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Co-occurrence of *Sinuspores sinuatus* (Artüz) Ravn, 1986 with established palynological markers indicating younger strata: AK-1X well section (Pennsylvanian, Zonguldak Basin, NW Turkey) and the correlation to the stratigraphic system

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ABSTRACT

Part of the AK-1X well section from the Amasra area of the Zonguldak Basin in NW Turkey (Asia Minor) has been palynologically revised. Over the depth range –342.05 to –344.90 m atypical co-occurrences of the key stratigraphic spore species *Sinuspores sinuatus* together with *Vestispora fenestrata*, *V. laevigata*, *Torispora securis* and *Thymospora* spp. are recorded. By correlation to the 'selected spore ranges and spore zonation of the Carboniferous system in Western Europe', often used as a standard, these palynological assemblages would be correlated to the upper Bolsovian by the presence of *Thymospora* spp. with some reworked older material, represented by *S. sinuatus*. Alternative spore ranges are considered in this study, and miospore ranges of selected species from Western Europe and North America are discussed. The correlation of the palynological record from the re-investigated AK-1X well section to the chronostratigraphy corresponds with ages around the Duckmantian–Bolsovian boundary, and correlation to the uppermost Duckmantian is discussed as a possibility. However, recent studies lead to the conclusion that a lower Bolsovian age determination for the AK-1X well section is also most probable. Accordingly, *Sinuspores sinuatus* has a slightly expanded range top in NW Turkey and some taxa such as *Thymospora* spp. occur slightly earlier here than in Western Europe.

Keywords: palynology, Turkey, Bashkirian, Moscovian, Duckmantian, Bolsovian, Westphalian B, Westphalian C, Atokan, *Sinuspores*

1. INTRODUCTION

In the frame of IGCP575 (International Geological Correlation Programme 575) a short well section of the AK-1X well (well name changed due to economic interests), located in the Amasra area of the Zonguldak Basin of NW Turkey (Fig. 1 A, B), has been revised. An atypical co-occurrence of palynological species such as *Sinuspores sinuatus*, *Vestispora fenestrata*, *V. laevigata*, *Torispora securis*, and few *Thymospora* spp. has been observed in the palynological assemblages from NW Turkey. All these species are well-known and most form part of the 'selected spore ranges and spore zonation of the Carboniferous system in Western Europe' (CLAYTON et al., 1977), which became, in modified form, part of the 'Carboniferous Time Scale' (e.g. GRADSTEIN et al., 2004). The application of this palynostratigraphic

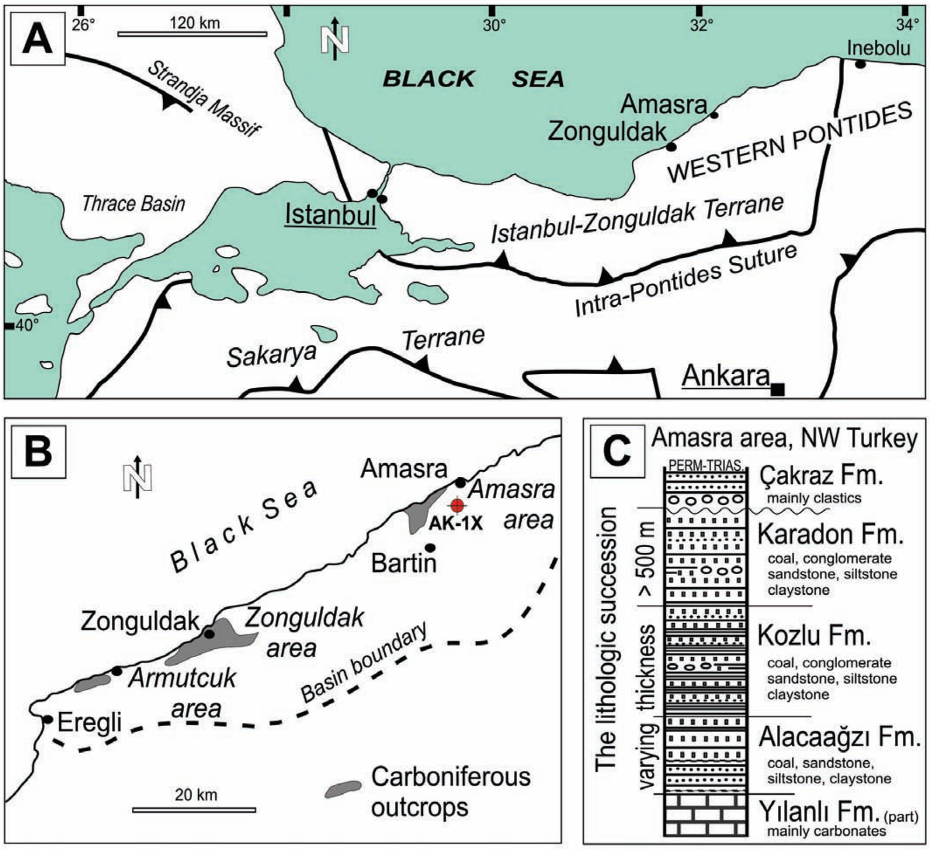


Figure 1: Geographical and geological overview. Map A) shows the wider frame of the study area and the structural affiliation. Modified and simplified from OKAY & TÜYSÜZ (1999), OKAY & GÖNCÜOGLU (2004), OKAY (2008), and STOLLE (2011). Map B) focuses on the Zonguldak Basin and its coal mining districts. The approximate location of the AK-1X well is revealed. The map is simplified from YALCIN et al. (2002). Part of the Pennsylvanian succession of the Amasra area is simplified and depicted in C) for overview (Alacaagzi, Kozlu, and Karadon formations). Illustrated column according to the stratigraphy in TÜYSÜZ et al. (2004) (including the Kozlu Fm.), and modified from AKBAS et al. (2002) (where, as an example for outcrop stratigraphy, the Karadon Fm.– Cakraz Fm. contact is shown). A thickness of more than 500 m for the Karadon Fm. was recorded by CANCA et al. (1994) from well data (Amasra-1 well).

zonation to the palynological record of the AK-1X well section, would indicate the upper Bolsovian (the upper Westphalian C) for the investigated deposits from NW Turkey. The enigmatic presence of *Sinuspores sinuatus* would, in that case, have to be interpreted as being recycled from older rock material. In Western Europe and North America this spore is only known from deposits of the Namurian, Westphalian A, and Westphalian B (stages according to the references of the original literature, e.g. in SMITH & BUTTERWORTH, 1967, as *Punctatisporites sinuatus*; in KOSANKE, 1988, as *P. sinuatus*; in PEPPERS et al., 1993 as *S. sinuatus*).

However, because the specimens of *Sinuspores sinuatus*, identified in the AK-1X well section, as well as the surrounding palynofacies, showed no indication of reworking or recycling, attempts have been made in this study to look for alternative spore ranges and further evidence, of whether contemporaneous primary deposition of all these spores would have been possible. The first and last occurrences of miospore ranges presented in RAVN (1986), HOWES (1988), and PEPPERS & BRADY (2007) were particularly useful, in combination with the stratigraphic framework of GRADSTEIN et al. (2004) and OGG et al. (2008), in concluding an age around the Duckmantian–Bolsovian transition (Westphalian B–Westphalian C transition) for the palynological assemblages from NW Turkey.

