

A reappraisal of the Carboniferous macrofloras of the Zonguldak – Amasra Coal Basin, north-western Turkey



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ABSTRACT

The Zonguldak – Amasra Coal Basin in north-western Turkey has Carboniferous terrestrial deposits ranging in age from Arnsbergian to late Asturian or possibly early Cantabrian. They yield macrofloras that allow detailed biostratigraphical correlations with sequences in Europe. These correlations suggest there are substantial gaps in the Zonguldak – Amasra succession, with middle to upper Namurian, upper Langsettian, Duckmantian and lower Asturian strata apparently being missing. This in turn suggests the area was subjected to significant tectonic instability during Pennsylvanian (late Carboniferous) times and that this might have been instrumental in initiating the progressive change in composition and eventual collapse of the coal swamp biome across Variscan Euramerica during Westphalian times.

Keywords: Palaeobotany, Biostratigraphy, Pennsylvanian, Zonguldak-Amasra Coalfield

1. INTRODUCTION

Pennsylvanian (late Carboniferous) coal-bearing deposits have been known in north-western Turkey in the vicinity of Zonguldak since the early 19th century (SCHLEHAN, 1852; SPRATT, 1877), and there were a number of early studies on the stratigraphy, including the plant biostratigraphy, notably by ZEILLER (1896, 1899) and RALLI (1896). For many years, coal mining was on a relatively small scale and mainly by foreign companies, and it was not until the mines started to be nationalised in the mid-1930s (GÜNEY, 1967) that there was a marked expansion in geological studies (RALLI, 1933; HARTUNG, 1937; JONGMANS, 1939; GRANCY, 1939; ARNI, 1939); some background comments to these investigations can be found in WAGNER & VAN AMEROM (1995) and WAGNER (1997). Plant biostratigraphy played a pivotal role in these studies, with numerous published species lists and in some cases specimens illustrated. After the 1939–1945 war, interest in the palaeobotany of these coal-bearing beds was continued mainly by JONGMANS (1955), and two of his students, EGEMEN (1958, 1959) and WAGNER (in STOCKMANS, 1962, p. 664, fig. 6). WAGNER (1984) made some brief comments on the

Turkish data in his seminal biostratigraphical analysis of Carboniferous Euramerican floras, and subsequently (in KEREY et al., 1986) he made a more in depth analysis and figured several plant fossils.

The stratigraphical sequence in the Zonguldak – Amasra Coal Basin has potentially much significance. If, as suggested by WAGNER (in STOCKMANS, 1962), there is an essentially complete succession of Namurian and Westphalian strata here, it would potentially provide a key link between the successions of the Caucasus and Donets, and the rest of Variscan Euramerica (sensu CLEAL et al., 2010). Moreover, CLEAL et al., (2010, 2011) have suggested that the progressive breakdown in the coal swamp biome in Euramerica during Westphalian times may have been initiated in the easternmost part of the area and a better understanding of how the Zonguldak – Amasra coal-bearing succession relates biostratigraphically to neighbouring areas will clearly be critical to understanding this major change in biotas and habitat. This paper will review the available published data on the distribution of plant macrofossils in the Zonguldak – Amasra Coal Basin and discuss the implications for the stratigraphic age of these deposits.

2. GEOLOGICAL BACKGROUND

The Zonguldak – Amasra Coal Basin is the primary source of hard coal in Turkey, with proven reserves of 1.1×10^9 tonnes (İNANER & NAKOMAN, 2004). During the 19th century, this area was usually referred to as the Heraclée or Heraclea Coal Basin, after the port with the current written name of Ereğli. Nowadays, however, it is usually referred to as the Zonguldak – Amasra Coal Basin, after its two main coal mining towns (Fig. 1), and this is the name that will be used in this paper.

The basin was formed on part of the Pontide Block, a Gondwana-derived microcontinent that had docked with Baltica probably by Ordovician times (KALVODA & BÁBEK, 2010). The Pontides formed a passive margin along this part of Laurussia on which an essentially regressive sequence was deposited, with Ordovician – Silurian marine clastics, Middle Devonian – Mississippian shallow marine limestones, and uppermost Mississippian and Pennsylvanian terrestrial deposits (YANEV et al., 2006). The Carboniferous terrestrial deposits, which lie conformably on the Viséan marine limestones of the Yılanlı Formation, are about 2100 m thick and were derived from the Laurussian landmass to the north (KEREY, 1985). Based on divisions introduced by RALLI (1896, 1933) this terrestrial interval is usually divided into four formations, as summarised in Table 1.

3. CHRONOSTRATIGRAPHY AND BIOSTRATIGRAPHY

Late Carboniferous biotas were characterised by strong global provincialism, which was largely the result of latitudinal climatic zones (WAGNER, 1994). This has caused major problems with establishing global biostratigraphic correlations and consequently with developing a global chronostratigraphic scheme. Recent improvements in the resolution of radiometric dating (DAVYDOV et al., 2010; SCHMITZ & DAVYDOV, 2012; WATERS & CONDON, 2012) are now offering the potential of circumventing these biostratigraphical problems and a practical global chronostratigraphy for the Carboniferous System may appear in the foreseeable future. For now, however, the currently accepted IUGS global chronostratigraphy for the Carboniferous (e.g. HECKEL & CLAYTON, 2006) remains a theoretical aim rather than a practical tool for the upper part of the system, at least outside of the low-latitude marine realm where the boundary stratotypes (GSSPs) of the stage boundaries are located; there remain, for instance, discrepancies between the biostratigraphical (e.g. KULLMANN et al., 2007) and radiometric (DAVYDOV et al., 2010; WATERS & CONDON, 2012) evidence for locating accurately the base of the IUGS Moscovian Stage within the palaeotropical terrestrial sequences.

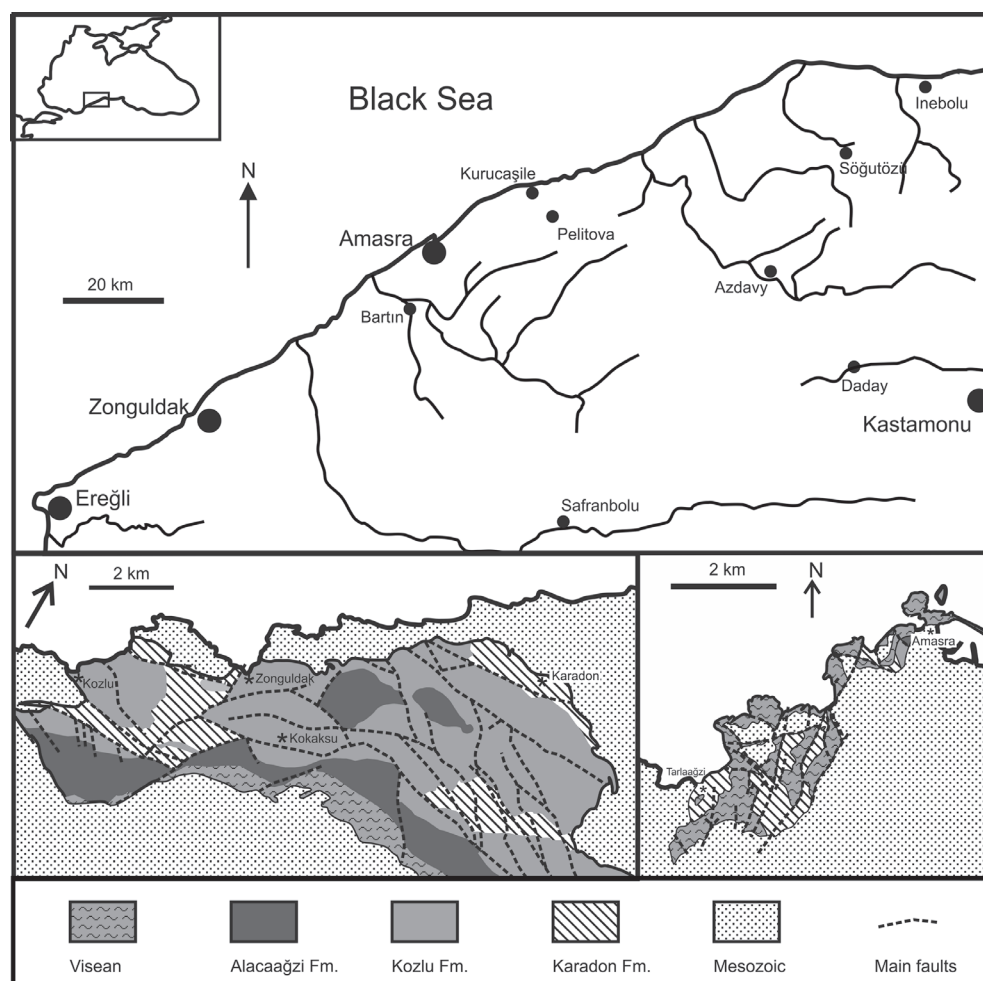


Figure 1: Location of the Zonguldak – Amasra Coal Basin. The upper map shows the main localities in the basin, with a small inset showing their position relative to the Black Sea (redrawn from JONGMANS, 1955). Bottom left is a simplified geological map of the Zonguldak Coalfield (redrawn from GÜNEY, 1967). Bottom right is a simplified geological map of the Amasra Coalfield (redrawn from TOKAY, 1962).

Table 1: Lithostratigraphic divisions of the Zonguldak – Amasra Coal Basin, based on KEREY (1982) and KEREY et al. (1986).

Formation	Member	Facies	Palaeoenvironment	Thickness	Stratigraphical age
Kızıllı		Alternating coarse and fine clastic deposits; some thin coals, and red beds develop towards top of formation	Braided stream system in an intra-montane setting, becoming better drained towards top of section	280 m	Late Westphalian
Karadon		Alternating coarse and fine clastic deposits; some coals, mainly in the lower part of the formation	Braided stream and alluvial fan	500 m	Middle Westphalian
Kozlu	Dılaver	Alternating coarse and fine clastic deposits, with abundant coals	Fluvio-deltaic, floodplain	300–750 m	Early Westphalian
	Kılıç		Mainly lacustrine		
Alacaağzı	Asma	Mainly sandstones	Terrestrial	600 m	Namurian
	Tarlaağzı	Mixed coarse and fine clastics	Shallow marine		
	Gökgöl	Mixed coarse and fine clastics, with thin coals	Mainly terrestrial		
	Kokaksu	Limestones and clastic deposits	Mainly shallow-marine		

DIX (1934, 1937) developed the first biostratigraphical scheme for Carboniferous plant macrofossils using biozones, (in this case assemblage zones), that were defined independently of lithostratigraphy (BUREK & CLEAL, 2005). However, DIX (1934, 1937) was rather ahead of her time and her scheme was not widely adopted outside of Britain. It was not until WAGNER (1984) developed a comparable scheme to DIX's that Carboniferous plant biostratigraphy took on a modern aspect. Like DIX's scheme, WAGNER's was based on biozones determined from range charts that showed the stratigraphical distribution of the species. This time, however, the data on which the zones were established were taken from across Europe and North America, and so potentially the scheme should have wider application than DIX's. The zones were concurrent range zones although in a number of cases the boundary between zones was effectively made to coincide with chronostratigraphical stage / substage boundaries. According to WAGNER (1984) this made sense as many of the substage boundaries had been defined using macrofloral indices. The Asturian and stratigraphically higher substages were indeed defined mainly using macrofloral indices as the faunal data from these strata tend to be limited and often equivocal (e.g. BOUROZ et al., 1972; LAVEINE, 1977; WAGNER, 1998). However, the stratigraphically lower stages and substages were mainly defined on eustatic marine bands and/or changes in the faunas (WATERS, 2011), which tended to operate independently of the vegetation changes. Consequently, by forcing the zonal boundaries to coincide with the substage boundaries, parts of the WAGNER (1984) biostratigraphical scheme did not reflect the actual pattern of change in the macrofloras as well as DIX's (1934, 1937) scheme. Nevertheless, WAGNER's (1984) scheme has become widely adopted in the literature.

