A MIDDLE PENNSYLVANIAN MACROFLORAL ASSEMBLAGE FROM BELOW THE
ROCK ISLAND (NO. 1) COAL MEMBER, ILLINOIS: RESOLVING THE BOLSOVIAN–
ASTURIAN BOUNDARY IN THE ILLINOIS BASIN

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ABSTRACT

A taxonomic, quantitative, and biostratigraphic analysis is presented for a macrofloral assemblage collected from below the Rock Island (No. 1) Coal Member at the historical Friendship Farm locality in Rock Island County, on the northwestern margin of the Illinois Basin. The Middle Pennsylvanian (middle Moscovian) fossiliferous strata involve the middle Tradewater Formation, and are situated a short distance below the Atokan–Desmoinesian Stage boundary as defined by marine microfossils and palynology. The assemblage of 14 fossil-taxa is overwhelmingly dominated by pteridosperms, including *Laveineopteris rarinervis*, *Neuropteris flexuosa*, *Alethopteris serlii*, *Macroneuropteris scheuchzeri*, and *Mariopteris nervosa*, whereas lycopsids, sphenopsids, and ferns are comparatively rare. Homotaxial comparison with the macrofloral biozonation scheme established in Europe indicates an Asturian age for the assemblage, in all likelihood early Asturian (*Linopteris obliqua* Biozone). Similar comparisons with range limits documented in the Appalachian Basin yield a more ambiguous age, but an early Asturian age is equally probable. These findings indicate that the Bolsovian–Asturian Substage boundary of western Europe lies below the Atokan–Desmoinesian Stage boundary in the Illinois Basin, boundaries that have traditionally been correlated by palynology. The Middle Pennsylvanian interval near these boundaries is being increasingly recognized as one of significant environmental change, reflected in marked lithological and biological modifications throughout tropical Euramerica. However, the fact that the Bolsovian–Asturian and Atokan–Desmoinesian boundaries are not synchronous, albeit being broadly equivalent, suggests that the environmental perturbation was a protracted event that may have had global consequences.

KEYWORDS: Bolsovian; Asturian; Atokan; Desmoinesian; macroflora; biostratigraphy

1. INTRODUCTION

1.1 General remarks

Floristic analyses of American coals have revealed a prominent shift in dominance-diversity patterns in tropical wetland vegetation at the Middle–Late Pennsylvanian (Moscovian–Kasimovian) boundary, highlighted by a sharp decline in lycopsids and a coincident influx of tree ferns in peat-forming environments (Phillips et al., 1974, 1985; Phillips and Peppers, 1984; DiMichele et al., 2001). The floral changeover has been interpreted as a threshold-type ecosystem response (DiMichele and Phillips, 1996; DiMichele et al., 2009) to the overall warming and drying trend that affected equatorial Euramerica through the Pennsylvanian (Cecil et al., 1985; DiMichele et al., 2006; Roscher and Schneider, 2006; Peyser and Poulsen, 2008; Tabor and Poulsen, 2008; Tabor et al., 2013). However, this major reorganization of the wetland biome was presaged by more subtle changes that occurred close to the earlier Atokan–Desmoinesian Stage boundary and the broadly coeval Bolsovian–Asturian (ex Westphalian C–D) Substage boundary of western Europe, an event that is more poorly constrained but may have had equal significance as a portent to the Middle–Late Pennsylvanian restructuring.

Evidence for changing environmental conditions during the Middle Pennsylvanian near the Atokan–Desmoinesian and Bolsovian–Asturian boundaries includes: (i) perturbations in floristic patterns in both peat- and clastic-substrate wetland habitats, particularly the gradual rise of tree ferns and cordaitaleans at the expense of lycopsids and pteridosperms (Pfefferkorn and Thomson, 1982; Phillips and Peppers, 1984; Phillips et al., 1985; Cleal, 2007; Opluštil and Cleal, 2007; Cleal et al., 2009, 2012; van Hoof et al., 2013); (ii) increased sulfates and carbonates in coal-bearing strata (Cecil et al., 1985); (iii) a morphological shift in peat-forming mires from predominantly domed to planar and a corresponding increase in the ash and sulfur content of coals (Cecil et al., 1985; Greb et al., 2002; Neuzil et al., 2005); and (iv)

76 a change in the petrology and diagenetic history of fluvial sandstones (Bertier et al., 2008).

77 Fundamental questions remain about the mechanisms that caused these biotic and abiotic

78 responses in equatorial regions during the Middle Pennsylvanian. Records of southern-

79 hemisphere glaciation (Fielding et al., 2008) and global sea level (Ross and Ross, 1987;

80 Rygel et al., 2008; Eros et al., 2012) point to a marked decline in the volume of grounded ice

81 around this time, and attendant climatic adjustments may be the proximate driver of the

82 inferred environmental changes. Likewise, the duration and degree of synchrony of the

83 Middle Pennsylvanian event over tropical Euramerica have yet to be resolved, in part due to

84 the challenge of correlating largely terrestrial strata over such a vast area. One outstanding

85 question is whether the Atokan–Desmoinesian boundary of central and western USA

86 correlates with the Bolsovian–Asturian boundary of western Europe. Although interpreted as

87 equivalent based on palynological analyses of American coals (Peppers, 1996) and

88 homotaxial comparisons of macrofloral assemblages in the Appalachian Basin (Blake et al.,

89 2002), these chronostratigraphic boundaries were defined on fundamentally different grounds

90 and in widely separated areas. As such, exact coincidence is improbable; the boundaries

91 clearly are close, but just how close?

92 Bashforth et al. (in press) shed some light on this issue through a biostratigraphic

93 analysis of microfloral and macrofloral assemblages from the Minshall Coal Member and

94 overlying roof-shales at a locality in west-central Indiana (Clay County), on the eastern

95 margin of the Illinois Basin (Figs. 1.2, 2). Applying the biostratigraphic framework of

96 Peppers (1996) for this site, the Atokan–Desmoinesian and Bolsovian–Asturian boundaries

97 lie above the Minshall Coal at the top of the overlying Perth Limestone Member. However,

98 comparisons with macrofloral biozonation schemes indicate an early Asturian age for roof-

99 shales of the Minshall Coal, pointing to incongruence between the Atokan–Desmoinesian and

100 Bolsovian–Asturian boundaries. Accordingly, Bashforth et al. (in press, figs. 7.4, 7.5)

suggested that the boundaries might be decoupled, and proposed that the Atokan–Desmoinesian boundary could remain at the top of the Perth Limestone, but that the Bolsovian–Asturian boundary be lowered to a level at or below the Minshall Coal (Fig. 2). Under this scenario, uppermost Atokan strata in the Illinois Basin would correlate with the lowermost Asturian of western Europe.

1.2 Study objectives

This contribution further explores whether the Bolsovian–Asturian boundary lies below the Rock Island (No. 1) Coal Member, a correlate of the Minshall Coal (Fig. 2; Nelson et al., 2013), in the Illinois Basin. The paper illustrates and presents a quantitative and biostratigraphic analysis of an unpublished macrofloral assemblage collected in the 20th century from below the Rock Island Coal at a locality in Rock Island County, near Quad Cities, Illinois/Iowa, on the northwestern margin of the Illinois Basin (Figs. 1.2, 3.1). The locality, historically termed ‘Friendship Farm’ in field notes held by the Illinois State Geological Survey (ISGS), is significant because it played a leading role in Peppers’ (1996) placement of the Bolsovian–Asturian boundary in the Illinois Basin. To précis, Bode (1958, p. 230) identified *Neuropteris ovata* Hoffmann, 1826a, b in the assemblage, a taxon that is considered a key indicator of the Asturian in western Europe (see Section 2.2). Peppers (1996, p. 62) assumed the collected horizon to “...refer to the shale between the [Rock Island] coal and overlying [Seville] limestone or to clastic rocks in approximately the same position as the coal.” Arguing that “...*N. ovata* probably did not appear at exactly the same time in Europe as it did in the Illinois Basin...”, combined with palynological evidence for a Bolsovian age for the Rock Island Coal, Peppers (1996) placed the Bolsovian–Asturian boundary at the top of the Seville Limestone Member. Nonetheless, Bode (1958) and ISGS field notes indicate that the macrofloral assemblage was collected from *below* the rooted

paleosol of the Rock Island Coal. This revelation withdraws a key piece of evidence from Peppers' (1996) argument for correlation of the Atokan–Desmoinesian and Bolsovian–Asturian boundaries in the Illinois Basin, and supports the proposal of Bashforth et al. (in press) that the Bolsovian–Asturian boundary may lie below the correlative Rock Island Coal (Illinois), Minshall Coal (Indiana), and Empire coal bed (Kentucky). A reexamination of this historical collection was undertaken to identify and quantify the plant fossils, and to place the fossiliferous strata into biostratigraphic context based on comparisons with established macrofloral biozonation schemes in the USA and western Europe.

