Geologia Croatica	65/3	345–350		1 Tab.	2 Pls.	Zagreb 2012

A new species of *Selaginella* (Selaginellaceae) from the Bolsovian (Carboniferous Period) of the Zonguldak – Amasra Coal Basin, north-western Turkey

Zbyněk Šimůnek[1] and Barry A. Thomas[2]

[1] Czech Geological Survey, Klárov 3/131, 118 21 Praha 1, Czech Republic; (zbynek.simunek@geology.cz)
[2] Institute of Biological, Environmental and Rural Sciences, Aberystwyth University, Aberystwyth, Ceredigion SY231NL, UK; (bat@aber.ac.uk)

doi: 104154/gc.2012.23

Geologia Croatica

ABSTRACT

Shoot fragments of a new species of *Selaginella* BEAUV are described from the Bolsovian (Carboniferous Period) of Amasra, Turkey. The shoots are heterophyllous with three paired ranks of different sized leaves enabling it to be referred to the subgenus *Hexaphyllum* THOMAS. The size, shape and epidermal details of the leaves enable it to be differentiated from other Pennsylvanian species and referred to a new species *Selaginella amasrae* ŠIMŮNEK & THOMAS, sp. nov. This new record extends the early distribution of the subgenus suggesting that it first appeared in eastern Variscan Euramerica and the intermontane basins of central Europe, before spreading into the foreland basins of western Euramerica.

Keywords: *Selaginella*, Carboniferous, Turkey

1. INTRODUCTION

Most pteridologists recognise *Selaginella* BEAUV as the only genus of extant plants in the family Selaginellaceae MILDE that contains about 700, mainly tropical, species (TRYON & TRYON, 1981). Anisophyllous *Selaginella*-like fossils are also known from the Bolsovian onwards and THOMAS (2005) concluded that they were close enough to the anisophyllous species of extant *Selaginella* to be included in that genus. However, the presence of three, not two, pairs of leaves necessitated the erection of a new sub-genus, *Hexaphyllum* THOMAS, 2005. Nevertheless, *Selaginella* is a rare genus in the Carboniferous with approximately ten named species and even some of these have not been described in sufficient detail. Therefore, it was a great surprise when we found fragments of two tiny twigs of a *Selaginella* after dissolving a small rock fragment with coalified leaves. This sample was taken from the borehole number H 42 in Amasra during the ICCP 575 meeting's field excursion in Turkey in 2010.

2. GEOLOGICAL SETTING

The sedimentation of the Upper Devonian and Visean marine carbonates changed into terrestrial deposition during the Upper Visean and Lower Namurian in the Bartin-Amasra Basin (Derman and Özçelik, 1993). The Namurian Alacaağzi Formation, (up to 570 m thick in the Amasra coalfield), is formed of sandstone, siltstone and claystone sequences with thin uneconomical coal seams in its upper part (CANCA, 1994; KEREY et al., 1986). The Westphalian Kozlu Formation (Langsettian), is up to 900 m in thickness and composed of conglomerates, sandstones, mudstones and 18 mineable coal seams (CANCA, 1994;

KEREY et al., 1986). The younger Karadon Formation (mostly Duckmantian, Bolsovian and Asturian) comprises up to 550 m of conglomerates, sandstones and mudstones, and the lower part of this section contains the four most economical coal seams in the Amasra coalfield (CANCA, 1994). The sediments in the lower parts of the Karadon Formation are grey to dark grey while in the upper parts they are reddish grey in colour.

The subsequent Permian Aritdere Formation contains red coloured conglomerates, sandstones and mudstones and is unfossiliferous.

3. MATERIAL AND METHODS

A small fragment of black claystone with *Cordaites* UNGER leaves was taken from the borehole core Amasra, no. H 42, from a depth of 626.5 m (Hema Endüstri a.ş). This sample comes from the Karadon Formation and its age is Bolsovian (Moscovian) (CANCA, 1994). The cuticles were prepared by ŠIMŮNEK using standard methods (KERP 1990; KRINGS & KERP, 1997 and KERP & KRINGS, 1999). The plant remains were released from the rock using concen-

Table 1: Comparison of the species *S. gutbieri* (GÖPPERT) THOMAS, *S. stachygynandroiodes* (GEINITZ) THOMAS, *S. zeilleri* (HALLE) THOMAS and *S. amasrae* ŠIMŮNEK and THOMAS.

