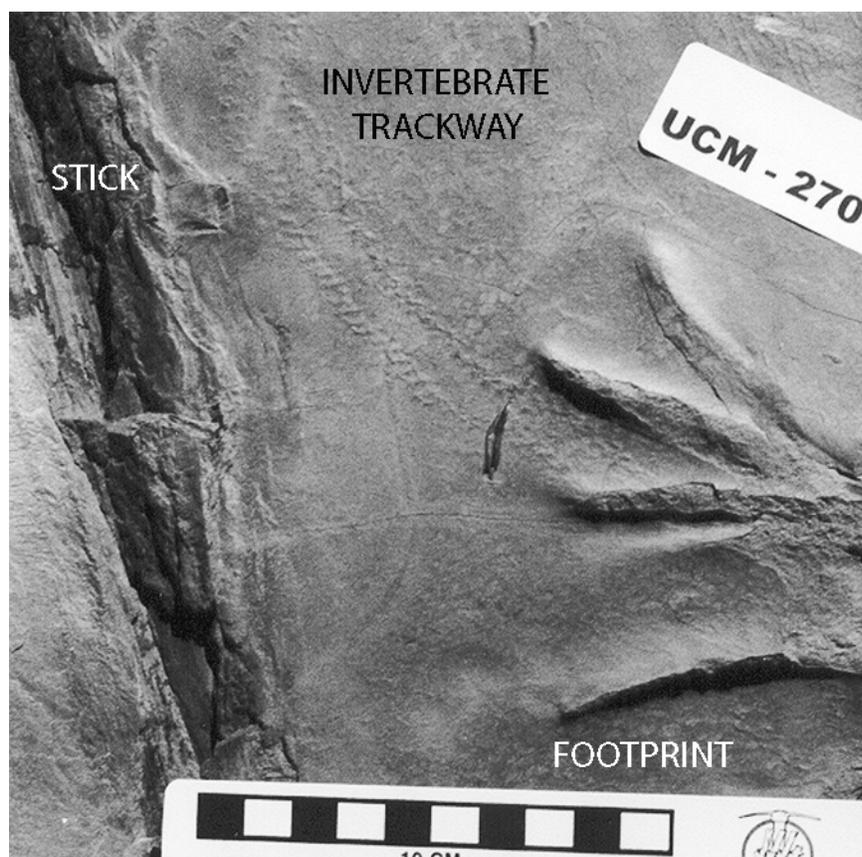


Field-Trip Guidebook
to the
Steven C. Minkin Paleozoic Footprint Site, Walker County, Alabama



David C. Kopaska-Merkel and Ronald J. Buta

2012

Alabama Paleontological Society
Birmingham, Alabama

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On facing page: Possible insect trackway with suggested interpretation.

Kopaska-Merkel, David C., and Buta, Ronald J., 2012, Field-trip guidebook to the Steven C. Minkin Paleozoic Footprint Site, Walker County, Alabama: Alabama Paleontological Society, 53 p.

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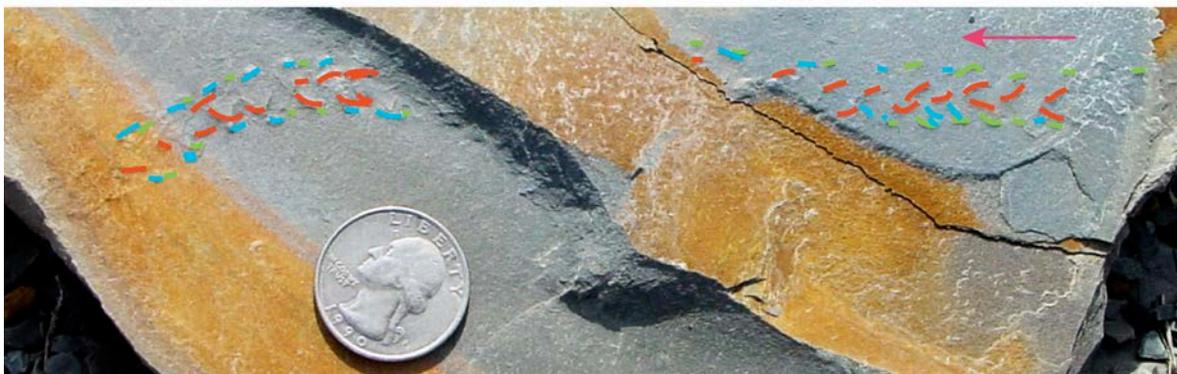
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surface track

undertrack



2012

Alabama Paleontological Society

Minkin Site tetrapods to a common scale

Nanopus reidia



Matthewichnus caudifer



Attenosaurus subulensis



Notalacerta missouriensis



Cincosaurus cobbi



1 foot



Figure 1. Steven C. Minkin Paleozoic Footprint site. A. Location and paleogeographic setting of Walker County and the Minkin site (Jim Lacefield). B. Field photograph, January 23, 2000, date of first BPS trip to the site.

Two critical decisions were made. 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. The first studies of the trackways led Pyenson and Martin (2001) to conclude early on that the Union Chapel Mine is “one of the most important Carboniferous tracksites in the world” (Buta and Minkin, 2005).

INTRODUCTION

A former coal mine in Walker County may be the most important fossil locality in the state of Alabama. Yet most of the fossils there are simply patterns in the rock; not shells or bones. How would you behave if you knew that more than 300 million years from now somebody would be looking at your footprints and wondering what you had been doing?

This guidebook is intended to introduce you to the Steven C. Minkin Paleozoic Footprint site, which is in Walker County, Alabama (Fig. 1). We want to give you an idea of the importance of the site, what can be found there, and how to identify some of the common fossils found there. A great deal of information about the site is available online; see the section entitled “Further Information” for how to find it. Contact the Alabama Paleontological Society. (<http://alabamapaleo.org>) if you want to visit the site.



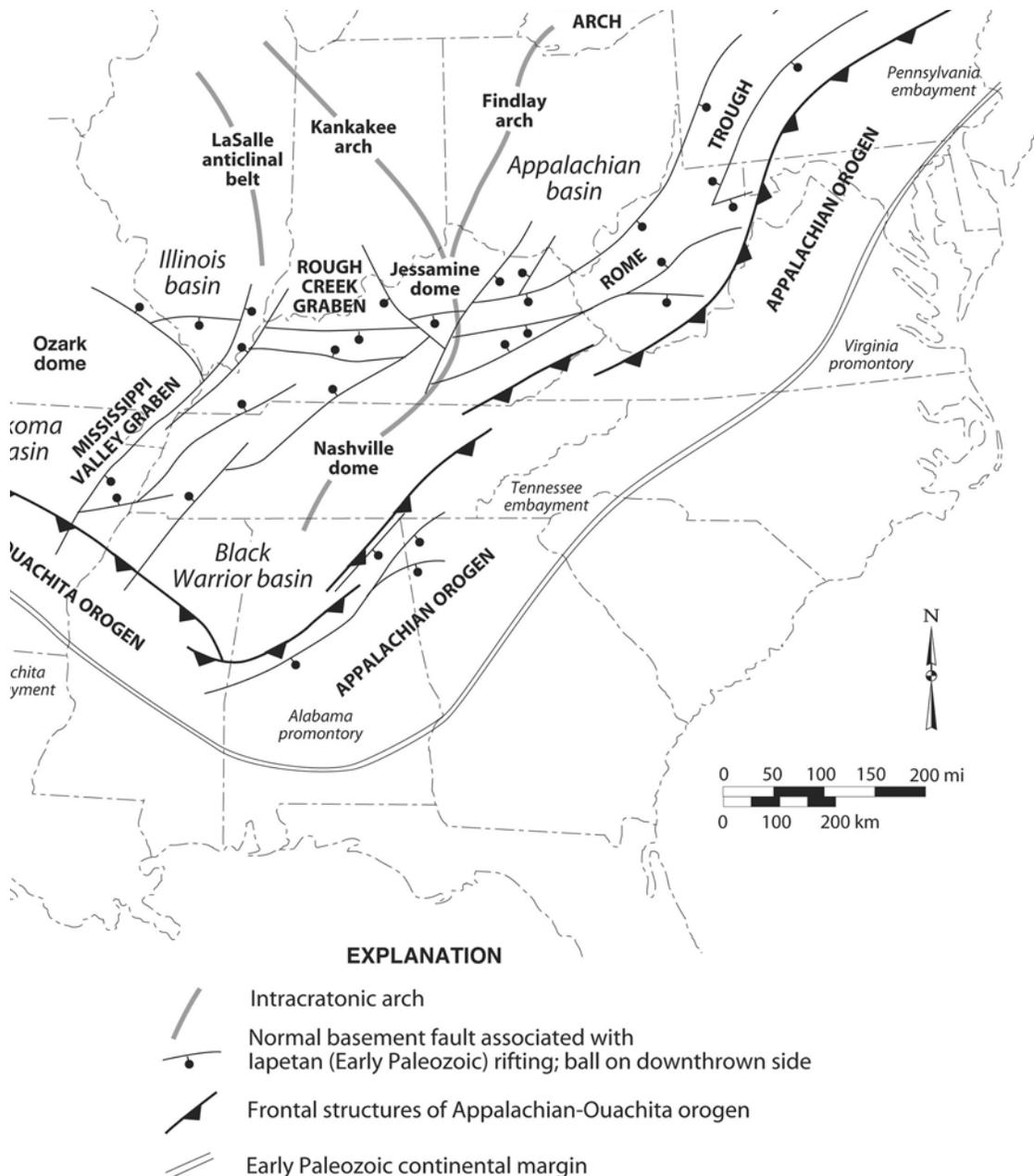
The Minkin site is the most important vertebrate trackway site of its age in the world. So said Hartmut Haubold, a German expert on vertebrate tracks, after he examined hundreds of specimens that had been collected from the site. Fossil vertebrate tracks have been known from the Black Warrior basin of Alabama at least since the 1920s (Aldrich and Jones, 1930). Between 1930 and 1999, even though tracks were discovered in several Alabama coal mines (Rindsberg, 1990; Jim Lacefield, 2010, personal commun.), no research was done on them, and they received little attention. Then everything changed.

Ashley Allen is a high school science teacher from Oneonta, Alabama. When he told his students that he would like to take them to visit a coal mine to look for fossils, Jessie Burton said his grandmother owned a mining company.

It was November of '99, and I went out there on a scouting expedition.... I find a slab that had a definite trackway going through it.... It looked like tire tracks of a small truck or little radio-operated vehicle.... I look around a bit longer, and I find another [trackway] that, in the Aldrich and Jones publication, is Bipedes aspodon, which I think they had listed as some sort of amphibian, but which we now recognize as an arthropod track.... I split [a] slab open, and there were three beautiful tetrapod trackways, ... little footprints running three different directions on the slab.... I yelled "Yahoo!" (Ashley Allen, 2010, personal commun.).

Since Ashley's discovery, thousands of specimens have been collected from the former Union Chapel mine, now the Minkin site. A substantial volume has been published about the site (Buta and others, 2005a), and another is in preparation, to be published by the University of Alabama Press. Scientific papers have been published; specimens are housed in museums, including the Smithsonian Institution in Washington D. C., the McWane Science Center in Birmingham, and the Alabama Museum of Natural History in Tuscaloosa; and the site continues to yield remarkable fossils every time it is visited.

Figure 2. Geologic setting of the Stephen C. Minkin Paleozoic Footprint site. A. Map showing tectonic setting of Black Warrior basin, after Thomas (1988).