CLEAL (1991) modified several aspects of WAGNER's (1984) scheme. Greater emphasis was given to what defined the boundaries, rather than the content of the zones, therefore changing them into interval zones. Also, a set of sub-zones was introduced based on some of the temporal changes in the coal swamp vegetation not reflected in the WAGNER (1984) scheme, notably those in the middle Langsettian, mid-

dle Bolsovian and upper Asturian substages. This more detailed approach helped maintain the integrity of the widely used WAGNER (1984) biozones, whilst also incorporating some of the more "natural" features of the DIX (1934) scheme.

4. PALAEOBOTANY

The following analysis will mainly focus on the biostratigraphy and (for the Kozlu Formation) the species diversities of the plant fossils. As is normal in palaeobotanical studies, the fossils are named as fossil-taxa (sensu CLEAL & THOMAS, 2010a,b, McNEILL & TURLAND, 2011), which refer to remains of particular parts of the plant rather than whole organisms. Using a similar approach to that advocated by CLEAL (2005, 2007) only the fossil-taxa for one plant part are listed for each plant group, mainly those of the foliage, except for the lycopsids in which the stem / bark fossil-taxa are given.

4.1. Alacaağzı Formation

Macrofloras are generally poor in this interval, and many of those that have been reported are difficult to place accurately in a stratigraphical context. However, ZEILLER (1899, p. 83), JONGMANS (1955, p. 58) and KEREY et al. (1986, p. 205) have reported plant fossils from several localities in the Zonguldak Coalfield and small outcrops to the west (Alacaağzı, Kireçlik, Teflenli). These plant beds all immediately overlie marine limestones presumably of the Kokaksu "Member" and so were probably in the Gökgöl "Member" (see Table 1). These macrofloras are all similar and are summarised in Table 2.

Fig. 2 shows the ranges of the stratigraphically most instructive species in the Alacaağzı Formation macrofloras plotted against the WAGNER (1984) / CLEAL (1991) biozones. This clearly indicates that the Alacaağzı Formation macrofloras belong to the *Lyginopteris stangeri* Zone, and probably the lower part of that zone. Although not included in the taxonomic lists in Table 2, JONGMANS (1955) repeatedly mentioned *Mesocalamites* stems from these beds,

Table 2: Macrofloras from the Alacaagzi Formation (Gökgöl "Member") in the vicinity of Zonguldak and the small outcrops to the west.

	1	2	3	4	5	6	7	8
<i>Sublepidodendron robertii</i> (NATHORST) CHALONER	X	X	X		X	X	X	X
<i>Eleutherophyllum mirabile</i> (STERNBERG) STUR			X	X		X		
<i>Sphenophyllum tenerimum</i> ETTINGSHAUSEN	X	X		X	X	X		
<i>Pecopteris aspera</i> BRONGNIART	?	X				?	X	
<i>Alloiopteris quercifolia</i> (GÖPPERT) POTONIÉ			X	X				
<i>Sphenopteris elegans</i> BRONGNIART		X	X	X		X	X	X
<i>Sphenopteris dissecta</i> BRONGNIART	?	?	?		?	?		X
<i>Lyginopteris distans</i> (STERNBERG) CLEAL, comb. nov.	X		X	X	X			X
<i>Lyginopteris fragilis</i> (BRONGNIART) PATTEISKY							X	X
<i>Lyginopteris dicksonioides</i> (GÖPPERT) NOVIK							X	
<i>Cardiopteridium nanum</i> (EICHWALD) WALTON		X	X	X		X	X	
<i>Adiantites oblongifolius</i> GÖPPERT		?	?			X	X	

Localities:

- 1 - Near Kirat and Tchatal-Déré, Zonguldak (ZEILLER, 1899)
 2 - Kokaksu Valley, Zonguldak (JONGMANS, 1955)
 3 - Ali-Mollah Seam, Kiliç Valley, Zonguldak (ZEILLER, 1899;
 JONGMANS, 1955)

- 4 - Kilimli tunnel, Zonguldak (JONGMANS, 1955)
 5 - Gökgöl section, Üzülmez Deresi, Zonguldak (KEREY et al., 1986)
 6 - Kireçlik mines (various coals) (ZEILLER, 1899; JONGMANS, 1955)
 7 - Alacaagzi (JONGMANS, 1955)
 8 - Teflenli (ZEILLER, 1899)

which WAGNER (1984) again suggested is a characteristic taxon of the *L. stangeri* Zone. Similar *L. stangeri* Zone macrofloras have been reported from the upper Rakovski Formation in the Dobrudzha Coal Basin, Bulgaria (KULAKSAZOV & TENCHOV, 1973; TENCHOV, 2004) and the lower Ostrava Formation in Upper Silesia, Czech Republic (PURKYŇOVÁ, 1970). In western Europe, such floras are poorly documented, although there are records from the Upper Limestone Formation in Scotland (WALTON et al., 1938). According to WAGNER (1984), this zone indicates a stratigraphical position in the lower Namurian Stage (Arnsbergian Substage) and thus a latest Mississippian age.

In the Amasra area to the east, the Alacaagzi Formation is more marine in character (KEREY, 1982; KEREY et al., 1986) and plant remains are consequently rarer. However, low diversity macrofloras comparable to those of the Gökgöl "Member" have been reported from near Güllük and Dökök (CHARLES, 1931; JONGMANS, 1955).

WAGNER (1984) suggested there are even older macrofloras from the Zonguldak area, belonging to the *Neuropteris antecedens* Zone, which would indicate a late Viséan or earliest Namurian age. WAGNER referenced JONGMANS (1955) for this opinion, but there is nothing recorded in this latter paper to support such a view. Since the Gökgöl "Member" represents the stratigraphically oldest extensive terrestrial deposits in the coalfield, older macrofloras from here would seem to be unlikely.

WAGNER (in STOCKMANS, 1962; 1984) also suggested that younger, "Namurian B" macrofloras (i.e. belonging to the *Lyginopteris larischii* Zone) occurred in the Zonguldak area based on evidence in JONGMANS (1955). From the species mentioned by WAGNER (in STOCKMANS, 1962) as suggesting a "Namurian B" age, it is likely that he was referring to the macroflora from north of the Kokaksu Valley listed by JONGMANS (1955, p. 58). This macroflora is very similar to those found in the overlying Koslu Formation except for the presence of rare sphenophytes compara-

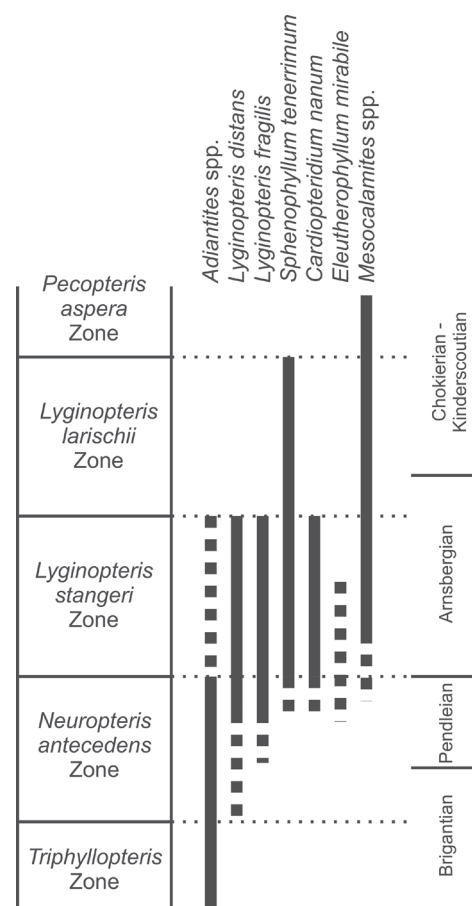


Figure 2: Stratigraphic ranges of the key macrofloral taxa found in the Alacaagzi Formation, plotted against the WAGNER (1984) / CLEAL (1991) biozonal scheme. Ranges mainly as given by WAGNER (1984).

ble with *Asterophyllites unguis* JONGMANS & GOTHAN and *Asterophyllites heimansii* JONGMANS & GOTHAN, which are only known from Namurian strata (JOSTEN, 1983 and references cited therein). However, the robustness of