	S. gutbieri (GÖPPERT) THOMAS	*S. stachygynandroiodes* (GEINITZ) THOMAS	*S. zeilleri* (HALLE) THOMAS	*S amasrae* ŠIMŮNEK and THOMAS
LATERAL LEAVES				
Size	<5 mm long 2 mm wide	6 mm long 2 mm broad	4.5–5.5 mm long 1.2 mm broad	1.2 mm long 600 µm broad
Angle of spread	50°	60–68°	60–68°	15°
Apex	Acute to acuminate	Elongate-acute to acuminate	Elongate-acute to acuminate	Elongate -acute
Margin	Apical third serrate	Entire	Entire	Dentate
Epidermal cells	42x10 µm	50–120x10–15 µm	70x15–20 µm	c. 40x15 µm
Stomata	42x28 µm	60x20 µm	60x20 µm	35x20 µm
MEDIAN LEAVES				
Size	<1.6 mm long 0.2 mm broad	2.5mm long 1.2 mm broad	2.5 mm long 1.2 mm broad	950 µm long 300 µm broad
Angle of spread	10–15°	40°	40°	10–15°
Apex	Acute to acuminate	Acute	Acute	Acute
Margin	Entire	Apex slightly dentate	Distinctly dentate (teeth up to c. 400 µm long, 150 µm broad and c. 12 cells across at base)	Dentate in lower part with teeth up to c. 150 µm long and 50 µm broad and c. 6 cells across at base)
Epidermal cells	42x7 µm	20–115x10–15 µm	30-45x12 µm	25x15 µm
Stomata	35x18 µm	60x20 µm	60x20 µm	35x20 µm
VENTRAL LEAVES				
Size	2 mm long 0.5 mm broad	1.5 mm long 0.25 mm broad	3 mm long 1 mm broad	550 µm long 200 µm broad
Angle of spread	>10°	>10°	c. 5°	Parallel to axis
Apex	Acuminate			Acute
Margin	Dentate	Entire	Dentate	Entire
Epidermal cells	42x7 µm	20–60x15 µm	30–45x12 µm	25x10 µm
Stomata	35x18 µm	35x18 µm	60x20 µm	Not seen

trated (38 %) hydrofluoric acid (HF) and then washed in distilled water. The resulting phytoleims were macerated in Schulze Solution (40 % nitric acid with a little potassium chlorate) for 27 hours and then bleached using 2 % potassium hydroxide solution until the whole oxidation products (brown) matter was released. After washing again in distilled water, some of the cuticles were mounted in glycerine jelly for light microscopy. Some leaves were mounted on a metal stub for observation by SEM.

4. DESCRIPTION

Fragments of the following taxa were obtained by maceration: *Selaginella sp*., *Cordaites* sp., *Neuropteris* sp., *Eusphenopteris* cf. *sauveuri* and *Eusphenopteris* sp. Observations here are restricted to *Selaginella*. Fragments of *Selaginella* were mounted on two slides, 550/1–2 (Coll. Nos: ZŠ 467 and 468), that are stored in the collections of the Czech Geological Survey, Prague. The SEM stub with *Selaginella* leaves is number 63, also in the Czech Geological Survey collections.

The largest fragment of *Selaginella* is a small shoot about 7mm long and 2mm broad, while the other fragments show just a few leaves or portions of leaves. Because they are such small pieces prepared by maceration, comparison with other species known as much larger shoots preserved as recognisable compressions is a little more difficult than usual. Nevertheless, there are recognisable lateral, median and ventral leaves on the Turkish specimens, the sizes of which, outlines and epidermal features were studied under the microscope. The lateral leaves depart at about 15 º from the axis and are about 1.2 mm long, 600 µm broad with elongate-acute apices and dentate margins. Epidermal cells are elongated along the leaves, about 40 x 15 µm in size, and stomata are 30 x 20 µm. The median leaves depart at about 10–15° from the axis and are about 950 µm long, 300 µm broad with acute apices and dentate margins in their lower parts. Epidermal cells are elongated along the leaves, about 25 x 15 µm in size, and stomata are 30 x 20 µm. The ventral leaves depart at about 10° from the axis and are about 550 µm long, 200 µm broad with acute apices and entire margins. Epidermal cells are elongated along the leaves, about 25 x 10 µm large. No stomata could be seen.