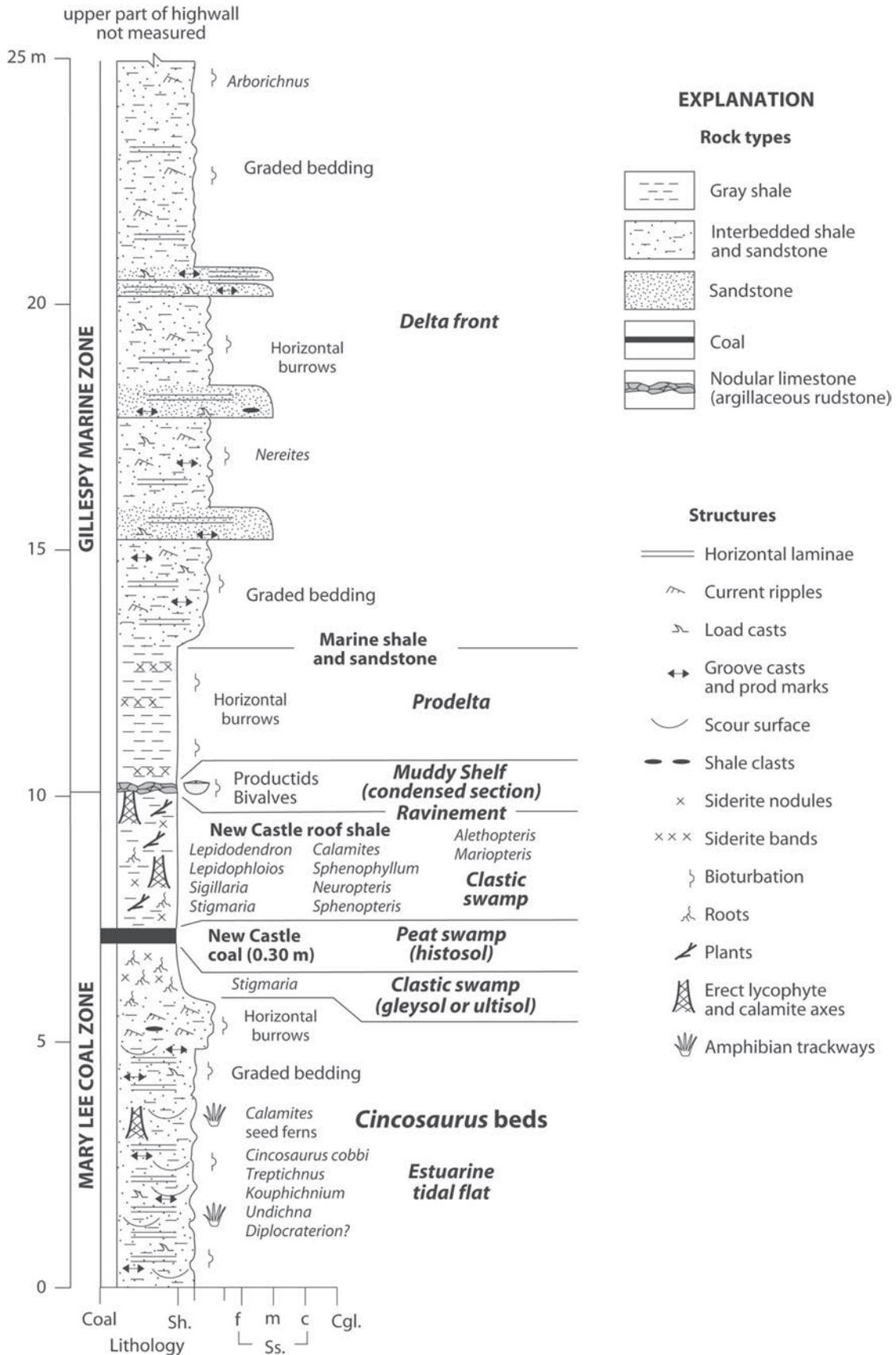


Figure 2. Geologic setting of the Stephen C. Minkin Paleozoic Footprint site. B. Measured stratigraphic section (Pashin, 2005).

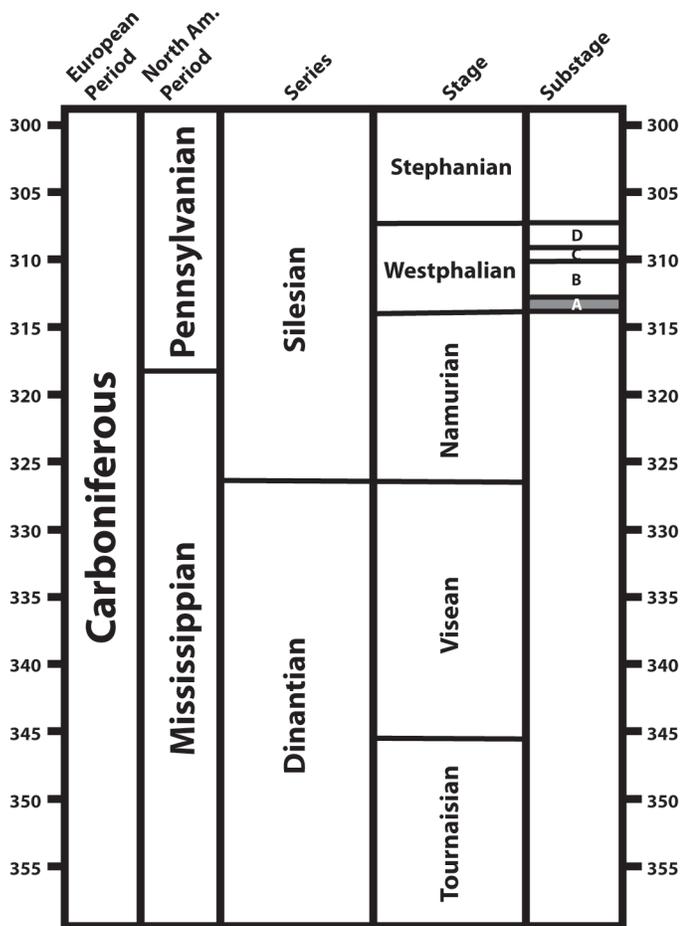


Figure 2. Geologic setting of the Stephen C. Minkin Paleozoic Footprint Site. C. Age of the track-bearing *Cincosaurus* beds (gray), Minkin site, Walker County.

GEOLOGIC SETTING

The geologic history of Alabama has been explained in a way that is accessible to the general public by Jim Lacefield (2000). The geologic setting of the Minkin Site was described by Buta and others (2005a). We briefly summarize it here.

The Minkin site is located in the Black Warrior basin (Fig. 2A), a depositional basin in west-central Alabama that is filled with Mississippian and Pennsylvanian rocks. The Pennsylvanian rocks in the basin are referred to as the Pottsville Formation. The Pottsville is a thick unit dominated by sand and mud eroded from the great Appalachian-Ouachita mountain chain of the eastern United States and Canada. Most of the coal deposits in the eastern United States, including Alabama, are in the Pottsville.

Why did so much coal form during the Pennsylvanian? This was a major episode of ancient mountain building in what is now eastern North America and northwestern

Europe. At the time, there was no Atlantic Ocean. You could walk from New England to old England. Tectonic plates collided, mountains pushed up, and long valleys formed between them. The climate was warm and humid, and large rivers ran along the valleys. Where the land was low and flat, swamps formed. Pennsylvanian swamp forests covered a lot of territory. They may have been comparable in scope to the modern taiga, or boreal forests, which today cover much of Earth's high northern latitudes. These ancient swamps were perfect places for the lush plant growth that eventually created some of the world's largest coal deposits.

Where does the Minkin site fit in? South of the ancient plateaus and west of the mountains of north and northeast Alabama lies the Black Warrior basin. This area sank while the mountains were rising. The basin filled with a wide variety of sedimentary rocks. Sedimentary rock in the basin approaches 2 kilometers in thickness, attesting to the vast volumes of sand, mud, and other material eroded from the Appalachian Mountains. Sediment that filled the Black Warrior basin included the coal that, more than 300 million years later, was mined at Union Chapel.

Most of the trace fossils collected at the Minkin site come from the *Cincosaurus* beds (Pashin, 2005), a thin layer of shale between the Mary Lee and New Castle coal seams of the Pottsville Formation (Fig. 2B). The *Cincosaurus* beds are about 313 million years old (Fig. 2C). Both of these coal seams were exposed at the Union Chapel mine when it was in operation, although the Mary Lee, the older unit, is now buried (and is therefore not shown on figure 2B). Pottsville coal seams are typically a meter or so (1-6 feet) thick. Each seam is all that remains of a succession of swamps that repeatedly occupied the area about 300 million years ago. The coal is the remains of plants: trees, shrubs, everything down to pond scum. These plants died and formed layers of peat that were buried by mud. Peat is organic rich soil that is thought to be the precursor of nearly all coal. The plants didn't decay because they were quickly buried and because the stagnant swamp water was depleted in oxygen. Bacteria that normally degrade plant material need oxygen. Heat, pressure, time, and chemicals dissolved in groundwater transformed the dead plant material. The process of coal formation strips away much of what composed the dead plants, leaving behind mostly carbon and hydrogen (with minor oxygen, nitrogen, and sulfur). The process is complex, and the result (coal) doesn't really look like it's made out of plants unless you examine it with a microscope. However, mud layers laid down before the coal swamp reached its peak, or that buried the swamp when environmental conditions changed, are a different story. Isolated fossil leaves, pieces of bark, seeds, roots, or other plant parts are commonly preserved in shale layers

associated with coals. These fossils indicate what kinds of plants lived in the ancient swamps, which in turn provides more information about the environmental conditions under which the plants grew. These shale layers may contain other kinds of fossils, too. In general, a 0.3 m (1 foot) thick Pottsville coal seam represents 3 m (10 ft) of original peat before compression (Pashin 2005).

A familiar principle in geology is that of superposition: sedimentary layers are arranged such that older layers are underneath younger layers. The *Cincosaurus* beds at the Minkin site were deposited in association with coal swamps, which are terrestrial. But some layers higher up on the cliff include marine fossils, such as brachiopods. So the higher, younger layers were deposited at the bottom of an ancient sea. The *Cincosaurus* beds themselves were formed either in fresh water, or in brackish water that was just slightly salty. We know this because amphibians were abundant and amphibians cannot live in salt water. There are common traces made by insects, and no insects live in salt water. Finally, the kinds of plants preserved in the *Cincosaurus* beds are typical of fresh-water swamps. Most of the trace fossils at the Minkin site appear to be restricted to the *Cincosaurus* beds, but similar trace fossil suites have been found at other coal mines in the Black Warrior basin in slightly younger or older rocks, associated with slightly older or younger coal seams (Rindsberg, 1990; Jim Lacefield and Ron Buta, unpublished field notes). So, just as swamp floras have been preserved in association with multiple coal deposits, traces of the animals that lived in those swamps have been preserved as well. Not all of the trace fossils from the Minkin site come from the *Cincosaurus* beds. For instance, *Arborichnus* and *Rusophycus*, two very different invertebrate resting traces, are found on deltaic sand beds that are quite a bit younger than the *Cincosaurus* beds.

This repetition of coal seams and associated fossiliferous shales is a result of cyclic sedimentation. Two of the biggest factors controlling sediment deposition during the early Pennsylvanian in the Black Warrior basin were mountain building and southern glaciation (Gastaldo and others, 1990; Pashin 1994, 2004; Pashin and Raymond, 2004). The Appalachian mountains were rising to the east and they shed great quantities of mud and sand into the basin. When the rate of sedimentation increased it was difficult for coal seams to form, because mud flooded the swamps and diluted the dead plant material. When the rate of sedimentation from the mountains decreased, and especially during early stages of sea level rise when water tables were high, thick layers of plant material accumulated and later became coal. In the same way that the recent glaciation caused environmental cycles in North America over the past few million years, Pennsylvanian glaciation on the southern continents

caused sea level to oscillate, and brought other climate changes as well. As glaciers waxed and waned, conditions became more or less conducive to coal formation. The repeated rock sequences thus produced are called cyclothems.

