PALEOBOTANY OF THE CORINTH COAL BED, UPPER PENNSYLVANIAN, SOUTHERN ILLINOIS

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Abstract—The Corinth Coal bed is a recently recognized stratigraphic unit in the lower part of the Upper Pennsylvanian Patoka Formation of the Illinois Basin, located between the underlying Chapel Coal and overlying Womac Coal in Southern Illinois. The Corinth Coal was deposited in one or more channels in response to a minor glacial cycle; peat accumulation in this setting was sufficient to support commercial mining operations. Corinth peat accumulation was terminated by a minor marine transgression. The palynoflora of the Corinth Coal is heavily dominated by marattialean tree ferns, particularly *Punctatisporites minutus*, with lesser amounts of *Cyclogranisporites orbicularis* and *Latosporites minutus*. The palynoflora of the Corinth Coal bears greater similarity to the underlying Chapel Coal than to the overlying Womac Coal. A macroflora collected from the gray roof shales of the Corinth Coal likely accumulated in brackish water, based on the occurrence of marine invertebrates. Two roof-shale macrofloral collections were made, 11 years apart, in the same surface mine,. The collections are each dominated by pteridosperms, particularly *Neuropteris ovata* and *Macroneuropteris scheuchzeri*. Small numbers of marattialean tree-fern remains also were identified, a pattern that is at odds with the palynology of the coal bed and with coal-balls collected from other Missourian-age coals of the U.S.A. Palynology shows definitively that the Corinth Coal lies between the Chapel and Womac coals, and is typical of the early Missourian of the U.S.A. The macroflora is not diverse and its composition is not diagnostic beyond being consistent with a Missourian age.

INTRODUCTION

Few macrofossil floras of any preservation type have been described from the Late Pennsylvanian of the Illinois Basin. Two are reported in detail from coal balls collected from the Friendsville (Willard and Phillips, 1993) and Calhoun (Willard et al., 2006) coals; several other coal-ball floras have been reported, in general terms, in the summary paper of Phillips et al. (1985). Some adpressed remains have been described as part of other studies with a taxonomic (e.g., Šimůnek, 2018) or paleoecological (e.g., Stull et al., 2012) focus. Palynofloras, in contrast, have been described in detail from numerous Late Pennsylvanian Illinois Basin coals (e.g., Phillips et al., 1974, 1985; Peppers, 1996).

Here we describe plant fossils, macroflora and palynoflora, from the Corinth Coal and roof shale in its type area in southern Illinois. Both microfossil and macrofossil assemblages are described. These floras were collected from a surface mine in Williamson County, Illinois (Fig. 1) that underwent several changes in ownership, including the Malone Mine in the 1970s from which no collections were made (Fig. 2a), the E & B Coal Company, Corinth Mine (Figs. 2b - d), collected in 1982, and its successor, the Phoenix Coal Company, Malone Pit, from which collections were made in 1993. Collected years apart, the floras represent assemblages from different, but proximate, areas.

The distribution of the Corinth Coal bed is understood in sufficient detail to indicate that the peat swamp from which the coal formed originated within a channel (Fig. 3), thus in a depression on the land surface, likely during the early phases of sea-level rise. This channel was most likely either abandoned or drainage was backed up and halted by base-level change. The three floras in question, then, that of the coal bed itself and those from the roof shale, likely accumulated during the life of the swamp flora and later, as it was drowned. Both macrofloras and palynofloras may have been derived from the landscape immediately surrounding the peat deposit and the ensuing mudflats, as the peat-swamp was flooded by waters carrying siliciclastic sediments, which would have terminated peat formation.

The peat-swamp (coal) flora is dominated by marattialean tree ferns to a high degree (Peppers, ISGS unpublished report on referred samples). Both macrofossil floras are well preserved in gray siltstone and are compositionally similar, dominated by pteridosperms, particularly *Neuropteris ovata* and *Macroneuropteris scheuchzeri*. Although of Late Pennsylvanian age, the macrofloras do not reflect the biomass dominance of marattialean tree ferns, as found in coal-ball studies of Late Pennsylvanian age coals of the Illinois Basin and elsewhere in the US (Phillips et al., 1985).

GEOLOGICAL BACKGROUND

The Corinth Coal is a minor coal bed found in the lower part of the Upper Pennsylvanian. Through localized mining in Southern Illinois, the coal has been long known but not recognized as distinct, generally confused with either the underlying Chapel Coal or the overlying Womac Coal. Further study has revealed, however, that this coal bed lies between those two more widespread coals (Fig. 3) and was formed as part of a distinct, but minor, glacial-interglacial cycle. It lately has been described as a new stratigraphic unit, the Corinth Coal Member (Nelson et al., 2023).

Field notes on file at the Illinois State Geological Survey reveal that the Corinth Coal Member was known and mined more than a century ago. In 1907 A.J. Ellis reported that a borehole indicated coal 45 cm (18 inches) thick at a depth of 12 m (40 feet) and this coal had been mined from shafts that had been backfilled. Just north of Dillingham Church, Gilbert H. Cady (undated) described an outcrop of coal 30 to 36 cm (12 to 14 inches) thick overlain by shale of which the basal portion contained "rich plant fragments". At another locality in 1923 Cady observed coal 88 cm (35 inches) thick in a streambed.

In 1932 Harold R. Wanless measured a section in a small ravine and designated this the type outcrop of the Dillingham cyclothem. The outcrop showed coal 76 to 91 cm (2.5 to 3.0 feet) thick overlain by gray shale and underlain by black, highly

FIGURE 1. Map showing location of mines and drill holes that serve as type and reference sections of Corinth Coal Member.

carbonaceous shale containing abundant plant fossils. Wanless did not indicate how the Dillingham relates to other named cyclothems and no mention of the Dillingham cyclothem has been found in his publications. Apparently, Wanless recognized that the Dillingham cyclothem was (1) distinct from other cyclothems he had named, and (2) too localized to warrant naming in a publication.

In 1977 the Malone brothers opened a small strip mine east of Corinth (Figs. 1, 2). The mine operated intermittently through 1979, producing a reported 10,687 tons of coal. Donald Malone reported that stripping revealed rooms and entries of abandoned underground mines with timbers still in place. In 1978, a coal sample was submitted to ISGS palynologist Russell Peppers who, in a memo of October 12th of that year, submitted a finding that the palynological profile of the coal was most similar to that of the Chapel Coal, although with some question. Peppers later, in response to the submission of additional coal samples, reported in greater detail on October 1, 1996 and May 30, 1997 that the Corinth samples were more like the Chapel than the Womac, though identical to neither; he entertained the possibility that the Corinth was a "stray coal similar to the Chapel Coal" but thought that unlikely. In 1980 the E & B Coal Company purchased the strip mine and continued sporadic coal production through 1983, with a total output of about 37,000 tons. Finally, the Phoenix Mining Company came in with larger and more modern equipment and extracted about 187,000 tons of coal between 1990 and 1993.

Collections examined in this report

Between 1977 and 1993 geologists from the ISGS visited the Malone, E & B, and Phoenix mines a total of seven times. Coal samples were collected for analysis, the coal and enclosing strata were described, and operational aspects of the mines were documented. Fossil plants were collected from coal roof shales on two occasions. Plant fossils were collected from shale in spoils at the E & B Coal Company Mine on July 1, 1982 (USNM Locality 38340); no coal was exposed at the time. On March 25, 1993, fossils were collected in the Phoenix Mine from shale in place above the coal bed (USNM DiMichele Field Collection IL1993-04).

Analysis of Compression-Impression Floras

The roof shale floras from the two collections were analyzed quantitatively. Abundances were calculated using the methods of Pfefferkorn et al. (1975), in which each hand sample is treated as a sampling quadrat. Taxa that are found on each hand-sample quadrat are noted only once, regardless of the number of specimens; Pfefferkorn et al. (1975) introduced this method because of the great differences in plant fragment sizes represented by different taxonomic groups - stem remains in the case of arboreous lycopsids, large leaves or leaf fragments in the case of such plants as *Taeniopteris*, pinnae and various sized pinnules or fragments of each in the case of seed ferns and marattialean ferns. Quadrat analysis produces a frequency distribution rather than a closed system where individual specimens are counted and abundances add up to 100%. When compared to count-based analyses, the results are often very similar, particularly the rank-order/dominance diversity pattern (DiMichele et al., 1991). For an applied example and modernization of this kind of analysis, see Bashforth and Nelson (2015), whose methods were used here. In this modification, each hand-sample surface is treated as a separate quadrat; part and counterpart faces are not counted twice. Also noted are "blank" surfaces on which there are no identifiable remains. When calculating frequencies, blank quadrats are subtracted from total quadrats, the resulting number used as the denominator in calculating taxon occurrence

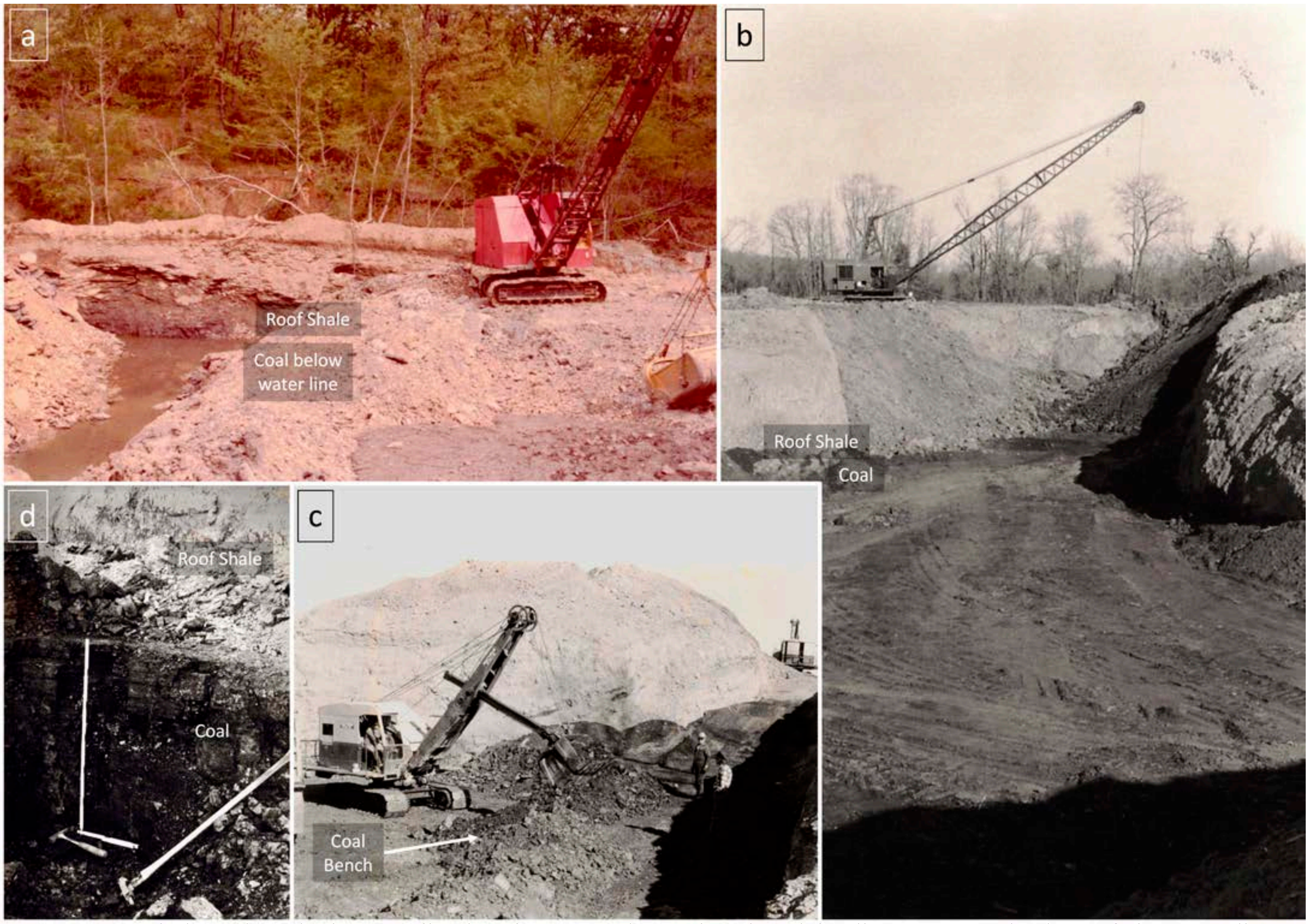


FIGURE 2. Corinth Coal, coal mine sampling locations. **a**, Malone Mine pit and dragline, 1993. Coal at base of pit at waterline. **b,** E & B Coal Company, Corinth Mine, and drag line, 1982. Coal at base of pit. **c**, E & B Coal Company, Corinth Mine, and loading shovel, 1982. Authors Nelson and DiMichele for scale. **d**, Corinth Coal face, E & B Coal Company, Corinth Mine, 1982. Fossils were collected from gray-shale roof immediately about the coal, visible in all photographs.

frequencies.

The number of blank surfaces gives some sense of the density of occurrences of various identified classes of remains. Relatively few blank surfaces were identified in these analyses, indicating the density of plant remains, which occurred on most of the surfaces of the collected specimens. The sum of the individual frequencies indicates the degree of cooccurrence of taxa on the quadrats. The closer the sum of frequencies is to 100%, the closer the collection is to having one taxon per quadrat. In both collections the frequency sum exceeds 200%, indicating common taxon cooccurrence on hand samples.

Analysis of Palynological Floras

One coal and two rock samples from the Corinth Coal horizon in southern Illinois were examined for palynological composition. The samples were first manually crushed to a powder using a mortar and pestle. Three grams of coal and five grams of rock were used for chemical maceration.

Spores and pollen were liberated from coal using Schultze's solution (concentrated nitric acid + potassium chlorate) to oxidize the vitrinite portion of the coal, followed by digestion with 5 % potassium hydroxide. After several washes with distilled water to clear the samples, the organic fraction was concentrated with a zinc chloride solution (specific gravity 1.8). Ethylene glycol monobutyl ether (2-ethoxybutanol) and ultrasonic vibration was used to remove amorphous organic matter (AOM) from the spore/pollen fraction (Eble, 2017).

Rock samples were first demineralized with hydrofluoric, hydrochloric, and nitric acids to remove silicate, carbonate, and sulfide minerals. Following this step, samples were neutralized with distilled water, and then treated identically to the coal samples. Strew mounts were prepared by mixing a small drop of the spore/pollen residue with polyvinyl acetate (PVAc) on microscope cover glasses. Once dry, the cover glasses were inverted and attached to microscope slides using a synthetic acrylic resin.

Line counts of 250 palynomorphs/sample were performed at a magnification of 640 X to document the relative numbers of palynomorph taxa present in each sample, with palynomorph data being reported as volume percent. The parent plant affinities of the recovered spores and pollen are drawn from summaries by Ravn (1986), Traverse (1988) and Balme (1995).

Organic Petrology

Coal petrographic pellets were constructed by mixing four to five grams of coal, hand crushed to -18 mesh (1 mm screen openings), with epoxy resin in 3.2 cm diameter phenolic ring molds and allowed to cure. Upon hardening, samples were ground using 320, 400, and 600 grit papers, and polished using 1.0, 0.3 and 0.05 micrometer alumina suspensions. Final polishes were achieved using 0.04 micrometer colloidal silica. Samples were point counted using a Zeiss Universal reflecting and transmitting, light microscope equipped with both white and fluorescent (UV) light sources. Point counts of organic

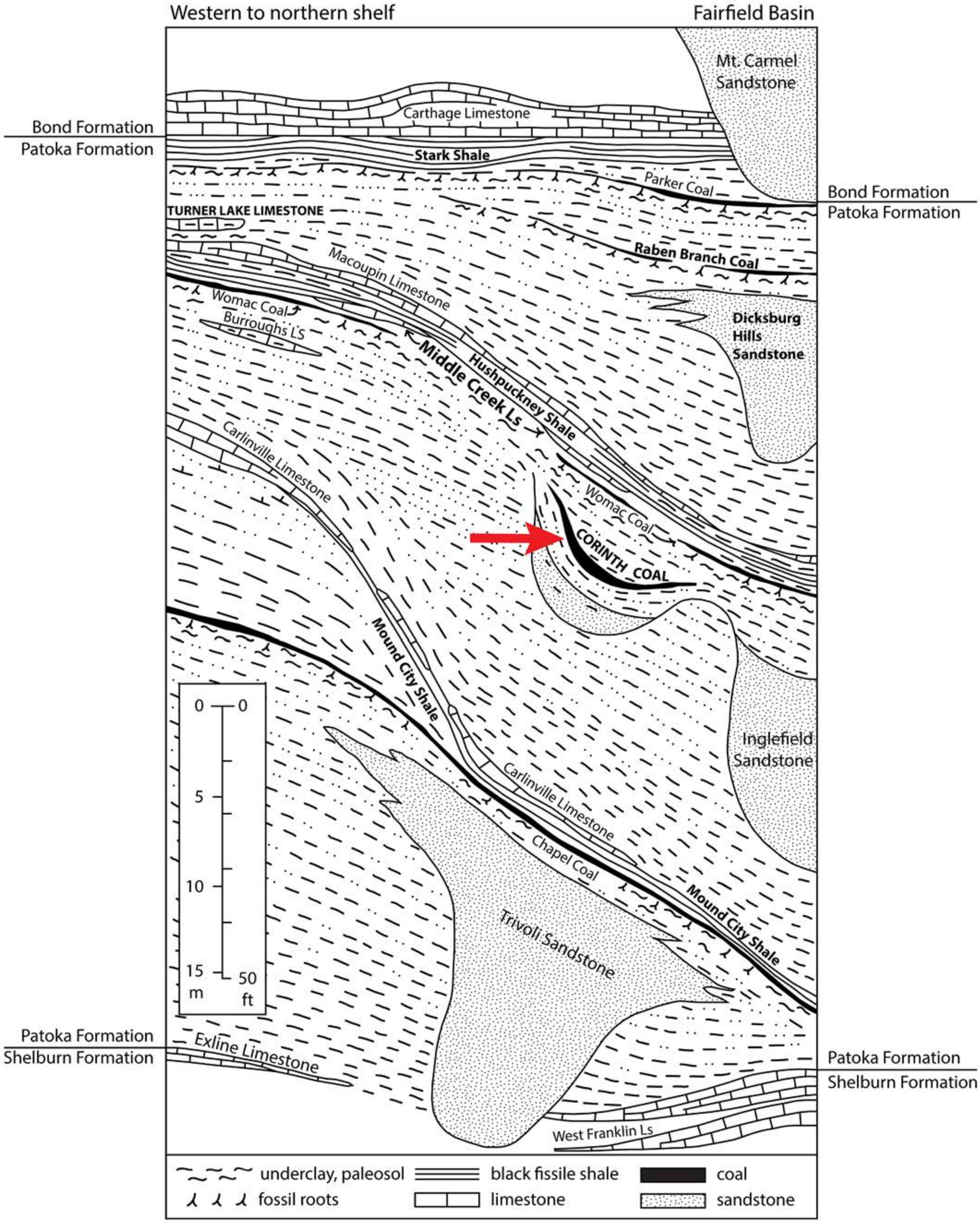


FIGURE 3. Generalized chart showing named members of the Patoka Formation in Illinois.

matter (macerals) were performed for each sample using a Zeiss epiplan 40X oil immersion objective, in conjunction with a 1.6X magnification changer (final magnification of 640X). A Zeiss 02 fluorescence filter set, with a 450-490 nm excitation filter, a 510 nm beam-splitter, and a 520 nm emission filter, was used in conjunction with a high-intensity metal halide light source for fluorescent light microscopy to confirm the identification of liptinite macerals.

Maceral percentages are based on 500-point counts of organic material for each sample, in accordance with ASTM D2799-23 (ASTM, 2023). All maceral percentages are reported on a volume percent, mineral matter free basis. Coal maceral terminology follows nomenclature outlined by the International Commission for Coal and Organic Petrology (ICCP, 1994, 2000; Pickel et al., 2017).

Vitrinite reflectance analyses were performed according to ASTM D2798-21 (ASTM, 2021) by first calibrating a Hamamatsu 928A photomultiplier with a glass standard of known reflectance. In this study, the standard used for calibration was a Schott SF13-714-276 glass standard with a certified reflectance value of 0.496 %. Following this, 50 random reflectance measurements were collected for each sample using an oil immersion objective (VRo random). Maximum reflectance (VRo maximum) values were calculated from the average VRo random values using the conversion formula: calculated VRo maximum = (VRo random * 1.09) – 0.034 (ASTM, 2021).

Specimen repositories

Macrofossil plant specimens illustrated in this paper reside in the Paleobotanical Type and Illustrated collection at the National Museum of Natural History (NMNH). Macrofossil specimen numbers are noted in the captions associated with the images. The remainder of the macrofossil collections are located in the general paleobotanical collections of NMNH under their respective USNM locality number (E&B Coal Company: USNM 38340) or field collection number (Phoenix Malone: DiMichele Field Collection IL1993-04). Palynological slides are housed in the Paleobotanical Slide Collection. They have been given the following USNM specimen numbers: E&B Coal Company, coal sample, 2 slides, USNM specimen number 787811; E&B Coal Company, roof-shale sample, 2 slides, USNM specimen number 787812; Phoenix Coal Company, Malone Pit, roof shale sample, 2 slides, USNM specimen number 787813.

Stratigraphic setting

In an unpublished manuscript, Nelson (1993) concluded that the coal at Corinth is probably the Womac Coal Member. Primary evidence included a section measured in the Phoenix Mining Company pit and continuous core from a nearby Old Ben Coal Company coal-test boring (Fig. 4). Under this interpretation, the gray non-marine shale overlying the Corinth coal was considered a “clastic wedge’ separating the coal from the marine limestone and black shale that normally rest directly on the Womac Coal. Identification of the Corinth with the Womac was carried forward through Nelson (2007), Myers and Obrad (2012), and Nelson and Denny (2015).

