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Late Visean Lyginopteridophytes from the Vicinity of the Town of Borovichi (Novgorod Region): 1. Calamopityales

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Abstract—Six species of Calamopityales (Lyginopteridophyta) are reported for the first time from the Upper Visean sandy–silty deposits of Central Russia (vicinity of the town of Borovichi). Among these species, *Sphenopteridium jurinae* O. Orlova et S. Snigirevsky is a newly described one. The taxonomic composition and terminology describing pinnately compound leaves are discussed.

Key words: fernlike plants, pteridosperms, morphology, Central Russia, Upper Visean.

INTRODUCTION

The Lower Carboniferous deposits from the vicinity of the town of Borovichi were studied for many decades. These interbedding sandy–clayey and carbonate beds characterize the marginal zone of an epicontinental basin. Most stratigraphic and paleontological papers focused mainly on the marine carbonate deposits of this region. The continental formations, often filled with plant fossils, remained poorly understood (Snigirevsky, in Balashov *et al.*, 1992). However, the largest localities of Late Visean plants are known precisely from the northwestern part of the Moscow Syneclise. One of these localities, the Porog Vittsaa-1 locality, is situated on the left bank of the Msta River, 6 km upstream from the town of Borovichi, near the Vittsa rapids. The Porog Vittsa-2 locality is on the right bank of the Msta River, 2.5 km upstream from locality no. 1 (Fig. 1). The plant remains are confined to sandstones, sandy interbeds, and clayey aleurites rich in plant debris and sedimentologically correlated to the united Putlino and Jogla formations of the Upper Visean (*Resheniya*..., 1990).

HISTORY OF STUDY OF VISEAN PLANTS FROM THE NOVGOROD REGION

Eichwald (1840, 1841, 1854) was the first to report about plant remains from the Lower Carboniferous deposits of the Novgorod Region. Zalessky (1905a, 1905b) described 13 taxa of fossil plants, including the new monotypic genus *Boroviczia* with the species *B. karpinskii* Zal., from the Visean of the Borovichi Region. The above-mentioned papers considered 11 lycopsid species, one arthrophyte species, and one species of seeds (with an uncertain taxonomic position) established by Zalessky. He reproduced this list of taxa in his later paper, devoted to the Carboniferous of the Moscow Basin (Zalessky, 1948, p. 195). Hecker (1980) contributed significantly to the study of burial types of stigmarias in the Upper Visean of the Novgorod Region.

TAXONOMIC COMPOSITION OF THE PLANTS STUDIED

Fragmentary sterile fronds of Lyginopteridophyta (pteridosperms) assigned to the orders Calamopityales and Lyginopteridales were discovered for the first time in the Upper Visean of the Novgorod Region (Porog Vittsa-1 and 2 localities: 58°21′ N, 33°57′ E) (Orlova and Snigirevsky, 2001). When describing, we use the system of higher plants proposed by Takhtajan (1986). In addition to the sterile fronds, fertile remains of Lyginopteridophyta are found in locality no. 2. They include synangia of *Telangiopsis* sp. 1 and cupules of *Rhynchogonium sulcatum* (L. et H.) Zal., earlier unknown in this region.

Impressions and cores of lycophyte strobili from the Upper Visean of the Novgorod Region (Porog Vittsa-2) were first discovered and tentatively ascribed to three species. The Porog Vittsa-1 locality is abundant in arthrophyte remains, earlier described by Zalessky as *Asterocalamites scrobiculatus* (Schloth.) Zeiller (=*Archaeocalamites radiatus* (Brongn.) Stur). In two localities in the vicinity of the town of Borovichi, more than 37 species belonging to 10 genera, 6 families, 6 orders, and 4 classes were registered (Orlova, 2001).