2. HISTORY OF STRATIGRAPHIC CONCEPTS

2.1 Atokan–Desmoinesian boundary

Like many North American provincial chronostratigraphic units, the Atokan and Desmoinesian stages evolved from lithostratigraphic units. Taff and Adams (1900, p. 273–274) gave the name “Atoka formation” to an ≈ 2000 m thick sandstone and shale succession near Atoka in southeastern Oklahoma. These rocks straddle the transition from passive margin (Ozark shelf) to deep oceanic trough (Arkoma Basin) during culmination of the Ouachita orogeny. As a lithostratigraphic unit, the Atoka Formation remains in use. Spivey and Roberts (1946) were the first to use ‘Atoka series’ in a biostratigraphic sense, basing its limits on fusulinids observed in central Texas. Keyes (1893) applied the term ‘Des Moines series’ to poorly exposed rocks along the Des Moines River in Iowa, and Moore (1932) was the first to attach faunal significance to the unit. The Atokan and Desmoinesian rapidly took precedence over other classifications, and Moore and Thompson (1949) produced a comprehensive fusulinid-based subdivision of the Pennsylvanian throughout the USA, using Atokan and Desmoinesian stages. With minor changes, this usage persists today.

Many problems attend delimitation of the Atokan and Desmoinesian stages, including incomplete exposure, lack of type and reference sections, dramatic facies changes within the Atokan, and sparse fossil content (Nelson and Lucas, in press). A symposium on the Atokan (Sutherland and Manger, 1984) addressed a number of issues but failed to achieve a consensus on definition. Nevertheless, biostratigraphers generally agree on the position of the Atokan–Desmoinesian boundary, based primarily on fusulinids (Sutherland and Manger, 1983; Groves, 1986; Douglass, 1987; Wilde, 1990; Wahlman, 2013), with supplemental information from palynomorphs (Peppers, 1996) and conodonts (Barrick et al., 2013). Macroflora have not played a role in defining the stages or their boundaries.

2.2 Bolsovian–Asturian (*ex Westphalian C–D*) boundary

Pruvost (1934) erected the ‘Westphalian D’ for an unnamed succession of upper Westphalian rocks (Assise de la Houvre) that conformably overlie ‘Westphalian C’ strata in the Lorraine Coalfield of France, and considered the chronostratigraphic unit equivalent to the ‘Zone à *Mixoneura*’ of Bertrand (1926). As interpreted by P. Bertrand, the fossil-genus *Mixoneura* (non Weiss, 1869) encompassed a group of fossil-species allied with *Neuropteris ovata*, and thus began the longstanding link between the Westphalian D concept and first appearance of the *N. ovata* complex (Bertrand, 1937; Jongmans and Gothan, 1937). Nonetheless, given that *N. ovata* is not present in the lower Assise de la Houvre, and that outside of the Lorraine Coalfield the taxon occurs in strata that are younger than the lithostratigraphic unit (Remy and Remy, 1964), the Westphalian C–Westphalian D boundary was redefined as corresponding to the base of the biozone of *N. ovata* (van Leckwijck, 1964). Laveine (1977) recognized the perils of relying on a single terrestrial taxon to identify the boundary [see Bode (1970) for a poignant example], and established a series of eight paleobotanical events (limits of the range or acme of significant macrofloral and microfloral

species) that took place in the lead up to the first occurrence of *N. ovata*. This framework has been employed in several Euramerican basins/coalfields, but because the presence of Westphalian D strata is now taken as the base of the *acme* of *N. ovata* (Cleal, 1978, 1984a), the first appearance of the species may be somewhat below (South Wales: Cleal, 1978; Central Asturian: Wagner and Álvarez-Vázquez, 1991; Appalachian: Blake et al., 2002), coincident with (Lorraine, Northern France: Laveine, 1977; Saarland: Cleal, 1984b), or above (Sydney: Zodrow and Cleal, 1985) the boundary placement.

The Westphalian C was renamed ‘Bolsovian’ when a boundary stratotype was formally designated in Bolsover, Derbyshire (Owens et al., 1985). As the original Westphalian D concept in the Lorraine Coalfield was based on inaccessible subsurface sections and comprised exclusively terrestrial strata with inherent biostratigraphic limitations, Wagner et al. (2002) proposed a boundary stratotype in a mixed marine and terrestrial succession in the Central Asturian Coalfield. The renamed ‘Asturian’ (after the Principality of Asturias) has yet to be formally ratified, but the term is generally used in place of Westphalian D.

3. GEOLOGICAL SETTING

3.1 Illinois Basin

The Illinois Basin (also called the Eastern Interior Basin) is an interior cratonic basin (Leighton et al., 1991), and one of several depocentres in the USA that contain coal-bearing strata of mainly Pennsylvanian age (Fig. 1.1). As now configured, the basin underlies much of Illinois and parts of western Indiana and western Kentucky, with small outliers in Iowa and Missouri (Fig. 1.2). The Illinois Basin contains a predominantly siliciclastic succession of Morrowan to Virgilian (Bashkirian to Gzhelian, upper Namurian to upper Stephanian) strata (Nelson et al., 1991, 2013), with accumulation influenced by glacioeustatic fluctuations that resulted in cyclic marine transgressions across the low-gradient continental platform

(Wanless and Shepard, 1935, 1936; Heckel, 1986; Watney et al., 1989; Langenheim and Nelson, 1992; Greb et al., 2003; Algeo and Heckel, 2008). Consistent with this paleogeographic setting, depositional environments in the Illinois Basin are intermediate between marine-dominated rocks of the Western Interior (Midcontinent) Basin and mainly deltaic to terrestrial strata of the Appalachian Basin (Fig. 1.1; Heckel, 1977, 1980; Nelson et al., 2013). In paleogeographic context, these basins developed near the paleoequator in the west-central part of Euramerica (Witzke, 1990). During the Atokan–Desmoinesian transition, they were separated from eastern areas of the continent (present-day Europe) by uplands of the Laurentian Shield and, in part, by the Appalachian-Variscan Mountains (Blakey, 2013). Tectonic deformation linked to the Ancestral Rocky Mountains orogeny took place in the Illinois Basin during the Pennsylvanian (McBride and Nelson, 1999), but some parts, including the Quad Cities area covered herein, seem to have been tectonically stable.

3.2 Study locality

The Friendship Farm locality is situated in Rock Island County, northwestern Illinois, near the subcrop limit of Pennsylvanian strata on the northwestern margin of the Illinois Basin (Figs. 1.2., 3.1). The pre-Pennsylvanian depositional surface is highly irregular in the Quad Cities area (Kolata, 2005). The Tradewater Formation (basal Atokan to middle Desmoinesian) either rests unconformably on Silurian(?) to Devonian rocks, or conformably above pockets of the Morrowan Caseyville Formation, which occurs in a small unnamed basin distinct from the larger Illinois Basin. Pertinent to this study, strata of the middle Tradewater Formation include the Rock Island Coal, which is the youngest Atokan coal (Peppers, 1996) and the most economically important coal in the area (Andros, 1915; Culver, 1925; Searight and Smith, 1969). The overlying Seville Limestone, which contains the fusulinid *Fusulinella iowensis* Thompson, 1934 (but not the genus *Beedeina* Galloway,

1933), is either latest Atokan (Douglass, 1987) or earliest Desmoinesian (Wahlman, 2013) in age (Fig. 2). The coal and limestone have highly sporadic distributions, both units being thickest in linear belts that overlie depressions on the surface of the underlying Bernadotte Sandstone or older ‘Pope Creek shale’ (i.e., paleovalleys; Wanless, 1957). The Rock Island Coal and Seville Limestone correlate with the Minshall Coal (uppermost Brazil Formation) and Perth Limestone (lower Staunton Formation) of Indiana, and with the Empire coal and Curlew Limestone of Kentucky (Fig. 2; The Tri-State Committee on Correlation of the Pennsylvanian System in the Illinois Basin; Nelson et al., 2013). The Bernadotte Sandstone is equivalent to the Murray Bluff Sandstone in southern Illinois (Wanless, 1957). For reference, the aforementioned middle Tradewater succession corresponds to the uppermost Abbott and lowermost Spoon formations in the discontinued classification of Kosanke et al. (1960).

