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Cuticular analysis of new Westphalian and Stephanian *Cordaites* species from the USA

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ABSTRACT

Four cordaitalean species from the USA are described here: *Cordaites olneyensis* Šimůnek, sp. nov., *Cordaites daviessensis* Šimůnek, sp. nov., *Cordaites kinneyensis* Šimůnek sp. nov. and *Cordaites minshallensis* Šimůnek sp. nov. They come either from below the Minshall coal or from its roof-shales in Indiana, at the Bolsovian-Asturian boundary, or from Stephanian age deposits in Illinois and New Mexico. The Westphalian cordaitaleans are from a seasonally dry habitat (between coal beds) or from a wet habitat (the roof-shales). In both cases, their cuticles have low stomatal densities on the adaxial surface; however, stomatal densities are high on the abaxial surface and stomata are arranged in stomatiferous bands. The Stephanian species come from the period where seasonal drought was more frequent, even during the wetter intervals of glacial–interglacial cycles, and cordaitalean cuticles have less variation between adaxial and abaxial surfaces. In these Late Pennsylvanian specimens, stomatal density was low on both abaxial and adaxial cuticles and stomata were arranged in stomatal rows on both sides.

1. Introduction

American cordaitalean cuticles have been studied mainly from coal balls (Harms and Leismann, 1961; Rothwell and Warner, 1984). In thin sections, it is possible to study paradermal sections of leaves, however, we usually cannot interpret well the complicated stomatal complexes from this kind of preservation and preparation. In paradermal sections, it is possible to see cell shapes and their dimensions, however the stomatal complex, which is often three dimensional, is difficult to reconstruct. Guard cells are usually slightly sunken below the epidermal surface level and, particularly for cordaitalean cuticles, have various crypts (outer stomatal cavity) above the cuticle surface that very rarely can be seen in thin section. The same can be said of papillae and cuticle thickenings, as regards leaves preserved in coal balls. Still, Stewart and Rothwell (1993) described cordaitalean cuticles as rather uniform with stomata on the lower epidermis arranged in discrete bands. In contrast to anatomical study of leaves in coal-ball preservation, when we study macerated cuticles from well preserved adpression (compression/impression) material, we can see the imprint of all cells including guard cells, crypts and other subsidiary cells in the form of a cuticle. Such cuticles can be studied by light microscopy with further information gained by scanning electron microscopy. The author does not know of any papers dealing with American cordaitalean cuticles prepared from adpression specimens. To address this gap in our knowledge, cuticles from cordaitalean coalified fragments in the collections of the Smithsonian Institution in Washington were prepared and described in order to permit comparison with cuticles from European specimens (Šimůnek, 2007).

2. Material and methods

All samples used in this paper come from the collection of the Smithsonian Institution. Two species were identified from Atokan-Desmoinesian boundary strata in western Indiana. This is approximately equivalent to the Bolsovian-Westphalian D boundary of Europe (Bashforth et al., 2016b). The first is from USNM locality 38,878, from shales below the Minshall coal bed, Brazil Formation (DiMichele et al., 2016), of either latest Bolsovian or earliest Westphalian D age. The second, from USNM locality 38,874, is from shales above a coal originally identified as the Buffaloville coal bed, but now known to be the Minshall coal bed (DiMichele et al., 2016), Staunton Formation, of early Westphalian D age. Six samples come from USNM locality 38,882, located in Richland County, Illinois, from the informally named "Lake Sara Limestone", a mixed siliciclastic-carbonate bed at the base of the Shumway Cyclothem (basal Virgilian = basal Gzhelian). All samples from this location belong to one cordaitalean species. Two samples come from the Kinney Brick Company Quarry of New Mexico (Missourian = Stephanian B; Lucas et al., 2011), USGS locality 10,087, and probably belong to different species, however, it is difficult to demonstrate this because cuticles of one specimen are poorly preserved.

Coalified fragments of leaves were macerated in Schulze's reagent, following Kerp (1990), Krings and Kerp (1997), and Kerp and Krings

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(1999). Prepared cuticles were slide-mounted to in glycerine jelly, or on a stub for observing in the SEM.

