PENNSYLVANIAN-AGE CORDAITALEAN WOOD FROM KNOXVILLE, IOWA

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Abstract—The remains of fossilized cordaitalean trees were discovered in the middle of the 20th century in surface and underground mines in south-central Iowa, in the vicinity of the town of Knoxville. With some uncertainty, the source coal is assigned to the Laddsdale coal beds (Lower Cherokee Group), which are early Desmoniensian, equivalent to early Asturian and middle Moscovian age. The plant remains were preserved both as compressions and petrifactions. The compressions consisted of prostrate, nearly entire trees, found lying on the upper surface of the underclay paleosol, at its point of contact with the coal bed. The prostrate trunks, which often had crown branches and roots in attachment, were up to nearly 40 m in length, and were without preferred orientation, sometimes overlapping one another on the underclay surface. Permineralized material was preserved as both upright tree stumps and prostrate logs. The permineralized stumps were rooted in the underclay and extended upward a short distance into the coal bed. Permineralization provides access to anatomical features, which show the logs and stumps to consist of pycnoxylic wood with narrow mostly one-, sometimes partially two-cell wide, multi-cell high rays, and a broad, septate pith. The permineralizing mineral is predominantly calcium carbonate, and of sufficient density to permit cut surfaces to be brought to a high gloss polish, thus first attracting the attention of fossil collectors and later, in the early 1960s, that of professional paleobotanists. Some of these permineralized specimens are on display in museums around the United States. The cordaitaleans were an ecologically diverse group, ranging from wetlands, including peatlands, to seasonally dry habitats, including mountainous areas. Two related observations suggest that the Iowa cordaitaleans were among the drought tolerant forms, and not the wetland types that are abundant in Iowa coals, as known from coal balls and palynology. They formed a gallery forest on a paleosol surface that formed under seasonally dry conditions. The location of these remains abundantly at the contact of the seat earth and coal bed indicates unequivocally that they were growing on the soil; this is almost certainly to have been prior to the initiation of peat formation. Emphasizing this latter conclusion is the form of permineralization, which is with calcite. Due to its sensitivity to pH, the calcite must have been precipitated prior to peat formation – it is not to be expected once organic matter, and associated organic acids, began to accumulate in the environment. Permineralized stumps projecting into the coal bed also indicate that permineralization was completed prior to peat formation around the tree remains; in addition, the hardness of the calcite, indicated both by the high polish the specimens take and by the slowness with which they etch in hydrochloric acid, indicates resistance to those weak acids, permitting the permineralized wood to survive without dissolution once peat formation began. To our knowledge, the paleobotanical significance of these fossils was not pursued further once they became known to professional paleobotanists, and no record of them has appeared in the scientific literature prior to this report. The mode of fossil preservation discussed here appears to be confined to a small area in Iowa.

INTRODUCTION

The discovery of fossil trees still in place, upright, or lying prone like fallen giants, has long been, and continues to be, a stimulus to the human imagination. Such fossils provide a direct link to lost worlds. And in the case of Pennsylvanian-age forests, several hundred million years old, to a world very unlike our own. Not only were the plants of that time greatly different from those of today, the animals would have been similarly unfamiliar to modern observers.

Upright and fallen remains of large trees are commonly encountered in coal mines working in Pennsylvanian-age strata in Euramerica, extending upward to Permian-age strata in China, where conditions suitable for peat formation continued long after they had disappeared from the equatorial regions farther to the west in what is now Europe and North America. For the most part, such trees are the remains of arborescent lycopsids, a group prominent in wetlands of the time, and well-known as icons of the "Coal Age" through the work of countless artistic renderings and museum dioramas. Yet, few members of the public ever get to observe these kinds of fossils in situ; that privilege is reserved to miners, mining engineers, geologists, and, during occasional visits to mines, paleontologists.

Here we report the occurrence of remains of upright and prostrate trees, but not of the kind most commonly encountered, the arborescent lycopsids. Rather, the trees are cordaitaleans, an extinct group of seed-producing plants, closely related to conifers. The remains are preserved both as compression fossils – large fallen trees lying on the contact of the coal bed and the shaly, so-called "underclay", or "seat earth", immediately below the coal – and as petrifactions, both standing trees and prostrate trunks permineralized by calcium carbonate. This latter form of preservation created fossils that, when prepared properly, take on a high gloss, leading avocational collectors to seek them, and also permitting these collectors, in many instances, to see the fossils in "the wild".

The remains of fossil trees described in this study were first discovered in coal mines in the area of Knoxville, Iowa. They became more widely known as local avocational collectors prepared and traded them to interested persons elsewhere. When the 1962 National Gem and Mineral Exposition was held in nearby Des Moines, hundreds of collectors travelled to the Knoxville area where these fossils were, at that time, being collected from active coal mines. This brought the fossils to national attention, including that of several prominent paleobotanists of the time, working for major U.S. universities. These fossils are no longer visible in the field; mining in the area ceased more than 50 years ago and all the pits have been flooded or backfilled.

BACKGROUND TO THE STUDY

Geographic and Geologic Setting

Knoxville (2020 population 7595) is situated in south-central Iowa about 50 km southeast of Des Moines, the state capitol (Fig. 1). The surrounding country is rolling farmland devoted mainly to corn, soybeans, cattle, and hogs. Kansan or older glacial deposits with a cover of loess mantle the uplands (Bennison and Chenoweth, 1984). Bedrock exposures are mainly found along streams. Near Knoxville and the bedrock mainly belongs to the lower part of the Cherokee Group: shale, sandstone, mudstone, coal, and minor limestone, which is of Middle Pennsylvanian (Atokan and early Desmoinesian) age (Hershey, 1969). These strata unconformably overlie rocks of Mississippian age, as exposed along the Des Moines River in eastern Marion County and encountered in drill cores that are housed at the Iowa Geological Survey (Fig. 2).

Coal mining in Iowa began in the middle 19th century and grew rapidly with the advent of railroads, peaking in the early 20th century and gradually declining thereafter. Strip mining gradually replaced underground operations beginning in the 1930s. The last coal mine in Iowa closed in 1995. Thin and erratically distributed coal seams and high sulfur content were key factors in the decline and end of Iowa's coal industry.

