)



Plate 110C. UCM 2528 RB. cf. *Diplichnites*, on same surface as *Attenosaurus subulensis* (see plate 35A).

**INSECT BURROWS**

Ichnotaxa: *Treptichnus aporum*, *Arenicolites longistriatus*  
(see Rindsberg and Kopaska-Merkel, 2005)

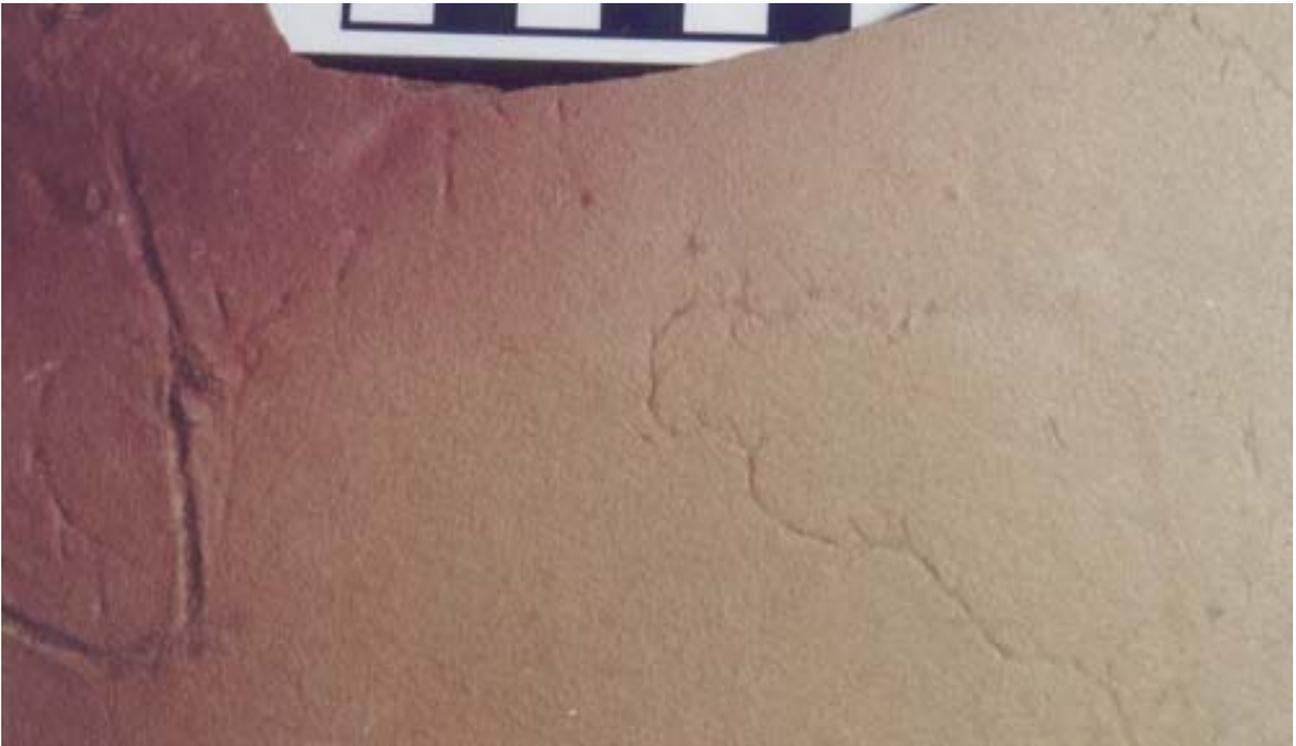


Plate 111A. UCM 92 TPA. *Treptichnus apsorum*. Note well-preserved burrow extensions past ends of U-burrow segments.



Plate 111B. UCM 143 BR. *Treptichnus apsorum*, *Planolites*-like aspect. Note that the burrows are made of distinct segments.

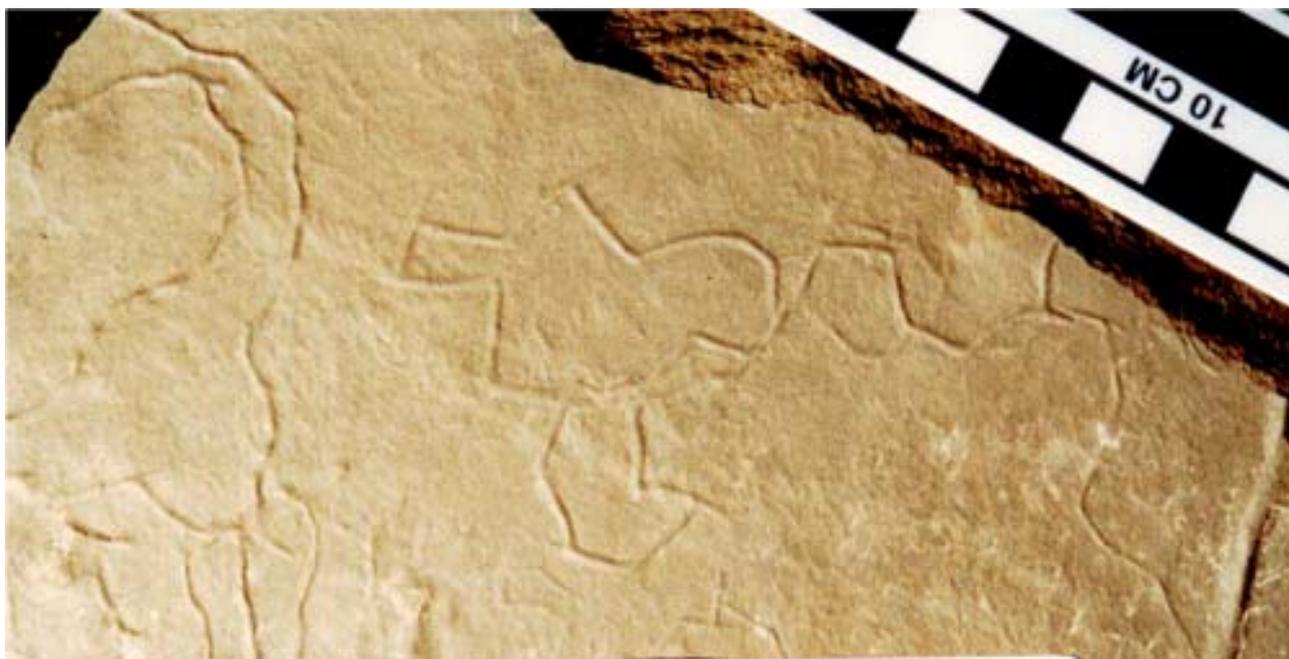


Plate 112A. UCM 147 BR. *Treptichnus apsorum*.

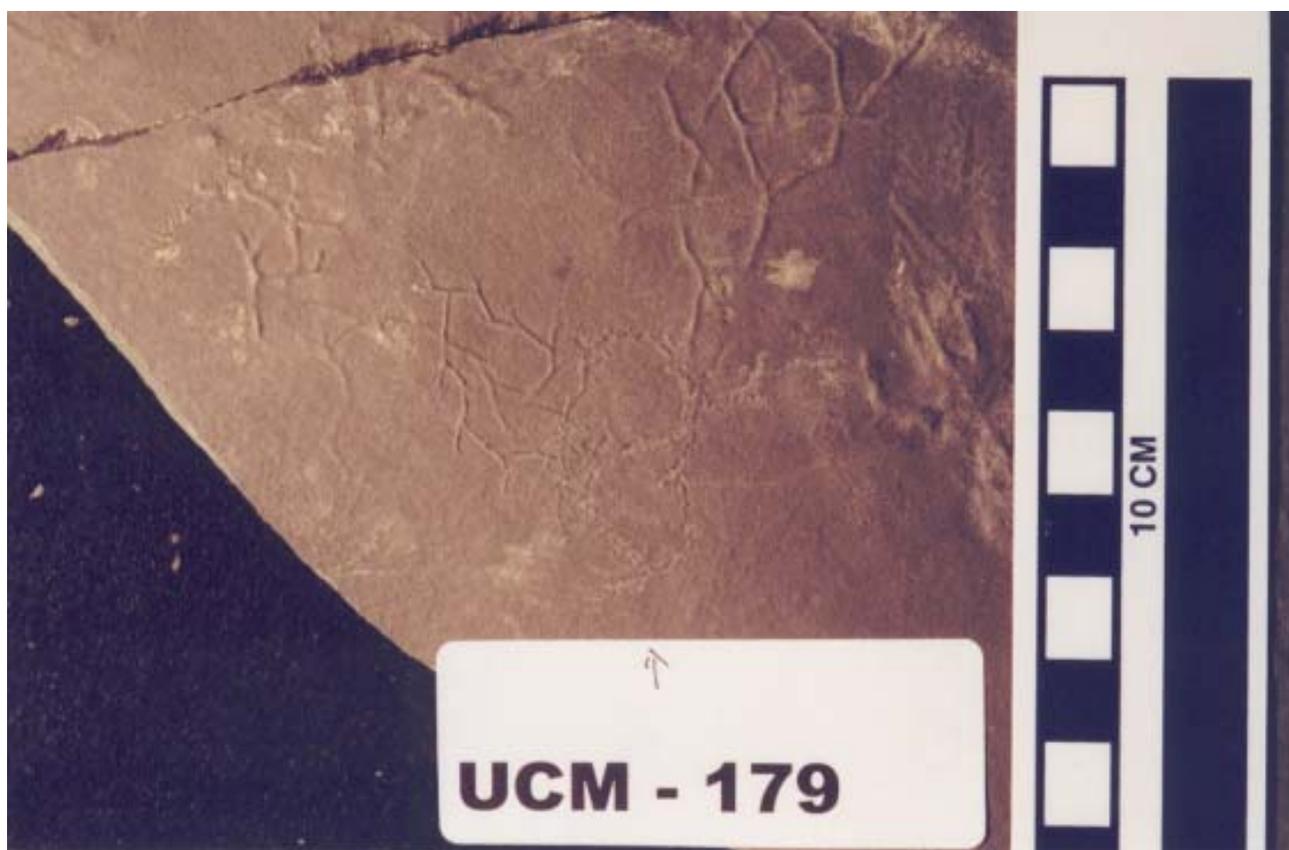


Plate 112B. UCM 179 BR. *Treptichnus apsorum*.



Plate 113A. UCM 180 BR. *Treptichnus apsorum* and *Arenicolites longistriatus*. These two trace fossils were both made by fly larvae or other arthropods behaving similarly.



Plate 113B. UCM 417 AA. *Treptichnus apsorum*. This horizon includes several specimens whose crossing mimics branching.



Plate 114A. UCM 419 AA. *Treptichnus apsorum*, *Arenicolites longistriatus*, and gas-escape structures.



Plate 114B. UCM 421 AA. *Treptichnus apsorum*.



Plate 115A. UCM 688 RB. *Treptichnus apsorum* and unidentified burrows.



Plate 115B. UCM 788 DKM. *Treptichnus apsorum*, *Arenicolites longistriatus*, and vertebrate trackway.



Plate 115C. UCM 1030 AA. *Treptichnus apsorum*, *Planolites*-like aspect.

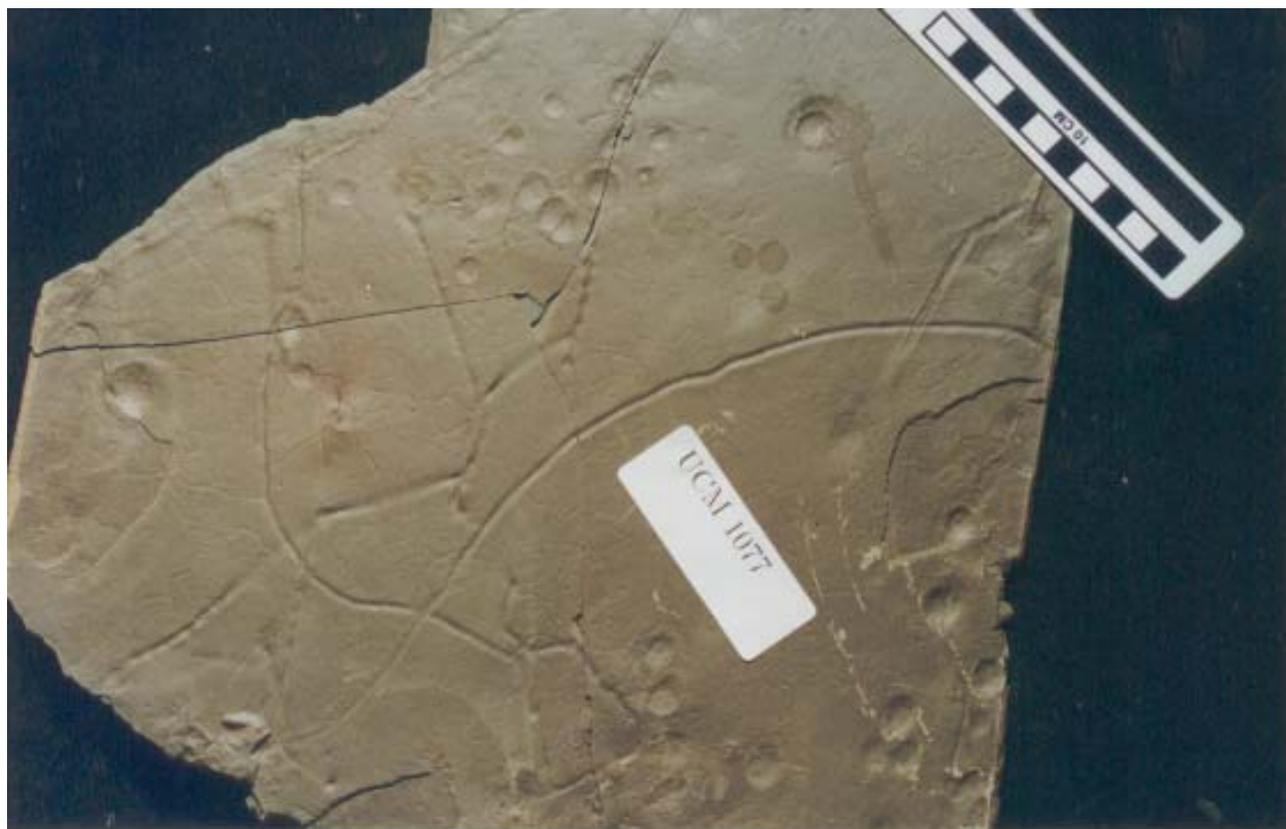


Plate 116A. UCM 1077 TPA. *Treptichnus apsorum* and *Arenicolites longistriatus*. Multiple specimens formed at different times.



Plate 116B. UCM 1805 RB. *Treptichnus apsorum*.



Stump cast of an arborescent lycopod collected from the Union Chapel Mine by Alabama Paleontological Society member Bruce A. Relihan in 2001. The specimen weighs 210 kg (460lb) and now resides on the grounds of the Anniston Museum of Natural History. Photo credit: Ron Buta.

## **ATLAS OF UNION CHAPEL MINE FOSSIL PLANTS**

DAVID L. DILCHER and TERRY A. LOTT

Florida Museum of Natural History, University of Florida, Gainesville, Florida 32611-7800, USA

This Plant Atlas is a compilation of photographs of the fossil plants that have been made available to us from the Union Chapel Mine, now the Steven C. Minkin Paleozoic Footprint Site. These specimens include those that were donated to the Paleobotanical Collection at the Florida Museum of Natural History (UF specimen numbers) and those photographed at “Track Meet 3 and Plant Fest”, a meeting held in Anniston, Alabama on May 12, 2001. The UCM-P numbers indicate specimens shown to DLD by private collectors that were photographed at this meeting and retained by the collectors. This Plant Atlas is an addition to the chapter on the Fossil Plants from the Union Chapel Mine, Alabama by Dilcher, Lott and Axsmith published in this monograph. Here we illustrate many more specimens than shown in the chapter on fossil plants including some plant fossils that are not illustrated or mentioned in the chapter.

Often a pictorial atlas is more useful and more appealing to both amateur and professional paleontologists. We present 112 pictures of the Union Coal Mine plants in 23 plates. A scale or scale bar (millimeter units) is included for each individual figure. A legend is prepared for each of the plates so that the specimens can be easily referenced. However the text and references given in Dilcher et al., (2005) should be consulted for more complete information about any specific specimen or species illustrated. This Plant Atlas should not be considered as a definitive list or compendium of plants from the Union Coal Mine, but as a working document illustrating those species known thus far. What is illustrated here should represent the more common species that occur in the roof shales of the mine. If in the future new species, not illustrated here, were found, it would be helpful if these could be included in the collection.

### **REFERENCE**

Dilcher, D., Lott, T. A., and Axsmith, B. J., 2005, Fossil plants from the Union Chapel Mine, Alabama; in Buta, R. J., Rindsberg, A. K. and Kopaska-Merkel, D. C., eds., Pennsylvanian Footprints in the Black Warrior Basin of Alabama: Alabama Paleontological Society Monograph no. 1, p. 153-168.

### **AUTHORS' E-MAIL ADDRESSES**

David L. Dilcher: [dilcher@flmnh.ufl.edu](mailto:dilcher@flmnh.ufl.edu)  
Terry A. Lott: [lott@flmnh.ufl.edu](mailto:lott@flmnh.ufl.edu)



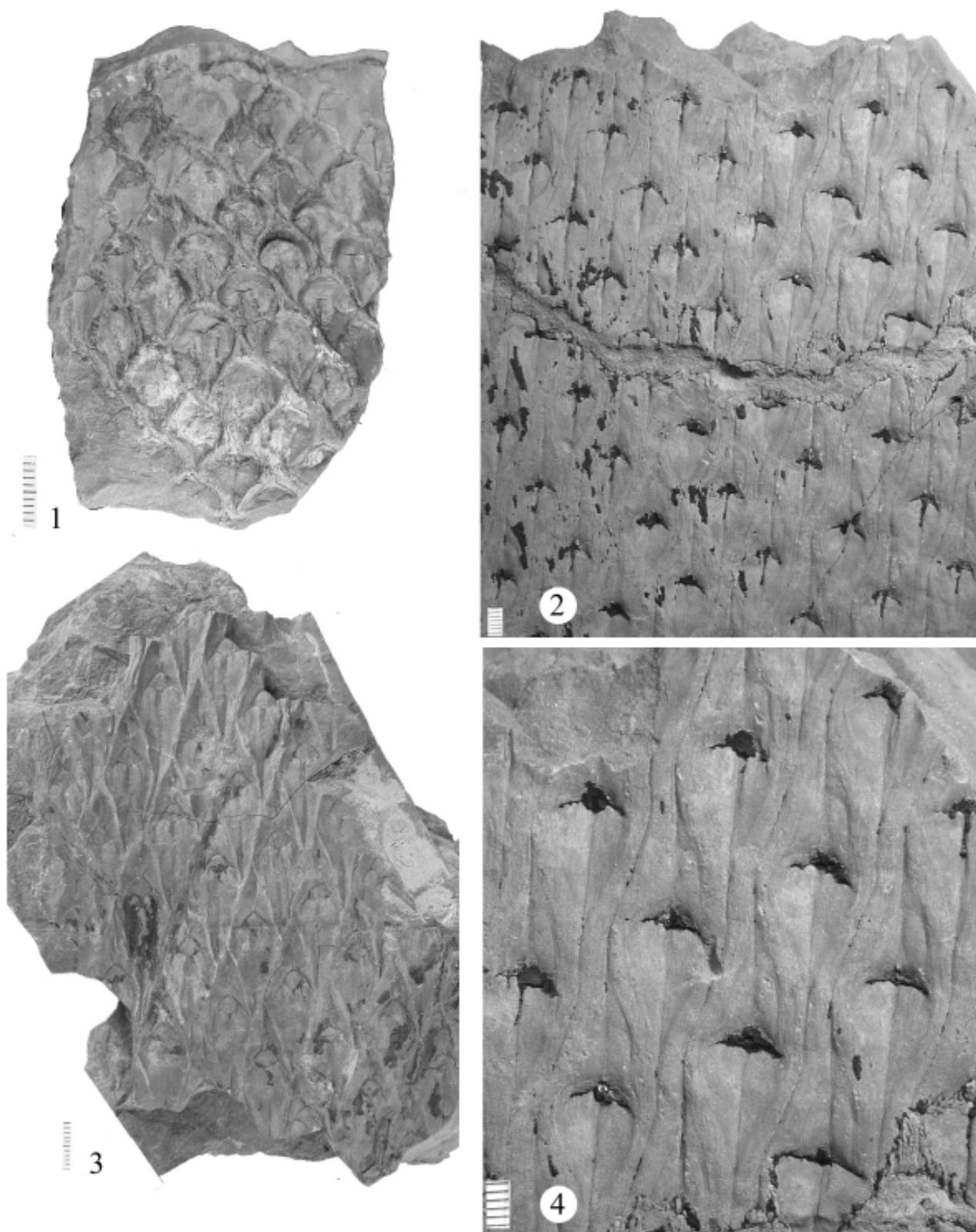


Plate 117. Figure 1: *Lepidodendron obovatum* UF 34008, leaf cushions on branch or young trunk of the tree. Figures 2-4: *Lepidodendron aculeatum* Fig. 2 and 4, UCM-P 173; Fig. 4 is an enlargement of Fig. 2 showing the details of the leaf cushions and leaf attachment area often still containing carbon residue; Fig. 3, UF 34014. All specimens represent *Lepidodendron* branches or trunks not yet decorticated.

