Co-occurrence of *Sinuspores sinuatus* (Artüz) Ravn 1986 with established palynological marker indicating younger strata: AK-1X well section (Pennsylvanian, Zonguldak basin, NW Turkey) and the relation 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. In depths of m342.05−m345.05 m remarkable co-occurrences of the key stratigraphic spore species *Sinuspores sinuatus* together with *Vestispora fenestrata*, *V. laevigata*, *Torispora securis*, and few *Thymospora* spp. are recorded. In correlation to the ‘selected spore ranges and spore zonation of the Carboniferous system in Western Europe’, often used as a standard zonation, these palynological assemblages would have to be related to the upper Bolsovian (e.g. by the presence of *Thymospora* spp.) – including some reworked older material (represented by *S. sinuatus*). Alternative spore ranges are in focus 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 transition. The relation to the uppermost Duckmantian is discussed. However, recent studies lead to the conclusion that a dating to the lowermost Bolsovian for the AK-1X well section also is adequate. Accordingly, *Sinuspores sinuatus* has a slightly
expanded range top in NW Turkey. Some species such as of *Thymospora* occur more or less earlier than in Western Europe.

**Keywords:** palynology, stratigraphy, Turkey, Zonguldak, coal, Carboniferous, Bashkirian, Moscovian, Duckmantian, Bolsovian, Westphalian B, Westphalian C, Atokan, *Sinuspores sinuatus*

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**Fig. 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 & GÖNCÜOĞLU (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 is revealed. Map is simplified from YALCIN et al. (2002). Part of the Pennsylvanian succession of the Amasra area is depicted in C) for overview. Simplified from AKBAS et al. (2002).

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. A remarkable ‘unusual’ co-occurrence of palynological species such as *Sinuspores sinuatus*, *Vestispora fenestrata*, *V. laevigata*, *Torispora securis*, and few *Thymospora* spp. have 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 zonation to the palynological record of the AK-1X well section would indicate an upper Bolsovian (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 only is 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).

But because the specimens of *Sinuspores sinuatus*, identified in the AK-1X well section, showed not any indication for reworking or recycling, some effort has been carried out for this study to look for alternative spore ranges and further clues, whether a contemporaneous first deposition of all these spores would have been possible. Particularly
first and last occurrences of miospore ranges presented in RAVN (1986), HOWES (1988),
and PEPPERS & BRADY (2007) were useful, in combination with the stratigraphic
framework of GRADSTEIN et al. (2004) and OGG et al. (2008), to conclude 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 at the Black Sea coast of the
western Pontides. The region belongs structurally to the Istanbul–Zonguldak Terrane (also
known as Istanbul Zone, e.g. OKAY, 2008, Fig. 1 A), which was during Carboniferous times
located more or less equator–near in the tropics (e.g. STAMPFLI, 2000). In early and late
Pennsylvanian the deposition of mainly clastics and coals took place. Nowadays, 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). Main mining
districts are the Armutcuk, Zonguldak and Amasra areas (Fig. 1 B). The coal-bearing
sequence is subdivided into the Alacaagzi, the Kozlu and the Karadon formations, and mainly
is 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 (the “Black
Underpants Formation”, RALLI, 1933) lies conform with a gradual contact on the Alacaagzi
Formation, and it is disconformably overlain by the Cakraz Formation (according to AKBAS
et al., 2002, Geological Map 1 : 100 000 with explanation). Younger, informal divisions
subdivide in the Amasra area into the Alacaagzi, the Kozlu and the Karadon formations in the
Amasra area (e.g. unpublished reports). The deposits of the Zonguldak area underwent
tectonic stress (e.g. YALCIN et al., 2002, fig. 1). TOKAY (1962) considered deposits from
the Amasra area as an allochthonous group, consisting of displaced and mixed slides of
Westphalian C, B, A and Namurian. The age determination of the Karadon Formation always has been controversial, and the unit was defined as Westphalian A, B and C (by YERGÖK et al., 1987)1, as Westphalian B, C and D (by DIL & KONYALI, 1978), whereas KEREY (1984) assumed an age of Westphalian B and C (discussed ages from AKBAS et al., 2002, Geological Map 1:100 000). The Pennsylvanian from NW Turkey has ever since been assigned to the European regional stages, for example originated in the Westphalian mining area ‘Ruhrgebiet’, Germany.

