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Fossil wood of *Eristophyton* sp. from the Carboniferous deposits of northern Russia (Arkhangelsk region)

Bois fossile d'Eristophyton dans les dépôts carbonifères du Nord de la Russie (région d'Archangelsk)

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ABSTRACT

Permineralised wood of *Eristophyton* sp. is first described from the Carboniferous deposits of the Arkhangelsk region, northern Russia. The specimens used in the study show scalariform thickening of the metaxylem tracheids both on radial and tangential walls. *Eristophyton* sp. indicates well preserved elements of secondary xylem: uni-, rarely biseriate xylem rays up to 15–16 cells high; uni-, multiseriate tracheid pitting only on radial walls; 1–8 contiguous cross-field pits and their inclined narrow apertures. A brief review and comparison with known anatomically preserved plants from the Lower Carboniferous of different localities of Scotland, France, USA and Poland is discussed.

RÉSUMÉ

Un bois perminéralisé d'*Eristophyton* sp. est décrit pour la première fois dans les formations carbonifères de la région d'Arkhangelsk, en Russie septentrionale. Les échantillons utilisés dans l'étude ici présentée montrent un épaississement scalariforme des trachéides de métaxylène sur les parois à la fois radiales et tangentielles. *Eristophyton* sp. révèle des éléments de xylène secondaire bien conservés : des rayons de xylène uni– rarement bisériés jusqu'à 15–16 cellules de haut ; une corrosion de trachéides uni- ou multisériée sur les parois radiales ; 1–8 cavités contiguës transverses et leur ouverture étroite et inclinée. Une brève revue et comparaison de plantes connues, anatomiquement conservées, des formations carbonifères de différentes localités d'Écosse, de France, des USA et de Pologne est discutée.

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1. Introduction

This article is dedicated to the description of the anatomically preserved plants found in the Carboniferous deposits of Russia. Anatomically preserved plants of this age are rare in Russia. First M.D. Zalessky (Zalessky, 1911) described plant fragments of *Mesopitys tchihatcheffii* Zal. preserved as permineralisations from the Permian deposits of Russia (Kuznetsk Coal Basin) and also distinguished the new Late Palaeozoic genera: Eristophyton Zal. and Callixylon Zal. based on the material from Poland (Goeppert's collection, Glätzisch-Falkenberg, the Lower Carboniferous), and from Ukraine (Zalessky, Donetsk Coal basin, the Upper Devonian). Subsequently Zalessky paid great attention to anatomy of the Late Palaeozoic plants of Russia in other publications (Zalessky, 1927; Zalessky, 1934) Then I.A. Shilkina (Shilkina, 1960) and V.G. Lepekhina (Lepekhina, 1965; Lepekhina, 1969; Lepekhina, 1972a; Lepekhina, 1972b) carried out an investigation of the wood remains from different parts of Russia. Shilkina (Shilkina, 1960) described new wood fragments of *Taxopitys arctica* Shilkina from the Upper Carboniferous of eastern Siberia. Lepekhina (Lepekhina, 1965; Lepekhina, 1972b) revised pycnoxylic gymnosperm woods of the Late Palaeozoic Age. She suggested separation of the group *Dadoxyleae* and determined five morphogenera for stems with only preserved secondary wood, because she considered that the structure of the secondary xylem was the most significant and stable features in comparison with those of the primary xylem. Lepekhina (Lepekhina, 1969) also characterised the distribution of the wood remains in the Upper Palaeozoic deposits of the Kuznetsk Coal Basin. In 1972 Lepekhina (Lepekhina, 1972a) made a new revision of the Late Palaeozoic gymnosperms according to their anatomical structures and showed a list of valid species (five Carboniferous species: *Araucarioxylon balachonskiense* V. Lepech., *A. rangeifoime* Lepech., *A. multiseriale* Lepech., *A. gorelovae* Lepech., and *Eristophyton fasciculare* (Scott) Zal. A lot of permineralisations (Calamitaceae, Lepidodendraceae, etc.) were studied by N. Snigirevskaya (Snigirevskaya, 1964; Snigirevskaya, 1967) from the Upper Carboniferous of the Donetsk basin (Ukraine). In 2003 S.M. Snigirevsky (Antashtchuk and Snigirevsky, 2003) described two wood fragments as *Palaeoxylon bourbachensis* Coulon et Lemoigne from the Upper Visean deposits of the Arkhangelsk region, northern Russia (exact location of locality was not indicated). Recently, a new fossil wood of *Tovoxylon alekseevii* O.Orl. (Orlova, 2009) was described from the same region (Late Visean; locality near the Tovskoe Lake, in the North of the Arkhangelsk region).