Position of the Corinth coal was evaluated again during preparation of a new online catalog of the Patoka Formation (Nelson et al., 2023). Evaluation of additional core records revealed that thin (less than 10 cm), shaly coal overlying well developed underclay locally lies at the base of the Macoupin marine shale and limestone. The thin shaly coal is at the normal position of the Womac Coal. Thus, as Wanless apparently concluded when he proposed the “Dillingham cyclothem”, the Corinth is a local coal intermediate between the Womac and Chapel.

The Corinth Coal Member is in the Patoka Formation and crops out near the unincorporated village of Corinth in eastern Williamson County, Illinois, in the vicinity of which it also was mined. Because mines and outcrops that formerly showed the Corinth Coal have been backfilled or are poorly exposed, a continuous drill core was selected as the type section (Nelson et al., 2023). That is the core from Madison Coal Corp. hole 21, drilled about 5 km north of Corinth in NE¼ NE¼ NW¼, Sec. 5, T8S, R4E, Williamson County (Fig. 1). In this core the Corinth Coal Member is 15 cm (0.5 foot) thick. Logs from Madison hole 21 are on file in Geologic Records at the ISGS and the core is in the Samples Library under call number C-4184.

As a reference section for the Corinth Coal, the core from Old Ben Coal Company’s borehole No. 49 was selected (Nelson et al., 2023). Hole No. 49 was drilled about 10 km north of Corinth in Sec. 18, T7S, R4E, Franklin County (Fig. 2). In the core, the Corinth Coal is about 39 cm (1.3 feet) thick in the depth interval from 169.8 to 171.1 feet. The core description from Hole No. 49 is on file at the ISGS but unfortunately, the core itself was not preserved.

In the Midcontinent Basin, a paleosol occurs at the top of the Snibar Limestone and base of overlying Elm Branch Shale, correlative with the Cramer Limestone in Illinois (Heckel, 2013). This minor regression and ensuing transgression may correlate with the Corinth Coal and its overlying clastics.

Description of Strata

Based on mine exposures and drilling records, the Corinth Coal member is believed to occupy a paleochannel eroded into the thick gray shales that overlie the Chapel Coal and Cramer Limestone (Fig. 5). Following in ascending order are descriptions of the rock units, beginning at the base of the paleochannel.

Below Corinth Coal

Drilling records indicate that an upward-fining clastic succession filled the lower part of the paleochannel beneath the Corinth Coal. From a lower erosive contact, sandstone grades upward to laminated siltstone and silty shale. As exposed in the surface mines, abundant large fossil plant stems and fronds of foliage occur as carbonized compressions in the shale within a few decimeters below the Corinth Coal. In contrast to the large majority of Pennsylvanian coal deposits in the Illinois Basin, the Corinth Coal lacks underclay, which is to say, non-fissile claystone containing fossil root traces and interpreted as a paleosol that developed prior to peat formation.

Corinth Coal Member

As presently known, the Corinth Coal is confined to a small area in eastern Williamson County and parts of adjacent Franklin, Hamilton, and Saline Counties. Maximum thickness of the coal is approximately 90 cm (3.0 feet). The coal is bright-banded, rich in vitrain. The basal 10 to 15 cm commonly contains laminae of dull coal and carbonaceous shale, grading downward to carbonaceous, plant-bearing shale. The coal lacks an underclay paleosol. The Corinth Coal is absent or reduced to coal stringers within shale and sandstone in several boreholes northwest of the mined area (Fig. 5).

Gray clastics

Separating the Corinth Coal from the underclay of the overlying Womac Coal is an interval of gray, largely fine-grained clastic rocks as thick as 11.3 m (37 feet). The lower part is dark gray, laminated shale that is finely silty and contains plentiful lenses and bands of siderite. Well preserved plant fossils are abundant near the base and persist up to about 3 m (10 feet) above the base. Sparse pectenoid pelecypods have been found in this shale; they are typical of brackish-water environments. Upward the shale becomes lighter gray and laminae of siltstone and very fine sandstone become increasingly numerous. Planar and cross-lamination are well developed. Contact to the Womac underclay is gradational.

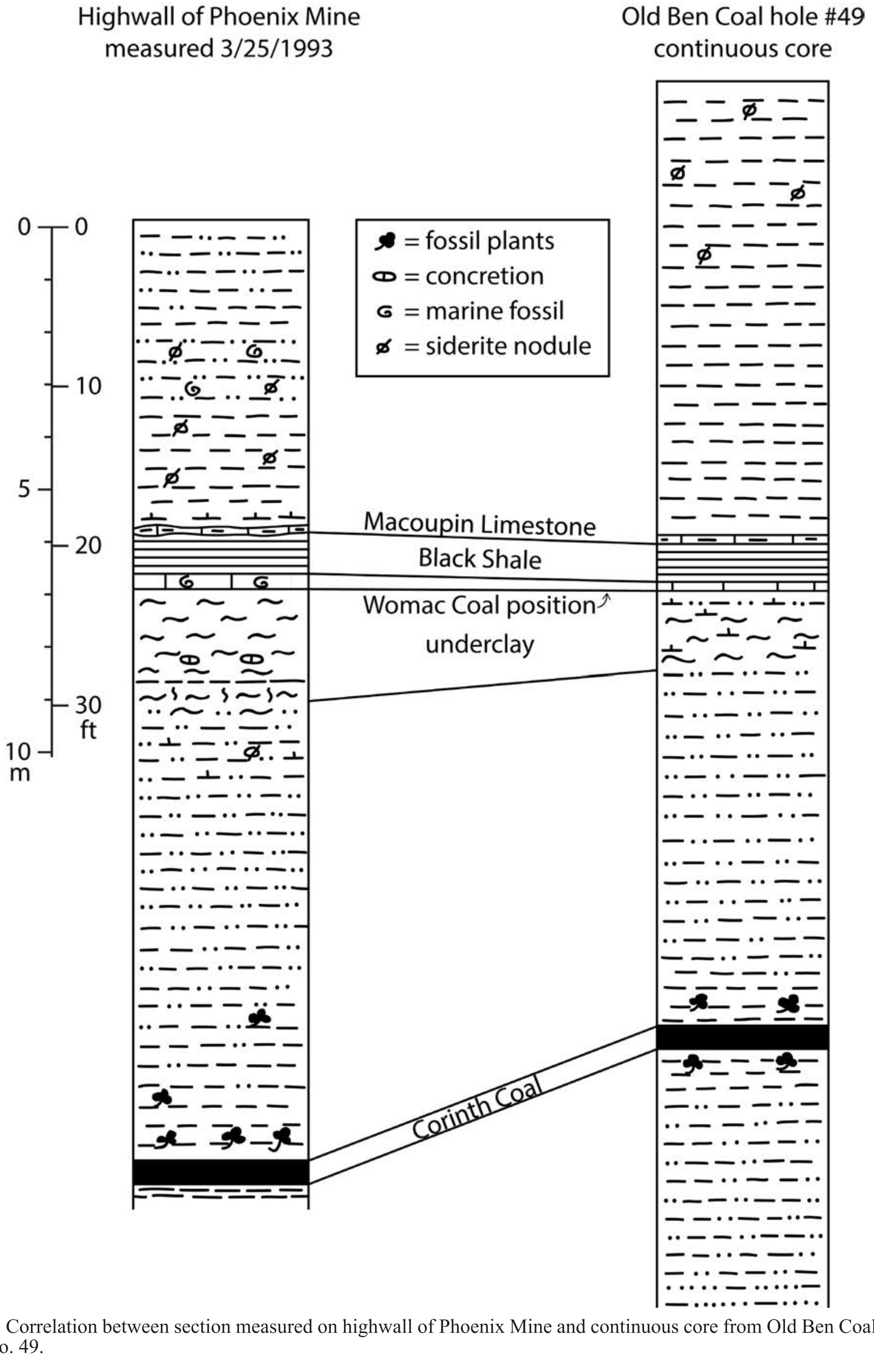


FIGURE 4. Correlation between section measured on highwall of Phoenix Mine and continuous core from Old Ben Coal Company borehole No. 49.

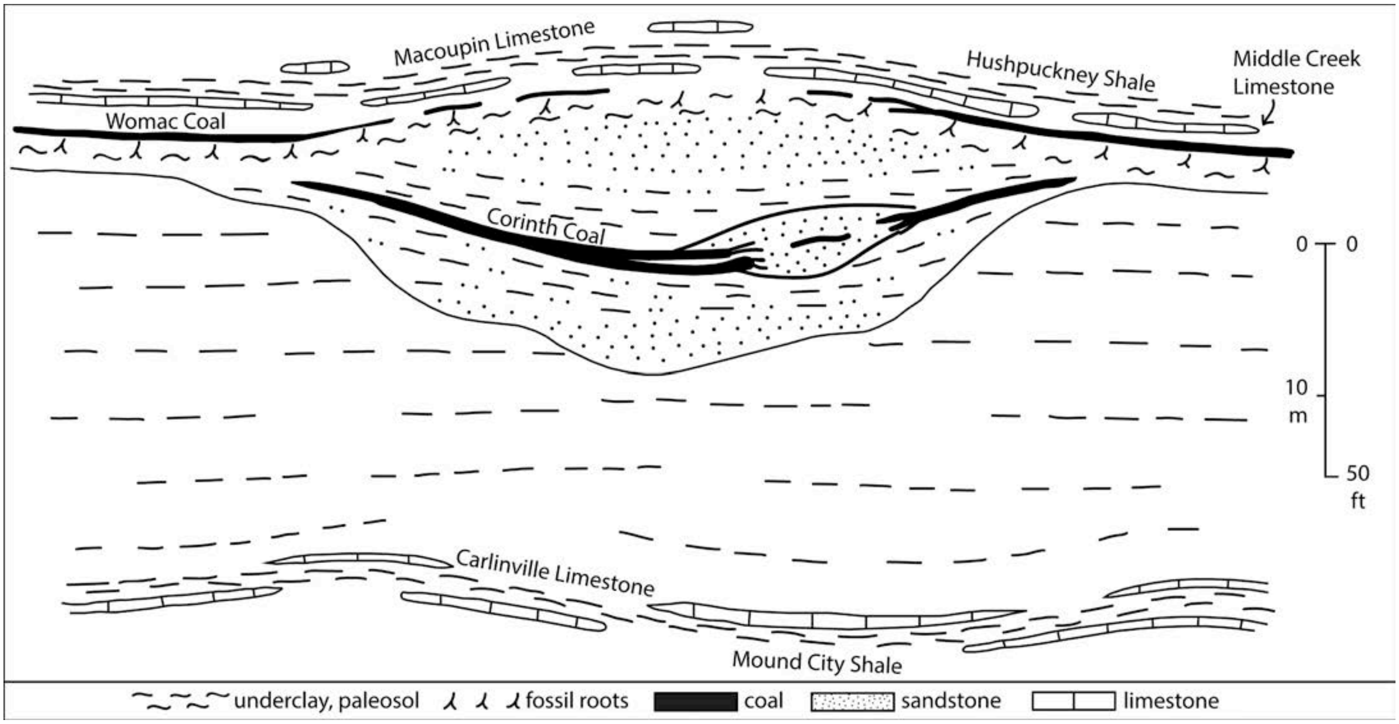


FIGURE 5. Diagram based on mine exposures and borehole data illustrating the relationship of the Corinth Coal member to enclosing strata. No horizontal scale.

ENVIRONMENT OF DEPOSITION

The Corinth Coal occupies a depression eroded into a clastic substrate prior to formation of the underclay of the overlying Womac Coal. Chronologically, the depression likely originated as a fluvial channel as sea level dropped during the glacial phase of a minor cycle. Climate during this phase of a cycle, regression and the early phases of glacial maximum, was probably seasonally dry, based on analyses of underclay paleosols associated with late Middle and Late Pennsylvanian-age coal beds, which are vertic, and increasingly calcic through time (e.g., Joeckel, 1989, 1995; Cecil et al., 2003; Rosenau et al., 2013). As the cycle reached glacial maximum, rainfall began to become less seasonal and climate more humid (sensu Cecil, 2003, regarding the number of months during which rainfall exceeded evapotranspiration) raising the water table across the landscape. In combination with sea-level rise and changing climate, sand and silt began to fill the depression, until terrestrial wetland vegetation encroached into areas of shallow standing water. By empirical observation, that of coal filling the channel, the channel was permitting the accumulation of thick organic matter from which most siliciclastic sediment was precluded. That clean, low-ash coal resulted from the diagenesis of that peat indicates that the landscape had become highly vegetated with roots and associated microorganisms greatly stabilizing the soil surface and cutting off clastic input into the developing peat body. Areas of open water, kept open by fluvial or tidal currents, remained along the axis of the depression and no peat was deposited here.

Peat accumulation likely persisted into the late glacial phases and terminated during the transition from glacial to interglacial. This is indicated by the resumption of clastic sedimentation in concert with eustatically driven marine transgression, a time during which climate would have become more seasonal due to changes in atmospheric circulation brought on by ice retreat and polar warming (e.g., Cecil et al., 2003; Horton et al., 2012). An increase in seasonality is accompanied by reduced vegetational cover in a drainage basin, reduced soil stability and an increased in siliciclastic input to streams and rivers and into the channel-bound peat swamp (see further discussion of this in DiMichele et al., 2020, section 3.1.2). Although we did not recognize tidal indicators in the clastics overlying the Corinth Coal, the planar and cross-lamination and the sparse brackish-water fauna suggest tidal activity in gradually shoaling water, marked by transition from sideritic clay-shale in the lower part to siltstone and very fine sandstone in the upper portion.

Subsequent regression led to subaerial exposure of the regional landscape, accompanied by development of a thick paleosol. This paleosol has gleyed colors, slickensides, and carbonate nodules, consistent with overall reducing conditions and a seasonally dry, monsoonal climate. During the latter part of sea-level lowstand, the climate again shifted to humid (sensu Cecil, 2003), enabling accumulation of the peat that became the Womac Coal. However, differential compaction along the axis of the former depression where the Corinth peat accumulated resulted in a low rise where Womac peat either did not accumulate or was subsequently eroded. Womac peat accumulation was terminated by a marine transgression marked by limestone and black phosphatic shale, followed by a regression marked by the Macoupin Limestone, and overlying shale, siltstone, and sandstone. Marine strata of the Macoupin cyclothem correlate to the major Swope cyclothem in the Midcontinent (Heckel, 2013).

MACROFOSSIL FLORAS – CORINTH COAL ROOF SHALE

Taphonomy

The fossil flora collected from the Phoenix Malone mine was preserved in a relatively soft gray siltstone that forms the roof shale of the Corinth Coal. Plant remains varied from occurring in relatively dense mats (Fig. 6) to being widely scattered in the matrix. Preservation was generally excellent including axes of various kinds, foliage, and, rarely, the remains of fine roots. Plant remains did not show evidence of being preferentially oriented by the current. The muddy sediment was deposited in mm scale beds or laminae that were separated by plant remains, and the surfaces were undulatory, likely due, in part, to the presence of the abundant organic debris. The density of plant remains, and

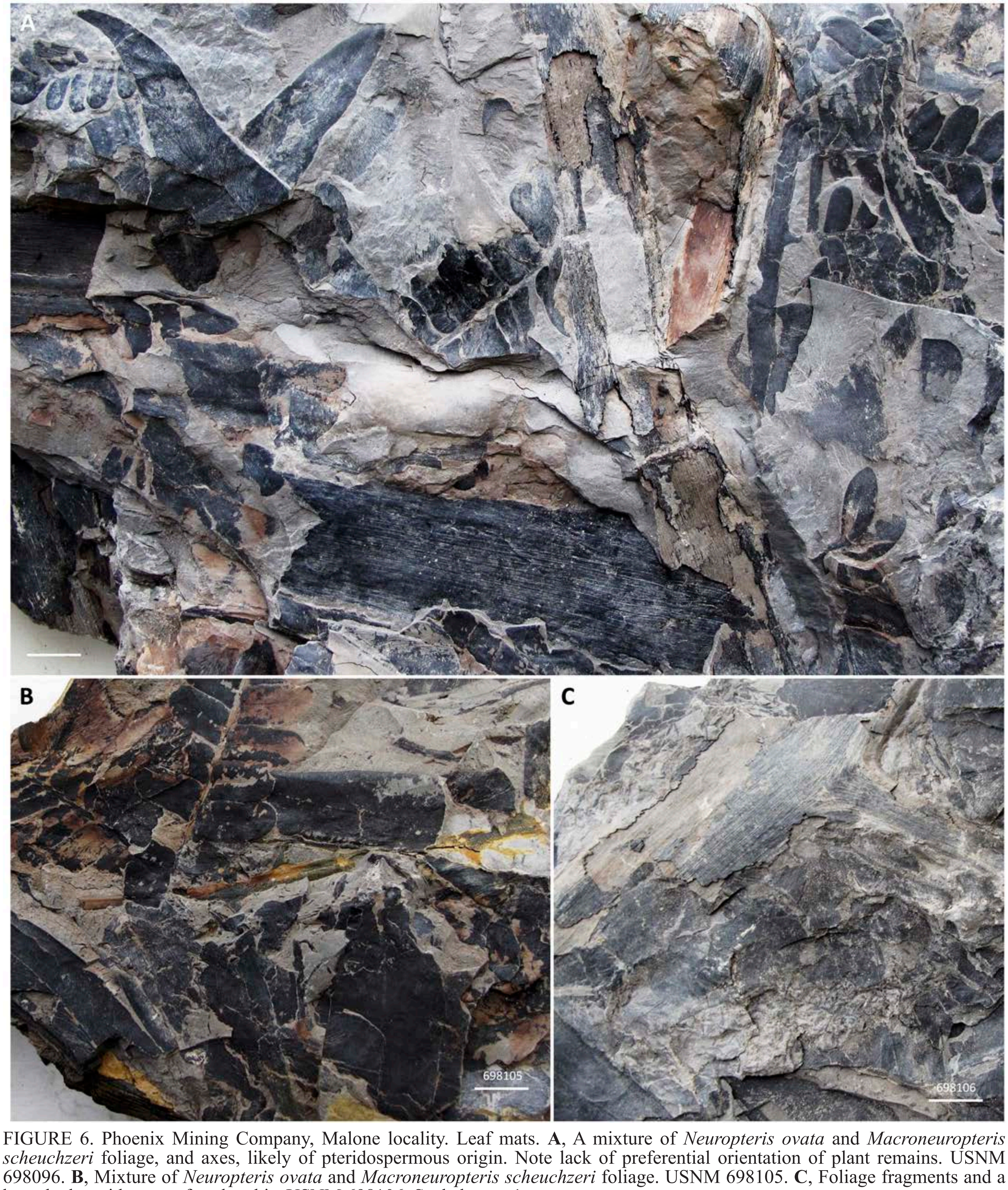


FIGURE 6. Phoenix Mining Company, Malone locality. Leaf mats. **A**, A mixture of *Neuropteris ovata* and *Macroneuropteris scheuchzeri* foliage, and axes, likely of pteridospermous origin. Note lack of preferential orientation of plant remains. USNM 698096. **B**, Mixture of *Neuropteris ovata* and *Macroneuropteris scheuchzeri* foliage. USNM 698105. **C**, Foliage fragments and a branched pteridosperm frond rachis. USNM 698106. Scale bars = 1 cm.

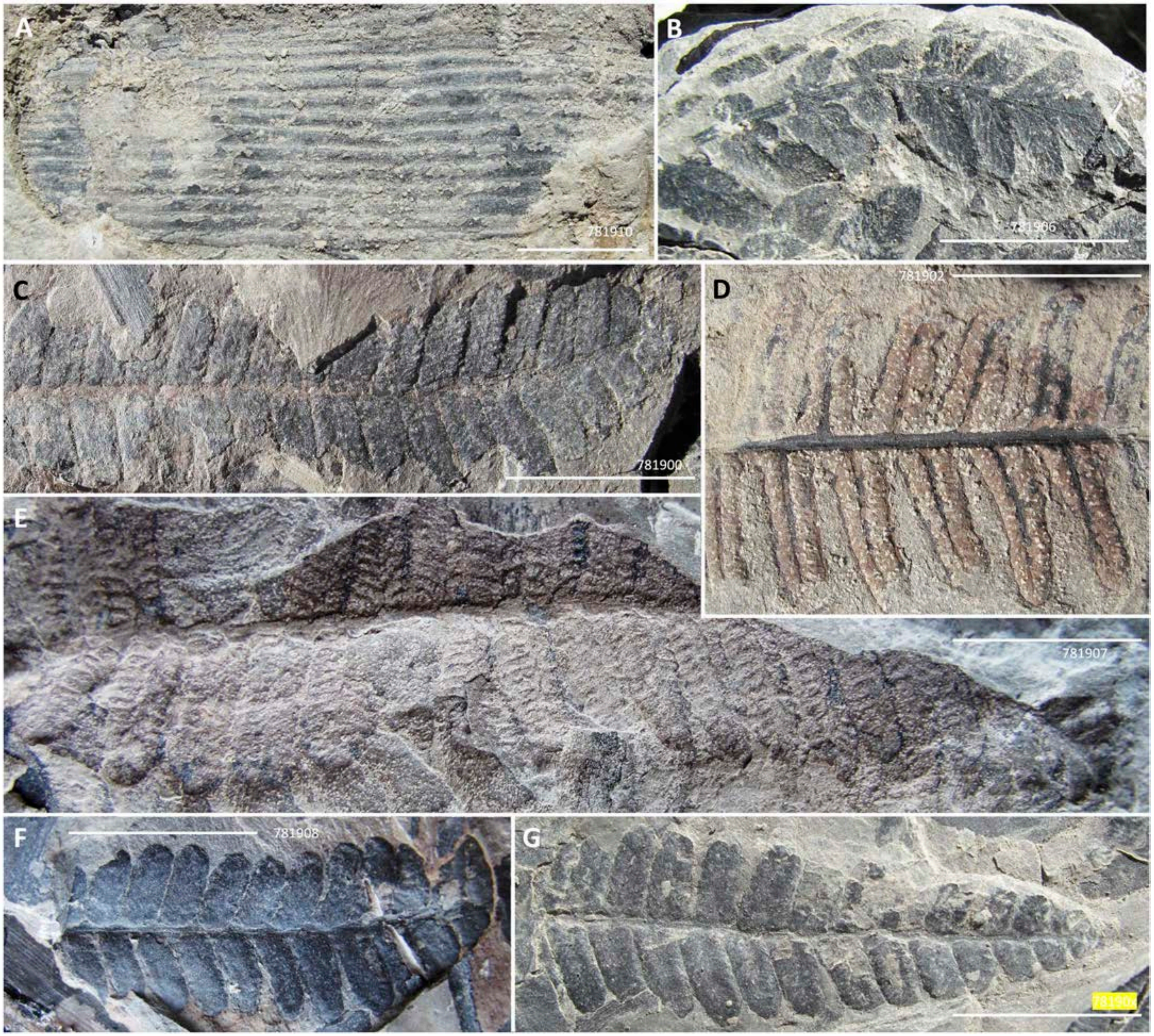


FIGURE 7. Pteridophytic plants from the E&B locality. **A**, *Calamites* stem. USNM 781910. **B,** *Oligocarpia gutberi*. USNM 781906. **C**, *Creulopteris lamuriana*. USNM 781900. **D**, *Creulopteris lamuriana*. USNM 781902. **E**, Possibly fertile specimen of *Creulopteris lamuriana* or *Danaeites emersonii*. Lateral venation is simple to once forked and parts of the pinnule appear to have laterally elongate sporangia. USNM 781907. **F**, Possibly fertile marattialean foliage. Note the decurrent midveins suggersting lobate pecopterid affinities. USNM 781908. **G**, Possibly fertile marattialean foliage. USNM 781906. Scale bars = 1 cm.

the presence of some large size stems points to limited transport.

