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An arborescent lycopsid stem fragment from the Palliser Formation
(Famennian) carbonate platform, southwestern Alberta, Canada, and its
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Abstract: A partially silicified stem fragment of an arborescent lycopsid, tentatively identified as *Leptophloeum rhombicum*, is documented from peritidal carbonates in the Palliser Formation (Upper Devonian; Famennian) of southwestern Alberta. An unlikely inhabitant of these tidal flats, the log must have rafted in from a relatively nearby land area. The most probable candidate sources are either the Kootenay island arc to the paleo-northwest or hypothetical Montania to the southwest. The specimen is evidence that either or both these equatorial areas had a humid paleoclimate and vegetated coastal marshes and swamps.

Résumé : Un fragment d'une tige partiellement silicifiée d'un lycopside arborescent, provisionnellement identifié comme *Leptophloeum rhombicum*, est documenté dans

un niveau d'une succession de carbonates péritidaux de la Formation de Palliser d'Alberta de sud-ouest. Un habitant peu probable de cet environnement maréal, cette tige a flotté probablement d'une superficie relativement proche. Les deux candidats les plus possibles sont l'île arc de Kootenay au paléo-nord-ouest ou le terrain de Montania hypothésisé au sud-ouest. Le spécimen est la preuve que l'un ou les deux de ces régions équatoriales avait un paléoclimat humide et des marches côtières végétalisées.

Key words: lycopsid, Palliser Formation, Famennian, Upper Devonian, Alberta

Introduction

Fossil plants of Late Devonian age are known from a number of localities in eastern North America, Arctic Canada and elsewhere in the world and prove to be quite diverse, although their record is dwarfed by that of the Carboniferous due to far greater distribution of appropriate facies and consequently abundance of collecting sites (DiMichele and Gastaldo 2008). Likewise, however, they appear to have mainly inhabited tropical wetlands that developed on flood plains, coasts and deltas (e.g., Scheckler 1986; Greb et al. 2006; Cressler 2006). Here we document an unusual occurrence of a fossil arborescent lycopsid preserved as a silicified stem fragment in tidal flat dolomite of a Famennian-aged carbonate platform. Although lycopsids have been found in the Middle Devonian of Washington (Benca et al. 2014) and Arizona (Canright 1970), the specimen appears to be the only example of a fossilized tree-sized plant of Late Devonian age yet discovered in western North

America. It is clearly allochthonous but demonstrates that forested wetlands were present in relatively nearby land areas under a humid paleoclimate.

Geological Setting and locality

Western Canada in the Late Devonian was in an equatorial location facing Panthalassa and flanked by an island arc (Fig. 1A). The Famennian-age Palliser Formation and its subsurface equivalent Wabamun Group of the Alberta Shelf extends from southern Saskatchewan to just west of the present-day Rocky Mountain Trench in southeastern British Columbia and northwestern Montana, and north past the Peace River Arch (Halbertsma 1994; Fig. 1B). It thus represents one of the largest carbonate platforms to have existed on Earth (Peterhänsel and Pratt 2008). Anhydrite was deposited in the inner part of the platform in the subsurface of southeastern Alberta and southern Saskatchewan during much of Wabamun time. However, the uppermost interval, the Big Valley Formation, is characterized by silty shale and argillaceous limestone (Halbertsma 1994), which pass westward into limestone and dolomite belonging to the Costigan Member in the Rocky Mountains. This probably signaled a transition from arid conditions to a more humid paleoclimate. The Costigan Member is considered to span the *Palmatolepis marginifera*, *P. trachytera*, *P. postera* and lower *P. expansa* biozones (Richards and Higgins 1988; Johnston and Chatterton 2001).

The Costigan Member by Jura Creek, north of Exshaw in the Front Ranges, is 44 m thick (Meijer Drees et al. 1993) and consists of intercalated subtidal, finely bioclastic–peloidal limestone and peritidal limestone and dolomite (Richards and

Higgins 1988; Meijer Drees and Johnston 1994; Peterhänsel and Pratt 2008). The uppermost 2 m are fossiliferous bioclastic limestone containing laminar stromatoporoids; this interval is in sharp contact with the lower Costigan Member, possibly indicating a subaerial erosion surface and hiatus (Richards and Higgins 1988; Johnston and Chatterton 2001; Peterhänsel and Pratt 2008).

The fossil-bearing sample was collected from the creek bed downstream of the type section of the Exshaw Formation. It consists of a tidal flat carbonate (Fig. 2A) likely from a peritidal interval in the lower Costigan Member, and therefore belongs to the uppermost *P. marginifera* to lower *P. trachytera* zones (Meijer Drees and Johnston 1994).