5. COMPARISON

Most plant fossils, like living plants, should be distinguishable on gross morphological features alone (THOMAS, 1997), but anatomical details of the epidermis have been shown to be valuable taxonomic features in fossil lycophytes. THOMAS (1966, 1967, 1968, 1970, 1974, 1976) showed this to be the case in arborescent lycophytes while THOMAS & MASARATI (1982), THOMAS (1985, 1992, 1997), THOMAS, B.A., CLEAL C.J. & BARTHEL, M. (2004), BEK et al. (2001) and THOMAS (2005) have shown the same to be true with herbaceous species.

There are three species of Carboniferous *Selaginella* shoots that have been described in sufficient detail to be worthy of comparison with the Turkish specimens. *Selaginella gutbieri* (GÖPPERT) THOMAS, *S. stachygynandroiodes* (GEINITZ) THOMAS and *S. zeilleri* (HALLE) THOMAS are all known from leaf and epidermal characters. Other species such as *Selaginellites elongatus* (GOLDENBERG) HALLE and *Paurodendron fraiponti* (LECLERQ) FRY need re-investigating, while others such as *S*. cf. *leptostachys* (GOLDENBERG) THOMAS (BEK et al., 2001) are not known in sufficient detail to make a detailed comparison with the Turkish specimens.

The characters of all four species are summarized in Table 1 showing the differences in leaf size, leaf shape and epidermal characters. The most obvious difference between the new Turkish *Selaginella* and all the others is its much smaller overall size, with its correspondingly much smaller leaves. Indeed, because of the small size, it might easily be overlooked if preserved as a compression on dark shale. The larger species, *Selaginella gutbieri*, *S. stachygynandroides* and *S. zeilleri* are much more obvious as compressions with their spreading lateral leaves and overlapping median leaves. Extant species of heterophyllous *Selaginella* form full sized leaves close behind their growing apices, so it is extremely unlikely that the Turkish shoots are parts of a larger plant. The size difference of the shoot and its leaves, together with the relatively tight arrangement of its leaves against the stem, the details of its leaf outlines and epidermal cells lead us to the conclusion that the Turkish *Selaginella* is a new species.

6. SYSTEMATICS

Class Lycophyta

Family Selaginellaceae
***Selaginella* P. BEAUV,**
subg. *Hexaphyllum* THOMAS
***Selaginella amasrae* ŠIMŮNEK & THOMAS, sp. nov.**
(Pl. 1, Figs. 1–6, Pl. 2, Figs. 1 and 2)

Anisomorphic shoot about 2mm broad with three paired ranks of leaves. Lateral leaves spreading at 15° to the long axis, c.1.2 mm long, 600 µm broad near the base, apex elongate-acute, margins dentate, epidermal cells 40x15 µm, stomata 30x20 µm. Median leaves spreading at 10–15° to the long axis c. 950 µm long. 300 µm broad near the base, apex acute, margins dentate in lower part, epidermal cells 20x15 µm, stomata 35x20 µm. Ventral leaves parallel to the axis, 550 µm long and 200 µm broad near the base, apex acute, margins entire, epidermal cells 25x10 µm, stomata not seen.

Holotype: Here designated (Pl. 1, Fig. 1), Slide No: 550/1.

Repository: Coll. No. ZŠ 467 (slide 550/1) and ZŠ 468 (slide 550/2) Czech Geological Survey, Klárov 3/131, 118 21 Prague 1, Czech Republic.

Etymology: Named after the Coalfield where it was collected.