The documented macrofloral assemblage was collected in a northwest-southeast trending ravine that opens out to the Rock River, south of Illinois Route 84/Colona Road between Colona and Moline, Illinois (Fig. 3.1; SW 1/4, Section 9, Township 17N, Range 1E). Historically termed Friendship Farm, the flat plateau through which the ravine cuts is now the site of TPC Deere Run Golf Course. ISGS field notes (H.E. Culver: 1921–1924; H.R. Wanless: 1930; E.T. Benson: 1935?; D.M. Moody: 1958) provide measured sections of strata above and below the Rock Island Coal, which was exploited in the vicinity in small-scale slope and drift mines in the early 1900s (Fig. 3.1; Searight and Smith, 1969; Obrad and Chenowith, 2009). The approximate trace of outcropping coal and position of plant-fossil-bearing rocks shown in Figure 3.1 are based on a return visit by one of us (WJN) in March 2014, and corroborate ISGS field notes that the fossiliferous strata are situated *below* the Rock Island Coal.

3.3 Stratigraphic section and correlations

The schematic section in Figure 3.2 represents the amalgamation of measured sections in the ISGS field notes of Wanless from 1930 and Moody from 1958. The basal unit is poorly exposed and comprises ≈ 5 m of plant-fossil-bearing, medium to dark grey, slightly micaceous shale that contains occasional siderite nodules and becomes lighter in color and increasingly fissile upwards. This description is consistent with the lithology of fossiliferous slabs in the collection, which can be segregated into yellowish light grey, silty claystone and light to medium grey shale, probably interbedded on a centimeter to decimeter scale but with light-colored beds more common upwards. The stratigraphic position and lithology of this unit are consistent with the Pope Creek shale (= 'Member 14') at the top of the 'Pope Creek cyclothem' of Wanless (1957, p. 70). At some exposures in the county, this shale is eroded out and replaced by the Bernadotte Sandstone, the lowest unit of the overlying 'Seville cyclothem'. As the Pope Creek shale overlies the Pope Creek Coal Member, which correlates with the Upper Block Coal Member of Indiana (Wanless, 1957), the documented macrofloral assemblage is equivalent to an interval somewhere between the Upper Block and Minshall coals of the Brazil Formation (Fig. 2). The exact level(s) from which plant fossils were collected is uncertain, but Bode (1958, p. 229) stated that it occurred "...at the base of the seam...below an about 2 m thick root horizon." This description is interpreted to imply a horizon in the uppermost part of the shale succession below the Rock Island Coal (Fig. 3.2).

The ISGS field notes of Wanless record a possible unconformity (based on lithology change and the superjacent unit having a lensoid base) near the top of the fossiliferous shale (at ≈ 5 m in Fig. 3.2), which may correspond to the base of the Seville cyclothem as defined by Wanless (1957). The underclay beneath the Rock Island Coal contains root impressions and is oxidized with yellow mottling, whereas the coal itself is ≈ 55 cm thick, largely bright banded but bony near the base, and pyritic. Approximately 2 m of dark grey, fissile, hard 'slate' overlies the coal, within which there are two irregular beds (8–15 cm thick) of dark

bluish grey, argillaceous, semi- to non-crystalline limestone that locally contain stringers of white calcite. The lithology of the limestone, particularly the bluish coloration, is consistent with the Seville Limestone (Andros, 1915; Culver, 1925; Wanless, 1957; Searight and Smith, 1969). This limestone is the lowest occurring Pennsylvanian carbonate in the area, and the only one associated with a mineable coal (Searight and Smith, 1969). Although the Rock Island Coal and Seville Limestone are thin in the measured section, it is notable that mine records for the ‘Old’ Stoehr Mine (Mine Index No. 4867, Obrad and Chenoweth, 2009), ~250 m further up the ravine (Fig. 3.1), indicate a maximum thickness of 122 cm for the coal, which is overlain by a well-developed limestone caprock within a 12-m radius of the shaft. Such dramatic thickness changes point to the presence of a paleotopographic low, perhaps a paleovalley, on the pre-Seville cyclothem surface at the head of the ravine; this surface may correspond to the position of the postulated unconformity noted in Figure 3.2.

The upper half of the section is sporadically exposed and will not be considered further, although the mixed succession of sandstone and shale may correspond to the ‘Delong cyclothem’ of Wanless (1957).

4. MACROFLORAL ASSEMBLAGE

4.1 Collections

Two separate collections from the Friendship Farm locality exist in the ISGS Paleobotany Collection (ISGS PB accession numbers) in Champaign-Urbana, Illinois. The ‘Kosanke collection’ comprises 57 slabs [ISGS PB-1759–1815 (note: 1772 is missing)] that, according to the logbook, were collected by R.M. Kosanke. No date is given, but Kosanke worked at the ISGS from December 1942 to April 1963. It also is possible that Kosanke only entered the data into the logbook, with specimens collected by previous workers. However, the Kosanke collection probably does not involve material documented by Bode (1958), who

identified “*Linopteris* cf. *münsteri*” [= *Reticulopteris muensteri* (Eichwald, 1840) Gothan, 1941; Table 1), a fossil-species that would be easily recognized if present. More certainty surrounds the ‘Pfefferkorn collection’, which comprises 40 slabs (ISGS PB-4300–4337) collected by H.W. Pfefferkorn in 1970. As stated in Section 3.3, fossiliferous slabs can be segregated into yellowish light grey, silty claystone and light to medium grey shale, although a gradation exists because these lithologies are interbedded. The Kosanke collection contains a mixture of light and dark slabs, whereas the Pfefferkorn collection is exclusively light slabs. Light-colored slabs from both collections are indistinguishable, indicating derivation from the same bed, probably from the upper part of the fossiliferous succession; dark-colored slabs probably came from a slightly lower level (Fig. 3.2) (see Section 3.3).

4.2 Quantification and general characteristics

Table 2 presents a quantitative breakdown of the rock slabs and fossil-taxa in the Kosanke and Pfefferkorn collections, and for the macrofloral assemblage as a whole. Of the 97 slabs collected, 157 slab faces bear macrofloral remains (i.e., excluding barren faces and counterparts). The quantification technique used is a variant of that described by Pfefferkorn et al. (1975): each slab face was treated as a quadrat, and a fossil-taxon was recorded as ‘present’, regardless of the number of specimens on the face. Through this process, 395 macrofloral occurrences were recorded on the 157 fossiliferous slab faces. Excluding axes that could not be tied to a fossil-plant taxon with confidence (termed ‘unidentifiable’ macrofloral occurrences in Table 2), there were 293 ‘identifiable’ macrofloral occurrences.

Of the 14 fossil-taxa identified (Table 2), 10 can be considered ‘biological’ taxa (i.e., a reassembled conceptualization of a whole fossil plant; cf. Cleal and Thomas, 2010), whereas only four ‘non-biological’ taxa were recorded [*Cyperites bicarinatus* Lindley et Hutton, 1832, *Lepidostrobophyllum* sp. cf. *L. alatum* Boulter, 1968, *Calamites* Brongniart, 1822 (sp.

indet.), and medullosalean seeds]. When relative abundances for the entire macrofloral assemblage are considered, pteridosperms are the predominant (78.8%) and most diverse plant group (five biological fossil-species). It is noted that the vast majority of unidentifiable macrofloral occurrences consists of pteridosperm axes, so this group is overwhelmingly dominant. The lycopsids (8.5%; two biological fossil-species), sphenopsids (6.5%; one biological fossil-species), and ferns (6.1%; two biological fossil-species) are relatively uncommon. Cordaitalean remains (e.g., *Cordaites* Unger, 1850) are absent.

