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PECULIARITIES IN THE COMPOSITION OF THE CARBONIFEROUS MEGAFLORA IN SVOGE AND DOBRUDZHA COALFIELDS (BULGARIA)

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The Svoge Coalfield is an intramontane depression in the Variscan Range, probably 2000 metres above sea level. The Dobrudzha Coalfield is a depression in the Variscan foredeep, at least 190 metres above sea level. The composition of the Pendelian to Bolsovian megafloras of both coalfields is compared. The differences affect mainly the composition of the pteridosperms. In the Svoge Coalfield *Lyginopteris, Lonchopteris, Reticulopteris* and *Linopteris* are not present. *Eusphenopteris, Alethopteris, Mariopteris, Neuropteris* and *Paripteris* are represented by one or two species, but disappear earlier than in the Dobrudzha Coalfield. *Neuralethopteris* is represented by some local species and *N. schlehanii* also disappears earlier than in Dobrudzha. In the Dobrudzha Coalfield, genera with reticulated veins are well represented, including some neuropterids with frequently semi-reticulated veins. These differences allow for the interpretation of the effects of cooling, which are greater in the Svoge Coalfield. A sequence is established of the sensitivity of genera to cooling. Regional drought in the Dobrudzha Coalfield resulted in intensive vein reticulation in *Neuropteris*.

Key words: Bulgaria, Carboniferous, megaflora, peculiarities, climate.

INTRODUCTION

Fluctuations in climatic factors such as temperature, moisture, and gas components are greater in the Earth's atmosphere than in its hydrosphere.

Therefore, terrestrial fossil vegetation is more suitable for the study of climatic changes in the past than the fossils of marine inhabitants. This paper will, therefore, compare the fossil megafloras in the Svoge and Dobrudzha coalfields, with the aim of assessing some of these climatic effects.

During Late Palaeozoic times Bulgaria was situated in the Variscan realm (Tenchov 1989), the main elements of which are shown in Fig.1. Carboniferous deposits in northern Bulgaria are known from outcrops and drillings (Fig. 2). Table 1 shows the sedimentary sequence and the megafloral composition of the common chronostratigraphical intervals of the two main coalfields in the area, in the Svoge and Dobrudzha areas. The study of the megaflora from the Dobrudzha Coalfield had just started when the author (Tenchov 1976) realised how little the plant fossil species diversity was in the Svoge Coalfield, and he defined it as a poor one. The estimated altitude is about 2000 metres, which will have determined the somewhat low temperature here. The Dobrudzha Coalfield flora is rich in plants with a reticulated venation, which indicates a stronger influence of dry air.

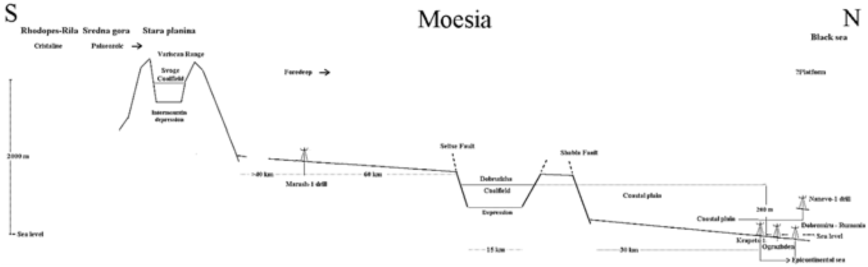

Fig. 1. - Syntheses profile across the Variscids in Bulgaria.

