LYCOPHYTE DISTRIBUTION IN THE PENNSYLVANNIAN OF THE DOBRUDZHA COALFIELD, BULGARIA AND THEIR VALUE IN CLIMATIC INTERPRETATION

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Abstract The Pennsylvanian species of Lycophyta known from the Dobrudzha coalfield, Bulgaria are outlined focusing on the distribution of species in the sequence. The habitat in the presented milieu and the influence of climatic changes are discussed.

Keywords: Dobrudza Coalfiled, Pennsylvanian, Lycophyta, Climatic influence.

INTRODUCTION

The Dobrudzha Coalfield is a sequence of Pennsylvanian (Upper Carboniferous) strata lying in the northeastern corner of Bulgaria (Fig. 1). About 1,800 m of uppermost Namurian to lowermost Stephanian coal-bearing strata occur below a thick post-Carboniferous cover. Details of the sequence was discovered through a series of deep-boreholes drilled during the 1960s, and have been described by Nikolov (1988) and Tenchov (1993, 2005, 2007). The lithostratigraphy was described by Tenchov & Kulaksuzov (1972).

About 11,700 specimens collected from the Dobrudzha bore holes and another 1000 from North-West Bulgaria outcrops, have been accessible since 2012 at the Museum for Geology and Palaeontology of the Geological Paleontological Faculty' Mining Geological University "Sveti Ivan Rilski" Sofia. This includes about 2000 specimens of lycophytes including some that have already been published.

The known Lycophyta from the Bulgarian Carboniferous were originally published by Tenchov (1987), although more data has been provided by Thomas & Tenchov (2004), Thomas (2007) and Thomas (in Cleal et al, 2010). The species *Lepidophloios giganteus* Tenchov has been revised and referred to *Sublepidophloios* Sterzel as *Sublepidophloios giganteus* (Tenchov) Thomas, Tenchov, Howell (Thomas et al., 2013). Further samples collected later provide a few more taxa which are reviewed here.

The symbols used in the species descriptions are: DC for Dobrudzha Coalfield; SC for Svoge coalfield; F for formation; R# - the borehole number in the Dobrudzha Coalfield, SL – for the distance in metres over the coal seam, 11 - the base of the Mogilishte Formation.

At present 56 taxa of Lycophyta are established. From them the four that are only known from the borehole F are not regarded here.