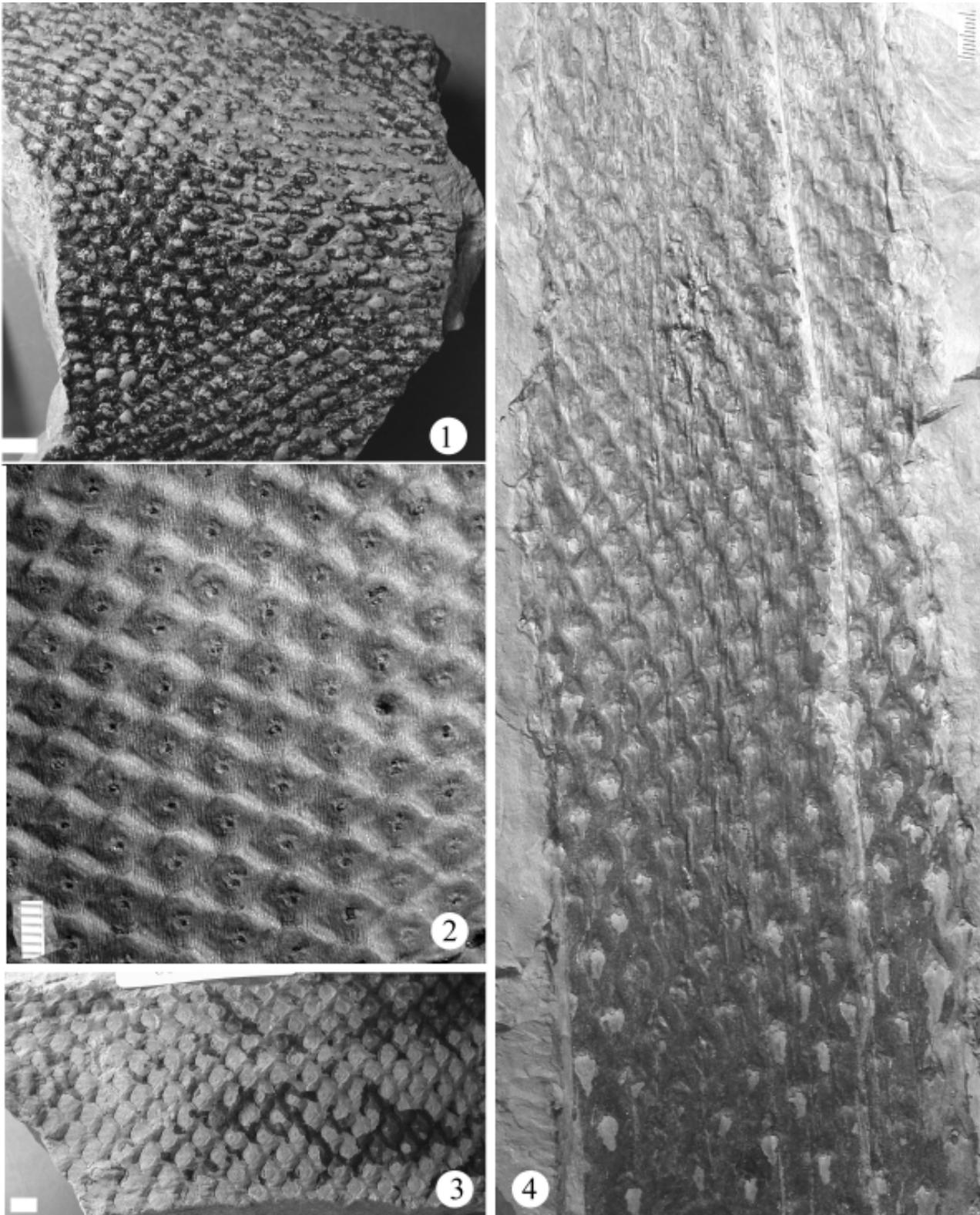


Plate 118. Figure 1, 2, 3 *Lepidophloios laricinus* Fig. 1, UCM-P 155; Fig. 2, UCM-P 159; Fig. 3, UCM-P 160. Fig. 2 shows the typical wide triangular-shape of *Lepidophloios* leaf cushion with the leaf scar in the lower half of the cushion. Immediately above the leaf scar is a ligule scar. Fig. 3 is orientated sideways. Figure 4: *Lepidodendron obovatum* UCM-P 015 larger axis not yet decorticated showing leaf cushions.

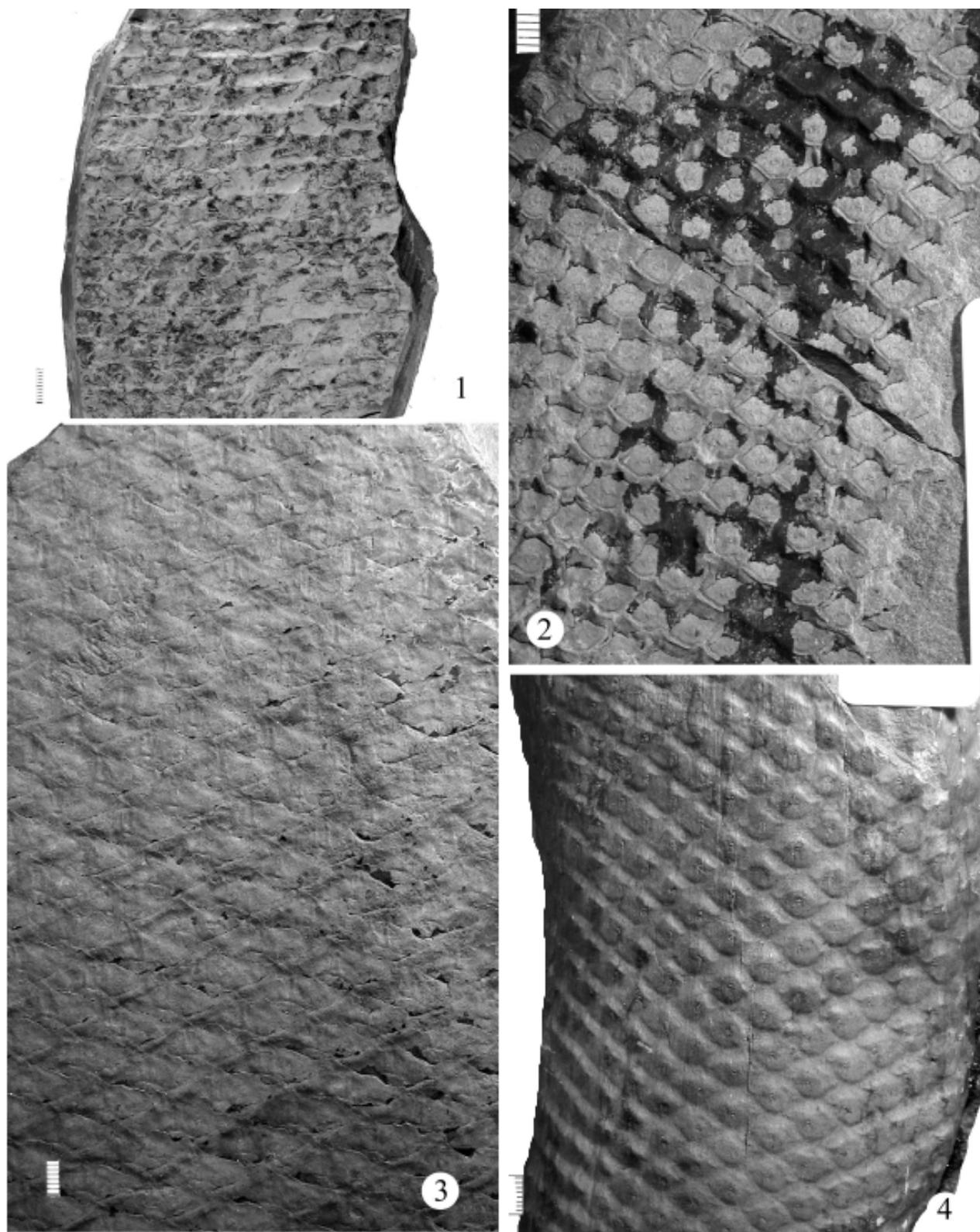


Plate 119. Figures 1, 3, 4: *Lepidophloios laricinus* Fig. 1, UF 34371; Fig. 3, UCM-P 172; Fig. 4, UCM-P 180. Figs. 1 and 3 show the typical laterally elongated diamond-shape of the leaf cushions of *Lepidophloios*. Fig. 3 shows the nature of the overlapping leaf cushions. Figure 4 illustrates this species in a slightly decorticated condition in which only the outer most bark layer is lost. This might be considered by the name *Aspidaria*. Figure 2: *Sigillaria elegans* UCM-P 165. More or less isodiametric leaf scars. In several scars the central vascular leaf trace, bordered on either side by cleft-shaped parichnos scars, can be seen. Rarely the ligule scar at the top of the leaf scar can be seen.

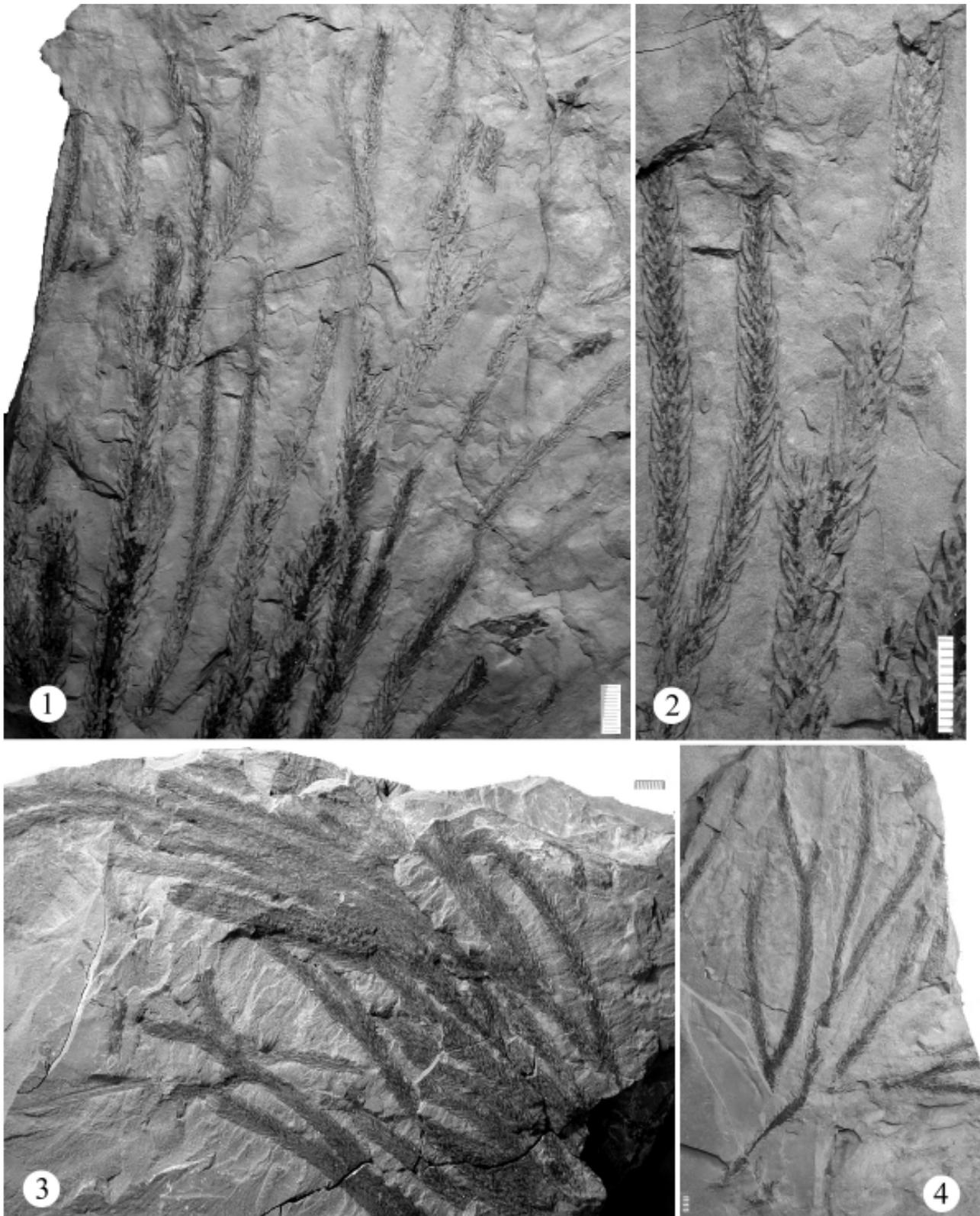


Plate 120. Figure 1-4: *Lepidodendron lycopodioides* Fig. 1 and 2, UCM-P 221, Fig. 2 is an enlargement of Fig. 1; Fig. 3, UCM-P 163; Fig. 4, UCM-P 224. Terminal branches of a *Lepidodendron* tree showing their elongate nature, dichotomous branching and attached leaves.

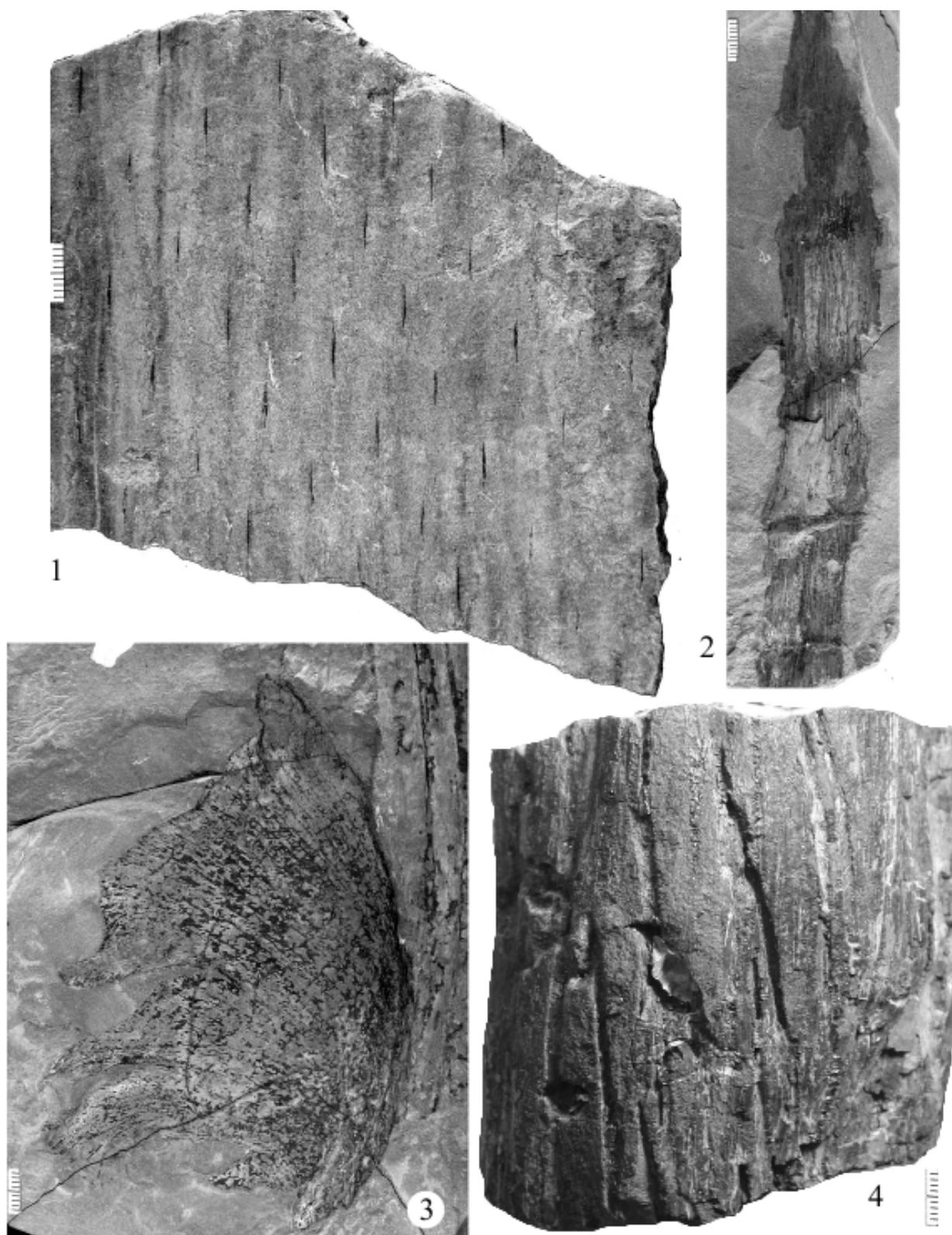


Plate 121. Figure 1: *Aspidiopsis* sp. UF 34013. Deeply decortified layer or internal cast of the innermost layer of the tough and thick outer cortex of a Lycopod tree or large branch. The scars are produced by the steeply arching vascular tissue for the numerous leaves that transverse this tissue from the inner vascular cylinder to the outer surface of the tree. Figure 2: *Calamites* sp. UF 33985. Poorly preserved pith cast of a *Calamites* stem or branch. Figure 3: *Cyclopteris* sp. UF 34046'. A vegetative specialized leaf that often occurs at the base of a larger frond or leaf of seed ferns. This is somewhat like a stipule in flowering plants. Figure 4: Branch UCM-P 200. A stem or branch cast of undetermined affinities. Perhaps fern or seed fern in nature.

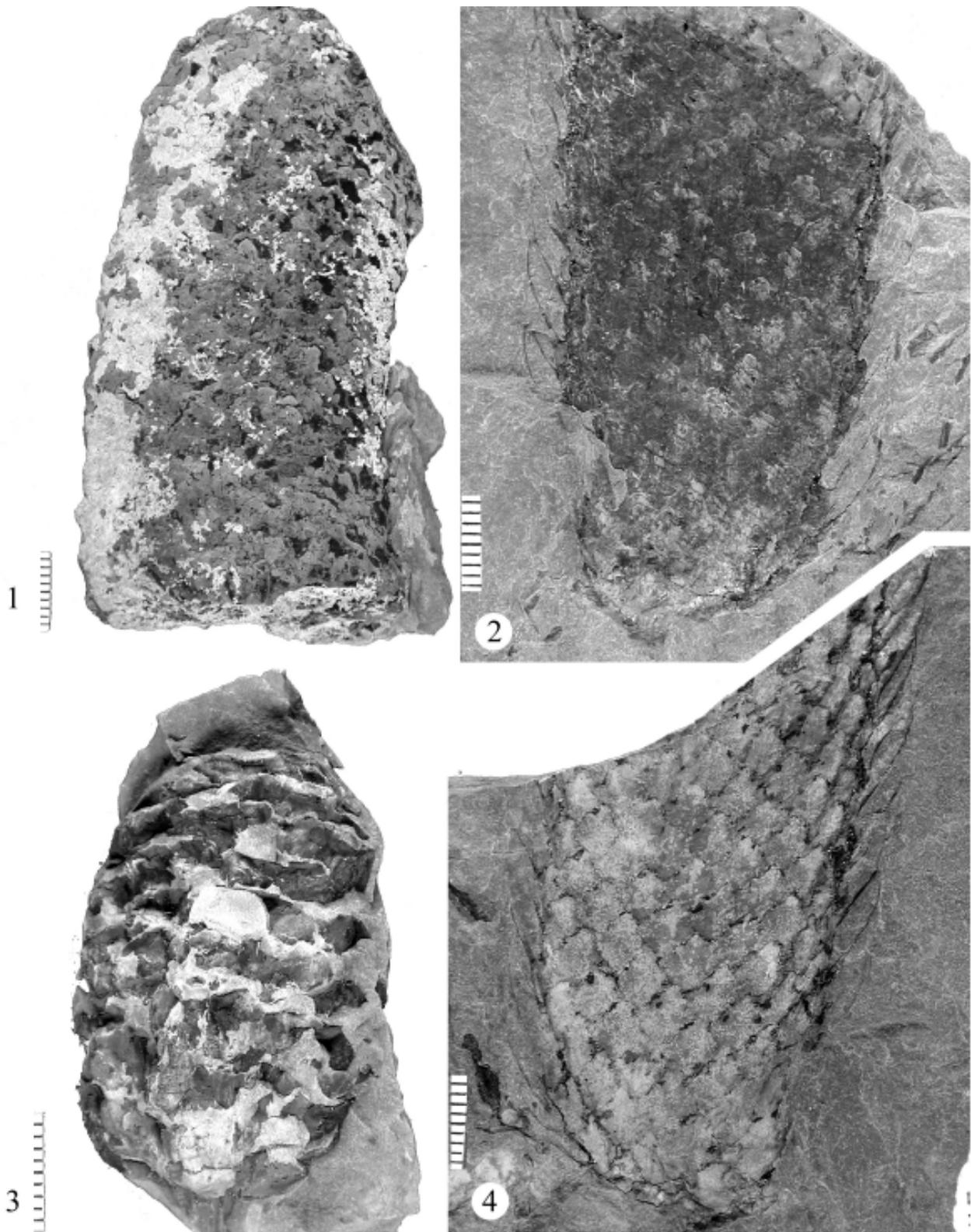


Plate 122. Figure 1, 3: *Lepidostrobus* sp. B Fig. 1, UF 34375; Fig. 3, UF 34042. Casts of lycopod cones showing the leaf-like overlapping sporophylls in broken, face on position and sometimes the hollow areas between them where the sporangia were located can be seen (esp. in Fig 3). Figure 2, 4: *Lepidostrobus* sp. A Fig. 2, UF 33933'; Fig. 4, UF 33993. Part and counterpart of a lycopod cone compression showing the overlapping sporophylls and their leaf-like terminal tips along the cone margins.