History of Discovery

John M. Barnett, maternal grandfather of coauthors Bob and Doug Wilson, brought the fossil wood to public attention during the 1950s (Fig. 3). As told by Harriet Heusinkveld in her book *Coal Mining Days in Marion County, Iowa,* Barnett was born in 1882 and began working in local coal mines at an early age. Eventually he became a foreman and, saving his money, acquired mineral rights on his own land and opened an underground mine, Barnett Coal Company No. 3. The Barnett mine was active from 1939 to 1947 and removed coal beneath approximately 7 acres (2.8 hectares). Around the same time the Beard (or Byron Beard) Coal Company began strip-mining coal on Barnett's and neighboring farms, and eventually encountered fossil logs and stumps in their pits. Heusinkveld writes (p. 165), "The family obtained a new interest and a claim to fame when in 1954 they discovered huge lengths of beautiful *Lepidodendron* trunks in their back yard…. Scientists proclaimed the great significance of this find. When the news was made public, rockhounds from many states rushed to the area. In 1961 [actually July 1962], at a three-day exposition at the Barnett farm, people from all over the nation came and camped at the farm and across the road. Jack Barnett did not wish to sell the specimens but was glad to trade for other specimens which people had to offer. In fact, he traded 2½ tons of *Lepidodendrons*. He exhibited them at the State Fair and contributed many specimens to science departments at colleges and universities."

Despite the references above to *Lepidodendron*, few, if any of the specimens that Bob and Doug Wilson observed and collected in the pits around the family farm belonged to that genus. The logs and stumps observed in the pits and as polished specimens dominantly resembled those illustrated here (Figs. 3, 4, 5, and 6). That is to say, they were solid wood (mineralized) having a pronounced grain, like most modern deciduous and evergreen trees. Among trees of the Carboniferous Period, cordaitaleans and coniferophytes are the best known groups that possessed trunks of solid wood (DiMichele and Phillips, 1994). In contrast, the trunks of *Lepidodendron* and other lycopsids, distant relatives of modern diminutive quillworts, had only a small cylinder of centrally located wood. An important support tissue was a rind of decay-resistant bark, possibly impregnated with water resistant chemicals (Boyce et al., 2010). Between the wood and bark were various parenchymatous tissues, also

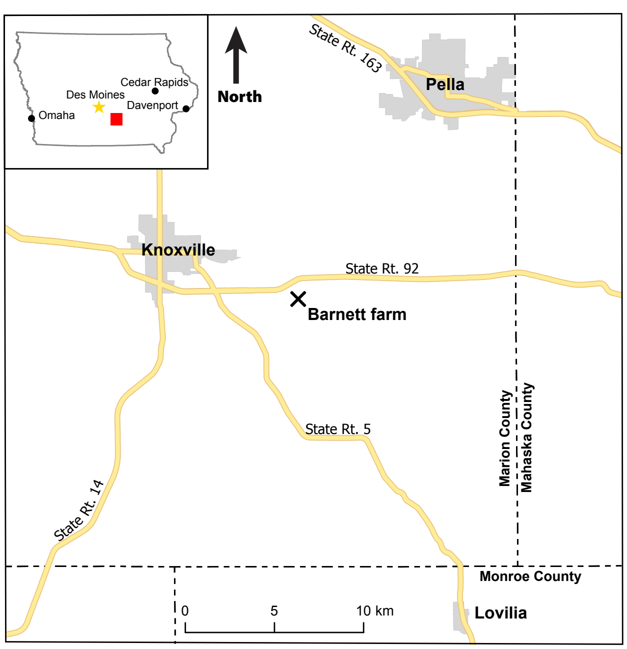

Fig. 1. Location Map

FIGURE 1. Map showing location of the general sampling area and of the Barnett Farm, located southeast of Knoxville, Iowa.

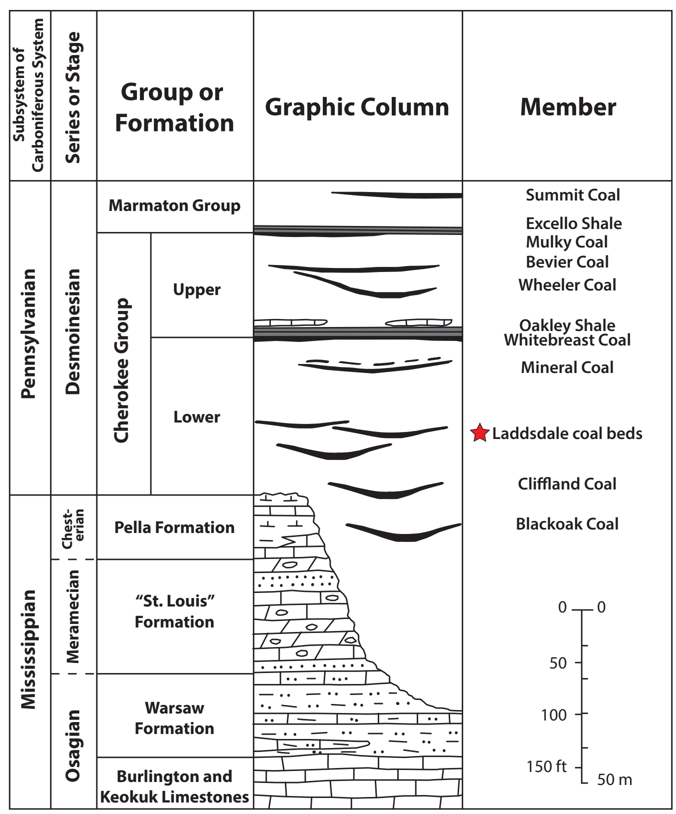

FIGURE 2. Stratigraphic column showing the major Iowa coal beds. The Laddsdale coal beds, from which the fossil remains were found, are marked with a star. Note the irregular contact with the Mississippian surface and the young age of that contact. The study area is far from the seaward edge of the Illinois Basin and would have been filled and, ultimately, planated, late in the Pennsylvanian compared to areas further to the south and west. As a result, the older coal beds tend to be lenticular.

FIGURE 3. Photograph of John and Sarah Moline Barnett seated on fossil log. Image from the *The Des Moines Tribune,* November 1, 1962, page 26,

important in support of the living tree ((D'Antonio and Boyce, 2020), but that decayed more readily than the bark, creating a post-mortem stem and tree stump with a hollow interior (Gastaldo, 1986; Thomas and Seyfullah, 2015). Thus, nearly all fossil lycopsid logs are found either in a flattened condition if prostrate, or as casts if found upright. Occasionally, some of the authors of this paper (the Wilson brothers) found fragments of lycopsid fossils, with their distinctive patterned bark, in spoil banks. These were always fragile and broken and difficult to reconstruct as logs. Such fossils never were seen in the roof shales or underclay of the coal. Rather, lycopsid fossils collected from spoils were associated with sandstone and probably came from above the coal and the overlying shale (this shale was described, however, as a "slate" suggesting that it was most likely a fissile, marine black shale).