The Kosanke and Pfefferkorn collections show marked differences in taxonomic composition, albeit with some overlap (Table 2). With the exception of a few (uncounted) appendages of stigmarian rhizomorphs, no other lycopsid organs were observed in the Pfefferkorn collection. Whereas sphenopsids are rare in the Pfefferkorn collection, fern remains are equally rare in the Kosanke collection. Both collections contain strikingly similar proportions of pteridosperms, although *Neuropteris flexuosa* Sternberg, 1825 and *Alethopteris serlii* (Brongniart, 1833-34) Göppert, 1836 are more abundant in the Kosanke collection; medullosalean seeds are only found in the Kosanke collection, and *Mariopteris nervosa* (Brongniart, 1833-34) Zeiller, 1879 is only found in the Pfefferkorn collection. It is significant that cordaitalean remains are absent in both. Differences in composition and relative abundance suggest that specimens were not collected from the exact same site, although mutual representation of the dominant pteridosperm taxa indicates derivation from the same fossiliferous succession below the Rock Island Coal. Such incongruences are interpreted to reflect the patchy distribution (and preservation) of taxa in Pennsylvanian wetland communities from clastic substrates (Bashforth et al., 2010, 2011).

5. IDENTIFICATIONS

Brief remarks are presented for the fossil-taxa identified in this study (except *Calamites* sp. indet.). Although no synonymy lists are given, comparisons were made with type material where possible, and authorities for all taxon names are cited in the References.

5.1 *Lycopsids*

5.1.1 *Cyperites bicarinatus* Lindley et Hutton, 1832 emend. Rex, 1983

Fourteen slab faces contain isolated, linear lycopsid leaves characterized by longitudinal ridges and furrows, conforming to the emended diagnosis of this fossil-species (Rex, 1983). Wider examples of *Cyperites* Lindley et Hutton, 1832 tend to belong to sigillarians and narrower leaves to lepidodendroids (Bashforth, 2005). Although both lycopsid groups are present in the assemblage, the width of the leaves suggests derivation from a lepidodendroid (e.g., cf. *Diaphorodendron* sp. indet.).

5.1.2 cf. *Diaphorodendron* DiMichele, 1985 (sp. indet.)

Two very thin axial fragments, which bear crowded, elongate-quadrilateral leaf cushions and show no evidence of infrafoliar parichnos traces beneath the leaf scars (Plate I, 7), probably represent distalmost lateral branches of an arborescent tree of the Diaphorodendraceae (DiMichele, 1985; DiMichele and Bateman, 1992). The high L:W ratio of the leaf cushions indicates assignment to *Diaphorodendron* rather than *Synchysidendron* DiMichele et Bateman, 1993, which in similarly thin axes tends to have equidimensional leaf cushions (DiMichele et al., 2013; Moore et al., 2014). Details of the leaf scars are not preserved, precluding species assignment.

5.1.3 *Lepidostrobophyllum* sp. cf. *L. alatum* Boulter, 1968

Eight slab faces contain lycopsid sporophylls (Plate I, 4) typified by laminae that are linear-lanceolate, parallel-sided, and have acuminate tops and basal lateral angles that appear flush with the pedicel top. The sporophylls are morphologically similar to elongate examples of *L. alatum* (cf. Boulter, 1968), although the lack of evidence for the characteristic alate pedicel precludes confident assignment. The sporophylls probably were derived from monosporangiate cones of *Achlamydocarpon varius* (Baxter, 1959) Taylor et Brack-Hanes, 1976, which were produced by the Diaphorodendraceae (Phillips, 1979; Leisman and Phillips, 1979; DiMichele, 1985; DiMichele et al., 2013).

5.1.4 *Sigillaria* sp. cf. *S. tessellata* Brongniart, 1828

A thin sigillarian axis (Plate I, 1) with a faintly impressed exterior surface has straight-sided ribs, each rib being separated by a narrow furrow and containing a vertical row of crowded leaf scars [*Eusigillariae*, *Rhytidolepis* section, *Eurhytidolepis* subsection of Crookall (1966)]. Leaf scars fill most of a rib, are somewhat hexagonal with rounded margins, and appear to contain three foliar cicatricules. Preservation negates certain identification, but the specimen compares well with some syntypes of *Sigillaria tessellata* (Brongniart, 1837, pl. 162, figs. 1–4) and other illustrated examples of the taxon (e.g., Bell, 1938, pl. 100, fig. 2; Crookall, 1966, pl. 87, fig. 3; Wittry, 2006, p. 110, fig. 1).

5.2 *Sphenopsids*

5.2.1 *Sphenophyllum emarginatum* (Brongniart, 1822) Brongniart, 1828 emend. Batenburg, 1977

Sixteen slab faces contain poorly preserved examples of this common and widespread fossil-species (Plate I, 5, 6), which is characterized by whorls of cuneate leaves with straight lateral margins and obtusely rounded teeth on a straight to slightly convex distal margin.

Although a markedly heterophyllous taxon, all observed specimens represent undivided leaves from last-order branches (e.g., Abbott, 1958, pl. 44, fig. 66, pl. 45, fig. 72; Batenburg, 1977, pl. 2, figs. 3–6, pl. 4, figs. 1, 3, 4), and compare well with the holotype (Brongniart, 1822, pl. 2, fig. 8; Remy and Remy, 1977, text-fig. 237a, b; Storch, 1980, pl. 1, fig. 1).

5.3 Ferns

5.3.1 *Lobatopteris* Wagner, 1958 — *Crenulopteris* Wittry et al., 2014 complex (sp. indet.)

Four slab faces contain small and poorly preserved fragments of a fern of the *Lobatopteris* — *Crenulopteris* complex (cf. Wittry et al., 2014). The terminal (Plate I, 3) and more proximal (Plate I, 2) part of a single pinna are illustrated, as is a lobate pinnule (or distal ultimate pinna) of another specimen (Plate I, 8). As the taxon mainly seems comprise non-lobate elements, assignment to *Lobatopteris*, rather than *Crenulopteris*, is more probable. Although the preservation state precludes specific determination, the general morphology resembles the holotype of *Lobatopteris miltonii* (Artis, 1825) Wagner, 1958, which was reillustrated by Shute and Cleal (1989) and Pšenička et al. (2009, pls. 1, 2). Likewise, the specimens are similar to the syntypes of *Pecopteris vestita* Lesquereux, 1879-80 and *Pecopteris pseudovestita* White, 1899, which Pšenička et al. (2009) and Wittry et al. (2014) reillustrated and synonymized with *L. miltonii*.

5.3.2 cf. *Crossothea communis* (Lesquereux, 1884) Kidston, 1923

Thirteen slab faces contain fragments of sphenopteroid fern fronds that bear fructifications. One morphologically variable fossil-species in different phases of maturity is presumed to be involved; end-member states are illustrated. The less common, less mature type (Plate II, 1, 2) retains some of the lamina and is characterized by circular to oval, closed sori (<1 mm in diameter) inserted near the end of lobes of divided pinnules, the degree of

pinnule division increasing proximally. In the more common, more mature type (Plate II, 3, 4), the lamina is reduced to disc-like segments, each bearing on its abaxial surface a circular sori that has separated to reveal approximately 10 radially arranged, elongate microsporangia. The best comparison is with *Crossotheca communis* (Kidston, 1923, pl. 89, figs. 10, 10a; Bell, 1938, pl. 35, figs. 2, 3), and specimens of *Crossotheca* sp. illustrated by Brousmiche (1983, pl. 27, figs. 3, 3a).

5.3.3 *Sphenopteris* (Brongniart, 1822) Sternberg, 1825 (sp. indet.)

One incomplete ultimate pinna (Plate II, 8) is characterized by small pinnules with crenulate lateral margins and sparse, undivided lateral veins that branch from a decurrent midvein. Myriad sphenopteroid ferns share this morphology, but the salient characters of the fragment are similar to the sterile holotype of *Crossotheca communis* (Lesquereux, 1884, pl. 104, figs. 1, 1a) and the example illustrated by Kidston (1923, pl. 89, figs. 9, 9a, 9b). Accordingly, the specimen not been counted as a distinct biological taxon in Table 2.

5.4 *Pteridosperms*

5.4.1 *Mariopteris nervosa* (Brongniart, 1833-34) Zeiller, 1879

Six slab faces contain frond elements of this fossil-species (Plate II, 9), which is typified by vaulted, subtriangular, and basally confluent pinnules, and a robust and deeply marked but sparse venation. Specimens conform in all respects to the lectotype (Brongniart, 1833-34, pl. 95, fig. 1), which was reillustrated by Corsin (1932, pl. 61, figs. 1, 2).