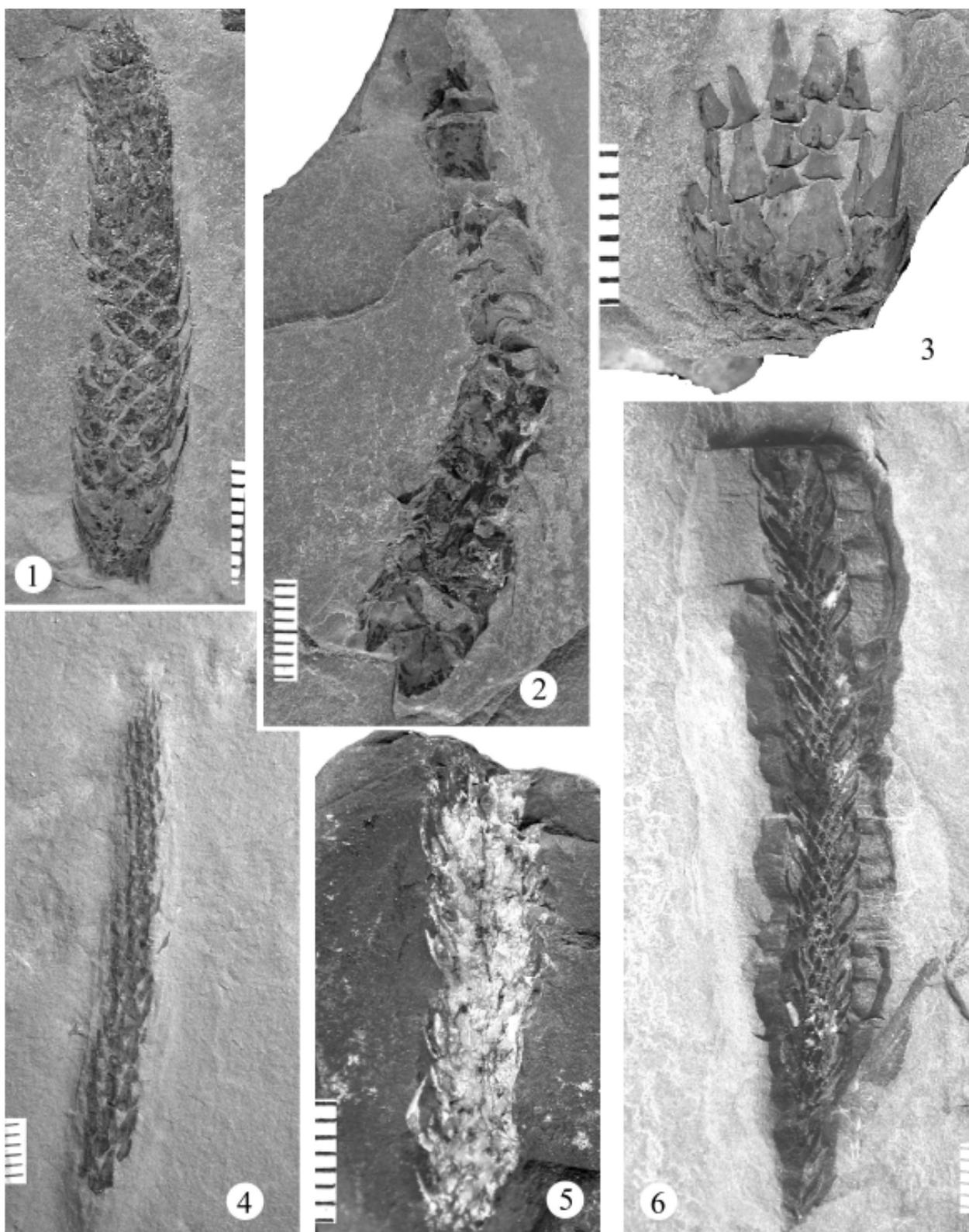


Plate 123. Figure 1, 5: *Lepidostrobus* sp. A Fig. 1, UF 34007; Fig. 5, UF 34372. Compressions of lycopod cones showing overlapping sporophylls. Figure 2: *Sigillariostrobus quadrangulatus* UF 34367. Compression of a cone of *Sigillaria*. It has the typical angular pattern. Figure 3: *Lepidostrobus* sp. B UF 34365. Compression of the base of a cone or portion of a broken cone showing the broad nature of the sporophyll lamina as it extends past the sporangia and how they taper to a leaf-like tip. This is very much like the compression of what is named *Lepidocarpon* when it is found petrified. This means the cone was female and produced megaspores. Figure 4, 6: *Lepidodendron lycopodioides* Fig. 4, UCM-P; Fig. 6, UCM-P 219. Near terminal branches of lycopod trees.

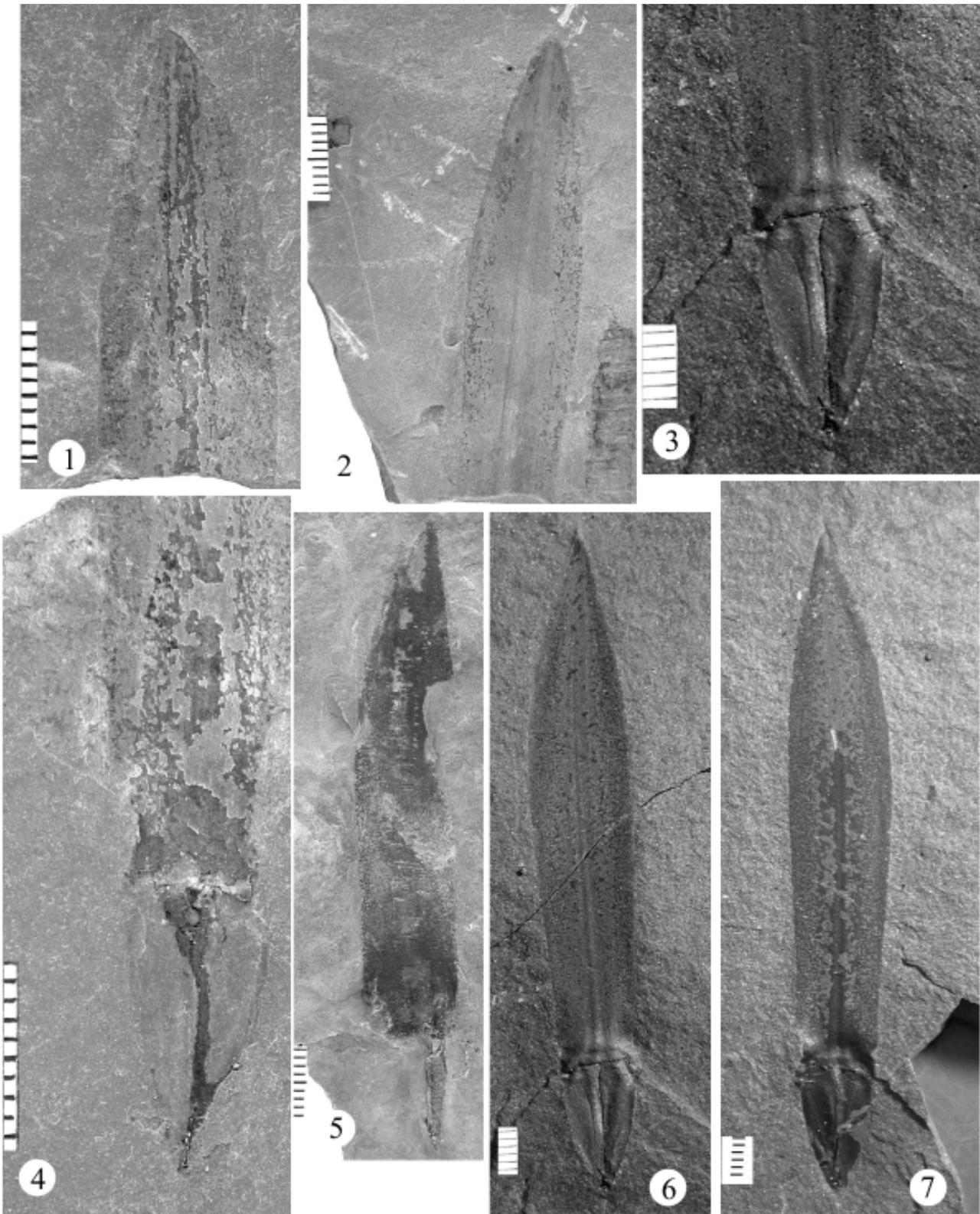


Plate 124. Figure 1-6: *Lepidostrobophyllum* cf. *majus* Fig. 1, UF 34374; Fig. 2, UF 34369a; Fig. 3, UCM-P 154, an enlargement of Figure 6; Fig. 4, UF 34374; Fig. 5, UF 34377; Fig. 6, UCM-P 154; Fig. 7, UCM-P 153. Compressions of the typical dispersed sporophylls.

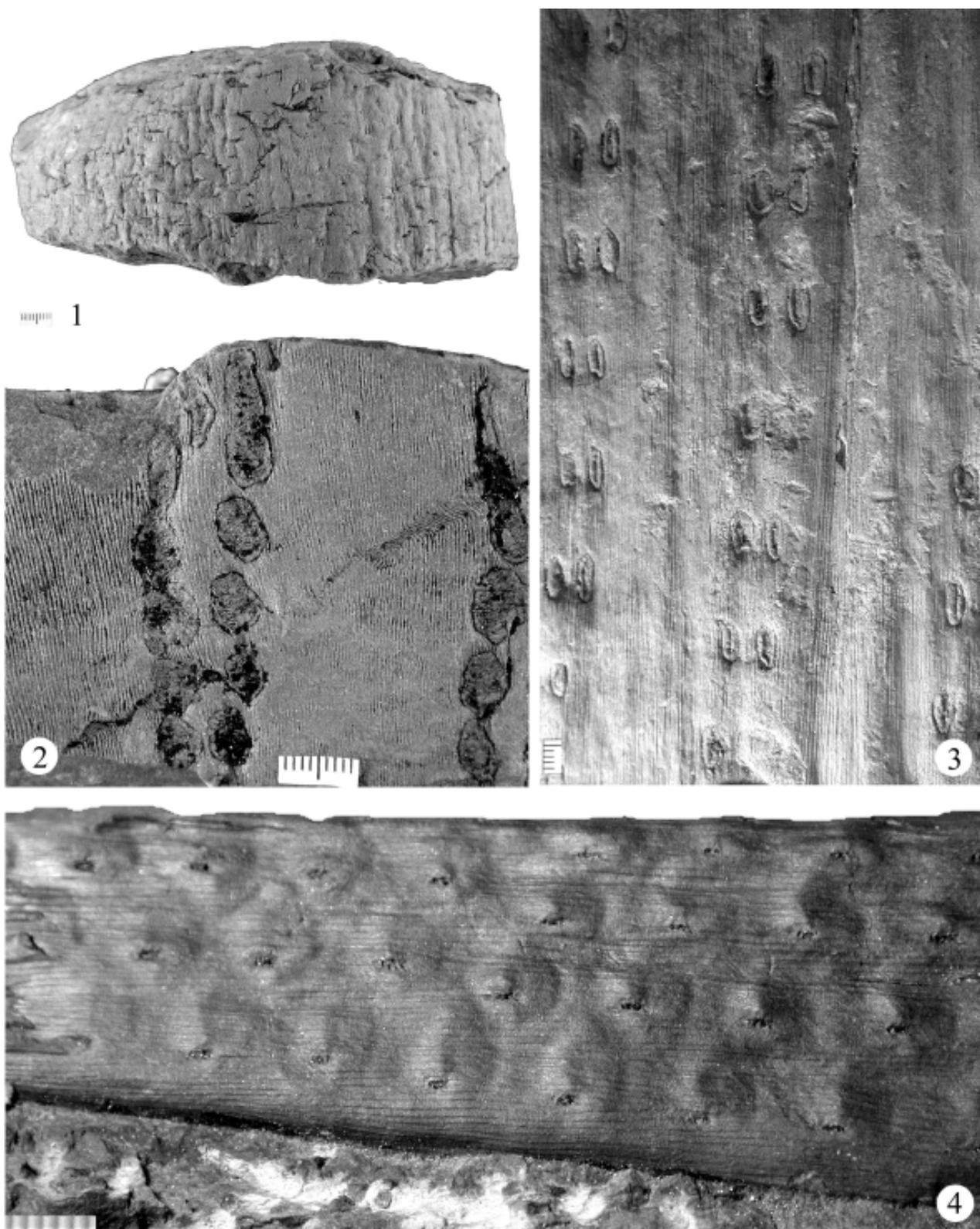


Plate 125. Figure 1-4: *Syringodendron* sp. Fig. 1, UF 34379; Fig. 2, UF34016; Fig. 3, UCM-P 162; Fig. 4, UCM-P. Fig. 1 is an internal cast of a small *Sigillaria* stem or branch. Figs. 2 and 3 clearly show the parichnos scars that formed from the thin walled tissue important in allowing the transport of oxygen through the thick periderm layers to the inner tissues of the stems and few branches of the sigillarian trees. Fig. 4, decorticated stem of *Sigillaria*.

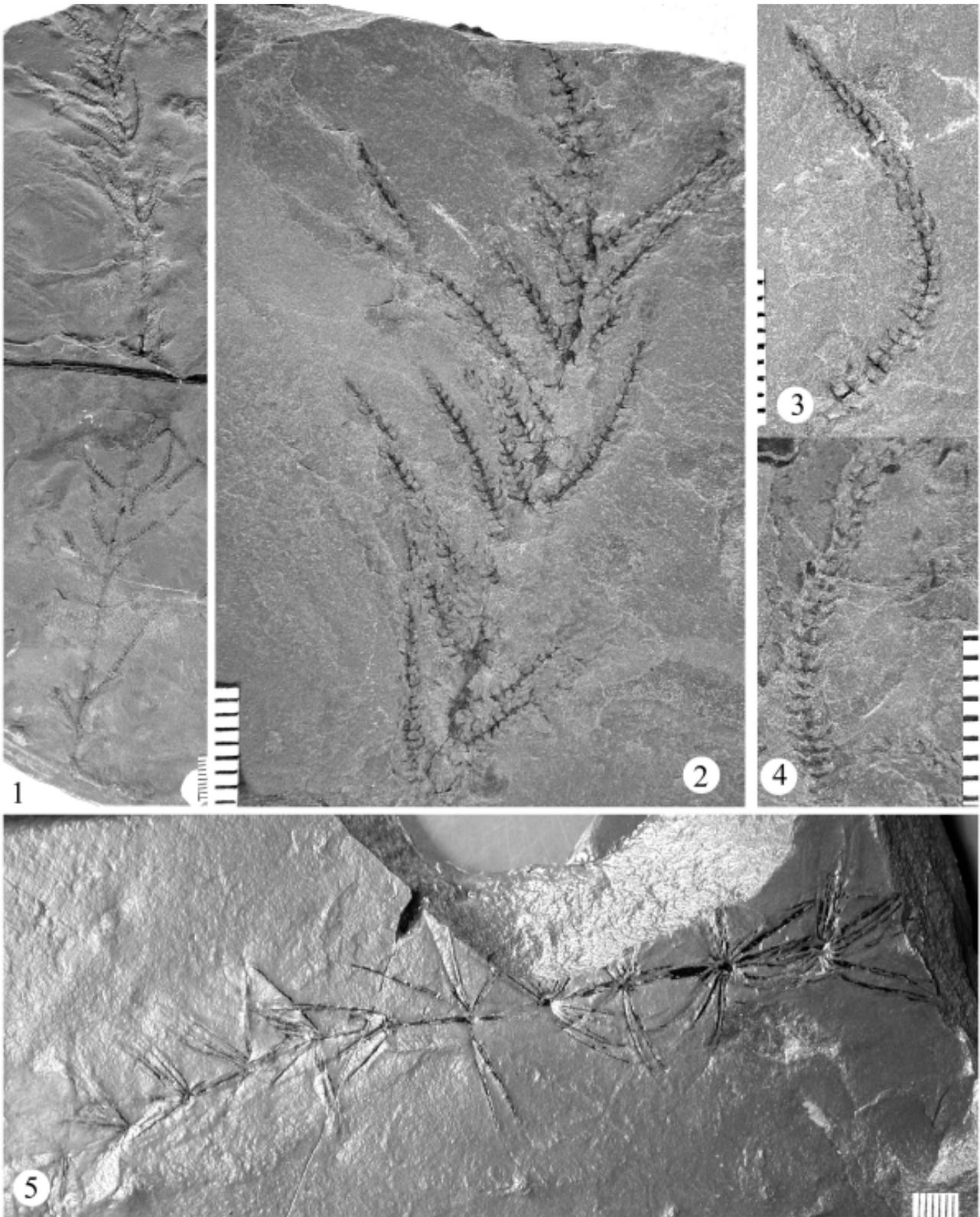


Plate 126. Figure 1-4: *Asterophyllites charaeformis* Fig. 1, 2, UF 34373a, Fig. 2 is an enlargement of upper portion of the branch shown in Figure 1.; Fig. 3, UF34010; Fig. 4, UMC-P. Typical compressions of axes and branching axis (Figs.1 and 2) of the *Calamites* tree. Note that at each node there are whorled leaves arranged at nearly right angles to the stems. These are lateral branches to the calamitean tree. Figure 5: *Asterophyllites* sp. UCM-P 218. Compression of a different species of a leafy branch of a calamitean tree. Note the numerous whorled leaves and the narrow elongate nature of the individual leaves.

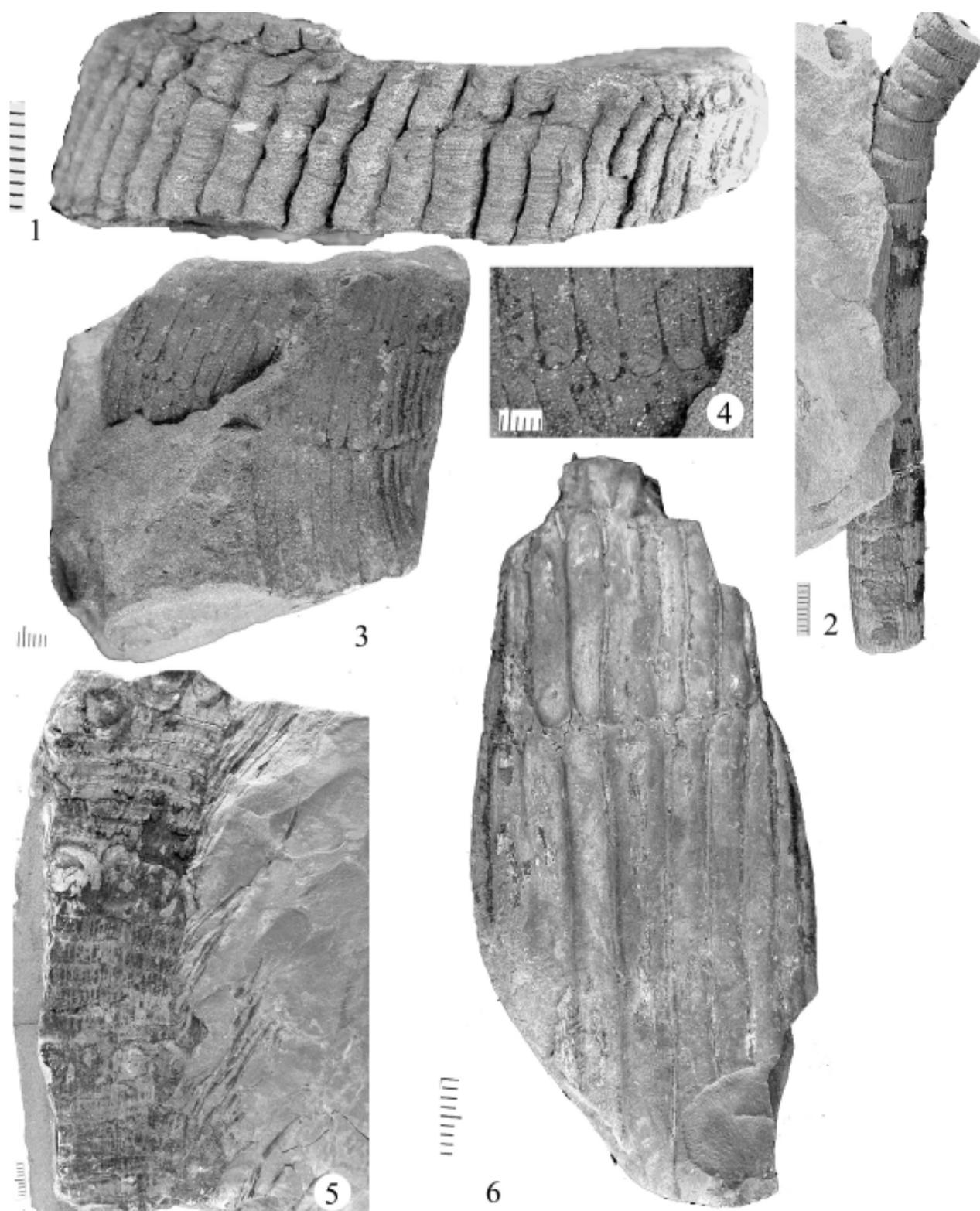


Plate 127. Figure 1: *Calamites undulatus* UF 34047. Pith cast of *Calamites* showing one node. The longitudinal grooves may be formed from the deep extensions of the woody tissue into the pith area of the stem. Figures 2-4, 6: *Calamites suckowii* Fig. 2, UF 34043; Fig. 3, UF 34019; Fig. 4 is an enlargement of one node of Fig. 3. Fig. 6, UF 34366. Pith casts and portions of pith casts showing typical nodes and ribbing of the casts. Fig. 4 shows the branch scars located just above the node while the node shows the alternating pattern of the primary xylem (first formed wood) that occurs at each node (also seen in Fig. 6). There are 14 nodes shown in the internal pith cast shown in Fig. 2. Figure 5: *Calamites goepperti* UF 33994. Compression of a calamitean stem or branch showing numerous nodes at which leaves (perhaps *Asterophyllites*) are attached and large branch scars located just above the nodes but occupying most of the internodal area of the stem.