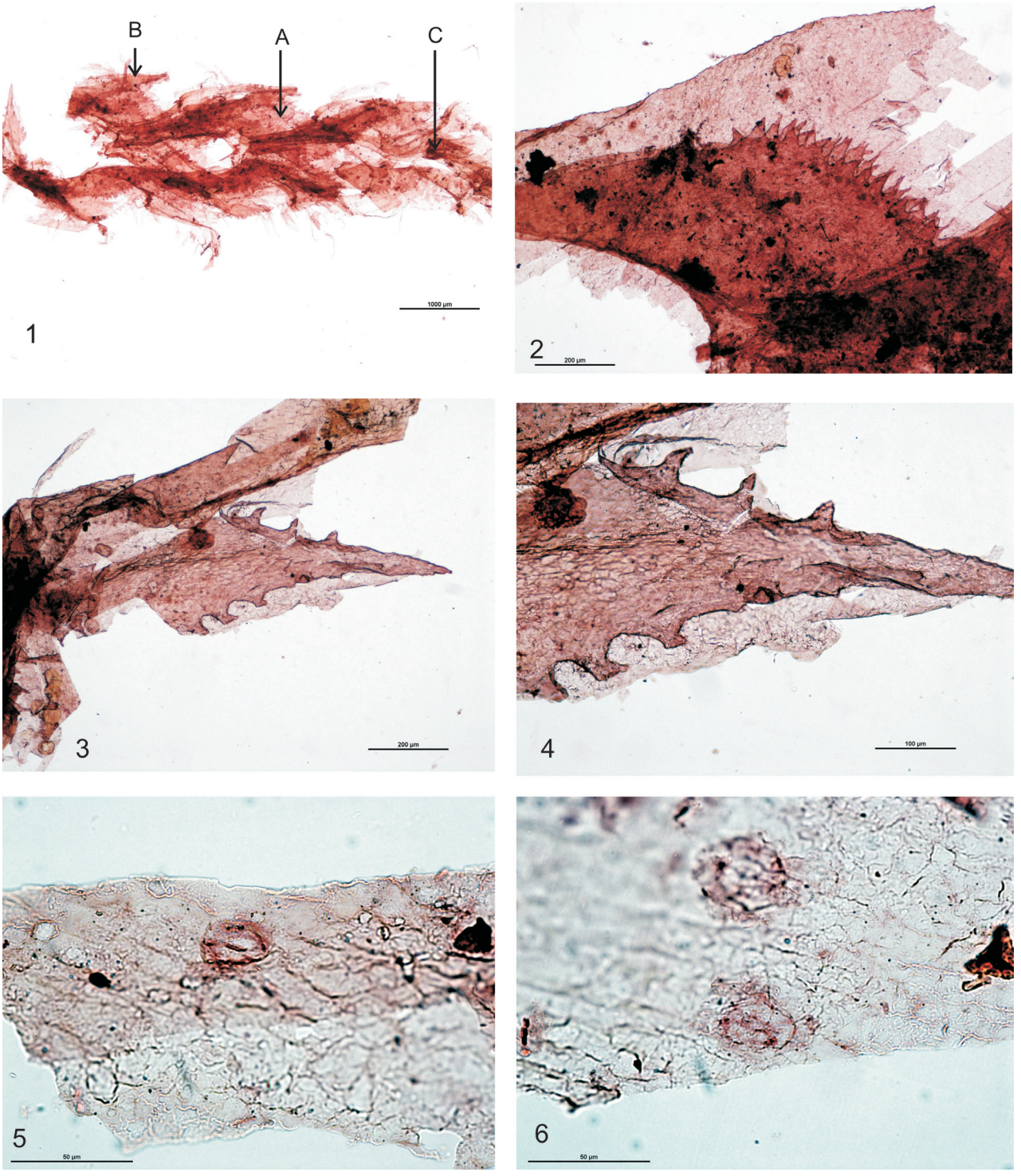
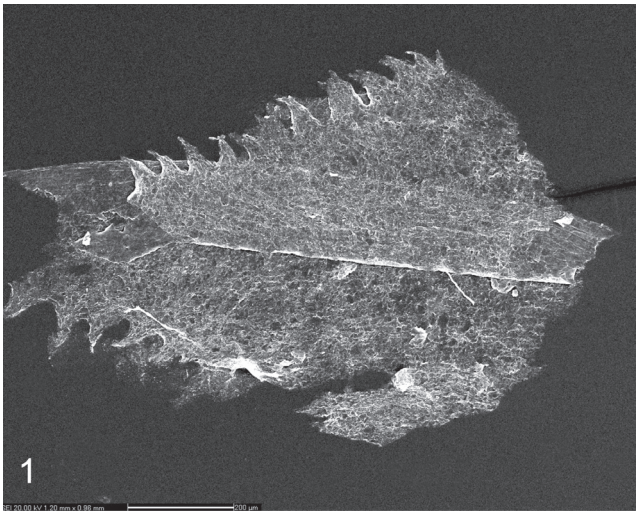


PLATE 1
Selaginella amasrae ŠIMŮNEK & THOMAS sp. nov. Specimen No: ZŠ 467 (Slide No: 550/1) except photo 2 = ZŠ 468 (Slide No: 550/2).