2. THE STUDY AREA: GEOLOGICAL BACKGROUND

The Zonguldak Basin is situated in the north–west of Turkey (Asia Minor) on the Black Sea coast of the western Pontides. The region belongs structurally to the Istanbul-Zonguldak Terrane (also known as the Istanbul Zone, e.g. OKAY, 2008, Fig. 1 A), which was, during Carboniferous times, located within the tropics and more or less on the equator (e.g. STAMPFLI, 2000). During the Pennsylvanian epochs, deposition of mainly clastics and coals took place. At present, the Zonguldak coalfield is a productive mining area (YALCIN et al., 2002, see also for further aspects on general geology, stratigraphy and geological setting of the basin). The main mining districts are the Armutcuk, Zonguldak and Amasra areas (Fig. 1 B). The coal-bearing sequence is subdivided into the Alacaagzi, Kozlu and Karadon formations, and is mainly composed of conglomerates, sandstones and claystones, though each unit has more or less characteristic lithologies in its area. The investigated interval of this study is assigned to the Karadon Formation of the Amasra district. There, the Karadon Formation (named after the village Karadon, e.g. RALLI, 1933) lies conformably on the Kozlu Formation (CANCA et al., 1994; TÜYSÜZ et al., 2004) (Fig. 1 C), and it is disconformably overlain by the Permian-Triassic Cakraz Formation (AKBAS et al., 2002), or by younger sediments (e.g. Cretaceous in the subsurface, CANCA et al., 1994). According to well data, the formation can have a thickness of c. 500 m in the Amasra area (CANCA et al., 1994; TÜYSÜZ et al., 2004). The Zonguldak Basin underwent strong tectonic deformation (folding and faulting, e.g. YALCIN et al., 2002, fig. 1). TOKAY (1962) considered deposits from the Amasra area to be an allochthonous group, consisting of displaced and mixed slides of Westphalian C, B, A and Namurian age deposits. The age determination of the Karadon Formation was controversial in the past, and the unit was defined as Westphalian B, C and D (by DIL & KONYALI, 1978), as Westphalian A, B and C (by YERGÖK et al., 1987)[1], whereas KEREY (1984) considered an age of Westphalian B and C. KARAYIGIT & ORHAN (1997) assigned ages of Westphalian B, C, and D. Westphalian B and C were considered in a recent study by TÜYSÜZ et al., (2004). Palynology and palaeobotany (macro plant fossils) were the main methods for the dating of clastic sections in the area. The Pennsylvanian from NW Turkey has traditionally been assigned to the European regional stages, for example to those that originated in the Westphalian mining area of 'Ruhrgebiet', Germany.

3. MATERIAL AND METHODS

This study is based on a revision of palynological data from the Amasra area, NW Turkey. Dark claystones, rich in organic matter, and coals from a drill core of the AK-1X well served as the raw material for palynological processing according to standard preparation methods.

The approximate location of the AK-1X well in the Amasra area is shown in Figure 1 B. The wider core section was assigned to the Karadon Formation (Fig. 1 C). The lithology of the core segment, relevant for this study, is depicted in Figure 2 as well as the productive sampling positions.

The palynostratigraphic concept of this study was using events specific to a single taxon (e.g. its first and last occurrence), preferably of palynological markers and in comparison with different regions. Previously, McLEAN et al. (2004), remarked (for a sequence along the Langsettian-Duckmantian boundary in Britain): "Recognition of the biozonal boundaries of CLAYTON et al. (1977) is also problematic, because the stratigraphic criteria that are used to define the base of the NJ Biozone (range top of *S. rara*, range top of *Sinuspores sinuatus*, range base of *Microreticulatisporites nobilis*) do not occur at the same horizon.", and proposed: "The difficulties in these interpretations relate to using several criteria to define assemblages or assemblage biozones. A more suitable approach may be to define biostratigraphic units using events specific to a single taxon."

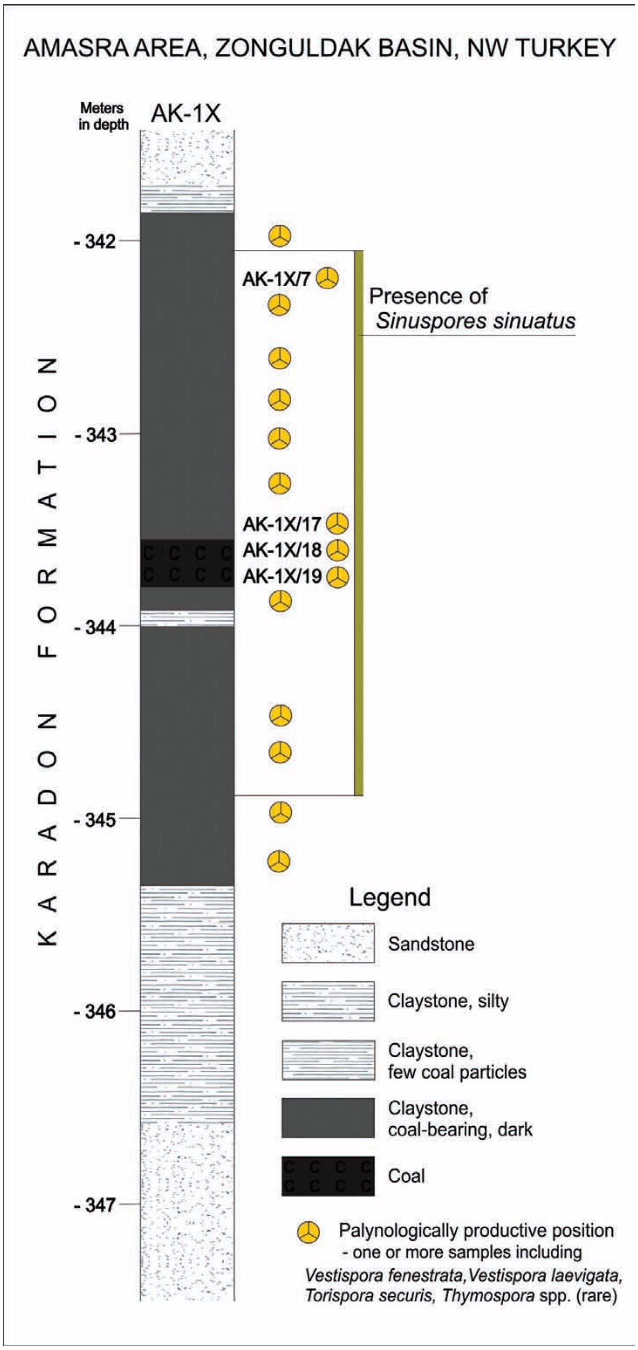


Figure 2: The palynologically re-investigated AK-1X well section (this study) of the Amasra area is shown with simplified lithologies. Occurrences of the relevant species *S. sinuatus* are indicated (marked by the vertical thick line), together with palynologically productive sample positions.

[1] YERGÖK, F.A., AKMAN, Ü., TEKIN, F., KARABALIK, N.N., ARBAS, A., AKAT, U., ARMAGAN, F., ERDOGAN, K. & KARAKULLUKCU, H. (1987): Bati Karadeniz Bölgesinin Jeolojisi I.– Unpubl. report, MTA Report No. 2818, Ankara.

During the palynological investigations of this study, the features of the entire palynological assemblage were also taken into consideration (e.g. composition/ main components, co-occuring taxa, content and condition of organic matter), and are involved in the interpretation of the palynological data.