The E&B Corinth flora also was collected from a blocky gray shale immediately above the Corinth Coal. At this location, the plant fossils were preserved somewhat differently from those at Phoenix Malone. Here the plant fossils were more scattered in the matrix and the shale was not as finely laminated. As far as could be determined, the plant remains did not present any evidence of current alignment. Preservation was, again, good to excellent, but transport of the plant remains appeared to be greater than at the Phoenix Malone location.

Both collections had horizons that were rich in siderite and some of the plant remains were preserved in this way. As will be seen in the plant descriptive sections that follow, siderite preservation can greatly enhance details (e.g., Fig. 15A, 18D) and preserved some plant remains, primarily axes, in three dimensions (e.g., Fig. 17C, D).

Pteridophytes

Pteridophytic plants occurred in much greater diversity and abundance in the E&B collection than in that from the Malone Pit. These included rare calamitalean stem remains (Fig. 7A), found only at E&B, but without accompanying foliage. Rare remains of the small fern *Oligocarpia gutbieri* also were found only at E&B (Fig. 7B, Fig. 8A, B).

The most commonly found pteridophytic remains were those of marattialean tree ferns. Only a single specimen was found in the Malone collection (Fig. 17B), which appears to be a lobate marattialean, given the deeply incised pinnae and the density and clustered nature of the lateral veins, lacking a clear midvein, that enter each of the lobes. More tree-fern remains

FIGURE 8. **A** and **B**, Pteridophytic plants from the E&B locality. Different perspectives and lighting of the same specimen (USNM 781888). The main specimen appears to be a marattialean fern with elongate abaxial synangia (heavy arrow points to the same spot in each image). There are forms of marattialeans with sporangia of this type. Note also the presence of *Oligocarpia gutbieri* pinnules (O, at arrow). Scale bars = 1 cm.

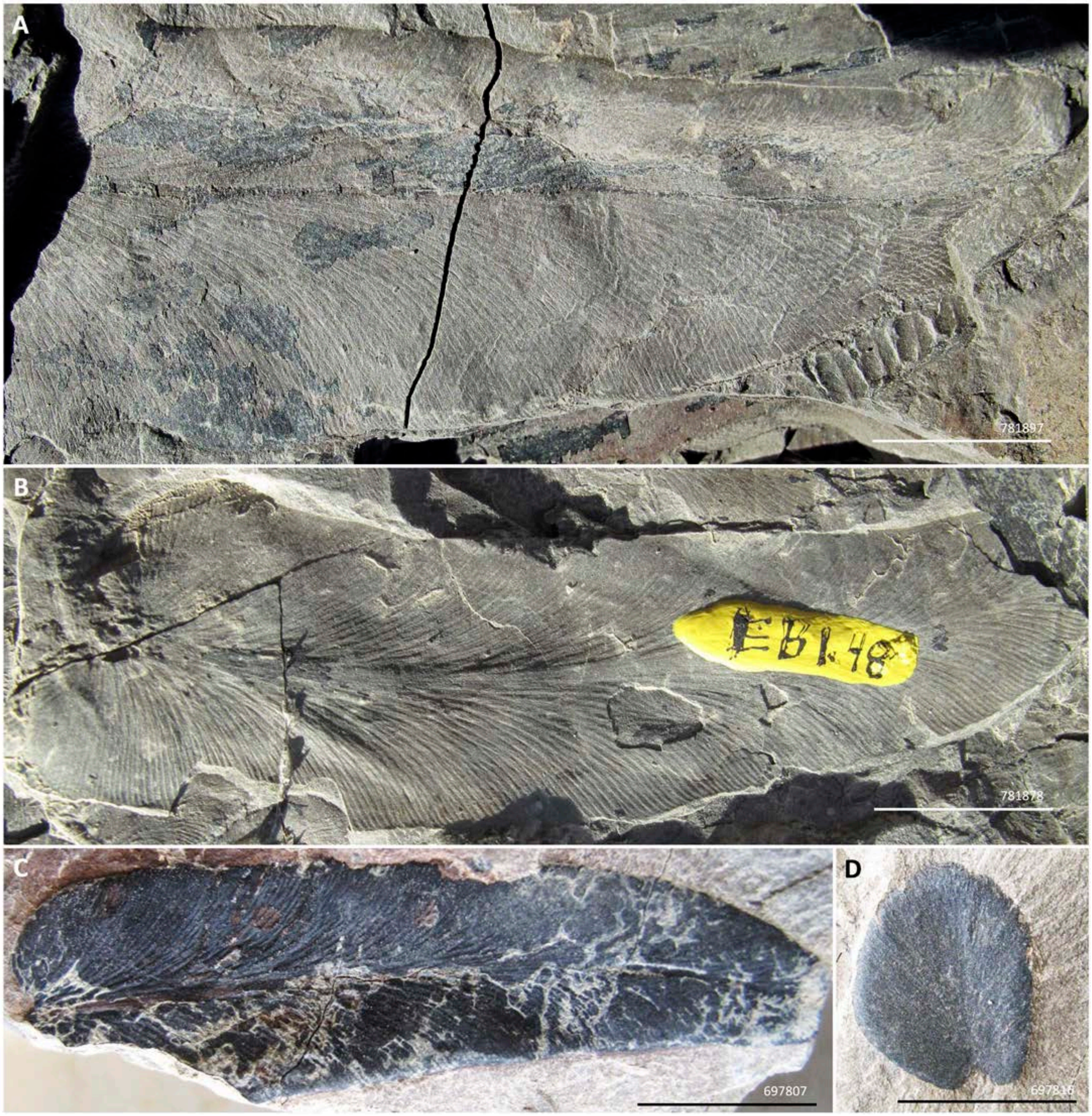


FIGURE 9. *Macroneuropteris scheuchzeri* from the E&B locality. **A**, Large, fragmentary pinnule with characteristic thin midvein and fine, arching lateral veins. Subepidermal hair-like resin canals are concentrated near the pinnule apex. USNM 781897. **B**, Large pinnule, partially permineralized with iron, enhancing features. Note sigmoidal shape of lateral veins, particularly their upward inflection prior to reaching the margin. Base is somewhat lobed and almost clasping. USNM 781878. **C**, Pinnule of typical shape and venation, but without visible subepidermal resin canals. USNM 697807. **D**, Small, free basal pinnule. USNM 697816. Scale bars = 1 cm.

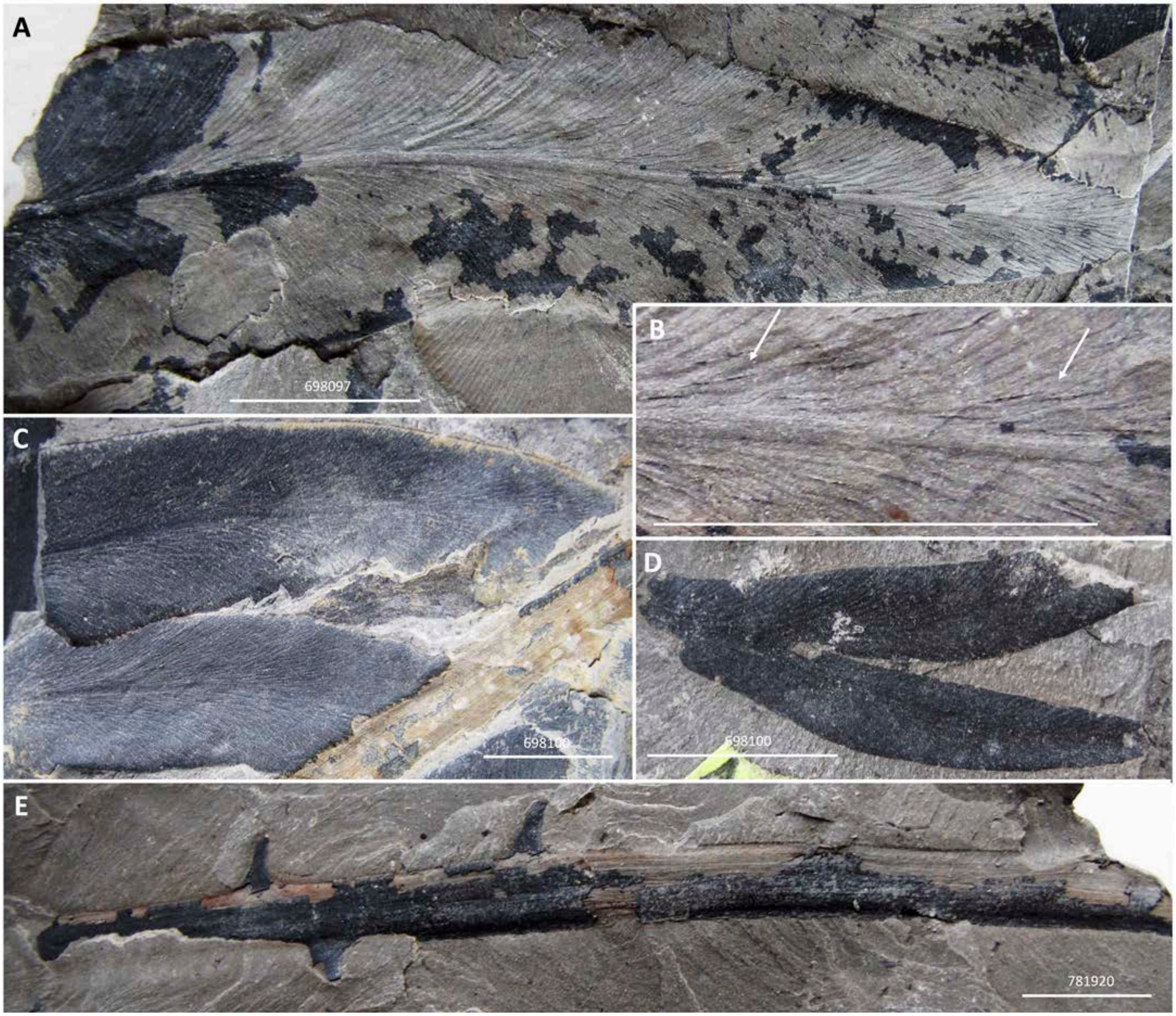
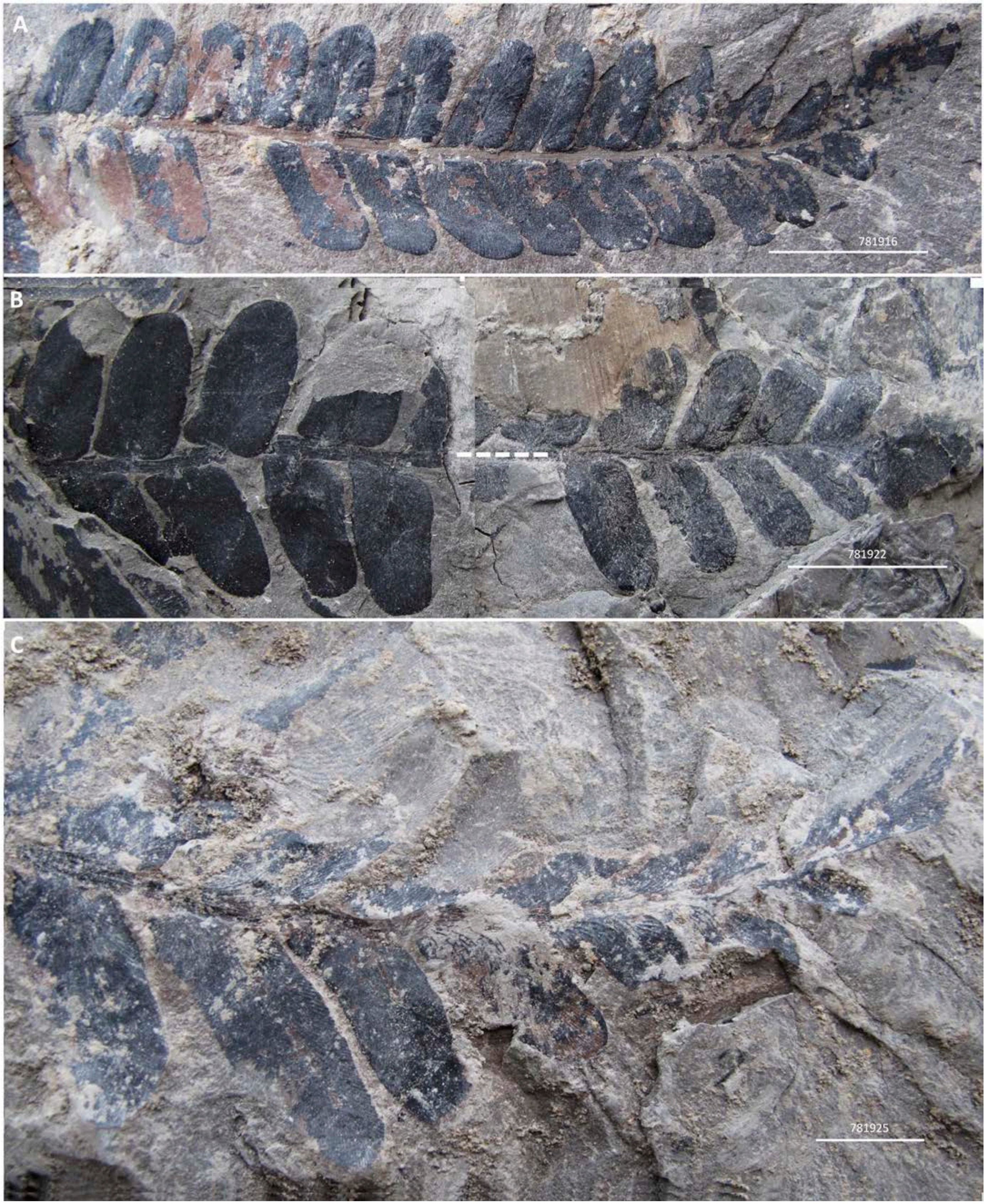


FIGURE 10. *Macroneuropteris scheuchzeri* from the Malone locality. **A**, Pinnule with subepidermal resin canals distributed across the surface of the pinnule. This is an abaxial view, which emphasizes the robustness of the midvein. USNM 698097. **B,** Subepidermal resin ducts ("hairs") crossing venation (arrows); higher magnification view of central part of USNM 698097, illustrated in 10A. **C**, A pair of pinnules, in adaxial view. Apparency of the midvein is greatly reduced, however the presence of subepidermal resin canals can be seen across the surfaces of the pinnules. USNM 698100. **D**, Anomalous pinnule of a type often found near the apex of a frond. USNM 698100. **E**, Rachis segment from which the pinnules have been shed, leaving spine-like projections at what were the attachment points of the pinnules. USNM781920. Scale bars = 1 cm.

FIGURE 11 (facing page). *Neuropteris ovata* from the Malone locality. **A**, Specimen with characteristic pinnule shape and venation. Apical pinnule is relatively narrow. USNM 781916. **B**, Specimen with characteristic pinnule shape and venation. Apical pinnule is broader and shorter than in the specimen illustrated in (**A**). This specimen was longer than as shown in the illustration; the central area was poorly preserved and, thus, was cropped and compressed along the pinna axis (dashed line) to allow the specimen to be illustrated at the same magnification as the others in this figure. USNM 781922. **C**, Specimen with more elongate, and thus relatively narrow pinnules. Apical pinnule is narrow but adjacent pinnules are partially fused to it, as is typical of the species. USNM 781925. Scale bars = 1 cm.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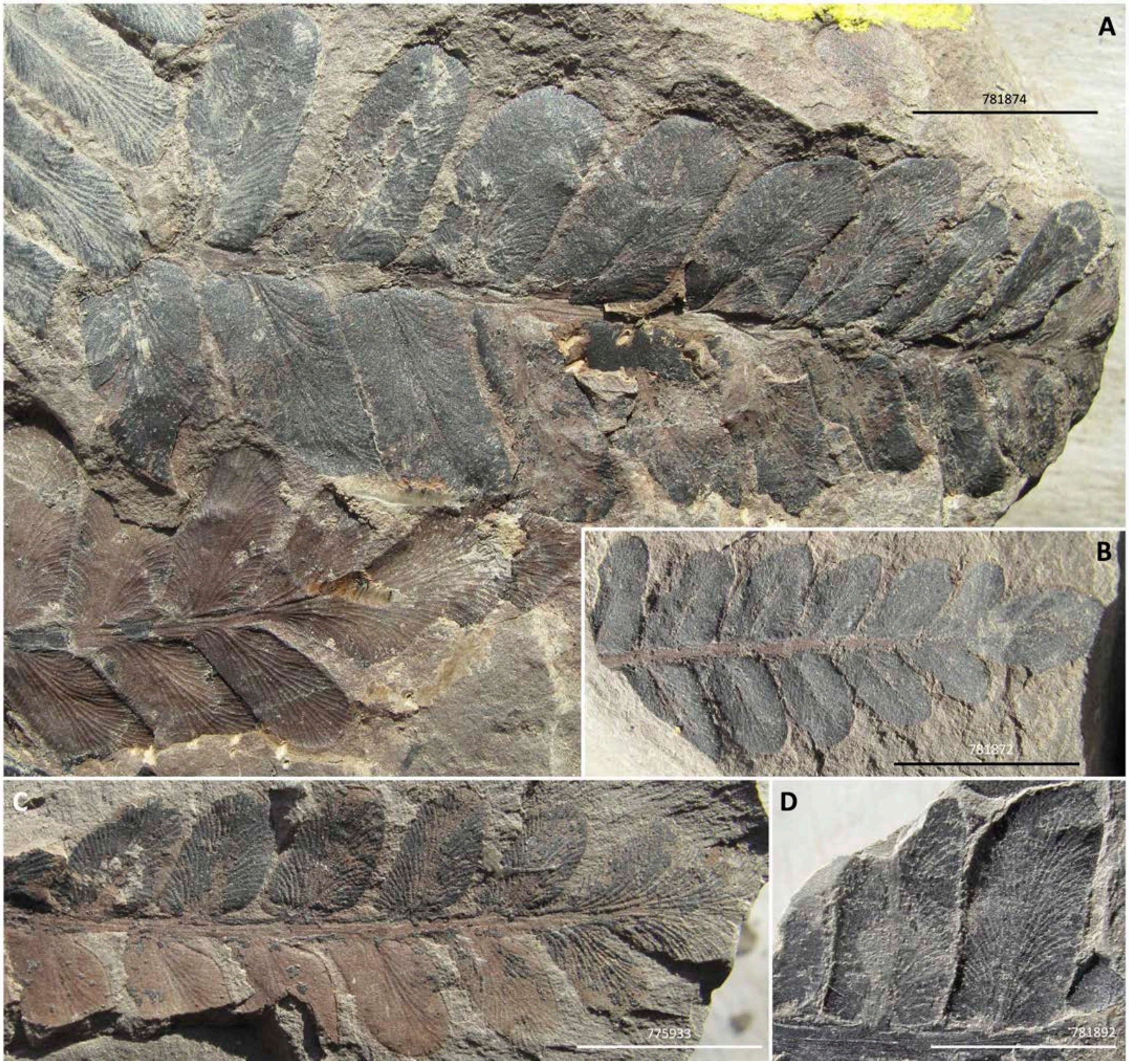


FIGURE 12. *Neuropteris ovata* from the E&B locality. **A-C**, Specimens with typical pinnule shape. **B** and **D** have the shorter, wider form of apical pinnule. **B**, illustrates a specimen in which partial iron permineralization has accentuated the venation. **A** and **D**, Examples of pinnae with larger, but still typical, pinnule shape and venation. The complete pinnule in **D** also shows an asymmetrical pinnule apex. **A**, USNM 781874. **B**, USNM 781872. **C**, USNM 775933. **D**, 781892. Scale bars = 1 cm.

were found at E&B, which are most similar to *Crenulopteris lamuriana* (Wittry et al., 2015), a typically Missourian species (Wagner and Álvarez-Vázquez, 2010); this taxonomic revision was challenged by Wagner and Álvarez-Vázquez, 2016, who prefer continued use of *Lobatopteris lamuriana*. This foliage (Fig. 7C-D) is characterized by elongate, narrow pinnules with complex shape changes between different parts of the larger frond. Elongate, unlobed pinnules tend to have strong midveins that are slightly decurrent. In other parts of the frond pinnules are lobed in association with the development of candelabra-like lateral venation. These forms transition to fully lobed pinnae with small lateral pinnules generally lacking midveins. Figure 7E may be a fertile specimen of *C. lamuriana* or it may be a partially fertile specimen of *Danaeites* cf. *emersonii* given its strong, sparely forked lateral venation, and the suggestion of laterally elongate sporangia on some pinnules. There also are forms of marattialean foliage in the E&B collection (Fig. 7F-G) that are shorter with lower length-to-width ratios than *C. lamuniana* and may be *Asterotheca*-type fertile foliage; venation in these is difficult to discern but the presence of sporangia is suggested by the undulatory surfaces. The decurrent midveins in Figure 7F suggest that this may be part of a lobate form.