Main contributions in anatomy, systematic and evolution of the Carboniferous permineralised plants mainly from Scotland, France and USA (Cribbs, 1938) have been published by D.H. Scott (Scott, 1902; Scott, 1924), W.S. Lacey (Lacey, 1953), A.G. Long (Long, 1979; Long, 1987), J. Walton (Walton, 1957), J. Galtier and A.C. Scott (Galtier and Scott, 1990; Galtier and Scott, 1991; Galtier and Scott, 1994), J. Galtier et al. (Galtier et al., 1998; Galtier et al., 1993), A.L. Decombeix et al. (Decombeix et al., 2006; Decombeix et al., 2007), J. Galtier and B. Meyer-Berthaud (Galtier and Meyer-Berthaud, 2006).

Our collection consists of various wood remains from two localities. Wood fragments used in the study are kept in the collections of the Department of Paleontology, Geological Faculty, MSU.

2. Material and methods

Permineralised (hematite) wood remains come from yellow ferruginous sandstones of two localities, which are situated on the South of the Arkhangelsk region. The first one (outcrop K276), is near the Voya River (Fig. 1). Sandstone sample ($50 \times 20 \times 30$ mm) with small fragments resembling wood was split chemically, i.e. macerated with high-test hydrogen peroxide. Then "dispersed" wood fragments were selected (above 30 pieces) with a stereomicroscope Olympus SZ-6045. The other locality (borehole RPK3) is 40 km to the north from the first one (Fig. 1). The wood fragments have been extracted from the pieces of two very brittle specimens of stem. The biggest fragment of stem is up to 50 mm long and 65 mm wide, and was easily broken during the preparation. More than 15–20 stem pieces of each specimen were selected and studied.

All pieces of selected or macerated woods have been studied and photographed with a scanning electron microscope (CAMSCAN). Six to eight series of scanning electron microscope (SEM) for each specimen were made. Unfortunately, no other fossil remains (invertebrates, spores) were found in these localities.

3. Description of *Eristophyton* sp.

This taxon is represented by two specimens of stem and a lot of small "dispersed" wood fragments from the sandstone sample (Plate I–III). The specimens (RPK3/4-1, RPK3/4-7) are from a very brittle decorticated stem. A lot of wood fragments from different places of the stem were studied with SEM. Main significant anatomical features of this stem are indicated in Table 1. The secondary xylem (Plate II5) and some tracheids of primary xylem (Plate I2, 4) are well-preserved in the stem, nothing is known of the pith. In oblique-radial section metaxylem elements have been observed in three-dimensional view (Plate I2, 4). Metaxylem tracheids are narrow (17–29 μm in diameter), hexagonal in shape. They have scalariform thickening both on radial and tangential walls. Secondary xylem is of pycnoxylic type. In radial section the polygonal (frequently hexagonal) narrow tracheids are above 800 μm long and 22–45 μm (average 32 μm) wide (Plate II5). The tracheids have mainly uniseriate and biseriate bordered pitting (Plate I3), rarely triseriate (Plate I1). The pits are round to hexagonal in shape (Plate I3), 7–13 μm (average 8–9 μm) in diameter. Pit apertures are inclined (Plate I1), slit-like (up to 1 μm wide, 7 μm long). There is no pitting on tangential walls. Xylem rays (Plate I6) are uni- and biseriate (14–20 μm wide), not high (commonly 10–15 cells or 170–355 μm high) and relatively long (530 μm in visible length). Ray cells are rectangular in shape (Plate II2). The width of the ray cells is 9–20 μm, their height is 17–33 μm (average 23 μm). In radial section, ray cells are 21–48 μm long. The distance between neighboring rays in radial section is 103–250 μm. There are 1–5 (frequently