Two newspaper articles accessed on www.newspapers.com shed further light. The *Des Moines Tribune,* November 1, 1962, page 26, featured John Barnett and his "fossil farm" (Fig. 3). The three-day public gathering at the farm coincided with the National Gem and Mineral Exposition in Des Moines in July 1962. The article credits the late H.R. Straight of Adel, described as "a veteran rock collector", with initial identification of the fossil specimens. Later, Dr. Chester A. Arnold of the Museum of Paleontology, University of Michigan, and Dr. Robert W. Baxter of the University of Kansas Botany Department came for study. "Both proclaimed the discovery as significant", according to the newspaper article. Specimens were donated to the University of Michigan and to Simpson College in Indianola, Iowa. At least one specimen was taken to the University of Kansas, where it was cut, polished, and remains on display at the University of Kansas Museum (Fig. 4).

The second article, from the *Des Moines Register* (September 15, 1963) featured 18-year-old Bob Wilson and his discovery of "rare fossil seeds". While walking through the strip mine on his grandfather's farm, Wilson cracked open a rock, revealing fossil seeds that he sent to Dr. Baxter of Kansas for identification. The latter replied, "It looks as though you have found some very nice specimens of *Trigonocaris* (sic), which was the seed of a large fern-like type of plant that we know as *Medullosa.*" Baxter also identified some of the logs found on the Barnett farm as cordaitaleans. Jack Musgrove, curator of the Iowa Historical Museum at Des Moines, also examined Wilson's seeds and remarked that they "are so perfect you can make microscopic peels of them to study the cellular structure." The geological origin of these seeds is uncertain, but it is unlikely they came from the same fossiliferous horizon as the cordaitalean trunks; they may have been preserved in coal-ball concretions, from the coal itself, or from nodules preserved in the roof strata.

The Barnett farm area is not the only place in Iowa where petrified wood has been found associated with coal. Horick (1974, p. 21) stated that petrified wood "can be found in operating and abandoned coal strip mines east and southeast of Knoxville and in the Pershing, Bussey, Oskaloosa, and Lovilia areas of Marion, Mahaska and Monroe Counties…Several large *Cordaites* [sic] logs can be observed on the Lee Deeringer property southeast of Knoxville in the NW¼ Sec. 33, T75N, R19W, Marion County." The Deeringer farm is about 5 km southwest of the Barnett farm, which Horick did not specifically mention. According to Horick, the wood is "mainly of the gymnospermous tree *Cordaites* [sic – *Cordaites* is a fossil leaf; the wood would be called by a different name, not determinable from the specimens at hand]" and had been replaced by calcite, pyrite, and marcasite.

So far as we are aware, no scientific articles ever were published about the mineralized fossil plants of the Knoxville area. Through newspaper articles (*Des Moines Register,* 11/1/1962 and 9/15/1963) we know that prominent paleobotanists visited the area and obtained specimens, but no publications were forthcoming. In addition, other prominent paleobotanists studied and published on Iowa Pennsylvanian floras, including among others William C. Darrah, Roy Graham, Aureal Cross, L.R. Wilson, Theodore Delevoryas, Wilson N. Stewart, Jeffrey Schabilion, Tom Phillips, and Anne Raymond, but none mentioned these particular cordaitalean specimens. Nearly all the work of these scientists focused on coal balls, permineralized peat-stages of coal beds found within coal itself (Phillips et al., 1976).

FIGURE 4. Cordaitalean log in transverse section. This specimen is on display at the Museum of Natural History of the University of Kansas. The specimen is permineralized with $CaCO_3$, as determined by Rudolf Serbet (see text). Image courtesy of Laura Mohr and Rudolf Serbet, University of Kansas, Natural History Museum. Scale bar = 1 cm.

