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Aspects of Romanian Palaeozoic Palaeobotany and Palynology. Part III. The Late Carboniferous flora of Baia Nouă, Sirinia Basin

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ABSTRACT

The Cucuiova Formation is a Pennsylvanian (late Carboniferous) coal-bearing unit in the intramontane Sirinia Basin, which was formed in the Danubian Units of the South Carpathians. The main coal seam in the Cucuiova Formation was worked at Baia Nouă (Nové Doly) and this locality has yielded a typical adpression coal flora. Previous studies have suggested that this flora was Moscovian (late Westphalian or even earliest Stephanian) in age. However, newly collected samples from Baia Nouă have included abundant *Neuralethopteris*, which clearly indicates a late Bashkirian (Langsettian) age. This suggests a possible link with the Svoge Basin in northern Bulgaria, which is another intramontane basin located on the Balkan Terrane with early Westphalian coal-bearing deposits.

Keywords: Pennsylvanian, Palaeobotany, Romania, Biostratigraphy, Palaeogeography

1. INTRODUCTION

Early–Middle Pennsylvanian (late Carboniferous) age coal-bearing strata in Europe can be found in two general depositional settings (OPLUŠTIL & CLEAL, 2007; CLEAL et al., 2010, 2011). The most extensive deposits were formed in paralic settings, most notably on the Variscan Foreland and associated basins between the British Isles and northern Turkey, in the Donets Basin of eastern Europe, and the Cantabrian Basin of the Iberian Peninsula. Together, these basins cover an area of up to 9 x10^5 km^2 (CLEAL & THOMAS, 2005). In addition there are several intramontane basins associated with the Variscan Mountains, such as Saar-Lorraine (France and Germany), West and Central Bohemia (Czech Republic), Svoge (Bulgaria) and the Stephanian basins of southern France. Although much smaller than the paralic basins, they are of interest because of what they tell us about the evolution of the Variscan Mountains and the distinctive fossil biotas that they yield, especially the macrofloras, which probably reflect at least in part their relatively high elevation during Pennsylvanian times.

There is evidence of at least two such Pennsylvanian-age intramontane basins in the south Carpathians in Romania, the Reşița Basin within the Getic Nappe and the Sirinia Basin in the western Upper Danubian realm (Danubian Units). Neither is particularly well exposed and what coal mining did occur there has now ceased. Nevertheless, both have yielded fossil biotas which are of biostratigraphical and palaeobiogeographical interest (see DRAGASTAN et al., 1997 and POPA, 2005 for historical reviews). In the present paper we document macrofloras from the Sirinia Basin found at Baia Nouă (also known in the Czech language as Nové Doly) located in the Dubova Commune, Mehedinți County, in the central area of the Iron Gates Natural Park, the largest natural park in Romania.

2. GEOLOGICAL CONTEXT

Baia Nouă is a small coal mining locality in the southern part of the Almăj Mountains in the South Carpathians (Text-fig. 1A, B). It occurs in the southern part of the Sirinia Basin, a sedimentary area also variously known as the Svinița zone (RĂILEANU et al., 1963), the Svinița – Svinecea Mare sedimentary zone (NĂSTĂSEANU, 1984; NĂSTĂSEANU et al., 1981), or the Svinița – Fața Mare zone (RĂILEANU, 1953, 1960). It is the westernmost sedimentary area of the Upper (Internal) Danubian Units (CODARCEA, 1940, RĂILEANU, 1953; BERZA et al., 1983), an important tectonic part of the South Carpathian chain. The Upper Danubian Units correspond to the Upper Danubian depositional realm, which includes a western molasse basin (the Sirinia Basin, including both Pennsylvanian and Cisuralian sediments) and an eastern molasse basin (the Presacina Basin, including Cisuralian sediments), separated by a ridge (the Iablanița-Rudăria ridge).

The Sirinia sedimentary zone includes Upper Palaeozoic (Pennsylvanian – Cisuralian, confined to the Palaeozoic Sirinia Basin sensu-strictum) and Mesozoic (Lower Jurassic – Cretaceous) sediments. The Upper Palaeozoic deposits were considered to be the Variscan molasse of the Danubian Units (RĂILEANU, 1953, NĂSTĂSEANU et al., 1973, NĂSTĂSEANU, 1987) and consist of the Pennsylvanian (upper Carboniferous) Cucuiova Formation (Text-fig. 1C) overlain by the Cisuralian (lower Permian) Povalina and Trescovăț formations (STĂNOIU & STAN, 1986). The Permian formations were reinterpreted by A. SEGHEDI et al. (1999) and I. SEGHEDI (2010), the latter author defining the pyroclastic sequences interbedded with terrigeous sequences as the result of subaequous lacustrine eruptions passing to subaerial volcanism.

The Cucuiova Formation (STĂNOIU & STAN, 1986) consists of sandstones, mudstones and one or two coal seams (Text-fig. 1C), with local basic lava flows. The main coal seam is a metamorphosed bituminous coal, and varies in thickness between 1m and 15m (MATEESCU, 1964) due to strong Alpine deformation that affected the Variscan molasse. The Cucuiova Formation is best exposed near Baia Nouă due to extensive mining works, although outcrops (now covered) have also been described around the Cucuiova Hill (locus typicus) and along the Povalina Valley, the Dragosela Valley (outcrops and exploration galleries) and the Cameniița Valley (Text-fig. 1B). A review of the outcrops, micro- and macrofloral contents, ages of sequences and ranges was published by POPA (2005).

