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Palynostratigraphy of dinosaur bone-bearing deposits from the Upper Cretaceous of Western Bulgaria

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ABSTRACT:

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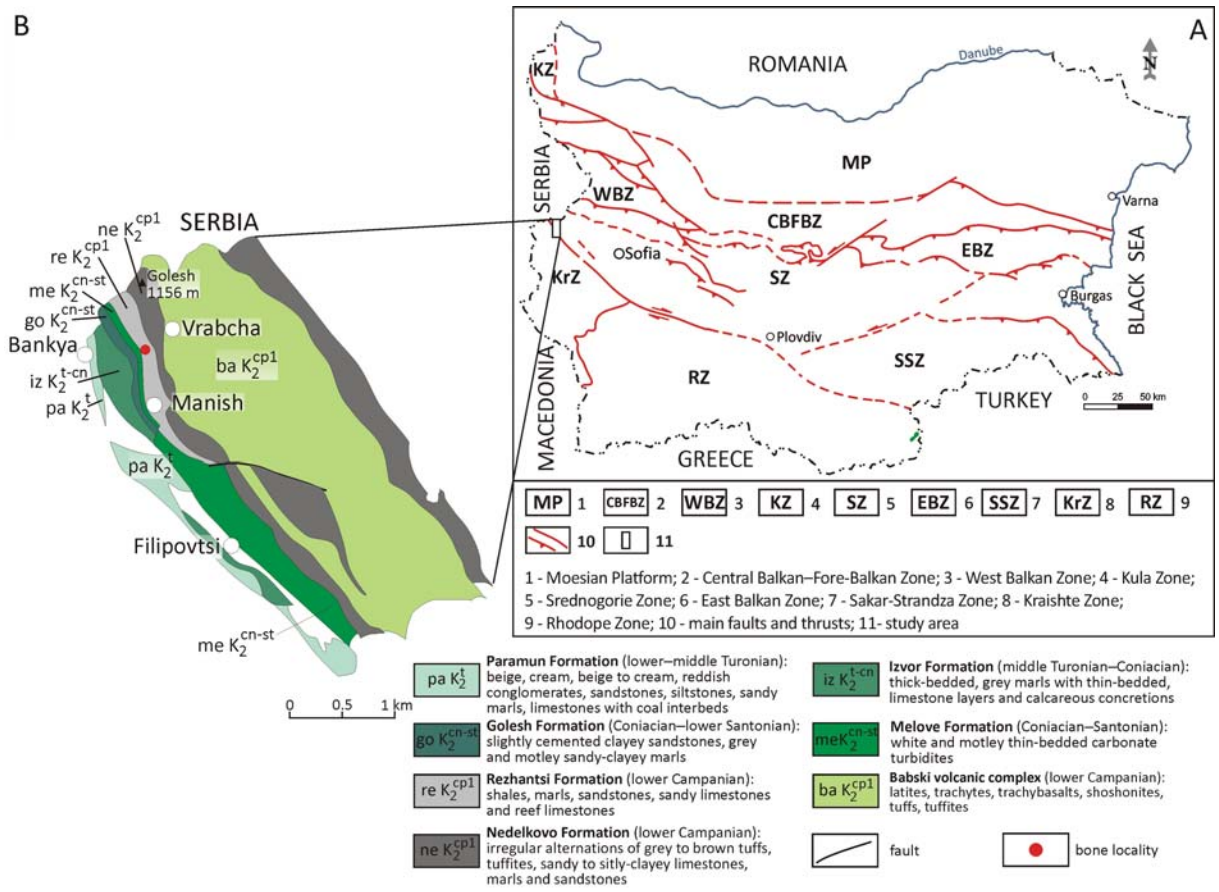
Palynological investigation of the Vrabchov dol locality (Western Bulgaria) which recently yielded fragmentary dinosaur bones attributed to the clade Titanosauria, reveals well-preserved sporomorph assemblages dominated by angiosperm pollen from the Normapolles group, spores and rare gymnosperms. The age assessment of the studied sequence is based on the diagnostic Normapolles species, such as *Oculopollis orbicularis* Góczán, 1964, *Oculopollis zaklinskaiae* Góczán, 1964, *Krutzschipollis spatiosus* Góczán in Góczán *et al*., 1967 and *Krutzschipollis crassus* (Góczán, 1964) Góczán in Góczán *et al*., 1967. The concurrent presence of these pollen species suggests a late Santonian–early Campanian age for the succession. The sporomorph association is encountered in a palynofacies dominated by continental elements, including translucent phytoclasts (tissues, wood remains and plant cuticles). The sedimentary succession shows no evidence of marine elements and a very low proportion of AOM that attests to deposition within a lagoonal to foreshore marine environment, with high continental input and short transportation. The vegetation in the studied area was primarily composed of a range of Normapolles-producing angiosperms and secondarily of pteridophyte spore-producing plants. Gymnosperms were rare. Such a vegetation pattern reflects a warm, seasonally dry climate during the late Santonian–earliest Campanian in the studied area. The dinosaurs inhabited a wet lowland area, probably rich in herbaceous plants.