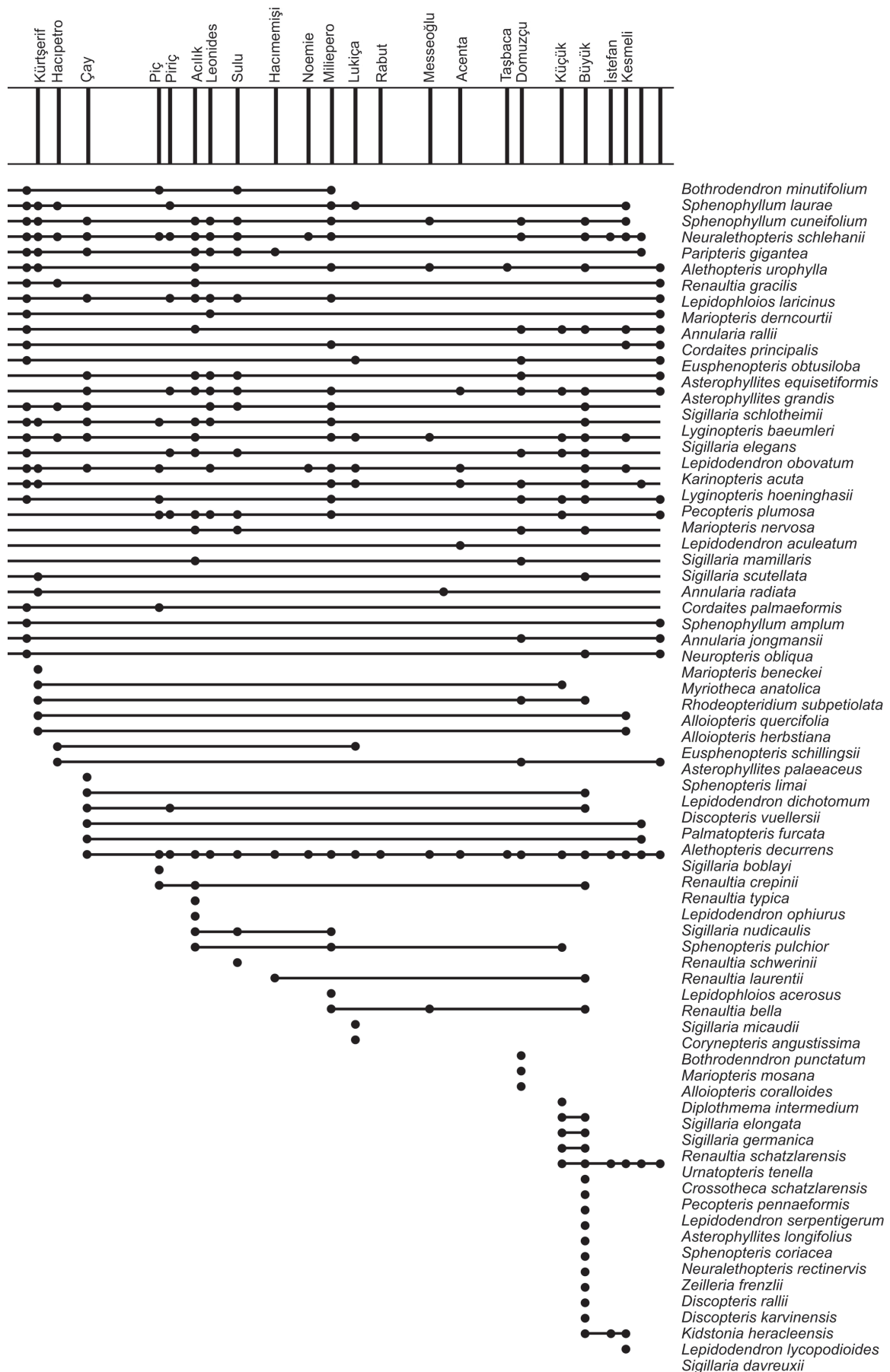


Figure 3: Stratigraphic distribution of the macrofloral species of the Kozlu Formation plotted against the lithostratigraphic sequence given by NAKOMAN (1977) (see also KEREY, 1985 and KEREY et al., 1986). Black dots on the range bars designate recorded occurrences of species.

these species as stratigraphical indices for the middle Namurian Stage remains unproven and the identifications were anyway only given with a “cf.” At the moment it seems more likely that these Kokaksu Valley macrofloras originated from the Koslu Formation.

KEREY et al. (1986) mentioned lycopsid remains from the Asma “Member” at the top of the formation (e.g. *Lepidodendron rimosum* STERNBERG) but these are biostratigraphically uninformative.

4.2. Kozlu Formation

This is the main productive interval of the basin for coal and there have been many workings especially in the vicinity of Zonguldak. ZEILLER (1899), JONGMANS (1955), EGEMEN (1959) and KEREY et al. (1986) have provided stratigraphical records of the Kozlu Formation macrofloras from the Zonguldak mines, from which it has been possible to establish a detailed biostratigraphical model (Fig. 3).

A total of 76 species have been reported from the formation. Excluding the stratigraphically highest and lowest two macrofloras (to help remove the edge effect inherent when using through-range data – see FOOTE, 2000 and CLEAL, 2007 for further discussion on edge effect in such analyses) estimated landscape-scale species diversities (i.e. species diversities within the area of the coalfield) vary from 33 to 56 species (mean 43.2, s. d. 5.0) and local-scale diversities (i.e. species diversities observable at a particular locality) from 3 to 37 species (mean 11.2, s. d. 7.9). This is essentially similar to the diversities recorded by CLEAL (2007) in the Langsettian Substage in South Wales (landscape diversities mean 38.5, s. d. 5.6; local-scale diversities 13.8, s. d. 5.6). Very similar local-scale diversities were also reported by WING & DIMICHELE (1995) from various Pennsylvanian macrofloras from North America.

Although there seems to be some variation in the biostratigraphical distribution of the species through the succession, this is mainly due to 24 singleton species. Of the 52 species that occur at more than one stratigraphical level, 39 (75 % of the non-singleton species) range through virtually the entire formation, from the Kürtşerif, Hacıpetro or Çay coal seams near the base to the Büyük or stratigraphically higher seams at the top. Nearly all of the species that have not been recorded to range through the entire formation are lycopsids and herbaceous, sphenopteroid ferns, which are all rare and therefore subject to potential taphonomy-induced sampling problems. There appears, therefore, to be little significant change in the macrofloras through the formation.

When plotted against the biozonal scheme of WAGNER (1984), the Kozlu Formation macrofloras correspond to the *Lyginopteris hoeninghausii* Zone (Fig. 4). CLEAL (1991) and CLEAL & THOMAS (1994) argued that the zone could be divided into a lower, *Neuralethopteris jongmansii* Subzone and an upper, *Laveineopteris loshii* Subzone, based on the appearance of several taxa, notably *Laveineopteris loshii* (BRONGNIART) CLEAL et al., (date) *Laveineopteris tenuifolia* (STERNBERG) CLEAL et al. (1990) *Neuropteris heterophylla* BRONGNIART and *Lobatopteris miltonii* (ARTIS)

WAGNER. This change can be recognised in Britain (CLEAL, 2005, 2007), northern France (LAVEINE, 1987) and northern Germany (JOSTEN, 1991), where it occurs about one-third of the way up the Langsettian Stage. Since none of these species have been convincingly documented from the Kozlu Formation, it seems reasonable to conclude that this interval belongs to the *N. jongmansii* Subzone and is thus early Langsettian in age. EGEMEN (1959) reported *L. miltonii* from Kozlu Formation macrofloras from Çataldere and Virancıkdere, but he stated that the specimens were poorly preserved and none were illustrated. JONGMANS (1955) also mentioned *L. miltonii* from the Leonodas and Sulu seams, but with no comment or justification for the identifications. Significantly, ZEILLER (1899) stated that this species was absent from the Kozlu Formation.

A Langsettian age for the Kozlu Formation is in general accord with the views of JONGMANS (1955) and KEREY et al. (1986). These latter authors suggested that the lower part of the formation might range down into the Yeadonian (“Namurian C”) Substage but without giving evidence in support of this idea. The fact that *Lyginopteris hoeninghausii* and *Mariopteris dernoncourtii* range down into the lowest part of the Koslu Formation (Fig. 4) strongly suggests that the formation does not in fact extend below the base of the

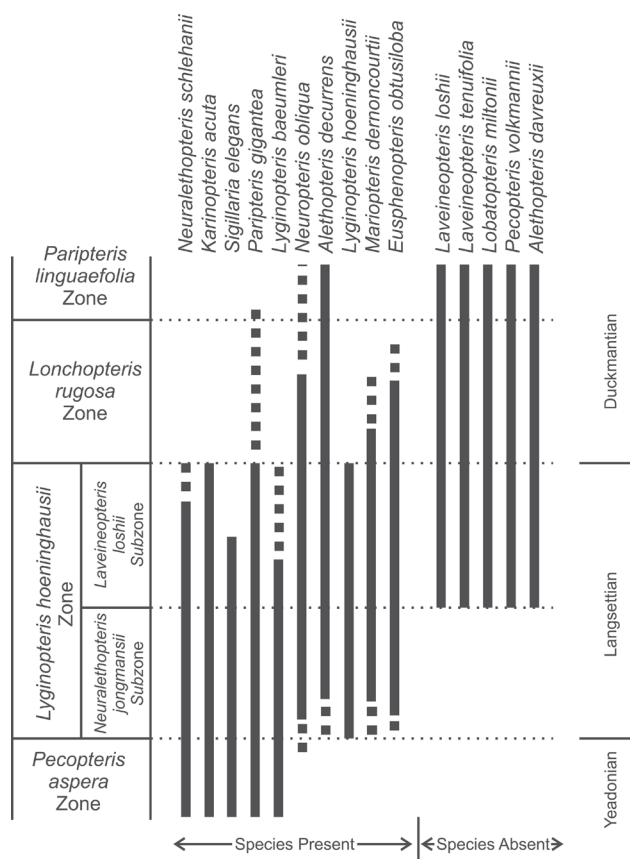


Figure 4: Stratigraphic ranges of the key macrofloral taxa found in the Kozlu Formation (based mainly on records in JONGMANS, 1955) plotted against the WAGNER (1984) / CLEAL (1991) biozone scheme. Ranges mainly as given by WAGNER (1984), CLEAL & THOMAS (1994) and CLEAL (2005, 2007).

Table 3: Macrofloras from the Karadon Formation.

	1	2	3	4	5	6	7	8	9	10
<i>Lepidodendron aculeatum</i> STERNBERG		X								
<i>Lepidodendron obovatum</i> STERNBERG <i>auct.</i>					X	X				X
<i>Bothrodendron minutifolium</i> BOULAY									X	
<i>Sigillaria ovata</i> SAUVEUR					X					
<i>Annularia radiata</i> (BRONGNIART) STERNBERG			X		X	X	X	X	X	X
<i>Annularia rallii</i> (ZEILLER)								X	X	X
<i>Annularia spinulosa</i> STERNBERG	X	X				X				X
<i>Annularia sphenophylloides</i> (ZENKER) GUTBIER					X		X		X	X
<i>Asterophyllites charaeformis</i> (STERNBERG) UNGER			?		X					X
<i>Asterophyllites equisetiformis</i> BRONGNIART		X			X				X	X
<i>Sphenophyllum emarginatum</i> (BRONGNIART)	X	X		X	X				X	
<i>Sphenophyllum cuneifolium</i> (STERNBERG) ZEILLER	X	X			X	X	X	X	X	X
<i>Sphenophyllum majus</i> (BRONN) BRONN		X						?	?	
<i>Alloiopteris sternbergii</i> (ETTINGSHAUSEN) POTONIÉ					X				X	
<i>Alloiopteris coralloides</i> GUTBIER				?	X					X
<i>Oligocarpia brongniartii</i> GÖPPERT									X	
<i>Renaultia chaerophylloides</i> (BRONGNIART) ZEILLER	X				X					
<i>Renaultia crepinii</i> (STUR) GOTHAN		X							X	
<i>Renaultia footneri</i> (MARRATT) BROUSMICHE					X					X
<i>Sphenopteris limai</i> ZEILLER		X			X			X	X	
<i>Pecopteris plumosa</i> (ARTIS) BRONGNIART	X									
<i>Lobopteris miltonii</i> (ARTIS) WAGNER		X					X			
<i>Eusphenopteris neuropteroïdes</i> (BOULAY) NOVIK					X					?
<i>Eusphenopteris nummularia</i> (GUTBIER) NOVIK			X				X		X	?
<i>Eusphenopteris striata</i> (GOTHAN) NOVIK			?	?						
<i>Mariopteris dernoncourtii</i> ZEILLER				X	X					
<i>Mariopteris nervosa</i> (BRONGNIART) ZEILLER		X			X	X	X		X	X
<i>Mariopteris sauveurii</i> (BRONGNIART) ZEILLER					X					
<i>Mariopteris soubeiranii</i> ZEILLER					X					
<i>Palmopteris furcata</i> (BRONGNIART) POTONIÉ	X			?			?		?	?
<i>Alethopteris lonchitica</i> STERNBERG	X	X			X	X	X		X	
<i>Alethopteris davreuxii</i> (BRONGNIART) ZEILLER							X			
<i>Lonchopteridium karvinense</i> (PURKYŇOVA) KEREY et al.				X						
<i>Reticulopteris muensteri</i> (EICHWALD) GOTHAN		X	X		X		X		X	X
<i>Macroneuropteris scheuchzeri</i> (HOFFMANN) CLEAL et al.		X	X		X	X	X	X	X	
<i>Laveineopteris rarinervis</i> (BUNBURY) CLEAL et al.		X			X			X	X	X
<i>Laveineopteris tenuifolia</i> (STERNBERG) CLEAL et al.		?					?	?	?	X
<i>Paripteris</i> spp.				X			X		X	X
<i>Linopteris neuropteroïdes</i> (GUTBIER) ZEILLER	X		X		X	X	X	X	X	X
<i>Linopteris obliqua</i> (BUNBURY) ZEILLER	X	X	X		X		X		X	X
<i>Cordaites principalis</i> (GERMAR) GEINITZ	X		X							?