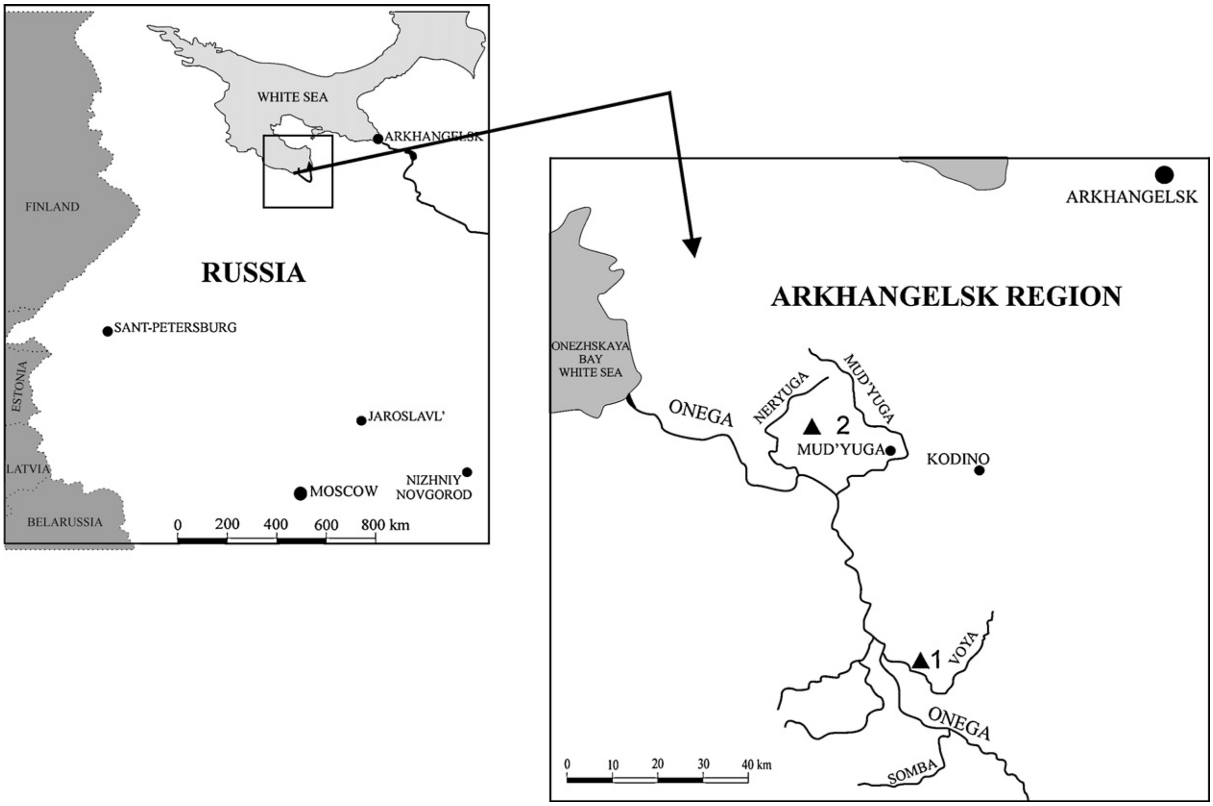

Fig. 1. Geographic position of the localities: 1 – outcrop K276; 2 – borehole RPK3.

Fig. 1. Position géographique des localités : 1 – affleurement K276 ; 2 – puits RPK 3.

2–3) contiguous pits in each cross-field (Plate I5). Mainly, they are arranged in two horizontal rows. The pits are 6.5–10 μm in diameter; rounded in shape with inclined narrow apertures. True growth rings are invisible.

The biggest "dispersed" wood piece from specimen K276/1 is up to 4000 μm long and 2100 μm wide (Plate III1). Secondary xylem is pycnoxylic type. Tracheids of secondary xylem (Plate II3) are narrow 13–50 μm (average 22–32 μm) wide, not so long (up to 640 μm long), hexagonal in shape (Plate III5). Tracheid pitting, only on radial walls, is predominantly biseriate (50%) and triseriate (12.5%), rarely uniseriate (37.5%). Multiseriate pits (Plate II1) are contiguous and alternate (araucarian), while uniseriate ones are free. Pits are rounded and hexagonal in outline, 5.2–12 μm (average 6–8 μm) in diameter, with inclined narrow-elliptical oblique apertures (up to 2 μm long and 8 μm wide). Rays are rare, only uniseriate (Plate III6). Most xylem rays (Plate III6) are short (3 cells or up to 120 μm high), several rays are larger (up to 16 cells or up to 380 μm high). The rays are 127–190 μm long in radial section, some rays exceed 225 μm long. Ray cells are rectangular or square (Plate III6), 23–72 μm long in radial section. Their height is 15–36 μm (commonly 30 μm). Cross-fields (Plate II4; Plate III3, 4) show 1–8 round-hexagonal pits (commonly 3–5 pits) 6–10 μm (7.5–9 μm) in diameter. Cross-fields pits are arranged in 1, frequently 2–3 rows. They are contiguous or free. Pit apertures are inclined elliptic or slit-like in shape.

4. Discussion

Described above specimens show some identical characters: absence of pitting on tangential walls, uni-, rarely biseriate rays up to 15–16 cells high, 1–3 rows of tracheid pitting on radial walls, similar diameter of pits, from 1 to 8 round, hexagonal pits with inclined apertures of the pits in cross-fields. They correspond to a single taxon. Among Carboniferous plants of gymnospermous affinities, our wood most closely resembles in ray organization and pitting the species *Eristophyton sp.* described by Galtier and Scott (Galtier and Scott, 1994) from the Late Visean of France. As shown in Table 1 *Eristophyton sp.* is similar to described above wood remains in ray height (average 7.4 cells high), ray width (generally 1–2 cells wide), multiseriate pitting only on radial walls, cross-field pitting, etc. Therefore, the wood fragments under study are determined as *Eristophyton* sp., and their age is assumed to be Late Visean.