4. CO-OCCURRENCE OF PALYNOLOGICAL SPECIES IN THE WELL SECTION

Figure 2 shows the palynologically re-investigated AK-1X well section and the positions from where specimens of the distinct large brown, trilete spore species *Sinuspores sinuatus* have been identified, (specimens illustrated in Pl. 1, Figs. 1–6). Over the depth range –342.05 – –344.90 m *S. sinuatus* co-occurs with *Vestispora fenestrata*, *Vestispora laevigata*, *Torispora securis*, and *Thymospora* spp. (Pl. 1). From the stratigraphic perspective this co-occurrence seemed to be unusual. All these species are well-known and most form part of the 'selected spore ranges and spore zonation of the Carboniferous system in Western Europe' (CLAYTON et al., 1977). The zonation has in the meantime been established, with slight modifications by partial updates, as the microfloral zonation component of the Carboniferous Time Scale (GRADSTEIN et al., 2004). In CLAYTON et al. (1977), the lower limit of the NJ Zone is marked by, amongst others, the youngest range of *S. sinuatus* (as *Punctatisporites sinuatus*). The lower limit of the NJ Zone related to the early Westphalian B in 1977, is now equivalent with the lower Duckmantian and upper Bashkirian. According to CLAYTON et al. (1977), the base of the succeeding SL Zone (considered to be lowermost Westphalian C by the authors), coincides with the appearance of the first monolete spores *Torispora securis* and *Vestispora fenestrata*. The lower limit of the succeeding OT Zone (equating to the boundary between Westphalian C and D according to the authors), coincides with the appearance of monolete verrucose spores of the genus *Thymospora*. Applying the 'zonation of the Carboniferous system in Western Europe' to the palynological record from the AK-well section from NW Turkey, would result in an age determination in the range from latest Bolsovian (Westphalian C) to Asturian (Westphalian D), or younger, based on the presence of *Thymospora* spp. Occurrences of *Sinuspores sinuatus* would have to be interpreted as being reworked from older strata.

S. sinuatus was first described by ARTÜZ from the Sulu and Büyük seams of the Zonguldak area of NW Turkey, later recorded by IBRAHIM-OKAY & ARTÜZ (1964) from the Domuzcu seam. The early finds were considered to be from Westphalian A sediments, as well as records for example in AKYOL (1974) (Westphalian A, Namurian) and NAKOMAN (1976, e.g. as *Sinuspores sinuatus* and *Canisporites corpulentus*) from the same area. AKGÜN & AKYOL (1992) reported it from the Amasra area (as *Sinuspores coronatus*) as well as AGRALI & KONYALI (1967, as *Sinuspores sinuatus* and *S. coronatus*). Outside of NW Turkey, the spore was recorded from Europe and North America, for example from the Russian Platform (EINOR, 1996), Scotland (BUTTERWORTH & WILLIAMS, 1958) and the North American midcontinent (RAVN & FITZGERALD, 1982) under *S. sinuatus* or under a synonym. According to the common literature the age range was considered to be (late) Visean (e.g. ETTENSOHN & PEPPERS, 1979; EINOR, 1996) to late Westphalian B (KOSANKE, 1988, West Virginia).

Whether a) *Sinuspores sinuatus* identified in the short AK-1X section is the same as the type species of ARTÜZ (1957), and whether b) the assignment of the AK-1X section to the Duckmantian (Westphalian B), based on the record of KOSANKE (1988), would be explicable and reliable is the subject of the following discussion.

5. BRIEF TAXONOMIC OUTLINE – *S. SINUATUS* FROM THE TYPE AREA

Sinuspores sinuatus (Artüz) Ravn 1986 was first described by ARTÜZ (1957) from the type locality in the Zonguldak district of the Zonguldak Basin, as having a size of 90–130 µm, a trilete mark of ¾ of the radius, slightly opened and straight. On the surface of the spore are sine curve-like infrastructures present, which appear on the dark background as a light construction. At the margin of the spore body, a deep dark brown equatorial zone exists, which is 15–17 µm broad and structureless. In his emendation of the species, RAVN (1986) attributed a wider size range of 75–130 µm, and an exine thickness of 5 µm and more. SMITH & BUTTERWORTH (1967) described their specimens (under *Punctatisporites sinuatus*) as having an exine up to 5 µm in thickness (laevigate and with fine infrasculpture), usually highly folded, with folds broad and situated around the periphery of the spore, but sometimes also following the laesurae, giving the appearance of broad lips. The thickness of the exine (thickenings at sine curve-like structures and/or exine accumulation by fold) is responsible for the dark brown areas on the spore body. The specimens found in the short AK-1X well section (e.g. Pl. 1, Figs. 4–6) are clearly assignable to the species *S. sinuatus*, based on their morphological features, such as distinct sine curve-like structures, the deep dark brown belt zone at the margin of the spore body, and sizes given in the original description.

6. CORRELATION OF MIOSPORE RANGES AND DATING

The palynological record of the AK-1X well section (see APPENDIX I for more details) has been compared to palynological events beyond Western Europe. RAVN (1986) showed miospore ranges from Iowa, and also presented a comparison chart of the Iowa records compared with other regions (North America, Western Europe; Fig. 3 A). The given picture of first and last occurrences appears to be more individual in contrast to an overall zonation. However, it should be noted that dating was an individual process based on personal interpretation by each author. RAVN (1986) correlated the first occurrences of *Vestispora fenestrata*, *Torispora securis*, and particularly those of *Vestispora laevigata* and *Thymospora* spp. from the upper Kilbourn and lower

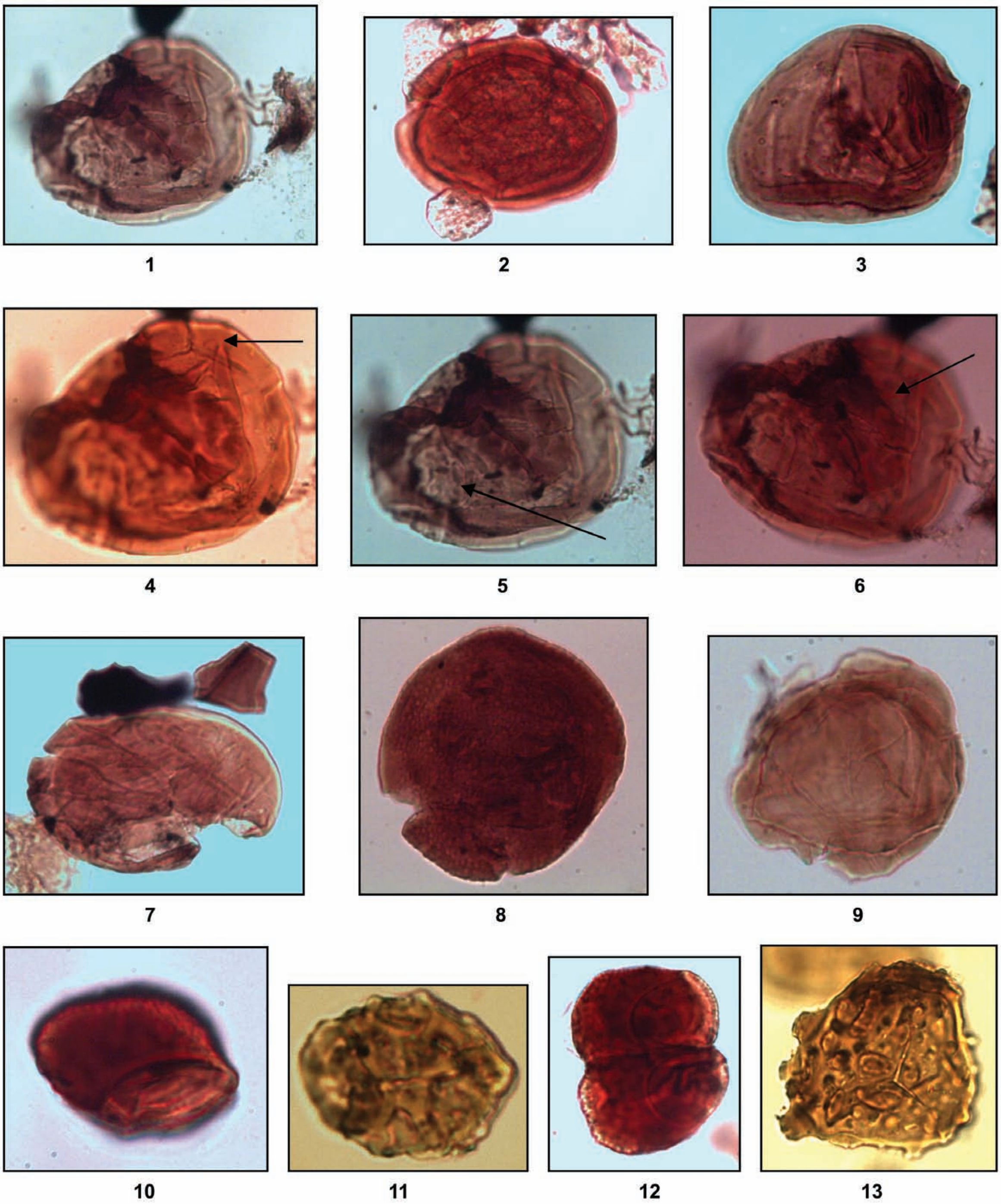


PLATE 1

Miospores of the AK-1X well from the Pennsylvanian of NW Turkey, relevant for this study. Each with dimensions in micrometres, slide number, and England Finder coordinates.