Key words: Palynology; Normapolles; Titanosauria; Santonian; Campanian; Palaeoecology.

INTRODUCTION

The Upper Cretaceous Western Srednogorie sedimentary rock succession at Vrabchov dol, a gully exposed between the villages of Bankya and Vrabcha in Western Bulgaria, has recently revealed a diverse tetrapod fauna, including fragmentary dinosaur bones. On the basis of osteohistological features, the dinosaur bones, attributed to the clade Titanosauria, represent the first documented occurrence of this group in Bulgaria (Nikolov *et al*. 2018). The sediments hosting the bones are represented by fine-grained terrigenous rocks and thin coal layers assigned to the Rezhantsi Formation and, based on calcareous nannofossils, so far dated to the early Campanian (Sinnyovsky *et al*. 2013).



Text-fig. 1. Tectonic sketch map of Bulgaria (A), after Ivanov (2017) and geological map of the Western Srednogorie in the area between the villages of Bankya and Vrabcha and adjacent areas (B), after Sinnyovsky *et al.* (2012, 2013), simplified

Remains of non-avian dinosaurs in Bulgaria are exceedingly rare, with all of the dinosaur material known so far being derived from the upper Maastrichtian bioclastic limestones recognised as the Kajlâka Formation (Jolkičev 1986) from north-western Bulgaria (Godefroit and Motchurova-Dekova 2010; Mateus *et al.* 2010; Nikolov *et al.* 2018). The recent age assessment of the Kajlâka Formation is based mainly on late Maastrichtian echinoids and rare ammonite species (Jolkičev 1986, 2006) but lacks palynological data.

The sedimentary sequence in the Vrabchov dol locality is characterised by fine grained, soft sediments, formed most probably in a foreshore to lagoonal palaeoenvironment. The only invertebrate macrofossils in the section studied consist of small to medium-sized gastropods and bivalves. Typically, these fossil groups are not particularly informative for detailed age determination, and, moreover, in this case they occur in only two levels of the sedimentary succession. For these reasons, we consider palynostratigraphy as the most reliable tool for dating these strata. Previous studies from Sweden and Spain (Vajda *et al.* 2013, 2016) have shown that palynological analyses of specific beds hosting dinosaur remains or dinosaur tracks may provide firm age assessment and, moreover, an insight into the past ecosystems inhabited by the fauna.

The present study aims to elucidate the age of the dinosaur-bearing strata at the Vrabchov dol locality and is the first study using palynology in the analysis of the Upper Cretaceous dinosaur-bearing rocks in Bulgaria. The results may also contribute to, and expand, the knowledge of the local stratigraphy of the Upper Cretaceous successions in the area, as well as the understanding of the palaeoenvironment during the time interval studied. The data and results reported herein once more highlight the application of palynology as a powerful tool for dating dinosaur finds in museums and universities.