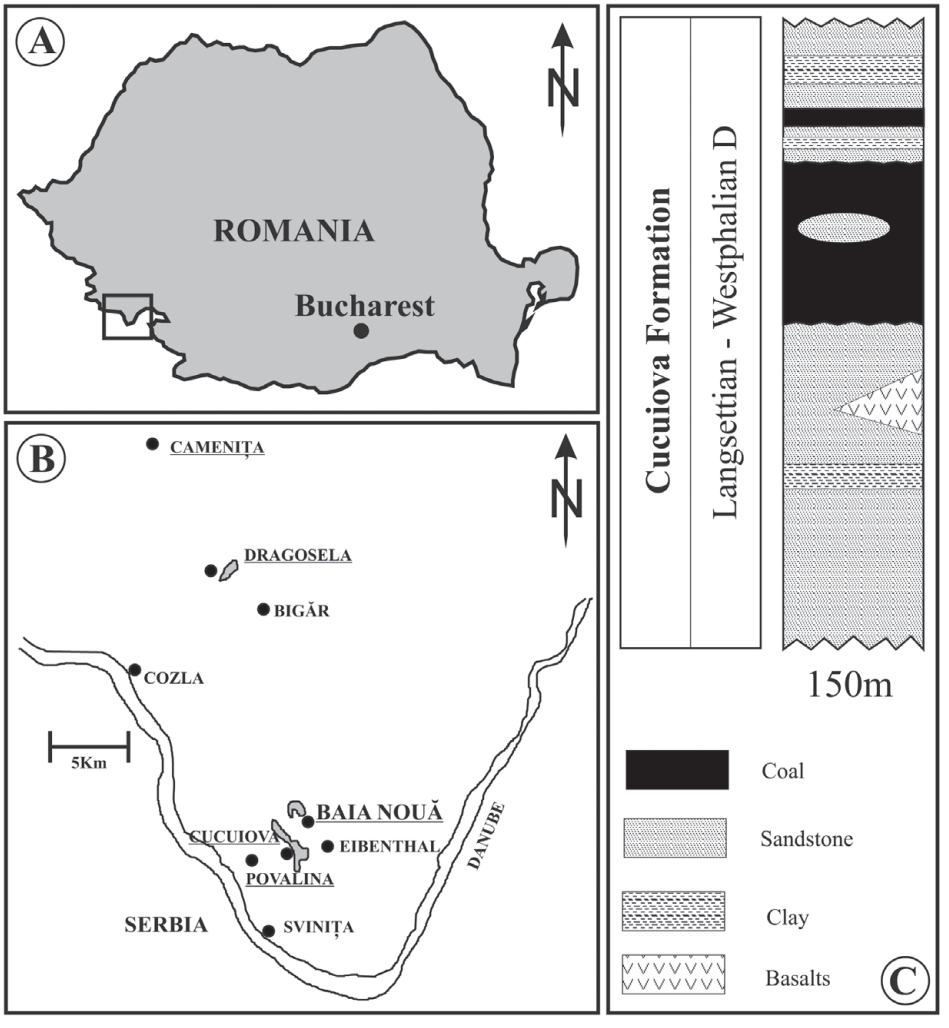

Figure 1: A. Location of the Baia Nouă area in south-western Romania. The marked rectangle represents the area shown in Fig. 1B. B. Occurrence of Carboniferous fossil plant localities in the Sirinia Basin (underlined names), and the distribution of the Cucuiova Formation (grey shading), within the tectonic boundaries of the Upper Danubian Unit. C. Lithostratigraphical log of the Carboniferous Cucuiova Formation, here dated as Langsettian – Westphalian D, previously considered in POPA (2005) as Bolsovian – Westphalian D. All redrawn from POPA (2005).

Table 1: Taxa previously published (and here updated from a nomenclatural point of view) from Baia Nouă, marked with * if the taxon was only cited, and with ** if the taxon was cited and also illustrated. This only includes papers providing new results and not those merely quoting the work of others.

	STUR (1870)	SCHAFARZIK (1894)	RĂILEANU (1953)	BIȚOIANU (1972a)	BIȚOIANU (1972b)	BIȚOIANU (1973)	BIȚOIANU (1974)	BIȚOIANU (1987)
Alethopteris lonchitica				**				
A. serli				*	*			
Alloiopteris coralloides					*		**	
Annularia cf. radiata			*					
Asolanus camptotaenia				**	**	**	*	
Asterophyllites longifolius				**	*	*	*	
Calamites carinatus				**	**	**	*	
C. cisti	*	*	*	**	*			*
C. suckowi				**	**			
Calamostachys germanica					*			
Cardiocarpus gutbieri					**			
Lepidodendron acutum				*	**	**		
L. obovatum				**	**	*		
L. ophiurus				**				
Lepidodendron sp.								*
Lepidostrobus sp.				**	**			
Mariopteris hirsuta				**	*	**	*	
M. micro-sauveuri					**			
M. nervosa				**	**	*		
M. sauveuri				**	**	**	*	
Mariopteris sp.				**	**			
Neuralethopteris schlehani				**	*	*		
Neuropteris arberi					*			
N. attenuata				**				
N. cf. *arberi*				**				
N. cf. *obliqua*					**			
N. gigantea							*	
N. ovata				**		**		
Neuropteris sp.			*					
N. tenuifolia				**	*	*	*	
Palaeostachya pedunculata				**	*			

Table 1: continued.

	STUR (1870)	SCHAFARZIK (1894)	RĂILEANU (1953)	BIȚOIANU (1972a)	BIȚOIANU (1972b)	BIȚOIANU (1973)	BIȚOIANU (1974)	BIȚOIANU (1987)
Pecopteris miltoni				**	*	*	*	
P. raconensis				**				
P. saraefolia				**	*	*		
Senftenbergia plumosa-dentata					*	**		
S. plumosa-dentata var. *delicatula*				**				
Sigillaria *polyploca*			*	**	**	**	*	*
Sigillaria sp.			*	*	**			
S. tesselata	*	*		**	**			*
Sphenophyllum cuneifolium				**	*	**	*	
Sphenopteris andraeana					*			
S. herbacea					*			
S. obtusiloba					*			
S. spiniformis					*			
S. stonehousei					*			
Stigmaria ficoides	*	*	*	**	*			*
Trigonocarpus sp.				*				

Bituminous coals were first discovered here in 1840 and have been extracted since 1874 (RĂILEANU et al., 1963); mining activities in Baia Nouă ended in 2006 for safety and financial reasons. Geological studies in the area date back to the second half of the 19th century (TIETZE, 1872; HANTKEN, 1878; SCHAFARZIK, 1894). MATEESCU (1964) described the petrography of the Baia Nouă coals, reporting various types of plant and fungal remains ranging from xylem tissues in fusinite, sporinite, resinite, and sclerotinite. The petrography of coals including sclerotinite from the Cucuiova Formation exposed in the Dragosela Valley was described by ILIE &BIȚOIANU (1966) and BIȚOIANU & ILIE (1968).

3. PREVIOUS PALAEOBOTANICAL STUDIES

The first palaeobotanical data dealing with Baia Nouă were published by STUR (1870; also quoted by TIETZE, 1872 and HANTKEN, 1878), citing the identifications by Constantin von Ettingshausen, and by SCHAFARZIK (1894), but no specimens were illustrated. In more modern times, the main palaeobotanical studies on Baia Nouă were undertaken by SEMAKA (1962, 1970) and BIȚOIANU (1972a, b, 1973, 1974, 1987). Geological studies by RĂILEANU (1953, 1960) also included new palaeobotanical data. These studies, which were concerned with biostratigraphy and sometimes (BIȚOIANU, 1987) palaeoecology, and mainly comprise just species lists although in a few cases specimens were illustrated. Other plant fossils from the Cucuiova Formation were recorded by MAXIM (1967, 1969) from the Cucuiova Hill area (along an un-named tributary of the Povalina Valley, south of Baia Nouă) and from the Dragosela Valley (BIȚOIANU, 1972a, b, 1973, 1974). DRAGASTAN et al. (1997) and POPA (2005) summarised the information then available. The identifications provided in the most important of these previous studies are summarised in Table 1.