The following slides and SEM stubs have been prepared from the above referenced specimens: *Cordaites olneyensis* Šimůnek, sp. nov., USNM 698228, slides 337/1–11, USNM 698231, slides 338/1–5, USNM 698229, slides 426/1–9, SEM stub 31, *Cordaites daviessensis* Šimůnek, sp. nov., USNM 698232, slide 438/1–10, SEM stub 37, *Cordaites kinneyensis* Šimůnek, sp. nov., USNM 698233, slide 343/1–2, *Cordaites minshallensis* Šimůnek, sp. nov., USNM 698233, slide 344/1–3, SEM stubs: 31, 37.

3. Geological setting

The Illinois Basin (Eastern Interior Basin) is an interior cratonic basin (Bashforth et al., 2016a, 2016b) that contains coal-bearing strata of predominantly Pennsylvanian age. It occupies most of Illinois, western parts of Indiana and Kentucky, and southeastern Iowa. The Illinois Basin contains a largely siliciclastic succession of Morrowan to Virgilian (Bashkirian to Gzhelian) strata, which accumulated on a low-gradient slope that dipped to a shallow epeiric sea (Bashforth et al., 2016a, 2016b). Glacioeustatic fluctuation from the paleo-west resulted in cyclic marine transgressions across the continental platform. The Illinois Basin lies between the marine-dominated rocks of the Western Interior (Midcontinent) Basin to the west and the mainly coastal to terrestrial strata of the Appalachian Basin to the east.

The *Cordaites* sample from USNM locality 38,878 comes from the now-closed Brazil Coal and Clay Company, Saline pit 1, in Clay County, west-central Indiana. The Brazil Formation contains the Lower and Upper Block coals in its lower part, and ends at the top of Minshall Coal (Mastalerz et al., 2003). Strata above the Minshall Coal, strata are assigned to the Staunton Formation. Recent considerations of plant macrofossils, palynomorphs and conodonts from these strata indicate that the Atokan-Desmoinesian (approximately Bolsovian-Asturian) Stage boundary lies near the horizon of the Minshall Coal (Bashforth et al., 2016b; DiMichele et al., 2016), which is at variance with the earlier determination of Peppers (1996). The sample was collected in the shales below the Minshall coal bed; these shales contain a flora from a seasonally dry environment (DiMichele et al., 2016).

The second sample comes from NERCO AMC South Pit in Daviess County in Indiana, USNM locality 38,874. This is from shales above the Minshall Coal (previously thought to be the Buffaloville, which, in comparison with its type section is one coal above this level; DiMichele et al., 2016), Staunton Formation. The coal misidentified as the Buffaloville in Daveiss County, Indiana is correlative with the Minshall coal and may have been a single continuous peat bed at their time of formation. The name "Minshall Coal Member" is applied in Clay, Fountain, Greene, Owen, and Parke Counties, Indiana, whereas "Buffaloville Coal Member" is applied farther south. In Daviess County, this coal is equivalent to the Minshall, not to the Buffaloville in its type area, in Spencer County, Indiana (Hatch and Affolter, 2002).

The last studied *Cordaites* specimens from the Illinois Basin come from the upper part of the Pennsylvanian sequence preserved in this basin. The uppermost McLeansboro Group includes all Pennsylvanian rocks in Illinois above the Danville (No. 7) Coal (Desmoinesian, Missourian and Virgilian) and is made up of three formations - the Patoka, Bond, and Mattoon. The McLeansboro Group contains well developed cyclothems and marine members, including thicker, less argillaceous limestones. Coals are not very thick or extensive. Most are less than 1 ft thick, although some coals are up to 4 ft (1.2 m) thick. Variegated claystones, many of them dominantly red, occur several decimeters above and below some of the limestones. They are much less common in other Pennsylvanian strata. Light olive or tan argillaceous limestone units up to 3–4 ft (90–120 cm) thick and bearing only ostracodes, *Spirorbis*, and very few pelecypods are present in the McLeansboro, particularly in the upper part. The Shumway Limestone in the middle of the Mattoon Formation (cca 600 ft; 200 m thick) indicates the base of the Virgilian. The Shumway Limestone and the thin coal a few decimeters under it are exposed in Richland County. The limestone is directly underlain by a black fissile shale, the Teutopolis Shale, and overlain by gray shale. The *Cordaites* remains examined here come from silty limestone or carbonate-rich shale, the Lake Sara Limestone, and informally named unit that overlies the Watson Coal and is found beneath the black shale below the Shumway Limestone.