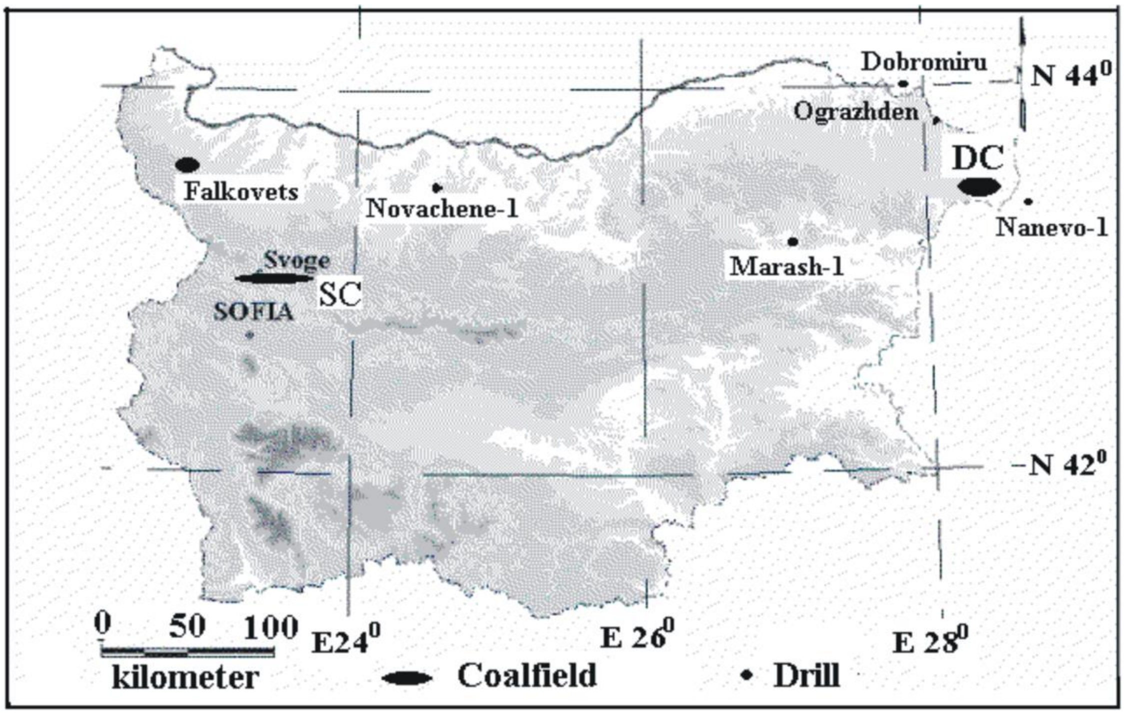

Fig. 1 Location of Dobrudzha Coalfield and some of the bore holes in Bulgaria.

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REMARKS ON THE DIFFERENT LYCOPHYTE ORGANS

Rhizophores:

Stigmaria Brongniart is the large dichotomizing rhizomorph base of Carboniferous arborescent lycophytes, such as *Lepidodendron* Sternberg, *Lepidophloios* Sternberg and *Sigillaria* Brongniart that bears spirally distributed roots or circular scars where the roots had once been. Many fragments of Stigmaria are found but there are very few complete specimens (Thomas & Seyfullah (2015). The main functions of the spreading rooting structures are to provide water for the plants and to support them from falling over in high winds and from sinking into the swamp by spreading the heavy load.

Trunks/stems:

Upright lycophyte stems are sometimes found in sandstones or shales above coal seams (e.g. Appleton *et al*. 2011; Thomas & Seyfullah 2016) but never in the coals themselves. It is the rapid inrush of sediment through as a result of severe weather conditions that can kill, entomb and ultimately infill the lycophytes (Thomas & Cleal, 2015).

Some lycophytes, such as *Lepidodendron* and *Lepidophloios*, branch profusely though dichotomous and pseudo-monopodial divisions while others such as *Sigillaria* branch only occasionally. Portions of the larger branches may be indistinguishable from those of the main axis, although the more terminal and smaller branches retain their leaves. The plants are believed to grow to a determinate pattern and size although in some genera like *Lepidodendron, Lepidophloios* and *Sigillaria* the branching may be supressed until the plants grow to, or over, the general canopy layer of the swamp vegetation. The apical growth of the stems and branches determines the helical arrangement of the leaf cushions or leaf scars.

The genera found in the Dobrudzha Coalfield are *Eleutherophyllum* (in Rakovski F – not considered here), *Lepidophloios* Sternberg, *Sublepidophloios* Sterzel, *Pinakodendron* Weiss, *Bothrodendron* Lindley & Hutton, *Cyclostigma* Haughton, *Sigillaria* Brongniart, and *Lepidodendron* Sternberg. Decorticated stems are not considered here.

Leaves:

Leaf laminae are abscised from stems, except in some taxa like *Eleutherophyllum*, and form an important ingredient of the swamps and of the subsequent coals. The generic names *Lepidophyllum* Brongniart, *Sigillariophyllum* Grand 'Eury and *Cyperites* Lindley and Hutton have been applied to them that are in some case many centimetres long. Abscission of the leaf laminae results in scars on the stems of *Sigillaria*, *Bothrodendron* and *Cyclostigma* and on the basal swollen parts of the leaves, the leaf cushions in *Lepidodendron*, *Lepidophloios*, *Sublepidophloios* and the smaller shoots of *Bothrodendron* (Thomas, 1967), which are one of the distinguishing features used in identifying species. Some of the leafy shoots have their laminae artificially removed during the splitting of the shale leaving a curved line (Pseudoscar) that can be mistaken for a badly preserved leaf scar (Thomas, 1970, 1977, 1978).