Trace Fossils

Animals can leave three kinds of evidence about their former existence: descendants, body fossils, and trace fossils. A small amphibian living in an Alabama estuary 313 million years ago might have left descendants. We could analyze and compare the genomes of living amphibians and learn quite a lot about the genetic makeup of their ancestors. We wouldn't learn anything about a particular time and place. Amphibians have hard internal skeletons, which provide a lot of information about their former appearance and physical capabilities. However, amphibian body fossils are rare. None have been found in Pennsylvanian rocks of Alabama, although they are known from strata of similar age in other parts of the world. Also, because bones can be moved by scavengers, water, and other agents after death, they may not be found in places where their former owners lived. Trace fossils (footprints, burrows, and any other marks made by once-living organisms) don't tell you exactly what an organism looked like. But they do tell you where it lived and how it behaved. Trace fossils are all about behavior. And it so happens that we have thousands of trace fossils from the Minkin site. Just for instance, we have tens of thousands of tetrapod footprints. We know how big the creatures were, how they moved, the kind of sediment they preferred to walk through, how they interacted when they met (who avoided or ate whom), whether they formed packs or herds, and how many toes they had, among other things. And because footprints in mud and other traces are too fragile to move, we know where ~~re-~~ all of the makers lived.

Some definitions are needed here. Most trace fossils at the Minkin site are either on the tops or the bottoms of beds. When an animal steps in mud it leaves an impression. When that mud is covered by other sediment, that hardened sediment becomes a counterimpression. A rock bearing fossil footprints may have impressions on its top surface and/or counterimpressions on the bottom surface. The impressions on the top will be indentations, just like fresh footprints. The counterimpressions on the bottom are raised. An impression is in negative epirelief, which simply means it is an indentation on the top of a bed. A counterimpression is in positive hyporelief, which means it is a protrusion from the bottom of a bed. It is not always obvious which is the top of the bed and which is the bottom, but we look for unequivocal evidence. For instance, a tetrapod footprint on the top of a bed will be depressed

and a similar footprint on the bottom of a bed will be raised. We also refer to undertracks. When an animal steps on a sediment surface its foot makes a depression in the surface. At the same time, underlying layers of sediment are compressed and deformed. Later, when sediment has become rock, it may split on one of those underlying surfaces. What you see there is an undertrack, and it won't look quite the same as a surface track. This depends on sediment consistency, animal weight, and depth below the surface.

FAUNA AND FLORA OF THE CINCO SAURUS BEDS

The Minkin site, specifically the *Cincosaurus* beds, is a lagerstätte, a remarkable fossil occurrence. How remarkable? Well over 4000 pieces of rock with trace fossils on them have been collected. Fifteen different species of trace fossils have been recognized (Table 1), as well as at least six different unnamed traces, and four arthropod body fossils (Atkinson, 2005; Beckemeyer and others, 2011). Thirty-one species of plant fossils were identified by Dilcher and others (2005). However, most of these come from shale layers in the roof of the New Castle Coal seam, and not the *Cincosaurus* beds. Only *Calamites* and some seed ferns are known from the *Cincosaurus* beds. Altogether, at least 50 species have been found at the site, of which about 25 were recovered from the *Cincosaurus* beds. An additional source of complexity in the study of ancient fossil communities comes from the fact that species of body fossils of animals, trace fossils, and body fossils of plants are not strictly comparable. This is discussed in the next section. Following that, we describe many of the kinds of fossils found at the site, and reproduce photographs of some specimens. We also cite other photographs, listed by UCM number, that can be viewed in the online database. Our descriptions rely chiefly on specimens in the online database.

The Definition of Species

The following is widely accepted as the definition of a biological species: a population or group of populations freely interbreeding in nature. Of course we don't know whether fossil organisms could or did interbreed. We fall back on proximity and morphology. In the case of body fossils, such as shells, we have a great deal of information about how these fossils look. When we find similar fossils that occur together and vary around an average form we call those a species. When we find similar fossils that vary around two different average forms (large or small, wide or narrow, having some special feature or lacking it, or some such) we may identify these as belonging to two species (we have to be careful not to confuse gender differences with species differences).

One source of complexity arises for body fossils that consist of multiple parts, like vertebrate skeletons. One first has to satisfy oneself that bones are fit together correctly, or are at least assigned to the correct species, before proceeding with further study. The approach described above works just fine for animals. Not so for plants. A leaf and a piece of bark do not necessarily make clear whether they came from the same plant. Paleobotanists identify species of leaves, bark, roots, flowers, and so on, knowing full well that many of these "go together." In other words, one species of living plant might correspond to four or five or more species of an existing fossil plant named for different plant parts. If you want to compare animal and plant species diversity, it might be best to look at whatever plant part is most diverse or most recognizable in the rock unit and use this as an estimate for the number of plant species (in the sense that we would use the term for living plants) that have been preserved. Trace fossils present a different problem. A footprint doesn't preserve a lot of morphological information about the foot that made it. Some toes may not leave an impression in some footprints, for instance. Two different creatures of about the same size may make footprints that are essentially indistinguishable. Also, a creature that can run, walk, crawl, hop, and burrow, can make multiple trace fossils that are assigned not just to different species but to different genera. Trace fossil species are named based on the physical appearance of the traces, without explicit reference to the organisms that made them. So a particular species of tetrapod might make trackways consisting of footprints and tail drag marks, which would get one trace fossil name. Another tetrapod of about the same size and shape, obviously different if we saw the skeleton, might make a trackway that we cannot distinguish from the trackway made by the first tetrapod. One of the tetrapods may dig burrows during droughts and perhaps the other species does not. We have no way of knowing that some of the trackways and all of the burrows were made by one kind of tetrapod and that the rest of the trackways were made by a different one. The number of trace fossil species, like the number of plant species, can be inflated relative to the number of biological species that left traces of their former existence (Martin and Pyenson, 2005).

Trace Fossils Ascribed to Invertebrates

Arborichnus repetitus Romano and Meléndez (1985). Minkin site trace fossils assigned to this taxon (briefly described by Lucas and Lerner (2005) and photographed by Buta and others (2005b) consist of paired grooves (in epirelief and, less commonly, ridges in hyporelief) flanking an oval central disturbed area (Fig. 3). Well-preserved specimens display four complete pairs of grooves.

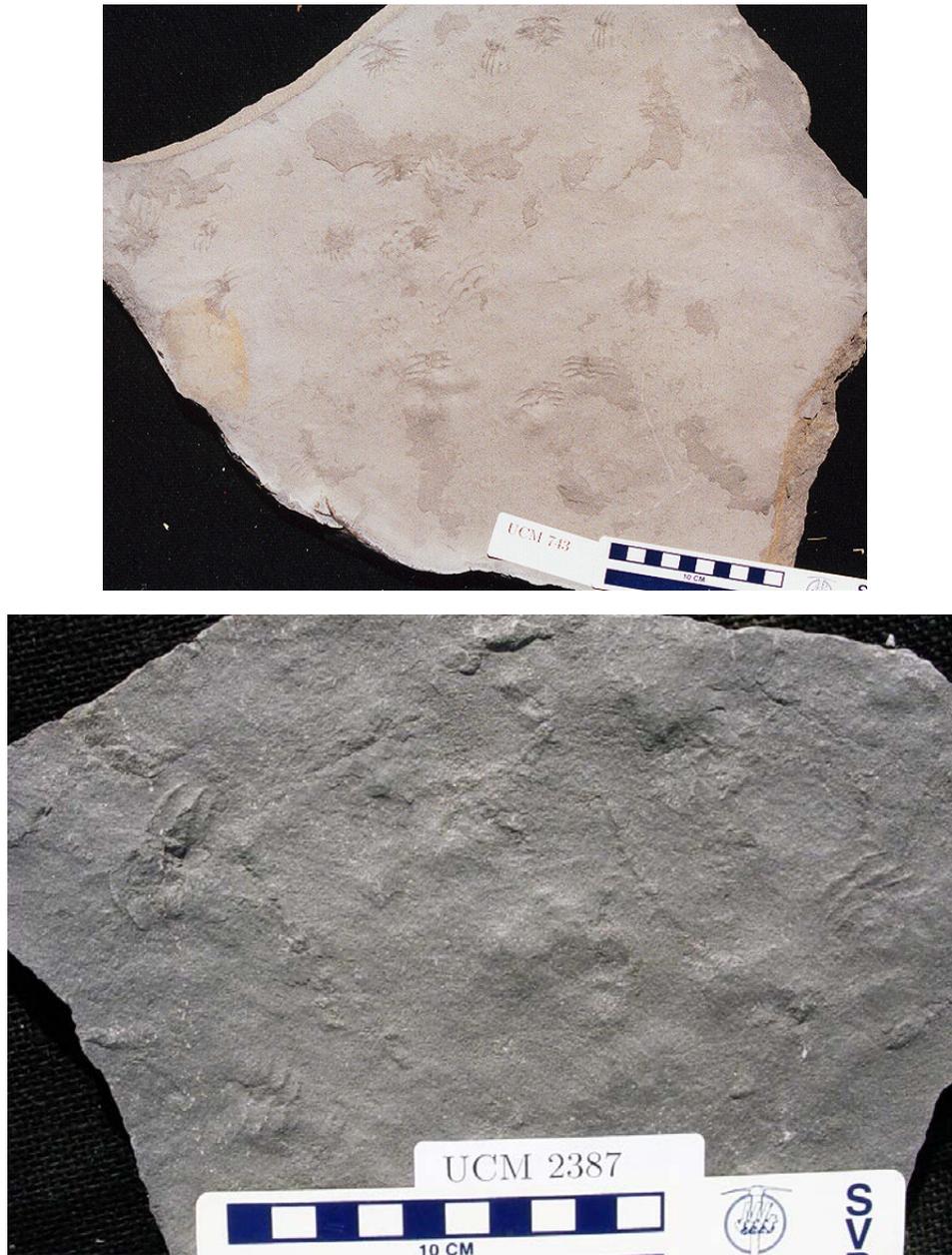


Figure 3. *Arborichnus repetitus*. A. Multiple arthropod resting traces on bottom side of slab. Note disturbed central area in some specimens. UCM 743. B. Another example. Note scarcity of co-occurring trace fossils. UCM 2233. Scales in fossil photographs in cm except as noted.

The grooves are straight to strongly curved and splay outward, almost like fireworks. Curved specimens are assumed by convention to be concave posteriorly. Successively more posterior pairs of grooves are slightly longer in some specimens. The central area is raised (in epirelief), but in some specimens is excavated at its anterior end [UCM 719, 2230]. A few specimens appear to bear traces of a pair of short grooves located anterior or posterior to four longer pairs (Plates 105b, 105a, 104b, in Buta and others (2005b); UCM numbers 415, 743, 1155, 2233, 2449). The grooves on one side of one specimen appear to bifurcate (split in two) at the proximal ends (close to the middle of the trace) with short posteriorly directed grooves just behind the

longer ones (UCM 888).

Specimens of *Arborichnus* from the Minkin site strongly resemble the original description of *A. repetitus*. The central disturbed area in some Minkin-site specimens may result from a difference in preservation. Both type specimens and the Minkin site specimens appear to be undertracks. If the type specimens were deeper undertracks, that could explain the disappearance of a central disturbed area.

Arborichnus is interpreted as an invertebrate resting or feeding trace. The makers appear to have had four pairs of legs. The central disturbed area suggests that the body was pressed into the sediment, likely during takeoff.

Another possible explanation for the central disturbed area is feeding at the sediment surface, but it's difficult to see how the appendages around the mouth could have reached as far back as the last pair of legs. The trace was made by an arthropod with at least 8 legs. The maker is not known, but was probably not a horseshoe crab, as has been suggested. Horseshoe crabs usually leave drag marks made by their "tails," their appendages are forked and commonly leave Y-shaped grooves, and their footprints are relatively short and differently arranged.

Minkin site *Arborichnus* are found on thick solid sandstone slabs. They come from higher in the stratigraphic section than the *Cincosaurus* beds, which means that they are younger. Specimens of *Arborichnus* occur with few other trace fossils. On the shifting sands where they lived, no other creatures were able to make a lasting impression. Most slabs bearing *Arborichnus* specimens have multiple traces (22 of 26 slabs figured in the online database), suggesting that the organisms commonly clustered together. However, collecting bias against heavy rocks with single traces may have caused slabs with multiple traces to be over-represented in collections.

