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SUPPLEMENTARY INFORMATION

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Sporophytes of polysporangiate land plants from the early Silurian period may have been photosynthetically autonomous

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Supplementary Information

Material

The most important part of the studied material comes from an historical museum collection gathered by the famous French palaeontologist Joachim Barrande, who lived in Prague during the second half of the 19th century. The studied plant fossils were long overlooked, being in a museum box depot, in a box labeled *Fucoides*, in accordance with understanding of the material at the time it was discovered, and thus seemingly uninteresting. The material was re-discovered by V. Turek from the National Museum, Prague, while moving the collection to the museum's new depository building. The best preserved specimen, a fertile cooksonioid plant is described here as a new species of *Cooksonia*. The locality Loděnice (Lodenitz) is handwritten by Barrande directly on the rock sample. This *Cooksonia* is here on the same bedding plane, in the same rock sample as a *Monograptus flemingii* (Salter) graptolite. Other specimens (e.g. specimens D 550, D 553) are commonly associated with the zonal index graptolite *Monograptus belophorus* (Meneghini) (Suppl. Fig. 4A), conspecific with its junior synonym *M. flexilis* Elles. This fact, identical lithology, and associated trilobite and shell-bearing fauna among all samples in this rediscovered box led us to infer that all the samples of cooksonioids that we studied from this box come from that *Monograptus belophorus* Biozone. *Monograptus belophorus* is confined to the lower part of the *Cyrtograptus rigidus* Biozone in the British Isles.[1,2] A separate *M. belophorus* Biozone underlying the *C. rigidus* Biozone (Suppl. Tab.) is recognized in peri-Gondwanan Europe.[3, 4]

The 'discovery' of this mislabeled box initiated a search for Barrande's original locality. The present authors were able to re-discover that original locality, where Barrande collected the specimens, and identified the stratigraphic level at the Loděnice-Špičatý vrch road cut (Barrandian area, Suppl. Figs 1, 2). A number of sterile fragments of cooksonioids have been newly collected in brown-grey calcareous and tuffaceous shale within this *M. belophorus* Biozone (Motol Formation, lower Wenlock, middle Sheinwoodian[4]), right next to the original Barrande locality (Suppl. Fig. 3). The layer with *Cooksonia* plant remains also contains diversified fauna. Besides *Monograptus belophorus* (Suppl. Fig. 4A), other stratigraphically important graptolites were found: *Monograptus flemingii, Monoclimacis meneghinii*, *Mediograptus antennularius*, *Pristiograptus* ?*dubius dubius*, *Paraplectograptus* sp. and a *Miraspis mira* trilobite (Suppl. Fig. 4B), allowing its direct correlation with the *M.*

belophorus Biozone in the Sheinwoodian Stage of the Wenlock Series (Suppl. Tab.). This fauna, including representatives of diversified trilobites and brachiopods, is known in great detail.[5,6] Layer 4 from Suppl. Fig. C, where the cooksonioids were found, consists of fine-grained laminated calcareous and tuffaceous shales (Suppl. Fig. 3, arrowed), while in layer 5, tuffaceous shales alternate with limestone intercalations. All sediments of the studied profile (Suppl. Fig. 3) originated in a moderately shallow, quiet-water environment[6] surrounding a volcanic island (Suppl. Fig. 2), from which our specimens washed down. The central part of the island, as presently understood, was situated about 2 km from the studied outcrop.[7,8,9] The distribution of tuffaceous and calcareous components in these sediments was governed by the intensity of volcanic activity[8], and the distance from the volcanic centre, as particles of various densities precipitated out in the water column at different distances from their volcanic source (Suppl. Fig. 2).

The *Cooksonia* fossils described here come from what was then the southern hemisphere, where the peri-Gondwana terranes and microcontinents, including those of the present Bohemian Massif, were situated at a medium latitude[10]. The fossiliferous layers containing these fossils are products of near-shore marine sedimentation of volcanic islands, the largest of which formed today's Svatý Jan Volcanic Centre.[6,7] The geological context of the Loděnice, Špičatý vrch locality, and the rich associated marine fauna support our hypothesis that *Cooksonia barrandei* grew on volcanic islands in the broadly defined Rheic Ocean.