4. MATERIALS AND METHODS

As pointed out by POPA (2005) previously published palaeobotanical data from Baia Nouă are mostly not supported today by collections, with the exception of one hand specimen in the S. Cotuțiu Collection (National Geological Museum, Geological Institute of Romania, Bucharest), two samples in the C. Eufrosin Collection and one sample in the I.Z. Barbu Collection (both in the historical collections of the Laboratory of Palaeontology, University of Bucharest). Further study of the Baia Nouă flora must therefore be based on freshly collected material.

Due to the tectonic evolution of the Sirinia Basin, plant fossils from Baia Nouă are exclusively adpressions (i.e. compression/impressions – see SHUTE & CLEAL, 1986) that lack cuticles or in situ spores.

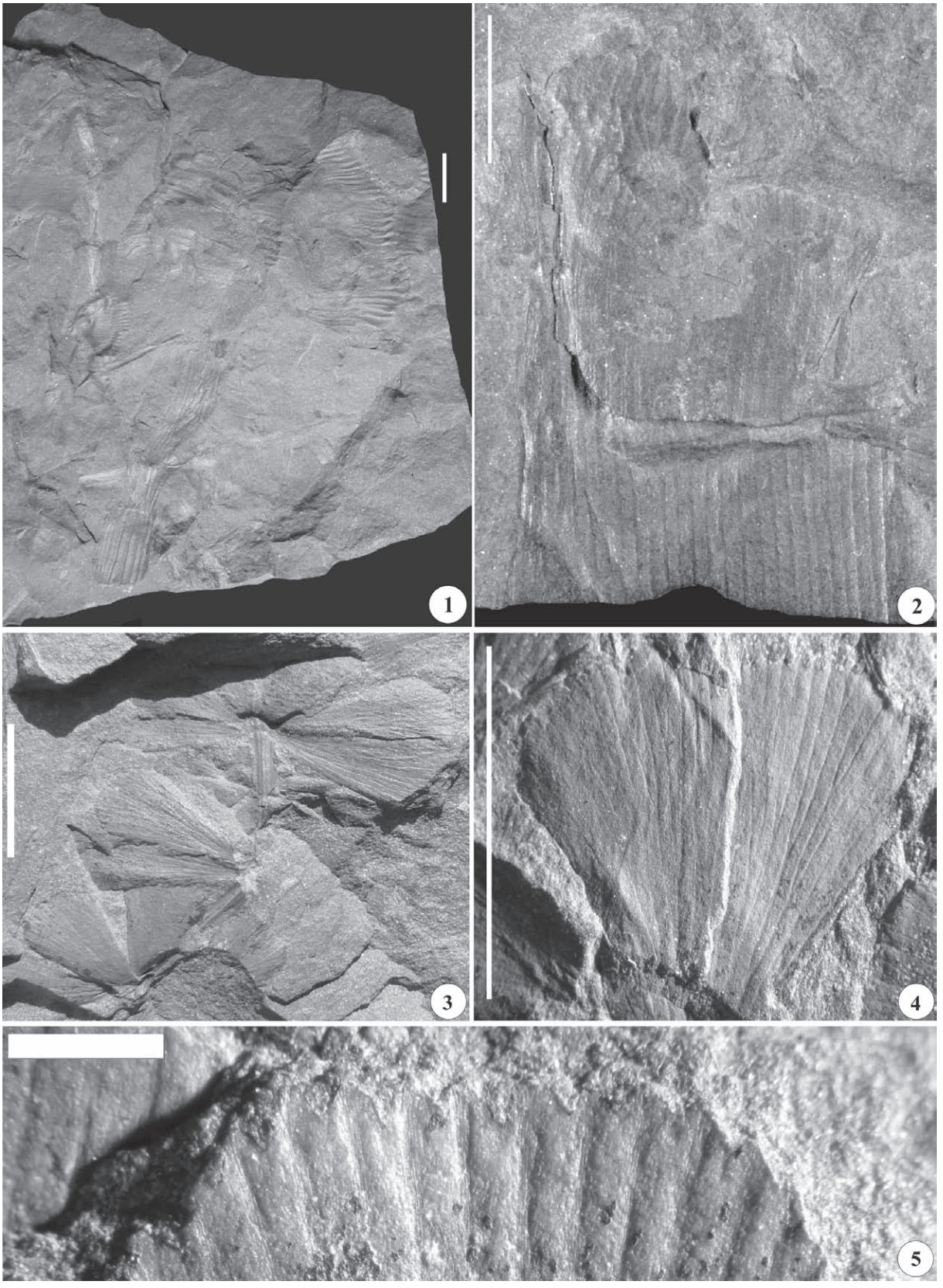

PLATE 1

1 *Calamites carinatus*, P41/C5/3, fragment 1, M.E. Popa Collection, University of Bucharest. Scale bar: 10mm.
2 *Calamites carinatus*, P41/C5/2, fragment 1, M.E. Popa Collection, University of Bucharest. Scale bar: 10mm.
3 *Sphenophyllum cuneifolium*, sample 0512, C. Eufrosin Collection, University of Bucharest. Scale bar: 10mm.
4 *Sphenophyllum cuneifolium*, sample 0512, C. Eufrosin Collection, University of Bucharest. Scale bar: 10mm.
5 *Sphenophyllum cuneifolium*, sample 0512, C. Eufrosin Collection, University of Bucharest. Scale bar: 1mm.

Plant fossils tend to be relatively rare here, the M.E. Popa Collection comprising just 65 hand specimens collected since 1996 from the sterile dump of the former mine; these specimens are now curated at the Laboratory of Palaeontology, University of Bucharest. In addition, in 2011 a silicified wood fragment was collected from the same sterile dump and is the subject of a separate study. The fossils were recorded as separate, individual fragments belonging to hand specimens, according to the standard detailed by POPA (2011).

The lithological context of the fossils is represented by dark, fine, coalified sandstones and mudstones. Paleosoils are frequent, samples which can be interpreted as belonging to stigmarian root horizons.

The fossils were photographed using a Panasonic DMC-L10 digital camera with an Olympus 35mm Zuiko Macro lens and a Kaiser copy-stand with two Ikea fluorescent lateral lights. For close-up work, a Carl Zeiss Stemi GZS dissecting microscope was used, to which a Canon Powershot A640 digital camera is attached. Digital images taken with the dissecting microscope were enhanced using the Carl Zeiss Axiovision Extended Focus software for increasing the depth of focus, and archived with the Carl Zeiss Asset Archive software.

5. SYSTEMATICS

This is not intended as a detailed systematic analysis of these species, and the synonyms quoted below are merely the records of publication of the basionym, the most important combinations of the basionym, and any specimens that have been previously illustrated from the Cucuiova Formation. Since none of the specimens preserve anatomy or reproductive structures we have made no attempt to place them in suprageneric taxa other than classes.