An additional form of fertile foliage, possibly of marattialean affinity, is shown in Figure 8. Two such specimens were found, one of which is illustrated in the figure under two different light exposures. The elongate, robust pinnules appear to bear long abaxial sporangia or synangia. Marattialean foliage somewhat like this was reported from coal-balls as the *Scolecopteris*

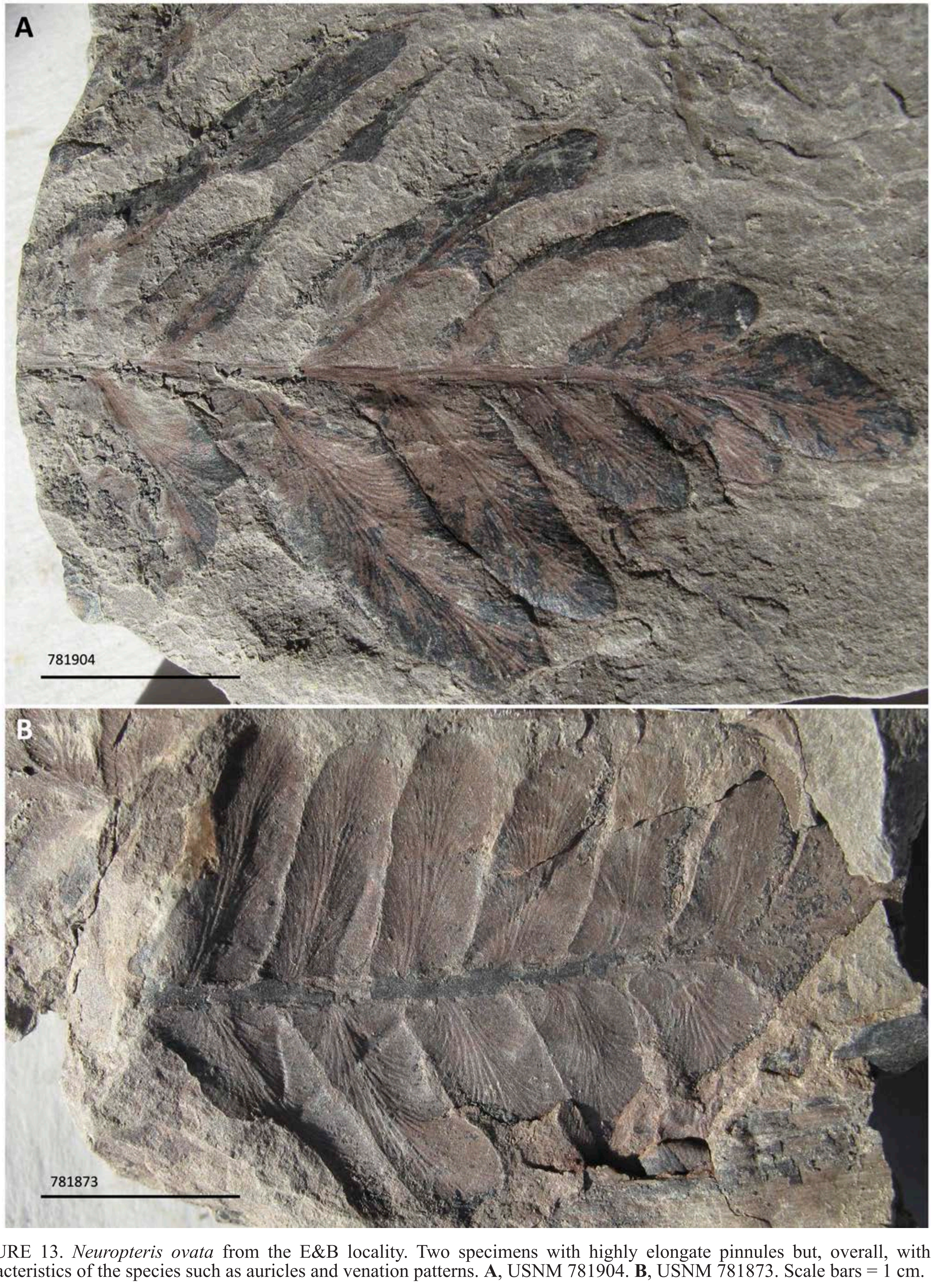


FIGURE 13. *Neuropteris ovata* from the E&B locality. Two specimens with highly elongate pinnules but, overall, with the characteristics of the species such as auricles and venation patterns. **A**, USNM 781904. **B**, USNM 781873. Scale bars = 1 cm.

FIGURE 14. Miscellaneous pteridosperm remains from the Malone locality. **A**, Large pteridosperm stem. This view shows only one side of this specimen, which wrapped around the hand specimen and had an internal cavity filled by the matrix sediment. USNM 781914. **B**, Cyclopterid pinnule. Large. No evidence of a "fringe" characteristic of *Neuropteris ovata*. USNM 781917. Scale bars = 1 cm.

latifolia Group by Lesnikowska (1989). However, a certain identification of these specimens is not possible.

Pteridospermous Seed Plants

Pteridosperms are the dominant element, represented by the largest number of individual fragments, in both the E&B and Malone collections. Two taxa, *Macroneuropteris scheuchzeri* (Figs. 9, 10) and *Neuropteris ovata* (Figs. 11, 12), were by far the most commonly encountered at both sites, and nearly entirely dominated the Malone collection. Specimens are illustrated from both collections, separated in the figures for each species.

Macroneuropteris scheuchzeri is a highly recognizable species as a consequence of its large pinnule size and distinctive lingulate shape. Pinnules were caducous, and thus are most often found isolated, not attached to rachises. The pinnule apices vary from bluntly rounded to narrowly triangular with most being tapered and narrowly rounded but not sharply pointed. Many pinnules are marked by one or a pair of basal lobes that often are free pinnules (e.g. Fig. 10D). Perhaps the most distinctive feature, and one that permits the separation of this species from other large-pinnuled pteridosperms, is the presence of small structures that appear to be "hairs", seemingly on the surface of the pinnules, often clustered near the base (e.g., Fig. 10A, C), whereas in others they may be distributed across the pinnule surface (e.g., Fig. 10A-C) or even concentrated near the apex of the pinnule (Fig. 10A). Careful dissection of pinnules, including removal of their cuticular coatings revealed that these were not hairs, but rather were subepidermal resin canals (Laveine and Oudoire, 2015), based upon the discovery that the chemical composition of the "hairs" was different from that of the cuticle, implying a distinct origin (Zodrow, 2014). Pinnules often are found with all the features of *M. scheuchzeri* but lacking these distinctive hair-like subsurface structures (e.g., Fig. 9C). Interestingly Laveine and Belhis (2007) found that the fronds of *M. scheuchzeri* were rather short, perhaps a meter or a bit more in length, compared to lengths of multiple meters in some species of, for example, *Alethopteris* (Laveine, 1986). Figures 10C and 10D illustrate other features typical of *M. scheuchzeri*, which often shows variability of pinnule morphology (Fig. 10C) and is frequently associated with rachis segments from which the caducous pinnules have been shed, leaving spine-like protrusions along the length of the axis (Fig. 10D).

Neuropteris ovata is one of the most common wetland Middle and Late Pennsylvanian plants in Euramerica, extending into the early Permian (Pfefferkorn, 2023), and occurring into the western reaches of the paleocontinent (e.g., Lucas et al., 2021). Its commonness has made it a prime suspect for stomatal analyses as a proxy by which to estimate the patterns of change in paleo-atmospheric CO_2 content (Cleal et al., 1999; Montañez et al., 2016; Šimůnek and Cleal, 2016.), as well as being an important stratigraphic marker for the later part of the Middle Pennsylvanian (e.g., Opluštil et al., 2022). The "species", in fact, may be a complex of species, and several different varieties have been recognized based mainly on cuticle morphology (e.g., Zodrow and Cleal, 1988; Cleal and Zodrow, 1989; Šimůnek and Cleal, 2016); however, no cuticle has been prepared from the Corinth Coal specimens to compare them with described Late Pennsylvanian varieties. The Corinth specimens of *N. ovata*

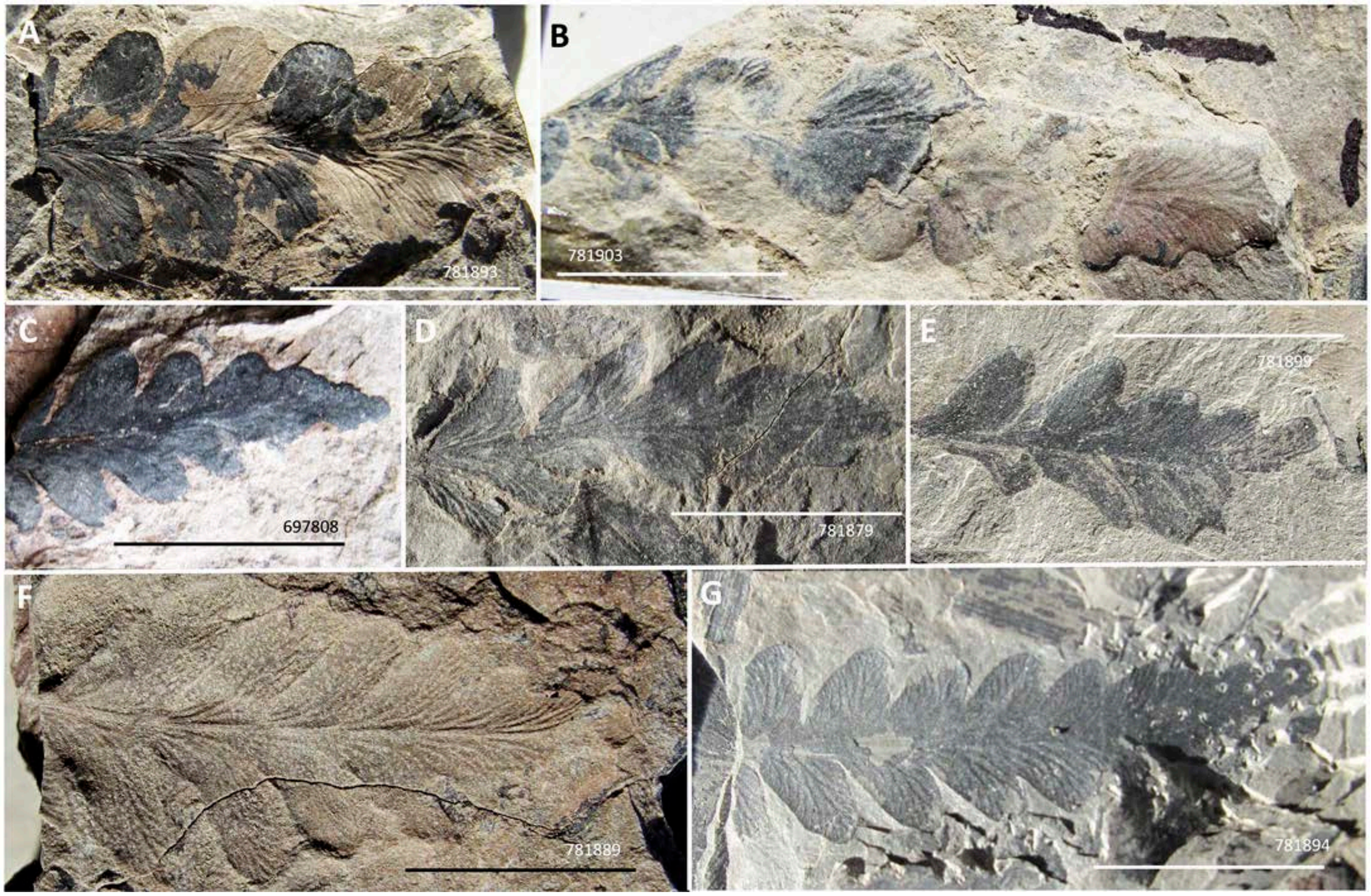


FIGURE 15. Pteridosperms from the E&B locality. **A**, *Odontopteris* cf. *schlotheimii*. The coarseness of the venation is consistent with this species, but the venation is somewhat too dense; typically this species has very sparse, widely spaced veins. USNM 781893. **B** - **E**, *Odontopteris* cf. *schlotheimii*. These specimens, all fragments of pinna termini, have relatively sparse venation but, again, as with the specimen illustrated in (**A**), the venation is denser than is typical for that species. **B**, 781903. **C**, USNM 697808. **D**, USNM 781879. **E**, USNM 781899. **F**, cf. *Odontopteris brardii*. Shape and venation are consistent with this species. USNM 781889. **G**, Specimen of uncertain affinity. USNM 781894. Scale bars = 1 cm.

vary from "typical", with pinnules narrowly attached to the rachis, becoming progressively more broadly attached in pinna apical regions, fusing to one another or to the apical pinnule to varying degrees. The apical pinnule in the Corinth specimens varies from elongate and narrow to, more commonly, shorter and more triangular but not inflated. In the most classic form (Figs. 11A, B; 12B, C), the pinnules are approximately 2 times longer than wide, have more or less straight lateral margins and an apex varying from broadly rounded to asymmetrical, somewhat truncated and angular on the basiscopic side. The base is marked by a basiscopic auricle. Lateral veins arch steeply toward the margin and meet it at a narrow angle. The midvein is weak and consists of a vein bundle, extending through about 2/3 of the length of the pinnule. Within the Corinth collection, however, are many specimens that have longer pinnules that appear narrow in their length-to-width ratios (Figs. 12C, 12A, D), the most extreme examples being the two specimens in Figure 13. Nonetheless, the pinnules maintain other characteristic features of apex, base, venation, pinna apical pinnule, and the patterns of basal attachment and fusion in the distal regions of the pinna. A few specimens of the cyclopterid pinnule *Cyclopteris fimbriata* also were found (e.g., Fig. 15A), which are part of the *N. ovata* frond.

A few other kinds of pteridosperm remains were found in the Phoenix collections. One is a fragment of a relatively large, strongly striate axis, perhaps a medullosan stem given its >10 cm diameter (Fig. 14A). Another is a moderately large cyclopterid pinnule several centimeters in diameter but lacking any features that might indicate affinity with a particular foliage type (Fig. 14B). No other pteridospermous remains were found at this location.

In the E&B collections, foliage of other kinds of pteridosperms was more abundant than in the Malone collection, contributing to the higher overall diversity recovered from the E&B site. The largest number of these pteridosperms are attributable to the genus *Odontopteris* (Fig. 15) and are represented almost entirely by the apical portions of pinnae. The greatest number of specimens appear to be *Odontopteris schlotheimii*, characterized by pinnules varying from rounded to narrowly triangular (a shape perhaps accentuated by drying prior to burial?), with sparse, prominent venation (Fig. 15A-E). The specimen illustrated in Figure 15F is similar to some of the specimens illustrated by Šimůnek and Cleal (2004) in their comparative study of small pinnuled odontopterids. *Odontopteris brardii* and *O. nemejcii* are both characteristic of the early Late Pennsylvanian and have pinnule sizes, shapes, and venation similar to the E&B specimen. However, cuticle, on which species differences increasingly are based, could not be prepared from the illustrated specimen. Also, as can be seen in the more distal, elongate pinnules of the specimen, the midvein extends through a considerable length of the pinnule, unlike that of *O. nemejcii*. Šimůnek and Cleal (2004, p. 29) note that *O. brardii*, in comparison to *O. nemejcii* "has more rhomboidal pinnules with straighter lateral margins and a blunter apex, and

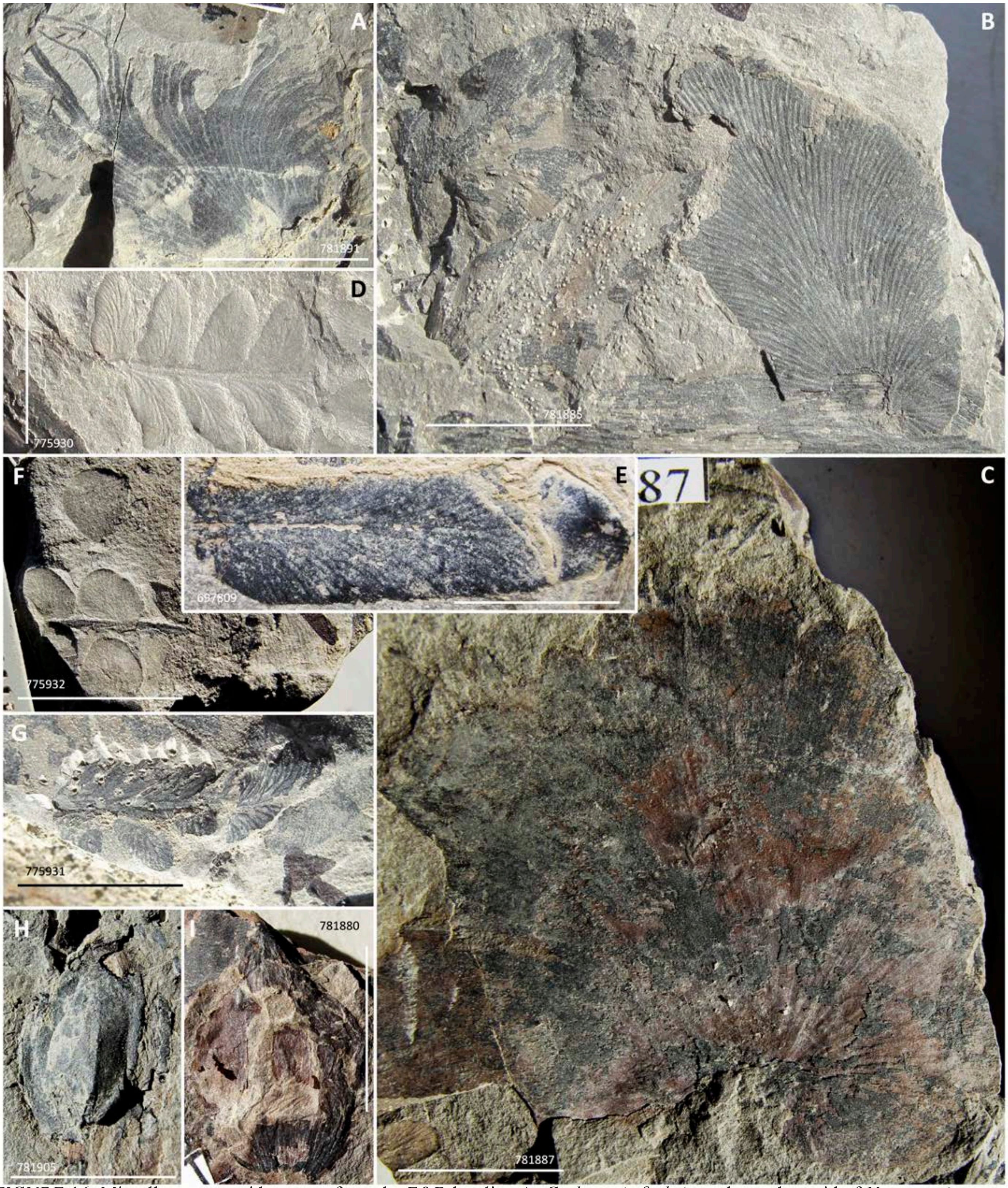


FIGURE 16. Miscellaneous pteridosperms from the E&B locality. **A**, *Cyclopteris fimbriata,* the cyclopterid of *Neuropteris ovata*. USNM 781891. **B**, Neuropterid pinnules that may be cyclopterids of *Laveineopteris nervosa* or pinnules of *Neuropteris rogersi*. USNM 781885. **C**, Large cyclopterid pinnule of uncertain affinity. The margin appears to be fimbriate, but that may be preservational. USNM 781887. **D**, cf. *Laveineopteris nervosa*, a species described from Central Europe of Late Pennsylvanian age. Identity of this specimen is uncertain. USNM 775930. **E**, cf. *Neurocallipteris planchardii* isolated pinnule. USNM 697809. **F**, Unidentified foliage of possible odontopterid affinity. USNM 775932. **G**, Foliage of uncertain affinity. USNM 775931. **H**, *Trigonocarpus* seed similar to *T. schultzianus*. USNM 781905. **I**, Seed with sarcotestal striations similar to those typical of *Rhabdocarpus*. USNM 781880. Scale bars = 1 cm.