The present paper is the first part of this study, which describes six species (including a new one) of the genera *Sphenopteridium* Schimper and *Adiantites* Goep-

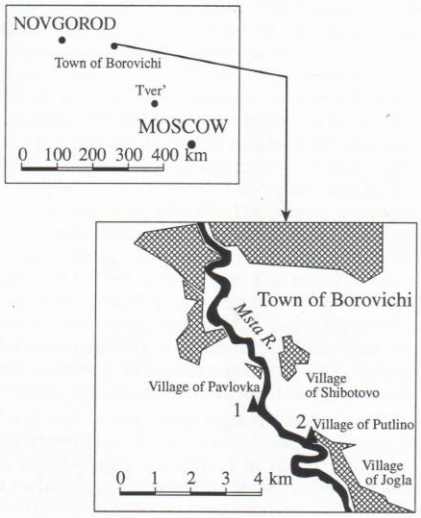

Fig. 1. Localities of Late Visean plants in the vicinity of the town of Borovichi (Novgorod Region): (1) Porog Vittsa-1 locality (left bank of the Msta River); (2) Porog Vittsa-2 locality (right bank of the Msta River).

pert (Calamopityales). Only *Sphenopteridium jurinae* O. Orlova et S. Snigirevsky, sp. nov. and *Adiantites antiquus* (Ett.) Stur were recorded in both localities (on the right and left banks of the Msta River). Four other species were found only in Porog Vittsa-2. The plants studied are preserved in various states: finds of *Sphenopteridium* consist of nearly complete fronds or penultimate pinnae; specimens of *Adiantites* are more fragmentary (incomplete ultimate pinnae or detached pinnules).

All the species described below were found only in the northwestern part of the Moscow Syneclise. Outside the Moscow Syneclise, they are known from the contemporary deposits of Kazakhstan (two common species, *Sphenopteridium bifidum* (L. et H.) Benson and *Adiantites antiquus* (Ett.) Stur), the Czech Republic (*Sphenopteridium pachyrrhachis* (Goepp.) Pot., *S. bifidum* (L. et H.) Benson, *S. gaebleri* Gothan, *Adiantites antiquus* (Ett.) Stur, and *A. machanekii* Stur), Great Britain (*Sphenopteridium pachyrrhachis* (Goepp.) Pot., *S. bifidum* (L. et H.) Benson, *Adiantites antiquus* (Ett.) Stur, and *A. machanekii* Stur), Poland (*Sphenopteridium pachyrrhachis* (Goepp.) Pot., *S. bifidum* (L. et H.) Benson, and *Adiantites antiquus* (Ett.) Stur), the United States (*Sphenopteridium bifidum* (L. et H.) Benson and *Adiantites antiquus* (Ett.) Stur), Spitsbergen (*Sphenopteridium bifidum* (L. et H.) Benson), and Spain and France (*Sphenopteridium pachyrrhachis* (Goepp.) Pot.). The resemblance of Late Visean members of the Calamopityales from the Moscow Syneclise to those from Great Britain and the Czech Republic is remarkable. In the Late Visean, these floras belonged to the Euramerian Phytogeographic Realm. The Calamopityales from the Upper Visean of Central Russia are described for the first time.

MATERIALS AND METHODS

During the last fifteen years, we collected plant remains from Upper Visean continental deposits of the northwestern part of the Moscow Syneclise. A total of more than 200 plant specimens (mainly impressions, and rarely, petrifactions) are housed at the Paleontological Museum (Department of Paleontology) of St. Petersburg State University (collection PM SPGU, no. 24) and at the Department of Paleontology of the Geological Faculty of Moscow State University (collection GF MGU, no. 289). The material was collected by the authors and N.S. Snigirevskaya (Komarov Botanical Institute of the Russian Academy of Sciences), A.V. Broushkin (Karpinskii All-Russia Geological Research Institute), Yu.V. Savitsky, P.V. Fedorov (SPGU), A.V. Bryantseva, S. Yu. Kharitonov, A.V. Shatulin, Yu.V. Shuvalova, and A.V. Yudin (MGU) in 1987 to 2001.

Describing fronds, we used the terminology proposed by Fedorov *et al.* (1956). A frond (= the compound leaf of pteridophytes and related plants) consists of the main rachis, from which rachises of subsequent orders deviate in opposite or alternative ways. These rachises support pinnae of different orders ending with pinnules. The pinnules are lobed or dissected and apical or lateral. The terms *dissected* and *divided* (with reference to pinnules and leaves) are often confused in both Russian and foreign paleobotanical literature. Actually, these variants are difficult to differentiate. Therefore, propose using the sole term *dissected* in description of such pinnules.