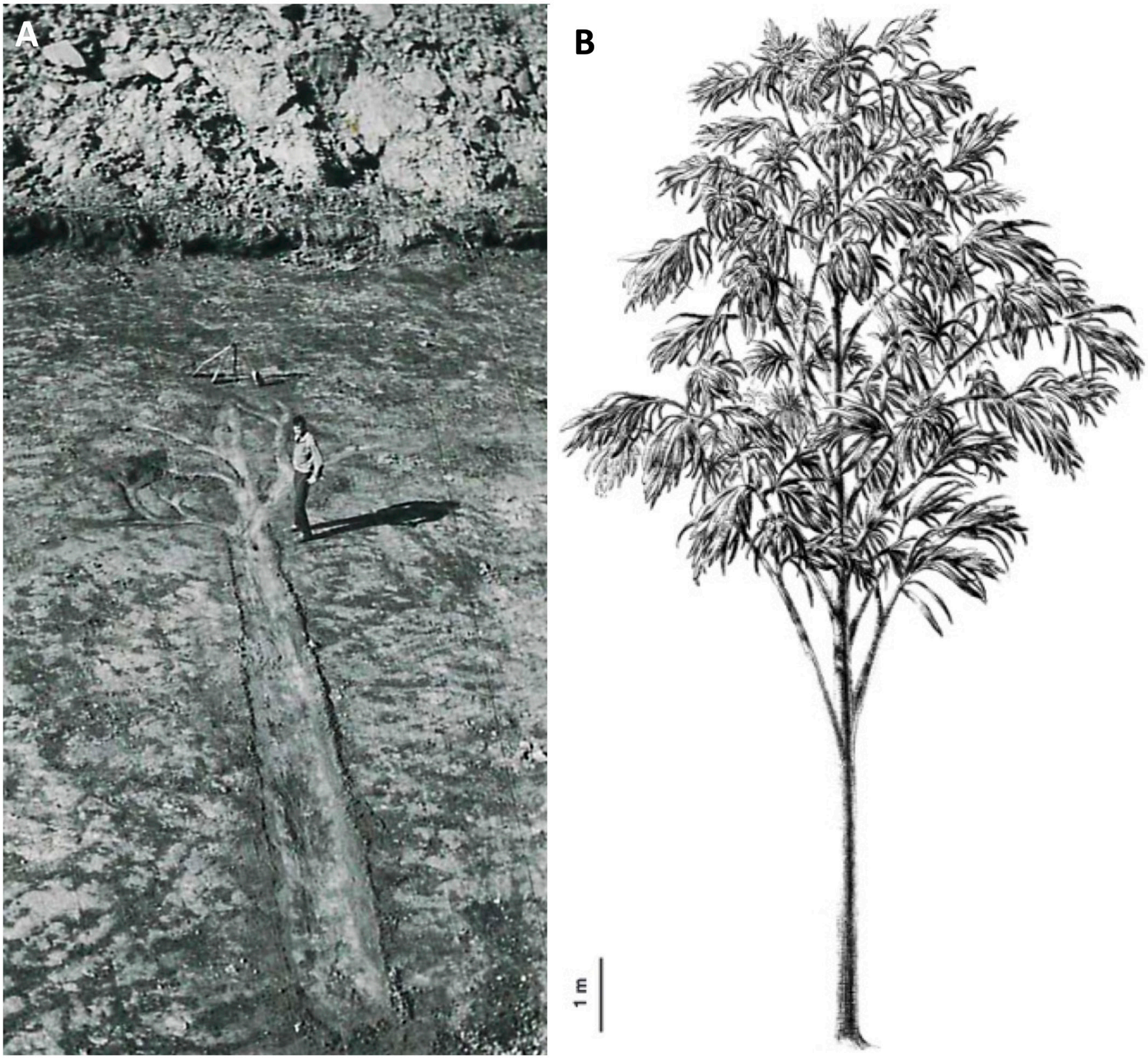

FIGURE 5. Cordaitalean tree architecture. **A,** Photograph of prone trunk with branches attached in floor of Beard Coal Co. pit after removal of coal. Photo was taken in the mid 1950s by Howard Barnett when his nephew, Doug Wilson (standing for scale), was in his early teens. **B,** Reconstruction of the cordaitalean tree bearing *Cordaites borassifolius*; note the general similarity of form to the Iowa tree. Reproduced from Šimůnek et al. (2009) with permission from the *Bulletin of Geosciences*, the author Z. Šimůnek, and the artist, J. Svoboda.

LOCATION: MINES IN BARNETT FARM AREA

An interactive map maintained by the Iowa Department of Natural Resources (DNR) (2021) identifies areas of surface and underground coal mining and provides information on individual mines (where known), including years of activity, type of mining, and identity of the coal seam that was mined.

The earliest mines in the area operated underground. The first was McCagg Mine No. 1, which was active from 1919 to 1924 from a slope entrance and removed about 78 acres (32 hectares) of coal. As noted above, John Barnett's slope mine operated from 1939 to 1947 and was located just east of McCagg. A third deep mine, Ramsey-Collins Fuel Company No. 1, was just east of Barnett's and removed coal from a shaft 84 feet (25 m) deep between 1940 and 1943.

With the advent of large shovels, draglines, and other earthmovers, strip mining began in Iowa during the 1930s. The Beard Coal Company operated most, if not all, of the pits from which the Knoxville area fossil wood specimens were obtained. We have learned little about these mines beyond the extent of the pits shown on the Iowa DNR map (2021), derived from aerial imagery and topographic maps. Precise years of operation are not on record, but aerial imagery accessed on www.historicaerials.com show that strip mining was under way in 1938 with one pit directly west of John Barnett's house and another south of the road and southeast of the house. Photography from 1950 and 1955 reveals more extensive workings farther south, along with expansion of the pit west of the Barnett home. Imagery from 1964 shows that strip mining had migrated northeast of the road and that most of the earlier pits had been backfilled or flooded. Today, some of the areas that Beard mined have been reclaimed

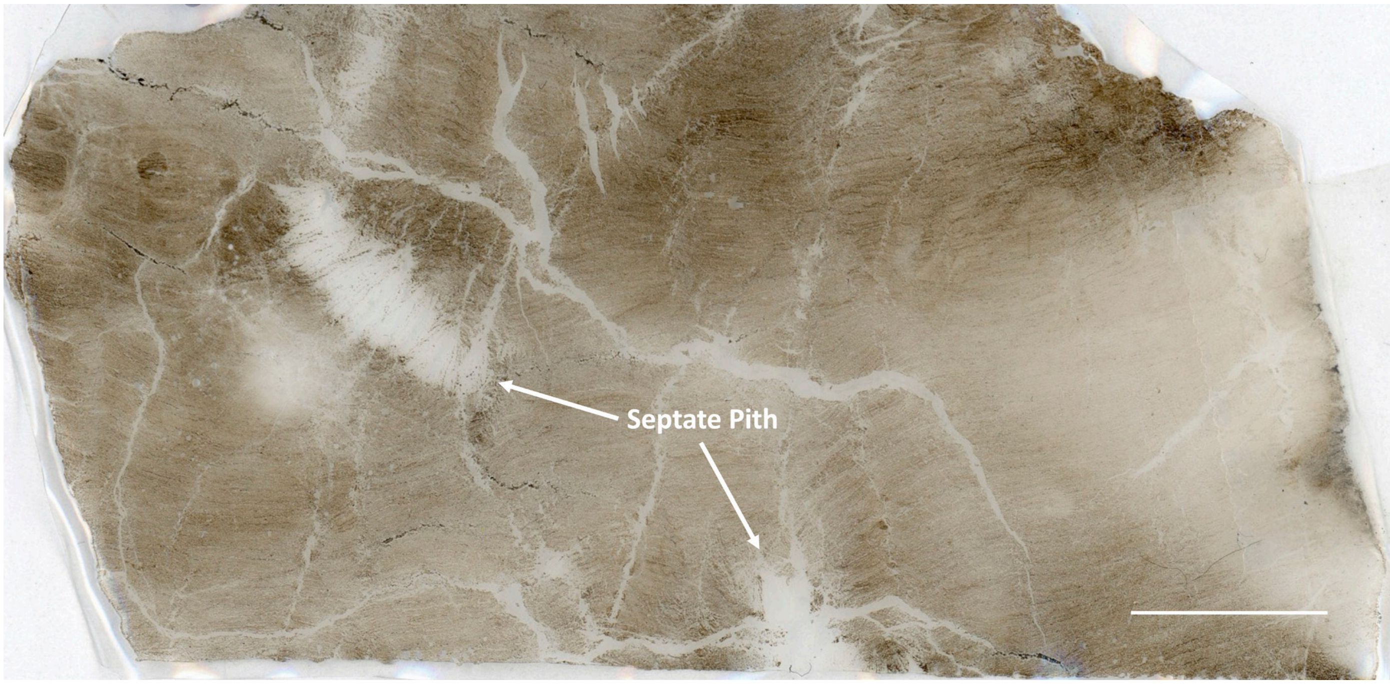

FIGURE 6. Cordaitalean wood. Oblique section through the center of a stem exposing the pith region, which is septate. Septate pith is a characteristic of cordaitaleans, but also may be found in other primitive coniferophytes. Thus, alone, it is not incontrovertibly diagnostic of affinity, but it consistent with a cordaitalean identity. Scale bar (lower right) is 1 cm.

and returned to crop production, whereas other spoil banks and pits are densely overgrown with brush and timber. No exposures of coal remain.