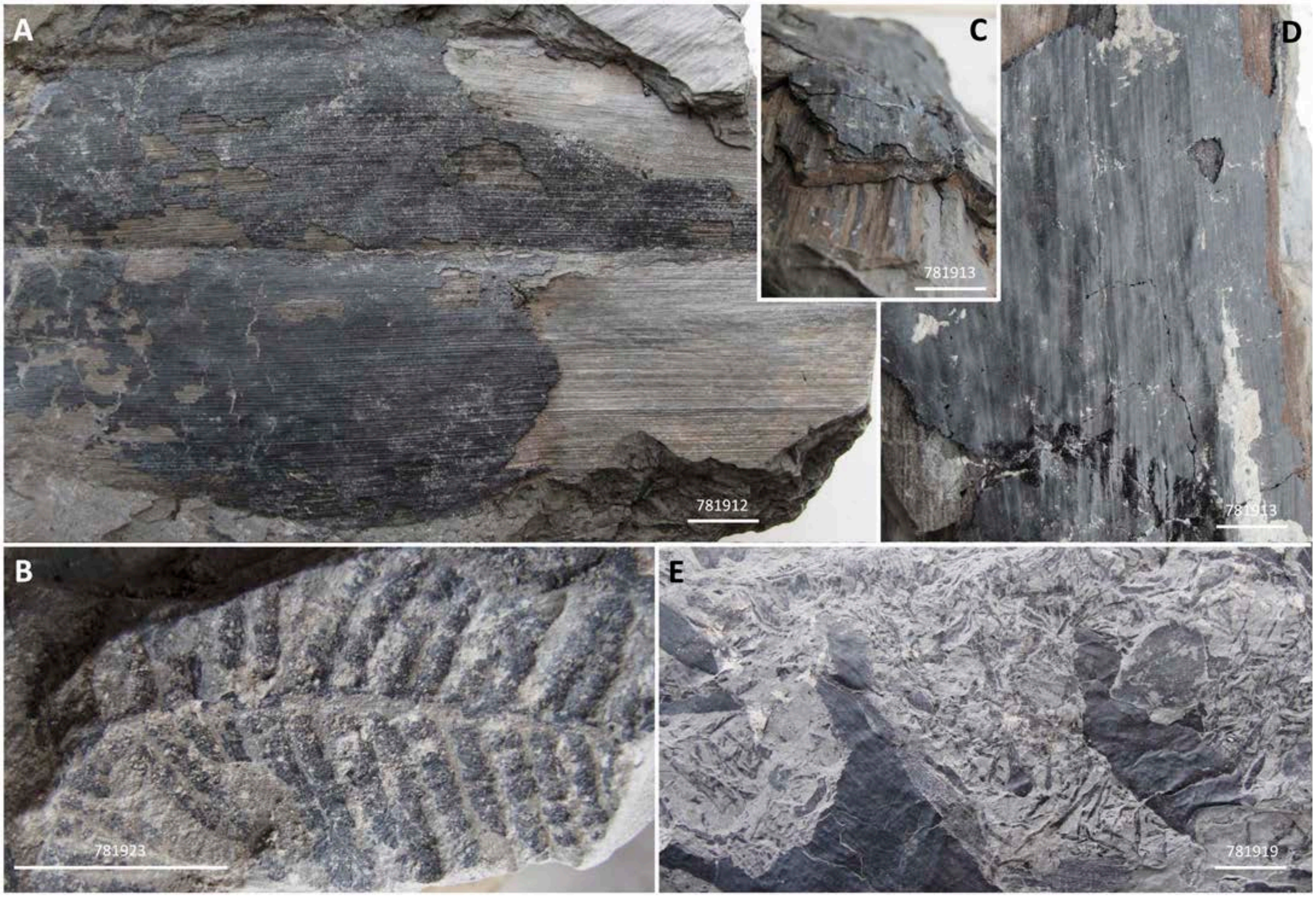


FIGURE 17. Miscellaneous specimens from the Malone locality. **A**, *Cordaites* sp. USNM 781912. **B**, Lobate marattialean fern foliage of uncertain identity. USNM 781923. **C** and **D**, Stem, or possibly rachis, preserved in three dimensions by iron-rich (probably siderite) sediment, with original organic matter preserved. USNM 781913. **E**, Fine roots scattered among foliar remains. USNM 781919. Scale bars = 1 cm.

a denser venation."

The foliage illustrated in Figure 15G is of uncertain affinity and may be a pteridosperm or even a filicalean fern. The pinnules at the more distal end of the specimen have indications of a constricted base, undulate margins, and strong, dichotomizing venation that lacks clear development of a midvein and has several independent veins inserted on the supporting rachis.

Additional remains of pteridosperms from the E&B collection are illustrated in Figure 16. This includes the already mentioned *Cyclopteris fimbriata*, which is part of the *Neuropteris ovata* frond (Fig. 16A). Other larger cyclopterids of uncertain affinity also occur as single specimens (Fig. 16B, C). Cyclopterids are specialized oval-shaped pinnules that occur on several different taxa of pteridosperms. Fragments of foliage with small pinnules of possible pteridosperm affinity include that in Figure 16D, which can be compared with *Laveineopteris nervosa* (Šimůnek and Cleal, 2022), recently redescribed from the early Late Pennsylvanian of Central Europe. This species also has been linked to cyclopterid pinnules similar those illustrated in Figure 16B. This specimen (Fig. 16B) also is similar to *Neuropteris rogersi* a rarely reported species, in shape, the coarseness of the venation, the cordate base, and strongly recurved lateral venation into that base. Of course, again, without cuticle, and with only a small fragmentary specimen, either identification can be no more than tentative at best. Another clearly neuropterid specimen is that illustrated in Figure 16E, which is an elongate pinnule with straight sides, a bluntly acuminate apex, and a cordate base that is slightly auriculate. The midrib is well marked and extends through 3/4 of the length of the pinnule; lateral venation is relatively straight, forks several times prior to termination, and meets the margin at ~45°. Possible affinities are with *Neurocallipteris*, cf. *N. planchardii*, a species that appears to be adapted to environments with periodic moisture stress (Luthardt et al., 2021). Additional scrappy remains (Fig. 16F, G) may be of pteridospermous affinity, especially Figure 16F, which may be an odontopterid given the rounded pinnule shape and the absence of a clearly developed midvein. Only two seeds/ovules were found in the entire Corinth Coal collection, both of which are radiospermic forms (Fig. 16H, I). Medullosan affinity with *Trigonocarpus*, is suggested for the seed in Figure 16H by the strong ribs and flattened outer rim, which appears to be a compacted sarcotesta rather than a wing. Compare with the illustration of *T. schultzianus* in Crookall (1976). The other seed (Fig. 16I) has multiple fine but raised striations originating at the base and extending to the apex, reflective of a fibrous sarcotesta, and with a somewhat taped apex, possibly a form of *Rhabdocarpus*.

Cordaitales

Each collection contains numerous striate objects that may be stems or rachises of pteridosperms or marattialean tree ferns, but in certain cases appear to be cordaitalean leaves (Fig. 17A, 18A). These are differentiable visually or with a lens by the pattern of the striations. If they are relatively more coarse, anastomose, and/or do not dichotomize unidirectionally, they most likely are axes (Fig. 16A, 17C, D). If striations are

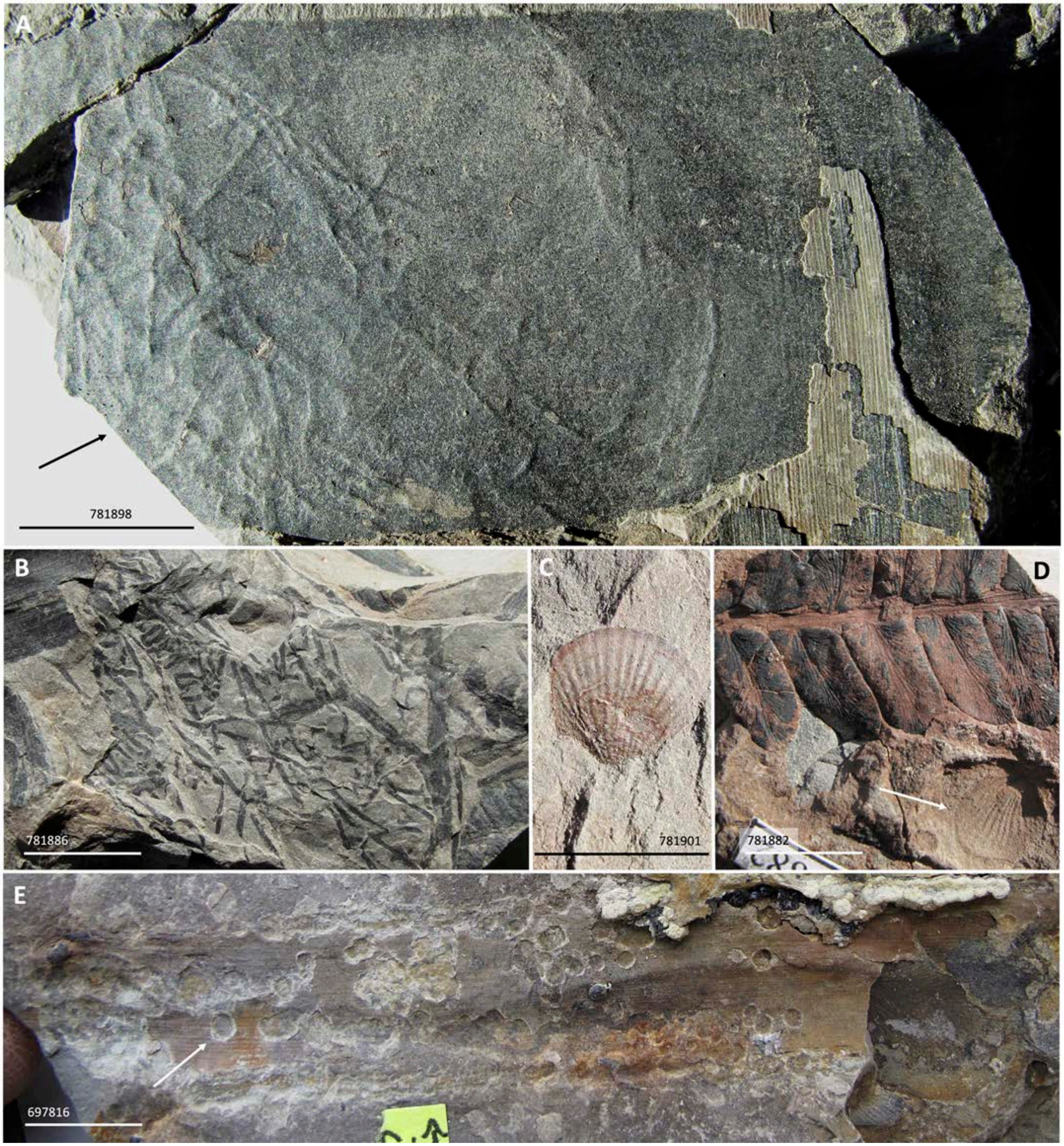


FIGURE 18. Miscellaneous and animal remains from the E&B locality. **A** Large *Cordaites* leaf fragment with fine venation (arrow), contrasting with the coarse and irregular striations of rachial or stem segments. USNM 781898. **B**, Fine roots typical of pteridosperms or calamitaleans. USNM 781886. **C**, Clam of the type found in association with leaf remains on several specimens. USNM 781901. **D**, Clam (arrow) in proximity to *Neuropteris ovata* foliage. USNM 781882. **E**, Cordaitalean leaf or striate axis with numerous adherent microconchids. USNM 697816. Scale bars = 1 cm.

TABLE 1. Quantitative analyses of the Corinth Coal macrofloras from the roof shale.

	E&B Coal Company		**Malone Mine**	
Taxon	Count	Frequency-%	Count	Frequency-%
Neuropteris ovata	111	59.0	32	51.6
Cyclopteris fimbriata	7	3.7	0	0.0
Neuropteris cf. *flexuosa*	33	17.6	9	14.5
Macroneuropteris scheuchzeri	21	11.2	48	77.4
Odontopteris schlotheimii	28	14.9	0	0.0
Neuropterids and Cyclopterids UN	19	10.1	3	4.8
Marattialean foliage various	19	10.1	0	0.0
Crenulopteris lamuriana	10	5.3	1	1.6
Cordaites	27	14.4	3	4.8
Calamites - stems	2	1.1	0	0.0
Sphenopterid ferns	1	0.5	0	0.0
Reproductive organs misc	4	2.1	0	0.0
Axes	74	39.4	36	58.1
Roots	17	9.0	10	16.1
Comminuted plant debris	6	3.2	3	4.8
Clams	12	6.4	1	1.6
Total Quadrats Examined	206	208.0	66	235.3
Empty Quadrats	18		4	
Relevant Quadrats/Denominator	188		62	

relatively finer, dichotomize in one direction only, and follow a straight, non-anastomosing pathway, they are more likely to be cordaitalean leaves. But some cordaitalean leaves have sclerenchyma strands between the veins. Had leaf bases or apices been found in the Corinth Coal collections, the confusion would have been resolved, but we did not identify these diagnostic features in the Corinth Coal collections. As has been noted by many other authors, differentiating pteridosperm and fern axes from cordaitalean leaves is a problem that may, most often, lead to underestimation of the importance of the cordaitaleans. In any event, remains of this kind were a minor component of the assemblage from either collection site.

Roots

Fine roots often were found among the various kinds of remains (Fig. 17E, 18A), B). These roots almost always were distributed on a bedding surface, suggesting that they were transported into the environment of deposition and, thus, not reflective of in situ rooting. However, there were occasional specimens in which fine roots were distributed through some multi-centimeter thickness of sediment; of course, this still may reflect transport of piece of rooted soil. Roots of the kind illustrated most likely were produced by pteridosperms or calamitaleans, among the possible options, based on the macrofloras.

The specimen illustrated in Figure 18A is most interesting. We interpret it as a cordaitalean leaf that has been superimposed on a mass of fine roots, the latter lying on a bedding surface. It also is possible that the fine roots have penetrated between this leaf and other layers of litter. A pattern similar to this can be found in coal-balls rich in cordaitaleans where fine roots may penetrate on horizontal planes between leaves within cordaitalean leaf mats.

Animal Remains

The remains of microconchids were present in both collecting locations (Fig. 18E). These animals produce a small planispiral shell and are found most commonly in attachment to axes or broad leaves, such as those of cordaitaleans. They are presumed to have attached to plant debris floating in the water column or on the water's surface. There has been dispute over whether these animals indicate marine, brackish, or fresh water (Zatón et al., 2012), but the consensus appears to be fresh to possibly brackish. In addition to these tubeworms, the shells of small bivalves were found in close association with the plant remains (Fig. 18C, D).

Quantitative Analysis

Results of the frequency analysis of the two roof-shale floras are presented in Table 1. Pteridosperms dominate both collections. In the E & B collection, which is approximately three times larger than the Malone collection, *Neuropteris ovata* is the most frequently encountered taxon. This is followed by a neuropterid that may simply be an elongate-pinnule morphotype of *N. ovata*, or possibly either *N. flexuosa* or *N. vermicularis*. Although frequencies cannot be added together because of the possibility of cooccurrence on some of the same quadrats, these two *Neuropteris ovata*-form specimens together account for a sum of over 75% of the quadrat occurrences. In descending order, the other most frequently occurring taxa are *Odontopteris schlotheimii*, *Cordaites*, and *Macroneuropteris scheuchzeri*. In contrast, the Malone assemblage is dominated by *Macroneuropteris scheuchzeri*, identified on 77.4% of quadrats, with *Neuropteris ovata* also abundant at 51.6%, and the

TABLE 2. Quantitative analyses of the Corinth Coal palynofloras from the roof shale and coal. x=present but discovered in the slide scan rather than the specimen count.

Sample ID	**Coal E&B**	**Shale Malone**	**Shale E&B**
Crassispora kosankei	0.4		
Total Lycopsid Tree Spores	**0.4**	**0.0**	**0.0**
Endosporites globiformis	X	X	X
Total Small Lycopsid Spores	**0.0**	**0.0**	**0.0**
Punctatisporites minutus (small)	70.0	61.2	61.2
Punctatisporites minutus (large)	3.2	13.2	13.2
Punctatosporites obliquus	1.2	0.4	X
Apiculatisporites saetiger	2.0	1.2	2.0
Spinosporites exiguus	1.6	2.0	2.0
Laevigatosporites minimus	0.4	2.8	4.0
Cyclogranisporites minutus	1.6		
C. orbicularis	11.2	4.0	1.6
C. multigranus		X	0.4
Total Tree Fern Spores	**91.2**	**84.8**	**84.4**
Granulatisporites piroformis	X	X	X
G. granulatus	X	X	
G. parvus	X	X	X
G. adnatoides	X		
G. verrucosus	X	X	
G. minutus	X		X
Lophotriletes commissuralis	X	0.8	
Deltoidospora subadnatoides	0.8	0.4	
D. sphaerotriangulus			X
Punctatisporites punctatus	0.4		
P. parvipunctatus		1.2	X
Raistrickia grovensis	X		
Apiculatisporites spinulistratus	0.4	0.4	X
Camptotriletes bucculentus	0.4		
Verrucosisporites verrucosus			0.4
V. donarii			0.4
Convolutispora tessellata	0.8		
Total Small Fern Spores	**2.0**	**1.6**	**0.8**
Vesicaspora wilsonii	0.8	2.0	X
Schopfipollenites ellipsoides		0.8	X
Total Seed Fern Pollen	**0.8**	**2.8**	**0.0**
Calamospora breviradiata	X	1.2	
C. straminea	0.4	0.8	2.8
C. pedata	0.4	X	0.8
C. microrugosa	0.4		X
Laevigatosporites minor	1.2	2.4	3.2
Total Calamite Spores	**2.4**	**3.2**	**6.8**

Sample ID	Coal E&B	Shale Malone	Shale E&B
Florinites florini	2.4	4.8	6.8
F. mediapudens	0.4	X	
F. milotti	X	0.8	0.4
F.visendus			0.4
Total Cordaite Pollen	**2.8**	**5.6**	**7.6**
Triquitrites bransonii		X	X
T. subspinosus	X	0.8	0.4
T. exiguus	X		
Total Unknown Affinity	**0.0**	**0.8**	**0.4**

Sample Description	Sample ID	USNM ID	Company Name	Geographic Location
Corinth Coal	C1	38340	E & B	Illinois
Corinth Shale	C2	1993-4	Phoenix Malone Pit	Illinois
Corinth Shale	C3	38340	E & B	Illinois

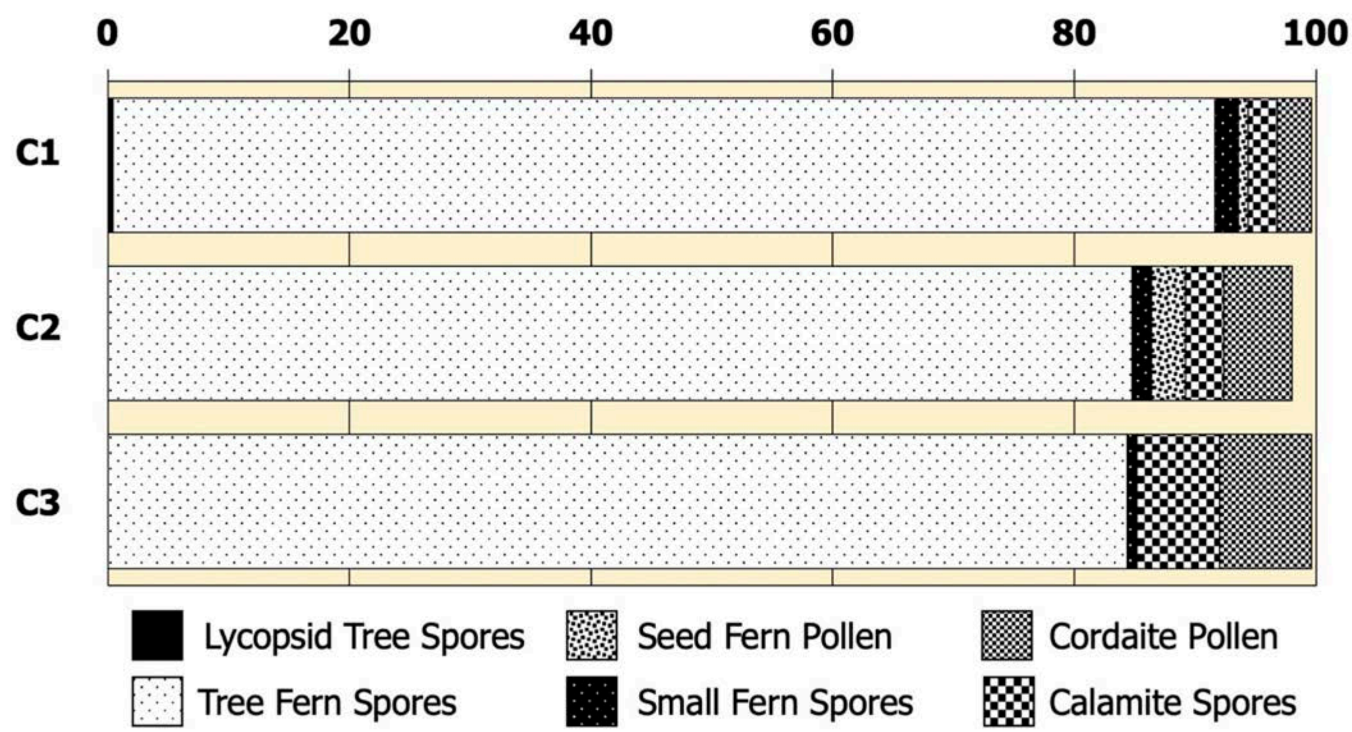


FIGURE 19. Quantitative results of palynological analyses: Corinth coal sample from the E&B Mine, Corinth roof-shale sample from the Phoenix Mine Malone Pit, and Corinth roof-shale sample from the E&B Mine.