SYSTEMATIC PALEOBOTANY

DIVISION LYGINOPTERIDOPHYTA

CLASS LYGINOPTERIDOPSIDA

SUBCLASS LYGINOPTERIDIDAE

Order Calamopityales

Family Calamopityaceae Gothan, 1926

Genus *Sphenopteridium* Schimper, 1874

***Sphenopteridium pachyrrhachis* (Goeppert) Potonie, 1899**

Plate 4, fig. 1

Sphenopteris pachyrrhachis: Goeppert, 1852, p. 143, pl. 13, figs. 3–5; Kidston, 1890, p. 425.

Archaeopteris pachyrrhachis: Stur, 1875, p. 64, pl. 8, figs. 8 and 9.

Sphenopteridium pachyrrhachis: Potonie, 1899, p. 131; Kidston, 1923, p. 164, pl. XXXVII, figs. 5–7; pl. XXXVIII, figs. 1–4; pl. XXXIX, fig. 5; pl. LXVIII, fig. 1; Walton, 1931, p. 360, pl. 25, figs. 21–23; Purkynova, 1970, p. 169, pl. 14, figs. 3 and 3a; Scott *et al.*, 1994, p. 255, figs. 2a and 2b.

Description. The fronds are fragmentary, and up to 60 mm long. The main rachis is slightly curved,

distinctly longitudinally striate, 5 mm wide, and bears alternate pinnae. At the point of attachment to the rachis, the pinnae are divided into two unequal parts at an angle of approximately 75° to each other. Adjacent pinnae are positioned at a distance of about 20 mm from one another. The length of the pinnae reaches 25 mm; the width is up to 20 mm. The rachis of the second order is slightly curved, narrow, and up to 0.75 mm wide. The alternate pinnae of the second order are attached to the rachis at an angle of 45–60°. The pinnae are rhomboidal, 7–10 mm long, and positioned at a distance of at 2.5–3 mm from each other. The ultimate rachis is straight and 0.25-0.3 mm wide: The pinnules are alternate, widely spaced or adjoing one another, rhomboidal, up to 3 mm long, and 0.3–0.5 mm wide in the middle part; occasionally, they are divided into four wedge-shaped segments. Veins are equal in length, fork two or more times, and enter each segment of the pinnules.

Comparison. *Sphenopteridium pachyrrhachis* greatly resembles *S. dissectum* (Goepp.) Schimper in frond morphology, but differs in the sculpture of the main rachis. *S. pachyrrhachis* shows a distinct longitudinal striation formed by long grooves, whereas *S. dissectum* has short hairlike ribs. The pinnules of *S. pachyrrhachis* are rhomboidal and are divided into four segments; those of *S. dissectum* are wedge-shaped and occasionally divided into two segments.

Occurrence. Tournaisian of the Great Britain and Germany; Upper Visean of Russia (Putlino and Jogla formations, Novgorod Region), Spain, France, and Great Britain; and Visean and Namurian (Serpukhovian) of the Czech Republic and Poland.

Material. Six specimens (impressions and counterparts) of fragmentary fronds from Porog Vittsa-2, Msta River, Novgorod Region.

***Sphenopteridium jurinae* O. Orlova et S. Snigirevsky, sp. nov.**

Plate 4, fig. 2

Etymology. In honor of A.L. Jurina (MGU) a prominent Russian paleobotanist and our teacher.

Holotype. GF MGU, no. 289/52, Moscow Syneclise, Porog Vittsa-2 locality (58°21′ N, 33°57′ E), right bank of the Msta River, vicinity of the town of Borovichi, Novgorod Region, Russia; Lower Carboniferous, Upper Visean, Putlino and Jogla formations.

Diagnosis. Leaf pinnate. Rachis slightly flexuous, 1.5 mm thick, smooth. Pinnae rhomboidal, 10–25 mm long and 8 mm wide, alternate, contacting or outlying. Rachis of pinna straight, smooth, 0.8–1 mm thick. Pinnules wedge-shaped, outlying, alternate, 5–7 mm long and 1.5–3 mm wide, divided into 2–4 lanceolate segments. Veins radiate from base of pinnules.