Systematic palaeontology

Cooksonia barrandei Libertín, Kvaček, Bek, Žárský, Štorch sp. nov.
(Figs 1A–E).

Holotype: D 552a,b, National Museum, Prague (Figs 1A–E).

Derivation of the name: Honouring Joachim Barrande, famous French palaeontologist living in Prague, author of the monograph Systême Silurien du centre de la Bohême.

Type locality: Loděnice, Špičatý vrch - Barrandovy Jámy.

Type horizon: *Monograptus belophorus* Biozone, Motol Formation, middle Sheinwoodian, Wenlock, Silurian.

Diagnosis. Axes robust, smooth, dichotomously branched, widening considerably in terminal part, terminally bearing lentil-shaped sporangia. Subtending axes broadly funnel-shaped, with prominent rim slightly exceeding width of subtending axis. *In situ* spores trilete, circular, crassitate, with microgranulate sculpture of *Aneurospora* type.

Description. The holotype (D 552a,b; Figs 1A, B) shows a bent axis 560 mm long and 1–1.5 mm broad. Axes of the studied specimens branch isotomously up to two times. In the basal and medial parts of the axis, there are preserved only small fragments of branching axes (Figs 1A, B, arrow). Both terminal branches are completely preserved, with somewhat pronounced overtopping. The left branch is 15 mm long, following the direction of the main axis, while the right branch is only 13 mm long. The terminal sporangia are lentil-shaped, 3–5 mm in diameter, borne on broadly funnel-shaped subtending axes with a 0.5 mm broad prominent rim (Fig. 1C). The left subtending axis is striated, showing a prominent 0.5 mm rim, and forming an ellipsoidal structure. The sporangium's location is marked by a lentil-shaped impression, 4 mm broad. This structure is documented in detail in Fig. 1C. The right subtending axis is less striated, showing remains of a fragmentarily preserved sporangium (Its major part is now missing, having been removed for sampling of *in situ* spores).

Spores found *in situ* are trilete and crassitate, with circular amb. Their size ranges from 10 to 15 µm. Rays of the trilete mark are straight, reaching the margin of the spore. The equatorial crassitudo is typically 1 µm thick. The distal surface is microgranulate; the sculpture of the proximal surface is not well exposed, but the visible portion is also microgranulate (Fig. 1E). Some of the spores (Fig. 1D) are still joined in tetrads, which may mean they were not completely mature. *In situ* spores are interpreted as *Aneurospora* type.

Discussion. Cooksonia barrandei resembles *C. pertoni* ssp. *apiculispora* from the Pridoli of England[11] in having similar whole plant habitus, and similar *in situ* spores. Spores of both plants are assigned to the genus *Aneurospora*. However, *Aneurospora* found in sporangia of *C. pertoni* ssp. *apiculispora* show crassitate trilete monads, with mostly laevigate proximal surfaces and microgranulate distal sculpture. The proximal surface sculpture of *Aneurospora* type spores from *C. barrandei* is not clearly visible, although the visible portion is

microgranulate, like the distal surface. Spores of *Aneurospora* type found in *C. pertoni* ssp. *apiculispora* also differ in size, being larger (18–30 µm) than those from *C. barrandei* (10–15 µm). In *C. pertoni* ssp. *Apiculispora*, sporangia are borne on abruptly expanded subtending axes, while *C. barrandei* shows shaped sporangia borne on gradually expanded subtending axes.