Localities:

1 – Taşkesen (JONGMANS, 1955)

2 – Çatalağzı, Gelik Valley (ZEILLER, 1899; JONGMANS, 1955)

3 – Along road to Çaycuma (JONGMANS, 1955)

4 – Behind primary school garden, Temmuz Mevkii, Zonguldak (KEREY et al., 1986)

5 – East of Söğütözü (JONGMANS, 1955)

6 – East of Dereustudere, near Söğütözü (JONGMANS, 1955)

7 – Kilçarman, near Söğütözü (JONGMANS, 1955)

8 – North of Karatepe, near Söğütözü (JONGMANS, 1955)

9 – Between Başköy and Ömerköy, near Söğütözü (JONGMANS, 1955)

10 – Özkem köy, near Söğütözü (JONGMANS, 1955)

Langsetian *L. hoeninghausii* Zone (in particular, compare with the range of *L. hoeninghausii* given in PATTEISKY, 1957).

Plant fossils in what was probably the Kozlu Formation were also reported by JONGMANS (1955) from several localities in the Azdavay and Amasra Coalfields. These macrofloras are all essentially the same as those found in the Zonguldak Coalfield, including *Lyginopteris baeumleri*, *L. hoeninghausii*, *Karinopteris acuta* and *Paripteris gigantea*, and lacking *Laveineopteris* spp., *Neuropteris heterophylla* and *Lobopteris miltonii*. Despite the reported absence of neurolethopterids, these macrofloras clearly belong to the Langsetian *L. hoeninghausii* Zone and probably the lower subzone.

4.3. Karadon Formation

Although the Karadon Formation occurs across the Zonguldak – Amasra Coal Basin, there has not been the same level of systematic collecting of plant fossils compared with the Kozlu Formation (as discussed above). They are best known from the Gelik Valley near Zonguldak; ZEILLER (1899) and JONGMANS (1955) mention a plant bed that outcrops at several localities including Taşkesen and Çatalağzı that has yielded a diverse macroflora. Diverse Karadon macrofloras have also been found in the vicinity of the villages of Azdavay and Söğütözü. Table 3 summarises the most diverse macrofloras that have been reported to date from this formation.

We do not know the relative stratigraphical positions of the various plant-bearing localities within the Karadon Formation and so it is impossible to develop the same type of biostratigraphical model as we have for the Kozlu Formation (as shown in Fig. 3). However, there is no obvious difference between any of the assemblages in the Karadon Formation except for how many species each contains; they may, therefore, all be treated together. If the ranges of the most widespread and abundant of the Karadon Formation species are plotted against the zones of the WAGNER (1984) / CLEAL (1991) scheme (Fig. 5) it indicates that they belong to the *L. rarinervis* Subzone. Similar macrofloras are widespread in Variscan Euramerica, having been reported from the Makedonka Formation in the Dobrudzha Coal Basin, Bulgaria (CLEAL et al., 2004), the Lembeck Formation in northern Germany (JOSTEN, 1991), the lower Pennant Formation in South Wales (CLEAL, 2007) and the South Bar Formation in the Canadian Maritimes (BELL, 1938); for a further discussion on the distribution of this subzone see CLEAL et al., 2010). In western Europe, the zone tends to range from about the level of the Cambriense Marine Band up to the base of the Asturian Substage, and so is regarded as an index for the upper Bolsovian Substage.

There is no evidence of *Lonchopteris rugosa* or lower *Paripteris linguaefolia* zone floras in the Karadon Formation. To the south of Zonguldak, at exposures along the road to Çaycuma and at Temmuz, JONGMANS (1955) and KEREY et al. (1986) reported similar macrofloras, but which lack *L. rarinervis* and include *Eusphenopteris obtusiloba* (BRONGNIART) NOVIK, and which they interpreted as

Duckmantian in age. In part justification for this opinion, KEREY et al. (1986, pl. 10, fig. 1) figured a specimen from here as *E. obtusiloba*. This interpretation depends on the accepted stratigraphical range of the latter species, which elsewhere does not normally range above the early Duckmantian *Lonchopteris rugosa* Zone (VAN AMEROM, 1975). The specimen figured by KEREY et al. (1986) does not show their surface features very clearly, but the pinnules are more deeply incised than is normal for *E. obtusiloba* and resemble more closely *Eusphenopteris striata* (GOTHAN) NOVIK. This would be more compatible with its co-occurrence with *Macroneuropteris scheuchzeri*, which does not normally range below the late Duckmantian *Neuropteris semireticulata* Subzone. It is likely, therefore, that these macrofloras are at the oldest, late Duckmantian and may in fact be as young as late Bolsovian.

JONGMANS (1955) reported another small macroflora from the Karadon Formation at Taarlağzı, east of Amasra, which includes *Sphenophyllum cuneifolium*, *Eusphenopteris* cf. *neuropteroides* (BOULAY) NOVIK, *Linopteris neuropteroides* and *Cordaites palmaeformis* GÖPPERT. JONGMANS suggested a Duckmantian age, but none of these species is diagnostic of the *Lonchopteris rugosa* Zone and the quoted assemblage is equally compatible with the *Paripteris linguaefolia* Zone.

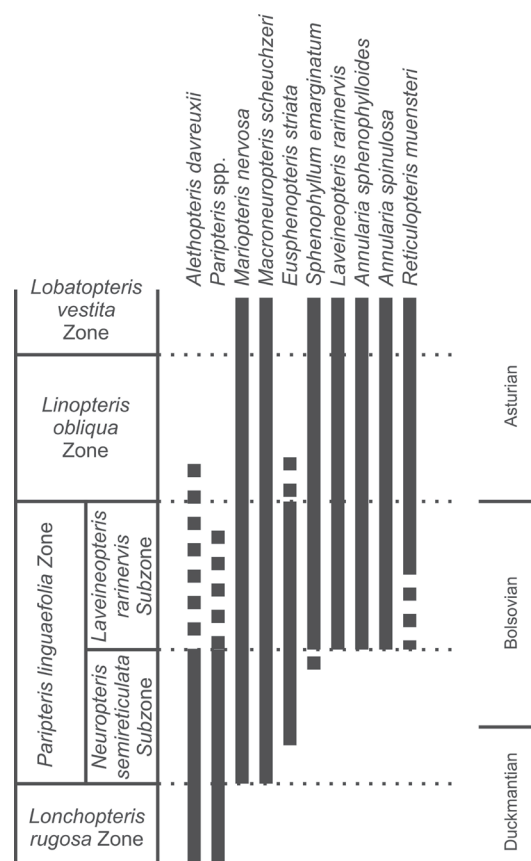


Figure 5: Stratigraphical ranges of the key macrofloral taxa found in the Karadon Formation, plotted against the WAGNER (1984) / CLEAL (1991) biozone scheme. Ranges mainly as given by WAGNER (1984), CLEAL & THOMAS (1994) and CLEAL (2005, 2007).

Table 4: Macrofloras from the Kızıllı Formation.

	1	2	3	4	5	6	7	8	9	10
<i>Bothrodendron minutifolium</i> BOULAY	X									
<i>Lepidodendron aculeatum</i> STERNBERG				X						
<i>Lepidodendron obovatum</i> STERNBERG auct.				X			X	X		
<i>Lepidodendron ophiurus</i> BRONGNIART		X								
<i>Sigillaria rugosa</i> BRONGNIART	X									
<i>Sigillaria tessellata</i> BRONGNIART				X						X
<i>Asolanus camptotaenia</i> WOOD		X								
<i>Annularia radiata</i> BRONGNIART				X		?			X	X
<i>Annularia sphenophylloides</i> (ZENKER) GUTBIER	X		X	X	X	X	X	X	X	X
<i>Annularia spinulosa</i> STERNBERG	?	X	?	X		X	X	X	X	
<i>Asterophyllites equisetiformis</i> BRONGNIART				X		X		X	X	X
<i>Sphenophyllum emarginatum</i> BRONGNIART	X	X	X	X	X	X	X	X	X	X
<i>Sphenophyllum majus</i> (BRONN) BRONN	X					X	X		?	X
<i>Sphenophyllum oblongifolium</i> (GERMAR & KAULFUSS)			X	X			X	X		
<i>Urnatopteris tenella</i> (BRONGNIART) KIDSTON			X							
<i>Sphenopteris limai</i> ZEILLER			?							
<i>Sphenopteris vuellersii</i> STUR			X							
<i>Hymenophyllites quadridactylites</i> (GUTBIER) KIDSTON							X			
<i>Renaultia rotundifolia</i> (ANDRÁ) ZEILLER						X	X			X
<i>Renaultia footneri</i> (MARRATT) BROUSMICHE						X		?		
<i>Zeilleria delicatula</i> (STERNBERG) KIDSTON				X						
<i>Pecopteris plumosa</i> (ARTIS) BRONGNIART		X	X	X		X	X			X
<i>Lobopteris vestita</i> auct.		X	X	X		X	X	X	X	X
<i>Acitheca polymorpha</i> (BRONGNIART) SCHIMPER		X		X						
<i>Ptychocarpus unites</i> (BRONGNIART) ZEILLER			X	X		X	X	X	X	X
<i>Cyathocarpus</i> sp.		X		X		X	X	X	X	X
<i>Eusphenopteris neuropteroides</i> (BOULAY) NOVIK		?		X				?	?	X
<i>Mariopteris nervosa</i> (BRONGNIART) ZEILLER						X		X	X	X
<i>Karinopteris daviesii</i> (KIDSTON) BOERSMA			?							
<i>Palmatopteris alata</i> (BRONGNIART) POTONIÉ			?					?		
<i>Sphenopteris coemansii</i> STUR	X									
<i>Dicksonites plukenetii</i> (STERNBERG) STERZEL				X	X	X	X	X		X
<i>Alethopteris lonchitica</i> STERNBERG	X		X				?	X	X	X
<i>Alethopteris ambigua</i> LESQUEREUX		X		X	X	X				
<i>Alethopteris pseudograndinioides</i> ZODROW & CLEAL				X		X		?		
<i>Alethopteris pontica</i> ZEILLER						X				
<i>Lonchopteris rugosa</i> BRONGNIART			X						?	
<i>Callipteridium jongmansii</i> (BERTRAND) WAGNER		X	?	X		X	?	?	?	
<i>Callipteridium armasii</i> (ZEILLER) WAGNER		X	?	X	X		X	X	?	?
<i>Neuropteris ovata</i> HOFFMANN	X	X	X	X	X	X	X	X	X	X
<i>Odontopteris reichiana</i> GUTBIER		X		?		?		?	?	
<i>Odontopteris cantabrica</i> WAGNER					?					
<i>Reticulopteris muensteri</i> (EICHWALD) GOTHAN	X		X	X		X		X	X	
<i>Macroneuropteris scheuchzeri</i> (HOFFMANN) CLEAL et al.	X	X	X	X	X	X	X	X	X	X
<i>Laveinopteris rarineris</i> (BUNBURY) CLEAL et al.	X	X	X	X					X	
<i>Linopteris obliqua</i> (BUNBURY) ZEILLER	X	X	X	X	X	X	X		X	X
<i>Linopteris neuropteroides</i> (GUTBIER) ZEILLER	X		X			X	X			X
<i>Cordaites</i> spp.	X			X		X	X			X