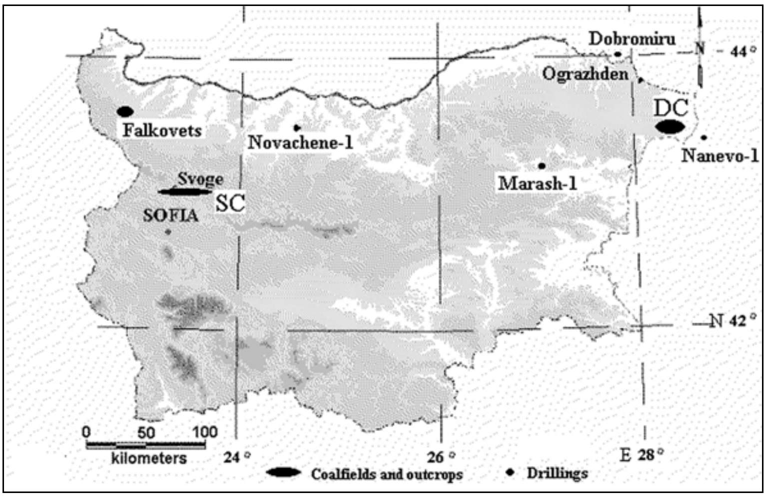

Fig. 2. - Bulgaria. Position of some drillings, Dobrudzha and Svoge Coalfield. Stephanian C-Permian sediments are not shown.

Table 1. - Stratigraphy of Svoge and Dobrudzha Coalfield.

Chronostratigraphy	Svoge Coalfield formations	Dobrudzha Coalfield formations
Stephanian B and later	erosion	erosion
Asturian – Baruelian	not presented	Krupen, Poliantsi, Gurkovo F
Bolsovian	Chibaovtsi F	Makedonka, Velkovo, Krupen F
Duckmantian	Berovdol, Chibaovtsi F	Mogilishte, Vranino, Makedonka F
Langsettian	Svidnya, Dramsha, Svoge F	Mogilishte F
Yedonian	Svidnia F	Mogilishte F
Alportian – Marsdenian	break	break
Pendelian	Tsarichina F	Rakovski F
Brigantian – Late Visean	unconformity	Rakovski F
Middle Visean	not established in near area	unconformity
Tournaisian-Early Visean	erosion	erosion
Devonian	Late Devonian	Middle Devonian

RESULTS

Geological background

The Svoge Coalfield is an intramontane depression amidst the Variscan range (Tenchov 2007). It is about 400 *km* to the SW of the Dobrudzha Coalfield with a latitude difference of about 1°, which is negligible in the context of this analysis. Hartung (1935), Němejc (1943) and Tenchov (1977) have collected more than 2500 specimens from 125 sites within the Svoge Coalfield. The majority of the sites are surface outcrops with the possibility for further sampling. In the Svoge Coalfield, 118 taxa have been established. This is a poor species diversity for the given time interval.

The Dobrudzha Coalfield was formed in a graben along the northern margin of the Variscan foredeep, at an altitude of at least 190 metres above sea level (Tenchov 2004). Fluvial and swamp deposits prevail, as well as several erosive breaks (Tenchov 1993). The positive area to the south of the graben is a gently inclined fluvial plain more than 60 *km* wide (Fig. 1), although it seems wider because there are no conglomerates. The relief of the positive area used to be flat and consisted of a plain with fluvial deposits and erosion near the faults. The sandstones and siltstones that fill the depression frequently contain plant remains. They are fragments of trunks, mainly of *Calamites* and less often of lycophytes, and recognizable pinna fragments and pinnules of ferns (Fig. 3). Plant detritus is concentrated in the clay parts of the fining-upwards cycles in the fluvial sediments. Coal grains indicate that some swamps also existed in the fluvial plain.

About 13000 specimens with megaflora have been collected from the core of 108 out of the 115 drills in the Dobrudzha Coalfield. The diversity of species is rich, with over 300 taxa. The change in the megafloral composition in the Dobrudzha Coalfield will be discussed in light of habitat and of climatic changes.

Fig. 3. - Sandstones with bark parts. Dobrudzha Coalfield.

The Nanevo-1 drill in the Black Sea produced about eight metres of core-drilled intervals in between 50 metres of uncored drilling. The 74 specimens collected here contribute nothing to the present study.

The Falkovets outcrop is rather small and its megaflora contributes nothing to the present study. The late Stephanian and Early Permian deposits with megaflora uncovered in NW Bulgaria (Tenchov 1973) are also not discussed.

Floristic analysis

Table 2 presents species diversity of SC and DC coalfield at a genus level or higher.