1 *Sinuspores sinuatus*, 101 µm, AK-1X/7.1.2, Q28.4.
2 *Sinuspores sinuatus*, 91 µm, AK-1X/17.1, O47, a relatively unfolded specimen.
3 *Sinuspores sinuatus*, 106 µm, AK-1X/7.1, U28.4.
4 *Sinuspores sinuatus*, same specimen as in 1), with focus on the trilete mark.
5 *Sinuspores sinuatus*, same specimen as in 1), with focus on an area with more or less well developed sine curve-like structures.
6 *Sinuspores sinuatus*, same specimen as in 1), with focus on an area, which appears relatively laevigate.
7 *Vestispora costata*, 106 µm, AK-1X/7.1.2, S48.3.
8 *Vestispora fenestrata*, 107 µm, AK-1X/7.1.1, L48.4.
9 *Vestispora laevigata*, 80 µm, AK-1X/7.3, D42.
10 *Torispora securis*, 24 µm, AK-1X/7.1.2, P29.3.
11 *Thymospora* sp., 31 µm, AK-1X/7.3, C31.
12 *Torispora securis*, 29 µm (one specimen), AK-1X/7.1.2, S48.3.
13 *Raistrickia fulva*, 58 µm (including ornament), AK-1X/19.1, C32.4.

Kalo formations to the upper Westphalian B (Fig. 3 B, also in HOWES, 1988). RAVN's (1986) dating approximately corresponds with a foraminiferal dating by LAMBERT (1988a) from the Iowa coal succession, namely from shale below the thick limestone overlying the Laddsdale coal (Fig. 3 B). LAMBERT (1988a) related the investigated strata to the *Beedeina* Zone (most of the specimens were 'primitive' forms of the genus *Beedeina*). Notably, some remaining species represented one of the youngest occurrences of the genus *Fusulinella* ('youngest' in an evolutionary sense). According to GRADSTEIN et al. (2004) the first *Fusulinella* are correlated approximately with the mid Bolsovian (mid Westphalian C, late Atokan) (Fig. 3 C). According to OGG et al. (2008), the first *Fusulinella* are correlated with the late Bolsovian (mid Westphalian C, late Atokan) (Fig. 3 D). The presence of the conodont species *Neognathodus medadultimus* in overlying strata from the lower part of the Floris Formation (LAMBERT, 1988b; HOWES & LAMBERT, 1988, e.g. p. 32) support these correlations. The appearance of *N. medadultimus* is according to GRADSTEIN et al. (2004, table 15.2, selected isotopic radiometric age dates) correlated with the upper Kashirian of the Moscow Basin (mid Moscovian, approximate Bolsovian–Asturian transition according to OGG et al., 2008).

Discussion of the biostratigraphic data from the underlying Kalo Formation (Fig. 3 B) requires a more comprehensive explanation. However, LAMBERT (1988b) stated that the conodont genera *Idiognathoides* and *Declinognathodus* do not range above the Blackoak Coal, and the species *Neognathodus bothrops* was explicitly identified from a limestone lens which overlies the Blackoak Coal (HOWES & LAMBERT, 1988) (Fig. 3 B). It should be noted that the *Neognathodus medexultimus–Neognathodus bothrops* Zone, (standard conodont zones of GTS2004 diagrams from Russian chart, GRADSTEIN et al., 2004), is correlated to the early Moscovian (around 311 Ma, Fig. 3 C), and includes according to OGG et al. (2008) the early Bolsovian (early Westphalian C, mid Atokan). BARRICK et al. (2004) stated that *Neognathodus uralicus* is a distinctive morphotype that is common in the southern Midcontinent, but has been referred incorrectly for instance to *Neognathodus medexultimus*. *N. uralicus* occurs in the *Neognathodus atokaensis* Zone, (conodont zones midcontinent North America), which was correlated by BARRICK et al. (2004, fig.1) to the mid Atokan (compare Figs. 3 C, D).

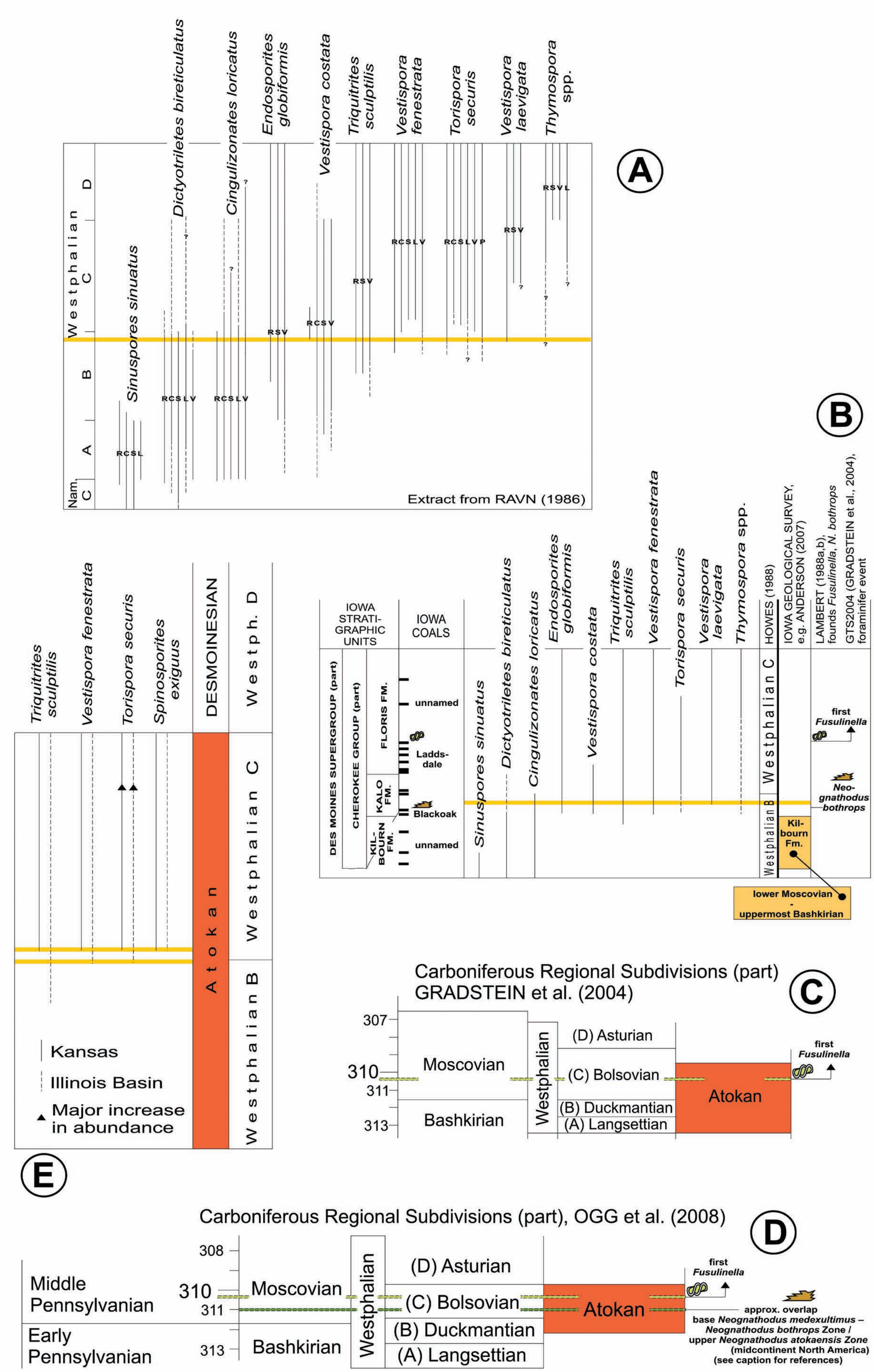
The underlying Kilbourn Formation of the lower Cherokee Group (Fig. 3 B) represents initial Middle Pennsylvanian deposition (e.g. ANDERSON, 2007, fig. 5, Pennsylvanian and Mississipian Stratigraphic Column of Iowa, Iowa Geological Survey). Accordingly, the base of the formation is assigned to the lowest Middle Pennsylvanian, but may range to the uppermost Lower Pennsylvanian. The lowest base of the formation corresponds, according to OGG et al. (2008), with the uppermost Bashkirian (Fig. 3 B), or with the early Atokan and a mid/ late Duckmantian, latest Early Pennsylvanian, respectively (Fig. 3 D).