Localities:

- 1 - Tarlaağzi, Amasra (ZEILLER 1899; Charles, 1931; JONGMANS, 1955)
 2 - Grancy, Pelitova Basin (JONGMANS, 1955)
 3 - Azdavay (JONGMANS, 1955)
 4 - Azdavay, "Rayon C" (JONGMANS, 1955)
 5 - Kirmaci (JONGMANS, 1955)

- 6 - Sögütüzü (JONGMANS, 1955)
 7 - South of Rive de Fleuve, north of Kızıllı (JONGMANS, 1955)
 8 - Red beds near Kızıllı (JONGMANS, 1955)
 9 - Between Cebeci köy and Başköy (JONGMANS (1955)
 10 - South of Kayabasi, near Sögütüzü (JONGMANS, 1955)

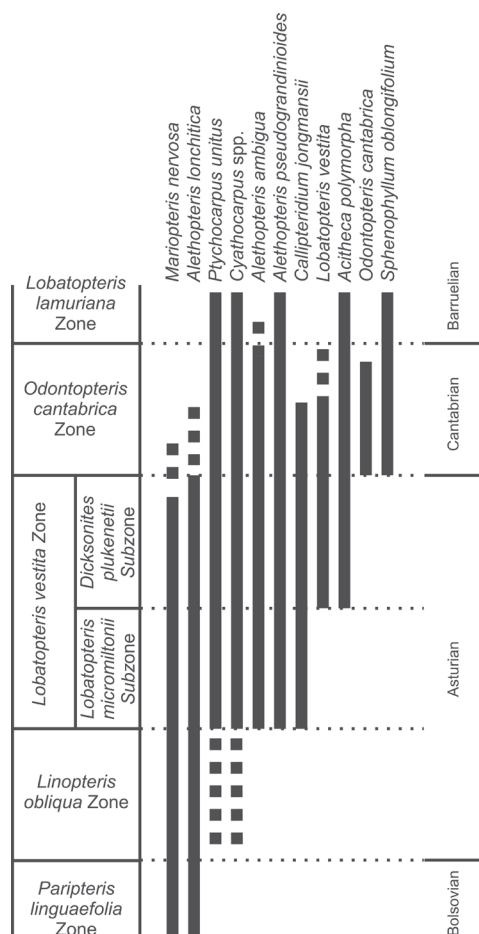


Figure 6: Stratigraphic ranges of the key macrofloral taxa found in the Kızıllı Formation, plotted against the WAGNER (1984) / CLEAL (1991) biozone scheme. Ranges mainly as given by CLEAL (1978, 1984, 1997, 2007), WAGNER et al. (1983), WAGNER (1984), ZODROW & CLEAL (1985), WAGNER & ALVAREZ-VÁZQUEZ (1991) and CLEAL & THOMAS (1994).

JONGMANS (1955) also reported “Karadon” macrofloras from localities near Koslu, which were reported to include *Neuropteris ovata*, *Callipteridium armasii* and *Cyathocarpus* sp. JONGMANS (1955) suggested an Asturian age for the macroflora and, if the latter two taxa can be confirmed, it would be to late Asturian in age. This is stratigraphically much younger than the other Karadon Formation macrofloras, and is more comparable in age to the overlying Kızıllı Formation (see below).

4.4. Kızıllı Formation

The macrofloras of the Kızıllı Formation are best documented for the Pelitova, Azdavavy and Söğütözü areas in the east of the coal basin, and from where numerous diverse assemblages have been documented (Table 4). There has been a general consensus that these strata are Asturian (“Westphalian D”) in age (JONGMANS, 1939, 1955; WAGNER in STOCKMANS, 1962; KEREY et al., 1986) partly through the regular appearance of *Neuropteris ovata*. However, other species that also regularly appear include *Dicksonites plukenetii*, *Callipteridium* spp., *Alethopteris ambigua*, *Alethopteris pseudograndinioides*, *Lobatopteris vestita*, *Acitheca*

polymorpha, *Ptychocarpus unitus* and *Cyathocarpus* spp. These strongly point to the *D. plukenetii* Subzone in the WAGNER (1984) / CLEAL (1991) scheme (Fig. 6). Similar macrofloras are known from the Gurkovo Formation in the Dobrudzha Coalfield, Bulgaria (CLEAL et al., 2004), the Libiąż Member in Upper Silesia, Poland (MIGIER & KOTASOWA in ZDANOWSKI & ŻAKOWA, 1995), the upper Heiligenwald Formation in Saarland (CLEAL, 1984), in many coalfields in southern Britain (CLEAL, 1997), the southern Cantabrian Mountains, Spain (WAGNER et al., 1983; WAGNER & ALVAREZ-VÁZQUEZ, 1991) and the upper Sydney Mines Formation in the Canadian Maritimes (ZODROW, 1986). Since the overlying *Odontopteris cantabrica* Zone is taken as an index for the Cantabrian Substage, the *D. plukenetii* Subzone is an index for the upper Asturian Substage.

At several localities there are also records of *Odontopteris* spp. and *Sphenophyllum oblongifolium*, which suggest possibly the early Stephanian *Odontopteris cantabrica* Zone; examples of these species were figured by ZEILLER (1899, pl. 4, figs 3–6; pl. 6, figs 4–5) which would seem to confirm these identifications. However, without some understanding of the species distributions through the formation, it is impossible to be sure if it is partly late Asturian and partly early Cantabrian in age, or if the entire interval is Cantabrian; both views would be compatible with the available biostratigraphical evidence.

5. DISCUSSION

Plant biostratigraphy indicates that the Zonguldak – Amasra Coal Basin has terrestrial deposits ranging in age from Arnsbergian (latest Mississippian) to late Asturian or possibly Cantabrian (late Middle Pennsylvanian). There has been a widespread assumption that the succession is continuous; for instance, KEREY et al. (1986, p. 211) stated that “there is little discernable evidence for physical breaks in the overall succession...” However, this is not borne out by the plant biostratigraphy, as there is no evidence of any macroflora in the Zonguldak – Amasra Coal Basin of middle or late Namurian, late Langsettian, Duckmantian or early Asturian age. The only stratigraphically informative macrofloras from the Alacağzı Formation (from the Gökğöl Member) indicate an Arnsbergian age. A marine fauna from the overlying Tarlağzı Member also indicates an early Namurian age (Pattison in KEREY et al., 1986). This apparent absence of middle and late Namurian macrofloras or faunas is difficult to reconcile with the suggestion by KEREY et al. (1986) that there is a gradational contact between the Alacağzı and Kozlu formations.

RALLI (1895) and ZEILLER (1996) recognised the sharp discontinuity between the macrofloras of the Kozlu and Karadon formations, suggesting that it was part of a regional unconformity. Significantly, KEREY (1982) also regarded the boundary to be an abrupt lithological break which he later (KEREY et al., 1986, p. 206) stated was at “...the base of a succession of thick conglomeratic layers just above the Agop Coal Seam.” Kerey (1982) interpreted this as a

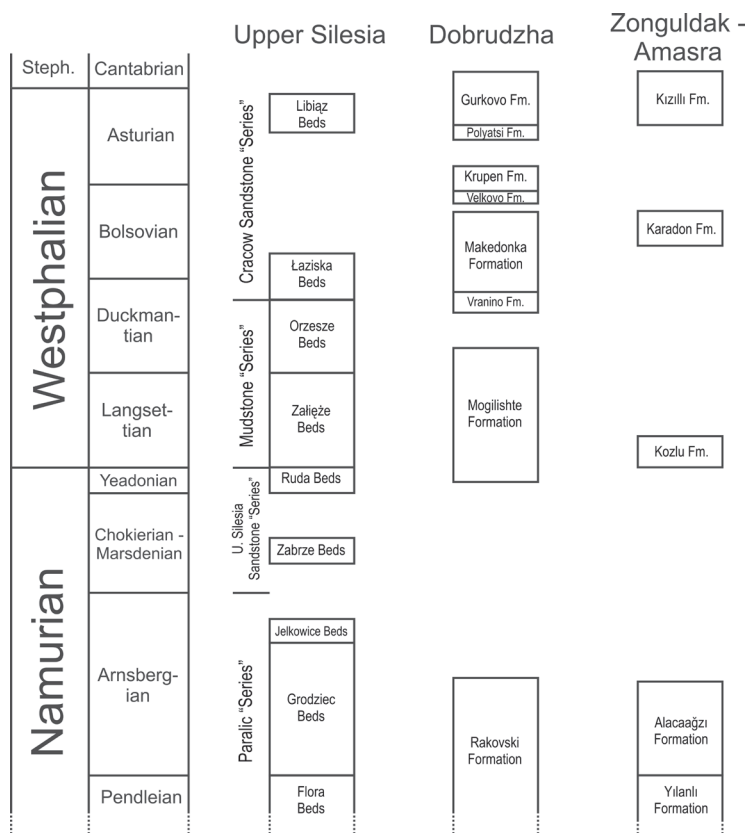


Figure 7: Correlation of the Carboniferous successions of the Zonguldak – Amasra Coal Basin, the Dobrudzha Coal Basin and the Upper Silesia Coal basin, based on macrofloral biostratigraphy. Based on data given in TENCHOV et al. (in NIKOLOV, 1988), KOTASOWA & MIGIER (in ZDANOWSKI & ŽAKOWA, 1995), CLEAL et al. (2004, 2010, 2011), TENCHOV (2004, 2005, 2007) and the present paper.

change from a predominantly meandering fluvio-lacustrine facies to a braided-stream and alluvial fan facies, but may also indicate a break in the sequence. ARNI (1939) and EGMEN (1959), in contrast, argued that there was a floristic transition between the Kozlu and Karadon formations, but this is not borne out by the available evidence: all of the diverse Kozlu Formation macrofloras unequivocally indicate the Langsettian *Lyginopteris hoeninghausii* Zone, and probably the lower part of that zone (notably with *Lyginopteris* and *Neuralethopteris*) and all of those from the Karadon Formation belong to the upper Bolsovian *Paripteris linguafolia* Zone, (notably with *Sphenophyllum emarginatum*, *Mariopteris nervosa*, *Macroneuropteris scheuchzeri*, *Laveineopteris rarinervis*).