3. MATERIAL AND METHODS

This study bases 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 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.

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Fig. 2: The palynologically re-investigated AK-1X well section of the Amasra area is shown with simplified lithologies. Occurrences of the for this study relevant species *S. sinuatus* are marked as well as the palynologically productive positions.

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 brown, big-sized trilete spore species *Sinuspores sinuatus*
have been identified (specimens in Pl. 1, Figs. 4–6). In depths of 342.05–345.05 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 partially updates) and is as microfloral zonation a component of the Carboniferous Time Scale (GRADSTEIN et al., 2004). In CLAYTON et al. (1977) the lower limit of the NJ Zone is marked (amongst others) by the end of the biozones of *S. sinuatus* (as *Punctatisporites sinuatus*). The lower limit of the NJ Zone was in 1977 related to the early Westphalian B, as is today, and is now also equivalent with the lower Duckmantian and upper Bashkirian. According to CLAYTON et al. (1977), the base of the (towards the younger) succeeding SL Zone (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 (boundary Westphalian C–Westph. 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’ for the palynological record from the AK-well section from NW Turkey, this would result in a dating to an age range of uppermost Bolsovian (Westphalian C) to Asturian (Westphalian D), or younger, based on the presence of *Thymospora* spp. Spores of *Sinuspores sinuatus* 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-OHAY & ARTÜZ (1964) from the Domuzcu seam. The early finds were considered as from Westphalian A as well as the records for example in AKYOL (1974) (Westphalian A, Namurian) and NAKOMAN (1976,
as *Canisporites corpulentus* from the same area. AKGÜN & AKYOL (1992) reported it from the Amasra area (as *Sinuspores coronatus*). Outside of NW Turkey the spore was recorded from Europe and North America, for example from the Russian Platform (EINOR, 1996), from Scotland (BUTTERWORTH & WILLIAMS, 1958), or from the North American midcontinent (RAVN & FITZGERALD, 1982), under *S. sinuatus* or under a synonym. According to the common literature the age range was considered as (late) Visean (e.g. ETTENSOHN & PEPPERS, 1979; EINOR, 1996) to upper 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 attempted to prove and discussed in the following.

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 Zonguldak district of the Zonguldak Basin in 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 existing sine curve-like infrastructures, which appear on dark background as light construction. At the margin of the spore body is a deep dark brown belt zone existing, which is 15–17 µm broad and structure-less. RAVN (1986) attributed in his emendation for the species a wider size range from 75–130 µm, and an exine thickness of 5 µm and more. The specimens (Pl. 1, Figs. 4–6) found in the short AK-1X well section are 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, clearly assignable to the species *S. sinuatus*. 

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Pl. 1: Miospores of the AK-1X well from the Pennsylvanian of NW Turkey, relevant for this study. Each with dimensions in micrometer, 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.

6. CORRELATION OF MIOSPORE RANGES AND DATING

The palynological record of the AK-1X well section has been compared to palynological events beyond Western Europe. RAVN (1986) depicted miospore ranges elaborated in Iowa, and also presented a comparison chart of the Iowa record compared to 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 first occurrences of *Vestispora fenestrata*, *Torispora securis*, and particularly those of *Vestispora laevigata* and *Thymospora* spp. from the upper Kilbourn and lower Kalo formations to the upper Westphalian B (Fig. 3 B, also in HOWES, 1988). RAVN’s (1986) dating approximately corresponds with a foraminifer dating by LAMBERT (1988) from the Iowa coal succession, namely from shale below the thick limestone overlying the Laddsdale coal (Fig. 3 B). LAMBERT (1988) 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*. According to
GRADSTEIN et al. (2004) first *Fusulinella* are correlated approximately with the mid Bolsovian (mid Westphalian C, late Atokan) (Fig. 3 C). According to OGG et al. (2008), first *Fusulinella* are correlated with the late Bolsovian (mid Westphalian C, late Atokan) (Fig. 3 D).