GEOLOGY

Information on geology of the coal mined near the Barnett farm is meager. The Iowa DNR (2021) identified all coal in the area as the Laddsdale Coal, but the agency does not reveal how this identification was made. The informal name "Laddsdale coal" arose in the late 19th century for coal mined south of Ottumwa and about 80 km southeast of Knoxville. Ravn et al. (1984, p. 28-31) defined the "Laddsdale Member of the Floris Formation" as a zone comprising as many as five coal layers together with intervening shale, mudstone, and sandstone. Pope (2012) used the informal term "Laddsdale coal beds". Based on fossil pollen, Ravn (1986) correlated the Laddsdale with the lower part of the Desmoinesian Stage and determined that the Laddsdale is younger than the Cliffland (Iowa) and Rock Island (Illinois) coals and approximately the same age as the New Burnside, Bidwell (now called Delwood), and Murphysboro coals of southern Illinois. These units are middle Moscovian on the global time scale and early Asturian Substage, Westphalian Stage on the Western European scale (Peppers, 1996).

A key fact about coal in the lower Cherokee Group of Iowa is that all of the seams are highly lenticular (Fig. 2). This fact explains the highly irregular outlines of surface and underground mines and why mechanization in Iowa lagged behind states such as Illinois, Kentucky, and Pennsylvania, where many of the coal beds are thick and continuous across large areas. Discontinuous coal ultimately was a big factor in the demise of Iowa's coal industry. Landis and Van Eck (1965, p. 28) wrote, "The coal beds in this [Cherokee] group are in general not continuous over large areas and appear to have been developed in isolated basins. The earliest sediments of this group were deposited on an erosional surface that locally had considerable relief, and this in part may have had a controlling influence on the development of the coal swamps." Regarding the Laddsdale coal, Landis and Van Eck (p. 39-40) continued, "Correlation of this bed from one area to another must be considered tentative because of a general lack of information and because Pennsylvanian rocks of eastern Iowa are often very thin and discontinuous. Correlation of the Laddsdale with coal beds in central Iowa is impossible with the present data…" Fossil spores from coal and marine fossils from associated limestone provide a means for long-distance correlation of Iowa coal beds, but such data are not available from Marion County.

Based on recollections of local people who worked in the mines or visited them while active, the coal mined on and near the Barnett farm averaged 1.2 to 1.5 meters in thickness, but locally reached as much as 3 m. In places the coal abruptly ended against what the miners called "faults". Overlying the coal was "slate", that is, hard dark gray to black shale; in the stratigraphic interval immediately below the Laddsdale coal zone, the Black Oak and Cliffland coals [Fig. 2], are overlain by marine black shale, both of which are rich in cordaitaleans, based on coal-ball analyses; Anne Raymond, written communication) . Below the coal was "underclay" or "fire clay", terms that generally refer to non-bedded claystone that varies from plastic to moderately competent. All of these characteristics are typical for lower Cherokee Group coals that were mined in Iowa and none are specific to any named seam.

FOSSILS

Based on the few available specimens and photographs and the memories of the Wilson brothers, four kinds of fossils were found in the strip mines southeast of Knoxville: (1) two preservational types of logs lying prone, in some cases with limbs and roots attached (Fig. 5A), one as permineralizations and the other as organic compressions, (2) permineralized upright stumps, in growth position, and (3) rare seeds, not found in association with the logs. We concern ourselves here only with the logs and stumps, which appear to be the same kinds of trees, cordaitalean gymnosperms, differently preserved. Identification of the fossils is based on their growth-architectural and anatomical features, discussed below. The significance of the seeds, which are radiospermic and ribbed, is unclear due to lack of provenance; they are not of a kind known to be produced by cordaitaleans.

Identification of the Cordaitalean Remains

Tree Architecture

The growth habit of the Iowa trees (Fig. 5A) indicates a long, straight, robust trunk that branches irregularly. Branches are thick, initially borne at a broad angle to the trunk, but then are ascendent. In addition, some specimens, of which we do not have illustrations, had attached roots. Large trees with branches in Pennsylvanian deposits are attributable to four known groups of plants: arborescent lycopsids, arborescent calamitaleans, and cordaitaleans, which are associated with wetland sedimentary systems formed under humid climates, and both cordaitaleans and conifers, which are associated with standing water deposits (as are virtually all fossil plant remains) but in sedimentary systems, and in association with other floristic elements, that indicate seasonally dry climatic conditions (Bashforth et al., 2021).

Lycopsids can be ruled out by the nature of the branching architecture and presence of attached roots. All lycopsid trees terminated in some form of dichotomizing crown of ever smaller diameter branches, which the Iowa trees do not display, Some arborescent lycopsids had lateral branches, but those branches were borne in two distinct rows, and were of a deciduous nature (DiMichele et al., 2013), leaving clearly marked scars on the trunk. In addition, arborescent lycopsid root systems, *Stigmaria*, are not known to uproot (DiMIchele et al., 2022), despite the frequent representation of such postures in artistic reconstructions of Pennsylvanian peat swamps.

Calamitaleans also can be ruled out architecturally, although some may have attained considerable heights, stem thicknesses, and had robust root systems (e.g., Rößler et al., 2012, 2014). Most of those known from Pennsylvanian wetlands were generally small, most often clonal, and with rather delicate, non-centralized root systems (e.g., Daviero and Lecoustre, 2000; Falcon-Lang, 2015). Most importantly for their recognition, calamitaleans had distinctive node-internode architecture in which all appendicular organs were produced at the nodes and thus had a whorled arrangement on the stem, distinguishing them from the crown architecture of the Iowa trees.