Sphenophyllum composition of the Svoge and Dobrudzha coalfields is nearly identical. *S. emarginatum* and *S. zwickawiense* do not appear in Svoge, and they are rare in the Bolsovian of Dobrudzha. *Calamites jubatus, C. sachsei* and *C. schutzeiformis* are missing from Svoge and the latter two are rare in Dobrudzha. Havlena (1979) regarded the local *Calamites tenuis* (Tenchov 1977) as *C. cistii* without indicating why. *Asterophyllites* species are common in both coalfields but *Annularia* species are rare in Svoge. This needs an explanation connected with *Asterophyllites*. The *Authophyllites* are rare plants represented by a few specimens - so there is no solid base for comparison. It seems the analysed groups were eurythermic.

In Svoge *Sigillaria* species are mainly found in the Svoge Formation, indicating a decline of the genus similar to that seen in Dobrudzha. The distribution of this genus needs to be studied over a larger region. In the Bolsovian in Svoge the presence of *Sigillaria brardii* is notable as it is the earliest known finding of this plant, which usually occurs in the Stephanian. Some lithological indications of drying are found in Svoge at this level and it is possible that *S. brardii* appeared in the cool high land and later migrated down to warmer regions. The composition of the other Lycophyta is generic, but more species are found in Dobrudzha. It is worth mentioning that *Pinakodendron* is found in both basins. There is an abrupt change in the composition of species of *Lepidodendron* after Bolsovian times in Dobrudzha. From the above statements it becomes clear that there are no notable differences in the composition of *Articulate* and *Lycophyta* during the examined chronostratigraphical span in either basin.

Table 2. - Svoge and Dobrudzha Coalfield megaflora composition.

S v o g e					Taxa found	D o b r u d z h a				
Namurian		Westfalian				Namurian		Westfalian		
Pend	Yed	Langs	Duck	Bols.	species species	Pend	Yed	Langs	Duck	Bols.
1	2	2	2	4	7 *Sphenophyllum* 8	1	2	4	4	4
1	1	5	5	5	5 *Calamites* 9	1	4	7	7	7
1	2	2	1	1	2 *Annularia* 8	1	5	7	7	6
5	4	2	3	4	9 *Asterophyllites* 9	-	3	6	5	5
-	2	-	-	-	2 *Autophyllites* 1	1	-	-	-	-
-	-	7	1	2	*Sigillaria*	-	-	3	7	1
8	2	2	6	5	*Lycophyta* - stem	2	10	9	11	12
1?	-	-	-	-	*Lyginopteris*	5	1	2	1	1
-	-	-	-	-	*Lonchopteris*	-	1	7	5	2
3	2	-	-	-	*Alethopteris*	-	1	1	4	5
-	1	2	-	-	*Mariopteris*	1	3	4	4	4
-	1	1	1	-	*Eusphenopteris*	-	2	9	13	12
-	1	1	1	1	*Paripteris*	1	3	4	4	4
-	-	-	-	-	*Linopteris*	-	1	5	4	5
-	3	1	-	-	*Neuralethopteris*	2	3	3	1	-
1	1	1	-	1	*Neuropteris*	-	1	3	9	9
-	-	-	-	-	*Reticulopteris*	-	-	-	1	1
					17 *Filicales* 20					

In contrast, there are clear differences in the seed ferns. *Lyginopteris* and *Lonchopteris* are missing in Svoge. The specimen determined as *Lyginopteris* by Hartung (1935) is part of a pinna that could belong to *Corynepteris* sp. It was widely believed that these genera were restricted to sea level altitudes and even required seawater (due to *Lyginopteris* being preserved in coal balls) until they were discovered among Dobrudzha flora. Dobrudzha was at least 190 metres above sea level (Tenchov, 2004) and is populated only by fresh water faunas. *Lonchopteris* has also been found in Turkey - Zonguldak coalfield (Egemen, 1959) and in Caucasus (Anisimova

1979) where marine influence was again absent. The presence of these plants in Dobrudzha may, therefore, simply reflect higher temperatures, perhaps linked to geographical latitude.