Arenicolites longistriatus and *Treptichnus apsorum* Rindsberg and Kopaska-Merkel 2005. *A. longistriatus* and *T. apsorum* are virtually ubiquitous in the *Cincosaurus* beds (a few examples: UCM 147, 417, 1030, 2026; Buta and others, 2005b). They are interpreted as two different expressions of burrowing by insect larvae. *A. longistriatus* consists of shallow U-shaped vertical burrows and *T. apsorum* brings together several varieties of zigzag horizontal burrows. These trace fossils are the two most common at

the site, commonly occur together, and are shown by the characteristics of transitional forms to have been made by the same critters. Trace fossil species are named by reference to their morphology, not according to who made them. This way, if interpretations change, names don't have to.

Species of *Arenicolites* and *Treptichnus* from other parts of the world are similar to the two described here, but are not necessarily made by the same organisms. The Minkin site specimens of *Arenicolites* and *Treptichnus* share certain diagnostic characteristics that strongly indicate in this particular case that both were made by one actor. For example, *Arenicolites* from the Minkin site have longitudinal grooves scored into the floors of the burrows (Fig. 4A). These grooves strongly resemble those in burrows made by modern fly larvae (Uchman, 2005). Specimens of *T. apsorum* from the Minkin site show the same kind of longitudinal grooves. Burrows made by modern fly larvae also resemble the Carboniferous *T. apsorum* in another way. Many specimens of *T. apsorum* consist of line segments in which successive segments are oriented at distinctly different angles, each segment jutting a short distance past the origin of the next one, just as in burrows made by modern fly larvae (Fig. 4B).

Body fossils of flies and their relatives are only known as far back as the late Triassic. A few arthropod body fossils have been found from the Minkin site, and none of these are flies. The Minkin site burrows in question might have been made by unknown early dipterans, or by other arthropods of similar body plan and behavior.



Figure 4. *Arenicolites longistriatus* and *Treptichnus apsorum*. Bottom sides of slabs. A. Large and clearly striated specimens of *A. longistriatus* associated with smaller *T. apsorum* and gas-bubble impressions. UCM 2038.



Figure 4. *Arenicolites longistriatus* and *Treptichnus apsorum*. Bottom sides of slabs. B. Several specimens of *T. apsorum* of quite different sizes, showing distinct blind burrow projections past places where burrow-direction changes. UCM 179.

Diplichnites gouldi Gevers 1971. *Diplichnites* is commonly interpreted as a myriapod (centipede or millipede) trackway. This name is assigned to meandering double rows of imprints that are closely spaced and very small (Fig. 5). Imprints are ellipsoidal or transverse or posteromesially directed scratches.

These distinctive trackways are uncommon at the Minkin site (examples include UCM 154, 155, 270, 370, 373, 393, 394, 953, 954, 1113-15, 1228, 1370, 1371, 1724, 1820, 1854, 2443). A few examples of *D. gouldi* occur with other trace fossils, notably *T. apsorum*.



Figure 5. *Diplichnites gouldi*. Typical specimen. Bottom side of slab. UCM 666.

Diplichnites was reproduced quite well in an experimental study using a living giant millipede (Davis and others, 2007).

Some authors have ascribed *Diplichnites* to other kinds of arthropods, such as trilobites. In opposition to this view, myriapods have many pairs of legs and don't taper much from head to tail. Most Carboniferous trilobites had 8 to 10 pairs of legs, and they tapered pretty sharply (Harrington, 1959). Their rear legs would have been set down in the sediment pretty close together compared to their front legs, which would have yielded traces resembling nested V's or multiple overlapping rows of foot impressions. Most kinds of trilobites would have been hard-pressed to make the simple double rows of imprints that comprise *Diplichnites*. Trilobite walking traces are more commonly assigned to *Petalichnus* (Rindsberg, 1990) than to *Diplichnites*. One piece of negative evidence suggests that Minkin site *Diplichnites* might not have been made by millipedes. Living millipedes have a characteristic behavior in which they travel some distance, stop, appear to search from side to side with their heads, and then continue moving forward. Modern millipede trackways show this behavior clearly; no examples are known from the Minkin site.

Kouphichnium sp. Nopsca 1923. This name has been applied to invertebrate trackways characterized by Y-shaped footprints that have been found at the Minkin site (for example, Lucas and Lerner (2005), their figure 2, E; as well

as UCM 67, 117, 437, 474, 901, 1207, 1337, 1376-78). *Kouphichnium* (Fig. 6) is made by crawling horseshoe crabs, as is well documented from study of living horseshoe crabs. Hundreds of specimens from the Minkin site have been called *Kouphichnium*. However, Nic Minter has concluded that some don't fit the description. At this point, there is no telling how many different kinds of multi-legged creatures were crawling around on the mud flats 300 million years ago. Minter notes: "*Kouphichnium* is a trackway that has groups of five tracks on either side of the trackway and a linear medial impression. The tracks on either side have opposite symmetry (i.e., the equivalent tracks on either side line up with one another and are 'in phase') and the inner four tracks on either side are simple and linear in form with occasional bifurcating terminations. The outer tracks on either side have a different morphology with a central region and then several imprints around this that make them superficially look like a tetrapod footprint." (Minter, 2010, personal commun.) Caster (1938) provided a detailed description and analysis of trackways that are now called *Kouphichnium* and compared them to trackways made by living horseshoe crabs. Horseshoe crabs can make a wide variety of trackways. When you add in the distortions found in undertracks, the possibilities multiply. The four illustrations included here are meant to show some of the possible variation (Fig. 6).

Many arthropods, such as trilobites and millipedes, have feet that all look about the same on a given animal



Figure 6. *Kouphichnium* sp. Illustrating the wide variety of trackways assigned to this species. A. Note Y-shaped marks made by biramous appendages. Bottom side of slab. UCM 117.

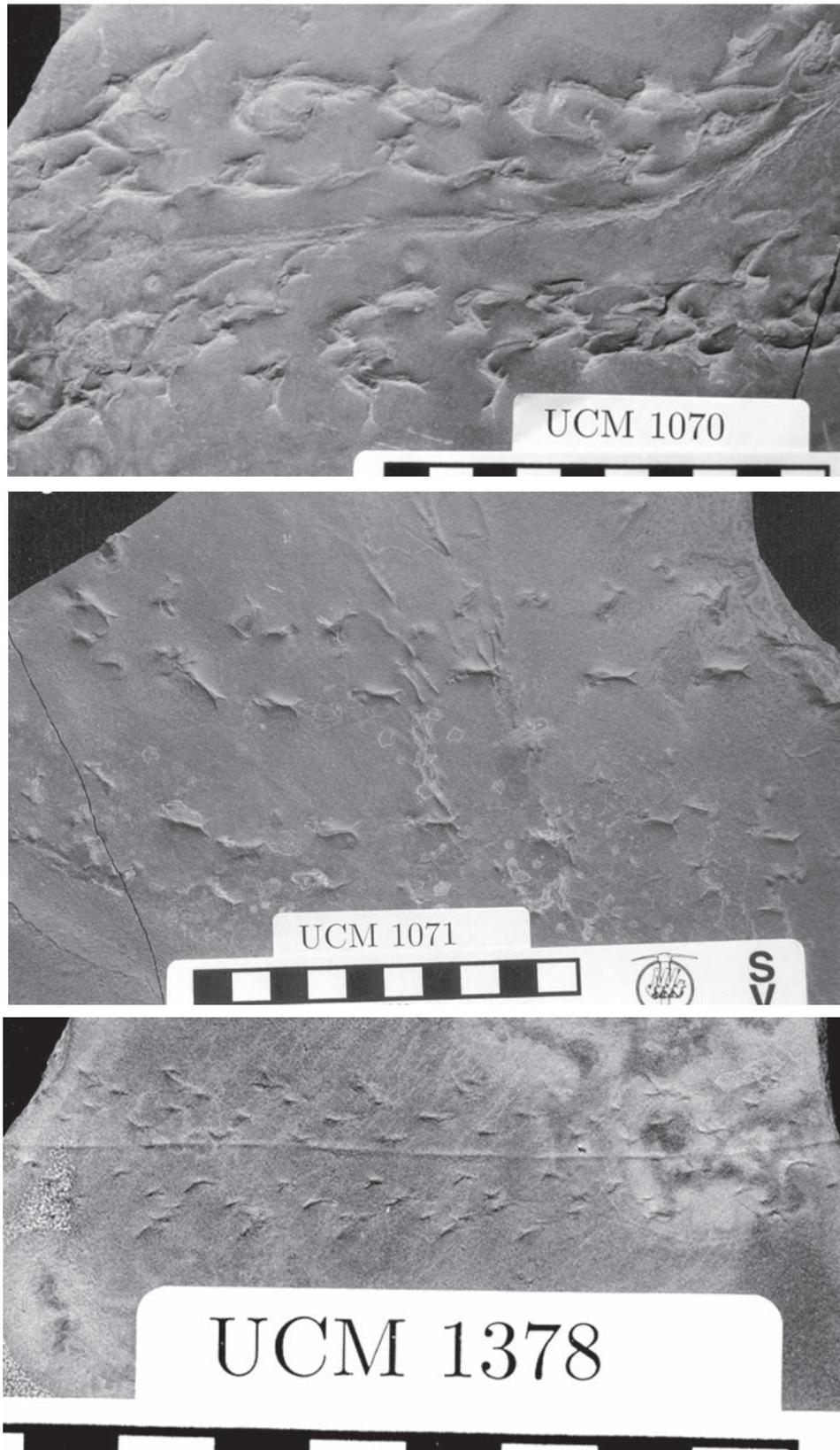


Figure 6. *Kouphichnium* sp. Illustrating the wide variety of trackways assigned to this species. B. Top side of slab. UCM 1070. C. A very different expression of the tracks. Bottom side of slab. UCM 1071. D. Yet another variation. Bottom side of slab. UCM 1378.

Horseshoe crabs have four or five pairs of walking feet that end with small pincers known as chelae. These are biramous appendages, which simply means that they have two tips, and they are pretty much like Y's. However, the back pair of legs on a horseshoe crab are tipped with spiny paddles. This is why they leave different kinds of footprints and it's why well-preserved horseshoe crab trackways are easy to recognize. Sea scorpions (eurypterids) were related to horseshoe crabs and also had more than one kind of foot. Horseshoe crabs and eurypterids are grouped together in the class Merostomata. It takes detailed detective work, and body-fossil information we don't have, to tell what kind of merostome made a given example of *Kouphichnium*. The *Cincosaurus* beds were deposited in fresh water or water that was almost fresh. Unfortunately, both horseshoe crabs and eurypterids could live in freshwater, so this doesn't help us discriminate between the two groups.

Rusophycus Hall 1852. Ovate, bilobate burrows characterized by paired, transverse scratches (Fig. 7). Scratches range from a few to more than a dozen pairs. Generally found in positive relief on the bottoms of beds. *Rusophycus* is an arthropod resting trace, almost exclusively Paleozoic in age, and mostly made by trilobites. Pennsylvanian trilobites had between 8 and 17 pairs of legs; most had 8-10 pairs (Harrington and others, 1959). Minkin site *Rusophycus* have 17 pairs of transverse scratches, which is certainly consistent with a trilobite origin. However, there are good reasons to think that some *Rusophycus* were not made by trilobites. First, trilobites died out at the end of the

Paleozoic era in the greatest mass extinction the world has ever known. Yet some *Rusophycus* occur in younger rocks, even though trilobites don't. Second, some *Rusophycus* are found in rocks thought on other grounds to have formed in fresh water. Trilobites, responsible for most occurrences of *Rusophycus*, were entirely marine. Other arthropods, such as spiders and scorpions, invaded freshwater and the land long before trilobites went extinct. Some of these adventurers may have been able to make *Rusophycus*. Any compact arthropod with many pairs of similar legs (such as pillbugs) can make *Rusophycus*. This body plan is a primitive arthropod type, which is why it is not common today. Modern arthropods have specialized limbs that have evolved to serve the creatures well in a variety of different ways.