Similarly, the suggestion by KEREY et al. (1986) that the boundary between the Karadon and Kızıllı formations is transitional is at variance with the macrofloral evidence, which indicates an absence of middle and late Asturian strata. Here again, KEREY (1982) and KEREY et al. (1986) stated that in the Pelitova and Azdavay areas the base of the Kızıllı Formation is marked by beds of pebbly sandstone, this time overlying a coal (the Tavan Seam), which tends to suggest a break in the sequence.

These age estimates were based on the macrofloral biostratigraphy developed by WAGNER (1984), CLEAL (1991) and CLEAL & THOMAS (1994), mainly in western Europe and North America. It is of course always possible that these biozones cannot be applied as far east as the Zonguldak – Amasra Coal Basin; it is notable that FISSUNENKO & LAVEINE (1984) reported discrepancies in the strati-

graphical ranges of certain plant fossil-species between western Europe and the Ukraine. In contrast, however, a study of the macrofloral biostratigraphy of the Dobrudzha Coalfield in northeastern Bulgaria showed that this biostratigraphy could be broadly applied when local factors (e.g. marine influence) were taken into account (CLEAL et al., 2004).

OKAY et al. (1994, 2006) and PHAROAH (1999) suggested that prior to the Late Cretaceous opening of the Black Sea, the Istanbul Block and Moesian Platform were located adjacent to each other. This would provide the palaeogeographical context to support the view of TENCHOV (1989) that the Zonguldak – Amasra Coal Basin is part of a belt of coal swamp deposits that extended westwards from the Zonguldak – Amasra Coal Basin to the Dobrudzha Coalfield in Bulgaria and Upper Silesia on the Czech – Polish border. Macrofloral biostratigraphy allows the succession in the Zonguldak – Amasra Coal Basin to be compared with these other areas (Fig. 7). This suggests individual units can be broadly correlated: the Alacaagzi Formation with the Rakovski Formation, the Kozlu Formation with the lower parts of the Załęże Beds and the Mogilishte Formation, the Karadon Formation with the upper part of the Makedonka Formation, and the Kızıllı Formation with the Libiąz Beds and the Gurkovo Formation. These units are not only similar in age – there are also broad similarities in the facies present (TENCHOV, 2005, 2007; KĘDZIOR et al., 2007). However, it is also clear that there is a progressive eastwards widening of the stratigraphical gaps in the successions. Such disruption to patterns of sedimentation was probably the result of tectonic instability resulting from the suturing of the terrane to the south and

west of the Pontides (the Sakary – Standja Terrane – OKAY et al., 2006) with the Moesian – Pontides Terrane. It has been suggested that the Sakary – Standja Terrane equates to Amorica in western Europe, and the Moesian – Pontides Terrane to Avalonia (STAMPFLI et al., 2002), and so this tectonism observable in northern Turkey is in effect an eastwards extension of the Variscan Orogeny.

Variscan tectonic activity would, therefore, appear to have started earlier and be more continuous in the area of the Moesian – Pontides Terrane than in more western parts of Variscan Euramerica. How much this was affecting sediment supply from the hinterland area and how much drainage patterns within the basin is still unclear. It would be informative to have the type of palynology-based vegetation analysis of the Zonguldak – Amasra Coal Basin as has been done in Dobrudzha (DIMITROVA & CLEAL, 2007) to determine the details of the tempo and pattern of vegetation change that took place here during Westphalian times. However, the evidence from the Zonguldak – Amasra Coal Basin would seem to support the view of CLEAL et al. (2010, 2011) that the disruption to the coal swamp biome during Westphalian times first started in these easternmost parts of Variscan Euramerica.

Although only a preliminary analysis of the published data, this paper provides new insights into the wider geological and palaeontological context of the Zonguldak – Amasra Coal Basin macrofloras. A detailed taxonomic review is now clearly needed, especially to improve our understanding of the palaeoecological and floristic setting of this area. The W.J. Jongmans Collection now at Naturalis (Leiden, the Netherlands) probably offers the best starting point for such an analysis.

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APPENDIX

TAXONOMIC REMARKS ON SELECTED SPECIES

These remarks are not intended to be exhaustive, but are merely to clarify the usage of some of the species names in this paper, and why they differ from those used in the original publications.

Lepidodendron obovatum STERNBERG *auct.* This species has been the subject of much confusion. THOMAS (1970) re-examined the type specimen and came to the conclusion that it was a synonym of *L. aculeatum* STERNBERG. However, many authors have referred specimens to *L. obovatum* that are really *L. mannabachense* PRESL. The distinction between *L. aculeatum* and *L. mannabachense* is based on surface features of their cushion and on their epidermal details (THOMAS, 1970), so we are uncertain to which of these two species the *L. obovatum* determinations should be referred.

Sublepidodendron robertii (NATHORST) CHALONER in BOUREAU et al., 1967 (= *Lepidodendron robertii* NATHORST, 1914). CHALONER (in BOUREAU et al., 1967) transferred *L. robertii* to *Sublepidodendron* presumably as it was thought to be eligulate, although this negative feature has yet to be clearly confirmed.

Cardiopteridium nanum (EICHWALD) WALTON, 1941 (= *Cyclopteris nana* EICHWALD, 1860; ≡ *Cardiopteridium spetsbergense* NATHORST, 1914; ≡ *Cardiopteridium waldenburgense* ZIMMERMANN, 1932). ZEILLER (1899) referred to this species as *Cardiopteris polymorpha* (GÖPPERT) SCHIMPER, but JONGMANS (1955) correctly attributed it to *Cardiopteridium*. JONGMANS used the species name *C. waldenburgense* but WALTON (1941) had earlier shown that this species merely represents slightly larger forms of *C. nanum*, the latter name taking priority.

Lyginopteris distans (STERNBERG) CLEAL & VAN WAVEREN, comb. nov. (= *Sphenopteris distans* STERNBERG, 1825; = *Sphenopteris bermudensisformis* SCHLOTHEIM ex ZEILLER, 1899; = *Lyginopteris bermudenseformis* (SCHLOTHEIM ex ZEILLER) PATTEISKY, 1929). This species was referred to as *S. bermudensisformis* by ZEILLER (1899) and JONGMANS (1955), who attributed the name to SCHLOTHEIM (1820). However, as SCHLOTHEIM's (1820) pre-dates the starting-point for the publication of plant fossil species names (ICBN, Art. 13.1 – McNEILL et al., 2006), the earliest valid publication of the name must be taken to be ZEILLER (1899). As pointed out by KVAČEK & STRAKOVÁ (1977), this is, therefore, predated by the nomenclatural synonym *S. distans*. Following PATTEISKY (1957), there can be little doubt that this species belongs to the fossil-genus *Lyginopteris* and so a new combination is proposed here.

Lyginopteris fragilis (SCHLOTHEIM ex BRONGNIART) PATTEISKY, 1955 (= *Sphenopteris fragilis* SCHLOTHEIM ex BRONGNIART, 1828; ≡ *Cheilanthes divaricatus* GÖPPERT, 1836; ≡ *Sphenopteris divaricata* (GÖPPERT) GUTBIER in COTTA et al., 1843). JONGMANS (1955) recorded this species as *Sphenopteris divaricata* but according to PATTEISKY (1955) this is a later taxonomic synonym of *Lyginopteris fragilis*. The latter name is usually attributed to SCHLOTHEIM (1820) but is regarded as published before the starting-point for the publication (ICBN, Art. 13.1).

Sphenopteris elegans BRONGNIART, 1822 (≡ *Sphenopteris adiantoides* SCHLOTHEIM ex LINDLEY & HUTTON, 1834). JONGMANS (1955) referred to this species as

S. adiantoides, attributing the name to SCHLOTHEIM (1820). However, SCHLOTHEIM's (1820) book pre-dates the starting-point for the publication of names for plant fossil-species (ICBN, Art. 13.1 – McNEILL et al., 2006). The earliest validly published use of this species name was by LINDLEY & HUTTON (1834), but this was predated by its taxonomic synonym *S. elegans*, and so the latter must take priority.