The Kinney Quarry site in central New Mexico is one of only a few fully described Late Pennsylvanian, Missourian-age floras in North America (DiMichele et al., 2013). Traditionally thought to be Virgilian, the stratigraphy was revised by Lucas et al. (2011), who placed it in the Missourian. Pennsylvanian strata in the Manzanita and Manzano Mountains rest unconformably on Precambrian granitic and metamorphic rocks and their thickness averages 450 m. The basal unit (Sandia Formation) is a relatively thin, predominantly sandy siliciclastic unit of mostly Atokan age (Krainer and Lucas, 2013). It is overlain by the Gray Mesa Formation of Desmoinesian age, the strata consisting chiefly of a succession (180 m thick) of massive, cliff-forming, gray, locally cherty limestone beds (Nelson et al., 2013). This limestone is overlain by the Atrasado Formation, which is composed of rhythmic sequences of arkosic sandstone, gray, tan, and red shale, and gray marine limestone of late Desmoinesian to earliest Wolfcampian age (Kues and Lucas, 1992). Seven members are recognized in the Atrasado Formation, in ascending order, Bartolo, Amado, Tinajas, Council Spring, Burrego, Story, Del Cuerto, and Moya (Lucas et al., 2011). The Atrasado Formation is overlain by the Bursum Formation, a thin sequence of Wolfcampian red to green shales and sandstones with thin beds of gray marine limestone (Kues and Lucas, 1992), that straddles the Pennsylvainan-Permian boundary. This general pattern of thick Middle Pennsylvanian limestone, Upper Pennsylvanian alternation of limestones and marine to nonmarine clastics, and early Wolfcampian red-clastic-dominated strata with minor marine limestone is typical of the Pennsylvanian—earliest Permian sequence throughout central New Mexico (Armstrong et al., 1979). Marine environments in this area ceased with deposition of the Wolfcampian to earliest Leonardian Abo Formation, which is composed of red terrigenous sandstones and shales derived from the north. About 28 m of the Tinajas Member, Atrasado Formation, are exposed in the Kinney Quarry (Lucas et al., 2011), well known by plant and animal remains.

4. Systematics

Class Pinopsida
Order Cordaitanthales Meyen, 1984
Family Cordaitanthanceae Meyen, 1984
Genus ***Cordaites*** Unger, 1850

4.1. Cordaites olneyensis Šimůnek, sp. nov. (Fig. 1a, Pls. I–III)

Derivation of name: After Olney village, Richland County, Illinois, U.S.A.

Holotype: USNM specimen 698230 designated here on Pl. I, Fig. 2, and cuticles prepared from it. Slides 426/1–9 figured on Pl. I, Figs. 4 and 5, Pl. II, Figs. 1–3, SEM stub: 31.

Type locality: USNM 38882; near Olney, Richland County, Illinois.

Type horizon: Basal limestone of Shumway Cyclothem, informally named the "Lake Sara Limestone", Mattoon Formation, McLeansboro Group, Late Pennsylvanian (equivalent to Stephanian).

Material: Six samples; three samples were used for slides 337/1–11, 337/1–5, 426/1–9.

Diagnosis: Large lanceolate leaves with fine parallel venation. Adaxial and abaxial cuticles do not differ morphologically in a substantial way. Stomatal rows are prominent, guard cells with swallowtail polar endings, lateral subsidiary cells more-or-less oblong, polar subsidiary cells small, rounded to oval.