Rusophycus at the Minkin site are found on the undersides of hard, thick sandstone beds higher in the section than the *Cincosaurus* beds. They are not associated with estuarine trace fossils such as horseshoe crab traces and amphibian trackways, which are so abundant in the *Cincosaurus* beds. Minkin site *Rusophycus* are well within the size range of known Carboniferous trilobites. These *Rusophycus* probably were made by trilobites, and, along with brachiopod shells, indicate times when marine water flooded the Minkin site long after deposition of the *Cincosaurus* beds.

Stiaria Smith 1909. *Stiaria* is a trackway with a central drag mark and repeated sets of paired linear or curvilinear depressions, three on each side (Fig. 8). The groups of three prints on either side are opposite



Figure 7. *Rusophycus* sp. Bottom side of slab. UCM 3781.



Figure 8. *Stiaria* sp. Multiple trackways on bottom side of slab. Note the small *T. apsorum*. UCM 1749.

one another, as if the animal progressed by making short hops. Examples include UCM 723, 1119, 1402, 1742, and 1748. Minkin site specimens are undertracks, and some retain only two pairs of depressions per set. And therein lies *Stiaria's* problem.

Undertracks of *Kouphichnium*, of which there are many, commonly don't show the pusher marks made by the posterior pair of walking/swimming appendages. The tracks look like *Stiaria* when the bifid nature of the appendages is not apparent (it commonly isn't). For a recent discussion of *Stiaria* in the strict sense, see Buatois and others (1998).

The makers of *Stiaria* were gregarious (Fig. 8). They thronged together like diehard fans at a music festival. However, most *Stiaria* occur apart from other kinds of traces, even where they are found in criss-crossing abundance. Their makers were abundant, and indulged in a common behavior en masse, but away from other animals. Were they feeding? We don't know. It is odd that such common and stunning trackways are so poorly understood.

Tonganoxichnus Mángano and others 1997. *robledoensis* Braddy and Briggs 2002. The species is named for the Robledo mountains of New Mexico, famed for vertebrate trackways, but home to beautiful and diverse invertebrate traces as well. The diagnosis of the species is as follows: "regularly repeated, bilaterally symmetrical, epichnial trace consisting of three medial imprints; a deep anterior elongate imprint (sometimes absent), a tapering (sometimes segmented) or hourglass-shaped posterior imprint, and a long thin, terminal imprint. Three pairs of short,

anteriorly directed, curvilinear (sometimes straight) imprints occur laterally." *T. robledoensis* (Fig. 9) is a jumping trace. For further discussion see Minter and Braddy (2006). Well-preserved examples illustrated in the online database include UCM 990, 1053, 1056 (possibly 8 walking legs), 1057, 1060, 1066 (shows directionality), and 1441. *Tonganoxichnus* is about the same width as *Stiaria* and they commonly occur together (Fig. 9B). Both trace fossils seem to have been made by hexapodal arthropods of the same size. These observations suggest that one critter made both, but here's what really clinches it. Several examples have been found of *Stiaria* turning into *Tonganoxichnus* and of *Tonganoxichnus* turning into *Stiaria* (Fig. 9B). Six of these examples are online (UCM 1287, 1349, 1410, 1411, 1514, 1928). These traces were attributed to monuran insects by Braddy and Briggs (2002).

Treptichnus apsorum. See *Arenicolites longistriatus*.

Trace Fossils Ascribed to Vertebrates

Attenosaurus subulensis Aldrich in Aldrich and Jones 1930. Interpreted to have been made by an anthracosaur (a proto-reptile). Anthracosaurs shared many characteristics with early reptiles, but their eggs, like those of modern amphibians, could only develop in water. Amniote eggs (one of the defining characteristics of reptiles and their descendents) are enclosed by specialized membranes and, if they're laid outside the body, protective shells. The amniote egg, more than anything else, allowed true reptiles to conquer the

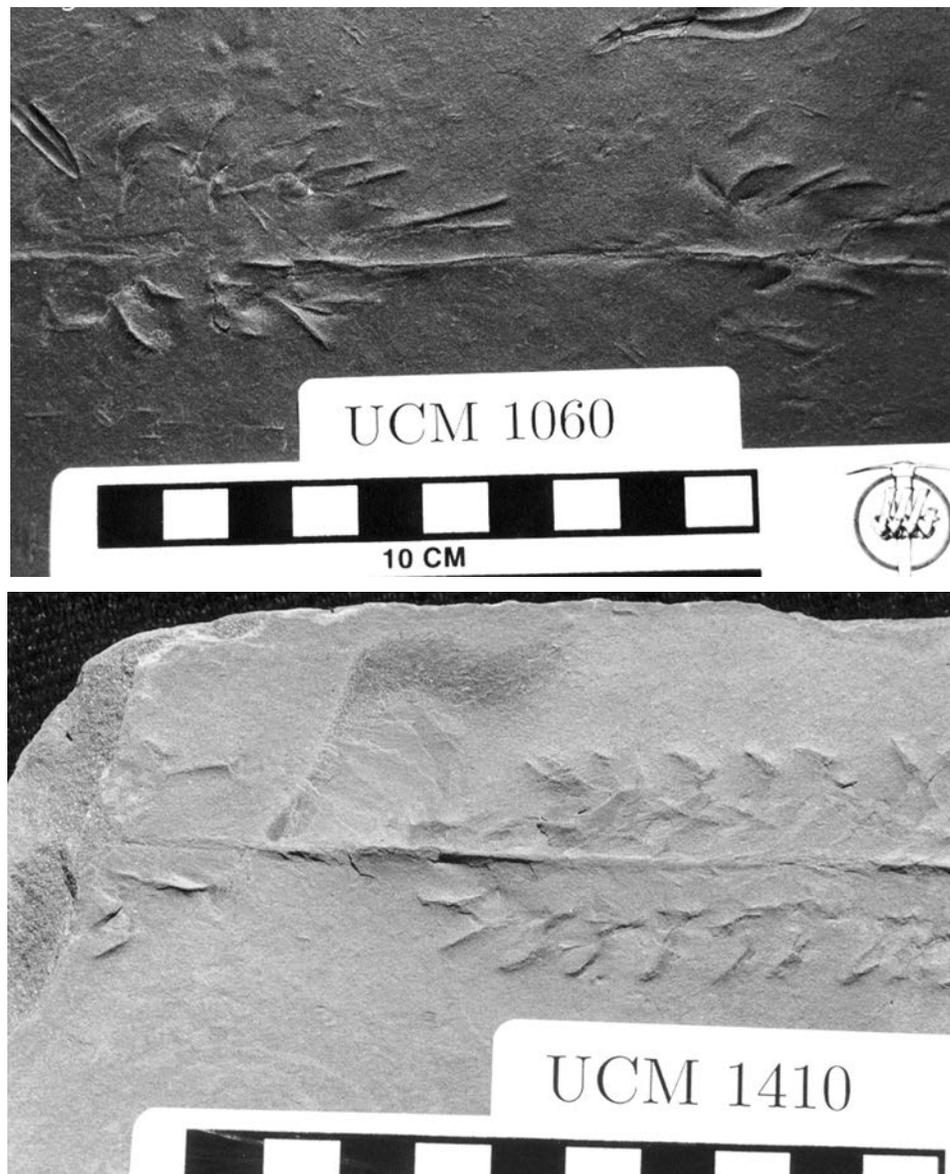


Figure 9. *Tonganoxichnus robledoensis*. Bottom sides of slabs. A. Insect was hopping from left to right. Note two fern leaflets. UCM 1060. B. Insect was moving from right to left. *Stiaria* changed to *Tonganoxichnus*. UCM 1410.

land. One of the most interesting things about the Minkin site is that amphibians, reptile-like amphibians, and early reptiles all left their trackways in the same place.

The original specimen from which this species was named has been lost, but numerous specimens from the Minkin site provide sufficient documentation (UCM 24, 124, 213, 1074, 1621 (largest known print), 1754, 2250, 2251; Fig. 10). The only reservation that Haubold and others (2005) had about referring these specimens to *Attenosaurus* is the possibility that *A. subulensis* (rare large tracks) and *Cincosaurus cobbi* (common small tracks) were made by different-sized members of a single species.

Minkin site specimens referred to as *A. subulensis* by Haubold and others (2005) are larger (up to 25 cm in pes length), exhibit a wider trackway pattern, and have different digit proportions (pentadactyl manus and pes imprints

4 are shorter than 3) than *Cincosaurus*. Because the specimens from the Minkin site are undertracks they don't look quite like the feet that made them, and it is difficult to compare them to specimens collected elsewhere. Problems with classifying and recognizing the trace makers of large Carboniferous tetrapod trackways were discussed by Haubold and others (2005).

A different analysis of the large tracks from the Minkin site divided them among three ichnogenera, and identified most specimens as traces of pelycosaurs, early amniote reptiles (Hunt and others, 2004). Amniotes lay eggs, like those of birds and modern reptiles, in which the embryo is protected by a tough membrane. This contrasts with amphibian eggs, which have little protection from drying out. The conclusion that most large tracks at the Minkin site were made by reptiles, which could lay their eggs on



Figure 10. *Attenosaurus subulensis*. Top side of slab. UCM 1074.

land, contradicts the interpretation given first that the trace maker had to lay its eggs in water. This is an ongoing scientific discussion, which will probably be settled by further careful research. In the meantime we know two things. First, the oldest known pelycosaur body fossils are late Pennsylvanian. If large Minkin site tetrapod tracks were made by pelycosaurs, they represent the oldest known pelycosaurs. And second, the *Cincosaurus* beds at the Minkin site were deposited at the interface between land and water. Whether the large tetrapods living there were tied to the water by fragile jelly-clad eggs or could roam inland more freely, their role as top carnivores on the mud flats was assured.

Cincosaurus cobbi Aldrich, in Aldrich and Jones (1930). Small tetrapod footprints (Fig. 11) interpreted to have been made by an amniote (reptile). One of the most significant things done by Haubold and others (2005) was the synonymy of eight different fossil species proposed by Aldrich in 1930. In other words, Aldrich looked at trackways of small reptiles and saw differences. Haubold and others looked at the same specimens (along with numerous specimens discovered since 1930) and saw similarities (for example, UCM 206, 209, 250, 252, 821, 1842). This is a common

theme in paleontology. When you only have a few specimens they all look different. Later, when additional specimens have been discovered, it becomes clear that there are intermediate forms among all or some of those that were found first. Some are larger and some are smaller. Some are fatter and some are thinner. They are all small reptiles of a particular Early Pennsylvanian species. Intermediate forms between *Attenosaurus* and *Cincosaurus* have not been recognized, suggesting that the large and small tracks represent two valid species.

Diagnosis (list of distinguishing characteristics; emended from Haubold and others, 2005). Tetrapod trackways with pentadactyl (five-toed) imprints of manus (forefoot) and pes (hindfoot), both in reptilian-like arrangements. The length of digits increases gradually from 1 (inside) to 4, and 5 (outside) is shorter and, on the pes, angled backward and outward. Known size range for the manus is 15 to 35 or 40 mm. The pes is slightly larger. Most trackways show the manus directed inward and the pes parallel to the midline, each related to the orientation of digit 3. The trackways are narrow.

In many undertracks the pes is reduced to 3 or 4 parallel digit imprints, which terminate posteriorly at a nearly straight, transverse line.