Cordaitaleans and conifers were evolutionarily closely related groups with similar woody stems and complex reproductive organs, including seeds. Conifer groups, particularly in the Pennsylvanian, were largely confined to habitats with seasonal rainfall and thus periods of soil moisture deficit. Conifers are known primarily from rock strata lying between coal beds and not from the coals themselves (e.g., Falcon-Lang et al., 2009; Richey et al., 2021). Conifers are not regularly reported as part of paleoequatorial fossil floras until the late Middle and Late Pennsylvanian, into the Permian. During the Permian, in particular, peat seldom formed in central regions of Pangea; during Late Pennsylvanian evidence from coal thickness and compositional characteristics, paleosol features, the beds in which conifers occurred and the plant fossils with which the co-occur suggest conifer growth during those parts of glacial interglacial cycles when conditions were unfavoriable for peat formation (e.g., Joeckel, 1995, 1995; Tabor and Montañez, 2004; Eble et al., 2006; DiMichele et al., 2020; Bashforth et al., 2021). In contrast, cordaitaleans are known to have occurred in abundance in peat-forming wetlands (Costanza, 1985; Raymond et al., 2010; Šimůnek and Florjan, 2013), both in peat itself and in surrounding wetland habitats. Cordaitaleans also extended, however, from those wet lowland environments into surrounding regions of greater moisture seasonality and deficit (Falcon-Lang, 2003; Falcon-Lang and Bashforth, 2005; Falcon-Lang et al., 2011; Šimůnek, 2004, 2018; Bashforth et al., 2016; Martino, 2017), and to higher elevations (Gastaldo and Degges, 2007; Gibling et al., 2010), where they may have experienced somewhat lower temperatures. As such, they were the "Oaks of the Paleozoic", and, as a group, had a much broader ecological tolerance than nearly any other evolutionary lineage.

Those cordaitaleans in swampy wetlands, especially of the Lower and Middle Pennsylvanian, often have been reconstructed as having habits similar to that of extant red mangrove *(Rhizopora mangle*), which has stems surrounded by prop roots (e.g., Cridland, 1964; Raymond, 1988). In the Upper Pennsylvanian, a scrambling, low-growing form has been described (Rothwell and Warner, 1984). Cordaitaleans with large, arborescent growth habits however, have been described only rarely from wetland habitats. Their rarity in coal-ball concretions may reflect taphonomic conditions in peat swamps unfavorable for the preservation of large logs and, even more so, for their permineralization by $CaCO_3$. Furthermore, small roots and small stems are produced and shed into, or penetrate in the case of roots, the accumulating peat layers in much larger numbers than large roots, branches, and main trunks. The writers have noted the occurrence of cordaitalean roots more than 10 cm in diameter (known by the organ-genus name *Amyelon*) in coal balls from a number of different coals, mainly from Atokan and lower Desmoinesian (Duckmantian and Bolsovian) strata. Large roots are preserved more commonly than large stems because roots grow into the peat, penetrating below the level of intense decay. Large roots indicate large trees. Large masses of wood, either root or stem, have been reported and illustrated in some published coal-ball studies (e.g., Greb et al, 1999). More to the point are reports from the Czech Republic of large, straight-trunked cordaitaleans from uppermost Duckmantian (Atokan equivalent) ash beds that buried peat-forming vegetation in growth position (Opluštil et al., 2009a, 2009b; Šimunek et al., 2009). These studies demonstrate unequivocally the presence in peat swamps of tall, woody, highly branched cordaitalean trees that had architectures similar to our Iowa specimens and are approximately the same geological age. We have reproduced from Šimunek et al. (2009, their figure 33), as Figure 5B, the illustration of the tree that bore the foliage *Cordaites borassifolius*, which appears to have architecture closely similar to the Iowa example.

As we have noted and will return to subsequently, it is important to recognize that the fossil woody trees and tree stumps described in this paper were not found in the coal bed itself. They clearly were growing on the paleosol surface, which, even were it to have experienced sub-humid to occasionally humid conditions during its genesis (we have no detailed descriptions of the paleosol), was not saturated enough through its period of formation for peat to have begun accumulating on its surface. Once the conditions had been reached for such accumulation to start, the forest that had been growing on the paleosol appears to have been killed. Thus, on the basis of gross morphology alone, without consideration of anatomical features of the wood, the tree remains could be interpreted to have been those of either conifers or cordaitaleans.

Wood Anatomy

We acquired two pieces of fossil wood from a specimen collected at the time strip mines were operating in the area of the Barnett Farm. These specimens were sectioned using an oil-lubricated rock saw. After washing, thin sections were prepared using the cellulose-acetate peel technique (Joy et al., 1956), the same method used for the preparation of coal-ball peels (Phillips et al., 1976). The specimens were etched in dilute (5% by volume) Hydrochloric Acid, dried, and the etched surface flooded with acetone, to which a thin sheet of clear cellulose acetate was applied. Once thoroughly dry, the acetate was removed, the peel scanned at high resolution, and the image examined. Peels also were examined under a dissecting microscope with high magnification lenses.

Cellular preservation of the specimens leaves something to be desired, but the cellular architecture is visible and it is possible to see the details of the cell files, both tracheidal and ray cells. Planes of section did not permit viewing of the tangential walls, and therefore the pitting of the cells, if any. Cellular preservation is not as good as that found in most coal balls, including those from Iowa coals. The calcite must be differentially soluble, reflected in the variable depth of etching across the surface of each specimen, again a feature not generally found in calcium-carbonate-preserved coal balls, where etching depths are usually relatively uniform across a cut surface. A further difference from coal-ball permineralization is the very high polish, almost mirror-like, which the study specimens take on (e.g., Fig. 4), which means the mineralization is very hard. In the experience of the authors, coal balls do not polish to such a gleaming surface.

One specimen, sectioned transversely, did not include the pith region of the stem. It revealed small-celled, pycnoxylic wood with numerous rays, generally one-cell, sometimes two-cells wide. No growth rings were visible.

The other specimen (Fig. 6) was sectioned obliquely, but through the central pith region of the stem, exposing that pith in two areas. This plane of section afforded some exposures that were advantageous for observation of the wood structure. One of the two areas clearly reveals that the pith is broad and that it is septate. Pith septae consist of thin plates of parenchymatous tissue separated by open space, indicating that the wood specimen did not have a solid core of pith parenchyma. The open spaces in the pith area are filled with calcium carbonate, strongly suggesting that these areas were open spaces at the time of mineralization and not a secondary effect of wood decay – there is no evidence of frayed or partially decayed wood bordering the pith that would suggest it was an artefactual consequence of decay. A septate pith is a characteristic of cordaitaleans. In compression and mold-cast preservation, the distinctive septate pith is described under the name *Artisia*. Even though typical of cordaitaleans, including that type found in the Czech ash-bed deposits mentioned above, septate pith anatomy may not be unique to cordaitaleans. This feature also is characteristic of other early coniferophytes and possibly early conifers. Falcon-Lang et al. (2014, 2016) reported evidence of first-year leaf abscission in woody, coniferophyte stems with broad, septate piths, growing in sabkha-like conditions, thus under relatively severe moisture stress. That both conifers and cordaitaleans exhibit diverse morphologies and habitats, and that these overlap to some extent, leaves a definitive identification problematic, and even allows that the Knoxville specimens belonged to a distinct evolutionary lineage of coniferophytes, given the diversity of that group (e.g., Looy, 2007).