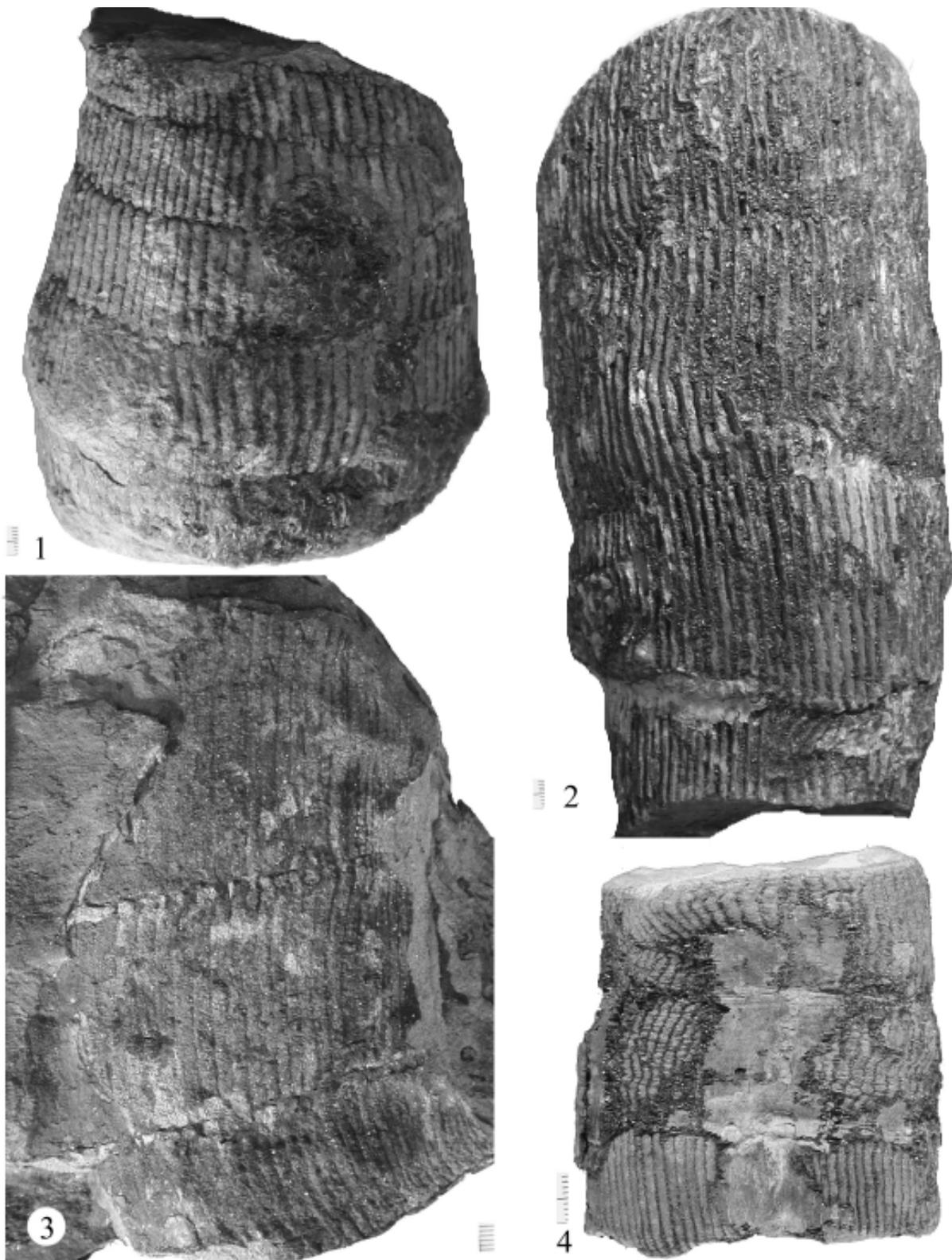


Plate 128. Figure 1, 4: *Calamites undulatus* Fig. 1, UCM-P 176; Fig. 4, UF 34018. Typical *Calamites* pith casts showing the nodes and internodes with the alternating grooves produced by the woody tissue of the stem. Fig. 4 shows distinct branch scars. Figure 2, 3: *Calamites* sp. Fig. 2, UCM-P 202; Fig. 3, UCM-P 025. Pith casts of *Calamites*.

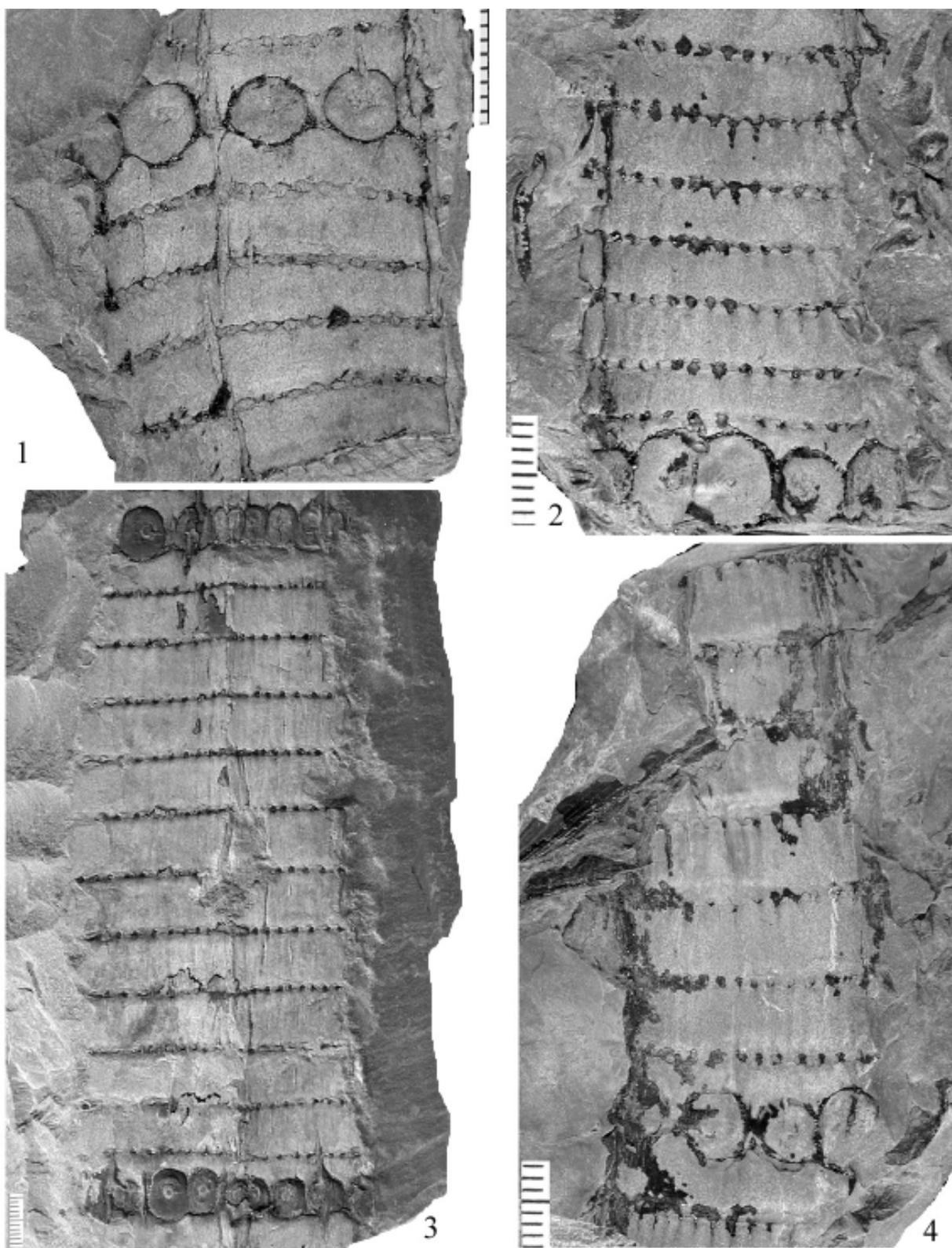


Plate 129. Figure 1-4: *Calamites goepperti* Fig. 1, UF 36866; Fig. 2, UF 48553; Fig. 3, UCM-P 201; Fig. 4, UF 33992. Compression fossils of the stems or branches of *Calamites* showing leaf scars at every node and numerous branch scars located above the node at only at a few select nodes. It is interesting to note that some species of *Calamites* have been characterized by their branching patterns and the number of nodes between the sets of branches. Fig. 3 clearly show that branching is either rare or spaced at every 12 node along the stem or branch.

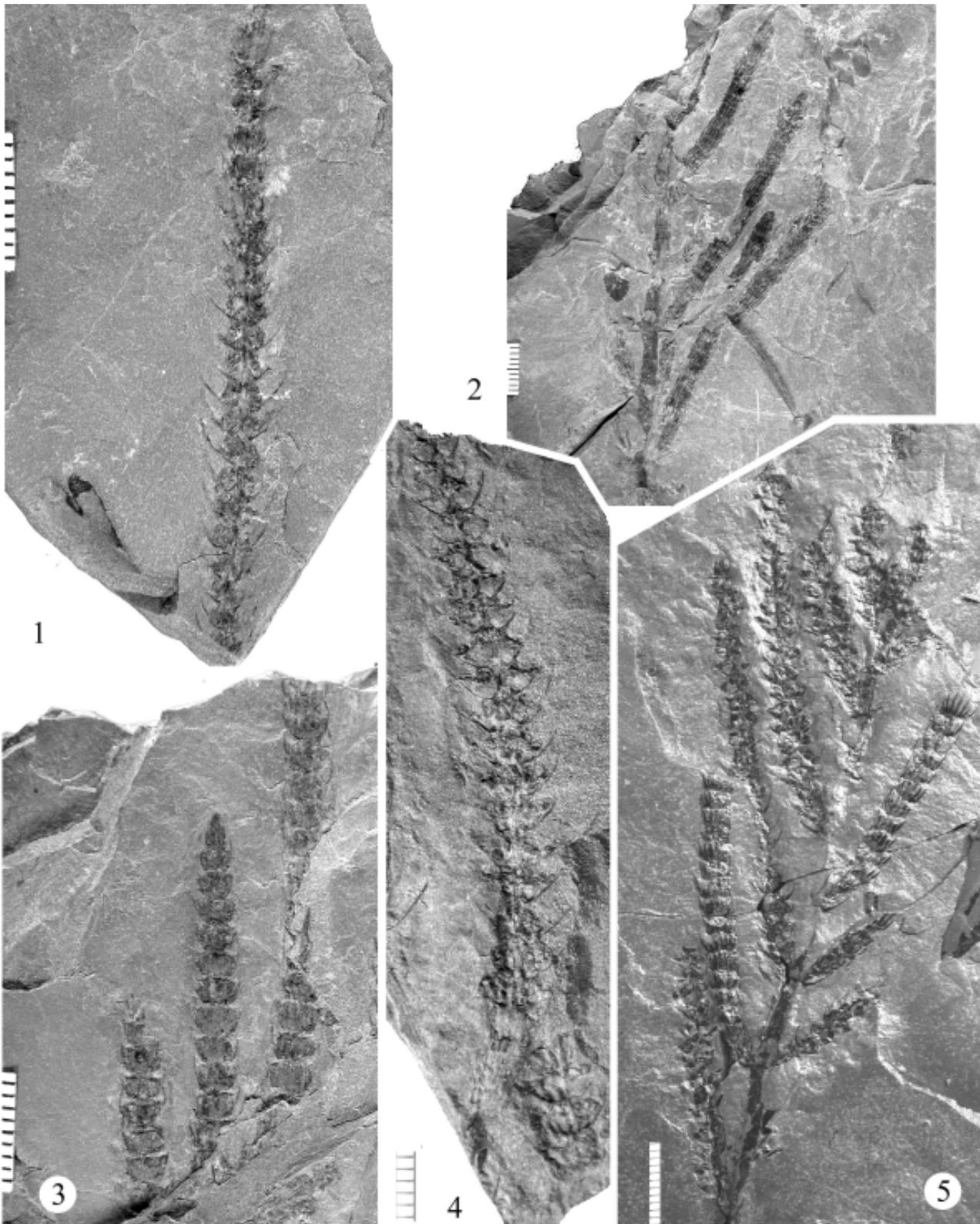


Plate 130. Figure 1: *Calamostachys* sp. Fig. 1, UF 34011. Isolated cone that shows the sporangia borne mid way between the sterile vegetative whorls. Figure 2, 3, 5: *Calamostachys* sp. Fig. 2, UF 34044; Fig. 3, UF 34045; Fig. 5, UCM-P 216. Compressions of *Calamites* branching axes bearing numerous cones. Figure 4: *Mazostachys* sp. UCM-P 194. Compression of an isolated cone of a *Calamites* tree. Because the fertile whorls are found just below the sterile vegetative whorls and the sporangia appear to be somewhat large we consider this to be a specimen of *Mazostachys*.

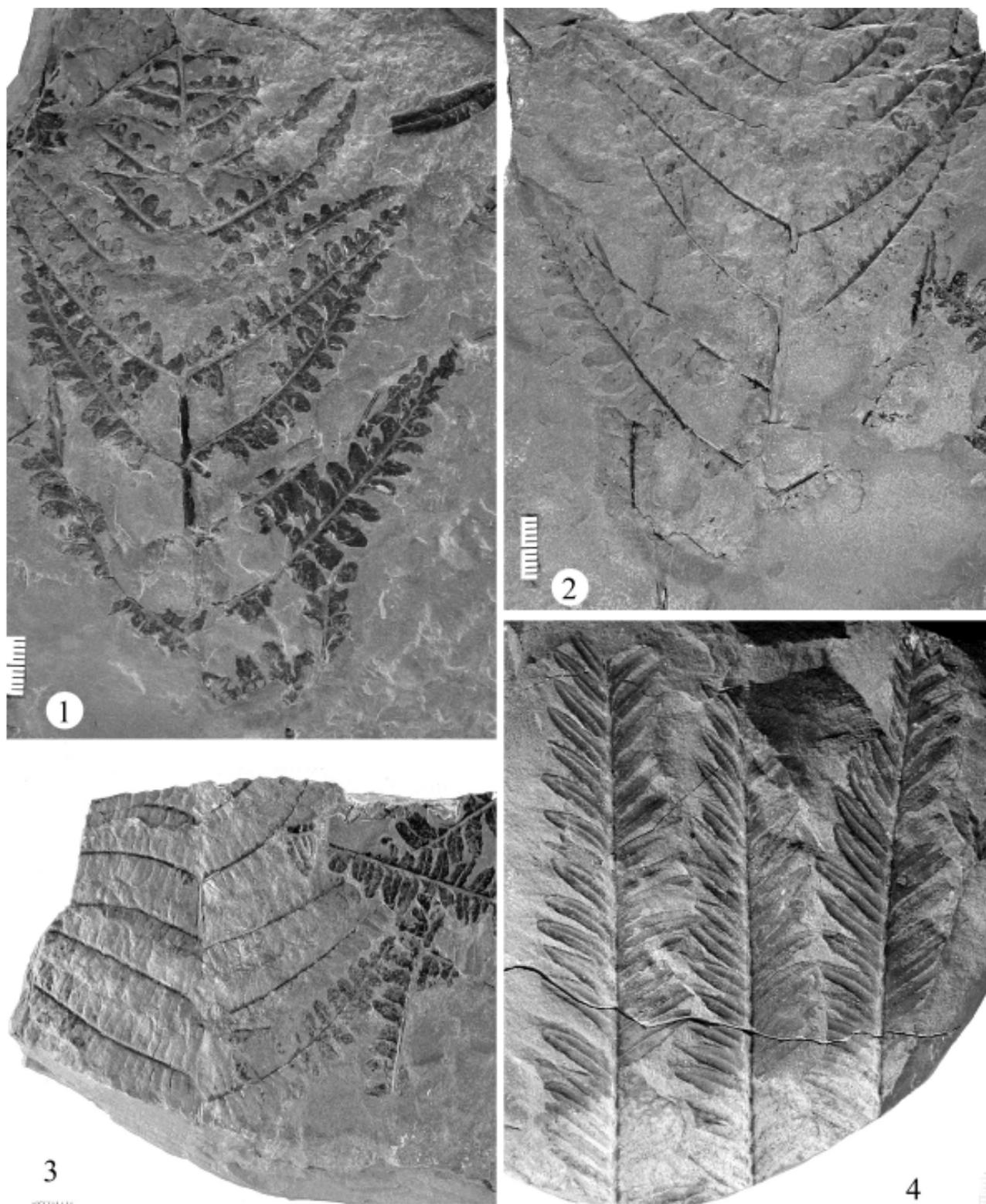


Plate 131. Figure 1-3: *Alethopteris valida* Fig. 1, UF 34037; Fig. 2, UF 34037'; Fig. 3, UF 34036. These figures show compression material of partial leaves or fragments of multiply compounded leaves of seed ferns. The pinnae are opposite. The ultimate pinnules are broadly attached to the rachis and opposite, typical of *Alethopteris valida*. This may have been the foliage of a *Medullosa* tree that bore the seeds and pollen organs shown on the following plates. Figure 4: *Neuralethopteris biformis* UCM-P 184. Compression specimen of a portion of a compound seed fern leaf. This leaf probably was 2 or 3 times compound and here are three pinnae that represent parts of the same leaf. These pinnae have characteristic pinnules of *Neuralethopteris* alternating along them. This may have been the foliage of a *Medullosa* tree that bore the seeds and pollen organs shown on the following plates.

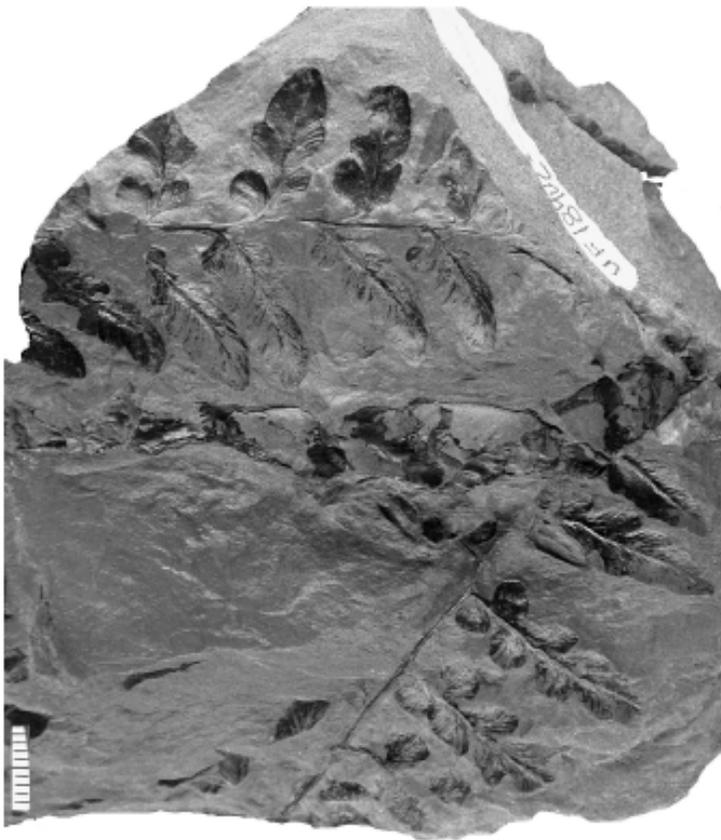


Plate 132. Figure 1: *Sphenopteris elegans* UCM-P 169. Compression of the mid section of a seed fern leaf of at least a fourth order (as shown here) compound leaf. The leaf may have had one or two more orders of compounding not shown here. Figure 2, 3: *Sphenopteris pottsvillea* Fig. 2, UF 34033; Fig. 3, UF 36875. Compression specimens of fern leaf fragments. These may have belonged to a fern-like plant or to an extinct seed fern-type plant.

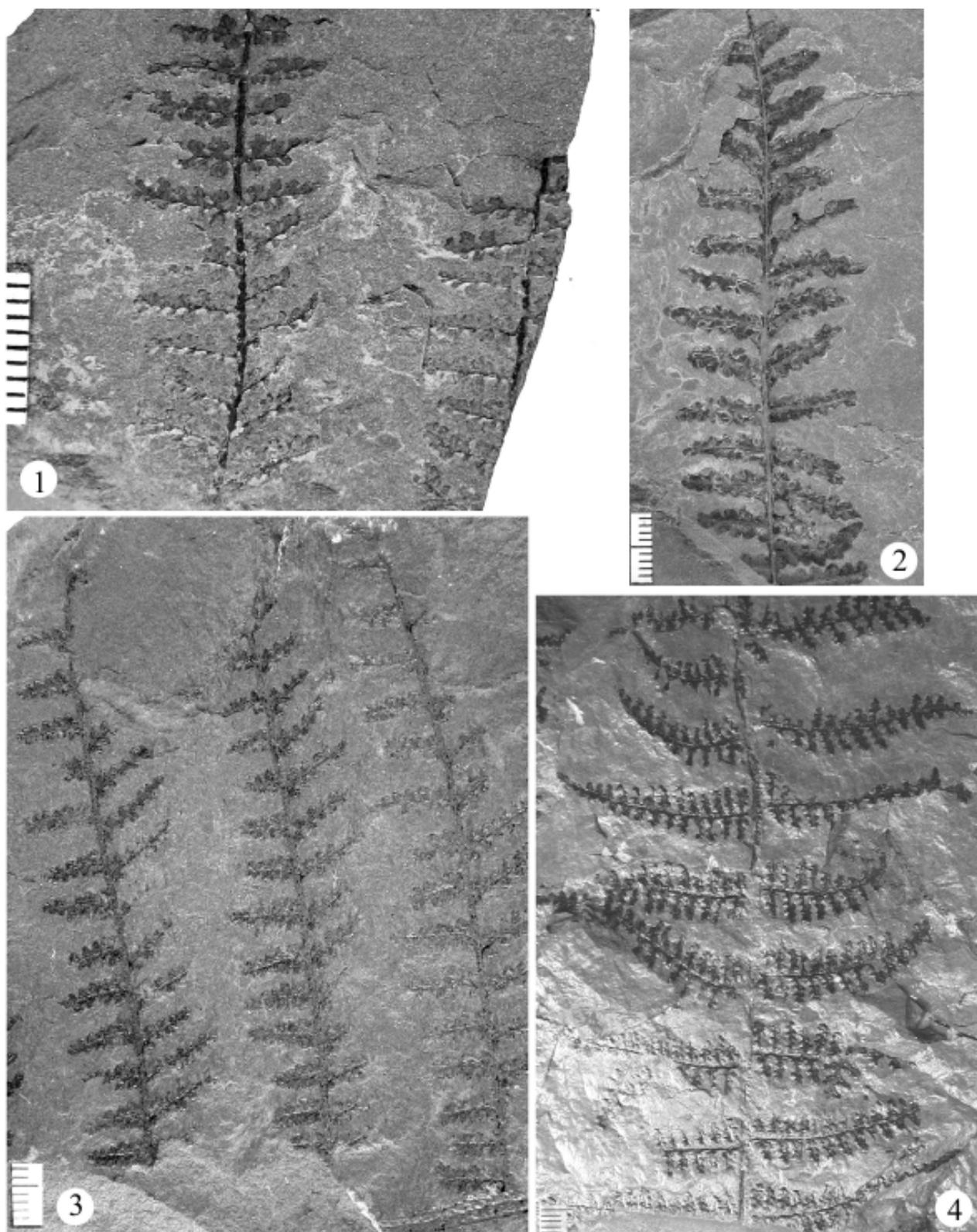


Plate 133. Figure 1-4: *Lyginopteris hoeninghausi* Fig. 1, UF 36870; Fig. 2, UF 34038; Fig. 3, UF 34039; Fig. 4, UCM-P 227. Leaf compressions that are at least three times compound and probably more times compound than this. The pinnae are opposite to alternately arranged along the rachis and the pinnules are alternately arranged along the pinnae. *Lyginopteris hoeninghausi* is often grouped with the sphenopterid seed fern foliage. These may be considered as foliage of the trees and shrubs that bore the seeds and pollen organs illustrated in the plates that follow.