A recent paper of PEPPERS & BRADY (2007) correlates the first occurrences of *Vestispora fenestrata* and *Torispora securis* to approximately the mid Atokan (lowermost Westphalian C) (Fig. 3 E). Their records from the Illinois basin range stratigraphically down to the uppermost Westphalian B (uppermost Duckmantian). Their records from Kansas range down to the lowermost Westphalian C (lowermost Bolsovian). PEPPERS & BRADY's (2007) correlation of the regional stages (approximately mid Atokan – Westphalian B–Westphalian C boundary) is in accordance with GRADSTEIN et al. (2004) (Fig. 3 C). It corresponds with GRADSTEIN's et al. (2004) Duckmantian–Bolsovian transition (Westphalian C–Westphalian B and Bashkirian–Moscovian transition, respectively).

Following KOSANKE (1988) with his range top of *S. sinuatus* in the uppermost Westphalian B (uppermost Duckmantian), and considering the miospore ranges of RAVN (1986), HOWES (1988), and PEPPERS & BRADY (2007), a 'co-deposition' or co-occurrence of *S. sinuatus* with the other palynological markers mentioned above, is clearly possible, based on contemporaneous occurrences of the parent plants. Adapting PEPPERS & BRADY's (2007) correlation of the regional stages (Fig. 3 E) to the Carboniferous Regional Subdivisions of OGG et al. (2008), (Fig. 3 D), PEPPERS & BRADY's approximate mid Atokan (first occurrence *T. securis*, first occurrence *V. fenestrata*) correlates to the earliest Bolsovian (early Moscovian).

In comparison with the data shown above, the investigated AK-1X well section of this study clearly correlates ap-

Figure 3: Charts of miospore ranges and Carboniferous subdivisions. In A): Comparison chart of selected miospore ranges observed in Iowa (RAVN, 1986 = R) to those reported from other areas (CLAYTON et al., 1977, western Europe = C; SMITH & BUTTERWORTH, 1967, Britain = S; LOBOZIAK, 1974, western Europe = L; VAN WIJHE & BLESS, 1974, western Europe = V; PEPPERS, 1970, 1979, Illinois Basin = P). Modified from RAVN (1986). Only species which also have been identified in AK-1X well section (this study) were chosen for illustration. The horizontal band, marks in comparison, the oldest age suggestion for the AK-1X well section (by the occurrence of *V. laevigata*). In B): Extract from HOWES (1988), and expanded. HOWES referred to miospore ranges of RAVN (1986) and his depiction of stratigraphic units in Iowa as well as on coal occurrences of the region. Foraminifer and conodont records of LAMBERT (1988a, b) are for this study included in chart B) as well as dating of the Kilbourn Fm., compiled and illustrated by ANDERSON (2007). The oldest age suggestion for the AK-1X well section (in comparison, by the occurrence of *V. laevigata*) is marked again as a horizontal band. In C): Some Pennsylvanian stages in relation to the regional subdivisions of the Carboniferous time scale of GRADSTEIN et al. (2004). The extension of the North America regional stage 'Atokan' for comparison with charts D) and E) is marked. The relevant foraminiferal event (from GRADSTEIN et al., 2004) has been included to chart C) for overview and comparison with charts A) and B) as it represents 'age control' for the palynological events. Chart D) displays the latest published relationships of some Pennsylvanian stages to the regional subdivisions of the Carboniferous time scale (OGG et al., 2008). The positions of relevant foraminifer and conodont results are included for overview ('age control' for the Iowa stratigraphic units in chart B) (conodont zones according to GTS2004, GRADSTEIN et al., 2004; BARRICK et al., 2004; OGG et al., 2008). In E): Extract of chart of selected miospore ranges observed in the Kansas and Illinois basins in relation to the regional stages (from PEPPERS & BRADY, 2007). The European regional stages probably have been adapted to the 'Atokan' according to correlations of GRADSTEIN et al. (2004) (compare to C).


A
Extract from RAVN (1986)
Nam. C
W e s t p h a l i a n
A
B
C
D
Sinuspores sinuatus
Dictyotriletes bireticulatus
Cingulizonates loricatus
Endosporites globiformis
Vestispora costata
Triquitrites sculptilis
Vestispora fenestrata
Torispora securis
Vestispora laevigata
Thymospora spp.
B
IOWA STRATI-GRAPHIC UNITS
IOWA COALS
DES MOINES SUPERGROUP (part)
CHEROKEE GROUP (part)
KIL-BOURN FM.
KALO FM.
FLORIS FM.
unnamed
Laddsdale
Blackoak
HOWES (1988)
IOWA GEOLOGICAL SURVEY, e.g. ANDERSON (2007)
LAMBERT (1988a,b), founds Fusulinella, N. bothrops
GTS2004 (GRADSTEIN et al., 2004), foraminifer event
Westphalian B
Westphalian C
Kil-bourn Fm.
first Fusulinella
Neo-gnathodus bothrops
lower Moscovian - uppermost Bashkirian
C
Carboniferous Regional Subdivisions (part) GRADSTEIN et al. (2004)
307
310
311
313
Moscovian
Bashkirian
Westphalian
(D) Asturian
(C) Bolsovian
(B) Duckmantian
(A) Langsettian
Atokan
first Fusulinella
D
Carboniferous Regional Subdivisions (part), OGG et al. (2008)
Middle Pennsylvanian
Early Pennsylvanian
308
310
311
313
Moscovian
Bashkirian
Westphalian
(D) Asturian
(C) Bolsovian
(B) Duckmantian
(A) Langsettian
Atokan
first Fusulinella
approx. overlap base Neognathodus medexultimus – Neognathodus bothrops Zone / upper Neognathodus atokaensis Zone (midcontinent North America) (see caption for references)
E
Triquitrites sculptilis
Vestispora fenestrata
Torispora securis
Spinosporites exiguus
DESMOINESIAN
Atokan
Westph. D
Westphalian C
Westphalian B
Kansas
Illinois Basin
Major increase in abundance

proximately to the Duckmantian–Bolsovian transition (Westphalian B–Westphalian C transition). This is corroborated by a comprehensive palynological data record from the Amasra area of the Zonguldak Basin. The range charts from AGRALI & KONYALI (1969) include a) the vertical extensions of 108 form genera (tab. 1), and b) the vertical extension of the species from 52 genera (tab. 2, I. Sporites, and tab. 3, II. Pollenites); their source material were cores from 18 wells and samples from mining galleries. Some taxa were reliably identified from their plates and descriptions. The palynological events of selected taxa, relevant for this study, were extracted from their charts and are compiled in Table. 1 from older to younger.