Taphonomy

The stem fragment with attached leaves is oriented parallel to bedding within microbial laminite (Fig. 2A) and is likely part of a small log that floated onto the tidal flat. The pith and primary and secondary xylem are not preserved and likely decayed before the log grounded. The curvature of the specimen, essentially a mold showing the interior of the bark, suggests it is vertically compressed by about one-quarter, probably from sagging as it rotted. It escaped complete decay perhaps in part because it was protected by cuticular wax, but it may have been enveloped in a microbial mat that became anaerobic under the surface. The periderm and exterior surface of the leaves are relatively coarsely permineralized by dark-coloured microcrystalline silica which in the lower area of the specimen is thickened due to overgrowth by light-coloured microcrystalline quartz cement (Fig. 2B, C). The

alternative that they were permineralized by calcite which was then preferentially replaced by silica seems less likely due to the absence of silica or chert elsewhere in the sample. The source of the silica is unknown, but the proximity of the Kootenay island arc to the west suggests that there could have been occasional deposition of volcanic ash. The hollow interior appears to have escaped being filled by calcite cement during burial.

Paleogeography

Late Devonian arborescent lycopsids were part of the tree components of plant communities that inhabited wetlands in low-relief fluvio-deltaic and shoreline settings (Scheckler 1986). There is no evidence that tropical carbonate tidal flats of this age, even those that were humid, supported lycophytes, sphenophytes, ferns or other macrophytic plants. In west-central North America, the Famennian shoreline lay far to the paleo-east and south beyond the shallow inner shelf where dominantly siliciclastic sediments were deposited (Fig. 1B). Given that the host facies records a tidal flat island located in the outer part of the platform, it is likely that the stem was carried by currents or waves from a low-relief land area seaward of the platform or adjacent to it but still some distance away. Long-distance rafting of stems and trunks into deeper water where they became waterlogged and sank has been reported in Upper Devonian strata (Chitaley and Pigg 1996; Chitaley and Cai 2001; Decombeix and Meyer-Berthaud 2013).

A paleoceanographic reconstruction for the Late Devonian (W. Kiessling maps in Copper 2002 and Webb 2002) postulates an eastward-directed equatorial surface

current in Panthalassa, with a large clockwise gyre to the north and a large counter-clockwise gyre to the south, much as in the present-day Pacific Ocean, even though the latitudinal climate gradient was considerably less. A source for the trunk fragment from the paleo-west or southwest would seem more likely than from the paleo-north, but the generalized and hypothetical nature of this reconstruction does not rule out the latter.

Famennian spores and plants have been recovered from fluvio-deltaic strata of the Parry Island Formation comprising the top of the Franklinian clastic wedge in Arctic Canada (McGregor 1994; Xue and Basinger 2016). This unit also contains coal (Goodarzi et al. 1994). Spores occur in the correlative deeper water strata belonging to Imperial and Tuttle formations of northern Yukon Territory and northwestern Northwest Territories (Chi and Hills 1976; Hills et al. 1984a, b). Some spore taxa such as species of *Auroraspora* and *Lagenicula* are lycopsids (e.g., Stevens et al. 2010). Famennian spores are also present in shale interbedded with limestone of the Kotcho Formation of southwestern Northwest Territories (McGregor *in* Richards 1989). Sourcing the trunk fragment from the Arctic Islands would require that it drifted upwards of 3000 km, which seems implausible.

The presence of a large land area in western Montana, Idaho and northeastern Washington and cored by Mesoproterozoic rocks, termed Montania, is hypothesized by the lack of lower and middle Paleozoic strata there. It may have been a source of detrital sediment in the Big Valley Formation (Grader et al. 2014). If so, it may have hosted suitable wetland habitats along its shores. Support for this possibility is the

presence of fossil plants in Lower Devonian fluvial and estuarine deposits on the flank of the Yellowstone Park Uplift (Caruso and Tomescu 2012).

Tectonic reconstructions of the Canadian Cordillera show a narrow elongated basin called the Prophet Trough, which separated the shallow-water craton from the Kootenay Arc (e.g., Morrow and Geldsetzer 1988, fig. 22; Sandberg et al. 1988, fig. 16; Halbertsma 1994, fig. 13.6; Nelson et al. 2006; Colpron and Nelson 2007). The Quesnel Terrane (or Quesnellia) lay outboard of this. A geographically limited component, the Harper Ranch subterrane in the present-day Okanagan area, contains arc-related fluvial to marine strata with possible lycopsid plant debris at the base which is late Famennian in age (Beatty et al. 2006). Thus, wetlands along the margin of the island arc represent another possible source for the log.

Systematic paleontology

Class Lycopsidea

Order Isoetales

Family Leptophloeaceae Kräusel and Weyland, 1949

DISCUSSION: The suprageneric classification adopted herein is that of Wang et al. (2005). It is recognized that Late Devonian arborescent lycopsids are transitional to Protolpidodendrales. Some specimens of the Givetian to early Frasnian herbaceous lycopsid *Haskinsia colophylla* (Grierson and Banks 1963) also bear leaf cushions that are rhombic in outline and leaves that are acuminate in plan view and falcate in lateral view. However, the large (~15 Myr) difference in age between occurrences of

species belonging to *Haskinsia* Grierson and Banks, 1983 and the specimen described here suggests a different taxonomic assignment, but do point to taxonomic issues which have yet to be solved, while at the same time indicating a conservative morphology for a great deal of geological time.