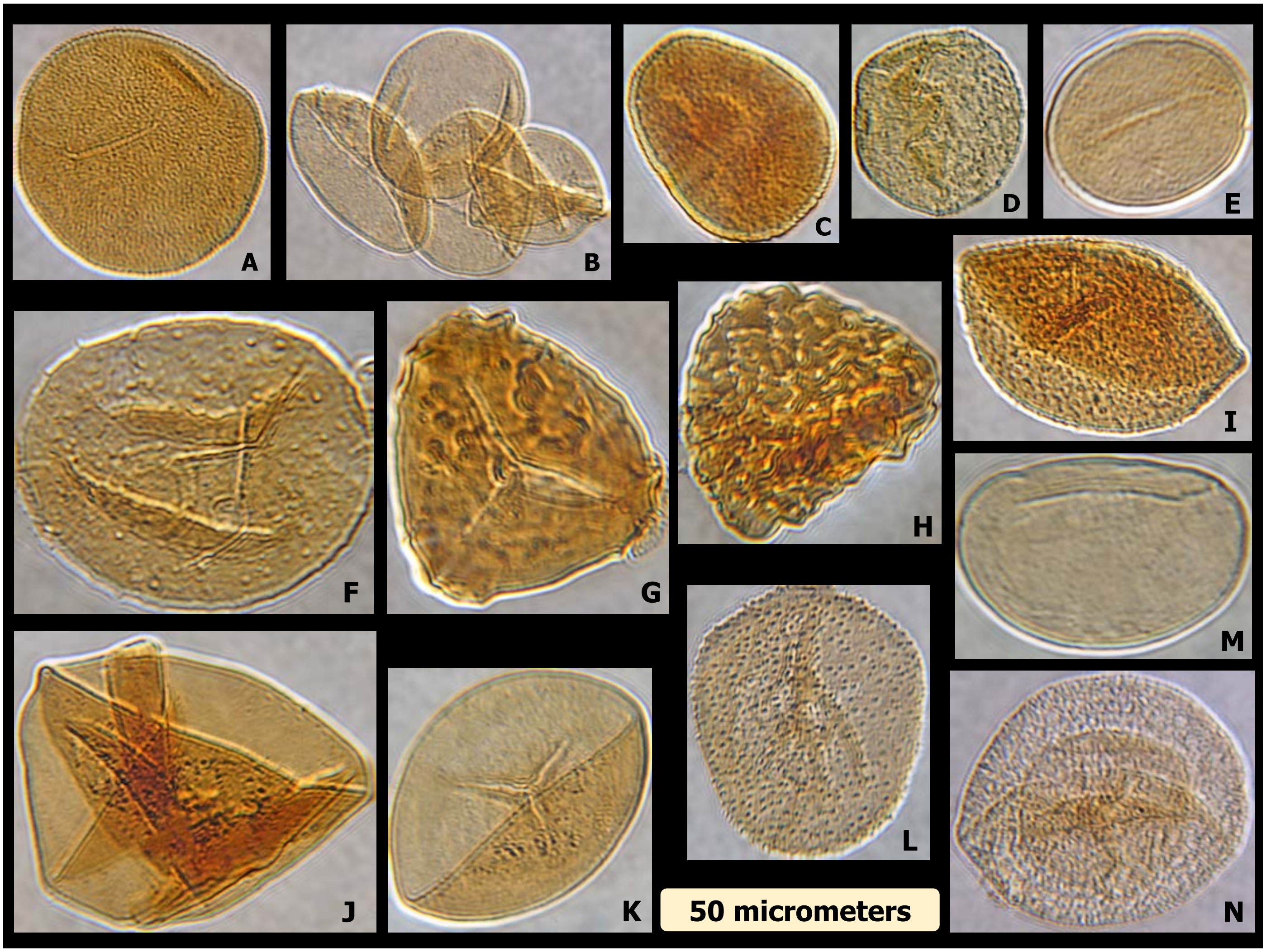


FIGURE 20. Spores and pollen in the Corinth coal bed. All images were acquired in white, transmitted light with Nomarski interference contrast illumination. **A,** *Cyclogranisporites orbicularis*. **B,** *Punctatisporites minutus* (multiple spores, large variety). **C,** *Punctatosporites obliquus*. **D.** *Apiculatisporites saetiger*. **E,** *Laevigatosporites minimus*. **F,** *Apiculatasporites spinulistratus*. **G,** *Triquitrites subspinosus*. **H,** *Microreticulatisporites hortonensis*. **I,** *Verrucosisporites donarii*. **J,** *Calamospora flexilis*. **K,** *Calamospora pedata*. **L,** *Crassispora kosankei*. **M,** *Laevigatosporites minor*. **N,** *Florinites mediapudens*. Scale bar at bottom applies to all palynomorph images.

Neuropteris with elongate pinnules at 14.5%. Marattialean tree-fern remains are notably rare in each collection, as are ground-cover plants such as small filicalean ferns, the sphenopsid *Sphenophyllum*, or various pteridosperms with sprawling habit, such as *Dicksonites* (Galtier and Béthoux, 2002).

PALYNOFLORAS – CORINTH COAL AND ROOF SHALE

Results of the palynological analyses are presented in Figures 19 - 22 and Table 2. The three Corinth coal and rock samples are numerically dominated by spores produced by tree ferns, comprising 84.4 to 91.2 % of the palynofloras (Fig. 1). These include *Punctatisporites minutus, P. obliquus, Laevigatosporites minimus, Apiculatisporites saetiger, Spinosporites exiguous, Cyclogranisporites orbicularis, C. minutus* and *C. multigranus. Punctatisporites minutus* occurs in two separate size ranges with small *P. minutus* (10 to 20 micrometers, aka. "buckshot spores") being more common than larger *P. minutus* (20 to 30 micrometers).

Small-fern spores are represented by several miospore genera, including *Granulatisporites, Lophotriletes, Deltoidospora, Verrucosisporites* and others. Although taxonomically diverse, they occur in minor amounts (0.8 to 2.0 %). Calamitalean spores are represented by species of *Calamospora* and *Laevigatosporites* and are also minor in abundance (2.4 to 6.8 %).

Lycopsid spores are represented only by *Crassispora*, produced by the lycopsid tree, *Sigillaria*. This type of spore was identified only in the coal sample.

Cordaitalean pollen, represented by *Florinites*, is consistently seen in minor amounts (2.8 to 7.6 %) and is more common in the two rock samples than in the coal. Likewise, seed-fern pollen, represented by *Vesicaspora* and *Schopfipollenites*), is also consistently seen in minor amounts (0.0 to 2.8 %).

ORGANIC PETROLOGY

On a mineral matter free basis, the Corinth coal consists of 58.8 % vitrinite, 17.6 % liptinite and 23.6 % inertinite (Figs. 23 - 26), markedly different from the thicker and more laterally extensive coals of the underlying Carbondale and Shelburn

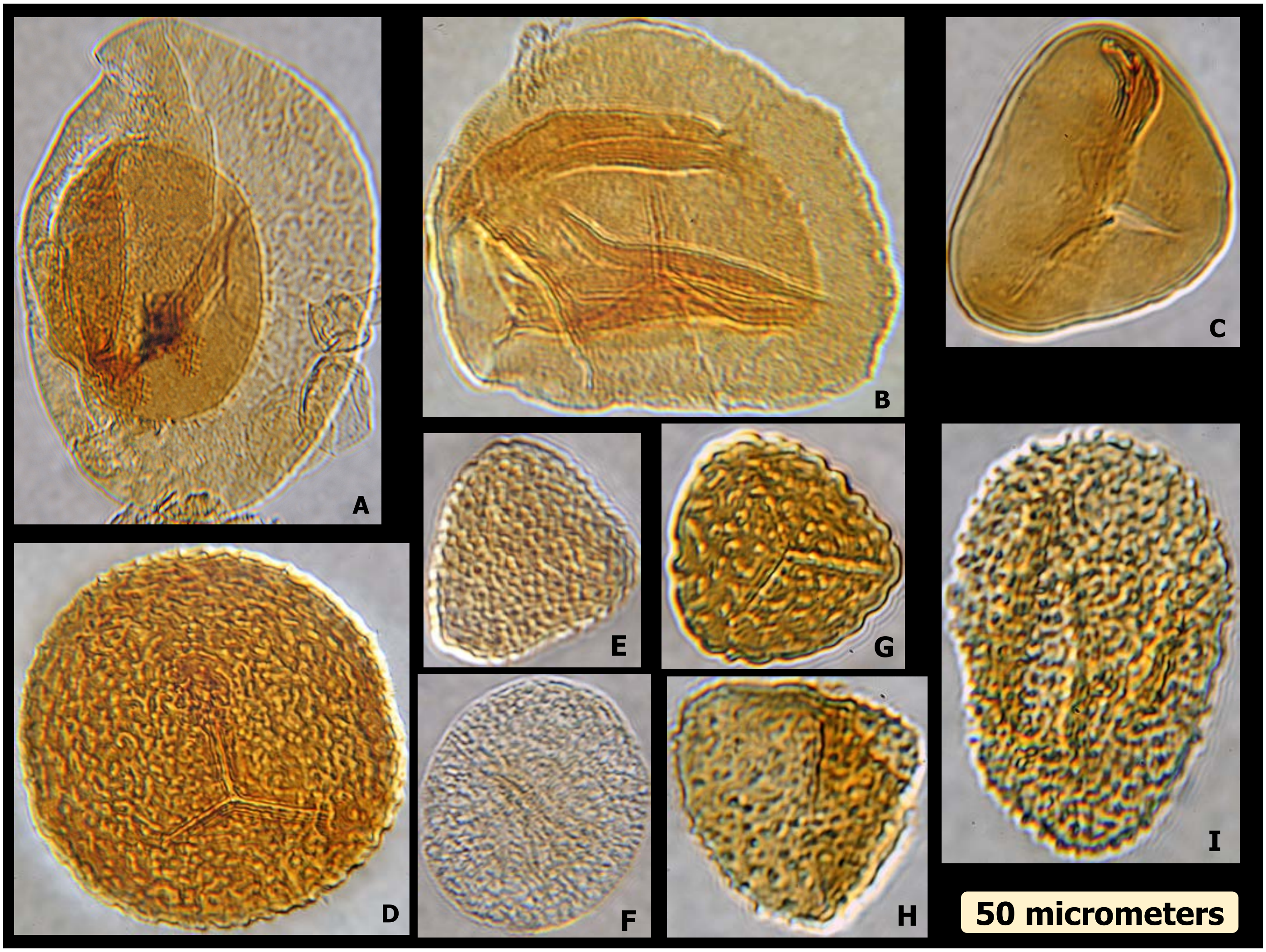


FIGURE 21. Spores and pollen in the Corinth coal bed. All images were acquired in white, transmitted light with Nomarski interference contrast illumination. **A,** *Florinites similis.* **B,** *Endosporites globiformis*. **C,** *Deltoidospora levis*. **D,** *Verrucosisporites sifati.* **E,** *Microreticulatisporites harrisonii*. **F,** *Florinites millotti*. **G,** *Microreticulatisporites nobilis*. **H,** *Lophotriletes microsaetosus.* **I,** *Verrucosisporites verrucosus.* Scale bar at bottom applies to all palynomorph images.

Formations that are uniformly dominated (typically >80 %) by vitrinite (Hower and Wild, 1981; 1982; Harvey and Dillon, 1985; Trinkle et al., 1983; Hower et al., 1990). A petrographic/palynologic study of Late Pennsylvanian coals in the western Kentucky portion of the Illinois Basin (Hower et al., 1994) found Missourian age coals assigned to the Patoka Formation to contain reduced amounts of vitrinite as well.

The reduced amount of vitrinite, and elevated amounts of liptinite and inertinite, in the Corinth coal may indicate an accelerated rate of botanical decay in the peat accumulating wetland that gave rise to the Corinth coal. An increased decay rate would preferentially diminish plant tissues that would become vitrinite. Liptinite macerals, by contrast, would effectively increase in abundance because of their natural resistance to decay.

The increased amount of inertinite in the Corinth coal may have a two-fold explanation. If inertinites were produced by fire (combustion), then they would be expected to increase at the expense of vitrinite (like liptinite macerals). However, they also may be the result of vitrinite decay, which is supported by the presence of macrinite and funginite (Fig. 4), two inertinite macerals that have been interpreted to be the result of botanical degradation (Hower et al., 2011).

DISCUSSION

There is a well documented change in coal-swamp floras between the Middle and Late Pennsylvanian based on both coal palynology (Phillips et al., 1974; Kosanke and Cecil, 1996; Peppers, 1997; Opluštil et al., 2022) and coal balls (Phillips et al., 1985). A similar change also has been documented in adpression floras from both Europe and the United States (Pfefferkorn and Thomson, 1982). The replacement of lycopsids by tree ferns in the swampiest settings, and the co-dominance of pteridosperms and tree ferns in coastal mudflat and floodplain habitats begins in all of these records in the Middle Pennsylvanian but proceeds to the Middle-Late Pennsylvanian boundary in a series of step-like changes (DiMichele et al., 2023). It is at the boundary that many species and genera of arboreous lycopsids disappear across west-central and western Pangea, and in much of the eastern parts of Euramerica as well.

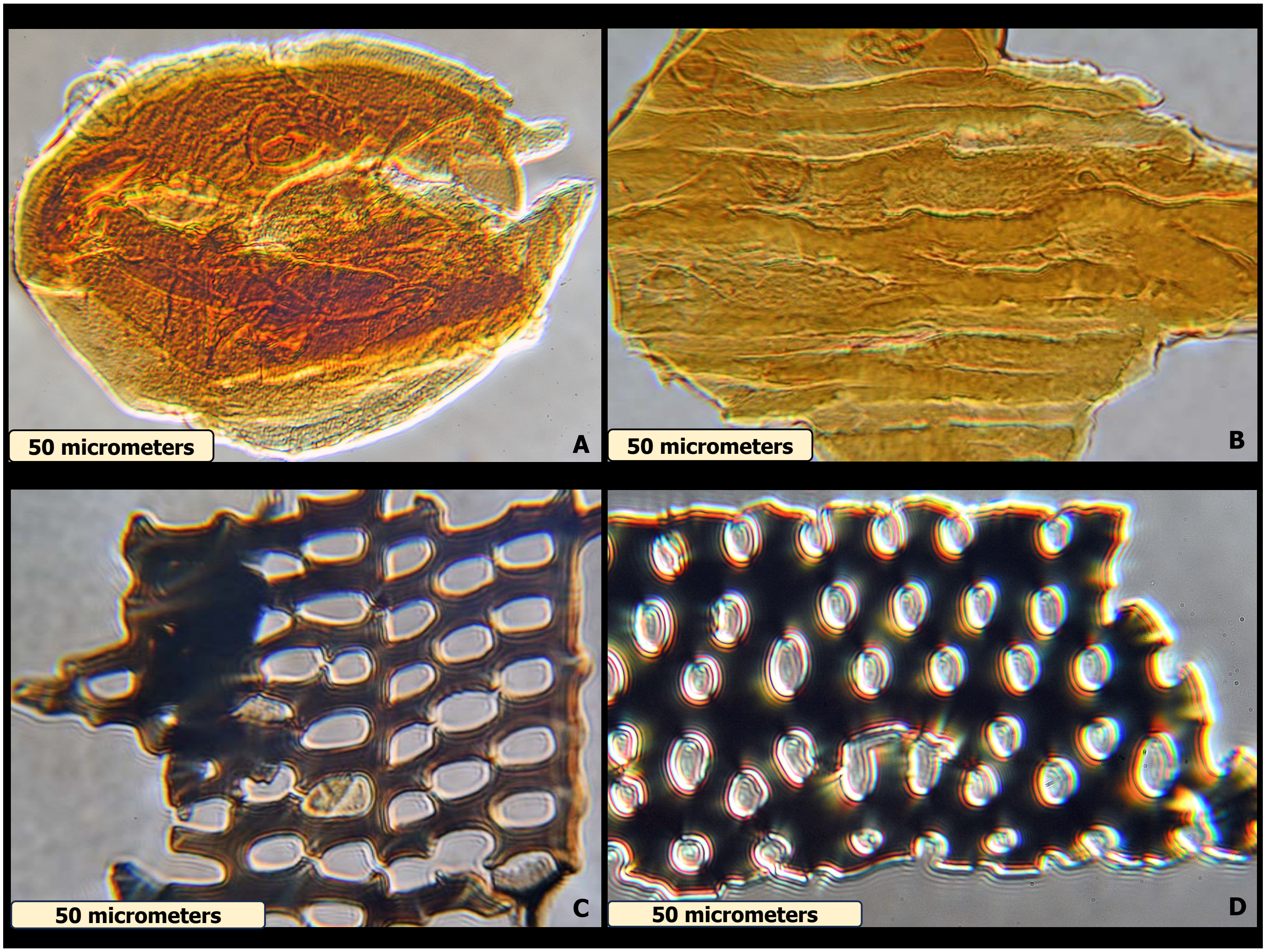


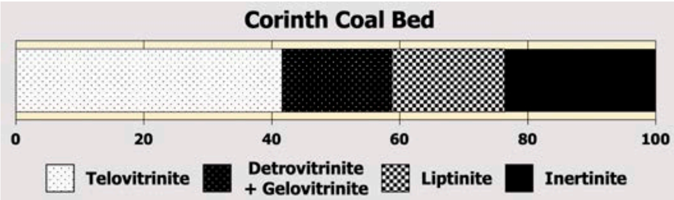
FIGURE 22. Corinth coal bed macerates. **A**, *Schopfipollenites ellipsoides*. **B,** Cuticle. **C,** Semi-opaque attritus, sclerenchyma or tracheidal. **D**, Opaque attritus, sclerenchyma or tracheidal. The taxonomic affinities of **B, C,** and **D** are unknown. Scale bars as indicated.

The Corinth Coal is one of the first coals to appear in the Missourian of the Illinois Basin. As such, it is of interest not only geologically but also because of the changes in the plants that made up coals of this period. The palynological studies of Peppers (e.g., 1996) indicate that there was considerable variation in palynomorph dominance-diversity composition from one coal to the next in the lower part of the Missourian. This suggests significant disruption of the ecological dynamics of wetland vegetation across this boundary, ultimately settling on marattialean tree-fern dominance in peat swamps (Phillips and Peppers, 1985) and a balanced dominance between pteridosperms and marattialean ferns in mineral substrate wetlands (Pfefferkorn and Thomson, 1982).

Macrofossil Paleobotany

The plant-fossil remains from the Corinth Coal roof shales are consistent with a Late Pennsylvanian, Missourian, age, as determined from the physical geology. They are not, however, restrictively diagnostic of that age. Given the low diversity of the flora and the broad geographic and stratigraphic ranges encompassed by the more securely identified taxa, a narrow stratigraphic position cannot be specified. The two most abundant taxa are *Neuropteris ovata* and *Macroneuropteris scheuchzeri*. The former might be rendered more diagnostic by cuticle preparation, that could reveal the subspecies and reflect more accurately on stratigraphic position (see comments above). *M. scheuchzeri*, however, terminates in Europe, on the eastern side of the Appalachian Mountains, in the “upper Cantabrian” according to Wagner and Álvarez-Vázquez (2010); in the United States, on the western side of that mountain range, *M. scheuchzeri* has been identified into the early Permian (Pfefferkorn, 2023), and occurs from the Appalachian basin into the western parts of the Pangean supercontinent (e.g., DiMichele et al., 2017a; Donovan et al., 2021). *Neuropteris ovata* displays a pattern similar to that of *M. scheuchzeri*, extending into the Permian in the USA (Pfefferkorn, 2023). The presence of *Odontopteris schlotheimii*, in some abundance at the E&B location, also is suggestive of an early Late Pennsylvanian age. This species, however, first appears in the late Middle Pennsylvanian (if *O. schlotheimii* and *O. cantabrica* are considered synonymous; Zodrow eet al., 2020; D'Angelo and Zodrow, 2022). Furthermore, although it may be distinct morphologically, the species is similar to others reported from the USA and Europe, in both the Middle and Late Pennsylvanian (*O. aequalis* from the Middle Pennsylvanian and *O. cantabrica* from the late Middle and early Late Pennsylvanian).

The ecological significance of the Corinth Coal roof-shale flora is its contrast with the Late Pennsylvanian floras reported



telinite	0.4
collotelinite	41.2
collodetrinite	16.0
vitrodetrinite	0.0
corpogelinite	0.0
gelinite	1.2
Total Vitrinite (mmf)	**58.8**
Telovitrinite (TV)	41.6
Detrovitrinite (DV) + Gelovitrinite (GV)	17.2
TV/DV +GV	2.4
sporinite	16.8
cutinite	0.0
resinite	0.0
alginite	0.0
exsudatinite	0.4
liptodetrinite	0.4
Total Liptinite (mmf)	**17.6**

fusinite	9.2
semifusinite	8.0
macrinite	1.2
micrinite	0.0
secretinite	0.8
funginite	0.8
inertodetrinite	3.6
Total Inertinite (mmf)	**23.6**
Average VRo random	0.62
Maximum VRo random	0.67
Minimum VRo random	0.57
Standard Deviation	0.03
Calculated VRo maximum*	0.64
Number of measurements	57

*calculated $VR_{o\ maximum} = (VR_{o\ random} * 1.09) - 0.034$ (ASTM D2798)

FIGURE 23. Distribution of macerals in the Corinth coal bed. Maceral abundance values are expressed as volume percent on a mineral matter free (mmf) basis. Vitrinite reflectance values are expressed as percent.

from the coals themselves, via studies of coal balls (Phillips and Peppers, 1984; Phillips et al., 1985; Willard and Phillips, 1993; DiMichele and Phillips, 1996; Willard et al., 2007) and palynomorphs (Phillips et a., 1974; Kosanke, 1988; Eble et al., 2006). Both of these records indicate clearly that the dominant elements of peat swamps were a diversity of marattialean tree ferns (Lesnikowska, 1989; Peppers, 1996). In contrast, the several Missourian-age roof shale floras we have examined from the Illinois Basin are almost uniformly dominated by pteridosperms in which marattialeans are a minor component or may even be entirely absent; the Corinth Coal flora is such an example. We have no immediate explanation for this pattern. It may be, as in the orthogonal transect described from the paleoriver channel margin several kilometers into the "swamp" (DiMichele et al., 2017b), that pteridosperms were concentrated in nearly monotypic stands in areas adjacent to the channel. The flora farther away showed first the appearance of marattialeans, and then arboreous lycopsids. Without information on a broader floral spatial distribution, which is no longer accessible because no mining currently is happening in this coal bed, we can only speculate on a similar pattern in the mudflats that developed above the Corinth Coal as sea level encroached.