Description. The fragmentary pinnate fronds are up to 50 mm long. The main rachis is slightly arched, 1.5 mm wide, and smooth. Occasionally, it is weakly longitudinally rugulose. The pinnae are rhomboidal, 10–21 mm long and 8 mm wide, gradually diminishing toward the frond apex, positioned apart or close to each other, attached to the rachis at an angle of 30–45°. The lower pinnae have up to eight pinnules on a rachis, and the upper pinnae have up to five pinnules. The distance between adjacent pinnae is 3–4 mm. The rachis of the second order is straight, in places, geniculate, 0.8–1.0 mm wide, smooth, and occasionally, longitudinally rugulose. Wedge-shaped alternate pinnules, divided into 2–4 lanceolate segments, are situated on the rachis of the second order at a distance of 2–3 mm from one another, at an angle of 20–25°. The lower pinnules are divided into three or four segments, the upper ones consist of two segments. The pinnules do not contact with each other. They are 5–7 mm long, 1.5–3 mm wide, with rounded apices. Venation is poorly preserved: at least two veins enter each segment.

Comparison. The new species differs from the closely related *Sphenopteridium bifidum* in thickness, external relief, curvature of the main rachis, and the shape of pinnules. The species being described has a narrow (1.5 mm wide), smooth, in places, weakly longitudinally rugulose, and a slightly curved main rachis and wedge-shaped pinnules, whereas *S. bifidum* has a relatively thick (4.5 mm wide), longitudinally striate, and straight main rachis and linear pinnules.

Material. Twelve impressions and counterparts of pinnae of different orders from Porog Vittsa-1 and 2 localities, Msta River, Novgorod Region.

***Sphenopteridium bifidum* (Lindley et Hutton) Benson, 1935**

Plate 4, fig. 3

Sphenopteris? bifida: Lindley et Hutton, 1831–1833, pp. 147–148, pl. 53, fig. 1; Kidston, 1883, p. 536.

Sphenopteris (Trichom.) bifida: Schimper, 1869, p. 412.

Telangium bifidum: Kidston, 1924, p. 454, pl. CIII, figs. 1, 1a, 1b, and 1c.

Sphenopteridium bifidum: Benson, 1935, p. 239; Shvedov *et al.*, 1963, p. 44, fig. 17; Purkynova, 1970, p. 172, pl. XVI, fig. 6, pl. VII, figs. 1–6; Purkynova, 2000, p. 250, pl. 1, fig. 2.

Description. These frond fragments are up to 70 mm long and up to 40 mm wide. The main rachis is straight, up to 4.5 mm wide, with a striate external surface. It bears alternate pinnae reaching 30 mm in length in the lower region of the frond and gradually tapering towards the apex to 8 mm. The distance between adjacent pinnae reaches 10 mm. The rachis of the second order is straight, up to 0.8 mm wide. Pinnae of the second order are attached at an angle of 25°. They alternate and are positioned at a distance of 3 mm from each other. The slightly curved ultimate rachis bears linear pinnules, divided into three or four alternate or, occasionally, opposite segments. The length of the pinnules is up to 7 mm; the width is up to 0.5 mm. Venation is uncertain.

Occurrence. Visean of Great Britain, the Czech Republic, Poland, Norway (Spitsbergen), Kazakhstan (Karaganda Region), and the United States (Illinois); Upper Visean of Russia (Putlino and Jogla formations of the Novgorod Region); and Namurian of the Czech Republic and Poland.

Plate 4

Explanation of Plate 4

Fig. 1. *Sphenopteridium pachyrrhachis* (Goepp.) Potonie, GF MGU, no. 289/42, fragmentary frond, ×4.

Fig. 2. *Sphenopteridium jurinae* sp. nov., holotype GF MGU, no. 289/52, general appearance of the frond, ×2.

Fig. 3. *Sphenopteridium bifidum* (L. et H.) Benson, GF MGU, no. 289/240, incomplete penultimate pinna, ×3.

Fig. 4. *Sphenopteridium gaebleri* Gothan, GF MGU, no. 289/70, fragmentary frond, ×4.

Fig. 5. *Adiantites antiquus* (Ett.) Stur, GF MGU, no. 289/104, incomplete ultimate pinna, ×4.

Fig. 6. *Adiantites machenekii* Stur, PM SPGU, no. 24/15-1, fragmentary ultimate pinna, ×4.

Figs. 1–4, 6. Novgorod Region, right bank of the Msta River, Porog Vittsa-2 locality; Lower Carboniferous, Upper Visean, Putlino and Jogla formations.