Recently a comprehensive review of the genus *Eristophyton* was given by A.L. Decombeix et al. (Decombeix et al., 2007). The Mississippian species of the genus were examined in that paper. The type species of the genus *Eristophyton* is *E. beinertianum* (Goepp.) Zal. from the Upper Visean of Poland, and the Upper Tournaisian of Great Britain. Another Mississippian species – *E. waltonii* (Lacey) Galtier et Scott comes from the Upper Tournaisian – Upper Visean of Scotland. *E. beinertianum* and *E. waltonii* have well-preserved primary xylem and a fragmentary data

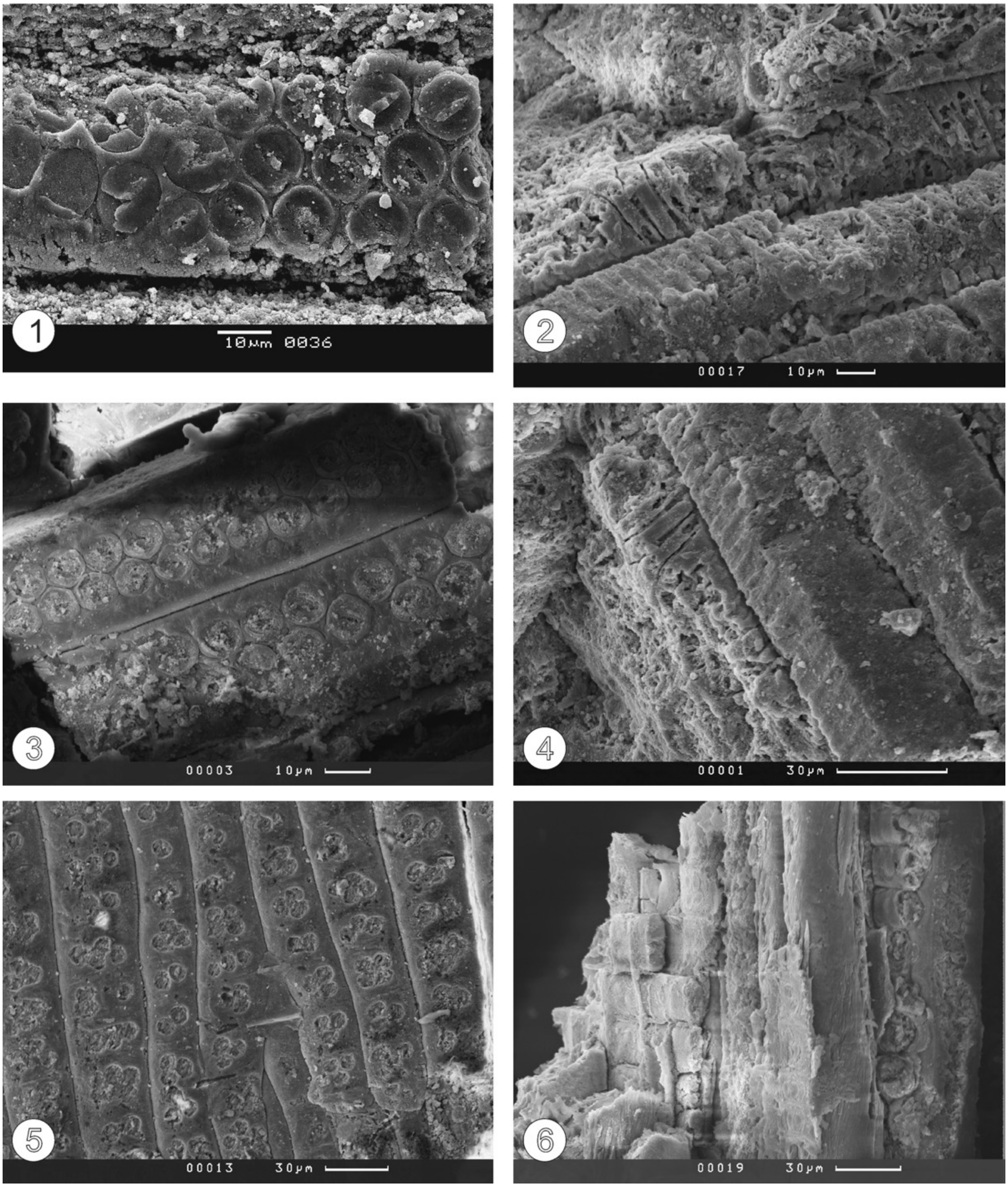

Plate I. *Eristophyton* sp. from the Carboniferous of northern Russia (borehole RPK3). **1**, **3**. Secondary xylem, radial longitudinal section, tracheids with biseriate (3) and triseriate (1) pitting, showing inclined slite-like apertures, 1 – RPK3/4-7a, 3 – RPK3/4-1 g. **2**, **4**. Primary xylem, oblique-radial section showing scalariform thickening of the tracheids both on radial and tangential walls, RPK3/4-1d. **5**. Secondary xylem, radial longitudinal section showing the pitting in cross-field areas, RPK3/4-1 g. **6**. Secondary xylem, oblique-tangential longitudinal section, showing structure of the rays, RPK3/4-7b.