Alethopteris is missing from the Pendleian of Dobrudzha, whereas in Svoge there are two species. Purkyňová (1970) described similar, rather simple Pendleian *Alethopteris* species from the more northern Silesian Basin. The Yeadonian of Svoge contains several specimens of *A. decurrens* and a species determined as *A. lonchitica* by Tenchov (1977). The latter determination is no longer acceptable because the holotype of *Alethopteris lonchitica* has been found (Zodrow & Cleal 1998). Plants similar to those found in Svoge are to be considered as an uninitiated species designated as "A. n. sp?" by Wagner (1968); Zodrow & Cleal (1998) also comment on this. Recently Wagner indicated some hesitation as to whether this might be *A. urophylla.* Higher in the sequence of Svoge no more *Alethopteris* are established. Abundant assemblages, rich in specimens of *Lonchopteris* and *Alethopteris*, are found in Dobrudzha.

The mariopterids in Svoge include frequent *M. acuta* and *M. muricata*, which range up into the Langsettian Substage. One *Mariopteris* sp. is from the Berovdol Formation. In Dobrudzha mariopterids are frequent up into the Cantabrian and are very diverse.

Eusphenopteris is very rare in the Yeadonian of the Svoge, and *E. hollandica* and the especially rare *E.* cf. *obtusiloba* in the Langsettian Svoge and Berovdol formations. In Dobrudzha, *Eusphenopteris* is both abundant and species rich in the Bolsovian and later floras.

Paripteris gigantea is quite widespread during Yeadonian and Langsettian times in Svoge, but rare in Bolsovian times. *Paripteris* is established in Dobrudzha with its full species spectrum, including *P. schutzeii* at the beginning of the Langsettian. The last specimens of *P. gigantea* are found at the base of the Stephanian. The local climate and conditions must have created a refuge for it. *Linopteris* is not established in Svoge whereas in Dobrudzha specimens are frequently discovered and are quite rich in species.

Neuropteris is represented in the Svoge by a few specimens of *Neuropteris obliqua*, more frequently in the Svidnya Formation and only rarely in the Svoge Formation. In Dobrudzha the genus is rich in specimens until the Asturian, and rare to the Cantabrian. *Macroneuropteris scheuchzeri* appears in high parts of the Svoge succession with several specimens. In Dobrudzha it is a common species.

Neuralethopteris is well represented in the Yedonian-Langsettian Svidnya Formation of Svoge, including some local species, but is only rarely found in the middle Langsettian Svoge Formation. Only *Neuraleth-*

opteris schlehanii is found in the middle part of the Langsettian. The genus appears in Dobrudzha during the Pendleian (Rakovski F.) and is found in its full species spectrum in the Yeadonian and Langsettian. *Neuralethopteris schlehanii* extends into the lower levels of the Duckmantian (Tenchov & Cleal 2010). It seems to me that *Neuralethopteris* is the key to understanding why seed ferns disappeared from the Svoge. *N. schlehanii* was widely distributed over a large region with swamp conditions from North America and Europe to Asia. Across the whole region it disappeared gradually, from the high lands of the Svoge during Langsettian times and finally, in Dobrudzha and in all other localities in early Duckmantian times. This was a time when global cooling was taking place, a process that is recorded in many other ways. The disappearance of *N. schlehanii* started from the northern swamps and then moved towards the southern swamps in Europe. The group of neuropterids that is richest in species is also affected by this. That group seems to embrace several different assemblages of species. The Svoge and Dobrudzha do not offer enough facts for discussion. It is only clear that the group of species allied to *Neuropteris obliqua* was the most resistant to the effects of cooling.

A sequence of genera with high sensitivity to cooling can be outlined by the Svoge - Dobrudzha comparison: *Lyginopteris*+*Lonchopteris*, *Alethopteris*, *Mariopteris*, *Eusphenopteris*, *Neuralethopteris*, *Paripteris*, N*europteris oblique*, *Reticulopteris*. In each of the genera at the species level, there is a specific sensitivity. In *Neuralethopteris* the most resistant to cooling was *N. schlehanii*; in *Paripteris* it was *P. gigantea*; in *Eusphenopteris* it seems to have been *E. obtusiloba*; and in *Neuropteris* it was *Neuropteris obliqua*.