Class Sphenopsida

Genus *Calamites* STERNBERG, 1820
Calamites carinatus STERNBERG, 1823
(Pl. 1, Figs. 1, 2)

1823 Calamites carinatus – STERNBERG, 1823, p. 39, pl. 32, fig. 1
1972a *Calamites carinatus* – BIȚOIANU, p. 394, pl. 2, fig. 1
1972b *Calamites carinatus* – BIȚOIANU, p. 126, 127, pl. 1, fig. 5
1973 *Calamites carinatus* – BIȚOIANU, p. 116, pl. 1, fig. 3

Material: Several fragments of this species are preserved on samples P41/C5/3 (Pl. 1, Fig. 1) and P41/C5/2 (Pl. 1, Fig. 2).

Description: Articulated, flattened stems with typical longitudinal ribs and internodes longer than broad (Pl. 1, Figs. 1, 2). Internodes width 20–40 mm, longitudinal rib density 9–11 per cm. All stems show nodal branch scars which suggest an opposite pair arrangement. The scars have ribs converging towards them, as well as convergent ribs within the scars themselves (Pl. 1, Fig. 2).

Remarks: The collected material consists of stems with oppositely arranged nodal branch scars and converging ribs typical of *Calamites carinatus*. This species was previous recorded from Romania by BIȚOIANU (1972 a, b, 1973, 1974), only from Baia Nouă, where it was considered Westphalian D (Asturian) in age. Elsewhere it has a stratigraphical range throughout the Westphalian Stage (e.g. CROOKALL, 1969; JOSTEN, 1991).

Genus *Sphenophyllum* BRONGNIART

Sphenophyllum cuneifolium (STERNBERG) ZEILLER, 1879 (Pl. 1, Figs. 3–5)

1821 *Rotularia cuneifolia* – STERNBERG, p. 33, pl. 26, figs 4ab
1879 *Sphenophyllum cuneifolium* – ZEILLER, p. 30
1972a *Sphenophyllum cuneifolium* – BIȚOIANU, p. 126, pl. 2, fig. 11
1973 *Sphenophyllum cuneifolium* – BIȚOIANU, p. 116, pl. 2, fig. 15

Material: Specimen 0512 of the C. Eufrosin Collection (Laboratory of Palaeontology, University of Bucharest) is littered with *Sphenophyllum cuneifolium* leaves and branches.

Description: Internodes 10–25 mm long and 2–6 mm wide, striated longitudinally, and slightly expanded at the nodes. At the nodes are whorls of 6–10 deltoidal, elongated, triangular leaves, 9–13 mm, rarely 14 mm long and 3–5 m, rarely 7 mm wide at the apex (Pl. 1, Fig. 3). All leaves of the whorl are equal in length. Lateral margins are straight; the distal margin is straight or slightly rounded, with 12–18 sharp, equal, triangular and symmetrical teeth (Pl. 1, Figs. 4, 5). From the base of the leaf, a single vein divides dichotomously several times to the apex, where each tooth receives a single vein (PL. 1, Fig. 5).

Remarks: The Baia Nouă material is typical for *Sphenophyllum cuneifolium* in the shape of the leaves, the apex and the symmetrical, sharp distal teeth. JOSTEN (1983, 1991) described *Sphenophyllum cuneifolium* from NW Germany with similar sized leaves to those from Baia Nouă, but those from the British Isles figured by CROOKALL (1929) and CLEAL & THOMAS (1994) tended to be rather smaller, typically no more than 12 mm long. The Romanian *Sphenophyllum cuneifolium* is similar in size to *Sphenophyllum majus* (BRONN) BRONN, but does not have the deeply sinused apex that *S. majus* typically has. Also, the leaves have affinities with *Sphenophyllum emarginatum* with respect to the slightly curved shape of their distal margins, but they have pointed teeth with straight or convex dental margins. The records of *Sphenophyllum cuneifolium* from Baia Nouă by BIȚOIANU (1972a, 1972b, 1973) were not accompanied by descriptions and the poor illustrations are difficult to assess. BIȚOIANU (1972a, 1973) considered *Sphenophyllum cuneifolium* to be a characteristic species for the Bolsovian – Westphalian D interval in the Sirinia Basin but elsewhere it ranges between the Kinderscoutian and Asturian substages (e.g. JOSTEN, 1983, 1991; CLEAL, 2005, 2007).