The short interval of the AK-1X well can be placed between positions (3) and (4). Species from (1) and (3) are already part of the palynological assemblages. *Sinuspores sinuatus* still occurs at this position, up to (4). *Spinosporites* species under (2) could not clearly be identified from the AK-1X well section. AGRALI & KONYALI (1969) observed that the presence of certain miospore types has very limited horizontal extension (regarding their entire study area). Considering the possibility of reworking or recycling of older rock material during the process of deposition, it should be noted that no other species besides *S. sinuatus* occur in the AK-1X well section that would indicate older ages (e.g. Langsettian or early Duckmantian, such as *Schulzospora* spp., *Bellispores* spp., in PEPPERS, 1996; OWENS et al., 2004). The environment of sedimentation in the positions of the coal band (Fig. 2), where *S. sinuatus* is present, can be described as relatively autochthonous. An extremely well-preserved microflora within those palynological assemblages displays the facies of a typical coal swamp. Sample AK-1X/18 includes as the main components *Torispora* 50%, *Laevigatosporites* 22%, *Densosporites* 14 %, *Florinites* 12 %, and *Punctatosporites*; AK-1X/19 includes *Laevigatosporites* 93%, *Florinites* 3 %, and *Cirratriradites*. Bisaccate pollen (signals from the hinterland) are non existent. The composition of the miospores (mainly from ferns and lycophytes) displays the influence of peat substrate and clastic substrate ever-wet vegetations of DIMITROVA et al. (2011), and the subordinate influence of a marginal vegetation. DIMITROVA et al. (2011) proved that the *Florinites*-producing cordaitanthaceans appear not to have been upland trees (as previously suggested), but occupied mainly coastal habitats, or riparian habitats on the margins of the wetland.

In other respect, no further species,which would indicate younger ages (e.g. a latest Bolsovian, Asturian), time-equivalent with occurrences of *Thymospora* spp. as for example shown in the range chart from Western Europe in CLAYTON et al. 1977 (e.g. *Spinosporites spinosus*, *Angulisporites splendidus* or *Savitrisporites camptotus*), occur in the AK-1X well section. These latter species are common in younger strata from NW Turkey (STOLLE & BUZKAN, 2011; STOLLE unpublished data). Even a key stratigraphic marker from CLAYTON's et al. (1977) zonation supports the considerations of this study. *Raistrickia fulva* (Pl. 1, Fig. 13; the holotype was described from the Zonguldak area) is present in the palynological assemblages, also in those of coal sample AK-1X/19 (see above, and Fig. 2). The upper range of *R. fulva* is according to CLAYTON et al. (1977) at the top of the NJ zone, and indicates as its youngest age, the earliest Bolsovian (Westphalian C). According to OWENS (in STEPHENSON & OWENS, 2006), the species only ranges from Kinderscoutian to Duckmantian. Whether the ages and relationship to the stages could be refined for the AK-1X well section is discussed below.

Table 1: Sequence of palynological events from selected palynological taxa from the Amasra area, NW Turkey.

Younger
(4) Range top of *Sinuspores sinuatus*
(3) Range base of *Vestispora fenestrata* (as *Foveolatisporites fenestratus*)
(2) Range base of *Spinosporites* (genus)
(1) Range base of *Torispora* spp. (incl. *T. securis*) / *Thymospora* spp. / *Vestispora* (genus)
Older

Based on data from AGRALI & KONYALI (1969)

7. DISCUSSION

As shown above, the co-occurrence of *Sinuspores sinuatus* and *Vestispora fenestrata*, *V. laevigata*, *Torispora securis*, and few *Thymospora* spp. is most likely based on contemporaneous first occurrences. Therefore dating of the AK-1X well section over the depth range –342.05 – –344.90 m, where these marker species occur, is in this study for the first time broadly related to the Duckmantian–Bolsovian transition (Westphalian B–Westphalian C transition).

Following RAVN (1986) and HOWES (1988), and also OWENS (in STEPHENSON & OWENS, 2006) regarding the upper range of *Raistrickia fulva*, the AK-1X well section could correspond to the uppermost Duckmantian (uppermost Westphalian B). The record of *S. sinuatus* in the Amasra area of NW Turkey and that of KOSANKE (1988, West Virginia, upper Westphalian B) would be approximate time-equivalents.

OWENS (1996) depicted a table of 'principal Upper Carboniferous palynological events in the Northern Hemisphere', in which the appearance of *Torispora* is placed at the base of the Bolsovian (Westphalian C). Following OWENS (1996), and also PEPPERS and BRADY (2007, their Kansas record with first *Vestispora fenestrata* and *Torispora securis* in their lowermost Westphalian C), and furthermore OGG et al. (2008) with the relationship that 'PEPPERS and BRADY's mid Atokan would be earliest Bolsovian (Westphalian C)', consequently the AK-1X well section would correspond to the lower Bolsovian (lower Westphalian C; lower Moscovian). The miospore range top regarding *S. sinuatus* would, according to this latter stratigraphic model, be slightly expanded in the Amasra area. Similar results have already been shown by AGRALI & KONYALI (1969) (Tab. 1), however, their reference to the regional stages (range top upper Westphalian C) has to be revised (details in prep., STOLLE et al.).

8. CONCLUSIONS

An atypical co-occurrence of miospore species such as *Sinuspores sinuatus*, *Vestispora fenestrata*, *V. laevigata*, *Torispora securis* and *Thymospora* spp. is observed in palynological assemblages from a short well section from the Amasra area of the Zonguldak Basin of NW Turkey.

Palynological re-investigation herein provides an age which corresponds with a time interval around the Duckmantian–Bolsovian transition (Westphalian C–Westphalian B boundary and approximating to the Bashkirian–Moscovian transition, respectively).

A correlation to the uppermost Duckmantian (uppermost Westphalian B; Bashkirian–Moscovian transition) for this section is possible. However, recent studies lead to the conclusion that a correlation to the lower Bolsovian (lower Westphalian C; lower Moscovian) for the AK-1X well section is most likely. This means that *Sinuspores sinuatus* has a slightly expanded range top in NW Turkey and some taxa such as *Thymospora* spp. occur slightly earlier here than in Western Europe.

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APPENDIX I

ADDITIONAL TAXA OF THE PALYNOLOGICAL RECORD OF THE AK-1X WELL SECTION, CO-OCCURRING WITH *SINUSPORES SINUATUS*

Alatisporites pustulatus, *Alatisporites* spp., *Calamospora* spp., *Cingulizonates* sp., *Cirratriradites saturnii*, *Crassispora kosankei*, *Densosporites triangularis*, *Densosporites* sp., *Dictyotriletes bireticulatus*, *Endosporites globiformis*, *Florinites junior*, *Florinites mediapudens*, *Laevigatosporites* spp., *Lycospora* sp., *Murospora kosankei*, *Punctatisporites* spp., *Punctatosporites* spp., *Raistrickia fulva*, *Raistrickia* spp., *Reinschospora* spp., *Reticulatisporites reticulatus*, *Thymospora* spp., *Torispora securis*, *Triquitrites* spp., *Vestispora costata*, *Vestispora fenestrata*, *Vestispora laevigata*

APPENDIX II

FULL NAMES (BRIEF HISTORY) OF SPECIES MENTIONED IN THIS PAPER

Alatisporites pustulatus (Ibrahim) Ibrahim, 1933

Angulisporites splendidus Bhardwaj, 1954

Canisporites corpulentus Nakoman, 1967 (synonymous to *Sinuspores sinuatus* (Artüz) Ravn, 1986)