Fig. 5. Novgorod Region, left bank of the Msta River, Porog Vittsa-1 locality; Lower Carboniferous, Upper Visean, Putlino and Jogla formations

Material. Eight specimens (impressions and counterparts) of pinnae of different orders from the Porog Vittsa-2 locality, Msta River, Novgorod Region.

***Sphenopteridium gaebleri* Gothan, 1913**

Plate 4, fig. 4

Sphenopteridium gaebleri: Gothan, 1913, p. 12, pl. 1, fig. 2; Purkynova, 1970, p. 170, pl. XIV, figs. 1 and 2a.

Description. The main rachis is straight and 3 mm wide, with longitudinal ribs. The pinnae are broadly wedge-shaped. Their observed length is 17–21 mm. They are alternating, and positioned at an acute (20°) angle to the rachis, at a space of 13 mm, and they don't contact with each other. The ultimate rachis (2 mm wide) bears alternate narrow wedge-shaped pinnules 8–12 mm long and 4–5 mm wide. The pinnules are attached to the rachis at an angle of about 15–20°. The pinnules are widely spaced. Basally, they are divided into 3 or 4 equal lanceolate segments. Venation is parallel. In each segment, more than two veins dichotomize several times.

Comparison. The species under description differs from *Sphenopteridium bifidum* in that it has wedge-shaped pinnae and pinnules and a wide (2 mm) ultimate rachis. *S. bifidum* has linear pinnules and a narrow rachis (0.5 mm wide). The pinnules of *S. gaebleri* are basally divided into 3–4 equal lanceolate segments, whereas those of *S. bifidum* are either with out division or divided into three or more segments, which are arranged alternatively or (more rarely) oppositely.

Occurrence. Upper Visean of the Czech Republic and Russia (Putlino and Jogla formations, Novgorod Region); Serpukhovian (Namurian) of the Czech Republic and Germany.

Material. Three specimens from the Porog Vittsa-2 locality, Msta River, Novgorod Region.

Genus *Adiantites* Goeppert, 1836

***Adiantites antiquus* (Ettingshausen) Stur, 1875**

Plate 4, fig. 5

Adiantum antiquum: Ettingshausen, 1865, p. 22, text-fig. 7, pl. 7, fig. 1.

Aneimites adiantoides: Schimper, 1874, p. 490.

Adiantides antiquus: Stur, 1875, p. 66, pl. XVI, figs. 4–6, pl. XVII, figs. 3 and 4; Kidston, 1890, p. 421, pl. 1, fig. 1.

Adiantites antiquus: Kidston, 1903, p. 819; 1923, p. 187, pl. XLV, figs. 1 and 2; Walton, 1931, p. 264, pp. 354–355, fig. 2; Tschirkova, 1937, p. 238, figs. 2 and 3; Novik, 1952, p. 264, pl. XLIII, figs. 1 and 2; Remy and Remy, 1959, p. 53, fig. 35; Purkynova, 1970, p. 167, pl. 12, figs. 1–4; 1985, p. 53, pl. III, fig. 3; Jennings, 1985, pp. 1148–1154, figs. 4–8; 1986, p. 316, pl. 111, fig. 5; Purkynova, 1988, p. 177, pl. II; Scott *et al.*, 1994, p. 255, figs. 3k, 4a, and 4b.

Description (Figs. 2b, 2c). The fragmentary pinnae of the penultimate order are up to 17 mm in length. They have a longitudinally striate rachis 0.8 mm thick. The smooth, occasionally weakly longitudinally striate rachis of the last order (up to 0.5–0.8 mm wide) bears rounded ultimate pinnae, which alternate at a distance of 2–3 mm from each other. The pinnae are up to 15 mm long. They usually comprise two opposite lateral pinnules and one or two terminal pinnules. The rachises of every order are narrow. The lateral pinnules