GEOLOGICAL SETTING

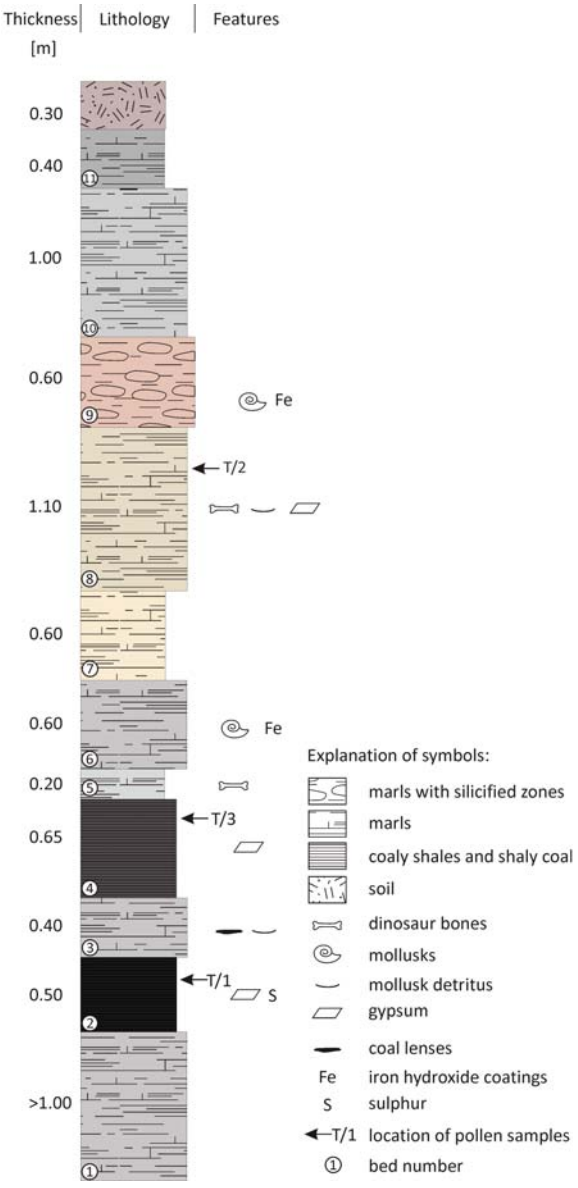
The Upper Cretaceous sedimentary succession exposed in the Vrabchov dol gully is located within the Western Srednogorie Zone (Western Bulgaria; Text-fig. 1A). The Srednogorie Zone is composed of a chain of strike-slip and pull-apart basin systems, developed during the Early Alpine orogeny in a back-arc setting. The rock successions in this zone are composed of Upper Cretaceous sedimentary rocks (mainly different types of limestones, marlstones and terrigenous lithotypes), volcano-sedimentary successions, and small intrusive bodies. The main characteristics and general geology of the studied area, as well as previous studies in relevant parts of the Western Srednogorie Zone are discussed in detail by Nikolov *et al.* (submitted).

The dinosaur bone remains and the studied palynological samples come from a sedimentary succession exposed in a small isolated outcrop in the north-western part of the Vrabchov dol gully, in the vicinity of the village of Vrabcha (Text-fig. 1B). The fossiliferous sediments yielding dinosaur bones belong to the recently introduced Rezhantsi Formation (Sinnyovsky *et al.* 2013; Text-fig. 1B). This formation comprises mainly shales, marls, sandstones, sandy limestones and reef limestones, and based on calcareous nannofossils is dated as the early Campanian. The sedimentary sequences of the formation are deposited predominantly in shallow marine palaeoenvironments, but sediments deposited in foreshore to lagoonal depositional environments also occur. The studied section has a total thickness of 8 m and is composed of grey to light grey marls, silicified marls, coal and coaly shales (Nikolov *et al.* 2018; Text-fig. 2). The relationship to the underlying and overlying rock successions is unclear in the outcrop since the boundaries are covered by shrubs, grass and soil (Nikolov *et al.* 2018). Thus, the early Campanian age of the Rezhantsi Formation accounts only for the shallow marine sediments of this formation and is not suitable for the entire section studied. The proposed lagoonal to foreshore marine origin of the succession studied excludes the presence of key Upper Cretaceous marine macrofossil groups, such as inoceramid bivalves and ammonites, which would have given a correct age assessment of the locality. Nikolov *et al.* (submitted), summarised all previous palaeontological investigations in this part of the Western Srednogorie Zone, including Vrabchov dol, and based on limited palaeontological data concluded that the stratigraphic range of the succession represents an interval from the lower Santonian to the lower Campanian.