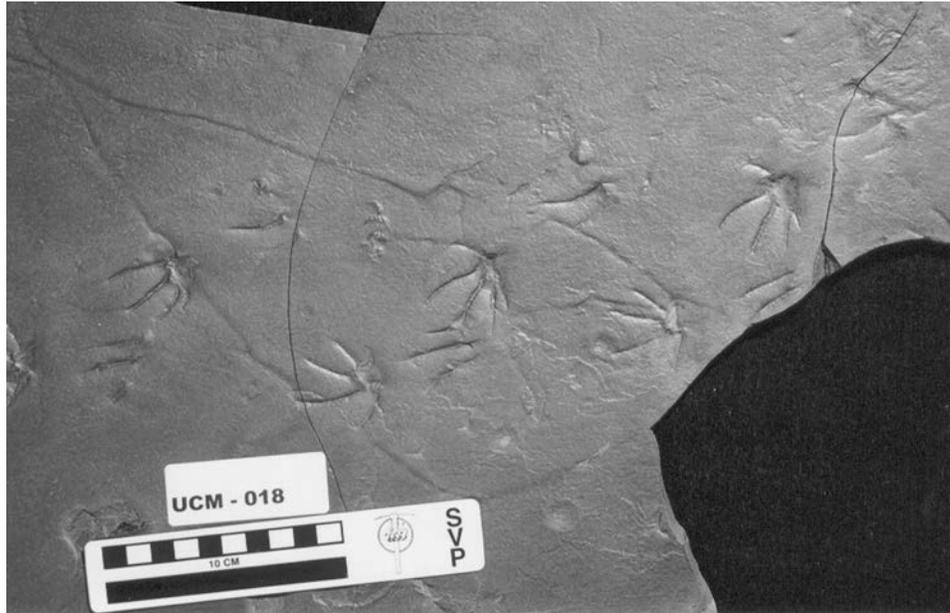


Figure 11. *Cincosaurus cobbi*. Top side of slab. UCM 18.

Nearly all specimens of *C. cobbi* from the Minkin site are undertracks. This means that the morphology of the species is poorly known. This is unfortunate, because *C. cobbi* is abundant, widespread (where we find Pennsylvanian tetrapod trackways in Alabama, especially in western Walker County, *C. cobbi* is one of the most common forms), and the name has been seriously misused (applied to almost any trackway of roughly the same size). A golden opportunity for a young researcher looking for a project!

Haubold and others (2005) noted that the huge variety of tetrapod trackways from the Minkin site makes it very important for understanding Carboniferous tetrapod footprints. In particular, the abundance and diversity of styles of preservation, and specifically of undertracks, at the Minkin site will enhance understanding of why they look the way they do and how to interpret characteristics of the trace-making organism and its behavior from undertracks.

Matthewichnus caudifer Kohl and Bryan 1994. Interpreted to have been made by a temnospondyl amphibian (Fig. 12). The name of the group refers to the characteristic appearance of the vertebrae in which some elements are separate. Early Pennsylvanian temnospondyls were abundant, and the group contained many small species that resembled salamanders. Temnospondyls differed from modern amphibians in several ways; many temnospondyls had bony armor and claws. Individual tracks range from a few mm to slightly more than 1 cm across. The span from left to right feet ranged up to about 2 cm. Manus tetradactyl (four toed), roughly as wide as long. Digits 2 and 3 of roughly equal length, slightly more than half the length of the entire print. Digits 1 and 4 also subequal, approximately 1/3 the length of the entire print. Pes pentadactyl, larger than manus, with digits of increasing length from 1 to 4, digits 3 and 5 subequal (Haubold and others, 2005). Other



Figure 12. *Matthewichnus caudifer*. Bottom side of slab. Note deeply impressed tail-drag mark. UCM 285.

examples include UCM 469, 652, and 969.

Nanopus reidiae Haubold and others 2005. Interpreted, like *M. caudifer*, to have been made by a temnospondyl amphibian. Individual tracks less than 1 cm across; trackways roughly 1-3 cm wide (Fig. 13). The makers of *N. reidiae* were, on average, slightly smaller than those of the related *M. caudifer*. Specimens assigned to this species include UCM 2, 4, 11, 140, 167, 177, 191, 281, 302, 312, 313, 318, 364, 448, and 1856.

The diagnosis (Haubold and others 2005) reads as follows. Footprints of tetrapods with tetradactyl (four-toed) manus and pentadactyl (five-toed) pes imprints. The length of pes digits 1 to 5 are nearly equal, pes digit 3 parallels the midline (direction of trackway), and digits 1 to 5 are outspread at an angle of 90°. The manus imprints are smaller, only 60% of the size of the pes imprints. Along the trackway, manus and pes imprints appear close together in sets with a changing pattern. In addition to the size difference, the relative lengths of pes digit impressions distinguish *N. reidiae* from *M. caudifer*.

Notalacerta missouriensis Butts 1891. *Notalacerta* is thought to have been made by an amniote because the gait is less sprawling than that typical of amphibians and because the manus had five toes. Four toes on the “hand” is typical of amphibians. Fossil bones have not yet been found at the Minkin site, but fossil reptiles are known from rocks of the same and slightly greater age in other places.

Specimens of *N. missouriensis* collected from Alabama indicate a pentadactyl manus about 18 mm long and pes about 22 mm long (Haubold and others, 2005). In trackways, the manus is directed inward and the pes directed outward, with a stride of 50 to 65 mm and a

proportionally wider trackway than that of *C. cobbi*. The digits of the manus increase substantially from 1 to 4, with the latter distinctly longer than the former. Trackway width and manus-digit proportions distinguish the species from *C. cobbi*. Important information about the characteristics of the species was published by Chesnut and others (1994). Only a few specimens have been recognized in the Minkin site material.

Undichna sp. Anderson 1976. All fish trails found at the Minkin site (more than 100 of them) belong to this ichnogenus (Fig. 14). Sinusoidal grooves, sometimes paired, are interpreted as a record of fins grazing the sediment surface as fish swam close to the bottom, perhaps in very shallow water. Living fish do the same thing. Martin and Pyenson (2005) illustrated examples and discussed what they showed about Pennsylvanian fish physical characteristics, behavior, and environment. They reported the earliest known example of schooling in fish. Many modern fish swim in schools. This is a sophisticated behavior that fish use to confuse predators. When did they learn to do this? The answer to this question has implications for predator-prey interactions in the ocean and fish behavioral evolution. Of the 2201 fossil slabs in the online Photographic Trackway Database, 94 contain *Undichna*. Nine (10%) exhibit parallel and/or overlapping *Undichna* made by fish moving at similar velocities (determined by the frequency of side to side movement of the caudal, or tail, fin), suggesting schooling behavior. Examples include UCM 64, 1728, 2237, 2382.

Most trace fossils from the Minkin site were collected from a thin interval called the *Cincosaurus* beds. But the thin sheets of shale where the trace fossils are found are not all the same. For instance, on the subaerial part of the

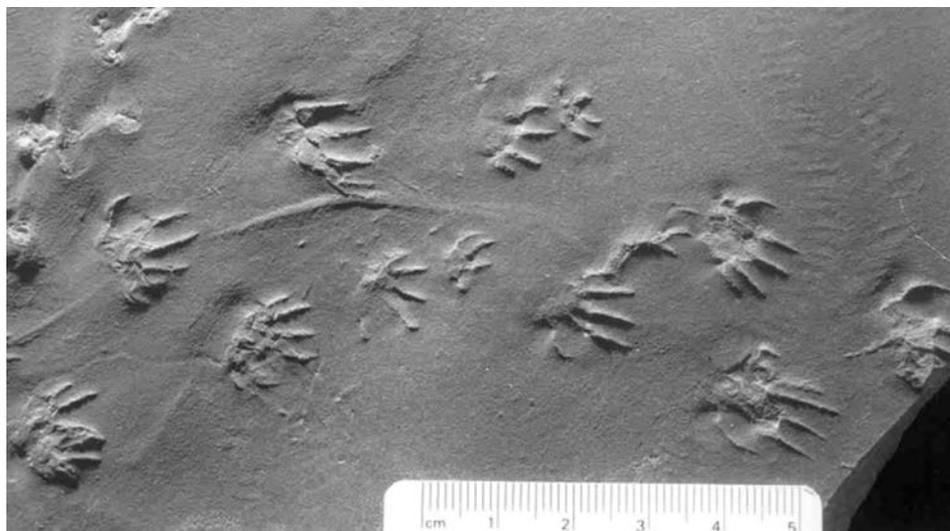


Figure 13. *Nanopus reidiae*. Bottom side of slab. Note faintly impressed invertebrate trackway on the right. UCM 357.



Figure 14. *Undichna* sp. Rare slab with two *Undichna* specimens, both showing the marks of two fins. Top side of slab. UCM 1731.

tidal flat, amphibians and reptiles lived together. The tetrapods shared space with horseshoe crabs, springtails, dipteran larvae, and millipedes. Winged insects hunted each other and probably landed on the mud. We haven't yet recognized their footprints, but several wings have been found (Atkinson, 2005). Fern leaves and other plant parts fell or were blown onto the muddy surface. Gas bubbles popped and rain fell, making similar but distinguishable impressions.

In shallow water just meters away small fish were abundant. The fish could not have been the only denizens of the estuary, yet other trace fossils are conspicuously absent from slabs bearing fish-fin traces. Of the 94 slabs bearing specimens of *Undichna* in the online database, 23 also include either *A. longistriatus* or *T. apsorum*, both made by fly larvae. This may seem like a lot, but dipteran larvae burrowed nearly half of all slabs bearing trace fossils. They are found on fewer than 25% of fish-trace slabs, indicating that the two kinds of organisms tended not to occur together. Only four other specimens include any trace fossil with *Undichna* (1 *C. cobbi*, 3 small meandering trails). Sixty-seven *Undichna* occur on slabs bearing no other trace fossils

whatsoever. Small fish were abundant in intertidal waters during deposition of the *Cincosaurus* beds, but we know virtually nothing about other organisms from that environment.

Undichna is limited to environments that 1) are hospitable to fish, and 2) don't experience much churning of the sediment by burrowers. Among these environments are lake deposits, and the relatively fresh parts of estuaries and bays (de Gibert and others, 1999), which serve as nurseries for young fish. The *Cincosaurus* beds are interpreted as relatively fresh-water deposits on other grounds, but the conclusion is corroborated by the presence of *Undichna*.

Body Fossils

In this section we consider arthropod body fossils, which are rare, but not brachiopod and mollusk shells. These are common, but not in the *Cincosaurus* beds. Marine shells come from higher (younger) strata. Marine shells at the Minkin site have not been studied in detail.