Planche I. *Eristophyton* sp. du Carbonifère de Russie septentrionale (puits RPK 3). **1**, **3**. Xylème secondaire, section longitudinale radiale avec corrosion bisériée (3) et trisériée des trachéides montrant des ouvertures inclinées comme des fentes, 1 – RPK3/4-7a ; 3 – RPK3/4-1 g. **2**, **4**. Xylème primaire, section radiale-oblique montrant un épaississement scalariforme des trachéides sur les parois à la fois radiales et tangentielles RPK3/4-1d. **5**. Xylème secondaire, section longitudinale radiale montrant la corrosion en domaines croisés RPK3/4-1 g. **6**. Xylème secondaire, section longitudinale obliquo-aengentielle, montrant la structure des rayons, RPK3/4-7b.

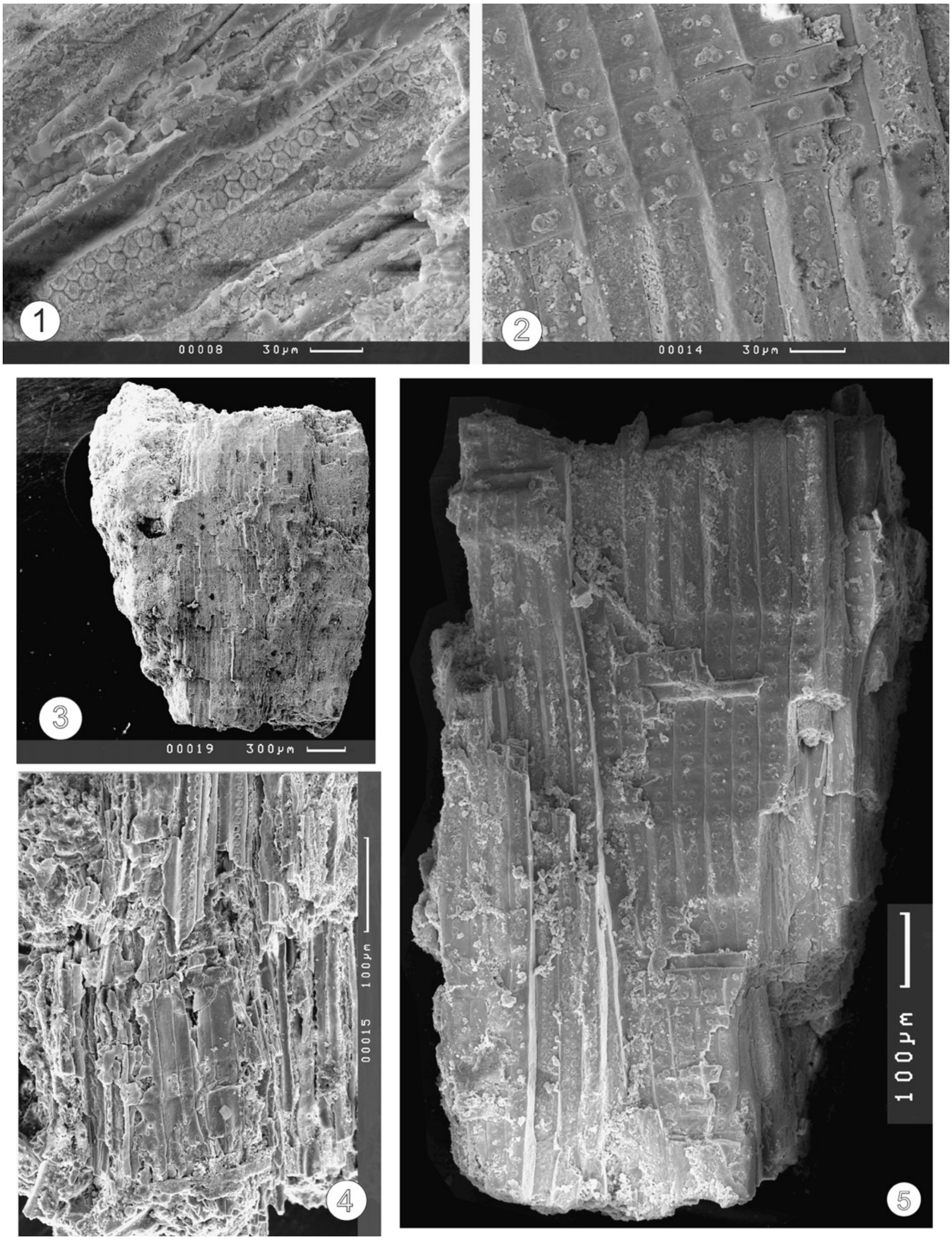

Plate II. 1, **3**, **4**. *Eristophyton* sp. from the Carboniferous of northern Russia (outcrop K276). **1**. Secondary xylem, radial longitudinal section, showing bi-triseriate pitting of tracheids on radial walls, F276-1-09. **3**. Secondary xylem, radial longitudinal section, general view, F276-1-05. **4**. Secondary xylem, radial longitudinal section, showing a part of ray, pitting in cross-field areas and uni-, biseriate pitting of the tracheids, F276-1-04. **2**, **5**. *Eristophyton* sp. from the Carboniferous of northern Russia (borehole RPK3). **2**. Secondary xylem, radial longitudinal section, showing cross-field areas and the pitting of the tracheids, RPK3/4-1 g. **5**. Secondary xylem, radial longitudinal section, general view, RPK3/4-1a.