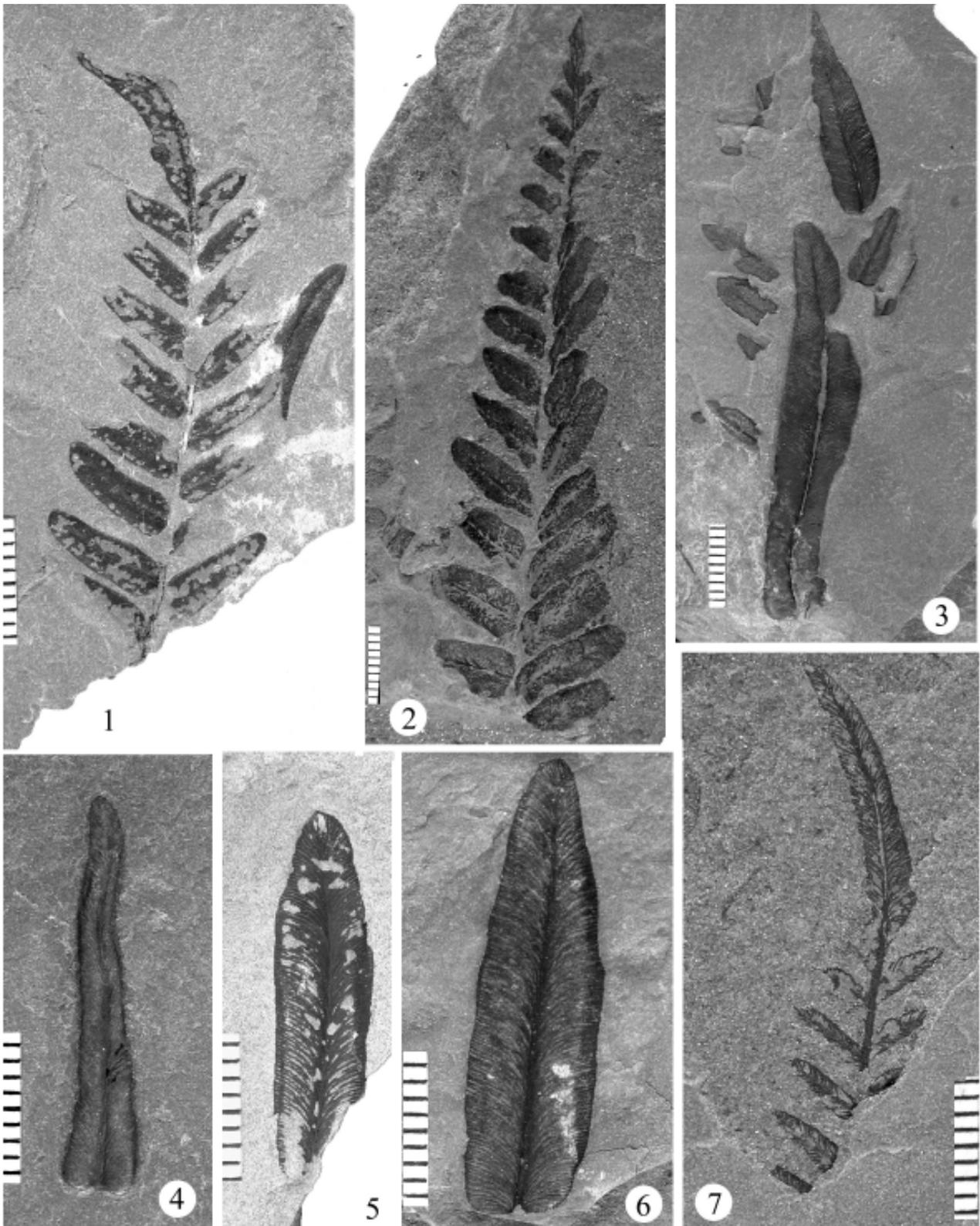


Plate 134. Figure 1, 3, 4-7: *Neuralethopteris biformis* Fig. 1, UF 34024; Fig. 3, UF 34027; Fig. 4, UCM-P; Fig. 5, UF 34028; Fig. 6, UF 34029; Fig. 7, UF 34023. Compressions of the ultimate portions and isolated pinnules of seed fern foliage. This species is characterized by the distinctive pinnule venation and large lateral pinnules with rounded distinct bases, each attached to the pinnae independently. The ultimate terminal pinnule is elongate. Figure 2: *Neuralethopteris pochontas* UF 34025. Compression of a seed fern pinnae bearing alternate, ovate pinnules that narrow at their base and the terminal pinnule is narrow, oblong with basal lobes.

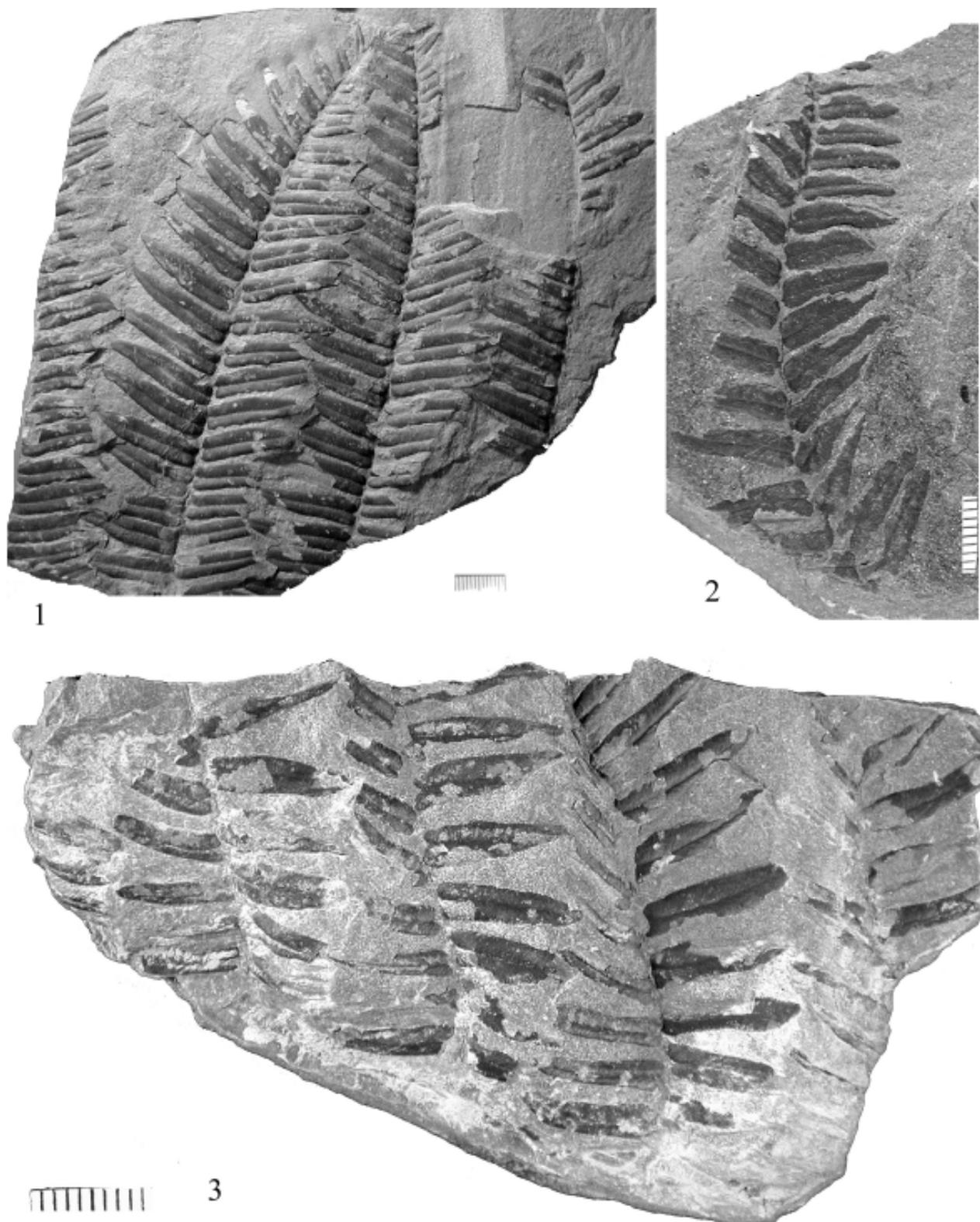


Plate 135. Figure 1: *Neuralethopteris biformis* Fig. 1, UCM-P 158. Compression of whole or partial, 4 pinnae with numerous pinnules. Foliage of seed fern plants such as *Medullosa*. Figure 2: *Neuralethopteris* sp. UF 34350. Compression of a single pinnae with several pinnules. Probably of seed fern origin. Figure 3: *Neuralethopteris pocahontas* UF 34022. Compression of 4 partial pinnae with numerous pinnules. Foliage of seed fern plants such as *Medullosa*.

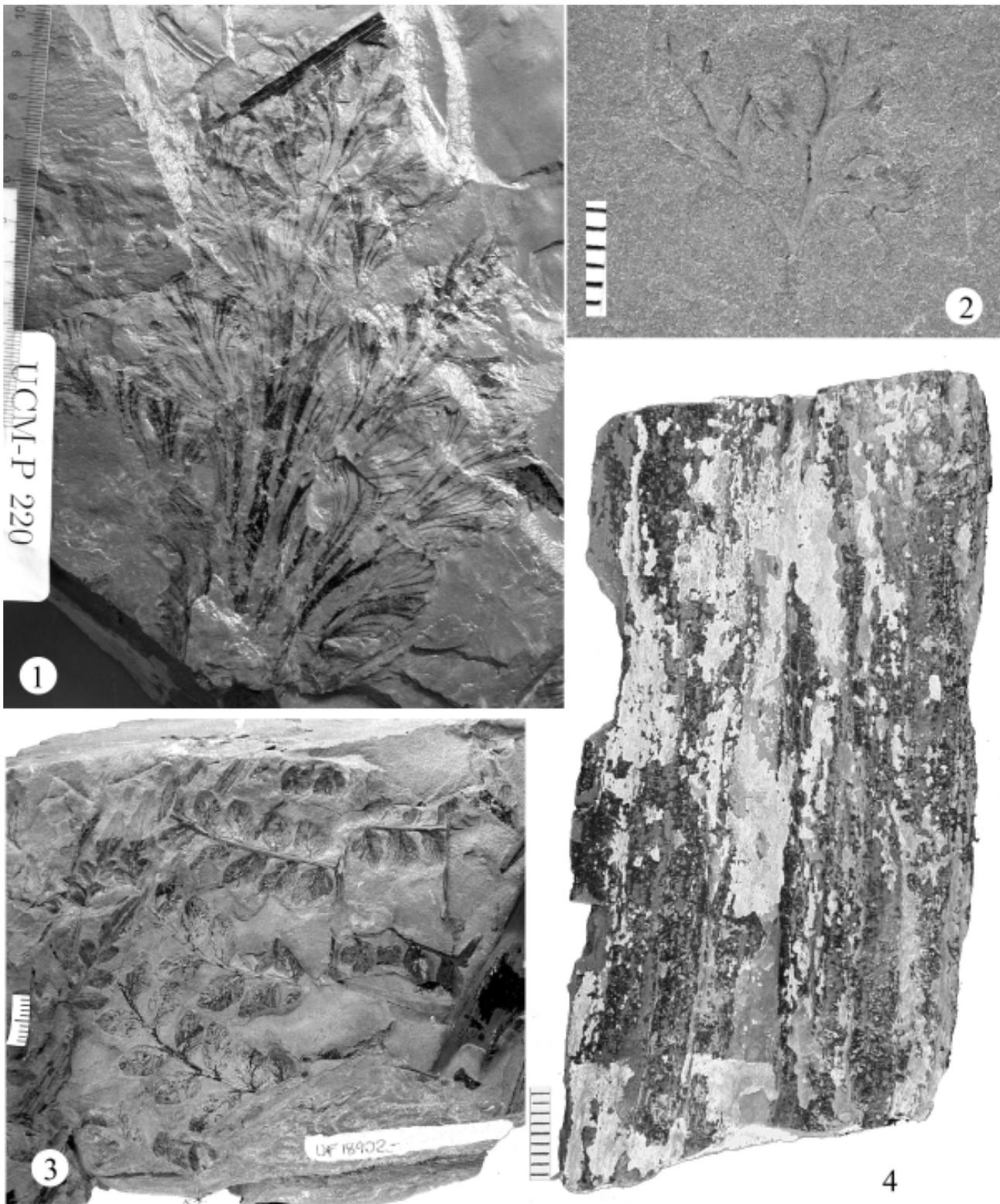


Plate 136. Figure 1: *Aphlebia* sp. UCM-P 220. Compression of ornate foliage-like material often associated with seed fern foliage. Probably attached directly to the main rachis of a large leaf. Figure 2: *Palmatopteris furcata* UF 34031. Impression of an ultimate pinnule of a fern or seed fern leaf showing a distinctive branching pattern. Figure 3: *Neuralethopteris pocahontas* UF 34035. Compression/ impression of numerous pinnae attached to a rachis. Each bearing numerous pinnules. Foliage probably at least 3 X compound and belonging to seed fern plants such as *Medullosa*. Figure 4 Trunk UCM-P. Cast of a trunk or large rachis perhaps of fern or seed fern origin.

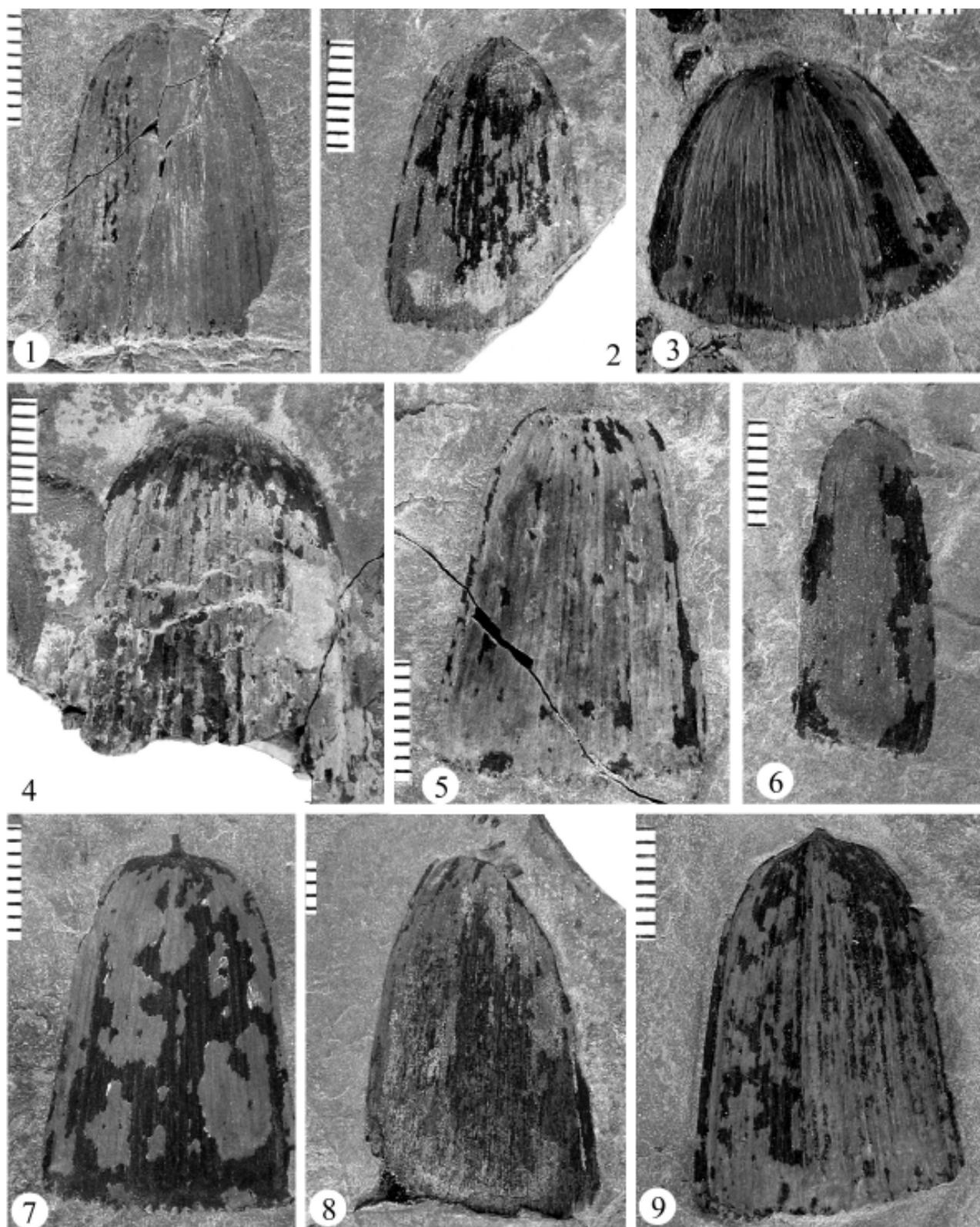


Plate 137. Figure 1-9: *Whittleseya elegans* Fig. 1, UF 36901; Fig. 2, UF 36890; Fig. 3, UF 36873; Fig. 4, UF 36896; Fig. 5, 34364; Fig. 6, UF 36891; Fig. 7, UF 34364'; Fig. 8, UF 36883'; Fig. 9, UF 36908. Compressions and impressions of pollen organs of a seed fern such as *Medullosa*. Note the long narrow tubes that give a linear striation appearance to the pollen organs. Each of these tubes was filled with pollen and it was shed in great abundance as these hung from the leaves of a *Medullosa* plant. Fig. 7 shows a short attachment stock.

## Plate 138

Figure 1-4, 8: *Trigonocarpus ampulliforme* Fig. 1, UF36879; Fig. 2, UF 36877; Fig. 3, UF 34362; Fig. 4, UF 36903; Fig. 8, UCM-P. Compression - impression mixed of the seeds and *Medullosa* and *Medullosa* - like plants. These fossils have preserved some aspects of the softer tissues of the outer parts of this large seed. The long "neck" of tissue surrounding the micropylar area can be seen. In Fig. 3 the nature of the outer and inner tissues in this micropylar extension can be seen. The center is almost a compressed cast of the chamber where the living part of the seed was contained. Fig. 8 shows a cast of this inner part of the seed also showing one of the ribs and the inner area of the micropylar opening as well as a compression of the tissues surrounding it. These seeds represent some of the larger seeds known from the Pennsylvanian.

Figure 5, 6, 9: *Trigonocarpus* sp. Fig. 5, UF 34040'; Fig. 6, UF 34040; Fig. 9, UF 34376. Internal casts of the seeds of *Medullosa*. The name comes from the three ribbed aspect of casts isolated from the matrix. These ribs come from the "ribs" associated with the position of the strands of vascular tissue. These casts reflect the size and shape of the internal chambers of the seeds occupied by the female gametophyte tissue (stored food) and embryo. These seeds represent some of the larger seeds known from the Pennsylvanian. Figure 8 and 9 are mixtures of cast and compression preservation.

Figure 7: *Carpolithes* sp. UF 34041. A partial cast of a seed perhaps coming from a seed fern. It is an internal cast of the proximal 1/3 of the seed. It appears to have 2 or the 3 ribs showing and is perhaps a *Trigonocarpus* similar to the casts shown in figs 5,6, and 9. It is especially interesting to note that *Neuraethopteris* foliage appears attached to one end and is closely associated with the cast along the left side of it. This might be showing attachment of this seed to a leaf with this type of foliage, but is not exposed sufficiently to prove this possibility.