A few arthropod body fossils have been found at the site, in the *Cincosaurus* beds (Fig. 15). All animal body

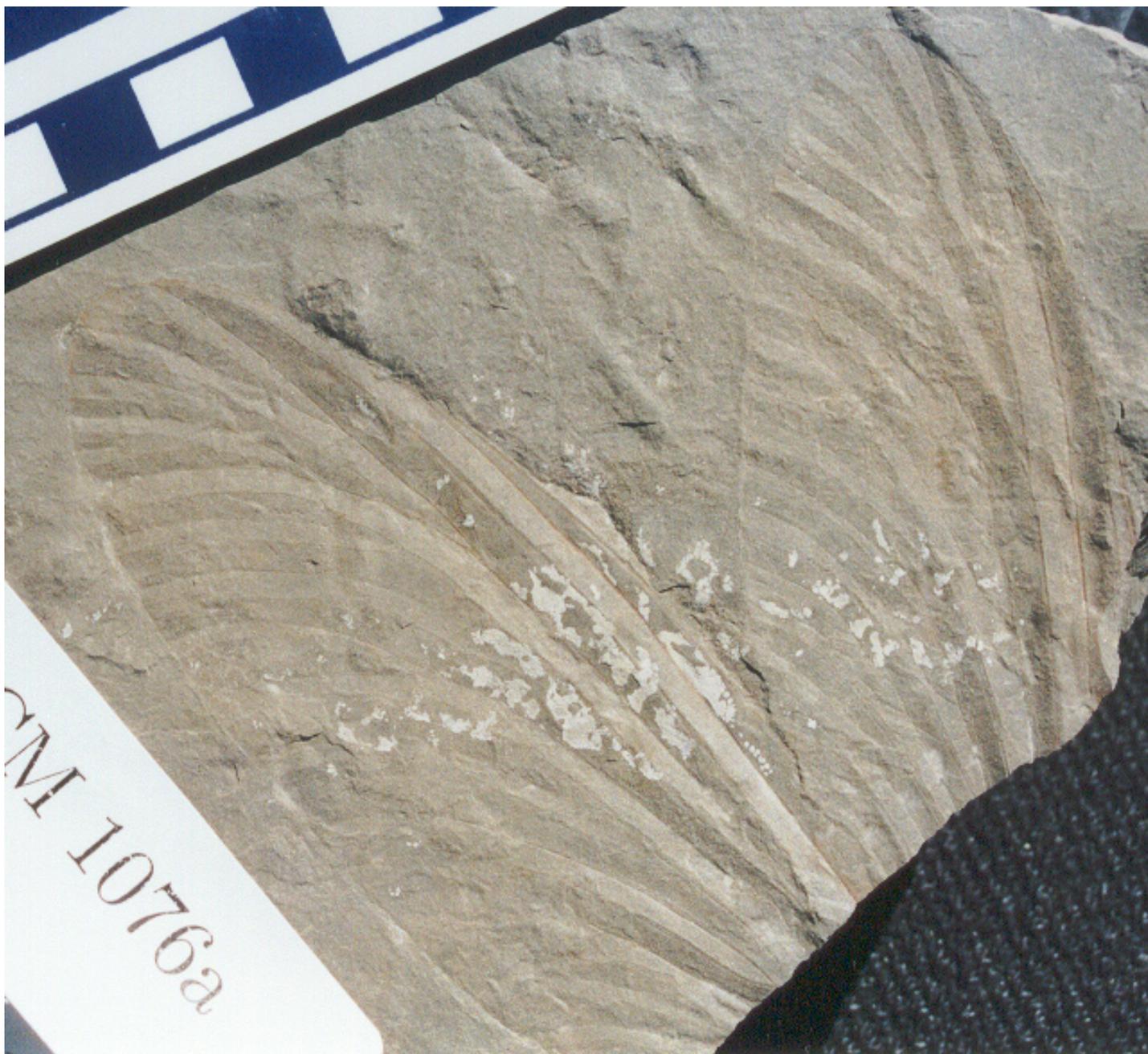


Figure 15. Arthropod body fossils. A. Wings of *Anniedarwinia alabamensis* Beckemeyer and Engel 2011. UCM 1076a. B. Trigonotarbid, an arachnid. UCM 2281.

fossils found at the site are invertebrates, and include three insect wings, one spider-like trigonotarbid, and two others of unknown nature. Arthropod exoskeletons are made of chitin, an organic material that is chemically more stable than bone in the acidic environments in and near coal swamps. This is why fragile insect wings have lasted while bone has not. All the specimens are preserved in laminated shale that seems to be from the *Cincosaurus* beds. All are different, and each of the wing specimens is a previously unknown species. Preliminary descriptions of some of these and another insect wing fossil from Alabama have been published (Atkinson, 2005; Beckemeyer and Engel, 2011). Any fossil arthropod is a rare and scientifically important discovery. Please show any possible body fossil to your trip leaders.

Plant Fossils

Plants are common and diverse at the Minkin site, although only seed ferns and *Calamites* (giant horsetails) are known from the *Cincosaurus* beds. However, plant fossils are common at almost every coal mine. After all, what's coal made out of? So even though well-preserved ferns, lycopods, and other components of the Westphalian A Stage (a unit of geological time ranging from 304-313 my) swamp forest are common in the spoil piles, they haven't received much attention. That's a shame, because a well-preserved, abundant, and diverse flora has been recovered from the site (Dilcher and others, 2005; Dilcher and Lott, 2005). Common plants found at the site include arborescent lycopods (bark and upper branch impressions), sphenopsids, ferns, seed ferns and cordaites. Examples of these major groups are still living today except for the seed ferns and the cordaites (a group distantly related to conifers). Lycopods, *Calamites*, and seed ferns dominate. The condition of the material indicates that it has not been transported far; the plants grew where we find them. The Minkin site was a peat swamp.

Plant fossils are common and widespread in the Pennsylvanian coal measures of the eastern United States. Plant fossils from the Pennsylvanian of Alabama have been illustrated by Gastaldo and others (1990), Lacefield (2000), Dilcher and others (2005), and Dilcher and Lott (2005) in readily accessible publications. Accordingly, only a few common forms are illustrated here (Fig. 16).

Trees evolved about 364 my (Scheckler, 2001), and forests with well-developed canopies by 345 my (Dilcher and others, 2004). By the Westphalian, forests had been around for about 35 my. The swamp forests of the Minkin site represented a well-established ecosystem. By this time, multi-story forest canopies had developed, though ecosystem complexity continued to increase. Carboniferous

forests contained lycopod "pole (or scale) trees" up to about 40 m (132 ft.) tall, and understory plants that subsisted on sunlight that made it through the open lycopod canopy (Scheckler, 2001). Large lycopods found at the Minkin site include *Lepidodendron* and *Lepidophloios*. Understory plants included *Cordaites* and relatives up to about 30 m (99 ft.) tall, the giant horsetail *Calamites* (up to about 20 m; 66 ft.), and tree ferns (up to about 10 m; 33 ft.). The roots of many of these plants show physical adaptations for swamp life (Dilcher and others, 2005), such as tissue containing open channels that make it easier for oxygen to reach submerged portions of roots.

Carboniferous forests were not like the forests of today. Most "trees" were open and did not branch and branch again to form dense canopies. Lycopods, the tallest trees, branched once, a few times, or not at all. They weren't furred with broad leaves in dense clusters on myriads of twigs. They had long narrow leaves that didn't stick around for long. *Calamites* looked like giant bamboo without the leafy side branches. Tree ferns, seed ferns, and *Cordaites* and its relatives were thick with leaves, but they were understory trees.

A NOTE OF CAUTION

The traces we have described are those found at the Minkin site. While tracks can be found at other coal mines in Walker County, the biota can differ from mine to mine. Different mines can preserve fossils from different environments as well as times, all recorded in Pottsville rocks.

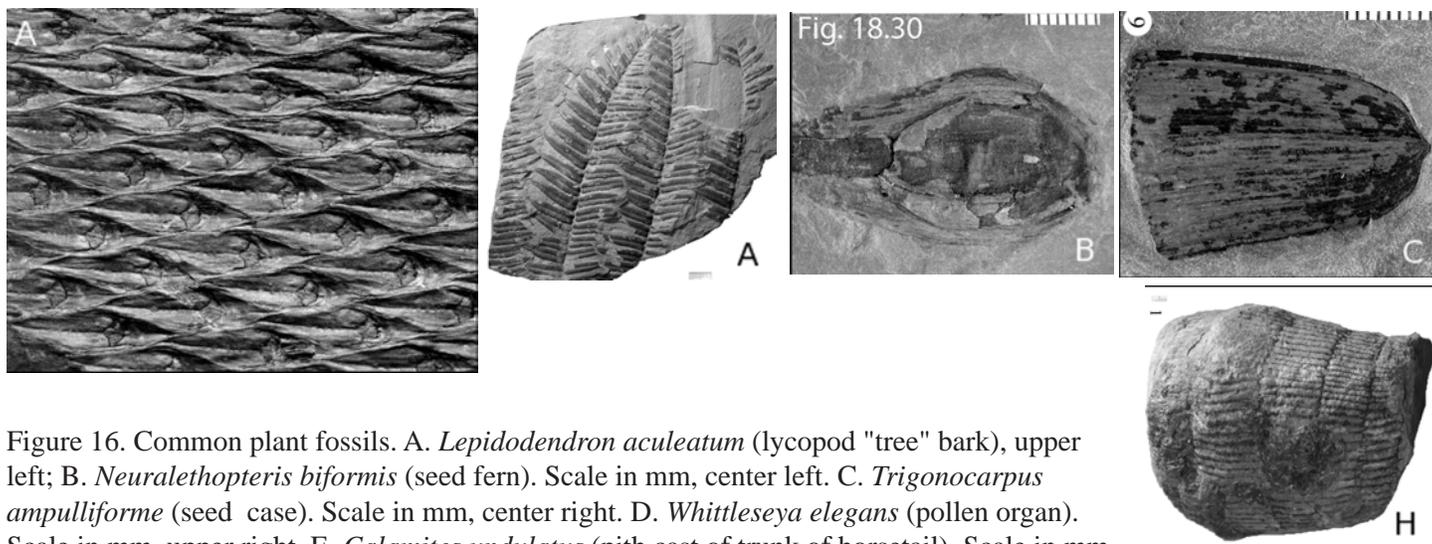


Figure 16. Common plant fossils. A. *Lepidodendron aculeatum* (lycopod "tree" bark), upper left; B. *Neuraethopteris biformis* (seed fern). Scale in mm, center left. C. *Trigonocarpus ampulliforme* (seed case). Scale in mm, center right. D. *Whittleseya elegans* (pollen organ). Scale in mm, upper right. E. *Calamites undulatus* (pith cast of trunk of horsetail). Scale in mm, lower right. (Dilcher and others, 2005)

FURTHER INFORMATION

Alabama Paleontological Society. Contact the Society if you want to visit the Minkin site.
http://alabamapaleo.org/Alabama_Paleontological_Society.html

Pennsylvanian Footprints in the Black Warrior Basin of Alabama (downloadable book). Also available as a printed book from the APS. <http://bama.ua.edu/~rbuta/monograph/monofiles/monofiles.html>

Encyclopedia of Alabama, Steven C. Minkin Paleozoic Footprint Site (online article about the site)
<http://eoa.duc.auburn.edu/face/Article.jsp?id=h-1371>

The Photographic Trackway Database (Online database of photographs of fossils from the site). This database was made before the fossils had received very much study. The fossil identifications are not necessarily accurate or complete.
<http://bama.ua.edu/~rbuta/monograph/database/database.html>

REFERENCES CITED

- 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, A., 1976, Fish trails from the Early Permian of South Africa. *Palaeontology* 19, 397–409.
- 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* 1, 169-176.
- Beckemeyer, R. J., and Engel, M. S., 2011, Upper Carboniferous insects from the Pottsville Formation of northern Alabama (Insecta: Ephemeropterida, Palaeodictyopterida, Odonatoptera): The University of Kansas Natural History Museum *Scientific Papers* 44, p. 1-19.
- Braddy, S. J., and Briggs, D. E. G., 2002, New lower Permian nonmarine arthropod trace fossils from New Mexico and South Africa, *Journal of Paleontology* 76, 546-557.
- Buatois, L. A., Mángano, M. G., Maples, C. G., Lanier, W. P., 1998, Ichnology of an Upper Carboniferous fluvio-estuarine paleovalley: the Tonganoxie Sandstone, Buildex quarry, eastern Kansas, USA, *Journal of Paleontology* 72, 152-80.
- 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* 1, 19-28.