1 Small shoot with its apex to the right, showing lateral leaves (A), median leaves (B) and ventral leaves (C), scale bar = 1 mm
2 Folded basal part of a lateral leaf overlapping part of a lateral leaf scale bar = 200 µm.
3, 4 A median leaf, scale bar = 200 µm (3) and 100 µm (4).
5, 6 Epidermis of lateral leaves showing epidermal cells and stomata, scale bar = 50 µm.
(Photo: Z. ŠIMŮNEK)



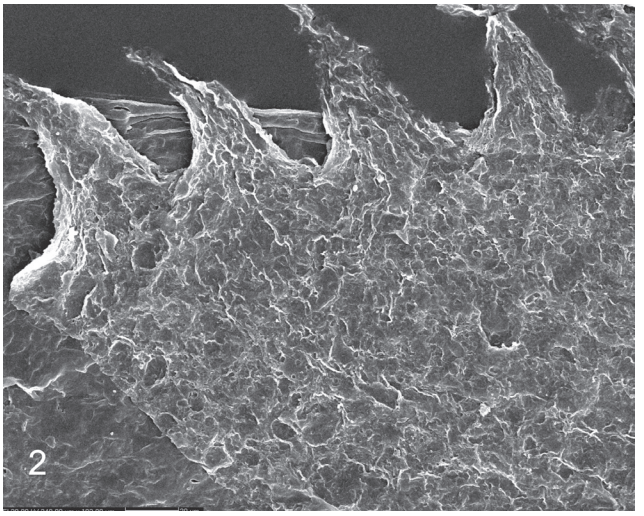


PLATE 2
Selaginella amasrae ŠIMŮNEK & THOMAS sp. nov. SEM stub. no. 63.

1 Basal fragment of lateral leaf with marginal teeth in SEM, scale bar = 200 µm.
2 Detail of marginal teeth in the leaf margin from Fig. 1, scale bar = 20 µm.

7. DISCUSSION

THOMAS (1992, 1997, 2005, 2009) summarised the stratigraphic ranges of the Pennsylvanian *Selaginella* fossils and suggested that the anisophyllous species made their first appearance in the Bolsovian of the Saar-Lorraine Basin (LAVEINE, 1989) and the Bolsovian of Ovčín (Pokrok), near Radnice, Western Bohemia (BEK et al., 2001). The new Turkish species is comparable in age with these. More are known from the later Asturian, having been described from the Sydney Mines Formation, Nova Scotia, Canada (BELL, 1938), Belgium (KIDSTON, 1911), the Bristol and Somerset coalfield in England (THOMAS & CLEAL, 1994), Zwickau in Saxony, Germany (THOMAS, 2005), Sarr-Lorraine, Belgium and the Nyřany Group of Coals, the Nyřany Member Nyřany, Plzeň Basin (Western Bohemia); and Ovčín (Pokrok), near Radnice, and the volcanic horizon directly overlying the Lower Radnice Coal, Radnice Member (Lower Bolsovian), Radnice Basin Western Bohemia (BEK et al., 2001).

The new locality extends the early distribution of Carboniferous anisophyllous species of *Selaginella* to Turkey. This new record appears to suggest that the subgenus *Hexaphyllum* first appeared in eastern Variscan Euramerica and the intermontane basins of central Europe before spreading into the foreland basins of western Euramerica. The small size of the Turkish *Selaginella* suggests that many other similar specimens have been overlooked. It remains to be seen if new discoveries will add information that will give a clearer picture of the origins and distribution of the anisophyllous species of *Selaginella*.

ACKNOWLEDGEMENT

This paper is a contribution to part of the International Geoscience Programme (IGCP Project 575) and was conducted with support of the Grant Agency of the Czech Republic (P210/10/0232) and the Research Aim of the Czech Geological Survey (MZP0002579801). The authors thank to head of the Hema Company (Amasra, Turkey) for permission to study the borehole sample.

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Manuscript received February 13, 2012
Revised manuscript accepted July 24, 2012
Available online October 30, 2012