Planche II. 1, 3, 4. *Eristophyton* sp. du Carbonifère de Russie septentrionale (affleurement K276). **1**. Xylème secondaire, section longitudinale radiale montrant une corrosion bi-triseriée des trachéides sur les parois radiales, F276-1-09. **3**. Xylème secondaire, section longitudinale radiale, vue générale, F276-1-05. **4**. Xylème secondaire, section longitudinale radiale montrant une partie de rayon, avec corrosion en domaines croisés, et corrosion uni- et bisériée des trachéides, F276-1-04. **2, 5**. *Eristophyton* sp. du Carbonifère de Russie septentrionale (puits RPK 3). **2**. Xylème secondaire, section longitudinale radiale montrant des domaines croisés et la corrosion de trachéides, RPK3/4-1 g. **5**. Xylème secondaire, section longitudinale radiale, vue générale, RPK3/4-1a.

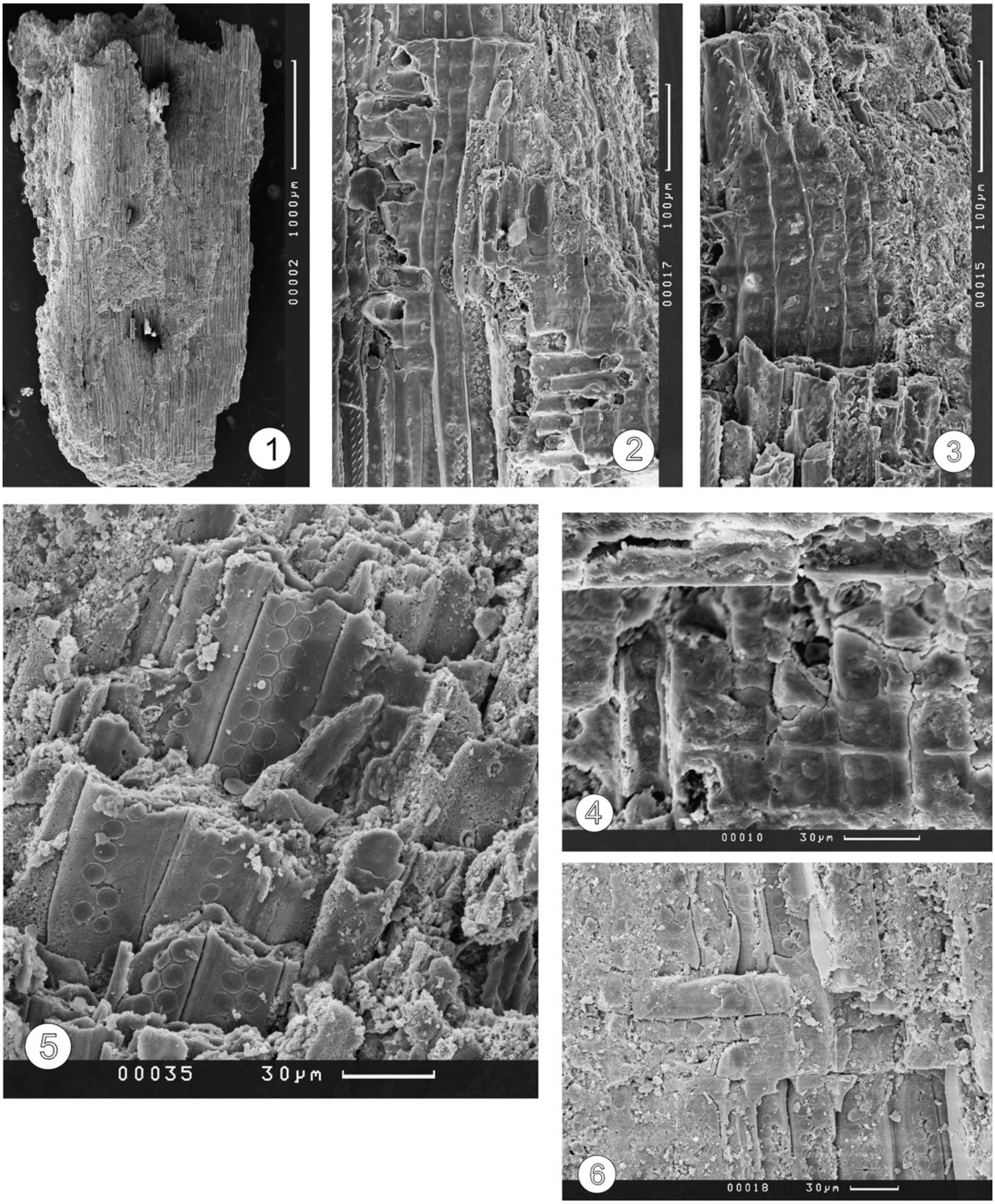

Plate III. *Eristophyton* sp. from the Carboniferous of northern Russia (outcrop K276). **1**. Secondary xylem, radial longitudinal section, general view, F276-1-11. **2**. Secondary xylem, radial longitudinal section, showing dilapidated rays and biseriate pitting of the tracheids, F276-1-12. **3**, **4**. Secondary xylem, radial longitudinal section, indicating pitting in cross-field areas, 3 – F276-1-04, 4 - F276-1-11. **5**. Secondary xylem, radial longitudinal section, pitting of the tracheids, F276-1-09. **6**. Secondary xylem, oblique-radial longitudinal section, showing uniseriate ray 3 cells high, F276-1-05.

Planche III. *Eristophyton* sp. du Carbonifère de Russie septentrionale (affleurement K276). **1**. Xylème secondaire, section longitudinale radiale, vue générale, F276-1-11. **2**. Xylème secondaire, section longitudinale radiale, montrant des rayons dilacérés et une corrosion bisériée des trachéides, F276-1-12. **3**, **4**. Xylème secondaire, section longitudinale radiale, indiquant une corrosion en domaines croisés, 3 – F276-1-04, 4 - F276-1-11. **5**. Xylème secondaire, section longitudinale radiale, corrosion des trachéides, F276-1-09. **6**. Xylème secondaire, section longitudinale obliquo-radiale, montrant un rayon unisérié de 3 cellules de haut, F276-1-05.

Table 1
Comparison of some significant parameters in specimens under study with measurements of the Early Carboniferous species. Average values are in bold type, rare parameters – in brackets, presence of feature is "+"; absence of description or feature is "–", faint parameters are indicated by "?".