The presence of plant fossils in gray shales that also contain animal fossils indicative of fresh to brackish water conditions is characteristic of macrofloras from a number of Middle

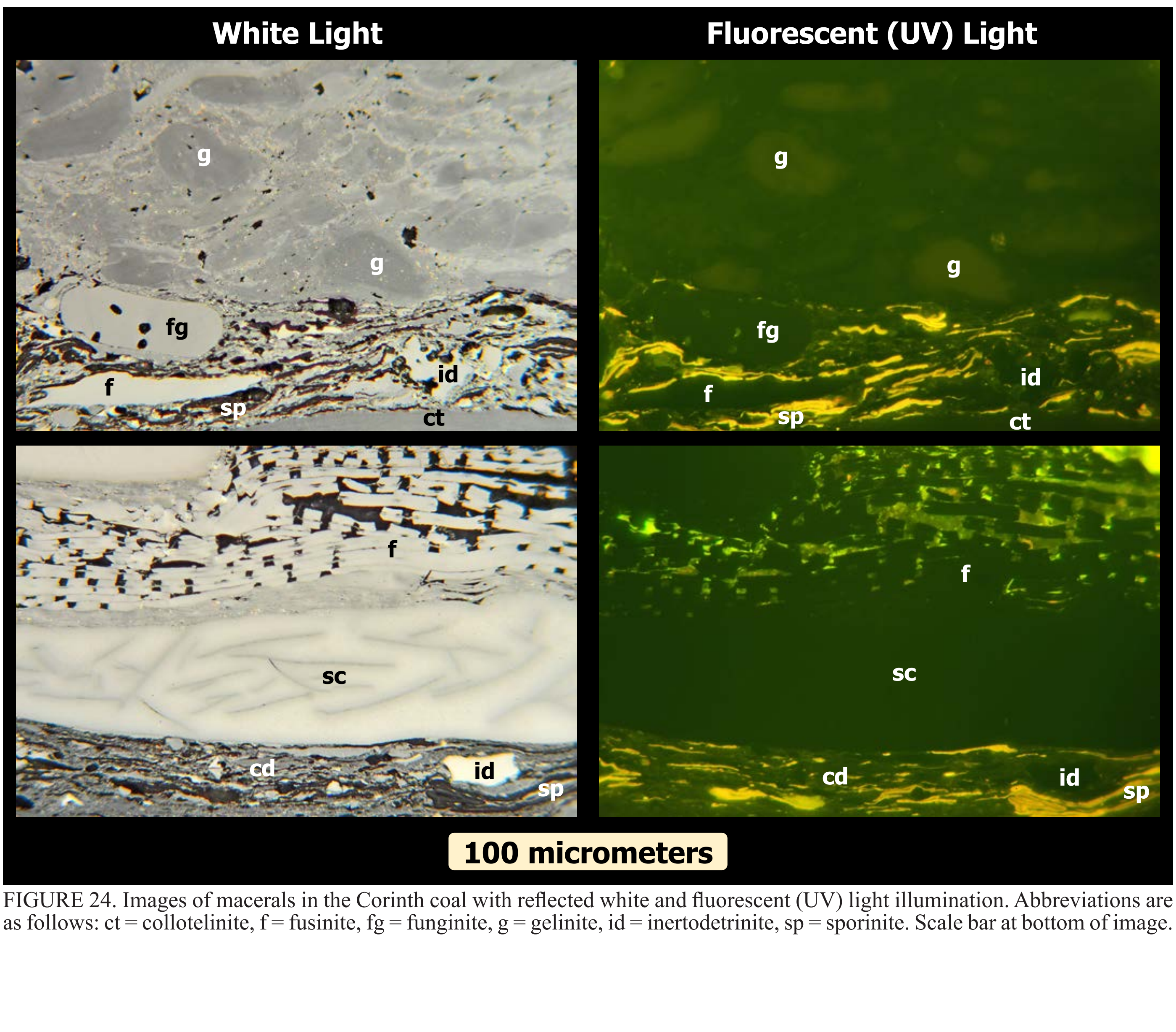


FIGURE 24. Images of macerals in the Corinth coal with reflected white and fluorescent (UV) light illumination. Abbreviations are as follows: ct = collotelinite, f = fusinite, fg = funginite, g = gelinite, id = inertodetrinite, sp = sporinite. Scale bar at bottom of image.

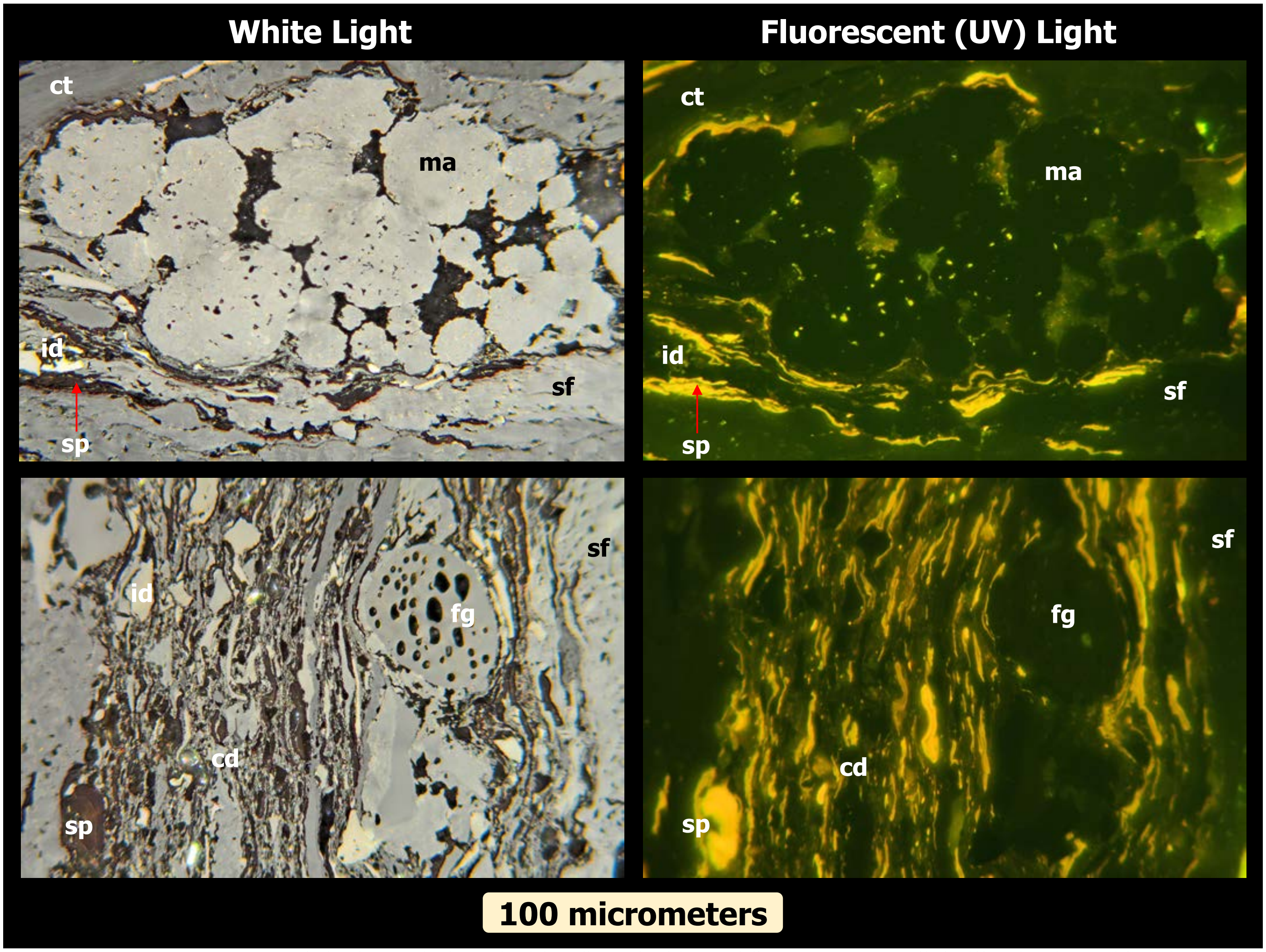


FIGURE 25. Images of macerals in the Corinth coal with reflected white and fluorescent (UV) light illumination. Abbreviations are as follows: ct = collotelinite, cd = collodetrinite, sf = semifusinite, fg = funginite, id = inertodetrinite, m = macrinite, sp = sporinite. Scale bar at bottom of image.

Pennsylvanian coals in areas flanking paleo-river channels (e.g., DiMichele et al., 2007; 2017b). Such channels have been considered to have formed during middle to late lowstand during the glacial phases of glacial-interglacial cycles and under humid climate conditions conducive to peat formation and preservation (Cecil et al., 2003). As peat accumulated such rivers were most likely black-water and were converted to estuaries as sea level rose. At the same time, a change from humid to subhumid climates resulted in the release of siliciclastics from up-river areas and the development of mudflats flanking the channel areas (Elrick et al., 2017; Nelson et al., 2020). As coastal drowning continued, the mudflats were buried and distinctive tidal sedimentology occurred in the areas flanking the now drowned rivers (e.g., Archer et al., 2016). The appropriateness of this sedimentary model to the roof shales of the Corinth Coal is questionable on two fronts. First, there are no river-channel deposits described from the horizon of the Corinth Coal in the study area. Second, at the time the plant-fossil collections were made, no mention was made in field notes of tidalite-type sedimentary features in the roof shales. Nonetheless, gray-shale roof strata are much less common than black, marine shales throughout the coal-measures of the Illinois Basin. The deposition of non-marine shales in lowland, coastal regions requires the transport of the sediment from inland, even if later driven landward by sea-level rise. Additionally, the presence of animals that reflect fresh-to-brackish water conditions is identical to the pattern seen in the better known Middle Pennsylvanian transitions from coal to gray roof shales (e.g., Nelson et al., 2020).

Palynology

All three palynological samples contain floras that warrant assignment to the *Punctatisporites minutus – Punctatosporites obliquus* (MO) miospore assemblage zone of the Illinois Basin (Peppers, 1985; 1996), which is early Late Pennsylvanian (Early Stephanian, Kasimovian) in age (Fig. 27). Late Pennsylvanian palynofloras in the Illinois and Appalachian Basins are typically dominated by tree fern spores (Eble et al., 2003, 2006, 2013). Other plant groups are represented, though typically in smaller amounts. Local variability, both temporally and spatially within individual coal beds, commonly occurs as increased percentages of *Endosporites,* the dispersed spore of the small lycopsid *Chaloneria* (Grady and Eble, 1990), and *Crassispora kosankei*, the dispersed spore of *Sigillaria* (Peppers, 1996). Although cordaitalean pollen (*Florinites*) also can be locally abundant, conifer pollen (e.g., *Pityosporites, Potonieisporites*) is rare.

R.A. Peppers, in his various internal ISGS reports on coal palynofloras, noted that of the Corinth Coal, at the time unnamed and undifferentiated, was more like the underlying Chapel Coal

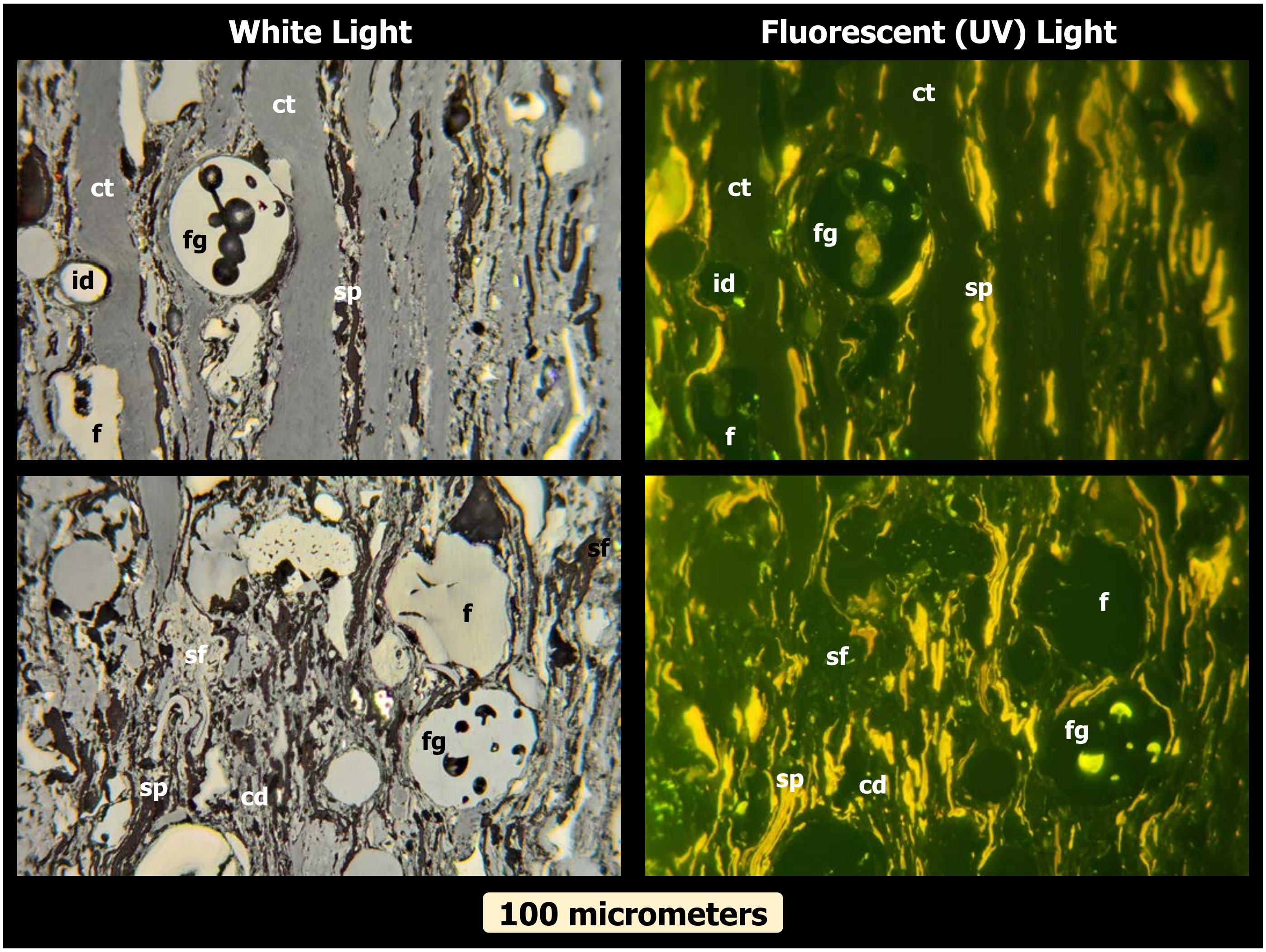


FIGURE 26. Images of macerals in the Corinth coal with reflected white and fluorescent (UV) light illumination. Abbreviations are as follows: ct = collotelinite, cd = collodetrinite, f = fusinite, sf = semifusinite, fg = funginite, id = inertodetrinite, sp = sporinite. Scale bar at bottom of image.

than to overlying Womac Coal. Unfortunately, to date, there are no coal balls reported from the Chapel, Corinth, or Womac coals to help interpret the significance of the palynofloral results. Differences in the palynoassemblages include abundance of the sigillarian lycopsid spore, *Crassispora*, in the Womac coal, which contains more of this spore than any other coal in the Illinois Basin. The Chapel Coal is characterized by the abundance of *Cyclogranisporites orbicularis* and distinctive taxa not present in the Womac Coal including *Verrucosisporites grandiverrucosus*, *Deltoidospora grandis*, *Indospora stewartii*, *Illinites unicus*, and *Vesicaspora wilsonii*. In comparison to these two better known coal palynofloras, the Corinth Coal is much more highly dominated by marattialean tree-fern spores than any other early Missourian/Kasimovian coal bed in the Illinois Basin.

Comparison of Macroflora and Palynoflora

In the shale samples analyzed in this study, there is a sharp distinction between the macroflora, which is dominated by pteridosperms, particularly *Neuropteris ovata*, *Macroneuropteris scheuchzeri*, and *Odontopteris schlotheimii*, and the palynoflora, which is dominated by a diversity of marattialean tree-fern spores, particularly *Punctatisporites minutus* of the small form. In both the Peppers analysis and that reported here, the tree-fern spore *Cyclogranisporites orbicularis* is abundant.

Tree-fern macrofossils are minor components of the roof-shale floras in each of the two macrofossil collections. This suggests that tree-fern spores are likely overrepresented in these shales compared to their standing biomass in the parent floras. This is a finding supported by coal-ball analyses of Middle Pennsylvanian coals, wherein tree ferns are not the dominant plants on a quantitatively determined biomass basis (Willard, 1993) but where the palynomorphs are far more abundant, in relative terms, than tree-fern remains in the coal-ball macroflora. This is more difficult to assess when comparing Late Pennsylvanian coal balls with palynofloras (e.g. Willard and Phillips, 1993; Willard et al., 2006), because of the general dominance, sometimes extreme dominance, of marattialean tree ferns in both kinds of these younger assemblages (Phillips et al., 1974, 1985). In these cases, where tree-ferns dominate both the palynoflora and coal-ball flora, the relative over- or under-representation, even the direction of the vector, cannot be determined clearly.

The relationship between these two measures of floristic composition, dominance, and diversity has been assessed rarely in side-by-side analyses of Pennsylvanian floras preserved in siliciclastic rocks. There even are few such analyses for coal floras, comparing quantified coal ball assemblages directly to the adjacent coal bed. The analysis reported here suggests significant over-representation of marattialean tree ferns within

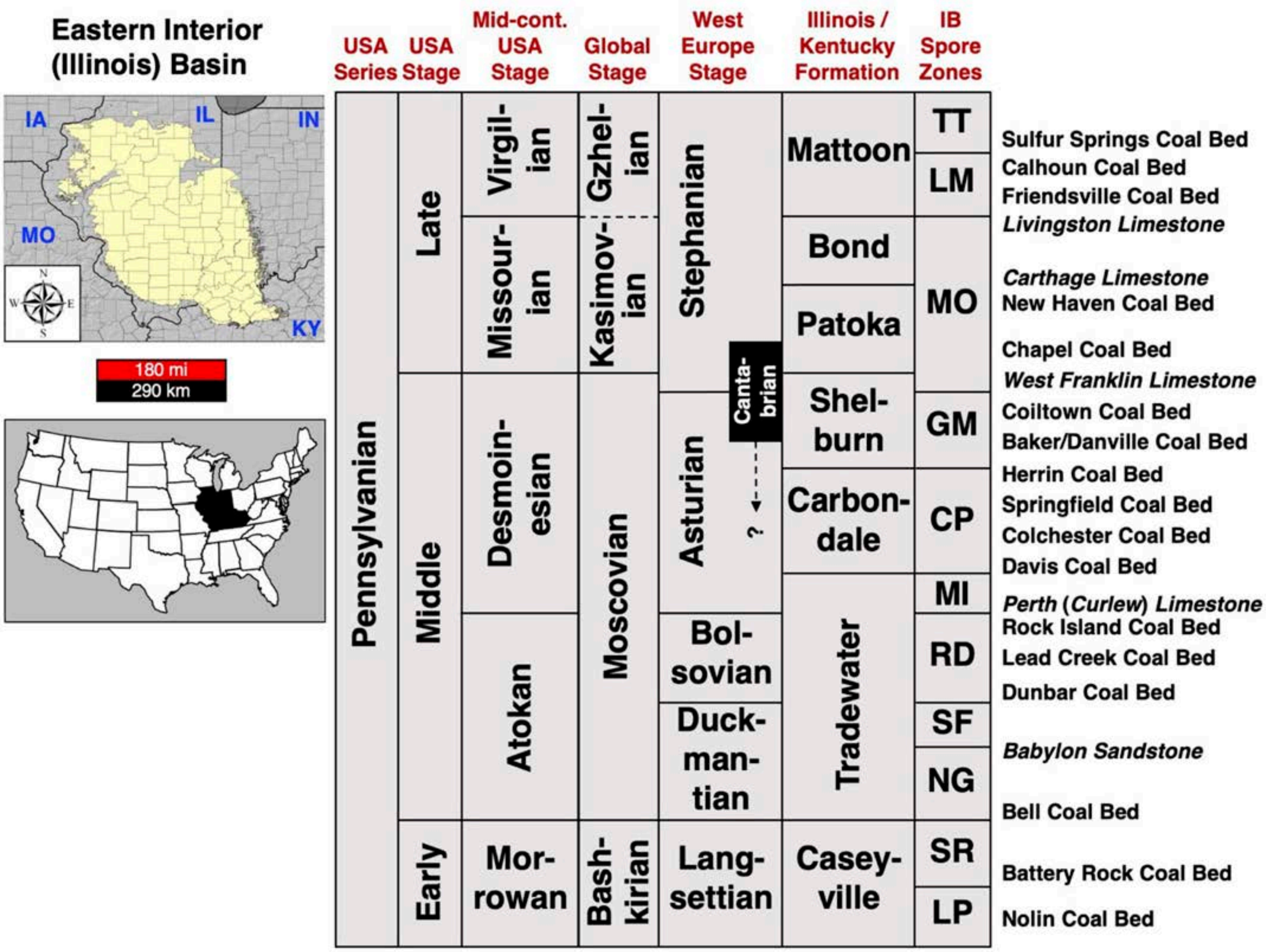


FIGURE 27. Stratigraphy of the Illinois Basin compared to other regional and global stratigraphic systems. The Corinth Coal lies in the MO Spore Zone, within the Patoka Formation, above the Chapel Coal. Extent of the Illinois Basin is shown in the upper left diagram. General location of the Illinois Basin is shown in the lower left panel; shading encompasses the U.S. states of Illinois, Indiana, and Kentucky.

environmental settings where those tree ferns are co-dominant or even minor elements of the vegetation. From a diversity perspective, however, the macroflora appears to be far less species diverse than indicated by the variety of spores in the palynoflora. This pattern suggests that there may be many rare species of marattialeans, present in low numbers, scattered within the standing vegetation. With the accumulation of such data it will be possible to develop a better understanding of these relationships.