- Buta, R. J., Rindsberg, A. K., and Kopaska-Merkel, D. C., eds., 2005a, Pennsylvanian footprints in the Black Warrior basin of Alabama: *Alabama Paleontological Society Monograph* 1, 387 p.
- Buta, R. J., Kopaska-Merkel, D. C., Rindsberg, A. K., and Martin, A. J., 2005b, 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* 1, 207-276.
- Butts, E., 1891, Recently discovered foot-prints of the Amphibian age in the Upper Coal Measure Group of Kansas City, Missouri: *Kansas City Scientist* 5, 17-19, 44.
- Caster, K. E., 1938, A restudy of the tracks of *Paramphibius*: *Journal of Paleontology* 12, 3-60.
- 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* 68, 154-158.
- Davis, R. B., Minter, N. J., Braddy, S. J., 2007, The neoichnology of terrestrial arthropods: *Palaeogeography, Palaeoclimatology, Palaeoecology* 255, 284-307.
- de Gibert, J. M., 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: *Palaeontology* 42, 409-427.
- Dilcher, D. L., and Lott, 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* 1, 339-365.
- 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* 1, 153-168.
- Dilcher, D. L., Lott, T. A., Wang, Xin, and Wang, Qi, 2004, A history of tree canopies, chapter 6, in Lowman, Margaret, and Rinker, H. B., eds., Forest canopies, 118-137.
- 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.
- 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* 45, 81-94.
- Hall, James, 1852, Paleontology of New York, volume II. Containing descriptions of the organic remains of the lower middle division of the New-York System, (equivalent in part to the Middle Silurian rocks of Europe): Albany, C. Van Benthuysen, 362 p.
- Harrington, H. J., and others, 1959, Treatise on invertebrate paleontology, part O, Arthropoda 1, Geological Society of America & University of Kansas Press, NY and Lawrence, KS, 560 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* 1, 75-111.
- Hunt, A. P., Lucas, S. G., and Lockley, M. G., 2004, Large pelycosaur footprints from the Lower Pennsylvanian of Alabama, USA: *Ichnos* 11, 39-44.
- 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* 68, 655-663.
- Lacefield, J. A., 2000, Lost worlds in Alabama rocks: a guide to the state's ancient life and landscape: Birmingham, Alabama Geological Society, 124 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* 1, 147-152.
- Mángano, M. G., Buatois, L. A., Maples, C. G., and Lanier, W. P., 1997, *Tonganoxichnus*, a new insect trace from the Upper Carboniferous of eastern Kansas, *Lethaia* 30, 113-125.
- Martin, A. J., and Pyenson, N. D., 2005, Behavioral significance of 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* 1, 59-73.
- Martin, A. J., Vazquez-Prokopec, G. M., and Page, Michael, 2010, First known feeding trace of the Eocene bottom-dwelling fish *Notogoneus osculus* and its paleontological significance, *PLOS One* 5, e10420. doi:10.1371/journal.

pone.0010420.

- Minter, N. J., and Braddy, S. J., 2006, Walking and jumping with Paleozoic apterygote insects, *Palaeontology* 49, 827-835.
- Nopcsa, F. B., 1923, Die Familien der Reptilien, *Fortschritte in der Geologie und Palaontologie* 2, 1-210.
- Pashin, J. C., 1994, Flexurally influenced eustatic cycles in the Pottsville Formation (Lower Pennsylvanian), Black Warrior basin, Alabama, in Dennison, J. M., and Ettensohn, F. R., eds., Tectonic and eustatic controls on sedimentary cycles: Society for Sedimentology, *Concepts in Sedimentology and Paleontology* 4, 89-105.
- Pashin, J. C., 2004, Cyclothems of the Black Warrior basin in Alabama: eustatic snapshots of foreland basin tectonism: *AAPG Studies in Geology* 51, 99-217.
- 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* 1, 39-58.
- Pashin, J. C., and Raymond, D. E., 2004, Glacial-eustatic control of coalbed methane reservoir distribution (Pottsville Formation; Lower Pennsylvanian) in the Black Warrior basin of Alabama: Tuscaloosa, Alabama, University of Alabama College of Continuing Studies, *2004 International Coalbed Methane Symposium Proceedings*, Paper 0413, 15 p.
- 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*, 33(2), 2.
- Rindsberg, A. K., 1990, Fresh water 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, Yuejin, eds, Carboniferous coastal environments and paleocommunities of the Mary Lee coal zone, Marion and Walker Counties, Alabama: *Guidebook for Field Trip VI*, 39th annual meeting, Southeastern Section, Geological Society of America, 82-92.
- 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* 1, 121-142.
- Romano, M., and Meléndez, B., 1985, An arthropod (merostome) ichnocoenosis from the Carboniferous of northwest Spain: *Ninth International Geological Congress*, Urbana, Illinois, v. 5, p. 317-325.
- Scheckler, S. E., 2001, Afforestation: the first forests, in, Briggs, D. E. G., and Crowther, P. R., eds., *Palaeobiology II*, Blackwell, 67-71.
- Smith, J., 1909, Upland Fauna of the Old Red Sandstone Formation of Carrick, Ayrshire: Kilwinning, Cross, 60 p.
- 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*, D-2, 471-492.
- Uchman, A., 2005, *Treptichnus*-like traces 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* 1, 143-146.

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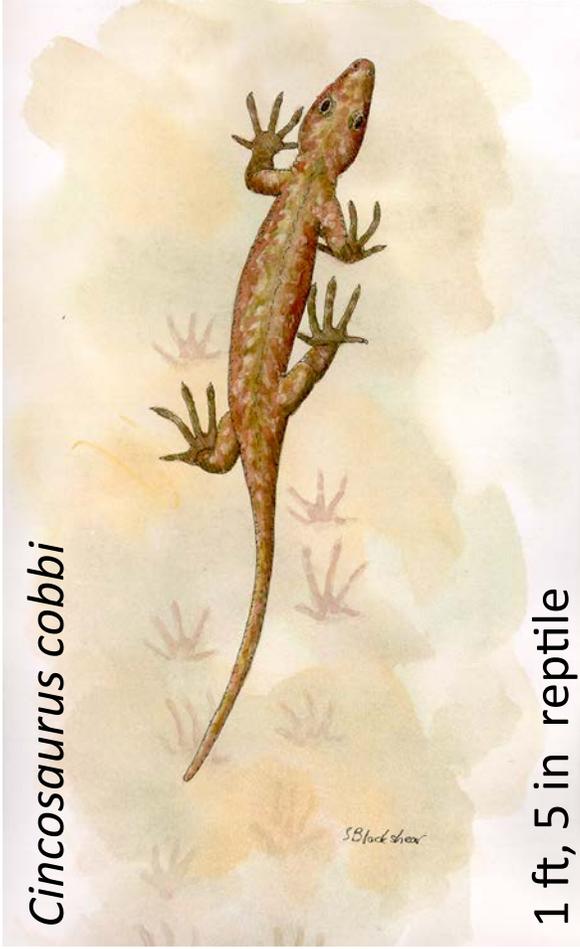
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Table 1. Fossil species found at the Minkin site

Kind of Organism	Taxon (general)	Taxon (specific)	Comments	UCM no.	Strat. Position*	
Invertebrate traces	Inferred maker Chelicerate	Kouphichnium			Cinc.	
		Myriapod	Diplichnites gouldi		Cinc.	
	Insect	Arenicolites longistriatus	same maker as T. apsorum		Cinc.	
		Treptichnus apsorum	same maker as A. longistriatus		Cinc.	
		Stiaria	same maker as T. robledoensis		Cinc.	
		Tonganoxichnus robledoensis	same maker as Stiaria		Cinc.	
	Trilobite	Rusophycus			higher than Cinc.	
	Unknown	Arborichnus repetitus			higher than Cinc.	
		Nereites			higher than Cinc.	
	Vertebrate traces	Inferred maker Amphibian	Matthewichnus caudifer			Cinc.
Nanopus reidiae					Cinc.	
Reptile		Attenosaurus subulensis			Cinc.	
		Cincosaurus cobbi			Cinc.	
		Notalacerta missouriensis			Cinc.	
Fish		Undichna			Cinc.	
		Unnamed traces	Some examples are listed			
arthropods with alternate foot placement				diverse	485j, k; 669	Cinc.
minute trackways double row, single row				1264, 1338	Cinc.	
possible Octopodichnus				73, 1384	Cinc.	
arthropod jumping traces				919, 4021	Cinc.	
ovoid resting trace				425	Cinc.	
coiled backfilled burrow				425	Cinc.	
Arthropod body fossils	Insect	Megasecoptera (Agaoleoptera unioleptera)	wing	2368, 2369	Cinc.	
		Syntonopterodea (Anniedarwinia alabamensis)	wings	1076a, b	Cinc.	
		Diaphanopterodea (Camptodiapha atkinsoni)	wing	3045	Cinc.	
	Arachnid	Trigonotarbid		2281	Cinc.	
	Unknown	abdomen			1881	Cinc.
		possible body fossil			1272	Cinc.
Plant fossils	Lycopod	Lepidodendron aculeatum			higher than Cinc.	
		Lepidodendron obovatum			higher than Cinc.	
		Lepidophloios larisinus			higher than Cinc.	
		Lepidostrobos			higher than Cinc.	
		Lepidostrobophyllum cf. majus			higher than Cinc.	
		Lepidophylloides intermedium			higher than Cinc.	
		Aspidiopsis			higher than Cinc.	
		Syringodendron			higher than Cinc.	
	Seed fern	Trigonocarpus ampulliforme			Cinc. or higher	

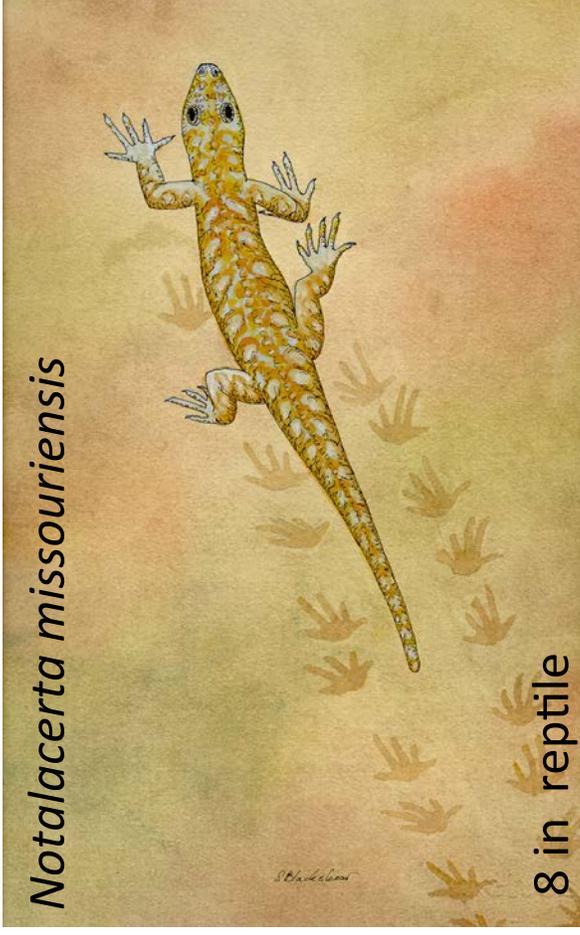
Kind of Organism	Taxon (general)	Taxon (specific)	Comments	UCM no.	Strat. Position*	
Plant fossils	Inferred maker Seed fern	Trigonocarpus sp.			Cinc. or higher	
		Whittleseya elegans			Cinc. or higher	
		Sphenopteris elegans			Cinc. or higher	
		Sphenopteris pottsvillea			Cinc. or higher	
		Neuralethopteris biformis			Cinc. or higher	
		Neuralethopteris pocahontas			Cinc. or higher	
		Lyginopteris hoeninghausi			Cinc. or higher	
		Alethopteris valida			Cinc. or higher	
		Cyclopteris sp.			Cinc. or higher	
		Neuralethopteris pocahontas			Cinc. or higher	
		Neuralethopteris biformis			Cinc. or higher	
		Myeloxylon sp.			Cinc. or higher	
		Holcospermum sp.			Cinc. or higher	
		Carpolithes sp.			Cinc. or higher	
	Horsetail		Calamites goepperti			Cinc. or higher
			Calamites undolatus			Cinc. or higher
			Calamites suckowii			Cinc. or higher
			Calamostachys			Cinc. or higher
			Asterophyllites charaeformis			Cinc. or higher
	Cordaitales		Artisia sp.			higher than Cinc.
		Cordaicarpon sp.			higher than Cinc.	
		Cordaites sp.			higher than Cinc.	

*Cinc.=Cincosaurus beds



Cincosaurus cobbi

1 ft, 5 in reptile



Notalacerta missouriensis

8 in reptile



Matthewichnus caudifer

6 in amphibian



Nanopus reidiae

6 in amphibian



Attenosaurus subulensis

3 ft mammal-like reptile