MATERIAL AND METHODS

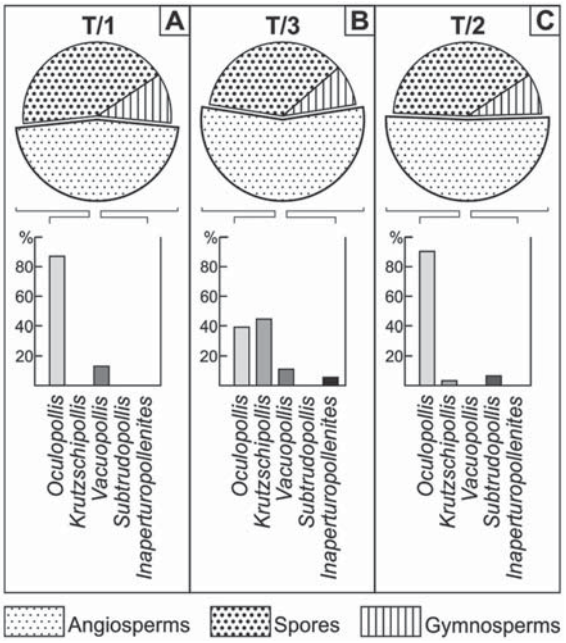
Three samples from the dinosaur-bearing succession were selected for palynological analyses. Sample T/1 is the lowermost sample, originating from bed 2, sample T/3 was taken 1.2 m above it, from bed 4, and sample T/2 is the uppermost sample from the host strata, adjacent to the bones, 2.5 m above sample T/3 (bed 8; Text-fig. 2).

The samples were processed according to standard palynological techniques in the Palynological Laboratory, Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences. About



Text-fig. 2. Lithological column of the section studied with location of the palynological samples

50 g sediment was processed including HCl and HF treatment, heavy liquid separation, and KOH treatment. The residues were finally sieved through 6–8 μm nylon meshes. Light microscopy slides were mounted in glycerine jelly. From each of the samples, two palynological slides were prepared and analysed for their palynological content. The slides are stored in the collections of the Sofia University "St. Kliment Ohridski". Semi-quantitative evaluation of the recognised sporomorph taxa is proposed for the assemblages. Palynofacies analysis involved counting the relative abundance of organic particles based on 300 counts per slide. The following palynofacies groups and ratios were used herein according to the classifications of Tyson (1995) and Batten (1996): (1) the ratio of continental to marine elements (C/M ratio); (2) the ratio of opaque to translucent phytoclasts (OR/TR ratio); (3) the size and shape of translucent and opaque phytoclasts; and 4) the relative proportion of amorphous organic matter (AOM).



Text-fig. 3. Abundance diagrams of the main palynomorph groups and angiosperm genera in the samples from Vrabchov dol: T/1 (A), T/3 (B) and T/2 (C). For each sample, the circular diagram shows the representation of the three main palynomorph groups and the histogram indicates the percentages of the main angiosperm Normapolles genera. For location of samples in the succession see Text-fig. 2

PALYNOLOGY

The three samples yield a well-preserved palynoflora and show a similar palynological composition. Overall, the assemblages reveal a moderate angiosperm pollen dominance over spores and gymnosperm pollen. Angiosperms are represented mainly by the morphologically characteristic pollen belonging to the Normapolles group. This diverse equatorially triaperturate pollen group first appears within the Cenomanian, reaches its acme during the Coniacian to Palaeocene interval, and declines rapidly in the Eocene (Góczán *et al.* 1967). During the Late Cretaceous it displays high species diversity and rapid evolution, becoming the most important tool for correlation and age assessment within the Normapolles microfloristic province of Europe and North America.

RESULTS

Sample T/1 (Bed 2)

The palynological assemblage of this sample is *Oculopollis*-dominated with rare representatives of *Vacuopollis* sp. The assemblage comprises: *Oculopollis principalis* Weyland and Krieger, 1953, *Oculopollis orbicularis* Góczán, 1964, *Oculopollis zaklinskaiae* Góczán, 1964 and *Vacuopollis* sp. Trilete spores account for up to 40% of the assemblage and belong mainly to *Verrucosisporites acrostichoides* Góczán, 1964, *Deltoidospora ordinata* Brelie, 1964 and *Cyathidites minor* Cookson, 1947. They are well preserved and often occur in tetrades. Gymnosperms comprise less than 11% being represented by *Araucariacites australis* Cookson, 1947 (Text-figs 3A, 4).