Cirratriradites saturnii (Ibrahim), Schopf, Wilson & Bentall, 1944

Crassispora kosankei (Potonié & Kremp) Bhardwaj, 1957 emend. Smith & Butterworth, 1967

Densosporites triangularis Kosanke, 1950

Dictyotrilets bireticulatus (Ibrahim) Potonié & Kremp, 1954 emend. Smith & Butterworth, 1967

Endosporites globiformis (Ibrahim) Schopf, Wilson & Bentall, 1944

Florinites junior Potonié & Kremp, 1956

Florinites mediapudens (Loose) Potonié & Kremp, 1956

Foveolatisporites fenestratus (Kosanke & Brokaw) Bhardwaj, 1956

Microreticulatisporites nobilis (Wicher) Knox, 1950

Murospora kosankei Somers 1952 (synonymous to *Westphalensisporites irregularis* Alpern, 1958)

Punctatisporites sinuatus (Artüz) Neves, 1961 (synonymous to *Sinuspores sinuatus* (Artüz) Ravn, 1986)

Raistrickia fulva Artüz, 1957 (first description from the Zonguldak area, NW Turkey)

Reticulatisporites reticulatus (Ibrahim) Ibrahim, 1933

Savitrisporites camptotus (Alpern) Doubinger, 1968 (synonymous to *Savitrisporites majus* Bhardwaj, 1957)

Schulzospora rara Kosanke, 1950

Sinuspores coronatus and *Sinuspores (Punctatisporites) coronatus* from AGRALI & KONYALI (1969) (new combination, no explanation given) adopted from *Punctatisporites coronatus* Butterworth & Williams, 1958, synonymous to *Punctatisporites sinuatus* (Artüz) Neves 1961 by SMITH & BUTTERWORTH (1967), synonymous to *Sinuspores sinuatus* (Artüz) Ravn, 1986

Sinuspores sinuatus (Artüz) Ravn, 1986

Spinosporites exiguus Upshaw & Hedlund, 1967

Spinosporites spinosus Alpern, 1958

Torispora securis (Balme) Alpern, Doubinger & Horst, 1965

Triquitrites sculptilis (Balme) Smith & Butterworth, 1967

Vestispora costata (Balme) Bhardwaj emend. Spode, in Smith & Butterworth, 1967

Vestispora fenestrata (Kosanke & Brokaw) Wilson & Venkatachala emend. Spode, in Smith & Butterworth, 1967

Vestispora laevigata Wilson & Venkatachala, 1963

Neognathodus atokaensis GRAYSON, 1984

Neognathodus bothrops MERRILL, 1972

Neognathodus medadultimus MERRILL, 1972

Neognathodus medexultimus MERRILL, 1972

Neognathodus uralicus NEMIROVSKAYA & ALEKSEEV, 1994

REFERENCES

AGRALI, B. & KONYALI, Y. (1969): Etüde des microspores du bassin Carbonifere d'Amasra.– Bulletin of the Mineral Research and Exploration Institute of Turkey, 73, 45–132.

AKBAS, B., ALTUN, I.E. & AKSAY, A. (2002): 1 : 100 000 ölcekli TÜRKIYE JEOLOJI HARITALARI No: 24 ZONGULDAK – E 28 PAFTASI [Geological Map of Turkey 1:100000, Zonguldak sheet E 28– in Turkish]. MTA Genel Müdürlügu, Ankara, Jeoloji Etütleri Dairesi, Ankara, 18 p.

AKGÜN, F. & AKYOL, E. (1992): Amasra-Bartın Karbonifer havzası kömürlerinin palinolojisi ve paleoekolojisi.– Turk.. J. Earth Sci., 1, 49–56.

AKYOL, E. (1974): Zonguldak Üzülmez bölgesi, Asma bölümündeki –50 kotlu galeri güney ve doğu kanatlarının kestiği Namuriyen ve Vestfaliyen A yaşlı damarların palinolojik incelemeleri.– MTA Enst. Derg., 83, 47–108.

ANDERSON, R.R. (2007): Geology of the Red Rock Dam and visitir center, Marion County, Iowa.– Geol. Soc. of Iowa, Guidebook 80, Iowa City, 14 p.

ARTÜZ, S. (1957): Die Sporae Dispersae der Türkischen Steinkohle von Zonguldak – Gebiet (Mit besonderer Beachtung der neuen Arten und Genera).– Rev. fac. sci. l'Univ. Istanbul. ser. B, 22, 239–278.

BARRICK, J.E., LAMBERT, L.L, HECKEL, P.H. & BOARDMAN, D.R. (2004): Pennsylvanian conodont zonation for midcontinent North America.– Revista Espanola de Micropaleontologia, 36, 231–250.

BUTTERWORTH, M.A. & WILLIAMS, R.W. (1958): The small spore floras of coals in the Limestone Coal Group and Upper Limestone Group of the Lower Carboniferous of Scotland.– T. Roy. Soc. Edin. Earth, 63, 353–392.

CANCA, N., BARLAS, O., KEYF, S., ERDOGAN, C., TUNCKILIC, G. & YALCIN, R. (1994): Jeoloji Etüdleri Dairesi ve Enerji Hammade Etüd Arama Dairesi Haritalarindan derlenerek Bati Karadeniz Bölge Müdürlügü tarafindan düzenlenmistir. Zonguldak 1993.– Maden Tetkik ve Arama Genel Müdürlügü, Litostratigrafi Birimleri Serisi-1, Ankara, Geological map 1:25 000.

CLAYTON, G., COQUEL, R., DOUBINGER, J. GUEINN, K.J., LOBOZIAK, S., OWENS, B. & STREEL, M. (1977): Carboniferous miospores of western Europe: illustration and zonation, report of Commission Internationale de Microflore du Paléozoïque working group on Carboniferous stratigraphical palynology.– Mededelingen Rijks Geolog. Dienst, 29, 1–71.

DIL, N. & KONYALI, Y. (1978): Carboniferous of Zonguldak area. In: Field Excursion on the Carboniferous Stratigraphy in Turkey, Guidebook. MTA Public., Ankara, 5–25.

DIMITROVA, T.K., CLEAL, C.J. & THOMAS, B.A. (2011): Palynological evidence for Pennsylvanian extra-basinal vegetation in Atlantic Canada.– J. Geol. Soc. London, 168, 559– 569. doi: 10.1144/0016-76492010-028

EINOR, O.L. (1996): The Former U.S.S.R. – In: WAGNER, R.H., WINKLER PRINS, C.F. & GRANADOS, L.F. (eds.): The Carboniferous of the World III, The Former U.S.S.R., Mongolia, Middle Eastern Platform, Afghanistan and Iran. IUGS Publication 33. Instituto Tecnológico Geominero de España –Nationaal Natuurhistorisch Museum, Madrid, 3–408.

ETTENSOHN F.R. & PEPPERS, R.A. (1979): Palynology and biostratigraphy of Pennington shales and coals (Chesterian) at selected sites in northeastern Kentucky.– J. Paleontol., 53 /2, 453–474.

GRADSTEIN, F.M., OGG, J.G. & SMITH, A.G. (eds.) (2004): A Geologic Time Scale 2004.– Cambridge University Press, Cambridge, New York, Melbourne, 589 p.

HOWES, M.R. (1988): Palynology of Cherokee Group coals.– In: HOWES, M.R. & LAMBERT, L.L. (eds.): Stratigraphy and depositional history of the Cherokee Group, south-central Iowa. Geol. Soc. of Iowa, Guidebook 49, 15–21.

HOWES, M.R. & LAMBERT, L.L. (1988): Stratigraphy and depositional history of the Cherokee Group, south-central Iowa.– Geol. Soc. of Iowa, Guidebook 49, Iowa City, 39 p.