DEDICATION

We dedicate this paper to our late friend and colleague Allen Archer, formerly of Kansas State University, with whom we enjoyed many years of collaborative work, and who greatly influenced our thinking on the environments of the Pennsylvanian-age lowlands.

ACKNOWLEDGMENTS

We thank Richard Winston and the late Tom Phillips for field assistance at the E&B company mine. The reviews of Debra Willard, Elizabeth Wilson, and Nathan Jud significantly improved the paper.

REFERENCES

Archer, A.W., Elrick, S.D., Nelson, W.J. and DiMichele, W.A., 2016, Cataclysmic burial of Pennsylvanian Period coal swamps in the Illinois Basin: Hypertidal sedimentation during Gondwanan glacial melt-water pulses. In: Tessier and Reynaud, J.-Y. (Eds.), Contributions to modern and ancient tidal sedimentology. Proceedings of the Tidalites 2012 Conference. International Association of Sedimentologists, Special Publication 48, 217–231.

ASTM International, 2021, ASTM D2798-21, Standard Test Method for Microscopical Determination of the Vitrinite Reflectance of Coal. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM International, 2023, ASTM D2799-23, Standard Test Method for Microscopical Determination of the Maceral Composition of Coal. ASTM International, West Conshohocken, PA, www.astm.org.

Balme, B.E., 1995, Fossil in situ spores and pollen grains: an annotated catalogue: Review of Palaeobotany and Palynology, v. 87, p. 81–323.

Bashforth, A.R. and Nelson, W.J., 2015, A Middle Pennsylvanian macrofloral assemblage from below the Rock Island (no. 1) Coal Member, Illinois: resolving the Bolsovian–Asturian boundary in the Illinois Basin: Review of Palaeobotany and Palynology, v. 222,

p. 67-83.

Cecil, C.B., 2003, The concept of autocyclic and allocyclic controls on sedimentation and stratigraphy, emphasizing the climatic variable. In: Cecil, C.B. and Edgar, N.T. (Eds.), Climate controls on stratigraphy: SEPM (Society for Sedimentary Geology) Special Publication 77, p. 13-20.

Cecil, C.B., Dulong, F.T., West, R.R., Stamm, R., Wardlaw, B. and Edgar, N.T., 2003, Climate controls on the stratigraphy of a Middle Pennsylvanian cyclothem in North America. In: Cecil, C.B. and Edgar, N.T. (Eds.), Climate controls on stratigraphy: SEPM (Society for Sedimentary Geology) Special Publication 77, p. 151–180.

Cleal, C.J. and Zodrow, E.L., 1989, Epidermal structure of some medullosan *Neuropteris* foliage from the Middle and Upper Carboniferous of Canada and Germany: Palaeontology, v. 32, p. 837-882.

Cleal, C.J., James, R.M. and Zodrow, E.L., 1999, Variation in stomatal density in the Late Carboniferous gymnosperm frond *Neuropteris ovata*: Palaios, v. 14, p. 180-185.

Crookall, R., 1976, Fossil plants of the Carboniferous rocks of Great Britain [Second Section]: Memoires of the Geological Survey of Great Britain, Palaeontology, v. 4, part 7, p. 841-1004.

D'Angelo, J.A. and Zodrow, E.L., 2022, Chemotaxonomic comparison of the seed ferns *Odontopteris cantabrica* and *Odontopteris schlotheimii*, Middle Pennsylvanian Sydney Coalfield, Canada: Lethaia, v. 55, p. 1-8.

DiMichele, W.A. and Phillips, T.L., 1996, Climate change, plant extinctions, and vegetational recovery during the Middle-Late Pennsylvanian transition: the case of tropical peat-forming environments in North America. In: Hart, M.L. (Ed.), Biotic Recovery from Mass Extinctions: Geological Society of London Special Publication 102, p. 201–221.

DiMichele, W.A., Phillips, T.L. and McBrinn, G.E., 1991, Quantitative analysis and paleoecology of the Secor coal and roof-shale floras (Middle Pennsylvanian, Oklahoma): Palaios, v. 6, p. 390-409.

DiMichele, W.A., Falcon-Lang, H.J., Nelson, W.J., Elrick, S.D. and Ames, P.R., 2007, Ecological gradients within a Pennsylvanian mire forest: Geology, v. 35, p. 415–418.

DiMichele, W.A., Lucas, S.G., Looy, C.V., Kerp, H. and Chaney, D.S., 2017a, Plant fossils from the Pennsylvanian–Permian transition in Western Pangea, Abo Pass, New Mexico: Smithsonian Contributions to Paleobiology 99, p. 1-40.

DiMichele, W.A., Elrick, S.D. and Nelson, W.J., 2017b, Vegetational zonation in a swamp forest, Middle Pennsylvanian, Illinois Basin, U.S.A., indicates niche differentiation in a wetland plant community: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 487, p. 71–92.

DiMichele, W.A., Bashforth, A.R., Falcon-Lang, H.J. and Lucas, S.G., 2020, Uplands, lowlands, and climate: Taphonomic megabiases and the apparent rise of a xeromorphic, drought-tolerant flora during the Pennsylvanian-Permian transition: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 559, 109965.

DiMichele, W.A., Eble, C.F., Pfefferkorn, H.W., Elrick, S.D., Nelson, W.J. and Lucas, S.G., 2023, Kasimovian floristic change in tropical wetlands and the Middle–Late Pennsylvanian Boundary Event: Geological Society, London, Special Publications, v. 535, p. 293-335.

Donovan, M.P., DiMichele, W.A., Lucas, S.G. and Schneider, J.W., 2021, Atlas of selected Kinney Quarry plant fossils, Late Pennsylvanian, Central New Mexico: New Mexico Museum of Natural History and Science Bulletin 84, p. 153-184.

Eble C.F., 2017, The use of glycol ethers to help reduce amorphous organic matter (AOM) in palynological preparations: Palynology, v. 41, p. 180–182.

Eble, C.F., Pierce, B.S., and Grady, W.C., 2003, Palynology, petrography and geochemistry of the Sewickley coal bed (Monongahela Group, Late Pennsylvanian), northern Appalachian Basin, USA: International Journal of Coal Geology, v. 55, p. 187-204.

Eble, C.F., Grady, W.C. and Pierce, B.S., 2006, Compositional characteristics and inferred origin of three Late Pennsylvanian coal beds from the Northern Appalachian Basin: Geological Society of America, Special Paper 399, p. 197-222.

Eble, C.F., Grady, W.C., and Blake, B.M., 2013, Dunkard Group coal beds: Palynology, coal petrography and geochemistry: International Journal of Coal Geology, v. 119, p. 32-40.

Elrick, S.D., Nelson, W.J., Ames, P.R. and DiMichele, W.A., 2017, Floras characteristic of Late Pennsylvanian peat swamps arose in the Late Middle Pennsylvanian: Stratigraphy, v. 14, p. 123-141.

Galtier, J. and Béthoux, O., 2002, Morphology and growth habit of *Dicksonites pluckenetii* from the Upper Carboniferous of Graissessac (France): Geobios, v. 35, p. 525-535.

Grady, W.C. and Eble, C.F., 1990, Relationships among macerals, miospores and paleoecology in a column of Redstone coal (Upper Pennsylvanian) from north-central West Virginia: International Journal of Coal Geology, v. 15, p. 1-26.

Harvey, R.D. and Dillon, J.W., 1985, Maceral distributions in Illinois coals and their paleoenvironmental implications: International Journal of Coal Geology, v. 5, p. 141-165.

Heckel, P.H., 2013, Pennsylvanian stratigraphy of Northern Midcontinent Shelf and biostratigraphic correlation of cyclothems: Stratigraphy, v. 10, nos. 1-2, p. 3-39.

Horton, D.E., Poulsen, C.J., Montañez, I.P. and DiMichele, W.A., 2012, Eccentricity-paced late Paleozoic climate change: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 331, p. 150-161.

Hower, J.C., Wild, G.D., Pollock, J.D., Trinkle, E.J., Bland, A.E. and Fiene, F.L., 1990, Petrography, geochemistry, and mineralogy of the Springfield (Western Kentucky No. 9) coal bed: Journal of Coal Quality, v. 9, p. 90-100.

Hower, J.C., Helfrich, C.T. and Williams, D.A., 1994, Palynologic and petrographic intervals in the Upper Pennsylvanian McLeansboro Group, Western Kentucky: International Journal of Coal Geology, v. 26, p. 117-126.

Hower, J.C., O'Keefe, J.M.K., Eble, C.F., Volk, T.J., Richardson, A.R., Satterwhite, A.B., Hatch, R.S. and Kostova, I.J., 2011, Notes on the origin of inertinite macerals in coals: Funginite associations with cutinite and suberinite: International Journal of Coal Geology, v. 85, p. 186-190.

International Committee for Coal and Organic Petrology (ICCP), 1998, The new Vitrinite classification (ICCP System, 1994): Fuel, v. 77, p. 349–358.

International Committee for Coal and Organic Petrology (ICCP), 2001, The new Inertinite classification (ICCP System, 1994): Fuel, v. 80, p. 459–471.

Joeckel, R.M., 1989, Geomorphology of a Pennsylvanian land surface; pedogenesis in the Rock Lake Shale Member, southeastern Nebraska: Journal of Sedimentary Research, v. 59, p. 469-481.

Joeckel, R.M., 1995, Upper Pennsylvanian paleosols in the Platte and Missouri valleys, Southeastern Nebraska; *in* Flowerday, C.A., Ed., Geological fieldtrips in Nebraska and adjacent parts of Kansas and South Dakota: Geological Society of America Guidebook 10, p. 121-135.

Kosanke. R M., 1988, Palynological analyses of Upper Pennsylvanian coal beds and adjacent strata of the proposed Pennsylvanian System stratotype in West Virginia: U.S. Geological Survey Professional Paper 1486, p. 1-24.

Kosanke, R.M. and Cecil, C.B., 1996, Late Pennsylvanian climate changes and palynomorph extinctions: Review of Palaeobotany and Palynology, v. 90, p. 113-140.

Laveine, J.P., 1986, The size of the frond in the genus *Alethopteris* Sternberg (Pteridospermopsida, Carboniferous): Geobios, v. 19, p. 49-59.

Laveine, J.P. and Belhis, A., 2007, Frond architecture of the seed-fern *Macroneuropteris scheuchzeri*, based on Pennsylvanian specimens from the Northern France coal field: Palaeontographica Abteilung B, v. 277, p. 1-41.

Laveine, J.P. and Oudoire, T., 2015, Partial alopecia for the Permo-Pennsylvanian seed-fern *Macroneuropteris scheuchzeri*: Review of Palaeobotany and Palynology, v. 216, p. 132-142.

Lesnikowska, A.D., 1989, Anatomically preserved Marattiales from coal swamps of the Desmoinesian and Missourian of the Midcontinent United States: Systematics, ecology and evolution: Ph.D. Thesis, University of Illinois, Champaign-Urbana, Illinois. 227 p.

Lucas, S.G., DiMichele, W.A., Krainer, K., Barrick, J.E., Vachard, D., Donovan, M.P., Looy, C., Kerp, H. and Chaney, D.S., 2021, The Pennsylvanian System in the Sacramento Mountains, New Mexico, USA: Stratigraphy, petrography, depositional systems, paleontology, biostratigraphy, and geologic history: Smithsonian Contributions to Paleobiology 104, p. 1-215.

Luthardt, L., Galtier, J., Meyer-Berthaud, B., Mencl, V. and Rößler, R., 2021, Medullosan seed ferns of seasonally-dry habitats: old and new perspectives on enigmatic elements of Late Pennsylvanian–early Permian intramontane basinal vegetation: Review of Palaeobotany and Palynology, v. 288, 104400.

Myers, A.R. and Obrad, J.M., 2012 (revised), Directory of coal mines in Illinois, 7.5-minute quadrangle series, Harco quadrangle, Williamson and Saline Counties: 32 p. and 3 maps, scale 1:24,000.

Montañez, I.P., McElwain, J.C., Poulsen, C.J., White, J.D., DiMichele, W.A., Wilson, J.P., Griggs, G. and Hren, M.T., 2016, Climate, $p\mathrm{CO}_2$ and terrestrial carbon cycle linkages during late Palaeozoic glacial-interglacial cycles: Nature Geoscience, v. 9, p. 824-828.

Nance, R.B. and C.G. Treworgy, 1981, Strippable coal resources of Illinois, Part 8, central and southeastern counties: Illinois State Geological Survey Circular 515, 32 p.

Nelson, W.J., 1993, The "Malone coal", northeastern Williamson and southeastern Franklin Counties, Illinois: Unpublished manuscript, Illinois State Geological Survey, 7 p.

Nelson, W.J., 2007, Bedrock geology of Pittsburg quadrangle, Williamson and Franklin Counties, Illinois: Illinois State Geological Survey, Illinois Geologic Quadrangle Map IGQ Pittsburg-BG, 2 sheets, map scale 1:24,000.

Nelson, W.J. and Denny, F.B., 2015, Bedrock geology of Harco quadrangle, Saline, Williamson, and Franklin Counties, Illinois: Illinois State Geological Survey STATEMAP Harco-BG, 2 sheets, map scale 1:24,000.

Nelson, W.J., Elrick, S.D., DiMichele, W.A. and Ames, P.R., 2020, Evolution of a peat-contemporaneous channel: The Galatia Channel, Middle Pennsylvanian, of the Illinois Basin: Illinois State Geological Survey Circular 605, 85 p.

Nelson, W.J., Heckel, P.H. and Obrad, J.M., 2023, Pennsylvanian Subsystem in Illinois, Patoka Formation: Illinois State Geological Survey, https://ilstratwiki.web.illinois.edu/index.php/Main_Page

Opluštil, S., Cleal, C.J., Wang, J. and Wan, M., 2022, Carboniferous macrofloral biostratigraphy: an overview: Geological Society, London, Special Publications, v. 512, p. 813-863.

Peppers, R.A., 1985, Comparison of miospore assemblages in the Pennsylvanian System of the Illinois Basin with those in the Upper Carboniferous of western Europe: Compte Rendu Ninth International Congress of Carboniferous Stratigraphy and Geology, v. 2, p. 483–502.

Peppers, R.A., 1996, Palynological correlation of major Pennsylvanian (Middle and Upper Carboniferous) chronostratigraphic boundaries in the Illinois and other coal basins: Geological Society of America Memoir 188, 111 p.

Peppers, R.A., 1997, Palynology of the Lost Branch Formation of Kansas—new insights on the major floral transition at the Middle-Upper Pennsylvanian boundary: Review of Palaeobotany and Palynology, v. 98, p. 223-246.

Pfefferkorn, H.W., 2023, Pennsylvanian-age plant macrofossil biostratigraphy in tropical Pangaea: uniformitarianism, catastrophes and the 'Cantabrian' problem: Geological Society, London, Special Publications, v. 535, p. 91-100.

Pfefferkorn, H.W. and Thomson, M.C., 1982, Changes in dominance patterns in Upper Carboniferous plant-fossil assemblages: Geology, v. 10, p. 641-644.

Phillips, T.L. and Peppers, R.A., 1984, Changing patterns of Pennsylvanian coal-swamp vegetation and implications of climatic control on coal occurrence: International Journal of Coal Geology, v. 3, p. 205–255.

Phillips, T.L., Peppers, R.A., Avcin, M.J. and Laughnan, P.F., 1974, Fossil plants and coal: patterns of change in Pennsylvanian coal swamps of the Illinois Basin: Science, v. 184, p. 1367-1369.

Phillips, T.L., Peppers, R.A. and DiMichele, W.A., 1985, Stratigraphic and interregional changes in Pennsylvanian coal-swamp vegetation: environmental inferences: International Journal of Coal Geology, v. 5, p. 43–109.

Pickel, W., Kus, J., Flores, D., Kalaizidis, S., Christanis, K., Cardott, B.J., Misz-Kennan, M., Rodrigues, S., Hentschel., A., Hamor-Vido, M., Crosdale, P. and Wagner, N., ICCP, 2017. Classification of liptinite – ICCP System 1994: International Journal of Coal Geology, v. 169, p. 40–61.

Ravn, R.L., 1986, Palynostratigraphy of the Lower and Middle Pennsylvanian coals of Iowa: Iowa Geological Survey Technical Paper 7, 245 p.

Rosenau, N.A., Tabor, N.J., Elrick, S.D. and Nelson, W.J., 2013, Polygenetic history of paleosols in Middle–Upper Pennsylvanian cyclothems of the Illinois Basin, USA: Part II. Integrating geomorphology, climate, and glacioeustasy: Journal of Sedimentary Research, v. 83, p. 637-668.

Šimůnek, Z., 2018, Cuticular analysis of new Westphalian and Stephanian *Cordaites* species from the USA: Review of Palaeobotany and Palynology, v. 253, p. 1-14.

Šimůnek, Z. and Cleal, C.J., 2020, The systematic and palaeoecological significance of *Neuropteris ovata* (Medullosales) cuticles from the Stephanian Stage of the Puertollano Basin, Spain: Spanish Journal of Palaeontology, v. 31, p. 231-243.

Šimůnek, Z. and Cleal, C.J., 2022, The last laveineopterid–The systematic and floristic relationships of *Laveineopteris nervosa* (Medullosales) from the Stephanian of the Czech Republic: Review of Palaeobotany and Palynology, v. 304, 104703.

Stull, G., DiMichele, W.A., Falcon-Lang, H.J., Nelson, W.J. and Elrick, S., 2012, Palaeoecology of *Macroneuropteris scheuchzeri*, and its implications for resolving the paradox of 'xeromorphic' plants in Pennsylvanian wetlands: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 331–332, p. 162–176.

Traverse, A., 1988, Paleopalynology: Unwin Hyman, Ltd., London, 600 p.

Trinkle, E.J., Hower, J.C. and Wild, G.D., 1983, Petrography of the Paradise (No. 12), Baker (No. 13), and Coiltown (No. 14) coals of the lower portion of the Sturgis Formation (Pennsylvanian) in western Kentucky: Geological Society of America Bulletin, v. 94, p. 1466-1474.

Wagner, R. H. & Álvarez-Vázquez, C., 2010, The Carboniferous floras of the Iberian Peninsula: a synthesis with geological connotations: Review of Palaeobotany and Palynology, v. 162, p. 239-324.

Wagner, R.H. and Álvarez-Vázquez, C., 2016, A reappraisal of *Pecopteris miltonii* (Artis) Brongniart, a mid-Westphalian (Early–Mid Pennsylvanian) fern: Proceedings of the Yorkshire Geological Society, v. 61, p. 37-53.

Willard, D.A., 1993, Vegetational patterns in the Springfield Coal (Middle Pennsylvanian, Illinois Basin): Comparison of miospore and coal-ball records: Geological Society of America Special Paper 286, p. 139-152.

Willard, D.A. and Phillips, T.L., 1993, Paleobotany and Palynology of the Bristol Hill Coal Member (Bond Formation) and Friendsville Coal Member (Mattoon Formation) of the Illinois Basin (Upper Pennsylvanian): Palaios, v. 8, p. 574-586.

Willard, D.A., Phillips, T.L., Lesnikowska, A.D. and DiMichele, W.A., 2006, Paleoecology of the Late Pennsylvanian-age Calhoun coal bed and implications for long-term dynamics of wetland ecosystems: International Journal of Coal Geology, v. 6, p. 21-54.

Wittry, J., Glasspool, I.J., Béthoux, O., Koll, R. and Cleal, C.J., 2015, A revision of the Pennsylvanian marattialean fern *Lobatopteris vestita* auct. and related species: Journal of Systematic Palaeontology, v. 13, p. 615-643.

Zatón, M., Vinn, O. and Tomescu, A.M.F., 2012, Invasion of freshwater and variable marginal marine habitats by microconchid tubeworms – an evolutionary perspective: Geobios, v. 45, p. 603-610.

Zodrow, E.L., 2014, Molecular self-assembly: Hypothesized for "hair" of *Macroneuropteris scheuchzeri* (Pennsylvanian-age seed-fern): International Journal of Coal Geology, v. 121, p. 14-18.

Zodrow, E.L. and Cleal, C.J., 1988, The structure of the Carboniferous pteridosperm frond *Neuropteris ovata* Hoffmann: Palaeontographica, v. 208B, p. 105-124.

Zodrow, E.L., Amelang, A., Costanza, S.H. and D'Angelo, J.A., 2020, Complex trichomes associated with foliar *Odontopteris schlotheimii* Brongniart, Manebach type locality, Germany: Implication for taxonomy: International Journal of Coal Geology, v. 219, 103340.