Sample T/3 (Bed 4)

This sample yields a well preserved and diverse palynoflora. Again angiosperm Normapolles pollen predominates, mainly *Oculopollis* spp. and *Krutzschipollis* spp. The following age diagnostic taxa were identified: *Oculopollis zaklinskaiae*, *Oculopollis orbicularis*, *Oculopollis principalis*, *Krutzschipollis crassus* (Góczán, 1964) Góczán in Góczán *et al*., 1967, *Krutzschipollis spatiosus* Góczán in Góczán *et al*., 1967, *Krutzschipollis magnoporus* Góczán in Góczán *et al*., 1967, *Vacuopollis pyramis* Pflug, 1953 and *Inaperturopollenites* spp. Trilete spores reach up to 36% in the assemblage and are attributed to *Vadaszisporites urkuticus* (Deak, 1964) Deak and Combaz, 1967, *Vadaszisporites sacali* Deak and Combaz, 1967, *Deltoidospora ordinata* and *Echinati-*

sporites spp. Gymnosperms again are represented only by single grains of *Araucariacites australis* (Text-figs 3B, 4).

Sample T/2 (Bed 8)

The palynological assemblage of this sample is dominated by angiosperm Normapolles pollen (51%). The most abundant taxa are representatives of *Oculopollis* spp., being represented by *Oculopollis zaklinskaiae*, *Oculopollis orbicularis* and *Oculopollis principalis*, as well as *Krutzschipollis spatiosus* and *Subtrudopollis* spp. Spores and gymnosperm pollen reach a relative overall abundance of 49%. The spore assemblage is strongly dominated by trilete spores *Deltoidospora ordinata* and *Cyathidites minor*. Gymnosperms are rare and represented by *Araucariacites australis* (Text-figs 3C, 4).

AGE ASSESSMENT OF THE SAMPLES

Following previous studies (Góczán 1964; Medus 1972; Antonescu 1973; Góczán and Siegl-Farkas 1990; Pavlishina 1994, 1999; Siegl-Farkas and Wagreich 1996; Pavlishina *et al*. 2004; Baranyi and Bodor 2012; Peyrot *et al.* 2013), a fairly accurate scheme of the Upper Cretaceous palynostratigraphy in Europe is available, with which the assemblages encountered at Vrabchov dol can be compared, correlated and evaluated. In this scheme, the Santonian and Campanian palynofloras are quite characteristic with their Normapolles genera and species composition. Representatives of *Oculopollis* spp., *Krutzschipollis* spp., *Trudopollis* spp., *Longanulipollis* spp., *Hungaropollis* spp. and *Magnoporopollis* spp. prevail in them.