Comparison

Neuralethopteris, Paripteris, Mariopteris, Lyginopteris are represented in the Rakovski Formation of Dobrudzha and other Pendleian deposits of the western European paralic coalfields, but they are missing from the Tsarichina Formation of Svoge. Characteristic Pendleian fossils such as *Sphenophyllum tenerrimum, Eleutherophyllum waldenburgense, Zeilleria moravica, Diplotmema patentissimum* are common in both Dobrudzha and Svoge. In Svoge there are several local *Alethopteris* species that are similar to those established in the Silesian Coalfield but are missing from Dobrudzha. At that time Dobrudzha was at sea level (Tenchov 2004: Fig. 7). Later, during Yeadonian times, in both coalfields *Neuralethopteris, Alethopteris, Mariopteris, Eusphenopteris, Paripteris* (Mogilishte Formation of Dobrudzha, Svidnya Formation of Svoge) are found. *Paripteris gigantea* and *Eusphenopteris hollandica* are found only in the Svoge. *Lonchopteris*, *Lyginopteris* and *Linopteris* are present in abundance in

Dobrudzha but are all missing from Svoge. Later on, during Langsettian times in Svoge (Svoge Formation) *Alethopteris* and *Eusphenopteris* are missing, as are the last specimens of *Neuralethopteris schlehanii*. In Dobrudzha the species diversity of *Neuralethopteris* (Tenchov & Cleal 2010) diminishes during the Langsettian and the last one (*N. schlehanii)* disappears during early Duckmantian times. The distribution of *Neuralethopteris* in Silesia and western Europe is similar**.** In Svoge the last *Mariopteris* species is found in the Berovdol Formation (Tenchov 1977).

Global cooling is regarded as the common reason for these extinctions. The cooling affected *Lyginopteris, Lonchopteris* and *Neuralethopteris* in Europe. Dobrudzha, at about 190 *m* above sea level, was more to the south than Silesian and the western European paralic coalfields. Maybe this is the reason for the later disappearance of *N. schlehanii* and *Lyginopteris baumlerii* in Dobrudzha at the beginning of Bolsovian, and of *Paripteris gigantea* during late Asturian times. The Svoge intramontane depression is in permanent uplift, along with the Variscan range (Tenchov 2007), with a suggested elevation of up to 2000 metres above sea level (Tenchov 1976), and this had a direct effect on the composition of seed ferns species there.

The possible reasons for the paucity of the Svoge megaflora are briefly reviewed. Not one of the sites has yielded more than 15 species. No more than 30 species are known from any of the formations. However, the sampling of the specimens is not the reason for the scarcity of species. The coarse grain composition of the sediments prevails in the sequence, with more than 50% being sandstone. At the same time, there are more than 20 coal-seams, which often have a preserved shale roof. The shale roofs were the main source of the fossil collection. Sites with such roof shales permitted the collection of many samples, and collecting would usually end only when no more new species could be found. This method eliminates the influence of the coarse sediments. Geographical isolation could also be assumed as a possible reason for the low diversity. The species composition of the megaflora indicates connections with the Silesian megaflora (Hartung 1935) and Saar megaflora (Tenchov 1975). The relatively high number of new species (18) is possibly influenced by the high altitude of the depression.

Ferns require additional study for the comparison.

DISCUSSION

The transformation from free veining to reticulated veining is based on observations of the Dobrudzha megaflora and can be explained by the climate of the time. The contribution of the Svoge megaflora is its lack of genera and species.