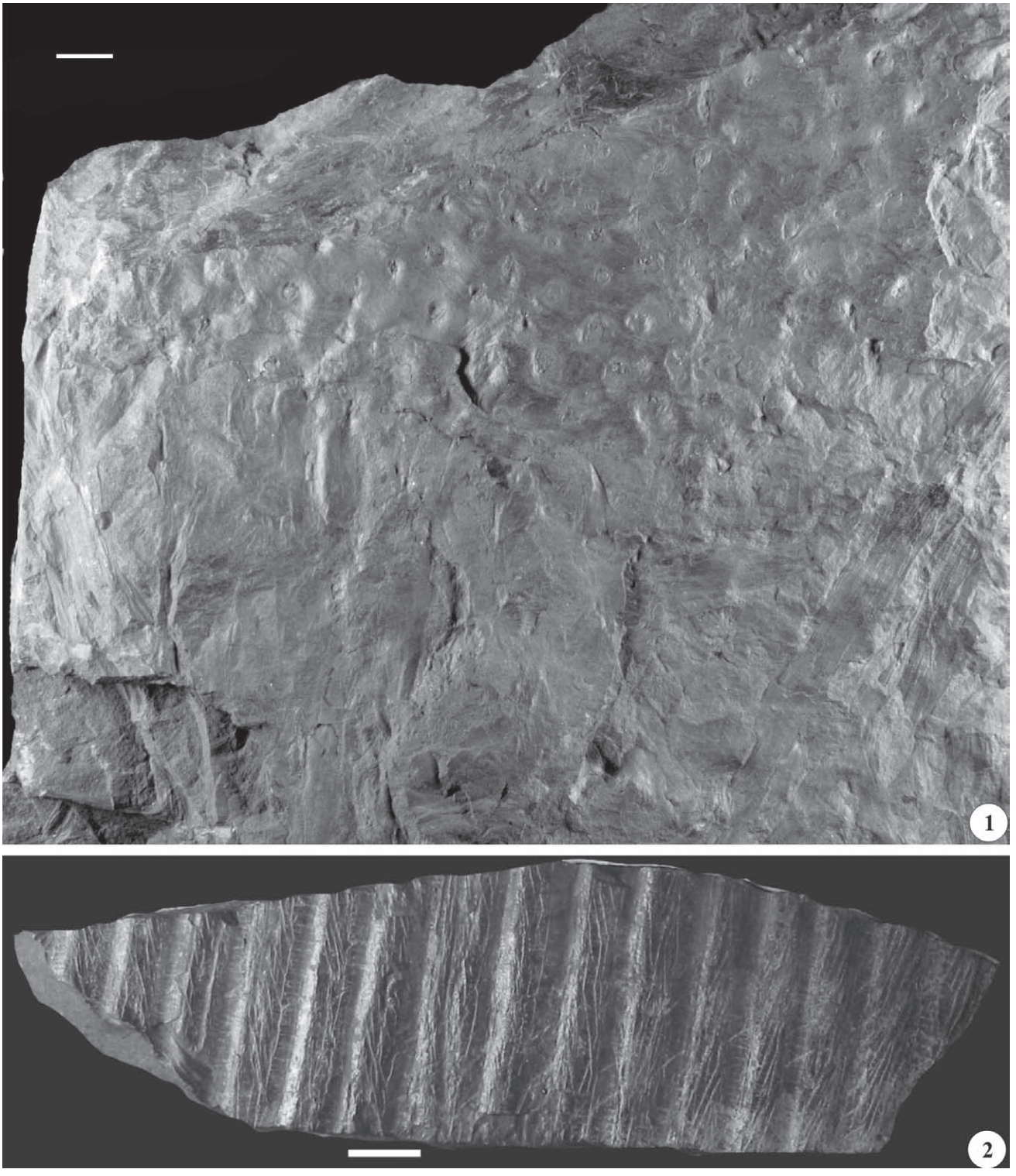

PLATE 2

1 *Stigmaria ficoides*, P41/C5/1, fragment 1, M.E. Popa Collection, University of Bucharest. Scale bar: 10mm.
2 *Sigillaria* sp. Sample 0558, fragment 1, I.Z. Barbu Collection. Scale bar: 10mm.

Class Lycopsida

Genus *Stigmaria* BRONGNIART, 1822
Stigmaria ficoides (STERNBERG) BRONGNIART, 1822
(Pl. 2, Fig. 1)

1820 *Variolaria ficoides* – STERNBERG, p. 24, pl. 12
1822 *Stigmaria ficoides* – BRONGNIART, p. 228.
1972a *Stigmaria ficoides* – BIȚOIANU, p. 126, pl. 2, fig. 9

Material: Casts of this fossil-species are abundant in the newly collected samples from Baia Nouă, such as fragment 1 of sample P51/C5/1 (Pl. 2, Fig. 1) in the M.E. Popa Collection (University of Bucharest).

Description: Rhizophore fragments of lycopsids, represented by fragments of flattened, cylindrical casts with circular, regularly distributed scars to which roots are often attached (Pl. 2, Fig. 1).

Remarks: *Stigmaria ficoides* has been cited from Romania both from the Reşița and from the Sirinia Basins. In both basins, the material is recorded in situ, with rootlets still attached. As a rhizophore, it could belong to any one of several lycopsid genera. MAXIM (1967) also cited *Stigmaria rugulosa* GOTHAN from here but this almost certainly just refers to specimens of *S. ficoides*.

Genus *Sigillaria* BRONGNIART, 1822
Sigillaria tesselata BRONGNIART, 1837
(Pl. 3, Fig. 1)

1837 *Sigillaria tesselata* – BRONGNIART, p. 436, pl. 162, figs. 1–4

Material: The only known example from Baia Nouă is Specimen No. 174 in the S. Cotuțiu Collection (National Geological Museum, Bucharest).

Description: The leaf scars are regular, 7–8 mm in outline diameter, somewhat rounded rather hexagonal in shape, some still weakly preserving densely grouped point-like marks. The leaf scars are closely spaced in longitudinal rows, adjacent scars almost touching each other. The vertical ribs separating the leaf scars rows are distinct, about 2 mm wide, strongly depressed and straight, distributed at intervals of 11–12 mm (Pl. 3, Fig. 1). There is no ornamentation between the leaf scars and the vertical ribs.

Remarks: The material shows the same leaf scar dimensions, density and distribution, and the lack of ornamentation between the scars as is typically shown by *Sigillaria tesselata*, such as documented by CROOKALL (1966) and JOSTEN (1991). This species ranges throughout the Westphalian Stage (e.g. JOSTEN, 1991; CLEAL, 2007) and there are also records from the Stephanian Stage (e.g. GRAND'-EURY, 1877).

Genus *Syringodendron* STERNBERG, 1820
Syringodendron sp.
(Pl. 2, Fig. 2)

Material: A single specimen, No. 0558 in the I.Z. Barbu Collection (University of Bucharest).

Description: An external cast showing widely spaced vertical ribs.

Remarks: *Syringodendron* is a fossil-genus of decorticated *Sigillaria*-like stems such as this one. It is possible that it was produced by the same species of plant that produced the *Sigillaria tesselata* stems, but it is impossible to be certain.

Class Cycadopsida

Genus *Neuralethopteris* CREMER, 1893 emend. LAVEINE, 1967
Neuralethopteris rectinervis (KIDSTON) LAVEINE, 1967 (Pl. 3, Fig. 2; Pl. 4, Figs. 1–5)

1888 *Neuropteris rectinervis* – KIDSTON, p. 314–315, pl. 1, figs. 2–4
1967 *Neuralethopteris rectinervis* – LAVEINE, p. 120, pl. 9

Material: This species has not been previously recorded from Baia Nouă but was one of the most abundant in the newly collected material.

Description: Pinnules occur rarely attached to a smooth pinna rachis (Pl. 4, Fig. 4) but more usually are found detached. The pinnules are linear, elongate (Pl. 3, Fig. 2), with a cordate or a weakly cordate base, and parallel margins converging quickly to a rounded apex (Pl. 4, Figs. 1–3). Pinnules vary between 5–20 mm in length, usually 15mm, and 5–7 mm in width. The midrib is rather thin, straight for most of its length but may be somewhat decurrent in its most proximal part (Pl. 4, Figs. 1–3), and occurs along a depression in the lamina. The midrib remains entire for about 90% of the pinnule length, and then divides at least once before reaching the pinnule apex. The secondary veins arise at 45–50° from the midrib, and then usually divide twice before reaching the pinnule margin (Pl. 3, Fig. 2; Pl. 4, Figs. 1–5). They bend quickly in the first half of the distance between the midrib and the pinnule margin, reaching the margin at 85–90° on the acroscopic side of the pinnule, usually a little more obliquely (75°) on the basiscopic side (Pl. 3, Fig. 2; Pl. 4, Fig. 2); this asymmetry in the venation does not seem to be related to taphonomy. The first division of the secondary veins occurs immediately next to the midrib, and the second just over half way between the midrib and margin. The dichotomies of the secondary veins occur at very narrow angles. The vein density along the pinnule margin varies between 48–60 veins per cm.

A rare, small, probably basal pinnule occurs on sample P41/C5/6 (Pl. 4, Fig. 5) together with more typical dispersed *Neuralethopteris rectinervis* pinnules which litter the hand specimen. It is 5.2 mm long and 2.2 mm wide, with a constricted but not cordate base (Pl. 4, Fig. 5), a rather wide midrib and denser secondary veins (vein density up to 80 per cm). However, the venation and pinnule geometry is otherwise similar to that of *Neuralethopteris rectinervis*.