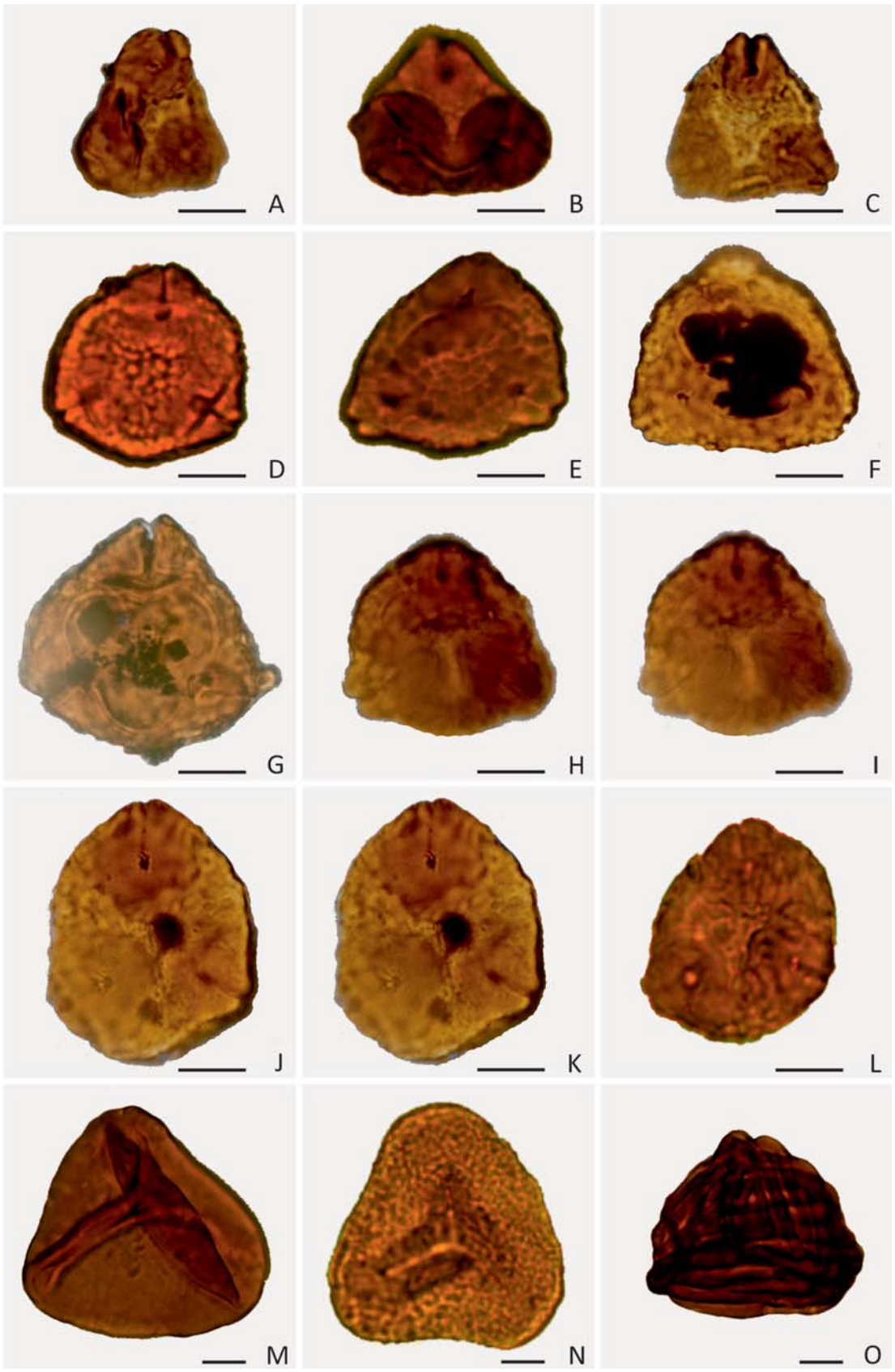
All Normapolles species recorded in this study are components of the existing pollen schemes for the Normapolles province. *Oculopollis zaklinskaiae*, *Oculopollis orbicularis*, *Krutzschipollis spatiosus* and *Krutzschipollis crassus* were first described from the Campanian of Hungary (Góczán, 1964) and were used as zonal eponymous index species in the Hungarian late Santonian to late Maastrichtian palynozonation (Góczán and Siegl-Farkas, 1990). Later, Siegl-Farkas and Wagreich (1996) refined the chronostratigraphy of this pollen succession and correlated it with the Austrian nannofossil zonation. Medus (1972) subdivided the Santonian−Maastrichtian interval in southern France and north-eastern Spain into five palynological zones and compared them to the Hungarian zonation proposed by Góczán (1964). Moreover, Medus (1972) recognised three types of pollen membrane within *Oculopollis* and pointed out that they successively occur in the Santonian. *Oculopollis* forma c = *Oculopollis orbicularis* makes its first occurrence in the middle part of the Santonian. Pavlishina (1994, 1999) reported two Normapolles assemblages from the Santonian and Lower Campanian in northern Bulgaria and calibrated them to the dinocyst zones in the same successions. She recognised two successive pollen assemblages, namely the *O. zaklinskaiae–Kr. crassus* Association in the lower and middle Santonian and the *Kr. crassus−Kr. spatiosus* Association in the upper Santonian–lower Campanian. Later, the Normapolles succession was used for age assessment and correlation of the continental to marine deposits of the Upper Cretaceous Gosau Group in the Northern Calcareous Alps, Austria (Pavlishina *et al.* 2004).