Reproductive organs:

The reproductive organs (cones) are produced at the ends of the branches in *Lepidodendron* and *Lepidophloios* and in bands on the main axis of *Sigillaria*. It is possible that the more intensive light at the canopy level might stimulate cone production. There is probably only one phase of reproduction in *Lepidodendron* and *Lepidophloios* so some time after the maturity of the reproductive organs the plant dies and ultimately decays and collapses into the swamp to form part of the resulting coal. This can result in open places for gametophyte formation, fertilisation and growth of the next generation.

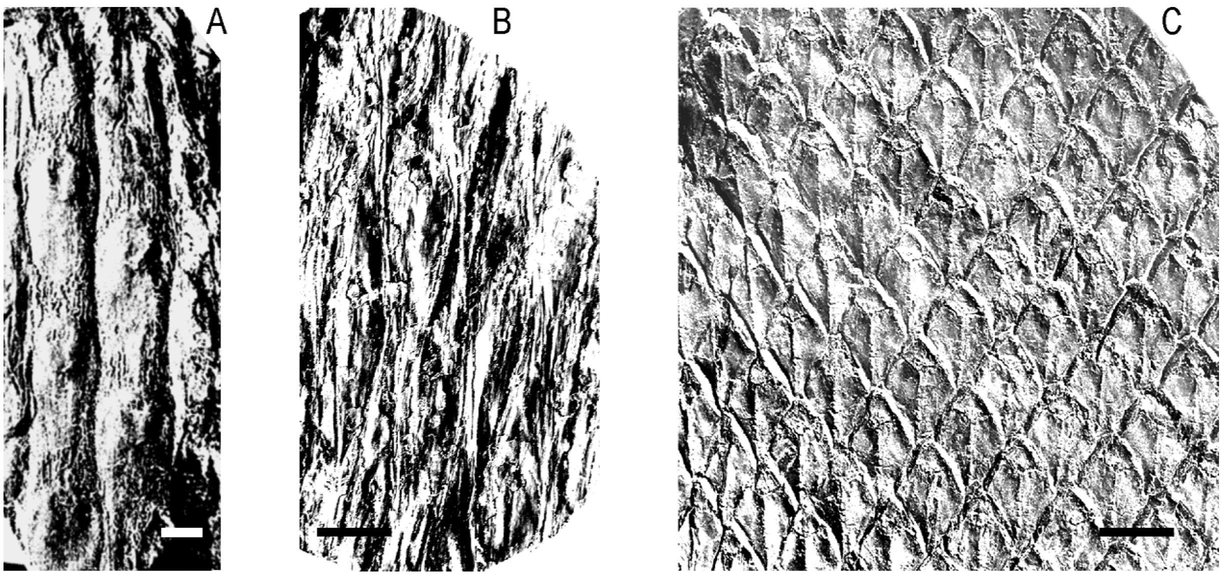

Fig 2. *Sigillaria* and *Lepidodendron* from Dobrudza coalfield. **A** *Sigillaria laevigata* Brongniart. No. 10614; **B** *Lepidodendron fusiforme* (Corda) Unger. No. 15265; **C** *Lepidodendron manabachense* Presl *sensu* Thomas. No. 8647 (Tenchov 1987, pl. 23, fig. 1 as *Lepidodendron obovatum*).

Generic names such as *Sigillariostrobus* (Schimper) Feistmantel, *Lepidostrobus* Brongniart, *Flemingites* Carruthers, *Lepidostrobophyllum* (Hirmer) Allen and others are used for adpression lycophyte strobili. *Lepidostrobophyllum* is also used for the individual sporophylls that have been shed from the parent cone, with each consisting of a basal (proximal) pedicel, with a large sporangium attached to its upper surface, and an apical (distal) leaf-like lamina. It can be difficult to relater individual sporophylls to meaningful species because there is a variation in sporophyll size and shape within a cone (Thomas, 1981).