Single vein meshes are observed in *Cardiopteridium waldenburgense* specimens from the top of Rakovski Formation (Pendleian) of Dobrudzha. There is no evidence between the Pendelian and Yedonian due to the lack of sediment. In the Yeadonian part of the Mogilishte Formation *Lonchopteris baurii* and *Linopteris neuropteroides* are found. This seems to be the earliest registered appearance in Europe for both species. Six *Lonchopteris* species and two *Linopteris* species are found in the lower part of the Langsettian. Findings of specimens of *Paripteris gigantea* with single or group vein anastomoses, and *Linopteris neuropteroides* with imperfect reticulation, date approximately from this period. Single vein meshes are observed in Europe in *P. gigantea*. Crookall (1959 p.135) mentioned that Potonié had observed single meshes more frequently in *P. pseudogigantea* than in *P. gigantea*, but the basin, stratigraphical level etc. are not recorded. In my opinion, when dealing with isolated *Paripteris* pinnules (this being the most frequent type of finding of them) the distinction between *P. gigantea* from *P. pseudogigantea* is rather arbitrary. Specimens showing the lower surface of the pinnule, where the midvein is present for up to two thirds of the pinnule's length, are usually regarded as *P. pseudogigantea*. Specimens showing the upper surface of the pinnule, where the midvein is missing or is very short, are attributed to *P. gigantea.*

In Dobrudzha, numerous specimens of paripterids have single vein meshes or groups of meshes in different parts of the pinnule. Linopterids often have imperfect meshes at different positions, but mainly adjacent to the midvein. When there are nearly equal zones with and without vein meshes, the genus and species names can be applied arbitrarily. In the *Linopteris* equivalent of *P. linguaefolia*, *L. havlenai* (Tenchov & Popov 1987), there is a fine reticulation of elongated meshes. *Linopteris* further develops with the appearance of *L. brongniartii* and other forms that only have regular reticulation.

At about the beginning of Bolsovian times, another reticulation process forms the sequence *Neuropteris obliqua – N. semireticulata – Reticulopteris muensteri* (Josten 1962, Tenchov & Popov 1990). This happens in Dobrudzha when swamp-lacustrine conditions prevail. Specimens of *N. semireticulata* and *R. muensteri* are represented mainly by parts of pinnae preserved in clayey sediment, and are indicative of the influence of dry air in the depression and in the swamp.

Megaspores with thicker cuticles, up to 0-1 *mm* (Konstantinova 1969), are present at about the level of coal seam M9. This coincides with a diminishing diversity of *Sigillaria*, and with a major change in the species composition of *Lepidodendron*, with the *L. aculeatum-obovatum* complex being replaced by *L. loricatum, L. subdichotomum* and *L. manabachense*. In the same direction are the observations of large amounts of megaspores in the sediments from Svoge that are obviously dry and incapable of germination (Fig. 4). It is quite possible that they died even in the strobili due to the dry air. The thickening of the cuticle is the first step towards adjustment to dry air. The next step is maybe an additional cover, which is related to the evolution towards Gymnosperms.

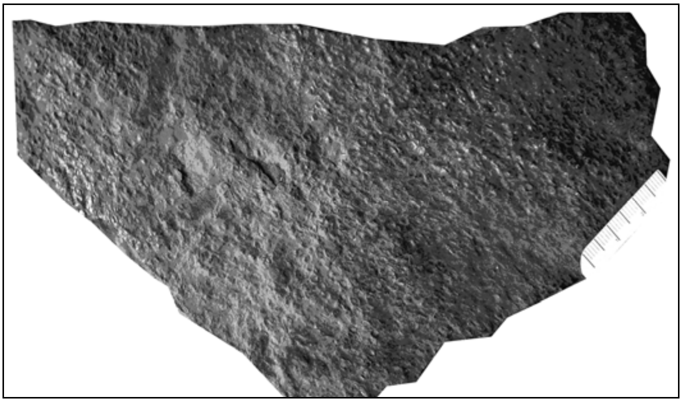

Fig. 4. - Dried megaspores. Svoge Coalfield, Chibaovtsi Formation, Mine Berov dol.

The regression of the seas and the corresponding expansion of the subaeral territory in Europe are accepted as the reason for the change in the regional climate which resulted in a continentalisation of the climate, with an increase in seasonality and periodic rainfall. The evidence of drying in the sediment over a large territory of the northern half of Europe is indicated by Strachov (1960) in very general terms. Another important event is the uplift of the Variscan ranges and the possible development of a rain shadow to the north of them. There is a similarity between the present day climate zones in southeast Europe and those during the Pennsylvanian in the same region. At present, large territories have a steppe-type of plant cover that reflects climatic seasonality with periodic dry spells.