A diagnostic feature of the Normapoles assemblages recognised in this study is the dominance and diversity of representatives of *Oculopollis* spp. In sample T/3, below the host strata, they are already associated with abundant *Krutzschipollis* spp., namely: *Krutzschipollis crassus*, *Krutzschipollis spatiosus*, and *Krutzschipollis magnoporus*, as well as with *Vacuopollis* spp. and *Inaperturopollenites* spp. The concurrent occurrence of such key taxa as *Oculopollis orbicularis*, *Krutzschipollis spatiosus* and *Krutzschipollis crassus* is considered to be age diagnostic. It suggests a late Santonian to early Campanian age for the dinosaur bone-bearing sedimentary succession near the village of Vrabcha based on the palynological results of this study (Text-fig. 4).

PALYNOFACIES ANALYSIS

Palynofacies analysis describes the total acid-resistant organic matter content of the sedimentary rock within a specific depositional environment. The study involves not only the identification of palynomorphs, but also a survey of plant debris and amorphous organic particles, their relative proportion, size, and preservation status. It provides clear signals for a specific set of environmental conditions such as duration of transport, distance to the coast line, water depth and energy, and oxidising conditions.

The palynofacies analysis carried out on the Vrabcha samples reveals an organic content dominated by translucent phytoclasts including tissue, wood remains, and plant cuticles. Opaque phytoclasts are rare, less than 8% in the assemblages. The shape of the phytoclasts is mostly equidimensional suggesting short transportation. Opaque particles are generally larger than the translucent ones. The OP/TR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ratio is low and shows predominance of translucent phytoclasts in all slides. The C/M ratio (continental to marine elements) is very high, since continental elements, together with pollen and spores, collectively make up a high proportion in the samples, up to 90%. Amorphous organic matter (AOM) is present (2%), but no marine components were identified. According to these observations, the palynofacies data in our study demonstrates deposition within lagoonal to foreshore marine palaeoenvironments, with short transportation of the continental elements, such as phytoclasts, spores, and pollen. Moreover, the rock type, rock texture and structure, as well as fast lateral changes with contemporaneous volcano-sedimentary and volcanic sequences, indicate the presence of a subaerial volcano edifice during the late Santonian to early Campanian times.

PALAEOECOLOGICAL INTERPRETATION

According to our palynological data, we conclude that the Late Cretaceous vegetation in the studied area was primarily composed of a range of Normapolles-producing angiosperms, and secondarily of pteridophyte plants and rare gymnosperms. Góczán *et al.* (1967) were the first to define the Normapolles microfloristic province, which was mainly confined to Europe and eastern North America. Later, emphasis was put on the climatic implications of this spatial distribution and on the morphological resemblance to pollen belonging to the families Sapindaceae, Juglandaceae, Myricaceae and Betulaceae (Batten and Christopher 1981; Dulić 2002). It was suggested that Normapolles-producing plants constitute a heterogeneous complex and reflect a wide variety of tropical−subtropical vegetation types, from forests to swamps. This vegetation played an important role in the Late Cretaceous Normapolles province and had its maximum diversity in Europe. A variety of Normapolles grains have now been found in flowers and their relationship to core Fagales is well established (Friis *et al.* 2011). In general, the group is thought to have been wind-pollinated and that Normapolles-producing plants grew in warm, seasonably dry climate conditions. The thick pollen wall and complex aperture of most pollen grains may have been an adaption to such conditions.

AGE OF THE VRABCHOV DOL LOCALITY *VS.* THE LATE CRETACEOUS VERTEBRATE FOSSIL RECORD OF EUROPE

Constraining the stratigraphic range of the sediments in the study area and providing an accurate age for the vertebrate fossils associated with them has some important implications for the Late Cretaceous vertebrate fossil record of Europe. The palynology-derived late Santonian−early Campanian age for the fossiliferous sediments in Vrabchov dol suggests that they capture a picture of a terrestrial ecosystem from a time interval, for which the European fossil record is somewhat sparser and spatially restricted, due to combination of high sea levels and ongoing tectonic events, but which marks an important moment in the evolution of terrestrial faunas in the region (Csiki-Sava *et al.* 2015).