REFERENCES

- ARNI, P. (1939): Neue geologische Gesichtspunkte für den Bergbau im westlichen Steinkohlenbecken Nordanatoliens.– Maden Tetkik ve Arama Enstitüsü Yayınlarından, Seri B: Irdeller, 4/17, 55–63.
- BELL, W.A. (1938): Fossil flora of Sydney Coalfield, Nova Scotia.– Canada Department of Mines and Resources, Geological Survey Memoir, 215, 1–334.
- BOUREAU, E., JOVET-AST, S., HØEG, O.A. & CHALONER, W.G. (1967): *Traité de paléobotanique 2. Bryophyta, Psilophyta, Lycophyta.*– Mason et Cie, Paris, 845 p.
- BOUROZ, A., KNIGHT, J.A., WAGNER, R.H. & WINKLER-PRINS, C.F. (1972): Sur la limite Westphalien–Stéphanien et sur les subdivisions du Stéphanien inférieur *sensu lato*. *Compte rendu 7e Congrès de Stratigraphie et de Géologie du Carbonifère* (Krefeld, 1971), 1, 241–261.
- BRONGNIART, A. (1822): Sur la classification et la distribution des végétaux fossiles en général, et sur ceux des terrains de sédiment supérieur en particulier.– *Mémoires du Muséum d'Histoire Naturelle*, Paris, 8, 203–240, 297–348.
- BRONGNIART, A. (1828): *Prodrome d'une Histoire des végétaux fossiles.*– F.G. Levrault, Paris & Strasbourg, 223 p.
- BUREK, C.V. & CLEAL, C.J. (2005): The life and work of Emily Dix (1904–1972).– In: BOWDEN, A.J., BUREK, C.V. & WILDING, R. (eds): *History of palaeobotany: selected essays.* Geological Society, London, Special Publication, 241, 181–196.
- CHARLES, F. (1931): Note sur le houiller d'Amasra (Asie mineure).– *Bulletin del la Société géologique Belgique*, 54, 151–178.
- CLEAL, C.J. (1978): Floral biostratigraphy of the upper Silesian Pennant Measures of South Wales.– *Geological Journal*, 13, 165–194.
- CLEAL, C.J. (1984): The Westphalian D floral biostratigraphy of Saarland (Fed. Rep. Germany) and a comparison with that of South Wales.– *Geological Journal*, 19, 327–351.
- CLEAL, C.J. (1991): Carboniferous and Permian biostratigraphy.– In: CLEAL, C.J. (ed.): *Plant fossils in geological investigation: the Palaeozoic.* Ellis Horwood, Chichester, 182–215.
- CLEAL, C.J. (1997): The palaeobotany of the upper Westphalian and Stephanian of southern Britain and its geological significance.– *Review of Palaeobotany and Palynology*, 95, 227–253.
- CLEAL, C.J. (2005): The Westphalian macrofloral record from the cratonic central Pennines Basin, UK.– *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, 156, 387–410.
- CLEAL, C.J. (2007): The Westphalian-Stephanian macrofloral record from the South Wales Coalfield.– *Geological Magazine*, 144, 465–486.
- CLEAL, C.J., OPLUŠTIL, S., THOMAS, B.A. & TENCHOV, Y. (2010): Late Moscovian terrestrial biotas and palaeoenvironments of Variscan Euramerica.– *Netherlands Journal of Geosciences*, 88, 181–278.
- CLEAL, C.J., OPLUŠTIL, S., THOMAS, B.A. & TENCHOV, Y. (2011): Pennsylvanian vegetation and climate in tropical Variscan Euramerica.– *Episodes*, 34, 3–12.
- CLEAL, C.J., TENCHOV, Y. & ZODROW, E.L. (2004): Review of the late Westphalian early Stephanian macrofloras of the Dobrudzha Coalfield, Bulgaria.– *Geologica Balcanica*, 34, 11–20.
- CLEAL, C.J. & THOMAS, B.A. (1994): *Plant fossils of the British Coal Measures.*– Palaeontological Association, London (Field Guide to Fossils), 222 p.
- CLEAL, C.J. & THOMAS, B.A. (2010a): Botanical nomenclature and plant fossils.– *Taxon*, 59, 261–268.
- CLEAL, C.J. & THOMAS, B.A. (2010b): Proposals to modify the provisions in the Code for naming plant fossils.– *Taxon*, 59, 312–313.
- COTTA, B., GEINITZ, H.B., GUTBIER, A., NAUMANN, C., REICHENBACH, L. & SCHIFFNER, M.A. (1843): *Gaa von Sachsen.* Arnold, Leipzig, 225 p.
- DAVYDOV, V.I., CROWLEY, J.L., SCHMITZ, M.D. & POLETAEV, V.I. (2010): High-precision U-Pb zircon age calibration of the global Carboniferous time scale and Milankovitch band cyclicity in the Donets Basin, eastern Ukraine.– *Geochemistry, Geophysics, Geosystems*, 11/1, doi:10.1029/2009GC002736 (22 p).
- DIMITROVA, T.Kh. & CLEAL, C.J. (2007): Palynological evidence for late Westphalian – early Stephanian vegetation change in the Dobrudzha Coalfield, NE Bulgaria.– *Geological Magazine*, 144, 513–524.
- DIX, E. (1934): The sequence of floras in the Upper Carboniferous, with special reference to South Wales.– *Transactions of the Royal Society of Edinburgh*, 57, 789–838.
- DIX, E. (1937): The succession of fossil plants in the South Wales Coalfield with special reference to the existence of the Stephanian.– *Deuxième Congrès pour l'Avancement des Études de Stratigraphie du Carbonifère*, Heerlen 1935, *Compte Rendus*, 1, 159–184.
- EGEMEN, M.R. (1958): On the significance of some forms of *Neuropteris gigantea* STERNBERG from the Carboniferous of Anatolia (Turkey).– *Journal of the Palaeontological Society of India*, 3, 179–184.
- EGEMEN, M.R. (1959): On the significance of the flora found in the İhsaniye Beds at Kozlu, Zonguldak.– *Révue de la Faculté des Sciences de l'Université d'Istanbul, Série B: Sciences Naturelles*, 24, 1–24.
- EICHWALD, E. (1860): *Lethaea Rossica ou Paléontologie de la Russie*, 1.– Schweizerbart, Stuttgart, 1657 p.
- FISSUNENKO, O.P. & LAVEINE, J.-P. (1984): Comparaison entre la distribution des principales espèces-guides végétales du Carbonifère moyen dans le bassin du Donetz (URSS) et les bassins du Nord-Pas-de-Calais et de Lorraine (France).– *Compte rendu 9e Congrès de Stratigraphie et de Géologie du Carbonifère* (Washington and Urbana, 1979), 1, 95–100.
- FOOTE, M. (2000): Origination and extinction components of taxonomic diversity.– *Paleobiology*, 26, 74–102.
- GÖPPERT, H. (1836): *Systema filicum fossilium.*– E. Weber, Breslau and Bonn, 486 p.
- GRANCY, W.S. (1939): Ueberblick über die bisherigen Aufschlussarbeiten und Ergebnisse im östlichen anatisches Steinkohlenbecken.– *Maden Tetkik ve Arama Enstitüsü Yayınlarından, Seri B: Irdeller*, 4/17, 75–88.
- GÜNEY, M. (1967): Underground mining operations in Zonguldak coal mines.– *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 68, 89–124.
- HARTUNG, W. (1937): Das Karbon des Balkangebietes einschliesslich Heraclea (Kl. -Asien).– *Compte rendu 2e Congrès pour l'Avancement des Études de Stratigraphie Carbonifère* (Heerlen, 1935), 1, 251–261.
- HECKEL, P.H. & CLAYTON, G. (2006): The Carboniferous System. Use of the new official names for the subsystems, series and stages.– *Geologica Acta*, 4, 403–407.

- İNANER, H. & NAKOMAN, E. (2004): Resources, quality and economic importance of solid fossil fuels in Turkey.– *Geologica Belgica*, 7, 245–250.
- JONGMANS, W.J. (1939): Anadolu Kömür Havzasının Şark Kısımlarında Bulunan Karbon Formasyonuna Ait Nebatî Fosiller Hakkında Etüd.– Maden Tetkik ve Arama Enstitüsü Yayınlarından, Seri B: *Irdeller*, 2, 1–40.
- JONGMANS, W.J. (1955): Notes paléobotaniques sur les Bassins houillers de l'Anatolie.– *Mededelingen van de Geologische Stichting, Nieuwe Serie*, 9, 55–89.
- JOSTEN, K.H. (1983): Die fossilen Floren im Namur des Ruhrkarbons.– *Fortschritte in der Geologie von Rheinland und Westfalen*, 31, 1–327.
- JOSTEN, K.H. (1991): Die Steinkohlen-Floren Nordwestdeutschlands.– *Fortschritte in der Geologie von Rheinland und Westfalen*, 36, 1–434.
- KALVODA, J. & BÁBEK, O. (2010): The margins of Laurussia in central and southeast Europe and southwest Asia.– *Gondwana Research*, 17, 526–545.
- KĘDZIOR, A., GRADZIŃSKI, R., DOKTOR, M. & GMUR, D. (2007): Sedimentary history of a Mississippian to Pennsylvanian coal-bearing succession – an example from the Upper Silesia Coal Basin, Poland.– *Geological Magazine*, 144, 487–496.
- KEREY, I.E. (1982): Stratigraphical and sedimentological studies of Upper Carboniferous rocks in northwestern Turkey.– Unpublished PhD thesis, University of Keele, 232 p.
- KEREY, I.E. (1985): Facies and tectonic setting of the Upper Carboniferous rocks of northwestern Turkey.– In: DIXON, J.E. & ROBERTSON, A.H.F. (eds.): *The geological evolution of the eastern Mediterranean*. Geological Society, London, Special Publication, 17, 123–128.
- KEREY, I.E., KELLING, G. & WAGNER, R.H. (1986): An outline stratigraphy and palaeobotanical records from the middle Carboniferous rocks of northwestern Turkey.– *Annales de la Société géologique du Nord*, 105, 203–216.
- KULAKSAZOV, G. & TENCHOV, Y. (1973): Stratigrafiya na dolniya Karbon ot Dobrudzhanskiya buglishchen basein.– *Izvestiya Geologicheskaya Institut, Seriya Stratigrafiya i Lithologiya*, 22, 39–53.
- KULLMANN, J., WAGNER, R.H. & WINKLER PRINS, C.F. (2007): Significance for international correlation of the Perapertü Formation in northern Palencia, Cantabrian Mountains. Tectonic/stratigraphic context and descriptions of Mississippian and upper Bashkirian goniatites.– *Revista Española de Paleontología*, 22, 127–145.
- KVAČEK, J. & STRAKOVÁ, M. (1997): Catalogue of fossil plants described in works of Kaspar M. Sternberg.– National Museum, Prague, 201 p.
- LAVEINE, J.-P. (1977): Report on the Westphalian D.– In: HOLUB, V.M. & WAGNER, R.H. (eds): *Symposium on Carboniferous Stratigraphy*. Geological Survey, Prague, 71–83.
- LAVEINE, J.P. (1987): La flore du bassin houiller du Nord de la France. Biostratigraphie et méthodologie.– *Annales de la Société géologique du Nord*, 106, 87–93.
- LAVEINE, J.P. (1997): Synthetic analysis of the neuropterids. Their interest for the decipherment of Carboniferous palaeogeography.– *Review of Palaeobotany and Palynology*, 95, 155–189.
- LINDLEY, J. & HUTTON, W. (1834): *The fossil flora of Great Britain*. Volume 2 (Part 2).– W. J. Ridgeway & Sons, London, 57–156.
- MCNEILL, J., BARRIE, F.R., BURDET, H.M., DEMOULIN, V., HAWKSWORTH, D.L., MARHOLD, J., NICHOLSON, D.H., PRADO, J., SILVA, P.C., SKOG, J.E., WIERSEMA, J.H. & TURLAND, N.J. (2006): *International Code of Botanical Nomenclature (Vienna Code)*.– A.R.G. Gantner Verlag, Ruggell, Liechtenstein, 568 p.
- MCNEILL, J. & TURLAND, J. (2011): Major changes to the *Code of Nomenclature* – Melbourne, July 2011.– *Taxon*, 60, 1495–1497.
- NAKOMAN, E. (1977): Études palynologiques des veines d'âge Namurien et du Westphalien A des secteurs de Karadon et d'Üzülmöz du bassin houiller de Zonguldak.– *Maden Tetkik ve Arama Enstitüsü Yayınlarından, Seri B: Irdeller*, 87, 67–96.
- NATHORST, A.G. (1914): *Zur fossilen Flora der Polarländer I (4)*.– P.A. Norstedt & Söner, Stockholm, 110 p.
- NIKOLOV, Z. (ed.) (1988): *Geologiya na Dobrudzhanskiya buglishchne basein*.– Tekhnika, Sofia, 170 p.
- OKAY, A.İ., SATIR, M. & SIEBEL, W. (2006): Pre-Alpide Palaeozoic and Mesozoic orogenic events in the eastern Mediterranean region.– In: GEE, D.G. & STEPHENSON, R.A. (eds.): *European lithosphere dynamics*. *Memoirs of the Geological Society*, London, 32, 389–405.
- OKAY, A.İ., ŞENGÖR, A.M.C., GÖRÜR, N. (1994): Kinematic history of the opening of the Black Sea and its effect on the surrounding regions.– *Geology*, 22, 267–270.
- PATTEISKY, K. (1929): *Die Geologie und Fossilführung der mährisch-schlesischen Dachschiefer und Grauwackenformation*.– *Naturwissenschaftliche Verein in Troppau, Opava*, 354 p.
- PATTEISKY, K. (1957): *Die phylogenetische Entwicklung der Arten von Lyginopteris und ihre Bedeutung für die Stratigraphie*.– *Mitteilungen der Westfälischen Berggewerkschaftskasse*, 12, 59–83.
- PHARAOH, T.C. (1999): Palaeozoic terranes and their lithospheric boundaries within the Trans-European Suture Zone (TESZ): a review.– *Tectonophysics*, 314, 17–41.
- PURKYŇOVÁ, E. (1970): *Die Unternamurflora des Beckens von Horní Slejško (CSSR)*.– *Paläontologische Abhandlungen, Abteilung B*, 3, 129–268.
- RALLI, G. (1896): *Le bassin houiller d'Héraclée*.– *Annales de la Société Géologique de Belgique*, 23, 151–267.
- RALLI, G. (1933): *Le bassin houiller d'Héraclée et la flore du Culm et du Houiller moyen*.– *Zellitch Frères, Istanbul*, 166 p.
- SCHLEHAN, M. (1852): *Versuch einer geognostischen Beschreibung der Gegend zwischen Amasy und Tyrla-asy and der Nord-Küste von Klein-Asien*.– *Zeitschrift der Deutschen Geologischen Gesellschaft*, 4, 96–203.
- SCHLOTHEIM, E.F. VON (1820): *Die Petrefactenkunde auf ihrem jetzigen Standpunkte durch die Beschreibung seiner Sammlung versteinerter und fossiler Überreste des Thier- und Pflanzenreichs der Vorwelt erläutert*.– *Gotha*, 437 p.
- SCHMITZ, M.D. & DAVYDOV, V.I. (2012): Quantitative radiometric and biostratigraphic calibration of the Pennsylvanian–Early Permian (Cisuralian) time scale and pan-European chronostratigraphic correlation.– *GSA Bulletin*, doi: 10.1130/B30385.1.
- SPRATT, T. (1877): *Remarks on the coal-bearing deposits near Erekli (the ancient Heraclea Pontica, Bithynia)*.– *Quarterly Journal of the Geological Society*, London, 33, 525–533.
- STAMPFLI, G.M., VON RAUMER, J.F. & BOREL, G.D. (2002): Palaeozoic evolution of pre-Variscan terranes: from Gondwana to the Variscan Collision.– In: MARTÍNEZ CATÁLAN, J.R., HATCHER, R.D., ARENAS, R. & DÍAZ GARCÍA, F. (eds): *Variscan – Appalachian dynamics: the building of the Late Palaeozoic basement*. Geological Society of America, Special Papers, 364, 263–280.
- STERNBERG, K.M. VON (1825): *Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt*, 1(4), Tentamen.– E. Brenck's Wittve, Regensburg, 48 + XLII p.
- STOCKMANS, F. (1962): *Paléobotanique et stratigraphie*.– *Compte rendu 4e Congrès pour l'Avancement des Études de Stratigraphie et de Géologie du Carbonifère (Heerlen, 1958)*, 3, 657–682.
- TENCHOV, Y.G. (1989): Possible position of the Variscan chains between the Balkan and Caucasus.– *Geologica Balcanica*, 19/3, 3–7.