Arborescent lycophytes are heterosporous, although individual cones may be monosporangiate, with only megaspores or microspores, or bisporangiate with both. In situ spores have become an integral part of describing fructifications (e.g. Chaloner, 1953; Thomas 1970; Brack-Hanes & Thomas, 1983; Bek & Oplustil, 1998, 2004; Thomas & Bek, 2014). This leads onto a comparison of the *in situ* spores with named genera and species of dispersed spores and then to using this information for palaeoecological interpretations.

The megaspores show an increase in cuticle thickness from mid Bolsovian upwards (Konstantinova, 1980). That may be the result of compensation for the increasing drying of the environment. Megaspores are liberated in large numbers and sometimes they land on surfaces that are almost immediately covered with more sediment. This is demonstrated by one of the Svoge samples (Fig. 3).

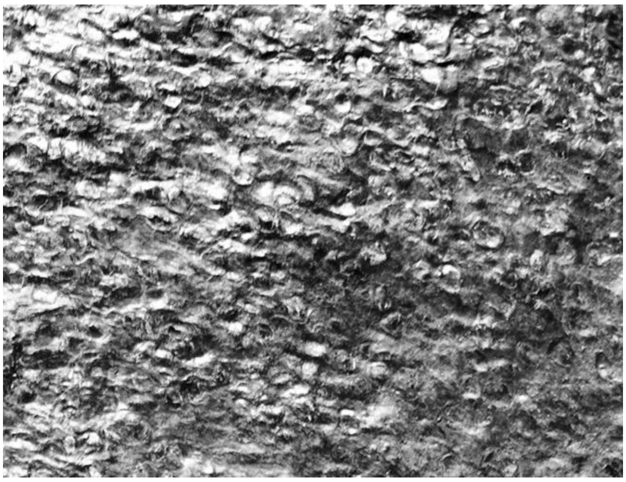

Fig. 3 Megaspores on the surface of shale. Svoge coalfield, Chibaovtsi Formation, Westphalian C.

Species list:

At present, 56 taxa of Lycophyta are recognised in the Dobrudzha Coalfield floras, except for the four that are known from Borehole F. They are:

Eleutherophyllum waldenburgense Stur

Pinacodendron musivum Weiss, *P. ohmanni* Weiss

Lepidophloios acerosus Lindley and Hutton

Sublepidophloios giganteus (Tenchov) Thomas, Tenchov and Howell.

Lepidostrobus ornatus Brongniart, *L. squarosus* Kidston.

Lepidostrobophyllum anthemis König, *L. brevifolium* (Lesquereux), *L. campbelianum* Lesquereux, *L. lanceolatum* (Lindley and Hutton), *L. lancifolium* Brongniart, *L.* cf. *lancifolium*, *L. majus* Brongniart, *L. morissianum Lesquereux*.

Cantheliophorus waldenbu rgense (Potonié) Thomas & Brack-Hanes 1991.

Cyperites bicarinatus Lindley and Hutton, *C.* cf. *svogense* Tenchov.

Lepidophylloides nervosus (Hartung) Tenchov.

Stigmaria ficoides (Sternberg) Brongniart, *S. undulata* (Göppert) Renault, *S. reticulata* Göppert, *Stigmaria stellata* Göppert, and a form with mixed sculpture of *S. rugosa* and *S. reticulata*.

Lepidodendron aculeatum Sternberg, *L. acutum* (Presl) Kidston (?*L. lycopodioides* Sternberg), *L. dichotomum* Sternberg, *L. fusiforme* (Corda) Unger, *L. subdichotomum* Sterzel, *L. jascheii* Roemer, *L. lycopodioides* Sternberg, *L. mannabachense Presl*, *L. ophiurus* Brongniart,. *acutum, L. rimosum* Sternberg,. *L wedekindii* Weiss, *L. veltheimi* Sternberg*i*, *L. wortheni* Lesquereux.

Sigillaria davreuxii Brongniart, *S. laevigata* Brongniart, *S. mamillarus* Brongniart *S. ovata* Sauveur, *S.* cf. *polleriana* Brongniart, *S. rugosa* Brongniart, *S. elegans,* (Sternberg*)* Brongniart.