5.4.2 *Alethopteris serlii* (Brongniart, 1833-34) Göppert, 1836

Thirty-nine slab faces contain the foliage of this common fossil-species (Plate III, 1, 2, 8). Wagner (1968) circumscribed *A. serlii* as having relatively large, strongly decurrent, and

biconvex pinnules with a bluntly acuminate to obtusely rounded apex. Midveins are non-decurrent and thin but well marked and extend straight to the summit. Lateral veins are equally thin and branch once or twice at wide angles, resulting in a slightly flexuous appearance, with some 30–35 veins per cm reaching the lateral margin. Despite exhibiting great morphological variability, specimens in the assemblage fit this description, including the venation density (range = 29–39, quartiles = 31–36, mean = 33 veins per cm, n = 16). They also compare well with the syntypes (Brongniart, 1833-34, pl. 85), three of which were reillustrated by Wagner (1968, pl. 56, figs. 162–164).

5.4.3 *Laveineopteris rarinervis* (Bunbury, 1847) Cleal, Shute et Zoderow, 1990

Eighty-seven slab faces contain frond fragments of this common and distinctive fossil-species, and the illustrations exemplify the substantial morphological variation involved in the taxon (Plate III, 3–7; Plate IV, 1, 7). Crookall (1959) and Laveine (1967) gave the most comprehensive documentation of *L. rarinervis*, and specimens in the assemblage conform to their descriptions in all respects. The salient features include relatively small, obliquely inserted, and ovate to linguaeform or subtriangular lateral pinnules, the base of which is semi-cordate with conspicuously rounded auricles. Terminal pinnules are oblong-deltoid. Midveins are robust and slightly flexuous, and lateral veins are diagnostically sparse (range = 20–39, quartiles = 23–29, mean = 27 veins per cm, n = 36).

5.4.4 *Macroneuropteris scheuchzeri* (Hoffmann, 1826a) Cleal, Shute et Zoderow, 1990

Twenty-four slab faces contain the remains of this iconic fossil-species (Plate II, 5–7; Plate IV, 8), which is recognized by its large pinnules, dense venation, and stiff, bristle-like structures, interpreted as subepidermal resin-filled canals (Laveine and Oudoire, 2015). Specimens comparable to those in the assemblage are present in the comprehensive studies of

Laveine (1967), Zodrow (2003), and Laveine and Belhis (2007). A range of morphologies is present, including one trifoliate example (Plate II, 6), although laciniate forms known as *Odontopteris subcuneata* Bunbury, 1847 are absent.

5.4.5 *Neuropteris flexuosa* Sternberg, 1825

Seventy slab faces contain ultimate pinnae and isolated pinnules of this fossil-species (Plate IV, 2–5, 9), which is similar to *Neuropteris ovata* but can be distinguished by having: (i) a large, asymmetric, deltoid terminal pinnule; (ii) relatively large lateral pinnules with a rounded acroscopic base and a conspicuously auriculate basiscopic base; and (iii) broadly attached pinnules only at the extreme top of a pinna. The venation density of specimens in the assemblage (range = 26–50, quartiles = 32–40, mean = 36 veins per cm, n = 23) is higher than at other North American sites (Bashforth et al., in press, fig. 16, table 5) or for the holotype (Stockmans, 1933, pl. 4, fig. 3), but is in accord with other material illustrated by Crookall (1959) from the type area in the UK. Cleal (1986, fig. 4) and Bashforth et al. (in press, pl. 2) provided side-by-side images of these two taxa for comparison.

5.4.6 Medullosalean seeds

Five large, isolated seeds (Plate IV, 6) comprise a nucellar cast (i.e., sediment-filled seed cavity, *sensu* Gastaldo and Matten, 1978) that is smooth with fine longitudinal striations, surrounded by a thin (≈ 1 mm thick) layer of coalified matter that may represent the sclerotesta, and a more distal wrinkled rim (2–5 mm thick) that may represent the fleshy sarcotesta. The dimensions (from edges of nucellar cast) are ≈ 40 –50 mm long and 15–30 mm wide. Although the seeds probably belong to *Trigonocarpus* Brongniart, 1828 of medullosalean affinity, the diagnostic commissural ridges are not evident; according to Hoskins and Cross (1946), such featureless and/or decorticated seeds should be assigned to

Carpolithus Sternberg, 1825. Although the seeds are almost invariably associated with *Neuropteris flexuosa*, the dimensions are altogether larger than seeds of this plant (Zodrow and McCandlish, 1980). Instead, the source may have been *Alethopteris serlii*, as this fossil-genus bore unusually large seeds (Zodrow, 2004, 2007).

6. BIOSTRATIGRAPHY

6.1 Comparison with Appalachian Basin biozonation

Remarkably, with the exception of a few reconnaissance studies (e.g., White, 1907, 1908, 1909), no comprehensive biostratigraphic scheme exists for the succession of adpressed macrofloras in the Illinois Basin. As noted by Phillips et al. (1973, p. 8), D. White worked to assemble such a framework up until his death (1935), but this essentially complete manuscript remains unpublished. Read and Mamay (1964) barely acknowledged the plant-fossil record of the Illinois Basin in their publication, in which upper Paleozoic strata of North America were segregated into 15 macrofloral zones. As such, biostratigraphic analysis relies on comparison with the Appalachian Basin.

Building on the work of previous authors (e.g., White, 1900; Darrah and Bertrand, 1933; Darrah, 1937; Gillespie and Pfefferkorn, 1979), Blake et al. (2002, fig. 1) produced a chart that correlates between lithostratigraphic units of the Appalachian Basin, chronostratigraphic units of midcontinental USA and western Europe, and macrofloral zones of the USA (Read and Mamay, 1964) and paleoequatorial Europe (Wagner, 1984). As shown in Figure 4, Blake et al. (2002, with updates from B.M. Blake, personal communication, 2014) followed Peppers (1996) in equating the Atokan–Desmoinesian and Bolsovian–Asturian boundaries, which they placed at the Upper No. 5 Block coal bed near the contact between the Kanawha and Allegheny formations. This level corresponds to the middle of Zone 9 (‘*Neuropteris rarinervis*’) of Read and Mamay (1964).

To determine the age of the Friendship Farm assemblage, the range limits of key fossil-taxa in the Appalachian Basin were compiled (Fig. 4), based on comparisons with existing range charts (Darrah, 1969, p. 109; Gillespie and Pfefferkorn, 1979, table 1; Blake et al., 2002, fig. 2). This exercise yields ambiguous results due to uncertainties in some range limits. In particular, Blake et al. (2002, fig. 2) indicated that the first appearance datum (FAD) of *Alethopteris serlii* is in the lower Allegheny (No. 6 Block coal bed = Lower Kittanning coal bed = lower Asturian), whereas Gillespie and Pfefferkorn (1979) placed the lower range limit in the upper Kanawha (Winifrede coal bed = lower Bolsovian). Multiple species may be involved in previous identifications of *A. serlii* (cf. Wagner, 1968; Scheihing and Pfefferkorn, 1980; Bashforth et al., in press), making the FAD difficult to pinpoint.

The lower limit of *Neuropteris flexuosa* in the Appalachian Basin is equally problematic. Darrah (1969) and Blake et al. (2002) placed the FAD in the lower to middle Allegheny (lower Asturian), although neither explicitly stated at which horizon. In contrast to Europe (see Section 6.2), Read and Mamay (1964) noted that the species occurs sparingly in Zone 8 (*'Neuropteris' tenuifolia*) before becoming abundant in Zone 10 (*Neuropteris flexuosa* and *Pecopteris* spp.). White (1900) also noted its appearance at the Coalburg coal bed in the upper part of the Kanawha (= middle Bolsovian). As determined by Bashforth et al. (in press), *N. flexuosa* does occur, albeit rarely, in middle Bolsovian strata in the USA [e.g., above the Lower Block Coal Member in Indiana (Wood, 1963); Fig. 2]. In Figure 4, the FAD is thus placed in the upper Kanawha (middle Bolsovian), at a level coincident with the FAD of *Neuropteris ovata* (Blake et al., 2002, fig. 2), with the base of the acme in the middle Allegheny (lower to middle Asturian) at the base of Zone 10.

Despite the biostratigraphic uncertainties and inconsistencies in the Appalachian Basin, the Friendship Farm assemblage primarily comprises species that first appear in the upper Kanawha (Bolsovian) but extend into and are more typical of the Allegheny (Asturian).