- TENCHOV, Y.G. (2004): Rakovski Formation (Carboniferous, NE Bulgaria) – stratigraphy, sedimentary conditions and interpretation.– *Geologica Balcanica*, 34, 85–96.
- TENCHOV, Y.G. (2005): Early Westphalian sediments of Dobrudzha Coalfield (NE Bulgaria) – an interpretation of their stratigraphy and sedimentation conditions.– *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, 156, 467–480.
- TENCHOV, Y.G. (2007): Late Westphalian and early Stephanian sediments of the Dobrudzha Coalfield, NE Bulgaria.– *Geological Magazine*, 144, 497–511.
- THOMAS, B.A. (1970): Epidermal studies in the interpretation of *Lepidodendron* species.– *Palaeontology*, 13, 145–173.
- TOKAY, M. (1962): The geology of the Amasra region with special reference to some Carboniferous gravitational gliding phenomena.– *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 58, 1–20.
- VAN AMEROM, H.W.J. (1975): Die eusphenopteridischen Pteridophyten aus der Sammlung des Geologischen Bureaus in Heerlen, unter besonderer Berücksichtigung ihrer Stratigraphie bezüglich des südlimburger Kohlenreviers.– *Mededelingen Rijks Geologische Dienst, Serie C-III-1*, 7, 1–202.
- WAGNER, R.H. (1984): Megafloral zones of the Carboniferous.– *Compte rendu 9e Congrès International de Stratigraphie et de Géologie du Carbonifère* (Washington, 1979), 2, 109–134.
- WAGNER, R.H. (1994): Climatic significance of the major chronostratigraphic units of the Upper Palaeozoic.– *Compte rendu 12e Congrès International de Stratigraphie et de Géologie du Carbonifère*, 1, 83–108.
- WAGNER, R.H. (1997): Wilhelmus Josephus Jongmans (1878–1957): the personality and his achievements.– *Mededelingen Nederlands Instituut voor Toegepaste Geowetenschappen. TNO*, 58, 17–30.
- WAGNER, R.H. (1998): Consideraciones sobre los pisos de la Serie Estefaniense.– *Monografías de la Academia de Ciencias Exactas Físicas Químicas y Naturales de Zaragoza*, 13, 9–19.
- WAGNER, R.H. & ALVAREZ-VÁZQUEZ, C. (1991): Floral characterisation and biozones of the Westphalian D Stage in NW Spain.– *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, 183, 171–202.
- WAGNER, R.H. & AMEROM, H.W.J. VAN (1995): Wilhelmus Josephus Jongmans (1878–1957): paleobotanist, Carboniferous stratigrapher, and floral biogeographer.– *Memoirs of the Geological Society of America*, 185, 75–90.
- WAGNER, R.H., FERNANDEZ-GARCIA, L. & EAGAR, R.M.C. (1983): Geology and palaeontology of the Guardo Coalfield (NE León – NW Palencia), Cantabrian Mts.– *Instituto Geológico y Minero de España, Madrid*, 109 p.
- WALTON, J. (1941): On *Cardiopteridium*, a genus of fossil plants of Lower Carboniferous age, with special reference to Scottish specimens.– *Proceedings of the Royal Society of Edinburgh, Section B*, 61, 59–66.
- WALTON, J., WEIR, J. & LEITCH, D. (1938): A summary of Scottish Carboniferous stratigraphy and palaeontology.– *Compte rendu 2e Congrès International de Stratigraphie et de Géologie du Carbonifère* (Heerlen, 1935), 3, 1343–1356.
- WATERS, C.N. (2001): Definitions of chronostratigraphic subdivisions: geochronology and event stratigraphy.– In: WATERS, C.N., SOMERVILLE, I.D., JONES, N.S., CLEAL, C.J., COLLINSON, J.D., WATERS, R.A., BESLY, B.M., DEAN, M.T., STEPHENSON, M.H., DAVIES, J.R., FRESHNEY, E.C., JACKSON, D.I., MITCHELL, W.I., POWELL, J.H., BARCALAY, W.J., BROWNE, M.A.E., LEVERIDGE, B.E., LONG, S.L. & McLEAN, D. A revised correlation of Carboniferous rocks in the British Isles. Geological Society Special Report, 26, 3–10.
- WATERS, C.N. & CONDON, D.J. (2012): Nature and timing of Late Mississippian to Mid-Pennsylvanian glacio-eustatic sea-level changes of the Pennines Basin, UK.– *Journal of the Geological Society, London*, 169, 37–51.
- WING, S.L. & DIMICHELE, W.A. (1995): Conflict between local and global changes in plant diversity through geological time.– *Palaios*, 10, 551–564.
- YANEV, S., GÖNCÜOĞLU, M.C., GEDIK, I., LAKOVA, I., BONCHEVA, I., SACHANSKI, V., OKUYUCU, C., ÖZGÜL, N., TIMUR, E., MALIAKOV, Y. & SAYDAM, G. (2006): Stratigraphy, correlations and palaeogeography of Palaeozoic terranes of Bulgaria and NW Turkey; a review of recent data.– In: ROBERTSON, A.H.F. & MOUNTRAKIS, D. (eds): Tectonic development of the eastern Mediterranean region. Geological Society, London, Special Publication, 260, 51–67.
- ZDANOWSKI, A. & ŻAKOWA, H. (1995): The Carboniferous System in Poland.– *Prace Państwowego Instytutu Geologicznego*, 148, 1–215.
- ZEILLER, R. (1896): Sur la flore des dépôts houillers d'Asie Mineure et sur la présence, dans cette flore, du genre *Phyllothea*.– *Comptes Rendus de l'Académie des Sciences, Paris*, 120, 1228–1231.
- ZEILLER, R. (1899): Étude sur la flore fossile du bassin houiller d'Héraclée (Asie Mineure). *Mémoires de la Société Géologique de France, Paléontologie*, 21, 1–91.
- ZIMMERMANN, W. (1932): Über *Cardiopteridium* u. *C. waldenburgerense* n.sp. aus den Waldenburger Schichten.– *Arbeiten aus dem Institut für Paläobotanik und Petrographie der Brennsteine*, 2, 219–232.
- ZODROW, E.L. (1986): Succession of paleobotanical events: evidence for mid-Westphalian D floral changes, Morien Group (Late Pennsylvanian, Nova Scotia).– *Review of Palaeobotany and Palynology*, 47, 293–326.
- ZODROW, E.L. & CLEAL, C.J. (1985): Phyto- and chronostratigraphical correlations between the late Pennsylvanian Morien Group (Sydney, Nova Scotia) and the Silesian Pennant Measures (south Wales).– *Canadian Journal of Earth Sciences*, 22, 1465–1473.

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