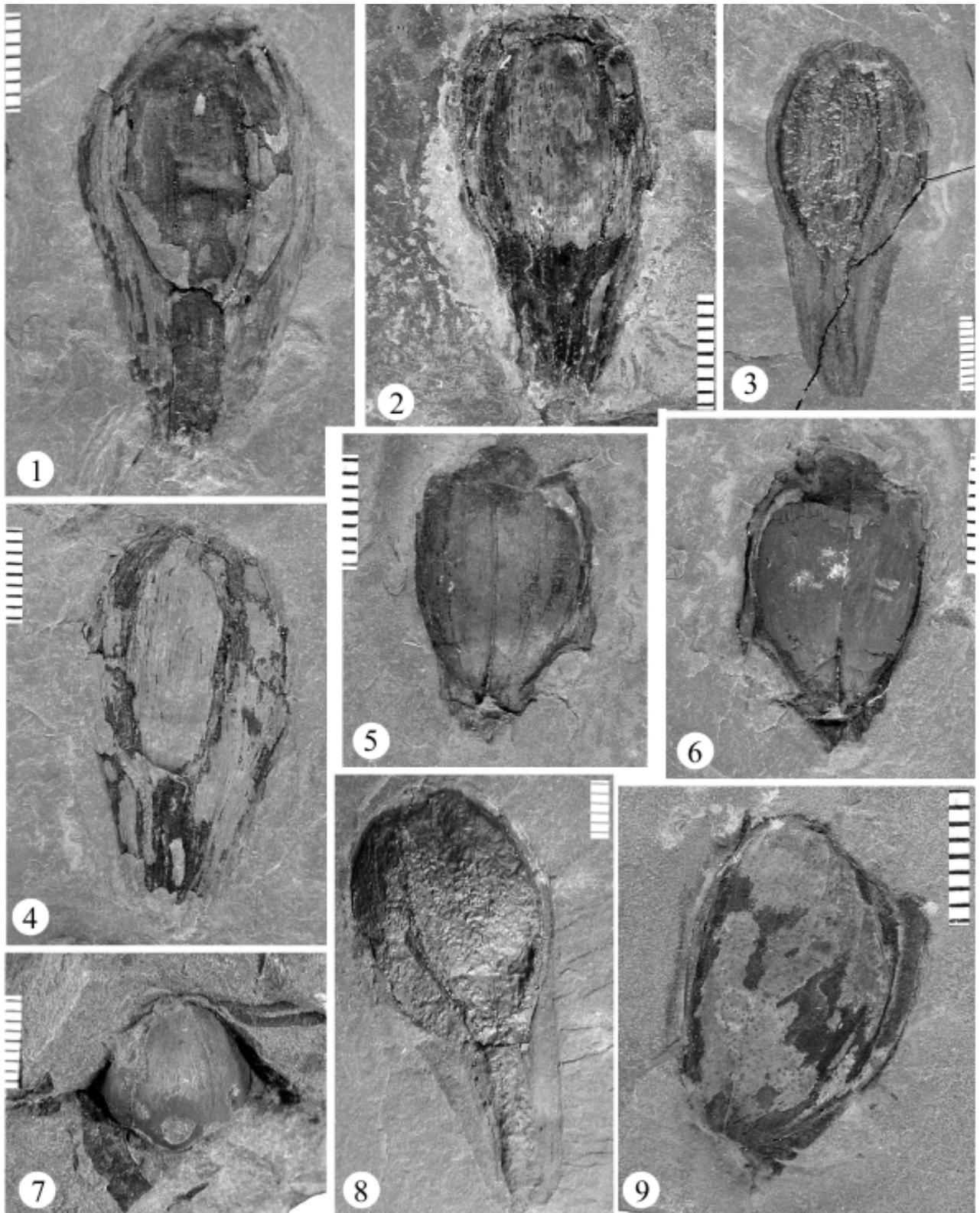


Plate 138. See facing page for caption.

## Plate 139

Figure 1: *Cordaites* sp. UF 33989, bar = 3 cm. Compression of a partial leaf of the *Cordaites* tree. This shows multiple veins with a central vein more prominent.

Figure 2: *Lepidophylloides intermedium* UF 34378. Compression of a lycopod leaf that clearly shows the thin central vein with 2 conspicuous lateral stomatal grooves on either side. The width of this leaf suggests the possibility that it could have affinities with *Sigillaria* (thus be a *Sigillariophyllum*) or it could represent a nice example of a *Lepidodendron* or *Lepidophloios* leaf.

Figure 3, 5: *Holcospermum* sp. Fig. 3, UCM-P; Fig. 5, UF 34370b. Compressions of seeds from a seed fern. Note the numerous ribs that can be seen in these seeds.

Figure 4: *Cordaicarpon* sp. UF 34368. Heart-shaped impression somewhat similar to *Cordaicarpon* which is the seed of a *Cordaites*. Not all of the details of the seed are evident and this structure could be a pair of cone scales or bracts of a seed plant.

Figure 6: *Sphenophyllum* sp. UCM-P 215. Compression of a stem with whorls of wedge-shaped leaves. *Sphenophyllum* was a common vein-like plant that covered the damp forest floor of the Pennsylvanian swamps. It is a Sphenopsid and produced complex cones bearing numerous spores.

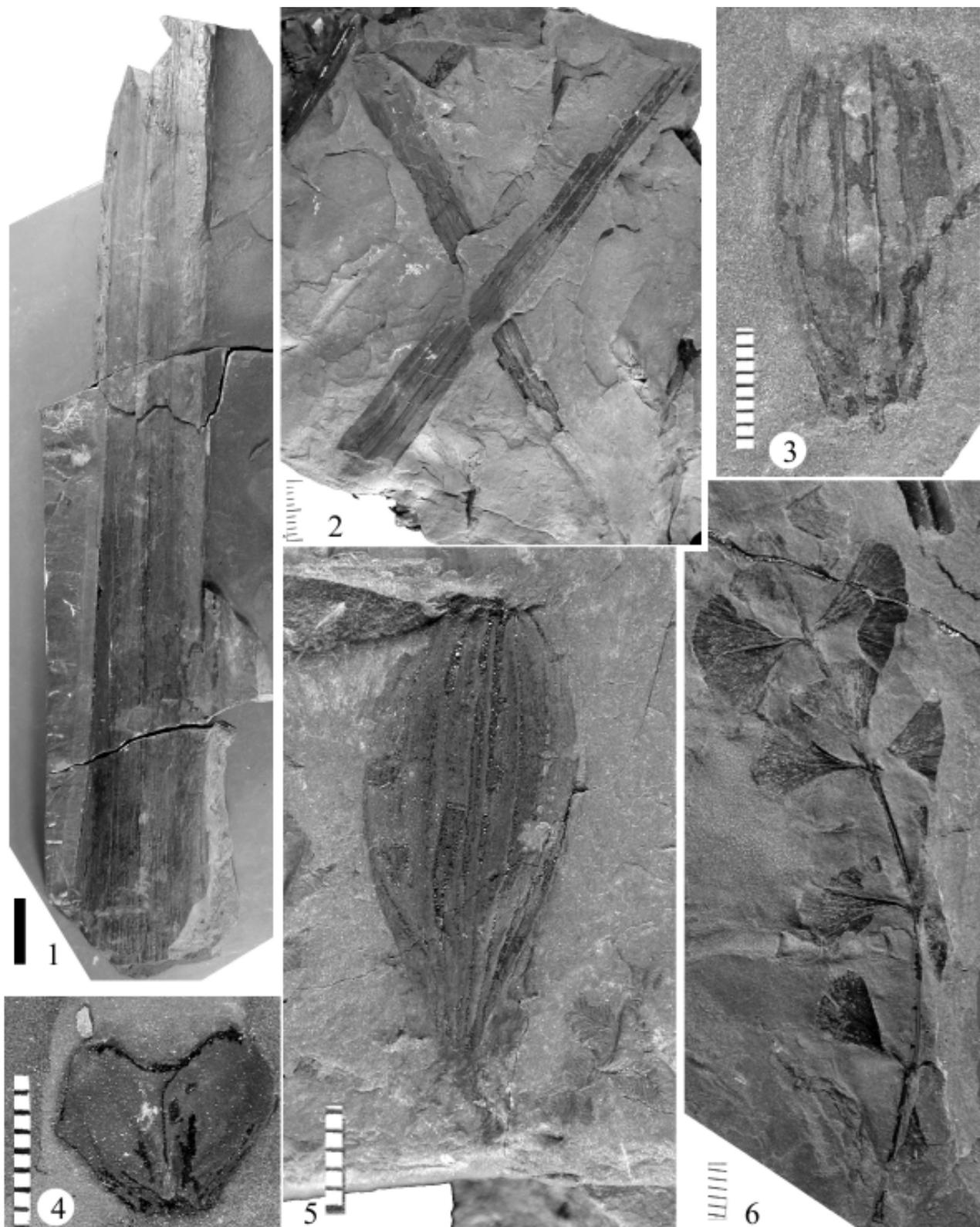


Plate 139. See facing page for caption.

# The State of Alabama



THE ALABAMA STATE LANDS DIVISION  
ALABAMA DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES  
takes pride in awarding this  
CERTIFICATE OF APPRECIATION

to

## THE ALABAMA PALEONTOLOGICAL SOCIETY

*In recognition and grateful appreciation of its commitment and dedication to the protection of Alabama's unique geological heritage through its untiring efforts in preserving the Steven C. Minkin Paleozoic Footprint Site at Union Chapel, Jasper, Alabama.*

*In sincere gratitude, we recognize and commend these outstanding efforts to insure that Alabama's ancient natural history is preserved for future generations.*



Done this 12th of March, 2005.

M. Barnett Lawley, Commissioner

James H. Griggs, State Lands Director

## **AUTHOR BIOGRAPHIES**



**Ashley Allen** is a science teacher at Oneonta High School in Oneonta, Alabama. He has been an avid fossil collector for many years, and currently serves as field trip coordinator for the Alabama Paleontological Society. Ashley discovered tetrapod trackways at the Union Chapel Mine in late 1999, and brought his findings to the attention of the APS. For Ashley, the Union Chapel Mine experience is part of what being a teacher is all about. "I try to convey to my science students the importance of communication in the scientific community," he says. "I want to be accurate in representing the principles the scientific enterprise is based on. Work done without proper communication is called a secret, not a discovery. I feel that any opportunity I get to show them how to use problem-solving skills, scientific reasoning, communication skills, and the ability to put things into a proper social and historical perspective is worth the effort."



**Dr. T. Prescott Atkinson** is a pediatric immunologist at the University of Alabama at Birmingham. He is a native of Montgomery, Alabama and attended public school there before attending Tulane University on a Naval ROTC scholarship, graduating Magna cum Laude with a BS in Biology in 1975. He served six years on active duty in the Navy before entering the MD-PhD program at Emory University, graduating Magna cum Laude in 1987. He completed his pediatric residency at the University of Alabama at Birmingham and Georgetown and a fellowship in Allergy and Immunology at the National Institutes of Health in 1992, after which he returned to take a full-time position as Assistant Professor of Pediatrics at UAB. He is married (wife Miriam, in photo) and has three children. He became interested in fossils while a high school student growing up in Montgomery and continues to enjoy this very stimulating hobby.



**Dr. Brian J. Axsmith** received his PhD in botany from the University of Kansas in 1998. He is presently assistant professor in the Department of Biological Sciences at the University of South Alabama, where he was recently awarded the Arts and Sciences Junior Faculty Award for Excellence in Scholarship. His research centers on the evolution of plants from the Mesozoic Era, with a special interest in the evolution of conifers.



**Dr. Ron Buta** received a PhD in astronomy from the University of Texas at Austin in 1984. From 1984-1986 he was a postdoctoral fellow at the Australian National University in Canberra and worked at the Mount Stromlo Observatory. From 1986-1988 he returned as a post-doc to the University of Texas to work with Gerard and Antoinette de Vaucouleurs on the *Third Reference Catalogue of Bright Galaxies*. In 1989, he joined the faculty of the Department of Physics and Astronomy of the University of Alabama in Tuscaloosa.

Dr. Buta's main research interests lie in the morphology and dynamics of galaxies, particularly barred and ringed spiral galaxies. He is a member of the American Astronomical Society, and has authored or co-authored more than 90 research articles and two books. He has been a member of the Alabama Paleontological Society since 1997 (when it was formerly called the Birmingham Paleontological Society). As an astronomer, he finds it easy to relate to geology and paleontology because of the vast timespans of the various processes observed. He believes the story of life on Earth is as interesting as the story of the stars.



**Dr. David L. Dilcher** is a Graduate Research Professor in the Florida Museum of Natural History at the University of Florida. For 24 years, he was a Professor in Biology and Geology at Indiana University (currently Adjunct Professor). His research includes the history of CO<sub>2</sub> in relation to climate change in the past, the reproductive biology of flowering plants, the nature of the earliest flowering plants, and the historical diversity of flowering plants and their paleogeography. He began his work in Paleobotany as an undergraduate cutting and peeling coal balls. He has collected and worked with Coal Age plants in several mid-western states before working on the fossil plants associated with the trackways in Alabama. He is a past President of the Botanical Society of America, and has been named Honorary Professor of Jilin University and Nanjing University in China and a Corresponding Member of the Senckenberg Museum in Germany. He was elected to the National Academy of Sciences in 1989.



**Prof. Dr. Hartmut Haubold** is Professor of Paleontology and Head of the Geiseltalmuseum, Institute for Geological Sciences and Geiseltalmuseum, Martin Luther University, Halle, Germany. He received his diploma from Martin Luther University in 1965, and became Professor of Paleontology in 1992. His research and scientific interests include the ichnology of tetrapods, fossil "reptiles", dinosaurs, taxonomy, phylogeny, and ecology of Late Paleozoic - Mesozoic terrestrial environments.



**Dr. G. Ed Hooks III** is an Assistant Professor of Biology at Longwood University. He became interested in paleontology as a child, but took a serious interest in a career in paleontology after taking a comparative vertebrate anatomy class at Auburn University, where he received the formal part of his education in Pre-Veterinary Medicine/Zoology. During his time at Auburn, he was advised in his research by Dr. James L. Dobie and began to interact with other area paleontologists such as Drs. James Lamb (Red Mountain Museum), Brown Hawkins (Alabama Museum of Natural History), and David Schwimmer (Columbus State University, Georgia), who taught him much that was, and still is, not taught in Alabama colleges and universities. He received his PhD in biology from the University of Alabama in 1998, under the supervision of Drs. Douglas Jones and Richard L. Mayden. He served first as Collections Manager and later as Curator of Vertebrate Paleontology for the Alabama Museum of Natural History from 1999-2003, before moving to his current position.



**Dr. Adrian P. Hunt** was born in Portsmouth England. He was always interested in the past whether it was history, archeology or paleontology. The dinosaur renaissance of the 1970s finally enticed him into paleontology. He received a bachelor's degree from the University of Manchester in 1979. He came to the United States in 1980 to go to graduate school, first at New Mexico Tech (MS 1984) and then at the University of New Mexico (Ph.D. 1994).

After graduate school he worked at the University of Colorado at Denver and Mesalands Community College, where he founded the Mesalands Dinosaur Museum. His principal research interests are in late Paleozoic-late Mesozoic tetrapods (including dinosaurs) and their footprints. In carrying out this research he has visited over 50 museums on three continents. He has authored over 500 scientific publications, including several co-authored and co-edited books. He is currently the Executive Director of the New Mexico Museum of Natural History and Science.



**Dr. Jim Lacefield** lives in rural Colbert County near Tuscumbia and is a retired Adjunct Professor of Biology and Earth science at the University of North Alabama. He has a doctorate in science education from the University of Alabama, with major subject concentrations in biology and geology. He is the author of *Lost Worlds in Alabama Rocks: A Guide to the State's Ancient Life and Landscapes*, a popular-level summary of the geologic history of Alabama. He also writes geology and natural history articles for *Wild South* magazine and other periodicals on a regular basis.



**Dr. David C. Kopaska-Merkel** has a bachelor's degree in geology/biology from the College of William and Mary, and a Ph.D. in geology from the University of Kansas. His dissertation focused on development and evolution of trilobites from western Utah. David has worked for Shell Oil Co. in New Orleans, the University of Toronto, the Northeastern Science Foundation in Troy New York, and the Geological Survey of Alabama, where he has been since 1989. He has published research in paleontology, petroleum geology, coastal geology, hydrogeology, and carbonate geology. He has published extensively about carbonate rocks of the Smackover Formation, which is Alabama's biggest hydrocarbon producing unit. His paleontology publications include several studies of trilobite development and evolution, and several recent papers on fossil reefs at the surface in north Alabama and in the subsurface in south Alabama.



**Allan J Lerner** is a native of New York City. As a child he often visited the American Museum of Natural History, which sparked within him a life long interest in paleontology. Allan received a Master of Science degree in Communicative Disorders from the University of New Mexico in 1989. He now works professionally as a speech/language pathologist for the Albuquerque school district. His long time avocation of paleontology led him to become a research associate at the New Mexico Museum of Natural History in 2000. Allan is a self-taught ichnologist, with a principal interest in the Early Permian record of the American southwest. Paleozoic invertebrates, particularly arthropods, are another area of interest. He is a member of the Paleontological Society and the New Mexico Geological Society.



**Terry A. Lott** is a research assistant in the Paleobotany section of the Florida Museum of Natural History. He received his B. S. in Botany at the University of Florida. Growing up in Hollywood, Florida, Terry's interests in plants started at an early age while helping family members involved in growing oranges and mangoes, and with ornamental plant nurseries. While attending Broward Community College and University of Florida, Terry worked at the Fort Lauderdale Research Center, University of Florida's Botany, Forestry, and Entomology/Nematology Departments. He became involved with several projects associated with the biological control of aquatic weeds. He joined the museum staff in 1990, his interest in Paleobotany developing after taking a course taught by Dr. David Dilcher. Terry lives in Hawthorne, Florida with his wife Debbie and daughter Annie.



**Dr. Spencer G. Lucas** is a paleontologist and stratigrapher who specializes in the study of late Paleozoic, Mesozoic, and early Cenozoic vertebrate fossils and continental deposits, particularly in the American Southwest. Dr. Lucas has extensive field experience in the western United States as well as in northern Mexico, Costa Rica, Jamaica, Kazakhstan, Soviet Georgia and the People's Republic of China. He received his PhD in 1984 from Yale University, and has published more than 500 scientific articles, co-edited 14 books, and authored 3 books. He has 12 years of museum experience and 17 years of teaching experience at the university level. He is currently Curator of Paleontology and Geology, New Mexico Museum of Natural History and Science. He is also a member of the Paleontological Society, Society of Vertebrate Paleontology, New Mexico Geological Society (honorary member), and the New Mexico Academy of Science (life member).



**Dr. Anthony J. (Tony) Martin** is a Senior Lecturer at Emory University in Atlanta, Georgia. He was born in Terre Haute, Indiana. He earned a B.S. in geobiology from St. Joseph's College in Indiana, a M.S. in geology from Miami University, Ohio, and a Ph.D. in geology from the University of Georgia. During his 14 years at Emory, he has taught courses on environmental geology, human and natural ecology, earth history, extinctions, and paleontology. He has also co-taught field courses in desert geology, dinosaurs, and modern and ancient tropical environments. His primary research interest is in ichnology, the study of traces left by organismal behavior in both modern and ancient environments, and in recent years he has taken an interest in tracking. He has published more than 80 abstracts and papers and presented at more than 50 professional meetings and public forums, including as an invited speaker at international symposiums. He is also the author of the textbook *Introduction to the Study of Dinosaurs* and is working on a trace fossil field guide to San Salvador Island (Bahamas).



**Steven C. Minkin** was a licensed professional geologist at the time of his death on 20 February 2004. From the time he was a young man, he loved to be in the outdoors. He enjoyed camping, spelunking, and hunting for arrowheads, artifacts, and fossils. After high school in Memphis, he went to the University of Tennessee and began a career in science. He earned a B.S. in Zoology and a Masters in Geology. Steve was fascinated with nature and was a life-long student of the natural sciences. He loved being a geologist because it gave him the opportunity to get outside of the office. As a professional geologist, Steve worked for many companies across the country. His work included exploration for energy companies and environmental oversight for national labs and military installations. He also was an Adjunct Professor of Geology at the University of Idaho and taught classes at night. Wherever Steve went he brought along his love and passion for science.



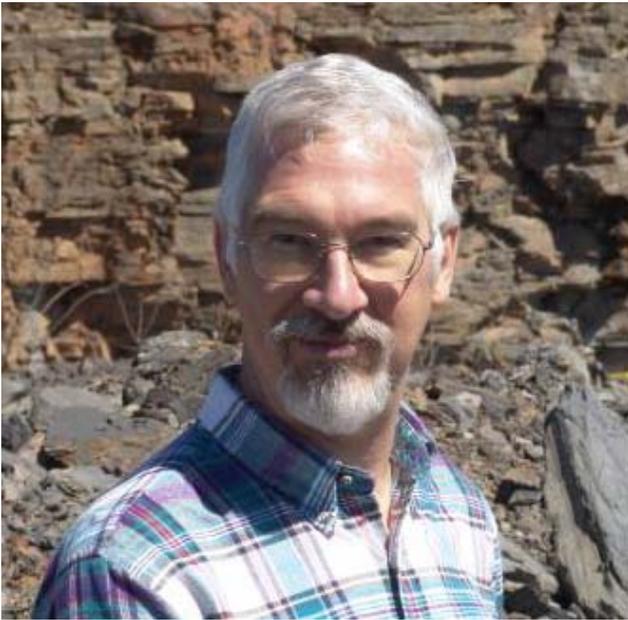
**Dr. Jack Pashin** received a Ph.D. in Geology from the University of Kentucky in 1990 and manages the Energy and Minerals Unit of the Geological Survey of Alabama. Jack's research focuses on coal geology and petroleum geology in the southern Appalachians and the northeastern Gulf of Mexico basin. He became interested in paleontology as a youth while scavenging Paleozoic fossils from stream valleys in northeastern Ohio. Jack has authored or co-authored more than 85 books, articles, and guidebooks on stratigraphy, structural geology, and paleontology and has received several awards recognizing his contributions. Dr. Pashin currently serves on the editorial boards of the American Association of Petroleum Geologists Bulletin and the International Journal of Coal Geology, is Past President of the Alabama Geological Society, and has been named an American Association of Petroleum Geologists Distinguished Lecturer.



**Nick Pyenson** is a graduate student in the Department of Integrative Biology and the Museum of Paleontology at the University of California, Berkeley. Born and raised in Canada, he graduated from high school in Cade, Louisiana, matriculated at Oxford College of Emory University, and finished with a B.S. magna cum laude in Biology at Emory University. Aside from his work on tetrapod ichnology at the Union Chapel Mine, Nick also conducted research on hominid paleoecology in Kenya as well as brain evolution in cetaceans (whales, dolphins and porpoises). Since 2002, Nick has been at UC Berkeley, focusing on the ecologically related changes in body size and morphology that have occurred in cetaceans over the past 30 million years.



**Bruce A. Relihan** is current president of the Alabama Paleontological Society. He has extensively collected trackways from the Union Chapel Mine and has contributed many excellent specimens to the trackway database and to museums in Alabama and New Mexico. Bruce first became interested in paleontology as a boy through field trips with his father to collect fossils and geodes near his home town of Chapman, Kansas. He attended Kansas State University and graduated in 1977 with a Bachelor's Degree in Horticulture. He worked in the retail and wholesale landscape and nursery industry until 1995, when he accepted his current position as Curator of Horticulture at the Birmingham Zoo.