Although a late Bolsovian age is possible, the fact that *Neuropteris flexuosa* and *Alethopteris serlii* are major components of the collection (Table 2) makes an early Asturian age most tenable. The assemblage probably corresponds to a level in the upper part of Zone 9 (*'Neuropteris' rarinervis*) or lower part of Zone 10 (*Neuropteris flexuosa* and *Pecopteris* spp.) of Read and Mamay (1964).

6.2 Comparison with European biozonation

Wagner (1984) produced the most comprehensive biostratigraphic framework for Carboniferous plant fossils, a scheme that comprises 16 biozones and, although primarily based on range data from western and central Europe, was intended to aid correlations throughout the Euramerican paleoequatorial realm. The introduction of several subbiozones has improved resolution (Cleal, 1991; Cleal and Thomas, 1994).

Comparison with the European biozonation (Fig. 5) is based on the compilation of taxon ranges in Cleal and Thomas (1994, figs. 92–94). Again, age assignment for the Friendship Farm assemblage is ambiguous because most taxa are long ranging, with FAD in the Bolsovian (or earlier) and LAD in the early Cantabrian (or younger). However, the appearance of *Neuropteris flexuosa* at the Bolsovian–Asturian boundary constrains the oldest possible age to the earliest Asturian. Equally importantly, several well-known and widely distributed species that first occur in the *Crenulopteris micromiltonii* Subbiozone are notably absent, including *Alethopteris lesquereuxii* Wagner, 1968, the plexus around *Cyathocarpus arborescens* (Sternberg, 1825) Weiss, 1869, *Ptychocarpus unitus* (Brongniart, 1836) Weiss, 1869, *Crenulopteris micromiltonii* (Corsin, 1951) Wittry et al., 2014, and *Callipteridium jongmansii* (Bertrand, 1932) Wagner in Wagner et Breimer, 1958 (cf. Cleal, 1978, 1984b; Zdzrow and Cleal, 1985; Cleal and Thomas, 1994). These criteria point to correlation with the early Asturian *Linopteris obliqua* Biozone (Fig. 5). Macrofloral assemblages of

equivalent age have been documented in the Nolton-Newgale and South Wales coalfields in the UK (Cleal and Thomas, 1992; Thomas and Cleal, 2001) and in the Piesburg area of northwestern Germany (Josten et al., 1984).

7. CONCLUDING STATEMENT

The macrofloral assemblage collected from below the Rock Island Coal at the historical Friendship Farm locality in northwestern Illinois comprises 10 biological fossil-species. Medullosalean pteridosperms are overwhelmingly dominant, with *Laveineopteris rarinervis*, *Neuropteris flexuosa*, *Alethopteris serlii*, *Macroneuropteris scheuchzeri*, and *Mariopteris nervosa* being the key elements, well-known fossil-species that had a pan-Euramerican distribution in wetland habitats (Cleal et al., 2009, 2012). By contrast, lycopsids, sphenopsids, and ferns are poorly represented. Homotaxial comparison with the biostratigraphic scheme established for European macrofossils (Wagner, 1984; Cleal, 1991; Cleal and Thomas, 1994) indicates that the assemblage is Asturian in age, in all likelihood early Asturian (*Linopteris obliqua* Biozone). Comparison with range limits in the Appalachian Basin (Gillespie and Pfefferkorn, 1979; Blake et al., 2002) yields a less conclusive result, but an early Asturian age is again probable. This finding corroborates Bode (1958, p. 230), who stated that “This flora still clearly belongs in the Westphalian D, but [the taxa] indicate relatively low horizons.”

Bashforth et al. (in press) documented an early Asturian macrofloral assemblage in Indiana from the roof-shale of the Minshall Coal, a correlate of the Rock Island Coal, and thus argued that the Bolsovian–Asturian Substage boundary of western Europe is either positioned at the top of this coal or somewhere beneath it. The (early) Asturian macrofloral assemblage recorded herein confirms this hypothesis; based on macrofloral content, the Bolsovian–Asturian boundary in the Illinois Basin is located below the correlative Rock

Island (Illinois), Minshall (Indiana), and Empire (Kentucky) coals (Fig. 2; Bashforth et al., in press, fig. 7.5). Boundary placement remains uncertain, but presumably is in the middle Tradewater Formation between the Pope Creek and Rock Island coals of Illinois and middle Brazil Formation between the Upper Block and Minshall coals of Indiana (Fig. 2). Clarification will depend on additional analyses of macrofloral assemblages through this part of the succession.

As discussed by Bashforth et al. (in press), decoupling the Atokan–Desmoinesian and Bolsovian–Asturian boundaries causes the least disruption to the preexisting chronostratigraphic framework in the Illinois Basin. Retaining the Atokan–Desmoinesian boundary at the Seville, Perth, and Curlew limestones and lowering the Bolsovian–Asturian boundary to below the Rock Island, Minshall, Empire coals has the following ramifications (Fig. 2): (i) all of the aforementioned coals and limestones are (lower) Asturian, as are the uppermost Brazil, lowermost Staunton, and a larger part of the upper Tradewater formations; and (ii) the transition between the *Radiizones difformis* (RD) and *Cadiospora magna-Mooreisporites inusitatus* (MI) microfloral zones of Peppers (1996) occurs in the early Asturian. In the Appalachian Basin, the effects of lowering the Bolsovian–Asturian boundary are limited (Fig. 4), and such a move perhaps is warranted given that the FAD of *Neuropteris ovata* occurs well below the Upper No. 5 Block coal, where the boundary currently is placed (Peppers, 1996; Blake et al., 2002, fig. 7). As it pertains to the macrofloral biozonation scheme of western Europe, the Atokan–Desmoinesian boundary probably is in the *Linopteris obliqua* Biozone (Fig. 5).

That the Atokan–Desmoinesian Stage and Bolsovian–Asturian Substage boundaries are not coincident based on macrofloral records is not unexpected. All of these chronostratigraphic concepts were initiated as lithostratigraphic units in widely separated areas of equatorial Euramerica, with accumulation occurring under fundamentally different

623 tectonic and depositional regimes. Delimitation of the Atokan–Desmoinesian boundary
624 remains open to debate, and a formal stratotype has yet to be defined for the Atokan
625 (Sutherland and Manger, 1984; Nelson and Lucas, in press). Stratotypes for the Bolsovian
626 and Asturian have been relocated from France to the UK and Spain, respectively, and the
627 latter has yet to be formally ratified (Owens et al., 1985; Wagner et al., 2002). Most
628 importantly, limits of the Atokan and Desmoinesian concepts are largely based on marine
629 microfossils (Sutherland and Manger, 1983; Groves, 1986; Douglass, 1987; Wilde, 1990;
630 Barrick et al., 2013; Wahlman, 2013), whereas terrestrial plant fossils define the base of the
631 Asturian (van Leckwijck, 1964; Laveine, 1977; Cleal, 1984a).

632 The myriad differences and uncertainties involved in the definition and delimitation of
633 the Atokan–Desmoinesian and Bolsovian–Asturian boundaries point to temporal and spatial
634 disjunction between the contacts. However, the fact that the boundaries are broadly
635 synchronous, at least in the wider perspective of geological time, over such a vast area of
636 equatorial Euramerica dictates that a major environmental shift must have caused the marked
637 lithological and biological changes that led to recognition of the lithostratigraphic-cum-
638 chronostratigraphic units in the first place. Further exploration of the mechanisms, timing,
639 and expression of this Middle Pennsylvanian event is necessary to understand how equatorial
640 biomes responded to environmental perturbations as Euramerica progressed from icehouse to
641 greenhouse conditions through the late Paleozoic (Gastaldo et al., 1996).

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1131

1132 **FIGURE CAPTIONS**

1133 **Figure 1.** Basins in contiguous USA that contain coal-bearing strata of Pennsylvanian age. **A.**
 1134 Western Interior, Illinois, Appalachian, and Michigan basins, and their components. **B.**
 1135 Illinois Basin, with position of locality studied herein in Rock Island County, Illinois, and
 1136 locality studied by Bashforth et al. (in press) in Clay County, Indiana.