Tableau 1
Comparaison de quelques paramètres significatifs des échantillons: RPK 3/4 et K276/1-9, avec mesure de taxa de bois carbonifères sous corrosion tangentielle. Les valeurs moyennes sont en gras, les paramètres rares – entre parenthèses, présence d'un trait donné, indiqué par « + », absence de description ou d'un trait donné, indiqué par « – », paramètres faibles indiqués par « ? ».

Species/Features	***Eristophyton* sp.**		***Eristophyton* sp.**	***E. cf. waltonii* Lacey**	***E. fasciculare* (Scott) Zal.**	***Dadoxylon ambiguum* Witham. sensu Frentzen**	***Endoxylon zonatum* (Kidston) Scott**	***Stanwoodia kirktonensis* Galtier et Scott**	***Bilignea solida* Scott**	***Protopitys scotica* Walton**	***Paleoxylon bourbachensis* Coulon et Lem.**
	RPK3/4-1 RPK3/4-7	**K276/1**									
Tracheid diameter, µm	22–**32**–45	13–**22**-**32**-50	15–**45**–95	20–40	30–45	30–**47**–70	12–48–60	20–**30**–50	**30**–60	40–60	32–**53**–88
Ray height, cells	(4) 10–15	**3**–16	1–**7.4**–23	1–**10**–30	1–35	1–**10–**35	**1–**9	**1–3–**10	1–10–(20)	**1–2**–3–(5)	3–**20**–78
Ray width, cells	1–(2)	1	1–**2**–3	1–**3**–5	**1**–(2–3)	1–**1.5**–2 (3)	**1**–2	1 (2)	1–(2)	1	1–**2** (3)
Ray cells height, Width, µm	17–**23**–33 9–20	15–**30**–36 –	16–43 8–27	22–46 14–38	– –	17–56 11–39	– –	30 20	– –	– –	30–60 17–25
Number of rows of pits	**1–2**–3	1–**2–3**	(1)–2–**3**–4	1–**2–3**–4	3–4	1–(2) **3–4**	**1–2**–3–4	2–3	2–4	Multiseriate	2–**3**–4
Pit diameter, µm	7–13	5.2–12	12–14	12	12–16	12	9–19	8–11	–	–	12–14
Cross-field pitting, cells	1–**2–3**–5	1–**3–5**–8	3–8	3–7	–	3–**5–7**–9	2–10	6–9	–	–	5–7
Cross-field pit diameter, µm	6.5–10	6–10	10	9–11	–	9*3	10–13	–	–	–	10–12
Cross-field pitting type	Inclined, slit-like	Inclined, slit-like	2 rows; oblique	Circular-oval simple	-	Oblique	Simple	-	–	–	Simple
Description of primary xylem	–	–	–	–	+	–	+	+	+	+	–
Reference	Present paper	Present paper	Galtier et al., 1998	Galtier et al., 1998	Scott, 1902; Galtier et al., 1993	Galtier et al., 1998	Scott, 1924; Lacey, 1953	Galtier, Scott, 1991	Scott, 1924	Walton, 1957; Galtier et al., 1998	Galtier et al., 1998; Antashtchuk, Snigirevsky, 2003
Age, region	Late Visean (?); Russia	Late Visean (?); Russia	Late Visean; France	Late Visean; France	Visean and Namurian A; Scotland	Late Visean; France	Visean; Scotland	Late Visean; Scotland	Tournaisian-and Namurian A; Scotland	Mid-Late Mississipian, Scotland	Visean; France, Russia