Both specimens reveal that the wood contains no longitudinally disposed parenchyma. The wood consists of ray parenchyma and thicker walled cells, which we interpret as tracheids (in the absence of a view of their tangential walls). There were no identifiable radially disposed tracheary cells associated with the rays. There was no evidence of sclerenchyma in the wood.

In the tangential section, the rays are numerous. They vary from a few cells in height to over 30; most are 8-10 cells high. They are all one row in width, except for the highest one observed, which was two cells wide at one end only, for perhaps only three cells of its total height.

The longitudinal sections through the pith region did not provide the kind of evidence of pith-margin cellular organization that might have led to a definitive solution to the identity of the wood. There are distinctive differences between wood of various cordaitalean lineages that have been linked to distinctive kinds of seeds (e.g., Costanza, 1985; Falcon-Lang, 2003). These differences have to do with the nature of the leaf traces, maturation of the primary xylem, and shape and size of the primary xylem bundles at the pith margin. Several kinds of cordaitaleans have been identified from Iowa coal-balls based on the occurrences of distinct kinds of seeds. There is some reason to believe, based on root-shoot ratios, that different kinds of cordaitaleans may have occupied different kinds of microhabitats within the Iowa peat swamps (Raymond, 1988). Given that the Iowa cordaitalean trees appear to have grown during the transition period from seasonally subhumid tropical climates to more humid tropical conditions with reduced seasonality, the former represented by siliciclastic soil environments and the latter by peat-forming environments, they almost certainly belong to species different from those identified in peat-forming floras. Fossil foliage or reproductive organs would have enabled us to narrow down identifications, but unfortunately none are available from the Barnett Farm area.

Fossil Preservation

The woody logs and upright stumps that attracted the most attention from scientists and avocational fossil collectors are permineralized by calcite ($CaCO_3$) that is light to medium brown and resembles that found in coal balls. Our identification of calcite is based solely on hardness and reaction to dilute hydrochloric acid (HCl). Quality of preservation varies, but collectors sought Knoxville wood for lapidary purposes because it took a high polish.

During preparation cellulose acetate peels were prepared of the two wood specimens mentioned above. This required slicing of the wood specimens with a diamond-blade saw lubricated with lightweight oil. After clearning, the specimens were etched ina a dilute, 5% solution of HCl. A variety of etching times were tried. Results proved much more variable than for coal balls, with different parts of the etched surfaces of fossil wood differing greatly in depths of etching. This may reflect differences in elemental composition of the carbonate.

Permineralization of the stumps and logs likely occurred very early in diagenesis, before organic matter/peat had accumulated around the woody remains. Accumulating organic matter would have weakly acidified the environment and precluded precipitation of calcite. The permineralized stems may have been in a subaqueous environment at the time calcium carbonate was precipitated within the wood, likely rapidly and facilitated by bacterial action, perhaps under dysoxic to anoxic conditions (Schopf, 1975). On the other hand, it is possible that the trees were permineralized while still standing and the prostrate, permineralized logs may have fallen over under their own weight before peat accumulation began. Were the trees to have died in a standing position, some may have become partially permineralized by capillary transport of mineral-rich waters up through the narrow xylary tubes. Water transport to a height of several meters can be obtained in this manner (Denny, 2011). If the water flooding the soil surface were enriched in carbonate, such early permineralization could account for the combination of prostrate permineralized and adpressed tree-trunk remains, some having fallen before permineralization and some afterward.

Whereas some proportion of the fossil cordaitalean trees were preserved in an upright position, projecting from the underclay-coal contact surface a short distance into the coal, other tree remains were preserved in a horizontal disposition on that same contact surface (Fig. 5A). Based on reports from the time, horizontally disposed tree remains were found both permineralized with calcite (Fig. 4) and as compression fossils (Fig. 5A). The prone logs were locally abundant, in some instances lying across one another. There was no indication of preferred directionality to the fall of the trees, The large, compressed remains represent trees that had died and decayed to some degree, judging by the condition of the crown branches, which appear to be partially broken with their more distal parts missing. The permineralized logs and stumps have calcite-filled cracks that extend more-or-less radially through the wood (Figs. 4, 6); this likely indicates that they had undergone shrinkage prior to or during the process of permineralization (Bashforth, 2005); this feature is also typical of cordaitalean wood found in coal balls (Anne Raymond, written communication); it also is seen on occasion in other "woody" tissues preserved in coal balls, such as lycopsid periderm.

According to reports of observers at the time (although we lack photographic or other direct evidence) some of the trees had been uprooted, and retained some of their roots, much as many modern treefalls do. In other cases, permineralized roots were observed in the underclay paleosol, sometimes still attached to the bases of permineralized upright stumps.

The mineralization of entire logs and stumps at the contact of an underclay and coal bed is unusual among the Carboniferous coal fields of the United States and seems to be confined to a small area in Iowa. According to Horick (1974), this type of preservation is limited to an area of southeastern Marion County and parts of adjacent Mahaska and Monroe Counties in Iowa. The only comparable specimens from Iowa were two cordaitaleans collected from either the Urbandale or Shuler Mine, both near Des Moines, during the early 20th century. The larger specimen was formerly displayed at Harvard University and had an incomplete trunk approximately 20 m long. The displayed trunk has been lost; whereabouts of the second specimen are unknown. These two specimens were known as the "whiskey trees" because they reportedly were exchanged for bottles of whiskey – during Prohibition (Anne Raymond, written communication, 2022). No such examples are known from the Illinois Basin (Illinois, Indiana, and western Kentucky), where three of us have decades of field experience and where voluminous publications and unpublished records related to coal geology are available. Our intimate colleague, the late T.L. Phillips of the University of Illinois, devoted his career to investigations of Carboniferous coal balls. His collections – likely the world's largest – contain no specimens of wood preserved in the manner of that from the Barnett farm and his publications and notes mention nothing of the sort.