1137

1138 **Figure 2.** Stratigraphy of Middle Pennsylvanian of Illinois Basin, showing correlation
 1139 between chronostratigraphic and lithostratigraphic units and American microfloral and

European macrofloral biozonation schemes (* indicates incomplete unit). Compiled from Cleal and Thomas (1994, figs. 92–94), Peppers (1996, pl. 1), Davydov et al. (2010, fig. 2), Falcon-Lang et al. (2011, fig. 1), and Nelson et al. (2013, fig. 2). Macrofloral assemblage documented herein collected from Tradewater Formation below Rock Island (No. 1) Coal Member of Illinois (black arrow), whereas assemblage reported by Bashforth et al. (in press) collected from lowermost Staunton Formation above Minshall Coal Member (grey arrow). Position of Bolsovian–Asturian Substage boundary, equivalent to Atokan–Desmoinesian Stage boundary according to Peppers (1996), shown as dotted line, whereas dashed line (with ?) and dashed down-arrow reflect need to lower boundary based on biostratigraphic data presented herein. Note that Cantabrian–Asturian Substage boundary poorly defined in Illinois Basin and elsewhere in USA, and that correlation between Pope Creek Coal and Tarter Coal members (Illinois) and Upper Block Coal and Lower Block Coal members (Indiana), respectively, approximate and based on Wanless (1957). Full names of microfloral biozones: *Torispora securis-Vestispora fenestrata* (SF), *Cadiospora magna-Mooreisporites inusitatus* (MI), *Schopfites colchesterensis-Thymospora pseudothiessenii* (CP), and *Lycospora granulata-Granasporites medius* (GM).

Figure 3. Details of historical Friendship Farm locality. **A.** Map of Section 9, Township 17N, Range 1E, showing northwest-southeast oriented ravine on northwestern side of Rock River south of Illinois Route 84/Colona Road between Colona and Moline, Illinois, the source of the documented macrofloral assemblage. Ravine cuts through what is now TPC Deere Run Golf Course. Approximate trace of outcropping Rock Island Coal Member and position of plant-fossil-bearing strata below seam based on return visit to locality in March 2014, whereas site of historical small-scale coal mines based on ISGS field notes of H.E. Culver from 1921–1924 and Obrad and Chenoweth (2009). **B.** Schematic section of strata exposed in

1165 ravine based on amalgamation of measured sections in ISGS field notes of H.R. Wanless
1166 from 1930 and D.M. Moody from 1958. Note that Rock Island Coal and Seville Limestone
1167 markedly thicker in vicinity of historical mines further up ravine (see Section 3.3 for details).

1168

1169 **Figure 4.** Biostratigraphic ranges of key pteridosperm species in macrofloral assemblage
1170 correlated with chronostratigraphic units, lithostratigraphic units of Central Appalachian
1171 Basin, and American macrofloral biozonation scheme of Read and Mamay (1964) (*
1172 indicates incomplete unit). Ranges compiled from Darrah (1969, p. 109), Gillespie and
1173 Pfefferkorn (1979, table 1), Blake et al. (2002, fig. 2), and B.M. Blake (personal
1174 communication, 2014). Age of assemblage ambiguous, but presumed to be early Asturian and
1175 corresponding to level equivalent to upper part of Zone 9 (*Neuropteris* 'rarinervis) or lower
1176 part of Zone 10 (*Neuropteris flexuosa* and *Pecopteris* spp.) of Read and Mamay (1964). Note
1177 that position of Bolsovian–Asturian Substage boundary, equivalent to Atokan–Desmoinesian
1178 Stage boundary according to Peppers (1996) and Blake et al. (2002), shown as dotted line,
1179 whereas dashed line (with ?) and dashed down-arrow reflect need to lower boundary based
1180 on biostratigraphic data presented herein.

1181

1182 **Figure 5.** Biostratigraphic ranges of key pteridosperm species in macrofloral assemblage
1183 correlated with chronostratigraphic units and European macrofloral biozonation scheme.
1184 Ranges compiled from Cleal and Thomas (1994), with updated (sub)biozone names based on
1185 taxonomic changes of Wittry et al. (2014). Age of assemblage is Asturian, probably early
1186 Asturian and equivalent to *Linopteris obliqua* Biozone (shaded). Note that position of
1187 Bolsovian–Asturian Substage boundary, equivalent to Atokan–Desmoinesian Stage boundary
1188 according to Peppers (1996), shown as dotted line, whereas dashed line (with ?) and dashed
1189 up-arrow reflect fact that boundaries are not coincident based on biostratigraphic data

1190 presented herein.

1191

1192 TABLE CAPTIONS

1193 **Table 1.** Fossil-taxa listed by Bode (1958, p. 230) from Friendship Farm locality, with
1194 current nomenclature and comments on identifications. Symbols: (a) very common, (b)
1195 common.

1196

1197 **Table 2.** Fossil-taxa in macrofloral assemblage from Friendship Farm locality below Rock
1198 Island (No. 1) Coal Member, Rock Island County, Illinois (Fig. 3), segregated into plant
1199 groupings, based on amalgamation of collections of R.M. Kosanke and H.W. Pfefferkorn
1200 held by ISGS (see Section 4.1 for details). Symbols: (a) considered to comprise the sterile
1201 equivalent of cf. *Crossothea communis*, and thus not counted as unique biological taxon; (b)
1202 total slabs in collection; (c) slab faces with macrofloral remains (excludes barren faces and
1203 counterparts); (d) identifiable macrofloral occurrences + unidentifiable macrofloral
1204 occurrences (e.g., indeterminate axes); (e) occurrence indicates presence (in any quantity) on
1205 slab face; (f) biological fossil-taxa + non-biological fossil-taxa (*Cyperites bicarinatus*,
1206 *Lepidostrobophyllum* sp. cf. *L. alatum*, *Calamites* sp. indet., and medullosalean seed); (g)
1207 reassembled conceptualization of whole fossil plant. See Section 4.2 for details.

1208

1209 PLATE CAPTIONS

1210 **Plate I.** Lycopside, sphenopsids, and ferns from Friendship Farm locality below Rock Island
1211 (No. 1) Coal Member, Rock Island County, Illinois (Fig. 3). Scale bars = 10 mm (1, 4) or 5
1212 mm (2, 3, 5–8). **1.** *Sigillaria* sp. cf. *S. tessellata* Brongniart, 1828 (ISGS PB-1811). **2, 3, 8.**
1213 *Lobatopteris* Wagner, 1958 — *Crenulopteris* Wittry et al., 2014 complex (sp. indet.) [2, 3 =
1214 ISGS PB-4337 (counterpart), 8 = ISGS PB-4337 (part)]. **4.** *Lepidostrobophyllum* sp. cf. *L.*

- 1215 *alatum* Boulter, 1968 (ISGS PB-1771). **5, 6.** *Sphenophyllum emarginatum* (Brongniart, 1822)
- 1216 Brongniart, 1828 (5 = ISGS PB-1790, 6 = ISGS PB-1783). **7.** cf. *Diaphorodendron*
- 1217 DiMichele, 1985 (sp. indet.) (ISGS PB-1807).
- 1218
- 1219 **Plate II.** Ferns and pteridosperms from Friendship Farm locality below Rock Island (No. 1)
- 1220 Coal Member, Rock Island Country, Illinois (Fig. 3). Scale bars = 10 mm (5–7, 9), 5 mm (1,
- 1221 4, 8), or X8 (2, 3). **1, 2.** Less common, less mature type of fertile cf. *Crossothea communis*
- 1222 (Lesquereux, 1884) Kidston, 1923 (ISGS PB-4336). **3, 4.** More common, more mature type
- 1223 of fertile cf. *C. communis* (ISGS PB-4326). **5–7.** *Macroneuropteris scheuchzeri* (Hoffmann,
- 1224 1826a) Cleal et al., 1990 (5 = ISGS PB-1815, 6 = ISGS PB-1765, 7 = ISGS PB-4300). **8.**
- 1225 *Sphenopteris* (Brongniart, 1822) Sternberg, 1825 (sp. indet.), presumed to be sterile form of
- 1226 cf. *C. communis* (ISGS PB-4325). **9.** *Mariopteris nervosa* (Brongniart, 1833–34) Zeiller, 1879
- 1227 (ISGS PB-4323).
- 1228
- 1229 **Plate III.** Pteridosperms from Friendship Farm locality below Rock Island (No. 1) Coal
- 1230 Member, Rock Island Country, Illinois (Fig. 3). Scale bars = 10 mm. **1, 2, 8.** *Alethopteris*
- 1231 *serlii* (Brongniart, 1833–34) Göppert, 1836 (1 = ISGS PB-1788, 2 = ISGS PB-1797, 8 = ISGS
- 1232 PB-4314). **3–7.** *Laveineopteris rarinervis* (Bunbury, 1847) Cleal et al., 1990 [3 = ISGS PB-
- 1233 1760, 4 = ISGS PB-4380, 5 = ISGS PB-4307 (see Plate IV, 1 for magnified view), 6 = ISGS
- 1234 PB-1774 (see Plate IV, 7 for magnified view), 7 = ISGS PB-1809).
- 1235
- 1236 **Plate IV.** Pteridosperms from Friendship Farm locality below Rock Island (No. 1) Coal
- 1237 Member, Rock Island Country, Illinois (Fig. 3). Scale bars = 10 mm (2–6, 8, 9) or 5 mm (1,
- 1238 7). **1, 7.** *Laveineopteris rarinervis* (Bunbury, 1847) Cleal et al., 1990 [1 = ISGS PB-4307 (see
- 1239 Plate III, 5 for reduced view), 7 = ISGS PB-1774 (see Plate III, 6 for reduced view)]. **2–5, 9.**