about characteristics of secondary xylem (tracheid pitting, cross-field, etc). Therefore it is extremely difficult to compare these two species (*E. beinertianum* and *E. waltonii*) with the studied material of *Eristophyton sp.* The third Mississippian species – *E. fasciculare* (Scott) Zal. described by Scott (Scott, 1902) and later Galtier et al. (Galtier et al., 1993) from the Visean – Namurian A of Scotland has well-preserved primary and secondary xylems. *E. fasciculare* shows mostly uniseriate, rarely bi-triseriate rays up to 35 cells high, and multiseriate tracheid. *E. fasciculare* differs (Table 1) from our specimens by higher rays, and absence of the tracheids with uniseriate pitting.

There are also several Early Carboniferous taxa resembling the wood fragments under study in some characteristics of secondary xylem, for instance in absence of pitting on tangential walls. As shown in Table 1 all these species show mainly uni-biseriate rays. Specimens under study resemble *Endoxylon zonatum* (Kidston) Scott (Lacey, 1953; Scott, 1924) from the Visean of Scotland in uniseriate (rarely biseriate) rays and in uni-multiseriate pitting, although the rays of the latter are shorter (generally 1, rarely up to 9 cells high), shape of radial pits is oval to rectangular, and pit diameter varies (from 9 to 19 μm). Besides, pores in cross-fields are simple.

Bilignea solida Scott (Table 1) described by Scott (Scott, 1924) from Tournaisian – Namurian A of Scotland shows (Table 1) the similar uni-, biseriate rays with in average 1–10 cells high and multiseriate pitting. But the character of pits is different: its pits are larger in diameter and oval to rectangular in shape. *B. resinosa* Scott differs from *Eristophyton* sp. by presence of pits on tangential walls, and uni-, biseriate pitting.

Some similarity is observed between species of the genus *Protopitys* with specimens under study. *P. buchiana* Goepp. shows resembling height and width of rays, but distinguishes by uniseriate pitting, larger rectangular pits on radial walls, and a great number of simple pits in cross-fields. Another species – *P. scotica* Walton known from the Mid-Late Mississipian of Scotland (Galtier and Scott, 1994; Walton, 1957) differs from our specimens (Table 1) by lower rays (generally 1–3 cells high). Besides, there is no information about its pitting in cross-fields.

In comparison with our specimens *Paleoxylon bourbachensis* Coulon et Lem. (Table 1) shows the same width in rays (1–2 cells) and multiseriate pitting. But main differences are in higher rays (up to 78 cells), and simple pores of pits in cross-fields. *Stanwoodia kirktonensis* Galtier and Scott (Galtier and Scott, 1991) from the Upper Visean of Scotland resembles (Table 1) our specimens in uni-, biseriate rays, and pitting (generally bi-triseriate). But *S. kirktonensis* shows shorter (1–10 cells high) rays, different character and number of cross-field pits (6–9 very small pits).

Dadoxylon ambiguum Witham sensu Frentzen known from the Late Visean of France (Galtier et al., 1998) resembles (Table 1) the wood of *Eristophyton sp.* in width of rays, pitting (uniseriate-multiseriate) of the tracheids and similar number of pits in cross-fields. In contrast, it is characterized by higher rays (up to 35 cells) and oval pits in cross-fields. The wood fragments under study differ from *Tovoxylon alekseevii* O. Orl. (Orlova, 2009) from the Upper Visean of northern Russia by absence of tangential pitting, taller rays (up to 16 cells instead 1 cells in high), character of the pitting on the radial walls (1–3 rows in contrast of uniseriate pitting), and inclined slit-like pores (instead simple round pores).

5. Results

The specimens described in this paper extend the recognition of systematical composition and taxonomic variability of the plants of gymnospermous affinities found in the Carboniferous deposits of the northern Russia. As noted above, earlier the woods of *P. bourbachensis,* and *T. alekseevii* were described from the Lower Carboniferous deposits of northern Russia. Present data suggest that three stems of gymnospermous affinities occurred in the Early Carboniferous plant association of the North Russia. There are *P. bourbachensis, T. alekseevii*, and *Eristophyton* sp. Besides, the similarity between the Late Visean anatomically preserved plant assemblages of France (Galtier et al., 1998) and northern Russia is supported by the presence of two similar taxa – *P. bourbachensis* and *Eristophyton* sp. in both areas.

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