Remarks: The newly collected material shows characters consistent with those of *Neuralethopteris rectinervis*, such as the pinnule shape and size, weakly cordate base, thin

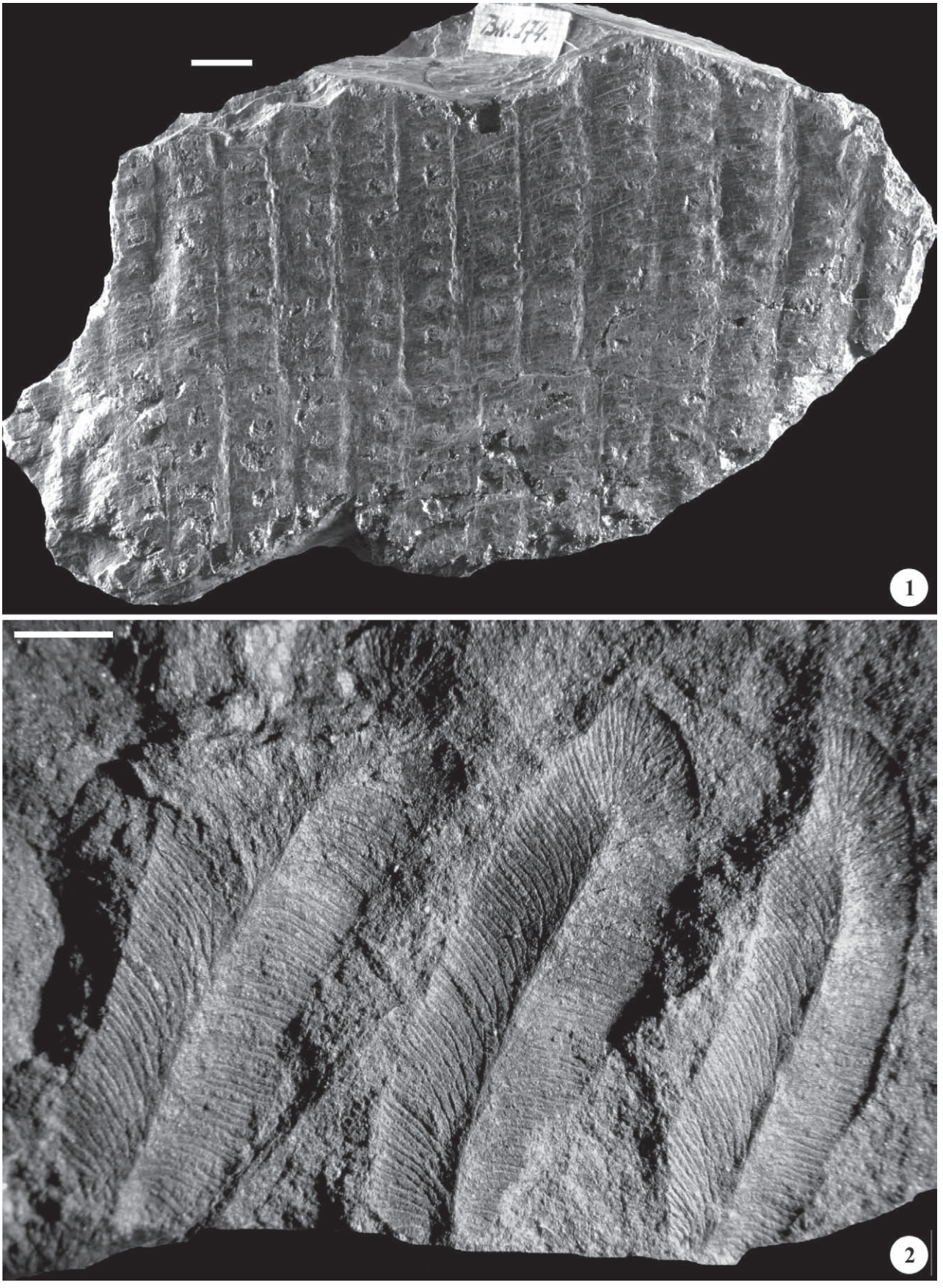

PLATE 3

1 *Sigillaria tesselata*, sample 174, fragment 1, S. Cotuțiu Collection, National Geological Museum in Bucharest. Scale bar: 10mm.
2 *Neuralethopteris rectinervis*, P41/C5/6, fragment 1, M.E. Popa Collection, University of Bucharest. Scale bar: 2mm.

midrib, and secondary vein shape, distribution and marginal density. It is the first time that *Neuralethopteris rectinervis* has been recorded from Romania, but the specimens compare closely with those that have been documented from northern France (LAVEINE, 1967), northern German (JOSTEN, 1991) and the Dobrudzha Coal Basin in Bulgaria (TENCHOV & CLEAL, 2010). The species is characteristic of the Langsettian Substage, especially of the lower part.

Neuralethopteris schlehanii (STUR) CREMER, 1893
(Pl. 5, Figs. 1–2)

1877 *Neuropteris schlehani* – STUR, p. 289, pl. 28, figs. 7, 8a, b, c
1893 *Neuralethopteris schlehani* – CREMER, p. 33
1972a *Neuropteris schlehani* – BIȚOIANU, pl. 2, fig. 12

Material: There is a single fragment in the C. Eufrosin Collection (Laboratory of Palaeontology, University of Bucharest), Specimen No. 0504. The original identification of this fragment was *Neuropteris tenuifolia* SCHLOTHEIM ex STERNBERG.

Description: The pinna rachis is smooth, 1mm wide, supporting pinnules inserted at 80–90° to its adaxial surface (Pl. 5, Fig. 1). The pinnules are elongated, straight-rectangular or slightly falcate, with a weakly cordate base, parallel margins and rounded apex (Pl. 5, Fig. 2); pinnule length 10–12 mm, pinnule width 3–4 mm. The pinnules are alternately or suboppositely attached to the rachis through a very short stalk or petiole that is directly continuous with the midrib. The entire frond fragment is preserved three-dimensionally, with rachises and pinnules preserved in different, convergent planes. The pinnule lamina is strongly folded abaxially, with a depressed midrib and margins. The midrib is rather thick, about 70–80% of the pinnule length, and usually straight or in falcate pinnules curved. The secondary veins divide twice, the first time immediately next to the rachis and the second time in the first half of the distance between the midrib and the pinnule margin. The veins reach the margins at 75–85° on the acroscopic side of the pinnule, but at 60° on the basiscopic side. Secondary veins do not bend strongly even next to the midrib, where the first dichotomy occurs. The vein density is 40–50 per cm on the pinnule margin.