A recent paper of PEPPERS & BRADY (2007) correlates first *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 (lowest Bolsovian). PEPPERS & BRADY’s (2007) correlation of the regional stages (approx. mid Atokan – Westphalian B–Westphalian C boundary) is in accordance with GRADSTEIN et al. (2004). It corresponds with their 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 under consideration of the miospore ranges of RAVN (1986), HOWES (1988), and PEPPERS & BRADY (2007), a ‘co-deposition’ of *S. sinuatus* with the further palynological marker mentioned above absolutely was possible (based on contemporaneous first embedding). 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 *T. securis*, first *V. fenestrata*) correlates to the earliest Bolsovian (early Moscovian).

The investigated AK-1X well section of this study clearly correlates approximately to the transition Duckmantian–Bolsovian (Westphalian B–Westphalian C transition). Whether ages and the relation to the stages could be refined for the AK-1X well section is discussed below.
Fig. 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 AKm1X well section (this study) were chosen for illustration. The horizontal band marks, in comparison, the oldest age suggestion for the AKm1X well section (by the occurrence of V. laevigata). In B): Extract from HOWES (1988). HOWES refers to miospore ranges of RAVN (1986) and his depiction of stratigraphic units in Iowa as well as on coal occurrences of the region. Foraminifer results of LAMBERT (1988) have been included in chart B). The oldest age suggestion for the AK-1X well section (by the occurrence of V. laevigata) is marked again. 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 in pink. The relevant foraminifer event (from GRADSTEIN et al., 2004) have been included to chart C) for comparison with charts A) and B) as it represents ‘age control’ for the palynological dating. Chart D) displays the latest published relation of some Pennsylvanian stages to the regional subdivisions of the Carboniferous time scale (OGG et al., 2008). In E): Extract of chart of selected miospore ranges observed in the Kansas and Illinois basins in relation to the chronostratigraphy (from PEPPERS and BRADY, 2007). The European regional stages probably have been adapted to the ‘Atokan’ according to correlations of GRADSTEIN et al. (2004) (compare to C).
7. DISCUSSION

About traces of contermination, resulting from reworking/recycling of older rock material during the process of deposition, it should be noted that beside *S. sinuatus* no other species occur in the AK-1X well section, which would indicate older ages (early, mid Duckmantian or Langsettian). As shown above, the co-occurrence of *S. sinuatus* with *Vestispora fenestrata*, *V. laevigata*, *Torispora securis*, and few *Thymospora* spp. is most likely based on contemporaneous first embedding. Therefore dating of the AK-1X well section in depths of -342.05−345.05 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), 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 approximately be time-equivalent.

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 relation that ‘PEPPERS and BRADY’ s mid Atokan would be earliest Bolsovian (Westphalian C)’, consequently the AK-1X well section would correspond to the lowermost Bolsovian (lowermost Westphalian C; lower Moscovian). The miospore range top of *S. sinuatus* would, according to this latter stratigraphic model, be slightly expanded in the Amasra area.
8. CONCLUSIONS

A remarkable ‘unusual’ co-occurrence of palynological species such as *Sinuspores sinuatus*, *Vestispora fenestrata*, *V. laevigata*, *Torispora securis*, and few *Thymospora* spp. can be observed in palynological assemblages from a short well section from the Amasra area of the Zonguldak Basin of NW Turkey.

Palynological re-investigation in the frame of this study provides an age which corresponds with a time interval around the Duckmantian–Bolsovian transition (Westphalian C–Westphalian B, and more or less around the Bashkirian–Moscovian transition, respectively).

A relation to the uppermost Duckmantian (uppermost Westphalian B; Bashkirian–Moscovian transition) for this section is possible. However, recent studies lead to the conclusion that a dating to the lowermost Bolsovian (lowermost Westphalian C; lower Moscovian) for the AK-1X well section also is adequate. This means that *Sinuspores sinuatus* has a slightly expanded range top in NW Turkey. Some species such as of *Thymospora* occur more or less earlier than in Western Europe.

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APPENDIX

Species mentioned in the text (full names with brief history).

*Sinuspores sinuatus* (Artüz) Ravn 1986

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

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

Vestispora laevigata Wilson & Venkatachala 1963