Cooksonia barrandei also resembles *Concavatheca banksii* (Habgood et al.) Morris et al. from the Lochkovian of England[12, 13] in having similar shape of terminal subtending axes, with characteristic rim and *in situ* spores.[13] According to Morris et al.,[13] *Concavatheca* differs from *Cooksonia* in having "extension of the sporangial cavity into the distally widening subtending axis as exemplified by changes in the shape of the epidermal cells". This character is not possible to distinguish in our material, although the shapes of subtending axes of both *C. banksii* and *C. barrandei* are very similar. The holotype of *C. banksii* is a charcoalified mesofossil, while our material is a compression. Due to different preservation states of the two species, direct and detailed comparisons cannot be made. However, there are more distinguishing characters between the above mentioned taxa, particularly in sizes of their axes, sporangia and spores. Interestingly, sporangia of *Cooksonia barrandei* are about ten times larger than *Concavatheca banksii*, while spores of *C. banksii* (*Ambitisporites avitus*[32]) are larger (13–28 µm) than those of *C. barrandei*. These spores have a laevigate sculpture, and are interpreted as *Iberospora* type.[33]

Three other subspecies of *C. pertoni* (*C. pertoni* ssp. *pertoni, C. pertoni* ssp. *synorispora* from the Pridoli,[31] and *C. pertoni* ssp. *reticulispora* from the Lochkovian[32]) described from Great Britain differ from *C. barrandei* in their spore morphology (*C. pertoni* ssp. *pertoni* bears spores of *Ambitisporites warringtonii*;[13] *C. pertoni* ssp. *synorispora* yielded *Synorisporites verrucatus*;[11] *C. pertoni* ssp. *reticulispora* has spores of *Synorisporites* sp.[12]). Other species of *Cooksonia* are less similar to *C. barrandei*. Our material differs from *C. cambrensis* from the Pridoli of Wales[14] in having only slightly widened subtending axes, and lenticular sporangia[14] (*C. cambrensis* has spherical sporangia). *In situ* spores are larger (on average 9–22 µm), and probably belong to the genus *Ambitisporites.*[15]

C. hemisphaerica from the Lochkovian of England[15] differs from *C. barrandei* particularly in having hemispherical shaped sporangia, and lacking the rim of the widened subtending axis. Its *in situ* spores are larger (22.5–34.5 µm), laevigate and assigned to the genus *Apiculiretusispora*.[15]

Cooksonia barrandei differs from *C. crassiparietilis* from the Lower Devonian of Kazakhstan[16] in a wider branching angle (60°), only slightly widened subtending axis and spherical to elliptical sporangia. This is the only *Cooksonia* species having thicker stems than *C. barrandei*. Its spores are much larger (60 μm) and are assigned to the genus *Apiculiretusispora*.[15]

From further megafossil material lacking *in situ* spores published from the Barrandian area, there is *C. bohemica.*[17,18] It is 10–12 million years younger than *C. barrandei*. *C. bohemica* from the Pridoli of Central Bohemia[18] differs from *C. barrandei* in having a wider branching angle, a short subtending axis, and kidney-shaped sporangia.

C. barrandei differs from *C. paranensis* from the Lochkovian of Brasil (Paraná Basin[19,20]) in shape of subtending axis and sporangium, particularly in having a dehiscence line, and lacking the rim of the widened subtending axis.

Small fragments assigned to *Cooksonia* from the uppermost Homerian of Tipperary in Ireland[6] differ from *C. barrandei* in size; their axes are only about 0.2 mm in diameter, with kidney-shaped or rounded sporangia, and only slightly widened subtending axes.[21]