Genus *Leptophloeum* Dawson, 1862

TYPE SPECIES: *Leptophloeum rhombicum* Dawson, 1862 from the Perry Formation (Upper Devonian) of southeastern Maine, by monotypy.

DISCUSSION: Dawson erected this taxon based on the equidimensional rhombic outline of the leaf cushion with a centrally located leaf scar (Dawson 1862, p. 316, pl. 12, fig. 8, pl. 17, fig. 53; 1863, pl. 18, fig. 19; 1871, pl. 8, figs. 88, 89, 89a). Besides the type species, five additional species have been assigned to the genus. However, the range of features observed in well-preserved material from Xinjiang assigned to *L. rhombicum* suggests that either there are only two valid species (Lemoigne 1982) or all are conspecific with the type species (Li et al. 1986). This is supported by variation seen in other lycopsids. Leaf base outline may vary within individual specimens relative to height of the stem (e.g., Schweitzer 2006; Gensel and Pigg 2010; Berry and Marshall 2015). Characteristics of the leaf cushions can also be variable (e.g., Schweitzer 1965, figs. 2–5; also 1999, fig. 22). Consequently, *L. rhombicum* had essentially a global distribution. Wang et al. (2005) depicted the tree as reaching 10–25 m tall and 0.3–0.4 m wide at the base.

?*Leptophloeum rhombicum* Dawson, 1862

Fig. 2B, C

HOLOTYPE: Stem fragment from the Perry Formation (USNM 4304-1), southeastern Maine, by subsequent designation (Dawson 1862, pl. 12, fig. 8; Smith and White 1905, pl. 6, fig. 1).

MATERIAL: Silicified leaves and periderm of a stem fragment in a float boulder (TMP 2016.020.0001).

OCCURRENCE: Lower Costigan Member, Palliser Formation (probably uppermost *P. marginifera* to lower *P. trachytera* conodont biozones), Jura Creek north of Exshaw, Front Ranges, Alberta. The sample was collected downstream of the type section of the Exshaw Formation (51°05'28"N, 115°09'33"W).

DESCRIPTION: The fragment is 6 cm long and 2 cm wide and consists of half of a stem that was gently ellipsoidal in transverse cross-section. It is longitudinally concave, essentially forming a mold of the stem viewed from the interior, with the external surface of the leaves and periderm silicified. The surface of the mold is slightly oblique, cutting deeper into the periderm away from the preserved leaves. The periderm exhibits rhombic (equidimensional) leaf cushions that are ~4 mm on each side; they share adjacent faces, which imparts a helical pattern with a

parastichy angle of 45°. The leaf scars are convex and elongate. The ligule pit appears to be preserved at the apex of some leaf cushions near the distal end of the specimen. Microphylls are simple, straight, acuminate in outline and ~10 mm in length. Their basal part is 2.5 mm in width and convex whereas the remainder is slightly curved axially. Other details such as falcate leaf shape are not preserved.

DISCUSSION: The specimen is poorly preserved and many primary features appear to have been obscured or modified by decay before permineralization. The identification is therefore tentative.

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Figure captions

Fig. 1A. Simplified global plate tectonic map (Mollweide projection) for the late Famennian–early Viséan based on figure 15 of Golonka (2002). The Laurentian portion of Laurussia is coloured light-blue. Black-outlined rectangle shows the study region depicted in Figure 1B. B. Simplified paleogeography of west-central North America in late mid-Famennian time. North America is rotated so that the

reconstructed paleo-equator is oriented west–east and approximately located across northern Alberta (e.g., Golonka 2002; compilation by R. Blakey 2016). The Palliser Formation is the outcrop equivalent of the subsurface Wabamum Group. The inner shelf succession comprising the Big Valley Formation is siliciclastic; it is parts of the underlying Stettler Formation that are anhydritic. The red star shows the location of the collecting site in Jura Creek, near Exshaw west of Calgary, Alberta.

Fig. 2A. Slabbed surface perpendicular to bedding through the fossil-bearing sample. The ellipse shows the location and approximate size of the lycopsid trunk fragment preserved in the counterpart. The lower half is light-coloured, microbially laminated, sparsely intraclastic dolostone with folded laminae at bottom. The upper surface of that bed is erosively overlain by dark-coloured, plane- and cross-laminated peloidal mudstone hosting a lens of light-coloured dolomitized grainstone penetrated by tubular burrows (*Planolites* isp.) filled with dark-coloured mudstone. Lower Costigan Member, Palliser Formation, Jura Creek (float sample). B. Interior view of silicified bark showing rhombic leaf cushions with a number of leaf molds at the edges and top (TMP 2016.020.0001). C. Latex cast of B flipped on its vertical axis. B and C are dusted with ammonium chloride sublimate.

Figure 1

284x237mm (300 x 300 DPI)

Figure 2

160x118mm (300 x 300 DPI)