Bothrodendron minutifolium Boulay.

Cyclostigma sp.

Comments on identification of selected specimens:

1. Specimens 15265 and 12566 from R179 1558 m SL 145 Mogilishte F. Westphalian A, are here referred to *Lepidodendron fusiforme* (Corda) Unger (Fig. 2B).
2. Specimens 8647 and 10521 from R90 1073 m SL135 Mogilishte F., Westphalian A, that were previously named *Lepidodendron obovatum* (Tenchov, 1987: pl. 23, fig. 1, pl. 23, fig. 5) are re-determined as *Lepidodendron manabachense* Presl *sensu* Thomas (1970) (Fig. 2C).
3. Specimen 10614 from, from R85 1458 m SL 385, Mogilishte F. Westphalian A, is determined as *Sigillaria laevigata* Brongniart (Fig. 2A).

DISTRIBUTION IN THE DOBRUDZHA COALFIELD AND CLIMATIC INFLUENCE.

For *Sigillaria* in the Balchik Group (Mogilishte, Vranino, Makedonka, Velkovo, Krupen and Gurkovo F.) are 9 species from the total of 11 with one to three specimens each. *Sigillaria rugosa* is largely distributed up to SL 800, with several specimens in Krupen F. and in the Gurkovo F - 3 there is *Sigillaria rugosa* and *S. ovata* (Fig. 4).

In the *Lepidodendron* column, *Lepidodendron aculeatum, L. acutum* and *L. manebachense* are most frequent up to about SL 800, with one later specimen in Krupen F. In contrast *L. loricatum* is found only in the late Westphalian.

Stigmaria, *Lepidophloios* and the numerous species of *Lepidostrobophyllum* do not show different distributions of their species. However, the paucity of *Stigmaria* and cone parts support the scarcity of Lycophyta trunks over Makedonka F. *Pinakodendron* and *Bothrodendron* are rare.

Lepidodendron and *Sigillaria* provide the basis for some consideration. They are large plants to which one may apply Cope's rule. They evolved when the atmosphere contains over 2000 ppm of CO2.