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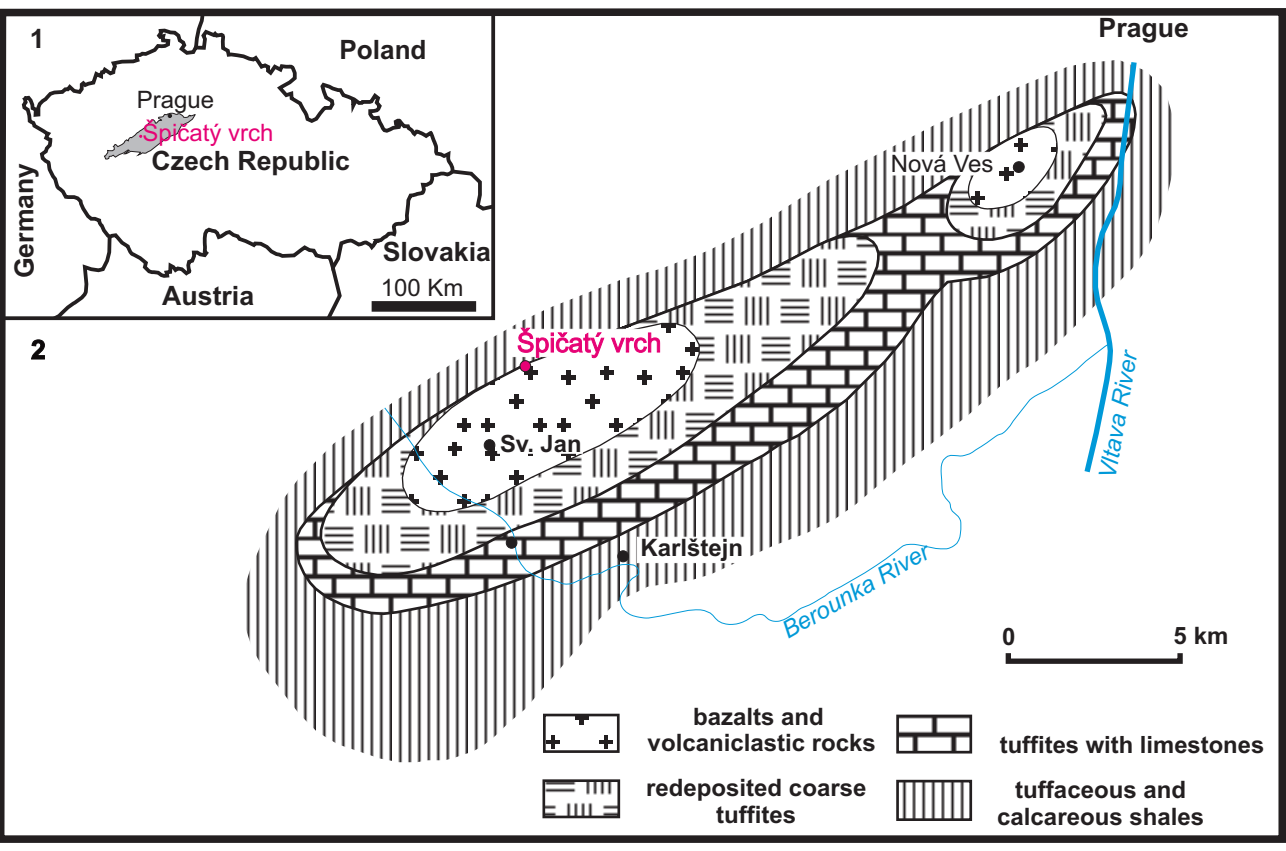
Supplementary Figures