Remarks: *Neuralethopteris schlehanii* is characterized by rather short pinnules compared to those of *N. rectinervis*, with a weakly cordate base and regular, parallel margins, and twice divided secondary veins with a marginal vein density of 36–48 per cm (TENCHOV & CLEAL, 2010). GOUBET et al. (2000) documented material with larger size variations, but with average length of 10 mm and width of 5 mm from North America, where this species records are rare. The Romanian fragment shows affinities with *Neuralethopteris rectinervis*, but the secondary vein distribution and density, pinnule base and general pinnule sizes are rather different. TENCHOV & CLEAL (2010) described this species from the Mogilishte Formation in northern Bulgaria (Dobrudzha Coalfield), where it is Langsettian in age. The Bulgarian material is similar to the Romanian material, although the former has slightly more triangular pinnules compared with the more rectangular shape of the latter. BIȚOIANU (1972a, b, 1973) cited *Neuropteris schlehani* and *Imparipteris* (*Neuropteris*) *schlehani* (Table 1) from Baia Nouă, but the illustration in BIȚOIANU (1972a) is difficult to interpret.

6. DISCUSSION

Most of the taxa that we document here from Baia Nouă are long ranging and of little value for indicating a stratigraphical age. The notable exceptions are the *Neuralethopteris* species, which elsewhere are regarded as reliable indices of floras of middle Namurian to lower Westphalian (Langsettian) age (LAVEINE, 1967; JOSTEN, 1983, 1991; CLEAL & THOMAS, 1994; CLEAL, 2005, 2007; TENCHOV & CLEAL, 2010). In the Appalachians it is restricted to the Pocahontas and lower New River formations, which are thought to correlate with the lower Langsettian Substage in the European chronostratigraphical scheme (GOUBET et al., 2000; BLAKE et al., 2002). In the Donets Basin (Ukraine) *Neuralethopteris* is restricted to the Bashkirian Stage (NOVIK, 1952; FISSUNENKO & LAVEINE, 1984), which is probably equivalent to the Namurian and early Westphalian stages.

Most previous studies have in contrast ascribed a late Westphalian or possibly early Stephanian stratigraphical age to the Baia Nouă flora. On the basis of the published species lists such an interpretation might be viable, but it is difficult to make a critical judgement as the published illustrations of the fossils are generally poor and there are few voucher specimens to verify the identifications. One of the key taxa listed in these earlier studies is *Neuropteris ovata* HOFFMANN, which would be a strong indicator of Asturian or Stephanian age, but the specimens figured by BIȚOIANU (1972a, pl. 2, fig. 15; 1972b, pl. 2, fig. 16) have linguaeform pinnules and a strong midvein, and look remarkably like the specimens described here as *Neuralethopteris rectinervis*. The presence of *Alethopteris serlii* (BRONGNIART) GOEPPERT would also suggest a late Asturian or Cantabrian age (e.g, see discussion in ZODROW & CLEAL, 1998) but the specimen figured by BIȚOIANU (1973, pl. 2, fig. 13) does not show the venation clearly (a feature critical for the correct identification of this species) and pinnules of similar shape also occur in *Alethopteris lancifolia* WAGNER, which is well-known from early Westphalian floras (e.g. WAGNER, 1961, 2005). The specimen figured by BIȚOIANU (1972a, pl. 3, fig. 19) as *Mariopteris nervosa* (BRONGNIART) ZEILLER, another indicator of a late Westphalian age, is similarly undiagnostic for this species. None of the illustrated specimens from Baia Nouă is in fact incompatible with a Langsettian age indicated by the evidence presented in this paper.

This makes the Sirinia Basin rather different from most of the other intramontane basins in Europe, which tend to be late Westphalian and Stephanian in age (e.g. DOUBINGER & VETTER, 1983; CLEAL et al., 2010, 2011). A well-documented intramontane basin in Europe that includes early Westphalian deposits and macrofloras is the Svoge Basin in Bulgaria (TENCHOV, 1976, 1977, 2007). In Eastern Serbia, within the Stara Planina – Poreč terrane (corresponding to the