IBRAHIM-OKAY, A.C. & ARTÜZ, S. (1964): Die Mikrosporen der Steinkohlenflöze Domuzcu und Cay (Westfal A) im Zonguldak Gebiet (Türkei). – Fortschr. Geol. Rheinld. u. Westf., 12, 271–284.

KARAYIGIT, A.I. & ORHAN, E. (1997): Zonguldak Coal Basin. Excursion Guide.– European Coal Conference '97, Dokuz Eylül Üniversitesi, Izmir, 5–10 May 1997, 18 p.

KEREY, I.E. (1984): Facies and tectonic setting of the Upper Carboniferous rocks of NW Turkey. – In: DIXON, J.E. & ROBERTSON, A.H.F. (eds.): The Geological evolution of the Eastern Mediterranean. Geol. Soc. London, Spec. Public., 17, 123–128.

KOSANKE, R.M. (1988): Palynological studies of Middle Pennsylvanian coal beds of the proposed Pennsylvanian System stratotype in West Virginia.– U.S. Geological Survey, Professional Paper, 1455, 73 p.

LAMBERT, L.L. (1988a): Fusulinids from the Cherokee Group of Iowa.– In: HOWES, M.R. & LAMBERT, L.L. (eds.): Stratigraphy and depositional history of the Cherokee Group, south-central Iowa. Geol. Soc. of Iowa, Guidebook 49, 23–26.

LAMBERT, L.L. (1988b): Cherokee Group conodonts from southeastern Iowa.– In: HOWES, M.R. & LAMBERT, L.L. (eds.): Stratigraphy and depositional history of the Cherokee Group, south-central Iowa. Geol. Soc. of Iowa, Guidebook 49, 27–30.

LOBOZIAK, S. (1974): Considerations palynologiques sur le Westphalian d'Europe occidentale.– Rev. Palaeobot. Palyno., 18, 271–289.

McLEAN, D., OWENS, B. & BODMAN, D. (2004): Palynostratigraphy of the Late Carboniferous Langsettian-Duckmantian boundary in Britain.– In: BEAUDOIN, A.B. & HEAD, M.J. (eds.): The Palynology and Micropalaeontology of boundaries.– Special Publication of the Geological Society of Great Britain, 230, 123–135.

NAKOMAN, E. (1976): Zonguldak kömür havzasının Karadon ve Üzülmez bölgelerindeki Namuriyen ve Vestfaliyen A taşlı damarların palinolojl incelemeleri. II. Nicel etüd.– M.T.A. Enst. Derg., 87, 80–110.

OGG, J.G., OGG, G. & GRADSTEIN, F.M. (2008): The Concise Geologic Time Scale.– Cambridge University Press, Cambridge, New York, Melbourne, 177 p.

OKAY, A.I. (2008): Geology of Turkey: a synopsis.– Anschnitt, 21, 19–42.

OKAY, A.I. & GÖNCÜOGLU, M.C. (2004): The Karakaya Complex: a review of data and concepts.– Turk. J. Earth Sci., 13, 77–95.

OKAY, A.I. & TÜYSÜZ, O. (1999): Tethyan sutures of northern Turkey.– Geol. Soc. London, Spec. Publ., 156, 475–515.

OWENS, B. (1996): Upper Carboniferous spores and pollen.– In: JANSONIUS, J. & McGREGOR, D.C. (eds.): Palynology: Principles and Applications, 2. American Association of Stratigraphic Palynologists Foundation, Dallas, 597–606.

OWENS, B., McLEAN, D. & BODMAN, D. (2004): A revised palynozonation of the British Namurian deposits and comparisons with Eastern Europe.– Micropaleontology, 50, 89–103. doi: 10.2113/50.1.89

PEPPERS, R.A. (1970): Correlation and palynology of coals in the Carbondale and Spoon Formations (Pennsylvanian) of the northeastern part of the Illinois Basin.– Illinois Geol. Survey Bull. 93, 173 p.

PEPPERS, R.A. (1996): Palynological Correlation of major Pennsylvanian (Middle and Upper Carboniferous) chronostratigraphic boundaries in the Illinois and other coal basins.– Geol. Soc. Am. Mem., 188, 1–111.

PEPPERS, R.A. & BRADY, L.L. (2007): Palynological Correlation of Atokan and Lower Desmoinesian (Pennsylvanian) Strata Between the Illinois Basin and the Forest City Basin in Eastern Kansas.– Cur. Res. Earth Sci., Bull. 253, part 1, 1–21.

PEPPERS, R.A., HOWE, W.B. & DEASON, K. (1993): Palynological zonation and physical stratigraphy of pre-Desmoinesian strata along a subsurface cross section in northwestern Missouri.– Geol. Soc. of America, Annual Meeting of North–central Section, Abstracts with Program, 25, p. 72.

RALLI, G. (1933): Le bassin houiller d'Héraclée et la flore du Culm et du Houiller Moyen.– Zellitch, Istanbul, 100 p.

RAVN, R.L. (1986): Palynostratigraphy of the Lower and Middle Pannsylvanian coals of Iowa.– Iowa Geol. Survey, Technical Paper No.7, Iowa City, 245 p.

RAVN, R.L. & FITZGERALD, D.J. (1982): A Morrowan (Upper Carboniferous) miospore flora from eastern Iowa, U.S.A.– Palaeontogr. Abt. B, 183/4–6, 108–172.

SMITH, A.H.V. & BUTTERWORTH, M.A. (1967): Miospores in the coal seams of the Carboniferous of Great Britain.– Special Papers in Palaeontology, No. 1, London, 324. p.

STAMPFLI G.M. (2000): Tethyan oceans.– In: BOZKURT, E., WINCHESTER, J.A. & PIPER, J.D.A. (eds.): Tectonics and Magmatism in Turkey and the Surrounding Area. Geol. Soc. London, Spec. Public., 173, 1–23.

STEPHENSON, M.H. & OWENS, B. (2006): Taxonomy Online 2: The 'Bernard Owens Collection' of single grain mount palynological slides: Carboniferous spores part I.– British Geological Survey Research Report, RR/06/05, Keyworth, 80 p.

STOLLE, E. (2011): Pollen-dominated "European" palynological assemblages from the Permian of NW Turkey (Asia Minor) – palaeogeographical context and microfloral affinities.– Geol. Q., 55/2, 181–186.

STOLLE, E. & BUZKAN, I. (2011): First documented palynological record from Kasimovian deposits of the Zonguldak Coal Basin, NW Turkey.– In: HAKANSSON, E. & TROTTER, J.A. (eds.): Programme & Abstracts: The XVII International Congress on the Carboniferous and Permian. Geological Survey of Western Australia, Perth, Australia, p. 118.

TOKAY, M. (1962): The geology of the Amasra region with special reference to some Carboniferous gravitational gliding phenomena.– M.T.A. Bull., 55, 1–20.

TÜYSÜZ, O., AKSAY, A. & YIGITBAS, E. (2004): Bati Karadeniz Bölgesi Litostratigrafi Birimleri.– Maden Tetkik ve Arama Genel Müdürlügü, Litostratigrafi Birimleri Serisi-1, Ankara, 92 p.

VAN WIJHE, D.H. & BLESS, M.J.M. (1974): The Westphalian of the Netherlands with special reference to miospore assemblages.– Geol. Mijnb., 53, 295–328.

YALCIN, M.N., INAN, S., GÜRDAL, G., MANN, U. & SCHAEFER, R.G. (2002): Carboniferous coals of the Zonguldak basin (northwest Turkey): Implications for coalbed methane potential.– AAPG Bull., 86/7, 1305–1328. doi: 10.1306/61EEDC88-173E-11D7-8645000102C1865D

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