**Dr. Andrew K. Rindsberg** has been studying the paleontology of Alabama for the Geological Survey of Alabama since 1989. Dr. Rindsberg has written numerous publications on Alabama geology, including field trip guidebooks and educational publications on fossils, and he is curator of the Survey's Paleontological Collection. Dr. Rindsberg's core areas are invertebrate paleoecology and ichnology. For seven years he coedited the Ichnology Newsletter with Alfred Uchman, helping to bring researchers on trace fossils together. Dr. Rindsberg graduated from Metairie Park Country Day School in metropolitan New Orleans (1971) and has degrees from Stanford University (1975), the University of Georgia (1983), and the Colorado School of Mines (1986), studying under Robert W. Frey and John E. Warme. He taught briefly at Auburn University and Southeastern Missouri State University before coming to the Geological Survey of Alabama.



**Prof. Alfred Uchman** was born in 1960 in southern Poland and graduated from the Jagiellonian University in Kraków. In 1990 he received his Ph.D. degree in geology from the same university. In 1996, he defended a habilitation thesis and in 2001, he received the professor degree. Currently, Prof. Uchman is director of the Institute of Geological Sciences of the Jagiellonian University, Kraków. His scientific interest is focused on different topics invertebrate ichnology of all ages and facies but especially on deep-sea facies. Prof. Uchman has carried out investigations in many countries of Europe and in Turkey and the U.S.A.

# Index

*Page numbers in italic type refer to illustrations; numbers in boldface refer to detailed discussions.*

## A

Aderholt, Robert 196, 197, 198  
 aestivating trace 92  
 agrichnial 132  
 Alabama Dept. of Conservation and Natural Resources 121  
 Alabama Museum of Natural History 76, 120, 173, 187, 191, 199, 201  
 Alabama Paleontological Society 3, 11, 15, 31, 59, 191, 201  
   incorporation 196  
 Alabama promontory 42  
 Alabama Surface Mining Commission 194, 195  
*Alabamasauripus* 147  
*Alabamasauripus aldrichi* 3, 6, 93  
 Aldrich, T. H. 60, 93, 191  
*Alethopteris* 52  
*Alethopteris valida* **161**, 162, 355  
 Allen, Ashley 19, 20, 76, 142, 147, 192, 194, **368**  
 allochthonous plant material 63  
 alluvial plain settings 116  
 ALMNH P.985.1.15 99  
 ALMNH P.985.1.16 104  
 ALMNH P.985.1.7 108  
 ALMNH PV987.0001 7  
 amateur paleontologists 187  
 amniotes 60  
*Amphibamus* 78  
 amphibians  
   feeding habits 62  
   temnospondyl 60, 203  
 amphipod crustaceans 123  
*Amphisauropus* 116  
 Anniston Museum of Natural History 195, 199  
*Anthichnium* 85  
*Anthichnium-Limnopus* assemblage 8, 115  
*Anthracodromeus* 78  
*Anthracopus* 75  
 anthracosaurs 93  
*Antiquatonia portlockiana* 52  
*Apatichnus?* 76  
*Aphlebia* 360  
 Appalachian orogenic belt 42  
 arachnid 173  
 arborescent lycopods  
   bark impression 193  
   *Lepidodendron* 155

*Lepidophloios* 155  
*Sigillaria* 155  
   stem impressions 155  
*Arborichnus* 24, 54  
*Arborichnus repetita* 147, **150**  
*Arborichnus repetitus* **321**, 322-325  
*Archaeothyris* 78  
 archedictyon 170  
*Archerpeton* 78  
*Arenicola carbonaria* 129  
*Arenicolites* 3, **123**  
*Arenicolites carbonarius* 129  
*Arenicolites curvatus* 129  
*Arenicolites longistriatus* **121**, 123, 129, 332-337  
*Arenicolites sparsus* 129  
*Arthraria* 129  
*Artisia* 160, **165**  
*Asaphestra* 78  
*Asperipes* 9  
*Aspidaria* 343  
*Aspidiopsis* 156, **157**, 345  
*Astartella concentrica* 52  
*Asteriacites* **138**  
*Asterophyllites* **159**, 351  
*Asterophyllites charaeformis* 159, 160, 350  
 Atkinson, T. Prescott 21, 76, 186, 195, 196, 199, **368**  
*Attenosaurus* 147  
*Attenosaurus indistinctus* 93  
*Attenosaurus subulensis* 3, 6, 19, 80, **93**, 94, **230**, 231-250  
 Auburn University Museum of Paleontology 187  
 Ausmus, David 76  
 Axsmith, Brian J. 193, **368**

## B

Badger, G. 76  
 Baird, Don 110  
 Baldwin, Jimmy, Jr. 142  
 bark  
   sub-surface 157  
*Baropus* 76  
*Batrachichnus* 3, 5, 6, 76, 85, 92, 115, 116, 147  
*Batrachichnus delicatulus* 85, 115  
*Batrachichnus plainvillensis* 85  
*Batrachichnus salamandroides* 85  
 Bay of Fundy 178  
 Bear Gulch Limestone 4  
*Bechera charaeformis* 159  
 Bechly, Günter 171  
 Bell, Gordon 192  
*Belorhaphe* 132  
*Belorhaphe protopalaeodictyum* 134  
 Bernard Price Inst. for Paleontological Research 193  
 biochronologies 116  
 bioirrigation 123  
 bioprint 122

- biotaxonichnofacies 113, 115  
 bipedalism 63  
 Birmingham News, The 198  
 Birmingham Paleontological Society  
   3, 15, 19, 59, 187, 191, 201  
 bituminous coal resources 39  
 bivalves 53, 148  
 Black Creek coal zone 40  
 Black Warrior Basin 31, 42, 55, 202  
   tectonic setting 43  
 Blake, Richard 196  
 brachiopods 3, 44, 53  
   strophomenid 52  
 brackish fluviotidal flats 125  
*Breyeria* 173, 174  
 Brookwood coal zone 40  
 Bryant, Joseph 22  
 Buckhorn Lagerstätte 4  
 Buildex, Kansas 9  
 Burgess Shale 4  
 burrows 33  
 Burton, Jessie 15, 192  
 Buta, Ronald J. 21, 76, 142, 192, 194, 195, 196, **369**
- C**
- Calamites* 19, 31, 33, 47, 50, 153, 345, 350  
*Calamites goepperti* 156, **159**, 351, 353  
*Calamites suckowii* 160, 351  
*Calamites undulatus* **159**, 160, 351, 352  
*Calamitina undulata* 159  
*Calamostachys* 158, **161**, 354  
 Campbell County, Tennessee 81  
 captorhinomorph reptiles 147  
 Carbon Hill, Alabama 191, 203  
*Carpolithes* 164, **165**, 362  
 Carriza Arroyo 4  
 cast formation 153  
 Castlecomer, Ireland 4  
*Cavernaecola* 129  
 CaWaCo 195  
 Cedrum Coal Mine 202  
*Cephalerpeton* 78  
*Chaetopterus variopedatus* 129  
 Chanute Formation 96  
*Chelichnus* 5, 114, 116, 117  
*Chelichnus duncani* 115  
 chironomids 123  
   larvae 143  
   larval traces 144, 145  
*Cincosaurus* 3, 60, 147  
*Cincosaurus* beds  
   3, 32, **46**, 78, 81, 85, 86, 92, 121, 125, 147  
   age 60  
   bedding thickness cycles 54  
   bedding thickness variations 52  
   cyclicality 48  
   estuarine nature 48  
   interpretation 47  
   lack of dessication 121  
   lithology 50  
   sedimentary structures 47  
   sedimentation 47  
   sedimentation rate 55, 60  
   siltstone-shale layers 51  
   spring-neap cycles 48  
   tidal flat nature 50  
   trace fossil assemblage 122  
*Cincosaurus cobbi*  
   6, 19, 24, 45, 79, 80, **96**, 101, 193, **251**, 253-  
   267  
*Cincosaurus fisheri* 96  
*Cincosaurus jaggerensis* 96  
*Cincosaurus jonesii* 93, 96  
 clairain 45  
 Clayton Lake State Park 5, 10  
 Clayton Lake tracksite 4  
*Clepsydrops* 78  
 coal ash  
   composition 46  
 coal balls 51  
 coal groups 40  
 coal swamp forests 153  
 coal swamp trees  
   reconstructions 166  
 coalbed methane 40  
*Cochlichnus* 147  
 Coconino Sandstone 5  
 Colbert County, Alabama 138  
 Colburn Gem and Mineral Museum 195  
 collembolans 169  
 Coma galaxy cluster 18  
 conglomerate units 44  
 Connecticut Valley 179  
*Cordaicarpon* 160, **165**, 364  
*Cordaites* 31, 153, 155, 160, **165**, 172, 173, 364  
*Cordaites grandifolius* 165  
*Cordaites mansfieldi* 165  
 Cordova Quadrangle 45, 155  
 Cornberg Sandstein 116  
*Corophioides* 129  
 crinoids 44  
 Crocker, Deborah A. 21  
 Cross Mountain Formation 81  
 crossbedding 55  
 crossveins 170  
 crustaceans 150  
*Cruziana* 147  
*Cursipes* 9  
*Cyclopteris* **163**, 164, 345  
*Cyperites bicarinata* 157

**D**

*Dadoxylon oldhamium* 161  
 Dakota Group 5  
 DeChelly Sandstone 117  
 decorticated stem 159  
 delamination **76**  
*Delitzschala bitterfeldensis* 169  
 delta-front environment 55  
*Dendrerpeton* 78, 92  
 deposit feeders 132  
*Desmoinesia muracatina* 52  
 DeWitt, Robert 22  
*Diadactes* 78  
 Dilcher, David L. 193, **369**  
*Dimetropus* 3, 5, 6, 9, 93, 116, 117, 147  
 Dinosaur National Monument 5  
 dinosaur tracks 5  
*Diplichnites* 35, 47  
*Diplichnites gouldi* 147, **148**, 327-330  
*Diplocraterion* 127, 129  
 Diptera 123  
 dipterans 123  
   larvae 143  
 diurnal systems 48  
 domichnial 123  
 dragonflies 169  
*Dromopus* 5, 9, 81, 116, 117  
*Dromopus agilis* 76  
 durain 45

**E**

Early Pennsylvanian 3, 32, 39, 67  
   paleoclimate **40**  
   tectonics **40**  
 Early Permian 170  
 eccentricity cycle 44  
 echinoderms 53  
 Eldridge, Alabama 191  
 Entrada Sandstone 5  
*Eremopteris* 161  
 ethics **189**  
 ethoichnofacies 113, 116  
*Eubrontes* 6  
 eurypterids 150  
 extramorphology 79

**F**

fauna 113  
   stenohaline 121  
 "feather-stitch trails" 130  
 Fern Springs Road Mine 76, 81, 82, 191, 203  
 ferns 153  
 fish behavior  
   abrupt turning 64  
   anal fins 63

caudal fins 63  
   following 64  
   mode of propulsion 63  
   multiple trails 65  
   parallelism 65  
   schooling 8, 64  
 fish trails  
   (see *Undichna*) 60  
 Florida Museum of Natural History 155  
 fodinichnial 132  
 foreland basins 42  
 fossil trackways  
   physical significance 109  
 fusain 45

**G**

Galloway Coal Company 3  
   Mine No. 11 8, 122  
 Garnett, Kansas 78, 96  
 gas-escape structures 19, 49, **177**  
*Gaskohle* 4  
 gastropods 53  
 genal spine imprints 150  
 Geological Survey of Alabama 45  
 George, Eldon 6  
*Geotimes* 198  
*Gephyrostegus* 78, 93  
 Gillespy coal zone 45, 53  
*Gilmoreichnus* 9, 116  
 glaciation 44  
 glenoacetabular distance 60, 63, **65**  
 gleying 50  
 Gondwana 40  
*Gordia* 136  
*Gordia indianaensis* **137**  
 graded beds 48  
*Grallator* 6  
 Granton shrimp bed 4  
 Great Track Layout 193, 194  
 Griggs, James 186, 197, 198, 199  
 GSA 1052-245 138

**H**

Hamilton Quarry 4  
 Hamrick, Bruce 196  
*Haplotichnus* 123, **136**  
*Haplotichnus indianensis* 125, **136**, 137  
*Haplotichnus ornatus* **137**, 138  
*Haptodus* 78  
*Harpagnichnus* 116  
 Hartselle Sandstone **138**  
 Haubold, Hartmut 74, 76, 196, 203, **369**  
 Hebert, Brian 6  
*Helminthopsis* 148  
 hemimatabulous 172  
 Hermit Shale 117

Herr, Larry A. 23  
 highwall 31, 33, 54, 170  
 Hindostan beds 125, 130  
*Holcospermum* **163**, 164, 364  
*Holcospermum maizeretense* 163  
*Holcospermum mammillatus* 163  
*Holcospermum multistriatus* 163  
 Holly Grove Mine 93, 96, 97  
   specimen 95  
 Holocene 147  
 holotypes 85  
*Homaloneura* 173  
 Hood, Samuel 194  
 Hooks, G. E. III 21, 112, 197, **370**  
 Hot Springs Mammoth Site 5  
 Howell, Ed 195  
 Hueco Group 8, 115  
 Hunt, Adrian P. 197, **370**  
 Huntsville Times, The 198  
*Hydromeda fimbriata* 96  
 hydromorphic paleosols 50  
*Hylonomus* 78  
*Hylopus* 75, 76  
*Hylopus ? trifidus* 76

## I

*Ichniotherium* 9, 116, 117  
 ichnocoenosis 113  
 ichnofacies 113  
   general 5  
 ichnofaunal traditions  
   biotaxonomic 113  
   ethological 113  
 ichnotaxonomy  
   general 4  
 insect feeding traces 147  
 insect larvae 147  
 intermontane environments 117  
 intertidal environment 32

## J

Jackson, Wendy Allen 195  
 Jagger coal seam 8, 170  
 Jagger coal zone 109  
 Jasper, Alabama 147  
*Jasper Daily Mountain Eagle* 195  
 Jasper Kiwanis Club 196  
 jawed fishes 63  
 Jefferson County, Alabama 48  
 Joggins, Nova Scotia 4, 81, 96, 178  
 Johnson, Randy 194, 195  
 Jones, W. B. 191

## K

Kansas, Alabama 76, 96, 97, 191

  unnumbered specimen 97, 98  
 Kansas City, Missouri 96  
 Karoo Basin 193  
 Kennedy, Paul 196  
 Keota, Oklahoma 9  
 Kinney Brick Quarry 4  
 Kopaska-Merkel, David C. 196, 197, **371**  
*Kouphichnium* 3, 16, 20, 47, 147, **148**  
*Kouphichnium aspodon* 122, **280**, 281-283, 302-306  
*Kouphichnium* isp. **280**, 283-296, 308-320  
*Kouphichnium rossendalensis* 150  
 Kukulová-Peck, Jarmila 172

## L

Labandeira, Conrad 173  
 Lacefield, James A. 76, 173, 191, 194, 196, **370**  
 Lagerstätten  
   Konservat 4  
   Konzentrat 4, **39**  
 Lais, Vicki 196  
 Lamb, James 192  
 Langsettian 177  
*Lanicoidichna* 129  
*Laoporus* 114  
 Lark Quarry 5  
 Lata, Tommy 15  
 Late Mississippian 42  
 Late Silurian 170  
 Laurasia 153  
 Laurussia 40  
 Le Formation 96  
 leaf cushions 155, 157  
*Lepidocarpon* 347  
*Lepidodendron* 31, 52, 155  
*Lepidodendron aculeatum* **155**, 156, 341  
*Lepidodendron laricinum* 157  
*Lepidodendron laricinus* 156  
*Lepidodendron lycopodioides* 344, 347  
*Lepidodendron obovatum* **155**, 156, 341, 342  
*Lepidofloyos laricinum* 157  
*Lepidophloios* 31, 52, 155  
*Lepidophloios laricinum* **157**  
*Lepidophloios laricinus* 157, 342, 343  
*Lepidophylloides intermedium* **157**, 158, 364  
*Lepidophyllum intermedium* 157  
*Lepidophyllum majus* 157  
*Lepidostrobophyllum* cf. *majus* **157**, 160, 348  
*Lepidostrobophyllum majus* 157  
*Lepidostrobos* **157**, 158, 346, 347  
 Lerner, Allan J **371**  
 limestone banks 42  
*Limnopus* 9, 76, 116, 117  
*Limnosaurus alabamensis* 96  
*Limnoscelis* 78  
*Limulicubichnus* 150  
 limulid resting traces 150

- Limulus* 150  
 listservs  
   Paleonet 198  
   Skolithos 198  
   VrtPaleo 198  
 lithofacies 81  
 longitudinal scars 157  
 Lott, Terry A. 193, **371**  
 Lower Carboniferous 169  
 Lower Pennsylvanian 153  
 Lower Permian Red Beds 85  
 Lowery, James 194, 196  
 Lucas, Spencer G. 197, **372**  
*Lychnophorites laricinum* 157  
 lycophytes 153  
 lycopods 153  
*Lyginopteris hoeninghausi* **161**, 162, 357  
 Lyons Sandstone 117
- ## M
- MacDonald, Jerry 6, 10, 112, 194, 196  
 MacDonald, Pearl 112, 196  
*Macromerion* 78  
 Mansfield Formation 125, 135, 136, 137  
 Mansfield, Indiana 9  
 Mansky, Chris 6  
 manus 60, 65  
 marine transgressions 44  
*Mariopteris* 52  
*Mariopteris pottsvillea* 161  
 Martin, Anthony J. 22, 120, 192, 197, **372**  
 Mary Lee coal bed 8, 45  
   ash content 46  
   heating value 46  
   interpretation 46  
   original peat thickness 46  
   sulfur content 46  
   thickness 45  
 Mary Lee coal group 177  
 Mary Lee coal seam 19, 31, 195  
 Mary Lee coal zone 3, 31, 40, 45, 76, 109, 147  
   ichnotaxa 80  
*Matthewichnus* **81**, 93  
*Matthewichnus caudifer* **81**, 82, **210**, 211  
 Mazon Creek 4  
*Mazostachys* 354  
 McCarthy, Milton 194, 195, 198  
 McCreary County, Kentucky 96  
 McWane Science Center 192, 199  
*Medullosa* 155, 355, 360, 361  
*Meganeura monyi* 169, 173  
 Megasecoptera wing 175  
*Mermia*  
   ichnofacies 147  
 mesotidal regime 48  
 mica 32  
 Milankovitch cycles 44, 46  
 Milner, Andrew R. C. 6, 10  
 Minkin, Missy 197  
 Minkin, Steven C. 20, 76, 192, 194, 195, **372**  
   Paleozoic Footprint Site 30  
 molluscs 44  
 Montceau-les-Mines 4  
 Morrowan 39  
 mud flats  
   formation 153  
*Myeloxylon* **163**, 164  
 myriapods 148
- ## N
- Nanopus* 76, **81**  
*Nanopus caudatus* 76, 81, 85, 92  
*Nanopus obtusus* 85, 92  
*Nanopus quadratus* 85, 92  
*Nanopus quadrifidus* 92  
*Nanopus reidiai* **85**, 86, 92, **210**, 212-229  
 negative relief 60  
 nematodes 147  
 neopterous insects 169  
*Nereites* 54  
*Neuralethopteris* **163**  
*Neuralethopteris biformis* 162, **163**, 355, 358, 359  
*Neuralethopteris pocahontas* 162, **163**, 358, 359, 360  
*Neuropteris* 47, **52**  
 New Acton Coal Company 15, 19, 121, 177, 194, 197  
 New Castle coal bed 45, **50**  
   sulfur content 51  
   thickness 50  
 New Castle coal seam 19, 121, 177  
 New Castle roof shale  
   erect plant axes 52  
   plant ecology 51  
   terrestrial setting 52  
 New Mexico  
   paleogeographic map 116  
 New Mexico Museum of Natural History and Science 197  
 NMMNH P-40012 7  
 nodular limestone **52**  
*Notalacerta* 3, 75, 76, 147  
*Notalacerta missouriensis* 80, **96**, 97, 202, **251**, 252
- ## O
- Okefenokee Swamp 46  
 Oneonta High School 192  
*Oniscoidichnus filiciformis* **138**  
*Ophiacodon* 78  
 opistosomal marks 150  
 Ordovician 42, 148  
 Orick, Billy 15, 195, 197  
*Ornithichnites* 75, 76  
 orogenic belts 42  
 orogenic highlands 42

Osborne, W. Edward 179  
 Ouachita orogenic belts 42  
 overbank sedimentation 46  
 oxygen isotope record 44  
 oxygenic partial pressure 169

## P

pace 63  
 pace angulation 63, 65  
 Palaeodictyoptera  
   biology 172  
   wing structure 171  
 palaeodictyopterans 169  
*Palaeophycus* 129, 147, **148**  
*Palaeophycus alternatus* 129  
*Palaeophycus striatus* 129  
*Palaeophycus triadicus* 129  
*Palaeophycus virgatus* 129  
 palaeopterous insects 169  
*Palaeosauropus* 75  
*Palaeosauropus caudifer* 81  
*Palaeothyris* 78  
 paleoecology  
   general 5  
 paleoenvironment 5  
*Paleosauripus* 9  
 Paleozoic tetrapod ichnofaunas  
   global map 114  
*Palmatopteris furcata* 360  
 Pangaea 39  
   plate reconstructions 42  
 paratypes 85  
 Pashin, Jack C. 31, 196, **373**  
 peat swamps 46  
 pelycosaurs 93  
 pes 60, 65  
 Peterson Dinosaur Quarry 6  
 Peterson, Rod 6  
 Peterson, Ron 6  
*Petrolacosaurus* 78  
 Phanerozoic 113  
 phantom taxon 79  
 photographic atlases  
   amniote trackways **251**  
   fish swimming traces **268**  
   large anthracosaur tracks and trackways **230**  
   small amphibian trackways **210**  
   xiphosuran resting traces **321**  
   xiphosuran traces **280**  
*Phycodes pedum* 132, 134  
 phytoliths 46  
 pith cast 159  
*Plangtichnus* 123  
*Plangtichnus erraticus* 134, 136  
*Planolites* 123, 133  
 Plant Fest 24

plants, fossil **153**, 341-365  
 Pleistocene glaciation 44, 47  
 polychaete worms 123  
 positive relief 60  
 Pottsville Formation  
   3, 8, 19, 31, **39**, 60, 76, 153, 170, 173, 177  
   age 42  
   coal production **40**  
   coal zones 40  
   coastal plain environments 44  
   cycle timespans 44  
   depositional cycles 42, 44, 45  
   generalized stratigraphic section 41  
   history of transgressions and regressions 42  
   lithology 44  
   paleoecology 8  
   paleoenvironment 43  
   paleogeography 46  
   peat swamp complexes 45  
   rock types 40  
   sediment types 44  
   stratigraphy **39**  
 Pratt coal zone 40  
 Precambrian 147  
 prosomal marks 150  
*Protoclepsydrops* 78  
*Protovirgularia* 147, **148**  
*Psaronius* 155  
*Pseudobradypus* 9, 76  
 pteridosperms 31  
 Pyenson, Nicholas D. 22, 193, 194, **373**  
 pyrite 32, 46