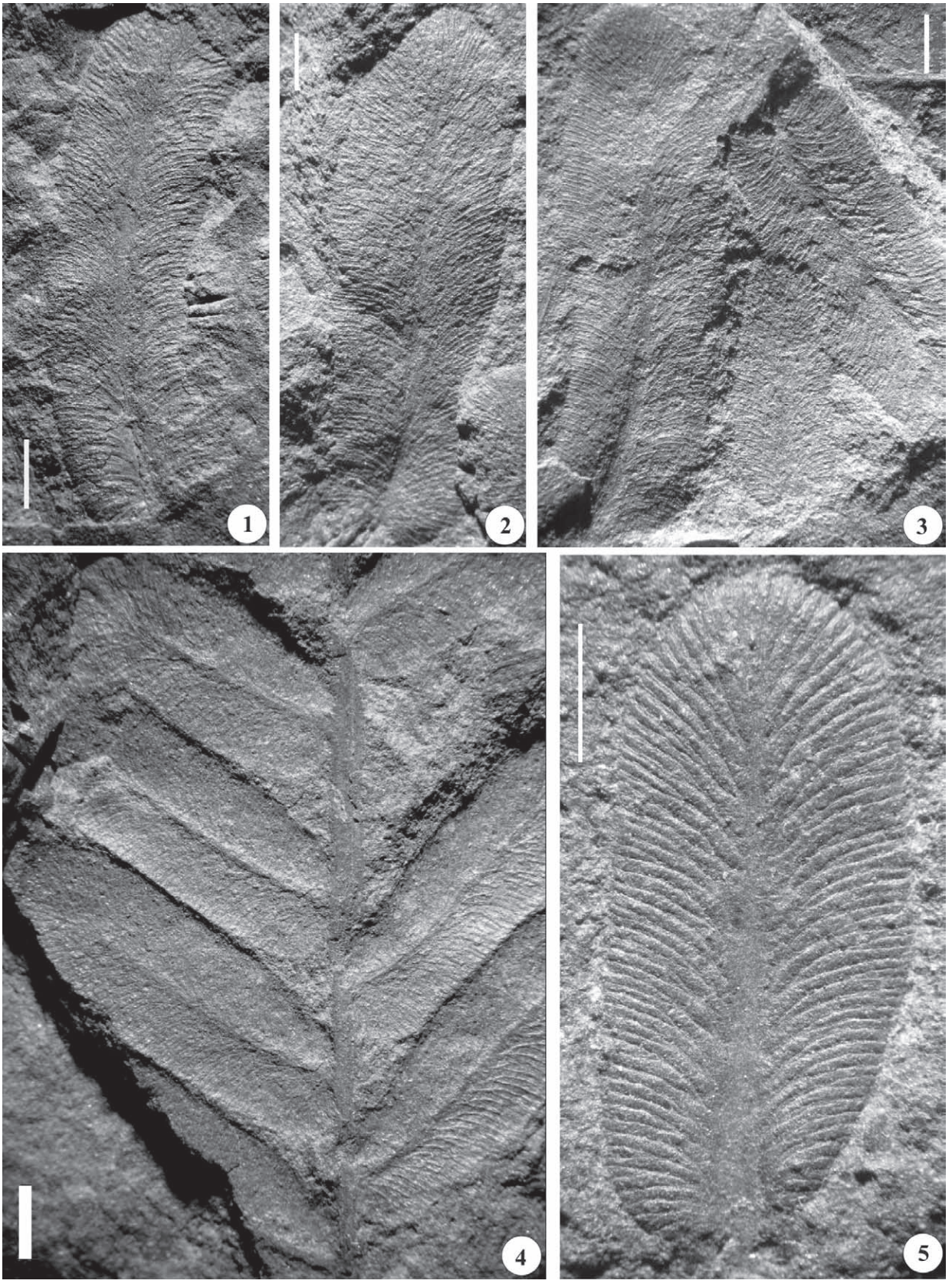

PLATE 4

1 *Neuralethopteris rectinervis*, sample P41/C5/23, M.E. Popa Collection, University of Bucharest. Scale bar: 2mm.
2 *Neuralethopteris rectinervis*, sample P41/C5/17, M.E. Popa Collection, University of Bucharest. Scale bar: 2mm.
3 *Neuralethopteris rectinervis*, sample P41/C5/11, M.E. Popa Collection, University of Bucharest. Scale bar: 2mm.
4 *Neuralethopteris rectinervis*, sample P41/C5/31, M.E. Popa Collection, University of Bucharest. Scale bar: 2mm.
5 *Neuralethopteris rectinervis*, sample P41/C5/6, M.E. Popa Collection, University of Bucharest. Scale bar: 2mm.

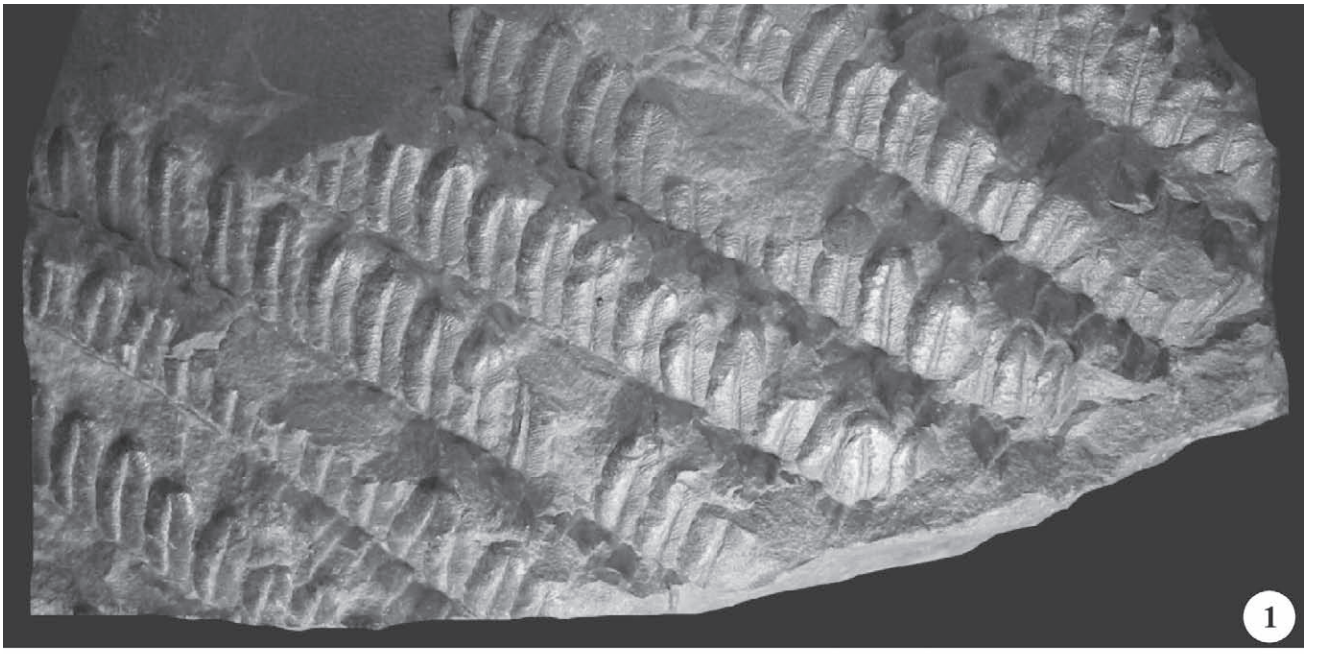

PLATE 5

1 *Neuralethopteris schlehanii*, sample 0504, C. Eufrosin Collection, University of Bucharest. Scale bar: 10mm.
2 *Neuralethopteris schlehanii*, detail of sample 0504, C. Eufrosin Collection, University of Bucharest. Scale bar: 1mm.

Upper Danubian Units), occur terrestrial sediments (KRSTIĆ & MASLAREVIĆ, 1997), with a floral assemblage dominated by lycopsids marking the Langsettian (Late Bashkirian) – Westphalian (Moscovian) interval (PANTIĆ, 1955, 1963, KRSTIĆ et al., 2005, DJORDJEVIĆ-MILUTINOVIĆ, 2010). Western Serbia includes a drifted, allochtonous Bashkirian – early Moscovian flora (KRSTIĆ et al., 2005) within the Stojković Formation, belonging to the Jadar Block Terrane, with a different tectonic setting to that of the Balkan Terrane.

The Svoge, Stara Planina-Poreč and Sirinia basins were positioned on the Balkan Terrane (YANEV, 2000; YANEV et al., 2005), a Gondwana-derived microplate that docked with Laurussia in late Carboniferous times and which ultimately became part of the Variscan Mountains. Whether this means there is a genetic link between the Svoge, eastern Serbia and Sirinia basins, however, must remain unclear until more is learnt about these Romanian deposits.

7. CONCLUSIONS

The study of the floral assemblage of the Cucuiova Formation in Baia Nouă is based mainly on freshly collected material as well as on previous, historical collections. The results show a series of key species (*Neuralethopteris rectinervis*, *N. schlehanii*) marking the Middle Namurian – Late Westphalian (Langsettian, Late Bashkirian) time interval, associated with species which have wider ranges, but which are not incompatible to the Langsettian age proposed for the lower part of the Cucuiova Formation in Baia Nouă. Therefore, Baia Nouă hosts the oldest Pennsylvanian (Langsettian) sediments in the Sirinia Basin, older than in any other Pennsylvanian locality in the Sirinia Basin (Cucuiova area, Povalina Valley, Cameniţa area, Dragosela Valley), in the Danubian Units and even in the South Carpathians. This age makes the Cucuiova Formation in Baia Nouă comparable to early Westphalian sediments of the Svoge and eastern Serbian (Stara Planina – Poreč) basins.

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