The current contribution provides important information for the study of the first vertebrate remains found at the Vrabchov dol locality (Nikolov *et al.* submitted). Histological analysis of the first two bone fragments tentatively suggests that they belong to a titanosaurian sauropod. This interpretation is particularly interesting because titanosaurs seem to be notoriously rare in the mid-Late Cretaceous of Europe (Csiki-Sava *et al.* 2015), to a degree that some palaeontologists have suggested that they had undergone a local extinction before being re-introduced to the European faunas in the late Campanian (Le Loeuff 1993). This apparent ‘sauropod hiatus’ has drawn considerable attention, but discoveries made in the last two decades (Nicosia *et al.* 1999; Mezga *et al.* 2006; Ősi *et al.* 2017) have shown that these dinosaurs were actually present in Europe throughout the Late Cretaceous and there are other factors at play behind their apparent absence (Mannion and Upchurch 2011).

Although there are numerous reports of tetrapod, mostly dinosaurian in nature, fossils from the Santonian of western and south-western Europe (Allain and Suberbiola 2003; Sanisteban and Suñer 2003; Godefroit and Lambert 2007; Carrano *et al.*

← Text-fig. 4. Microphotographs of representative pollen and spores in the samples from Vrabchov dol. **A** – *Oculopollis sibiricus* Zaklinskaya, 1963, sample T/1; **B**, **C** – *Oculopollis principalis* Weyland and Krieger, 1953, sample T/2; **D** – *Krutzschipollis magnoporus* Góczán in Góczán *et al*., 1967, sample T/3; **E**, **F** – *Krutschipollis crassus* (Góczán, 1964) Góczán in Góczán *et al*., 1967, sample T/3; **G** – *Krutschipollis spatiosus* Góczán in Góczán *et al*., 1967, sample T/3; **H**, **I**, **L** – *Oculopollis zaklinskaiae* Góczán, 1964, sample T/2; **J**, **K** – *Oculopollis orbicularis* Góczán in Góczán *et al*., 1967, sample T/3; **M** – *Deltoidospora ordinata* Brelie, 1964, sample T/2; **N** – *Vadaszisporites urkuticus* (Deak, 1964) Deak and Combaz, 1967, sample T/3; **O** – *Cicatricosisporites* sp., sample T/1. Scale bars equal to 10 μm. All photomicrographs were taken using conventional light microscopy. For location of samples in the succession see Text-fig. 2

2012), and few from the Adriatic−Dinaric Carbonate Platform and Italy (Nicosia *et al.* 1999; Buffetaut *et al*. 2002), the most taxonomically diverse fossil fauna from that time unquestionably comes from Hungary (Ősi 2004; Ősi *et al.* 2012). Until now, there were virtually no remains of terrestrial tetrapods from the sedimentary sequences of south-eastern Europe. The preliminary taxonomic evaluation of the fossil assemblage at the Vrabchov dol locality indicates a rich late Santonian–early Campanian vertebrate fauna (Nikolov *et al.* 2018), potentially one of the best found in Europe so far. Future comparisons with the Santonian vertebrate fauna of Hungary are of major interest, because they may reveal a lot about the isolated Late Cretaceous insular faunas, their composition and differences in between, and eventually elucidate the palaeobiogeography and migration history of some tetrapod groups. Large-scale ongoing studies of the Vrabchov dol locality and its fossil material aim at addressing these problems.

CONCLUSIONS

Based on palynological evidence, the sedimentary rock succession with dinosaur and other tetrapod fossils near the village of Vrabcha (Western Bulgaria) is dated as late Santonian–early Campanian. Palynofacies analysis reveals an organic content dominated by continental elements, including translucent phytoclasts (tissue, wood remains and plant cuticles), together with spores and pollen. The sedimentary succession shows no evidence of marine elements and a very low proportion of AOM that attests to deposition within a lagoonal to foreshore marine environment, with high continental input and short-distance transport. Considering the palynological data, we conclude that the vegetation was primarily composed of a range of Normapolles-producing angiosperms, with subordinate pterydophite spore-producing plants. Gymnosperms were rare in the study area. The vegetation pattern reflects a warm, seasonally dry climate during the late Santonian−early Campanian. Dinosaurs and other vertebrate fauna inhabited a wet lowland area, probably rich in herbaceous high-nutrient plants. The lack of large canopy trees must have facilitated traversing the landscape.

The age and palaeoecological data provided herein set the groundwork for future studies on the diverse local Late Cretaceous vertebrate fauna and allow for palaeoecological and palaeobiological comparisons with contemporaneous vertebrate faunas from the rest of Europe.

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