## Q

*Quadropedia prima* 96  
 quadrupedalism 63

## R

raindrop imprints 48  
 rainprints 177  
 Rajang Delta 48  
 Red Mountain Museum 192  
 Redpath Museum 76  
 Reid, Dennis 194  
 Reid, Dolores 15, 19, 85, 192, 194, 198  
 Reid, Don 6  
 Relihan, Bruce A. 76, 194, 195, **373**  
 Rheic Ocean 40  
*Rhizocorallium* 129  
*Rhyniella* 169  
 Rindsberg, Andrew K.  
   22, 192, 194, 195, 196, 197, 198, **374**  
 Robledo Mountains 6, 9, 92, 115, 116, 194  
   tracksites 4  
 Rocky Hill Dinosaur State Park 5  
 Rotliegende 115

## S

*Salichnium* 92  
 sandstone-shale couplets 147  
 Sangre de Cristo Formation 117  
*Sauropus* 75  
*Sauropus primaevus* 75  
*Sauropus sydnensis* 75  
*Sauropus unguifer* 75  
*Schmidtopus* 9  
*Science* 198  
 seed ferns 31, 153  
 Seilacherian ichnofacies 113  
*Selenichnites* 147, **150**  
*Selenichnites langridgei* 150  
 shale  
     burrowing 53  
     carbonaceous 33  
     compaction 121  
     pinstripe-bedded 47  
     rippled-bedded 47  
     roof 51  
 siderite 47, 53  
 siderite nodules 47, 51  
*Sigillaria* 31, 155, 349  
*Sigillaria elegans* 343  
*Sigillariostrobus quadrangulatus* 347  
*Skolithos* 180  
 sociology 5  
 Spencer, Thomas 22  
*Sphenophyllum* **52**, 364  
 sphenophytes 31  
 sphenopsids 153  
*Sphenopteris* **52**  
*Sphenopteris elegans* **161**, 162, 356  
*Sphenopteris hoeninghausi* 161  
*Sphenopteris pottsvillea* **161**, 162, 356  
*Spheropezium* 75  
*Spirodesmus interruptus* 134  
*Spirorbis carbonarius* 157  
 St. George Dinosaur Discovery Site 5  
 Stanley Cemetery Flora 153  
 Stanton Formation 96  
 Stephanian 78  
 Steven C. Minkin Paleozoic Footprint Site  
     121, 177, **199**  
     plaque 199  
*Stigmatia* 47, **52**  
 straddle 63  
 stratigraphy  
     general 5, 39  
     sequence 44  
 stride 63  
*Stylocalamites undulatus* 159  
 subaqueous environment 32  
 substrate 113  
 Surface Mining Control and Reclamation Act 191, 194

swamp forests 52  
 swimming speeds  
     *Undichna maker* 63  
 swimming trails 59  
*Syringodendron* 156, **159**, 160, 349

## T

Tambach Sandstein 117  
 taphonomy  
     general 4  
 telson drag  
     *Kouphichnium* 150  
 tetrapod behavior  
     abrupt turns 67  
     belly-dragging 69  
     diagonalism 65  
     gait 69, 79  
     group movement 65, 67  
     looping 67  
     manus-pes sequences 65  
     sideways movement 65  
     stimulus-response 67  
     tail-dragging 69  
     variations in speed 65  
 tetrapod body fossils 8  
 tetrapod ethnoichnofacies 116  
 tetrapod footprints **75**  
     Amniota 78  
     classification criteria  
         toe marks 76  
         "lumpers" 79  
         "splitters" 79  
     ichnotaxonomy 78  
     Microsauria 78  
     oblique progression 116  
     original surface issues 79, 81  
     original surface tracks 109  
     pace angulation 96  
     Reptiliomorpha 78  
     skeletal record 78  
     tail impressions 81  
     Temnospondyli 78  
     temnospondyls 81  
     undertrack issues 79  
 tetrapod ichnofacies 113  
*Thalassinoides* 134  
*Thenaropus* 75, 76  
*Theranopus* 75  
 tidal rhythmites 3, 147, 151  
 tipulids 123  
     larval traces 143, 145  
*Tisoa* 129  
*Tonganoxichnus* 9  
 Townley, Alabama 202  
 tracemakers 59  
 Track Meets 11, **20**, 59, 192, 201, 202

- T-shirt logo 22
- trackways
- captorhinomorph 9
  - horseshoe crab
    - (see also *Kouphichnium*) 20
  - population estimates 59
  - xiphosuran 33
- transitional preservation 96
- Treptichnus* 3, 59, **123**, 143
- ontogeny of tracemakers 125
- Treptichnus aequalternus* 134
- Treptichnus apsorum* **121**, **132**, 332-337
- Treptichnus bifurcus* 123, **134**, 135, 147, 151
- Treptichnus coronatum* 134
- Treptichnus meandrinus* 134
- Treptichnus lublinensis* 134
- Treptichnus pedum* 132, 134
- Treptichnus pollardi* 134
- Treptichnus rectangularis* 134
- Treptichnus triplex* 134
- Trichophycus* 129
- Trichophycus lanosus* 129
- Trichophycus venosus* 129
- Trigonocarpum* 165
- Trigonocarpus* 155, 164, 362
- Trigonocarpus ampulliforme* 164, 362
- trigonotarbid arachnid 175
- trilobites 150
- Triogonocarpus ampulliforme* **165**
- Trisaurus secundus* 96
- Tucker, Jay 76
- Tucker, Lauren 197
- Tuditanus* 78
- Tuscaloosa News, The 198
- Twieg, Kathy 21, 194, 195, 196
- U**
- U-burrows 122, 123
- UC 36076 137
- UC 36077 136
- UC 54099 135
- Uchman, Alfred **374**
- UCM (H002) 81, 84
- UCM (H003) 86, 89, 92
- UCM 0002 85, 214
- UCM 0004 85, 215
- UCM 0009 93
- UCM 0010 181
- UCM 0011 85, 215
- UCM 0016 93
- UCM 0017 96, 107, 253
- UCM 0018 96, 253
- UCM 0021 93
- UCM 0024 93
- UCM 0024/0025 238
- UCM 0025 93
- UCM 0026 92
- UCM 0060 85, 86, 88, 212
- UCM 0064 269
- UCM 0067 109, 266
- UCM 0068 225
- UCM 0071 224
- UCM 0074 269
- UCM 0076 63, 65, 66, 69, 85, 219, 220
- UCM 0078 109
- UCM 0084 63, 65, 85
- UCM 0087 96, 254
- UCM 0092 332
- UCM 0093 36, 269
- UCM 0098 245
- UCM 0107 150
- UCM 0118 283
- UCM 0124 244
- UCM 0125 109, 193
- UCM 0140 34, 85, 213
- UCM 0143 332
- UCM 0147 333
- UCM 0154 35, 148
- UCM 0159 85
- UCM 0167 85, 214
- UCM 0174 80, 96, 255
- UCM 0174/0175 101
- UCM 0175 80, 96, 255
- UCM 0177 85, 213
- UCM 0179 333
- UCM 0180 334
- UCM 0191 85, 212
- UCM 0195 85
- UCM 0196 85
- UCM 0199 93
- UCM 0200 93
- UCM 0202 233
- UCM 0205 80, 93, 234
- UCM 0208 96, 256
- UCM 0214 302
- UCM 0215 302
- UCM 0219 93, 234
- UCM 0223 96, 252
- UCM 0227 303
- UCM 0229 96, 100, 252
- UCM 0237 96, 256
- UCM 0242 80, 93, 235
- UCM 0249 85, 221
- UCM 0250 257
- UCM 0250-0263 96
- UCM 0251 257
- UCM 0252 258
- UCM 0253 109, 258
- UCM 0254 257
- UCM 0255 259
- UCM 0256 109, 259
- UCM 0257 258
- UCM 0258 260

UCM 0259 260  
UCM 0260 261  
UCM 0261 261  
UCM 0262 261  
UCM 0263 80, 102  
UCM 0267 109  
UCM 0270 93, 247  
UCM 0278 16  
UCM 0281 85, 216  
UCM 0282 93  
UCM 0285 81, 211  
UCM 0287 270  
UCM 0300 233  
UCM 0302 85, 216  
UCM 0311 85, 86, 87  
UCM 0312 85  
UCM 0313 85, 217  
UCM 0318 85, 217  
UCM 0331 16, 35, 109, 264  
UCM 0333 293  
UCM 0340 109  
UCM 0357 85, 86, 91, 218  
UCM 0359 17  
UCM 0364 85, 213  
UCM 0370 330  
UCM 0374 16  
UCM 0387 294  
UCM 0388 16, 304  
UCM 0393 327  
UCM 0394 327  
UCM 0417 334  
UCM 0419 335  
UCM 0421 335  
UCM 0426 303  
UCM 0430 303  
UCM 0437 304  
UCM 0447 85, 218  
UCM 0448 85, 217  
UCM 0455 61, 270  
UCM 0469 64, 80, 81, 82  
UCM 0477 305  
UCM 0479 290  
UCM 0482 263  
UCM 0484 70  
UCM 0485A 296  
UCM 0487 150, 297  
UCM 0489 282  
UCM 0490 282  
UCM 0507 247  
UCM 0523 229  
UCM 0546 284  
UCM 0553 223  
UCM 0556 284  
UCM 0569 250  
UCM 0571 85, 222  
UCM 0602 297  
UCM 0617 283  
UCM 0620 285  
UCM 0624 216  
UCM 0629 85  
UCM 0645 93, 94  
UCM 0649 85  
UCM 0652 81, 82, 83  
UCM 0662 282  
UCM 0666 327  
UCM 0669 227  
UCM 0670 262  
UCM 0672 262  
UCM 0675 262  
UCM 0676 228  
UCM 0677 70, 228  
UCM 0678 270  
UCM 0680 227  
UCM 0689 285  
UCM 0690 266  
UCM 0692 290  
UCM 0723 286  
UCM 0728 61  
UCM 0731 271  
UCM 0743 322  
UCM 0788 122, 336  
UCM 0806 276  
UCM 0808 219  
UCM 0827 305  
UCM 0833 85, 218  
UCM 0878 224  
UCM 0888 325  
UCM 0902 305  
UCM 0945 109  
UCM 0949 92, 222  
UCM 0953 328  
UCM 0954 328  
UCM 0959 286  
UCM 0969 81, 211  
UCM 0973 85, 90, 219  
UCM 0987 276  
UCM 0989 62, 270  
UCM 1029 271  
UCM 1030 336  
UCM 1031 85  
UCM 1047 271  
UCM 1051 150, 298  
UCM 1053 150, 298  
UCM 1057 298  
UCM 1058 150, 298  
UCM 1060 150, 299  
UCM 1061 150, 299  
UCM 1068 109, 264  
UCM 1070 281  
UCM 1071 281  
UCM 1072 282  
UCM 1074 34, 93, 231  
UCM 1075 67, 71, 96, 103, 109, 264  
UCM 1076 171

- UCM 1076a 172  
schematic of wing venation 173
- UCM 1077 337
- UCM 1088 224
- UCM 1092 243
- UCM 1093 239
- UCM 1095 243
- UCM 1096 254
- UCM 1117 287
- UCM 1118 284
- UCM 1119 287
- UCM 1124 294
- UCM 1141 80, 85, 86
- UCM 1142 80, 85, 226
- UCM 1152 323
- UCM 1153 323
- UCM 1154 324
- UCM 1156 324
- UCM 1157 325
- UCM 1168 182
- UCM 1206 93, 235
- UCM 1207 283
- UCM 1209 96, 252
- UCM 1214 80, 249
- UCM 1216 80, 93, 236
- UCM 1220 290
- UCM 1224 286
- UCM 1264 288
- UCM 1265 288
- UCM 1267 329
- UCM 1268 306
- UCM 1281 292
- UCM 1289 269
- UCM 1300 276
- UCM 1303 68
- UCM 1304 64, 67, 276
- UCM 1319 250
- UCM 1345 287
- UCM 1348 62, 65, 272
- UCM 1349 292
- UCM 1368 294
- UCM 1370 328
- UCM 1376 295
- UCM 1377 295
- UCM 1384 295
- UCM 1390 296
- UCM 1397 293
- UCM 1402 289
- UCM 1410 291
- UCM 1411 291
- UCM 1414 289
- UCM 1437 150, 299
- UCM 1438 237
- UCM 1441 150, 300
- UCM 1470 236
- UCM 1470-72 93
- UCM 1476 96, 105, 106, 265
- UCM 1477 109, 265
- UCM 1491 239
- UCM 1492 239
- UCM 1495 322
- UCM 1498 237
- UCM 1505 306
- UCM 1568 150
- UCM 1589 226
- UCM 1621 240
- UCM 1622 241
- UCM 1623 244
- UCM 1639 245
- UCM 1650 147
- UCM 1670 273
- UCM 1687 241
- UCM 1692 249
- UCM 1724 229
- UCM 1728 273
- UCM 1729 64, 67, 272
- UCM 1730 275
- UCM 1731 274
- UCM 1733 274
- UCM 1734 61, 273
- UCM 1735 309
- UCM 1737 308
- UCM 1738 308
- UCM 1740 309
- UCM 1742 310
- UCM 1744 311
- UCM 1748 311
- UCM 1749 312
- UCM 1752 150, 313
- UCM 1754 232
- UCM 1755 150, 313
- UCM 1757 314
- UCM 1758 315
- UCM 1761 316
- UCM 1762 150, 300, 313
- UCM 1764 315
- UCM 1767 317
- UCM 1771 317
- UCM 1772 317
- UCM 1777 318
- UCM 1780 318
- UCM 1781 319
- UCM 1786 320
- UCM 1788 319
- UCM 1794 320
- UCM 1797 223
- UCM 1798 238
- UCM 1801 291
- UCM 1805 337
- UCM 1814 225
- UCM 1815 267
- UCM 1817 242
- UCM 1820 329
- UCM 1821 226

UCM 1825 263  
 UCM 1838 225  
 UCM 1842 267  
 UCM 1856 215  
 UCM 1915 249  
 UCM 1924 248  
 UCM 2026 126, 128  
 UCM 2027 131  
 UCM 2029 131  
 UCM 2038 124  
 UCM 2072 178, 182  
 UCM 2237 274  
 UCM 2249 248  
 UCM 2253 247  
 UCM 2267 231  
 UCM 2379 240  
 UCM 2380 242  
 UCM 2382 275  
 UCM 2446 271  
 UCM 2448 272  
 UCM 2461 301  
 UCM 2466 301, 330  
 UCM 2469 296  
 UCM 2494 26  
 UCM 2495 293  
 UCM 2497 286  
 UCM 2507 229  
 UCM 2514 229  
 UCM 2516 275  
 UCM 2518 304  
 UCM 2528 246  
 UCM-P 15 342  
 UCM-P 153 348  
 UCM-P 154 348  
 UCM-P 155 342  
 UCM-P 158 359  
 UCM-P 159 342  
 UCM-P 160 342  
 UCM-P 162 349  
 UCM-P 163 344  
 UCM-P 165 343  
 UCM-P 169 356  
 UCM-P 172 343  
 UCM-P 173 341  
 UCM-P 176 352  
 UCM-P 180 343  
 UCM-P 184 355  
 UCM-P 194 354  
 UCM-P 200 345  
 UCM-P 201 353  
 UCM-P 202 352  
 UCM-P 215 364  
 UCM-P 216 354  
 UCM-P 218 350  
 UCM-P 219 347  
 UCM-P 220 360  
 UCM-P 221 344  
 UCM-P 224 344  
 UCM-P 227 357  
 UCM-P 25 352  
 UF 18902-33933' 346  
 UF 18902-33985 345  
 UF 18902-33986 159  
 UF 18902-33988 163  
 UF 18902-33989 165, 364  
 UF 18902-33990 159  
 UF 18902-33992 159, 353  
 UF 18902-33993 157, 346  
 UF 18902-33994 159, 351  
 UF 18902-34007 157, 347  
 UF 18902-34008 157, 341  
 UF 18902-34010 350  
 UF 18902-34011 161, 354  
 UF 18902-34013 157, 345  
 UF 18902-34014 155, 341  
 UF 18902-34016 159, 349  
 UF 18902-34018 159, 352  
 UF 18902-34019 351  
 UF 18902-34022 359  
 UF 18902-34023 163, 358  
 UF 18902-34024 358  
 UF 18902-34025 163, 358  
 UF 18902-34027 358  
 UF 18902-34028 358  
 UF 18902-34029 163, 358  
 UF 18902-34030 161  
 UF 18902-34031 360  
 UF 18902-34033 161, 356  
 UF 18902-34035 360  
 UF 18902-34036 161, 355  
 UF 18902-34037 355  
 UF 18902-34037' 355  
 UF 18902-34038 161, 357  
 UF 18902-34039 161, 357  
 UF 18902-34040 165, 362  
 UF 18902-34040' 165, 362  
 UF 18902-34041 165, 362  
 UF 18902-34042 157, 346  
 UF 18902-34043 159, 351  
 UF 18902-34044 354  
 UF 18902-34045 354  
 UF 18902-34046 163  
 UF 18902-34046' 163, 345  
 UF 18902-34047 159, 351  
 UF 18902-34350 163, 359  
 UF 18902-34351 163  
 UF 18902-34362 165, 362  
 UF 18902-34362' 165  
 UF 18902-34364 163, 361  
 UF 18902-34364' 163, 361  
 UF 18902-34365 157, 347  
 UF 18902-34366 159, 351  
 UF 18902-34367 347  
 UF 18902-34368 165, 364

UF 18902-34369a 159, 348  
 UF 18902-34369b 165  
 UF 18902-34370 165  
 UF 18902-34370b 364  
 UF 18902-34371 157, 343  
 UF 18902-34372 157, 347  
 UF 18902-34373a 159, 350  
 UF 18902-34373b 157  
 UF 18902-34374 159, 348  
 UF 18902-34375 157, 346  
 UF 18902-34376 362  
 UF 18902-34377 159, 348  
 UF 18902-34378 157, 364  
 UF 18902-34379 159, 349  
 UF 18902-36866 353  
 UF 18902-36870 357  
 UF 18902-36873 361  
 UF 18902-36875 356  
 UF 18902-36877 362  
 UF 18902-36879 362  
 UF 18902-36883' 361  
 UF 18902-36890 361  
 UF 18902-36891 361  
 UF 18902-36896 361  
 UF 18902-36901 361  
 UF 18902-36903 362  
 UF 18902-36908 361  
 UF 18902-48553 353  
 underclay beds 50  
*Undichna*  
     3, 8, 24, 32, 36, 47, 59, 60, 63, **69**, 122, 147, 151, **268**,  
     269-276  
     amplitudes 60  
 Union Chapel Mine  
     arthropod body fossils 169  
     as Lagerstätte 3, **39**  
     biostratigraphy 9  
     collectors 76  
     depositional environments 32  
     discovery 11, **15**, 191  
     estuarine nature 32  
     fish trail properties 60  
     Fossil Footprint Preservation Act 196  
     fossil plants 153  
     freshwater paleoenvironment 121  
     gas-escape structures 180  
     geography 8  
     highwall 31, 195  
     ichnofacies 8  
     ichnotaxonomy 6  
     insect wings **170**  
     invertebrate traces **121**, **147**  
     lithology 32  
     locality 3, 39, 121, 155  
     paleobiogeography 8  
     paleoecology 8  
     paleoenvironment 9, 31, 121, 151

    paleoequatorial setting 31  
     paleogeographical setting 32  
     photographs 2, 20, 21  
     photography of specimens 23  
     plant fossils **153**, 341-365  
     preservation 10  
     preservation effort award 366  
     rock colors 32  
     rock types 19, 31  
     sedimentation rate 67  
     shale properties 31  
     significance 6, 63, 109, 192  
     stratigraphic section **45**, 49  
     stratigraphy 8  
     taphonomy 6, 153  
     tetrapod traces 75  
     tidal flat nature 9  
     trackway exhibit 24  
     undertracks 6, 32, 60  
     vertebrate traces **59**, **75**  
     website 23, 147, 192  
 University of Alabama 188, 203  
 US Bureau of Land Management 194  
*USA Today* 198  
 Utley coal zone 40

## V

van Allen, Howard 6  
 vertebrate tracks  
     classification criteria 76  
     digitigrade 75  
     generic names 76  
     pentadactyl 75  
     plantigrade 75  
     properties 60  
     tetradactyl 75  
 vitrain 45

## W

Walker County, Alabama  
     3, 45, 147, 153, 170, 177, 191  
 Wapske Formation 132  
 Warrior coal basin 39  
 Westphalian A 3, 79, 173, 177  
 Westphalian B 81  
 Westphalian D 92  
*Whittleseya* 155  
*Whittleseya elegans* **163**, 164, 361  
 Workshop on Permo-Carboniferous Ichnology  
     25, 120, 203  
     logo 197  
 worm-like organisms 148

## X

xiphosuran traces 147  
 xiphosurans

unassigned traces **150**, 297-301, 313

## **Y**

Yacimiento Los Reyunos Formation 117

## **Z**

Zwickau, Germany 92