DISCUSSION

The cordaitalean trees found in association with the Laddsdale coal interval in south-central Iowa belong to a group of plants that had a wide range of ecological tolerances. One of the habitats in which various species thrived was wetlands, particularly peat-forming environments; cordaitaleans have been widely reported from coal balls found in Iowa coal beds (Raymond et al., 2010), and are more abundant in coals from this region than they are from any other coals in the broader Illinois Basin, Forest City Basin, and Midcontinent Shelf regions (see Phillips et al., 1985 for comparative data) of the USA. This finding is indicated not only by their vegetative remains, such as stems, leaves, and roots, but, more crucially, by their seeds, which are the most diagnostic organs of species diversity for this group. A greater diversity of cordaitalean seeds is known from upper Atokan and lower Desmoinesian coal-balls from Iowa coal beds, collectively, than from any other regions where coal balls occur in abundance (Brotzman, 1974).

In wetland settings, cordaitaleans were most abundant during in an interval of time from the lower Middle Pennsylvanian (Atokan/Duckmantian) through early Desmoinesian/Asturian, after which they underwent a marked reduction (Phillips and Peppers, 1984). During the cordaitalean-rich interval of the Middle Pennsylvanian, the particular cordaitalean species that predominated changed both through time and regionally along with other significant changes in composition of peat-swamp vegetation (Montañez, 2016). In the Murphysboro, Wise Ridge, and Mt. Rorah coals of southern Illinois, the dominant cordaitaleans produced mainly *Cardiocarpus spinatus* ovules/seeds (Costanza, 1985), a much less diverse cordaitalean assemblage than found in the approximately correlative Laddsdale coal zone in Iowa. This contrast may reflect differences in habitat variability and quality, those features being significantly greater in the Iowa region than farther to the east, as suggested by Raymond (1988). After the period of cordaitalean abundance in wetlands ended, the group persisted, although represented by species different from those of the late Atokan and early Desmoinesian. Cordaitaleans never again occurred at the significant biomass levels or diversity seen the earlier parts of the Middle Pennsylvanian (Phillips et al., 1985; Willard and Phillips, 1993; Pryor, 1996; Peppers, 1996; Willard et al., 2007).

During the Middle Pennsylvanian, cordaitaleans also were not only abundant in wetland habitats but also were abundant in a variety of non-wetland landscapes. In fact, the specimens reported here more likely belonged to cordaitalean groups tolerant of moisture stress than to those typical of wetland habitats with high standing-water tables. The plants were rooted in the paleosol beneath the coal bed, the environment of which is difficult to assess because we have no field notes or samples. However, equivalent coal beds in Illinois and Indiana, those of the Murphysboro coal interval in the upper part of the Tradewater Formation, were reported by Rosenau et al. (2013) to have been subtended by gleyed, sideritic protosols to gleyed vertisols, indicating some degree of seasonality, but still largely indicative of a subhumid to humid climate (climate terminology of Cecil, 2003). Gleying of a vertic soil requires removal of iron, which to be mobile requires conversion from its insoluble ferric to its soluble ferrous state; this state transition is possible under weakly acidic conditions, which might have accompanied the onset of excess organic matter accumulation on the soil surface as a prelude to peat formation. Gleying of a vertic profile thus indicates a polygenetic history (e.g., Rosenau et al., 2013) and furthermore indicates that the soils remained sufficiently well drained for iron in the profiles to be translocated downward or even removed. Thus, to the extent similar conditions prevailed to the west and north, in the Iowa region, the pre-peat conditions may have had abundant moisture, but seasonally distributed, and soils that rarely if ever were waterlogged. A sub-humid climate, sensu Cecil (2003), might be expected to produce such conditions in the tropics.

The late Middle Pennsylvanian demise of the wetland cordaitaleans was accompanied by the early appearances of conifers in seasonally dry habitats. Conifers began to appear in small numbers in these environments, even as cordaitaleans remained much more abundant in them, comparatively (Bashforth et al., 2016, 2021; DiMichele et al., 2016; Falcon-Lang et al., 2018). Considering that the two groups continued to coexist in seasonally dry landscapes well into the Euramerican Permian, based on the close co-occurrences of their fossilzed remains (e.g., Chaney and DiMichele, 2007; Koll and DiMichele, 2021), the rise of conifers may indicate the evolution of new ways of using resources such as light, water, or soil nutrients, or new ways to interact with the growing diversity of insect predators (e.g. Schachat et al, 2014).

Newspaper articles from the 1960s identified the fossil trees from the Barnett farm as *Lepidodendron* and cordaitaleans (often misapplying to the wood the name for foliage – *Cordaites*), and fossil seeds as *Trigonocarpus* (*Des Moines Register,* September 15, 1963, p. 14). An earlier article (*Des Moines Tribune,* November 1, 1962, p. 26) referred to fossil trees on the Barnett farm as "lepidodendron" The 1963 article attributes to Robert W. Baxter the recognition that the trees indeed were cordaitaleans and not *Lepidodendron* (in this case, a generic stand-in for the whole group of non-sigillarian arborescent lycopsids). Indeed, we have seen a copy of Baxter's sketchy field notes from his Barnett Farm visit in which he crossed out the words "lycopod periderm" and replaced them with "Cordaites wood." The initial misidentification is an easy mistake to understand. In U.S. coal mines, and in coal mines throughout Euramerica, the presence of lycopsid trees, preserved in a cast-mold fashion, was a common occurrence in certain facies types, whereas upright cordaitalean stumps had not been reported in such an association with coal beds. Tree stumps, sometimes even including large portions of standing trunks, were usually found at the interface between the coal bed and the overlying, almost always gray shale or sandstone roof strata (e.g., Thomas and Seyfullah, 2015). Also in the rock strata above the coal, prostrate lycopsid tree trunks were found commonly, again, under non-marine gray-shale or sandstone roof. Less frequently, tree stumps of lycopsids also were observed at the underclay-coal contact. As a result, a parsimonious initial interpretation of both the uncut/unprocessed petrifactions and compression fossils could easily be an arborescent lycopsid affinity. However, one look at the wood, and just a bit of puzzling over the morphology of the prostrate trees, quickly disabuses an experienced observer, professional or avocational, of the lycopsid identification.

Our only photograph of a fossil in place (Fig. 5A) shows a prone trunk with several branches attached lying on the claystone floor of the pit after the coal was removed. Doug Wilson, then in his early teens, stands for scale. The trunk is approximately 10 m long. Much larger specimens were encountered; John Barnett and a son reportedly discovered the remains of a 38 m [125-foot] tree in the red "fire clay" exposed in a surface mine of the Beard Coal Co. We suspect that not all the coal from this stratigraphic interval was removed in the mining operations of 50-80 years ago. So, one day, by some fortuitous stroke of fate, these fossils may yet again be exposed to public view. We hope there will still be sufficient interest to provide an opportunity for science to examine them still in the places they fell and became petrifactions, more than 300 million years ago.

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