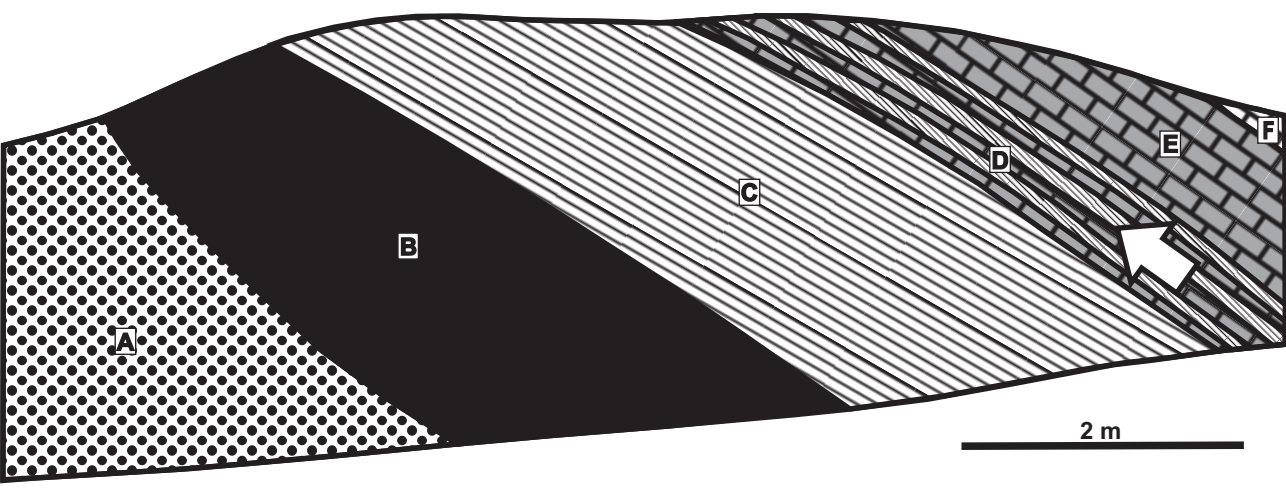


Fig. 1. Map of the Czech Republic, indicating location of the Prague Basin (Barrandian) with the Loděnice, Špičatý vrch locality.

Fig. 2. Macrofacies distribution of the early Silurian palaeogeography of Barrandian (modified according to Kříž [4]).

Fig. 3. Road cut Špičatý vrch - Barrandovy Jámy near Loděnice (photo: Motyčková, K.).

A. Laminated tuffaceous shales with limestone intercalations

B. Alkaline basalt lava

C. Tuffites and tuffaceous shales

D. Basal part of layer (0.5–1 m), laminated calcareous and tuffaceous shales with limestone intercalations (*Monograptus belophorus* Biozone) – the place where sterile cooksoniid plant remains were found (first occurrence of index graptolite *Monograptus belophorus* co-occurring with trilobite *Miraspis mira*).

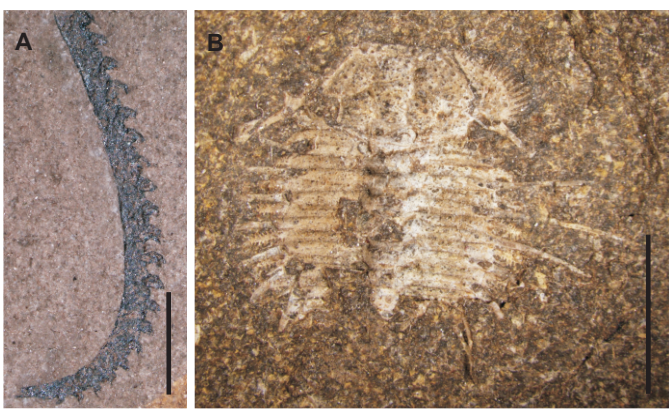
E. Medial and upper part of layer where laminated calcareous and tuffaceous shales gradually pass into platy limestones with interbedded tuffaceous shales (*Monograptus belophorus* Biozone containing, beside graptolites, diversified trilobite and brachiopod fauna[11, 31]

F. Platy limestones of *Cyrtograptus rigidus* Biozone with highly diversified trilobite and brachiopod fauna (*Miraspis mira*, *Cheirurus insignis, Trochurus speciosus, Diacalymene diademata, Niorhynx niobe, Cyrtia maior maior,* etc.)[11, 31]

Fig. 4. Associated fauna

A. Index graptolite *Monograptus belophorus* from the reverse side of *Cooksonia* specimen D 553, (scale bar 5 mm).

B. Trilobite *Miraspis mira*, along with plant fragments of *Cooksonia* specimen D 560, (scale bar 5 mm).



Supplementary Table

Stratigraphic positions of the earliest records of *Cooksonia* within graptolite zones of Barrandian (A) and Ireland (B).

Series	Stage / Age (Myr)	Czech Republic (Štorch,1994)	Graptolite ranges	Great Britain (Zalasiewicz *et al*. 2009)
WENLOCK	427.4	*ludensis*		B *ludensis*
	HOMERIAN	*deubeli-praedeubeli*	*M. flemingii*	
		frequens		*nassa*
		parvus-nassa		
		testis		*lundgreni*
		lundgreni	*M. belophorus*, *Me. antennularius*, *Paraplectograptus* sp., *P.? dubius dubius*	
	430.5	*radians*		
	SHEINWOODIAN	*perneri-ramosus*		*rigidus*
		rigidus		
		A *belophorus*		*dubius*
		dubius		
		riccartonensis		*riccartonensis*
				firmus
	433.4	*murchisoni*		*murchisoni*