- 1240 *Neuropteris flexuosa* Sternberg, 1825 [2 = ISGS PB-1773, 3 = ISGS PB-1785, 4, 5 = ISGS
1241 PB-1798, 9 = ISGS PB-4337 (counterpart)]. **6.** Medullosalean seed (ISGS PB-1784). **8.**
1242 *Macroneuropteris scheuchzeri* (Hoffmann, 1826a) Cleal et al., 1990 (5 = ISGS PB-4314).

Figure 1

Figure 2

Middle Pennsylvanian				U. Penn.*	SERIES
Moscovian*				Kasim.*	GLOBAL STAGES
Westphalian*				Stephanian*	STAGES WESTERN EUROPE
Bolsvian	↕	↔	Asturian	Cantabrian	SUBSTAGES WESTERN EUROPE
Atokan*			Desmoinesian		STAGES NORTH AMERICA
[SF] <i>T. securis</i> <i>V. fenestrata</i> *	[RD] <i>Radiizonates difformis</i>	[MI] <i>C. magna</i> <i>M. inusitatus</i>	[CP]	[GM]	MICROFLORAL BIOZONATION (PEPPERS, 1996)
<i>Paripteris linguaeifolia</i> *	<i>Linopteris obliqua</i>	<i>Crenulopteris acadica</i>	<i>Odontopteris cantabrica</i>		MACROFLORAL BIOZONATION (CLEAL AND THOMAS, 1994)
Raccoon Creek Group* ↓				McLeansboro Group*
Carbondale Formation	LITHOSTRATIGRAPHY ILLINOIS & KENTUCKY
				Carbondale Group	
Raccoon Creek Group* →				Carbondale Group
Staunton Formation	LITHOSTRATIGRAPHY INDIANA
				Mansfield Formation*	

Figure 3

Figure 4

SERIES	Lower Pennsylvanian*		Middle Pennsylvanian*		
GLOBAL STAGES	Bashkirian*		Moscovian*		
STAGES WESTERN EUROPE	Westphalian*				
SUBSTAGES WESTERN EUROPE	Duckmantian		Bolsovian	? ←	Asturian
STAGES NORTH AMERICA	Atokan			Desmoinesian*	
LITHOSTRATIGRAPHY APPALACHIAN BASIN	Kanawha Formation*			Allegheny Formation	Con.
FLORAL ZONES (READ & MAMAY, 1964)	Zone 7 <i>Megalopteris</i> spp.	Zone 8 <i>'Neuropteris' tenuifolia</i>	Zone 9 <i>'Neuropteris' rarinervis</i>	Zone 10 – <i>Neuropteris flexuosa</i> & <i>Pecopteris</i> spp.	
<i>Mariopteris nervosa</i> <i>Macroneuropteris scheuchzeri</i> <i>Alethopteris serlii</i> <i>Laveineopteris rarinervis</i> <i>Sphenophyllum emarginatum</i> <i>Neuropteris flexuosa</i>	<div><div></div><div></div><div></div><div></div><div></div><div></div></div>				

Figure 5

SERIES	Middle Pennsylvanian						U. Penn*
GLOBAL STAGES	Moscovian*						Kasimovian*
STAGES NORTH AMERICA	Atokan*			-----> ?	Desmoinesian		
STAGES WESTERN EUROPE	Westphalian*						Stephanian*
SUBSTAGES WESTERN EUROPE	Bolsovian			Asturian			Cantabrian
BIOZONES	Paripteris linguaefolia*			Linopteris obliqua	Crenulopteris acadica		Odontopteris cantabrica
SUBBIOZONES	Neuropteris semireticulata*	Laveineopteris rarinervis	Alethopteris serlii		Cren. micro-miltonii	Dick. plukenetii	
Macroneuropteris scheuchzeri							
Mariopteris nervosa							
Sphenophyllum emarginatum							
Laveineopteris rarinervis							
Alethopteris serlii							
Neuropteris flexuosa							

Table 1

Fossil-taxon (Bode 1958)	Current nomenclature	Comment
<i>Neuropteris ovata</i> ^a	<i>Neuropteris ovata</i>	Possible misidentification of <i>Neuropteris flexuosa</i>
<i>Neuropteris heterophylla</i> ^b	<i>Neuropteris heterophylla</i>	Probable misidentification (Langsettian to Duckmantian fossil-species)
<i>Neuropteris tenuifolia</i> ^b	<i>Laveineopteris tenuifolia</i>	Not seen in study collection
<i>Neuropteris scheuchzeri</i>	<i>Macroneuropteris scheuchzeri</i>	Abundant in study collection
<i>Neuropteris rarinervis</i>	<i>Laveineopteris rarinervis</i>	Abundant in study collection
<i>Linopteris</i> cf. <i>münsteri</i>	<i>Reticulopteris muensteri</i>	Not seen in study collection

Table 2

Plant group	Fossil-taxon	Kosanke collection (<i>n</i> [%])	Pfefferkon collection (<i>n</i> [%])	Totals (<i>N</i> [%])
LYCOPSIDS		25 [12.32]	absent	25 [8.53]
	<i>Sigillaria</i> sp. cf. <i>S. tessellata</i>	1 [0.49]	absent	1 [0.34]
	cf. <i>Diaphorodendron</i> sp. indet.	2 [0.99]	absent	2 [0.68]
	<i>Cyperites bicarinatus</i>	14 [6.90]	absent	14 [4.78]
	<i>Lepidostrobophyllum</i> sp. cf. <i>L. alatum</i>	8 [3.94]	absent	8 [2.73]
SPHENOPSIDS		17 [8.37]	2 [2.22]	19 [6.48]
	<i>Sphenophyllum emarginatum</i>	14 [6.90]	2 [2.22]	16 [5.46]
	<i>Calamites</i> sp. indet.	3 [1.48]	absent	3 [1.02]
FERNS		2 [0.99]	16 [17.78]	18 [6.14]
	<i>Sphenopteris</i> sp. indet. ^a	absent	1 [1.11]	1 [0.34]
	cf. <i>Crossotheca communis</i>	absent	13 [14.44]	13 [4.44]
	<i>Lobopteris</i> – <i>Crenulopteris</i> complex	2 [0.99]	2 [2.22]	4 [1.37]
PTERIDOSPERMS		159 [78.32]	72 [80.00]	231 [78.84]
	<i>Laveineopteris rarinervis</i>	50 [24.63]	37 [41.11]	87 [29.69]
	<i>Neuropteris flexuosa</i>	66 [32.51]	4 [4.44]	70 [23.89]
	<i>Macroneuropteris scheuchzeri</i>	10 [4.93]	14 [15.56]	24 [8.19]
	<i>Alethopteris serlii</i>	28 [13.79]	11 [12.22]	39 [13.31]
	medullosalean seed	5 [2.46]	absent	5 [1.71]
	<i>Mariopteris nervosa</i>	absent	6 [6.67]	6 [2.05]
CORDAITALEANS		absent	absent	absent
Slabs (<i>n</i>) ^b		57	40	97
Fossiliferous faces (<i>n</i>) ^c		103	54	157
Macrofloral occurrences (<i>n</i>) ^d		281	114	395
Identifiable macrofloral occurrences (<i>n</i>) ^e		203	90	293
Fossil-taxa (<i>n</i>) ^f		12	8	14
Biological' fossil-taxa (<i>n</i>) ^g		8	8	10