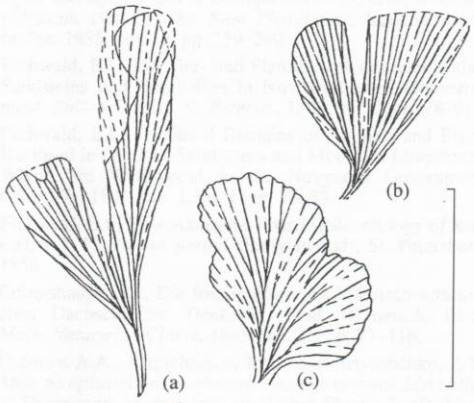

Fig. 2. Pinnule morphology of *Adiantites* from the Upper Visean of the vicinity of the town of Borovichi: (a) *Adiantites machanekii* Stur, PM SPGU, no. 24/15-5, pinnule is divided into two segments; (b, c) *A. antiquus* (Ett.) Stur: (b) MGU, no. 289/56, incomplete bilobate pinnule; (c) MGU, no. 289/72, incomplete terminal pinnule with an undulating rounded apical margin. Scale bar, 1 cm.

are broadly wedge-shaped. The apical pinnules are ovate, with a slightly undulating and rounded leaf margin (Fig. 2c), occasionally, bilobate (Fig. 2b). Each pinnule is petiolate. The petiole is up to 2 mm long and 0.3–0.5 mm wide. The transition from the pinnule base to the petiole is distinct. The length of the lateral pinnules varies from 8 to 13 mm. Their width varies from 5 to 8 mm. The maximum pinnule width is observed in the upper third of pinnule blade. The terminal pinnules are smaller (6.5–8 mm long and 2–5 mm wide). A solitary vein enters each pinnule. It dichotomizes three or four times and reaches the upper margin of the pinnule where three or four veins per 1mm are observed (Fig. 2b).

Comparison. *Adiantites machanekii* is especially similar to *A. antiquus* in pinnule shape and dimensions. *A. antiquus* differs from *A. machenekii* in that it has broader wedge-shaped pinnules with a rounded apex. *A. machenekii* has narrow pinnules with an obtuse apex. In addition, the species being described has a narrow and relatively long petiole. A sharp transition from the pinnule base to the petiole (observed in *A. antiquus*) is atypical of *A. machanekii*, which has a gentle transition from the pinnule base to a thicker and shorter petiole.

Occurrence. Visean of Great Britain, the Czech Republic, Poland, Kazakhstan (Karaganda Region), the United States (Illinois, West Virginia, and Pennsylvania), and Russia (Lower Visean of the Chelyabinsk Region and Upper Visean of the Putlino and Jogla formations of the Novgorod Region).

Material. Nine specimens representing penultimate and ultimate pinnae and isolated pinnules from the Porog Vittsa-2 (five impressions and two counterparts) and Porog Vittsa-1 localities (one impression with a counterpart), Msta River, Novgorod Region.

***Adiantites machanekii* Stur, 1875**

Plate 4, fig. 6

Adiantites machanekii: Stur, 1875, p. 68, pl. XVII, figs. 5 and 6; Kidston, 1923, p. 189, pl. XLVII, figs. 5 and 6; Walton, 1931, pp. 355–356, text-fig. 3, pl. 23, fig. 6, pl. 24, fig. 12; Havlena, 1961, p. 35, pl. 8, figs. 5 and 5a.

Description (Fig. 2a). The incomplete ultimate pinnae are up to 25 mm long. The penultimate rachis is 1.5 mm wide, and smooth, with a weakly pronounced longitudinal furrow. The ultimate rachis deviates from the penultimate rachis at a nearly right angle. The ultimate rachis is narrow, smooth, and 0.5 mm wide. It bears alternating, narrowly wedge-shaped petiolate pinnules, attached at an angle of approximately 25°. The petioles are 1–1.5 mm long and 0.5–0.8 mm wide, with a gradual transition to the pinnule base. Pinnules with obtuse apices occasionally consist of two segments, radiating from the rachis at an angle of 45° (Fig. 2a). The pinnules are 7.5–15 mm long and 2–3 mm wide. Their upper part is widest. A single vein enters each pinnule or segment and dichotomizes four to six times. There are three veins per mm in the upper margin of each pinnule (Fig. 2a).

Occurrence. Tournaisian of Ukraine (Lvov-Volhynian and Donets basins); Visean of Great Britain, the Czech Republic, and Russia (Putlino and Jogla formations, Novgorod Region); and Namurian of Belgium.

Material. Six specimens, including four impressions and two counterparts of incomplete ultimate pinnae from the Porog Vittsa-2 locality, Msta River, Novgorod Region.

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