CONCLUSION

The palaeobotanical record reveals relatively low species diversity in the Svoge Coalfield and a dominance of reticulated seed ferns in Dobrudzha. There is a long term (Yeadonian-Asturian) combined influence of cooling and periodic dryness in the region (Fig. 5), which gradually changes the conditions for plant growth. The species composition in lower rank taxonomic groups and the species diversity within genera reflect these changes. There may be an additional factor for the Lycophyta. Moreover, the drying leads to the transformation within some of the genera of seed ferns, manifested by an increased reticulation in the veining. The Dobrudzha area is part of a territory in which new species and genera of plants develop, which may not be a unique feature of this basin, but is recognisable here.

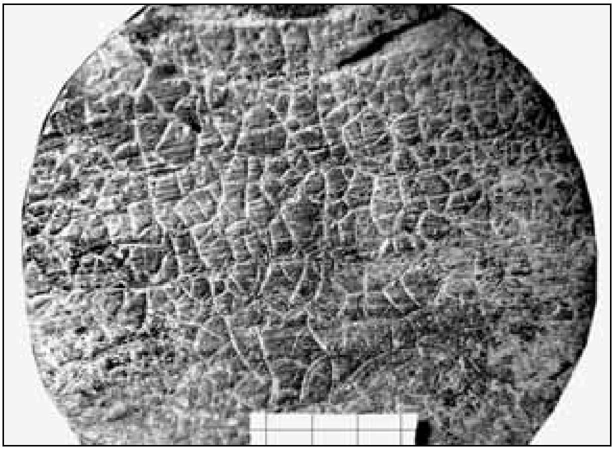

Fig. 5. - Drying cracks in cover of coal seam P3, Dobrudzha Coalfield. Sample 15467, Drill 199 at 1488 *m*. Gurkovo Formation, Cantabrian.

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ОСОБЕНОСТИ У САСТАВУ КАРБОНСКЕ МЕГАФЛОРЕ У УГЉОНОСНИМ БАСЕНИМА СВОГЕ И ДОБРУЏА (БУГАРСКА)

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Р Е З И М Е

У раду је приказан упоредни састав карбонске мегафлоре, углавном семених папрати, која је нађена у два угљоносна басена у Бугарској. Оба басена представљала су интрамонтане депресије Варисцинског планинског ланца, при чему је Басен Своге вероватно био 2000 м изнад нивоа мора, а басен Добруџа бар 190 м изнад нивоа мора.

У басену Своге нема примерака *Lyginopteris*, *Lonchopteris*, *Reticulopteris* и *Linopteris*, док су *Eusphenopteris*, *Alethopteris*, *Mariopteris*, *Neuropteris* и *Paripteris* представљени са по једном или две врсте које су ишчезле раније него у басену Добруџа. *Neuralethopteris* је представљен са неколико врста, од којих је *N. schlehanii* такође ишчезла раније него у Добруџи. У басену Добруџа, представници родова са ретикуларном нерватуром заступљени су у већем броју и у њих треба укључити и неке честе представнике неуроптерида са семи-ретикуларном нерватуром.

Ове разлике у саставу флоре могу се објаснити ефектима захлађења, који су били интензивнији у басену Своге, при чему је редослед осетљивости родова на захлађење био следећи: *Lyginopteri* - *Lonchopteris* - *Alethopteris* - *Mariopteris* - *Eusphenopteris* - *Neuralethopteris* - *Paripteris* - *Laveinopteris* - *Reticulopteris*. Код сваког од наведених родова примећена је и посебна интраспецијска осетљивост и то: код Неуралетхоптерис најотпорнији на хлађење је *N. schlehanii*; код *Paripteris* то су представници *P. gigantea*; код *Eusphenopteris* - вероватно припадници *E. obtusiloba*, док су код групе неуроптерида најотпорнији представници *Laveinopteris obliqua*.

Регионална суша у угљоносном басену Добруџа довела је до интензивирања ретикуларног облика нерватуре код *Neuropteris*.