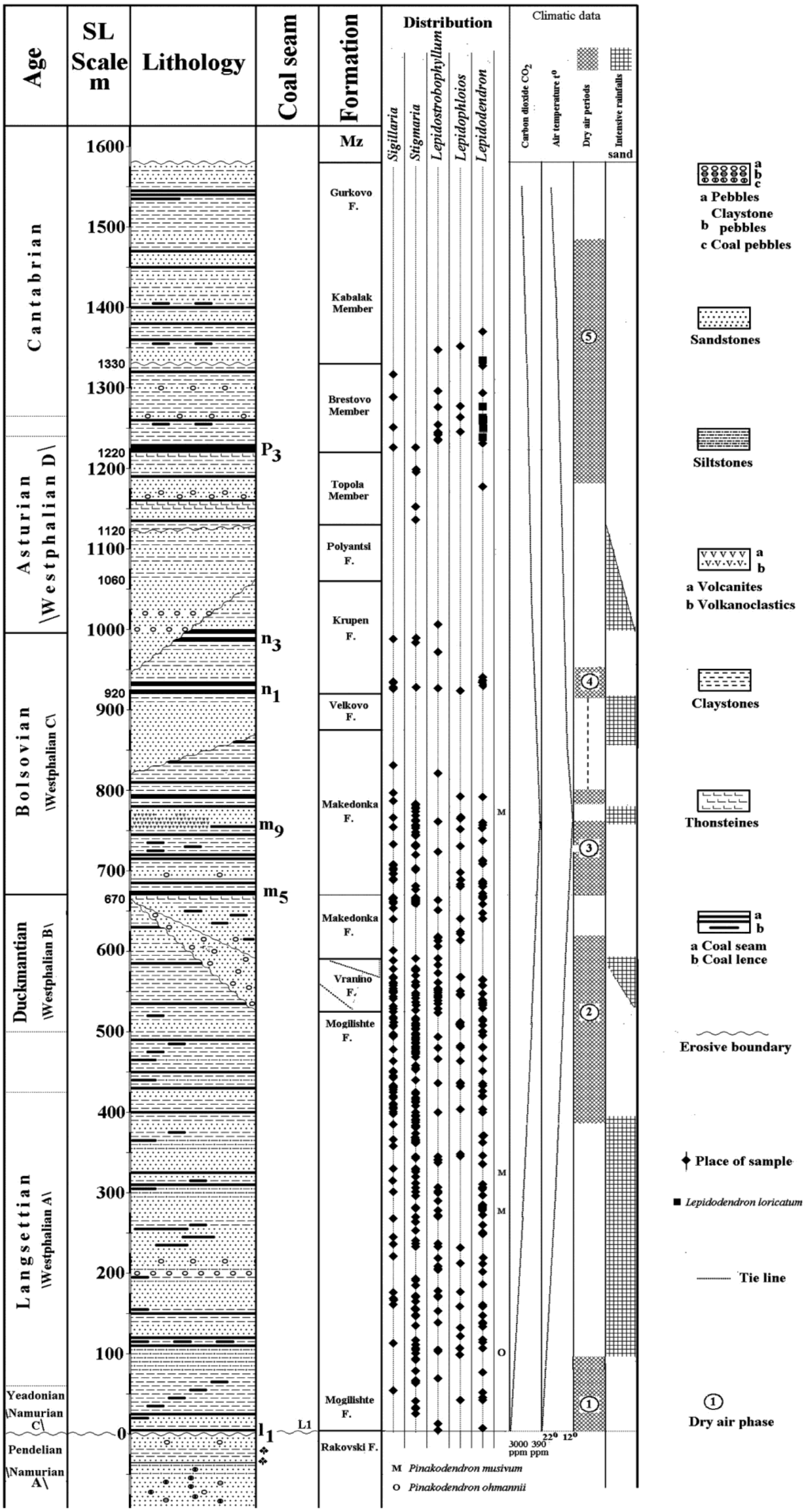

Fig. 4 Distribution of some genera. A more detail picture that shows species distribution is impractical, because only a few species have a large number of specimens.

They produce the main mass of swamp sediments (later coals) that practically decrease the carbon dioxide to about 300 ppm. See Cleal & Thomas (1999, 2005) for further discussion of climatic change, carbon dioxide levels and the loss of the lycophyte dominated swamps.
An event is detected in DC with the distribution of *Corynepteris* (Tenchov, 2010). It is correlated with a diminish of import of clastic sediments over the m10 coal seam – about SL 780 – and a drying episode that is associated with strong weathering to the South of DC, being evident by the quarts grain composition of the Velkovo F. Some fault forming activity during the Bolsovian led to about 170 m of erosion in DC with a break in the sedimentation. However, the duration of that break is not well reflected in the plant composition at n1 and n3 coal cover. There is similar composition to that at the top part of Makedonka F. and the first record at n3-n4 coal cover of *Pecopteris unitus* and its palynomorphs (Dimitrova & Cleal, 2007). Therefore, a rapid episode is most probable with only *Sigillaria rugosa* being found during that episode.

CONCLUSIONS

The Lycophyta of the Dobrudzha coalfield, especially *Lepidodendron* and *Sigillaria*, indicate two phases of distribution. The first is the interval of the Mogilishte, Vranino and Makedonka formations, in which there are many *Sigillaria* (notably *S. rugosa*) and the larger sized *Lepidodendron* such as *L. aculeatum*. The second is the Velkovo through to the Gurkovo formations, in which *Lepidodendron* and *Sigillaria* are much rarer, and represented by fewer and different species. The sedimentology indicates that drier conditions prevailed in the upper part of the Balchik Group (Tenchov, 1993, 2007), and this not only affected the Lycophyta, but also some of the pteridosperms and ferns (Tenchov, 2013) and sphenophytes (Tenchov & Thomas, 2015). This onset of drier conditions in late Bolsovian times is compatible with data from elsewhere in the Europe part of the Variscan foredeep (Cleal & Thomas, 1999, 2005).

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